# Public Document Pack

Sefton Council
www.sefton.gov.uk

Town Hall
Trinity Road
Bootle
L20 7AE

To: All Members of the Council

Date: 13 September 2024
Our Ref:
Your Ref:

**Contact:** Debbie Campbell
**Contact Number:** 0151 934 2254
**Fax No:**
**e-mail:** debbie.campbell@sefton.gov.uk

Dear Councillor

**COUNCIL - THURSDAY 12TH SEPTEMBER, 2024**

I refer to the agenda for the above meeting and now enclose the following documents which were unavailable when the agenda was published.

| Agenda No. | Item |
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| 5. | **Matters Raised by the Public** (Pages 3 - 208)<br>Schedule attached |
| 6. | **Questions Raised by Members of the Council** (Pages 209 - 218)<br>Schedule attached |

Yours faithfully,

P. Porter

Chief Executive

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**COUNCIL – 12TH SEPTEMBER 2024**

**QUESTIONS RAISED BY MEMBERS OF THE PUBLIC**

| **1** | **COUNCIL QUESTION FROM: Mr. Jeff Holloway** | |
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| | **MEETING DATE:** | 12 September 2024 |
| | **TO:** | Cabinet Member - Public Health and Wellbeing |
| | **SUBJECT:** | Pollution |
| | **QUESTION:**<br><br>From where I live, 1-2 miles on Hawthorne Road, Bootle, between Linacre Lane and Marsh Lane, there are two sites that in my opinion are causing serious pollution and health issues for residents that live in this area including my house. The dust our hoover is picking up is not normal dust but I believe it is cement dust from spot mix on Hawthorne Road and a hard-core breaking yard opposite. Why are two companies allowed to work within an area where there are hundreds of homes and both companies emit thousands of tons of possible poisonous dust a week in and around the surrounding area? When there are industrial areas by the docks these companies could use, I find it quite disturbing that Sefton Council and the environment department are not looking into the health of Sefton residents. | |
| | **Response:** | |
| | "In response to the question from Mr Holloway related to dust emissions from the Spotmix concrete batching process and the crushing and screening process opposite, operated by Dowhigh, I can advise, that due to their potential to emit certain pollutants both processes fall under the Local Air Pollution Prevention and Control Regime (Environmental Permitting Regulations 2016-as amended) which is administered and enforced by Local Authorities.<br><br>These processes are required to comply with strict environmental controls (based on national standards) which are designed to minimise air pollution and ensure any health and nuisance impacts are mitigated.<br><br>In accordance with the Environmental Permitting Regulations, Sefton Council has issued the operators of these processes with an Environmental Permit which contains a number of specific conditions controlling how the sites operate and ensures emissions including dust are minimised.<br><br>Officers from Environmental Health undertake regular compliance inspections to ensure the businesses are operating in accordance with their permits and pollutants are effectively controlled.<br><br>It is acknowledged that residential premises are located close to the businesses, however, the sites have the benefit of historical planning permission. | |

No recent complaints have been received by the Council regarding these sites but following the concerns raised by Mr Holloway I have asked the Environmental Health and Licensing Service Manager to arrange for the businesses to be inspected and following this, provide Mr Holloway with a comprehensive update".

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| 2 | **COUNCIL QUESTION FROM: Eileen O'Connor** | |
| | **MEETING DATE:** | 12th September 2024 |
| | **TO:** | Cabinet Member – Housing and Highways<br>Cabinet Member – Public Health and Wellbeing<br><br>***DELETE CABINET MEMBERS AS APPROPRIATE*** |
| | **SUBJECT:** | ***5G/phone masts safety concerns especially for children** |

**QUESTION:**

**The enclosed question and additional information sent to David McCoullough, Bill Esterson, Mayor June Burns and my local councillors. This question is for the next Council meeting due to be held on 12th September at Southport Town Hall. I wish to attend the next Council meeting in-person, in order to raise a supplementary question.**

**Kind regards**
**Eileen O'Connor**

**From: eileen@radiationresearch.org <eileen@radiationresearch.org>**
**Sent: 02 September 2024 11:32**
**To: 'David McCullough' <David.McCullough@sefton.gov.uk>; 'ESTERSON, Bill' <bill.esterson.mp@parliament.uk>; 'Karen Cavanagh' <Karen.Cavanagh@sefton.gov.uk>; 'Carol Richards' <Carol.Richards@sefton.gov.uk>; 'Peter Harvey' <Peter.Harvey@sefton.gov.uk>; 'mayorsoffice@sefton.gov.uk' <mayorsoffice@sefton.gov.uk>**
**Cc: 'Brian Stein' <brian.stein61@hotmail.com>**
**Subject: FW: Questions and Information for Sefton Council on 5G**

**Contact address:**
**Chairman Mr. Brian Stein CBE,**
**EM Radiation Research Trust, Chetwode House, Leicester Road, Melton Mowbray,**
**Leicestershire, LE13 1GAUK**

**2nd September 2024**

**For the attention of: David McCullough David.McCullough@sefton.gov.uk Bill Esterson MP bill.esterson.mp@parliament.uk, Cllr. Karen Cavanagh Karen.Cavanagh@sefton.gov.uk, Cllr. Carol Richards Carol.Richards@sefton.gov.uk, Cllr. Peter Harvey peter.harvey@sefton.gov.uk Mayor Cllr. June Burns mayorsoffice@sefton.gov.uk**
**Cc. Brian Stein CBE Chairman EM Radiation Research Trust**
**Sent via Email from Eileen O'Connor, Director EM Radiation Research Trust: eileen@radiationresearch.org**
**I am a resident living in Sefton and the Director for the EM Radiation Research Trust Charity.**

**We request a review of wireless radiation exposures from 2G, 3G, 4G, 5G and the IOT to be undertaken by Sefton Council as a matter of urgency.**

**Will Sefton Council revisit the request from Councillor David Irving at the 20/1/2022 Council meeting calling for the Council to site 5G masts at a safe distance from schools?**

**Sefton residents previously raised concerns about 5G via objections against masts with a petition that was presented to the Council meeting on 20 January 2022 calling for Sefton to Stop the 5G rollout. This meeting had a very low turnout with only 25 councillors attending out of the 66. At the end of the debate, Councillor David Irving proposed an amendment to site 5G masts at a safe distance from schools, however it was not seconded, and the amendment failed. If a majority of councillors had attended, there is a strong chance that the amendment might have been seconded, and the subsequent debate may have led to it being adopted.**

**Reasons for concern and especially for children**

**The EM Radiation Research Trust(RRT) recently called for a full investigation into the 4G LTE phone mast that is situated right next to Millstead Primary School, Everton after visiting the area with RF/EMF radiation measurements expert Glynn Hughes who recorded the highest peak reading he has ever taken in the UK at 1,554932 μW/m. This reading corresponds with readings recorded by Professor Lennart Hardell and Mona Nilsson of the Swedish Radiation Foundation who published seven case reports that include a total of 16 persons aged between 4 and 83 years that developed microwave syndrome within a short time after being exposed to 5G base stations close to their dwellings. Most prevalent symptoms were sleeping difficulty, headache, fatigue, irritability, concentration problems, loss of immediate memory, emotional distress, depression tendency, anxiety/panic, burning and lancinating skin, cardiovascular symptoms, pain in muscles and joints https://pubmed.ncbi.nlm.nih.gov/38889394/**

**The RRT letter was sent to the UK Health Security Agency (UKHSA), Cllr. June Burns Mayor of Sefton, Cllr. Richard Kemp CBE Mayor of Liverpool, Kim Johnson MP and other public officials calling for a full investigation into the deaths of the two children. Download here: Base-Station emissions and health concerns (radiationresearch.org)**

**We received a response from the UKHSA on 30th August 2024 which does not address many of the concerned raised in the RRT letter calling for an investigation into the published research demonstrating risks associated with the biological effects associated with wireless technology. We therefore cannot rely on the UKHSA and call on Sefton Council to investigate the risks associated with this technology and to seek advice from all experts in this field. The health and wellbeing of residents is paramount.**

**I would like to draw your attention to The International Declaration on the Human Rights of Children in the Digital Age. This important Declaration was delivered to the Secretary General of the United Nations on World Children's Day, November 20, 2023. The Declaration calls for the protection of Children from Involuntary Exposure to Non-Ionizing Radiation (NIR) and highlights a large and growing body of independent, peer-reviewed scientific studies demonstrated that man-made NIR has adverse biological effects. The Declaration | ICD (thechildrensdeclaration.org)**

**In May 2020, the EM Radiation Research Trust received support from Robert F. Kennedy Jr., and Dafna Tachover calling on the UK Prime Minister Boris Johnson and political leaders to protect the public and especially our children from the 'proven harms' of wireless radiation and 5G. This Open letter of Complaint is a response to an article published by the UK children's online newspaper First News claiming that 5G is safe. The Radiation Research Trust is still waiting to receive a response from the UK Government and First News. RFK, Jr. Joins EM Radiation Research Trust in Calling Upon UK Prime Minister to Halt 5G Deployment • Children's Health Defense – Radiation Research**

**The UK Stewart Report 2000**

**In 2000 the UK Government set up a committee to investigate the impacts of RF/microwave radiation. The committee was chaired by Sir William Stewart, Chairman of the UK Health Protection Agency and formerly Chief Scientific Adviser to the Government. This important investigation called for a precautionary approach due to the scientific uncertainties.**

- ***Section 1.18*** **There is now scientific evidence, however, which suggests that there may be biological effects occurring at exposures below these guidelines.**
- **Section 1.19 We conclude therefore that it is not possible at present to say that exposure to RF radiation, even at levels below guidelines, is totally without potential adverse health effects, and that the gaps in knowledge are sufficient to justify a precautionary approach.**
- **Section 1.42 The beam of greatest RF intensity should not be permitted to fall on any part of the school grounds or buildings without agreement from the school and parents.**
- **Section 1.53 Children may be more vulnerable because of their developing nervous systems, the greater absorption of energy in the tissues of the head and a longer lifetime of exposure.**

**Research has continued to raise concerns since the 2000 Stewart Report.**

- **Thousands of Peer-reviewed studies, including the $30 million U.S Toxicology Program and the world's largest animal study on RF mobile phone mast radiation by the Ramazzini Institute confirms a wide range of statistically significant DNA damage, brain and heart tumours, infertility, and RF/microwave radiation sickness injury symptoms.**
- **In 2011 the WHO/IARC classified Radiofrequency Electromagnetic Fields as a class 2B carcinogen (possibly carcinogenic to humans) The same classification as DDT and lead in Petrol. https://www.iarc.who.int/wp-content/uploads/2018/07/pr208_E.pdf**
- **The late Professor Yury Grigoriev said "A situation has emerged that cumulative EMF exposure of children may be comparable to adult exposure and may be equal to levels of occupational exposure of workers. The current standards are outdated and inadequate. Urgent action is needed to curb the negative impact from this physical agent." https://www.radiationresearch.org/news/important-information-from-professor-yury-grigoriev/**
- **EMA v East Sussex County Council (Special educational needs). The Upper Tribunal Judge Jacobs found that a child suffering with electrosensitivity should be considered disabled under the Equality Act 2010 and required an Education Health, and Care Plan (EHCP) https://phiremedical.org/news/**
- **Article written by Debra Fry the mother of a 15-year-old electrosensitive girl who committed suicide. Why Die for Wifi? My Chid Did – Will Yours? https://www.radiationresearch.org/news/why-die-for-wifi-my-child-did-will-yours/**
- **Health effects of electromagnetic fields on Children Jin-Hwa Moon MD,PhD Health effects of electromagnetic fields on children - PMC (nih.gov)**

**Concerns regarding the Government's use of ICNIRP**

**There are concerns regarding government's use of the ICNIRP 2020 radiation guidelines as highlighted in the paper by Einar Flydal et al. (2022) Self-referencing authorships behind the ICNIRP 2020 radiation protection guidelines. This paper concludes: "From our findings we draw the conclusion that the referenced literature used in ICNIRP 2020 to underpin its guidelines is neither varied, nor independent or balanced, and is by no means "consistent with current scientific knowledge", as claimed by ICNIRP 2020 [2 p. 484]. ICNIRP 2020 bases this claim within this small network only, a claim that runs contrary to the majority of biology-oriented researchers and publications within this research field. Hence, our review shows that the ICNIRP 2020 guidelines fail to meet fundamental scientific quality requirements as to being built on a broad, solid, and established knowledge base, uphold a view contrary to well established knowledge within the field,**

and therefore cannot offer a basis for good governance when setting RF exposure limits for the protection of human health.” https://pubmed.ncbi.nlm.nih.gov/35751553/

ICBE-EMF group called for a moratorium on 5G. A peer-reviewed paper on October 18, 2022, presented a scientific case for revision of the ICNIRP limits. The International Commission on the Biological Effects of Electromagnetic Fields (ICBE-EMF) challenged the safety of current wireless exposure limits to radiofrequency radiation (RFR) and is calling for an independent evaluation. This paper warns about the risks of exposure to radiation from 5G technology and claims that existing exposure limits for wireless radiation are inadequate, outdated, and harmful to human health and wildlife. The ICBE-EMF group reports that exposure limits for RF radiation set by ICNIRP and the FCC are based on invalid assumptions and outdated science.
https://ehjournal.biomedcentral.com/articles/10.1186/s12940-022-00900-9

We are told that councillors must base decisions for phone masts based on planning policy.
The key messages are:

• Councils should support next generation mobile technology (such as 5G)
• Councils should not impose a ban on new electronic communication development
• Councils must determine planning applications on planning grounds only; and Councils should not seek to set health safeguards different from the International Commission Guidelines for public exposure.

We would like to point out was that the National Planning Policy Framework (NPPF) is a set of guidelines and is not legally binding. It is our view that the main priority of local councils should be the best interests of residents, not simply to follow government guidance slavishly. Regarding 5G installations, it is the duty of the Council to take into consideration all evidence relating to potential effects on residents’ health, rather than relying exclusively on government and industry guidance.
In a landmark legal ruling in November 2021, campaigners in Brighton and Hove succeeded in overturning local authority approval for a 5G mast to be sited close to a primary school. At judicial review, it was found that the Council “failed to address the health impacts” of the mast. This finding has significant implications for all councils dealing with 5G applications, as it means there is a legal responsibility to investigate possible effects on health. The technology cannot simply be assumed to be safe.

Moreover, the approach taken recently by Glastonbury Town Concil is evidence that not all Councils feel constrained to adhere rigidly to government guidance in relation to 5G applications. In response to concerns raised by residents, Glastonbury Town Council set up a 5G Advisory Committee and carried out a six-month investigation, after which they resolved unanimously to continue their adoption of the Precautionary Principle; opposing the roll-out of 5G until further information is made available on the safety or otherwise of the

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| | **technology.**<br><br>**We therefore contend that the Council should be advised that not only is there is NO legal requirement to support 5G technology, but it is also the duty and responsibility of the Council to conduct a full safety investigation and risk assessment before approving 5G applications.**<br><br>**Respectfully Submitted,**<br><br><br>**Eileen O'Connor**<br>**Charity Director for the EM Radiation Research Trust**<br>**Website address: https://www.radiationresearch.org/**<br>**Email: eileen@radiationresearch.org** |
| | **Response:** |
| | **Review of evidence around safety 5G and public health impacts**<br>Sefton Council public health team have consulted with colleagues in the UK Health Security Agency who provide expert guidance on health protection matters, including advice regarding non-ionising radiation impacts on health. Th UK Health Security Agency have reviewed the evidence and provided the information below in relation to the safety and health impacts of radio waves, including 5G.<br><br>**Review of current evidence**<br>The health effects of exposure to radio waves have been researched extensively over several decades, and very many publications can be found in scientific journals and elsewhere.<br><br>Guidelines set by International Commission on Non-Ionizing Radiation Protection (ICNIRP) on limiting exposures to electromagnetic fields (EMF) have been developed based on careful analyses of the accumulated evidence. ICNIRP published updated guidelines on exposure to radio waves in 2020.<br><br>UKHSA is aware that different groups have concerns about EMFs and where they have proposed alternative limits, these do not appear to have a scientific rationale based on health effects in the same way as the ICNIRP guidelines. In formulating its advice, UKHSA aims to draw out a consensus position based on the totality of the scientific evidence through a process of systematic, critical and impartial review of the published literature.<br><br>UKHSA bases its opinion on evidence reviews from authoritative bodies that consider the whole-range of evidence available, taking account of the scientific quality and relevance of individual studies to human health, in developing their conclusions. The typical types of evidence reviewed are the human laboratory and epidemiological studies, animal studies and cellular studies. This is the approach adopted by officially mandated authoritative organisations such as, ICNIRP and the World Health Organization (WHO). UKHSA is not aware, therefore, that these initiatives are driven by any scientific evidence that has been overlooked in its own advice. |

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| | **Summary of evidence and public health impacts**<br>Many exposure measurements have been made at publicly accessible locations near to base stations and these have consistently been well within the ICNIRP guidelines.<br><br>It is possible that there may be a small increase in overall exposure to radio waves when 5G is added to an existing network or in a new area. However, the overall exposure is expected to remain low relative to guidelines and, as such, there should be no consequences for public health.<br><br>**Further information**<br>Please see the following webpages containing UKHSA's published advice on 5G and mobile phone base stations:<br><br>https://www.gov.uk/government/publications/5g-technologies-radio-waves-and-health/5g-technologies-radio-waves-and-health.<br><br>https://www.gov.uk/government/publications/mobile-phone-base-stations-radio-waves-and-health/mobile-phone-base-stations-radio-waves-and-health |

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| **3** | **COUNCIL QUESTION FROM:** Stephen Kelly | |
| | **MEETING DATE:** | 12 September 2024 |
| | **TO:** | Cabinet Member – Housing and Highways |
| | **SUBJECT:** | Planning application DC/2022/01727 - ICNIRP safety guidelines |
| | **QUESTION:**<br><br>The validity of the International Community for Non-ionized Radiation Protection (ICNIRP) Safety Guidelines for 5G mast planning does not form a robust technical and legal liability case based on the document content, and as detailed in the communication sent to Sefton Council Planning Department 4th September 2024.<br>Based on this the ICNIRP document should not be referenced by the planning Department as blanket approval in relation to health impact upon resident as a result of non-ionised EMF radiation exposure from 5G communication installations.<br>All current 5G installations must be reviewed in response to this and applications in review and approval status must be suspended until sufficiently quantitively evidence becomes available to protect the residents of Sefton and specifically affected by the site currently under construction in College Road, Crosby?<br><br>Please find a detailed explanation in the body of this email (below) communicated to Sefton Council Planning department.<br><br>I wish to draw to your attention the recent approval upon appeal planning application DC/2022/01727 by Sefton Council planning department.<br>The initial planning application was rejected, further to this Sefton Council Planning and building control have approved the appeal based on geographical location of the proposed site.<br>At the initial application an objection was raised based on health concerns by a local resident Eileen O'Connor (See attached letter from The EM Radiation research Trust | |

Charity 13th September 2022) this letter references the International Commission on Non-Ionizing Radiation Protection INCRIP.
These guidelines were used as reference by the planning team and considered to be sufficient for justification for approval in relation to health matters relating to the local community.
At this point I must draw your attention misinterpretation of the INCRIP guidelines and the consequential hazard to human health and the risk posed to the local community and more widely the Sefton residents regarding current and other planned sites.
It is widely acknowledged amongst the scientific community concerned with exposure to non-ionizing EMF radiation that the INCRIP safety guidelines must not be used for the blanket justification of 5G installations. The INCRIP document provides no quantifiable scientific research-based evidence as the basis for its conclusion. The reason for this point is that document scope and ambiguity of wording are as follows:

1. The document scope is based on the "protection of humans", environmental impact on wildlife is outside of the scope, therefore is not considered. What measures are the council taking to ensure no impact on local wildlife as none have been taken as part of the planning application?

   INTRODUCTION

   THE GUIDELINES described here are for the protection of humans exposed to radiofrequency electromagnetic fields (EMFs) in the range 100 kHz to 300 GHz (hereafter "radiofre-

2. The document acknowledges that adverse effects are associated with EMF exposure. The limits of exposure must be controlled. No risk mitigation actions are detailed in the planning application by the applicant. Members of the public which have medical procedures or metallic implants etc are outside of the scope of the document. There is no risk mitigation to prevent exposure to the many residents who come under this category.

**PURPOSE AND SCOPE**

The main objective of this publication is to establish guidelines for limiting exposure to EMFs that will provide a high level of protection for all people against substantiated adverse health effects from exposures to both short- and long-term, continuous and discontinuous radiofrequency EMFs. However, some exposure scenarios are defined as outside the scope of these guidelines. Medical procedures may utilize EMFs, and metallic implants may alter or perturb EMFs in the body, which in turn can affect the body both directly (via direct interaction between field and tissue) and indirectly (via an intermediate conducting object). For example, radiofrequency ablation and hyperthermia are both used as medical treatments, and radiofrequency EMFs can indirectly cause harm by unintentionally interfering with active implantable medical devices (see ISO 2012) or altering EMFs due to the presence of conductive implants. As medical procedures rely on medical expertise to weigh potential harm against intended benefits, ICNIRP considers such exposure managed by qualified medical practitioners (i.e., to patients, carers and comforters, including, where relevant, fetuses), as well as the utilization of conducting materials for medical procedures, as beyond the scope of these guidelines (for further information, see UNEP/WHO/IRPA 1993).

3. The document goes on to mention scientific based evidence as the basis for the document, however the word “unlikely is used on 7 occasions in the body of the text. The use of the word “unlikely” undermines the technical credibility of such a document **and therefore must not be taken as quantifiable fact.**

The document forms no robust technical or legal argument based on the ambiguity of wording alone.
The INCRIP organisation perspective is that of industry-based argument and not a scientific led study into the effect on human physiology. (See attached document Scientists warn of potential serious health effects of 5G September 11, 2017).
The scientific community have highlighted the lack of quantifiable testing to establish the safety posed by non-ionised radiation exposure long and short term, and in the case of 5G technology this evidence does not exist. It appears that those responsible for the decisions regarding the approval of such constructions in the public are as are not aware that such evidence does not exist. This is a misinterpretation of the guidelines that has potential consequences for the residents of our communities that no individual is acknowledging within Sefton Council.
It is stated “Safety guidelines” protect industry — not health”. And based on the evaluation of the document content INCRIP guidelines are obsolete and hold no scientific credibility.
As a concerned resident – I expect Sefton Council to mitigate all potential and actual risk to its residents by immediately reviewing the current 5G mast installation in the borough and suspend all applications in the review and approval stage until further conclusive evidence can be presented.
This letter presents the case for risk mitigation and the protection of the health of Sefton residents and specifically those impacted by the installation related to planning application DC/2022/01727 by Cornerstone Telecommunications
Attachments:

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| | • EILEEN_O_CONNOR Objection.PDF<br>• ICNIRPrfgdl2020<br>• Scientist_5G_appeal |
| | **Response:** |
| | “The Government have clearly set out the need to ensure that planning policies and decisions support the expansion of electronic communications networks, including next generation technology (such as 5G). They have made it clear that local planning authorities should not impose a ban on new electronic communications development.<br><br>It is the Government’s firm view that the planning system is not the place for determining health safeguards. In the Government’s view, if a proposed mobile base station meets the ICNIRP guidelines for public exposure it should not be necessary for a local planning authority to consider further the health aspects and concerns about them. With every planning application received by the authority, the operator must include a certificate of compliance with these radiation levels. Without this certificate, the application would not be determined or considered acceptable.<br><br>It is acknowledged that there are various studies questioning the acceptability of the ICNIRP. Sefton Council public health team have consulted with colleagues in the UK Health Security Agency who provide expert guidance on health protection matters, including advice regarding non-ionising radiation impacts on health.<br><br>Th UK Health Security Agency have reviewed the evidence and provided information to Sefton in relation to the safety and health impacts of radio waves, including 5G.<br><br>Considering the advice from the UK Health Security Agency, Sefton Council recognised that many exposure measurements have been made at publicly accessible locations near to base stations and these have consistently been well within the ICNIRP guidelines.<br><br>It is accepted that it is possible that there may be a small increase in overall exposure to radio waves when 5G is added to an existing network or in a new area. However, the overall exposure is expected to remain low relative to guidelines and, as such, there should be no consequences for public health.<br><br>The Local Planning Authority cannot agree to reviewing permissions already granted or suspend decisions on subsequent applications received in the Borough as there are no planning grounds to do so”. |
| **4** | **COUNCIL QUESTION FROM:**<br>Maria Walsh, Merseyside Residents Association |
| | **MEETING DATE:** 12th September 2024 |

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| | **TO:** | Cabinet Member Health, Wellbeing and Inclusion |
| | **SUBJECT:** | "**Climate Emergency**" declared by Sefton Council July 2019 |

**QUESTION:**

**"Where is the evidence for declaring a 'Climate Emergency', and where are the 'Cost Benefit Analyses' for all of the policies resulting from this declaration?"**

For clarity, and to be as helpful as possible in providing you with information, I have set out below the background and available evidence with regard to this issue:

On 18th July 2019 Sefton Council declared a "Climate Emergency". I submitted an FoI to Sefton Council, and received a response dated 19th June 2023. My FoI asked what Sefton's definition of a 'Climate Emergency' is and asked for Sefton to disclose the evidence to support the Council's decision to make this declaration. The answer I received was that the Council had *"**Not formally defined 'Climate Emergency'**"* and *that "**The declaration was member led and the data and evidence that members accessed is not held centrally**"*. This is an astonishing response given that you have made the life changing decision (for your residents) of declaring an 'Emergency', yet you do not have a formal definition of this emergency – nor do you have any evidence! Sefton Council then went on to produce various policies including the 'Climate Emergency Strategy', a 'Climate Emergency Action Plan' and a 'Low Carbon Transport Policy' – all without even having a definition of what the 'Climate Emergency' is - nor possessing any evidence!

All of these policies will have a dire effect on your residents. In pursuing these cult-like diktats you are responsible for enacting policies based on modelling rather than observation (i.e. flawed science). It is critical to understand the distinction between modelling and observation. In science, models are nothing more than opinions - they are not evidence. For example, there are almost one hundred different climate models none of which amount to evidence. All that matters in science is evidence derived from observation. This cult like dogma will result in the waste of hundreds of millions of pounds of financial resources, intrusion into the private lives of the people of Sefton and, in the process, the impoverishment of the people - with endless excuses for oppressive taxes, and the erosion of their freedoms. Your obsessive focus on Net Zero polices forgoes any, and all, considerations of costs and benefits to the people of Sefton and is, thus, both absurd and dangerous. You are accountable to the people of Sefton for the policy decisions you make and you, therefore, have a responsibility and a duty to fully consider the position of those scientists who provide evidence for their theories through observations. You have a duty to listen to the climate realists as well as the climate alarmists - the future well-being of the people of Sefton depends upon you doing so. I would also point out that this includes your friends and family! (I would also remind you of a very simple fact most of us were taught in Junior School – photosynthesis: the process of plants converting CO2 into oxygen – without which the planet will die!)

May I also draw your attention to your responsibilities as a Councillor with regard to the Councillor Code of Conduct, in particular this clause:

> *"2.3 Consider all matters with an open mind and make decisions based upon weighing the best evidence before me, fairly and on merit. Where you have been involved in campaigning in your political role on an issue which does not impact on your personal and/or professional life, you should not be prohibited from participating in a decision in your role as Member. However, you must ensure that your integrity is not compromised. You may be pre-disposed to a number of outcomes to a decision, based upon your, philosophy, beliefs or* ***political allegiance*** *(including any application of a Group whip), but this must not predetermine your actions or the outcome of a decision you are to make.* ***<u>You must always remain open to the potential for further evidence or argument to alter any previously expressed or held viewpoint at the time of making your decision</u>. For this reason, particularly in relation to contractual matters or those affecting individuals' civil rights,*** *it is often best to be cautious about how or if your views are expressed before coming to make a decision."*

I have enclosed three documents for your attention:

1. **A copy of the Clintel Declaration**: The Climate Intelligence (Clintel) foundation is an independent foundation informing people about climate change and climate policies. Clintel was founded in 2019 by Emeritus Professor of Geophysics, Guus Berkhout, and science journalist Marcel Crok. They issued a declaration in 2019 stating that there is **NO CLIMATE EMERGENCY**. For further details regarding the 1,944 scientists and experts who have signed this, and their evidence, please see their website:

   World Climate Declaration There is no climate emergency (clintel.org)

2. **A copy of a letter from a concerned citizen of Leeds** to all 99 Leeds City Council councillors: The subject matter - the flawed science behind C02 - is of grave importance. It is not only relevant to Leeds but the entire country because many councils have declared a 'Climate emergency' and are rolling out associated 'Net zero' policies. Consequently, the contents of the attached letter should be of the utmost concern to you, particularly the sections referring to lack of evidence and flawed science. I urge you to read the letter (including the content accessed via the links), watch the video and review the Conclusion, asking yourself what are the consequences for your residents of pursuing Net Zero policies based on flawed science?

2024-08-22_LetterTo
LeedsCouncil.docx

3. **"Absolute Zero":** A document commissioned by the UK Government in 2019. I would refer you, in particular, to the diagram on pages 6 & 7. This refers to aspirations of closing all airports, the cessation of all shipping and the removal of all Beef & Lamb by 2049. Please read the rest of this

document and you will realise how insane this whole ideology is.

You may also wish to explore "Personal Carbon Allowances - PCAs" – a system of allocating "Carbon Credits" which will track and surveil our every move – preventing us from leaving the house when we have used up our "Personal Allowance".

**"**The UK government has not officially introduced personal carbon allowances yet. However, there has been ongoing discussion and research on the topic. Personal carbon allowances (PCAs) would involve giving individuals a set amount of carbon credits that they could use for activities like household energy use and personal travel. If someone uses less than their allowance, they could sell the excess; if they need more, they could buy additional credits[12]**."**

Personal carbon allowances white paper | The Carbon Trust

2019-11-29-Absolute-Zero.pdf

**Response:**

Thank you for your question regarding the "**Climate Emergency**" declared by Sefton Council July 2019.

**Where is the evidence for declaring a 'Climate Emergency'**

The evidence accessed by Members, included the report produced by The Intergovernmental Panel on Climate Change (IPCC) which is the United Nations body for assessing the science related to climate change. The IPCC was set up in 1988 by the World Meteorological Organization (WMO) and United Nations Environment Programme (UNEP) to provide policymakers with regular assessments of the scientific basis of climate change, its impacts and future risks, and options for adaptation and mitigation. IPCC assessments provide a scientific basis for governments at all levels to develop climate related policies, and they underlie negotiations at the UN Climate Conference – the United Nations Framework Convention on Climate Change (UNFCCC).

The assessments are policy-relevant but not policy prescriptive: they may present projections of future climate change based on different scenarios and the risks that climate change poses and discuss the implications of response options, but they do not tell policymakers what actions to take. The work is undertaken by hundreds of leading scientists, with all work rigorously cross checked and verified before publication.

In their report "Intergovernmental Panel on Climate Change 1.5C report" (2018) Global Warming of 1.5 ºC — (ipcc.ch) the IPCC outline the risks associated with a 1.5 or 2 degree Celsius of warming, directly attributed to the release of greenhouse gases into the atmosphere through human activity. This included increased likelihood of temperature extremes, increased risk of drought/fires and extreme precipitation, impacts on biodiversity, more incidents of extreme weather, invasive species migration, sea level rises and acidification of oceans as they absorb increased amounts of carbon.

This and subsequent reports suggest that disadvantaged and vulnerable populations are least likely to be able to respond to any negative consequences of climate risks, and likely to be impacted most.

Sefton as a low-lying coastal authority must take account of any particular risks to

the local population in particular those most vulnerable.
Elected members are presented with information when considering decisions which are from sources that are credible, reliable, written by experts in that field, up to date and not biased. The sources include the UK Government, IPCC, UN. Elected members are fully aware and compliant with the Council's code of conduct.

**Definition of "Climate Emergency" –** as mentioned this was not provided in the FOI response as it was not specifically defined within the member declaration.
There is no one definition of climate emergency but it is broadly accepted to mean there is a need for increased action to reduce greenhouse gas emissions and be better prepared for the current and future effects of a changing climate. The Climate Emergency (unep.org) the United Nations provide additional information and an expanded definition.
**and where are the 'Cost Benefit Analyses' for all of the policies resulting from this declaration?"**
The current strategy was developed to ensure that actions were focused on Council operations and not the wider Sefton Community. Within the declaration the Council encourage others to adopt a similar approach to act and encourage the community to reduce emissions and be better prepared e.g. insulating homes which may also have financial and health benefits. Therefore, there is no obligation on residents, local businesses etc. to undertake any particular actions.
The strategy includes work to meet a net zero carbon target by 2030 which focuses on specific council actions, as well as the work to ensure the Council is better prepared to cope with any changes anticipated by a changing climate.
The UK government have set a national net zero target (2050) with a series of interim targets including a 2030 target (reduce carbon emissions by 68% 1990 baseline). This is to align with international commitments including the Paris Agreement's nationally determined contributions (NDCs). The Council's climate emergency strategy is therefore proportionate to national and international commitments, in particular, in the context of the wider Sefton area.
All work carried out to date by the Council has been from within existing resources. Investments made have been as a result of successful external funding applications, which in turn have brought additional future benefits at no cost to the Council.

The mitigation elements of the strategy (Net zero carbon by 2030) have some key actions identified these include:-

- Agile working; where an increased number of staff work at home. This has allowed the Council to utilise office space more efficiently, has reduced emissions from commuting and has been well received by staff.
  The decisions made by members on agile working have been fully scrutinised by senior staff and worker representatives and have provided a financial saving as well as a reduction in emissions.
- Upgrade of Bootle and Southport Town Halls; the roof insulation and external glazing improvements were funded through a successful Public Sector Decarbonisation Fund programme, with some match funding from the Council to ensure roof repairs and external painting at Southport were completed in the same time period. Reports to senior officers and members were completed to obtain permission to bid, to accept the funding and reports provided on the outcomes and ongoing management of the programme of work. The work has achieved energy savings which has reduced emissions and future costs, as well as helping to reduce the liability of future maintenance.
- LED Street lighting programme; This 4-year programme was fully assessed as an invest to save programme. The savings made from using less electricity (and fewer emission) are used to repay the loan amount with future savings accruing directly to the Council. Reports to members to agree to this programme and review progress are available online.
- All other/future work set out within the strategy as based around securing

| | |
|---|---|
| | external funding or providing a full cost benefit analysis which is reported through the usual Council's governance processes. |

[redacted]

Please see enclosed letter of objection against the phone mast application for College Road, Crosby. The letter of objection is also available to download from the EM Radiation Research Trust website.
https://www.radiationresearch.org/articles/college-road-crosby-phone-mast-objection/

EM-RADIATION
RESEARCH TRUST

The EM Radiation Research Trust Charity
Chairman Mr. Brian Stein CBE,
Chetwode House,
Leicester Road,
Melton Mowbray,
Leicestershire LE13 1GA

Email for the attention of John Kerr, (Case Officer)
Copied: EM Radiation Research Trust Chairman, Mr Brian Stein CBE
Cllr Les Byrom
Cllr Janet Grace
Cllr Michael Roche

13th September 2022

Dear John Kerr,

Ref: DC/2022/01727

I formally give notice of objection against phone mast application by Cornerstone Telecommunications for a 17.5m high street works column, supporting six no antennas, 2 no. 0.3m dishes and 2 no. equipment cabinets and ancillary equipment.

The EM Radiation Research Trust calls on Sefton Council to protect the health and safety of the local community, especially our children along with protecting the local area from the visual impacts associated with the clutter associated with the ancillary works and the overpowering visual impact of a 17.5m high street works column, with supporting cabinets and ancillary equipment.

This mast will create a blight on the landscape. The mast would be a constant reminder to the risks it poses causing fear, stress, and anxiety for the local community, this is a material consideration and should be considered.

Cornerstone Telecommunication supplied information to offer reassurance regarding health and safety concerns. The Radiation Research Trust would therefore like to respond accordingly.

Cornerstone Telecommunication's promotes the private members group known ICNIRP when offering reassurance for radiation safety.

Let us look at the International Commission on Non-Ionizing Radiation Protection (ICNIRP)

ICNIRP have faced criticism via the courts, from members of the EU parliament and scientific publications. In truth, the ICNIRP guidelines are deeply flawed and obsolete. – see Pall, M. (2018) [(1),] Hardell & Nyberg (2020) [(2)], Naren et al. (2020) [(3)], and Hertsgaard & Dowie (2018) [(4)].

The ICNIRP guidelines are set by a small, pro-industry/non-governmental organization of invitation-only, unelected private members who set guidelines for thermal heating. That means ICNIRP is only concerned whether this form of radiation causes burns, heatstroke, or shocks.

Many doctors and scientists are raising concerns about the biological effects associated with nonthermal frequencies, pulsations, and other signalling characteristics. There is a large body of science showing non-thermal biological and health effects from RFR exposure. What is profoundly misleading about that ICNIRP guidelines is that when the general public thinks about health concerns from a phone mast, they are not thinking shocks and heatstroke. The general public's concern related to RF radiation have to do with cancer, immune suppression, neurodegenerative diseases including Alzheimer's, Parkinson's and ALS, behavioural problems, learning disabilities, birth defects and infertility.

There are concerns regarding government's use of the ICNIRP guidelines. See - Self-referencing authorships behind the ICNIRP 2020 radiation protection guidelines. The Abstract concludes "the ICNIRP 2020 Guidelines fail to meet fundamental scientific quality requirements and are therefore not suited as the basis on which to set RF EMF exposure limits for the protection of human health. With its thermal-only view, ICNIRP contrasts with the majority of research findings, and would therefore need a particularly solid scientific foundation. Our analysis demonstrates the contrary to be the case. Hence, the ICNIRP 2020 Guidelines cannot offer a basis for good governance." Einar Flydal et al. (2022). [(5)]

Also, please read the important paper published on the National Library of Medicine from 2016 by neuroscientist Dr Sarah Starkey: Inaccurate official assessment of radiofrequency safety by the Advisory Group on Non-ionising Radiation 'The executive summary and overall conclusions did not accurately reflect the scientific evidence available. Independence is needed from the International Commission on Non-Ionizing Radiation Protection (ICNIRP), the group that set the exposure guidelines being assessed. This conflict of interest critically needs to be addressed for the forthcoming World Health Organisation (WHO) Environmental Health Criteria Monograph on Radiofrequency Fields. Decision makers, organisations and individuals require accurate information about the safety of RF electromagnetic signals if they are to be able to fulfil their safeguarding responsibilities and protect those for whom they have legal responsibility.' [(6)]

Politicians at the EU Parliament also raise concerns. Read the report by Klaus Buchner and Michele Rivasi, Members of the European Parliament, on ICNIRP and the long history of infiltration by telecom influence, and EU plans to roll out 5G. The International Commission on Non-Ionizing Radiation Protection Conflicts of interest, corporate capture, and the push for 5G. [(7)]

## Legal cases and Action

The UK ICNIRP guidelines along with the US guidelines are outdated and obsolete and are obviously not protecting public health. On Friday 13th August 2021 in the USA Robert F. Kennedy Jr.'s Children's Health Defense and the Environmental Health Trust successfully sued the FCC in a historic lawsuit against the FCC for ignoring 11,000 pages of scientific and medical evidence showing biological effects, so we can no longer rely on industry assurances of safety. (8)

The USA Children's Health Defense (CHD) launched a campaign on 9th September 2022 calling on the public to Stop 5G near Schools and to take action by emailing state and local officials saying, '**Our Children Are Not Guinea Pigs**!' The report provides details to the scientific literature that clearly documents adverse health effects of RF exposure, including developmental delays, memory and attention deficits, heightened risk to type 2 diabetes and changes to the blood predictive of cancer. CHD also raise concerns about cell towers and small cells posing **considerable fire safety threats**, compounding the existing risks to our children when placing masts near schools. (9)

The Radiation Research Trust received direct support from the USA's Children's health Defense (CHD) for a letter sent directly to Boris Johnson 27th April 2020 calling on the Government to halt the 5G deployment. Here is the statement from Robert F. Kennedy, Jr Chairman of CHD, and Dafna Tachover in support for the EM Radiation Research Trust:

"Robert F. Kennedy, Jr Chairman of CHD, and Dafna Tachover, Director of CHD's 5G & Wireless Harms project support the UK EM Radiation Research Trust in their call on the UK Government to defend the rights and health of UK citizens and especially children from Big Telecom's scheme to rollout 5G. The harms of radiofrequencies and microwave-based technologies have been proven scientifically and the harms are existing and widespread. We work daily with children who have been injured from this technology including from 5G small cell installations. The UK's ICNIRP based guidelines, just like the US's FCC, are decades obsolete and false. ICNIRP is an industry shell, and its scientists are tainted as has been confirmed by Courts. Robert F. Kennedy, Jr calls on Prime Minister Boris Johnson and political leaders to protect those who have been harmed already by this radiation and prevent further harm. We must stop the uncontrolled proliferation of wireless technology and the on-going deployment of 5G, which will exponentially increase exposure to this harmful radiation and consequently, the sickness of children, adults, and the ecosystem." (10)

Cornerstone Telecommunication offer ICNIRP as a 'certificate of safety' which does not provide any level of protection for industry or government decision makers. Previous Chairman for ICNIRP Paolo Vecchia presented at the EM Radiation Research Trust conference in September 2008. In his presentation, he made it clear that: "**the ICNIRP guidelines are neither mandatory prescriptions for safety, the "last word" on the issue nor are they defensive walls for Industry or others**." (11)
This statement makes it clear that the decision to adopt these guidelines into national legislation as 'sufficient to protect public health' is political.

**Considering this information, I call on Sefton Council and planning to dismiss any claims of safety for the phone mast based on ICNIRP.**

## The Stewart Report

Cornerstone Telecommunication's refers to (The Stewart Report). The Stewart Report was chaired by Sir William Stewart in response to the DTI request. The Stewart Report (2000, 2005) recommended that the beam of greatest intensity from a mobile phone mast antenna should not fall of any part of a school's grounds or buildings without the informed consent of the school and parents.

Sir William Stewart strengthened his call for concern in 2005 saying that the evidence for possible harm has become stronger in the (almost) 5 years since the publication of his original IEGMP Report. Sir William recommended that young people should be encouraged to minimise their use of a mobile phones, and that children under about 10 years old should not have one. Recently the EU REFLEX [11] project confirmed DNA and protein changes in repeated laboratory experiments that point towards the likelihood that mobile phone use and maybe base station microwave emissions may both be a cause of increased numbers of cancers." [12]

I was a member of Sir William Stewart's UK Health Protection Agency EMF Discussion Group. Sir William Stewart also presented at the EM Radiation Research Trust 2008 conference. He said: "There are additional factors that need to be taken into account in assessing any possible health effects. Populations as a whole are not genetically homogeneous, and people can vary in their susceptibility to environmental hazards. There are well established examples in the literature of the genetic predisposition of some groups, which could influence sensitivity to disease. There could also be a dependence on age. We conclude therefore that it is not possible at present to say that exposure to RF radiation, even at levels below national guidelines, is totally without potential adverse health effects, and that gaps in knowledge are sufficient to justify a precautionary approach." [13]

Cornerstone quote the Stewart Report, saying the evidence did not suggest that exposures to EMR below international guidelines could cause adverse health effects. They state that they adhere to the Stewart report and ICNIRP rules, but since 2010, there have been many publications pointing to actual harm of EMRs on children's health by mobile base stations – e.g. Meo et al (2019), studied exposure of adolescents at 2-10 mW/cm$^2$ EMR exposure from a mobile base station 200 metres from a school and this resulted in impairment of spatial working memory and attention, and delayed motor skills. [14]

The World Health Organisation

Cornerstone Telecommunication's also refers to the World Health Organisation but fails to mention the scientific consensus reached by the International Agency for Research on Cancer (IARC). IARC is a sub-group of the World Health Organization with its role to monitor and identify global causes of cancer. IARC members classified the entire RF/EMF spectrum as a"2B Possible Human Carcinogen" in 2011. The Radiation Research Trust would like to reinforce the fact that members of IARC with collective judgment found scientific consensus in reaching this decision. The vote was nearly unanimous: 29 to 1. [15]

The evidence of increased cancer risks has since been strengthened by further human studies, as well as toxicology studies in animals, which demonstrated clear evidence of tumours. The $30 million US National Toxicology Program (NTP) RF studies and the Italian Ramazzini Institute ten-year research project both found clear evidence of malignant tumours. Two different institutes with laboratories in different countries, totally independent of each other and both producing parallel consistent findings, reinforces the validity of these ground-breaking animal studies. An external peer-review panel of eleven scientists complimented the methodology of the NTP study and concluded that the results showed clear evidence of carcinogenic activity.

Many doctors and scientists are now calling for an urgent upgrade to the classification of RF - EMF from 2B to Group 1 (Known Carcinogen), the same category as tobacco. Dr Hardell stated unequivocally: "The agent is carcinogenic to humans."

In addition, many scientists are calling for action to better protect the public, including:

1) The International EMF Scientist Appeal to the United Nations (www.emfscientist.org)

2) Rejection of the current ICNIRP guidelines for not being protective of health (www.emfcall.org)
3) Halting the 5G rollout until adequate safety studies have been done. (www.5Gappeal.eu)

Important recent legal developments

**The case, EAM v East Sussex County Council (Special educational needs) features a child who suffers electrosensitivity.** Upper Tribunal Judge Jacobs found that the child should be considered disabled under the Equality Act 2010, and she required an Education, Health, and Care Plan (EHCP). **This ground-breaking legal decision is significant as it would be difficult for Sefton Council to shield children from exposure to radiation from a phone mast near a school should a child go on to develop or suffer with electrosensitivity because of exposure to radiation from the mast.** [16]

**In addition, The Secretary of State is to be challenged in the Court of Appeal** on failure to give adequate information to the public about the risks of 5G and to explain the absence of a process for investigation of any adverse health effects. Michael Mansfield QC, Philip Rule and Lorna Hackett of Hackett & Dabbs LLP represent the claimants. **The Court of Appeal has granted permission on two grounds concerning**:

1. The failure to provide adequate or effective information to the public about the risks and how, if it be possible, it might be possible for individuals to avoid or minimise the risks;
2. (a) The failure to provide adequate and sufficient reasons for not establishing a process to investigate and establish the adverse health effects and risks of adverse health effects from 5G technology and/or for discounting the risks presented by the evidence available; and/or (b) failure to meet the requirements of transparency and openness required of a public body.

These grounds advance a breach of the Human Rights Act 1998 by omissions and failings in violation of the positive obligations to protect human life, health, and dignity, required to be met by Articles 2, 3 and/or 8 of the European Convention on Human Rights. The case has been sent back to the Administrative Court. [17]

**Recently, a German court** has clarified in a lawsuit that property owners who rent space for base stations and mobile towers assume responsibility for health consequences of the activity. Although the radiation is lower than the relevant reference values from the authorities, this does not mean that the property owner is not responsible for negative health consequences. The same responsibility principles should also apply in the UK. [18]

**In June 2022, a 59-year-old UK social worker won 'early ill health retirement'** for disabling 'Electromagnetic Hypersensitivity (EHS): In relation to EHS, the Independent Registered Medical Practitioner (IRMP) report concludes: "Mrs. Burns has a medical condition that renders her permanently incapable of undertaking any gainful work. There currently are no treatments available for her condition; avoidance of emissions is the only way to significantly reduce her symptoms." Whilst such emissions were historically presumed to be biologically inert and are still purported to be safe by many to this day, there is now highly credible evidence to the contrary. [19]

Here in the UK, a landmark legal ruling in November 2021 took place at the Planning Court, Queen's Bench Division, High Court of Justice, London with campaigners successfully claiming against Brighton and Hove Council with Hutchison 3G as the interested party. The Honourable Mr Justice Holgate overturned the local authority approval for the 5G mast to be sited close to a primary school. The ruling found that the Council "**failed to address the health impacts**" of the mast. The Council was ordered to pay the claimants costs to the agreed sum of £13,340. This finding has significant implications for all councils dealing with 5G applications, it means there is a legal responsibility to investigate effects on health. The ruling highlighted the fact that the council failed to address health impacts of the proposed mast and to obtain evidence of the assessment of the proximity to the school. The case also states the council unlawfully determined that the highway safety implications of the cabinets and the concerns expressed by the council's highway team. Sitting and appearance, are also still a 'material planning consideration' under prior approval and must be given attention. (20)

I can assure you from personal experience that the detrimental impacts from this form of radiation are profoundly serious and real. I suffered with breast cancer in 2001 after living 100m from a phone mast in Wishaw, Sutton Coldfield and led the campaign against the mast after discovering an illness/cancer cluster surrounding the mast. I have since campaigned for 20 years. (21)

I would appreciate receiving a progress report for this application. I trust you will do all you can to protect the safety of the local community.

Yours sincerely,

Eileen O'Connor
Director
EM Radiation Research Trust (An independent Charity Registered No. 1106304 © The EM Radiation Research Trust 2003-2004)
www.radiationresearch.org

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INTERNATIONAL COMMISSION ON NON-IONIZING RADIATION PROTECTION

ICNIRP
INTERNATIONAL COMMISSION ON NON-IONIZING RADIATION PROTECTION

# ICNIRP GUIDELINES

## FOR LIMITING EXPOSURE TO ELECTROMAGNETIC FIELDS (100 kHz TO 300 GHz)

PUBLISHED IN: **HEALTH PHYS 118(5): 483–524; 2020**

PUBLISHED AHEAD OF PRINT IN MARCH 2020: **HEALTH PHYS 118(00):000–000; 2020**

OPEN

Special Submission

# GUIDELINES FOR LIMITING EXPOSURE TO ELECTROMAGNETIC FIELDS (100 kHz to 300 GHz)

International Commission on Non-Ionizing Radiation Protection (ICNIRP)[1]

*Abstract*—**Radiofrequency electromagnetic fields (EMFs) are used to enable a number of modern devices, including mobile telecommunications infrastructure and phones, Wi-Fi, and Bluetooth. As radiofrequency EMFs at sufficiently high power levels can adversely affect health, ICNIRP published Guidelines in 1998 for human exposure to time-varying EMFs up to 300 GHz, which included the radiofrequency EMF spectrum. Since that time, there has been a considerable body of science further addressing the relation between radiofrequency EMFs and adverse health outcomes, as well as significant developments in the technologies that use radiofrequency EMFs. Accordingly, ICNIRP has updated the radiofrequency EMF part of the 1998 Guidelines. This document presents these revised Guidelines, which provide protection for humans from exposure to EMFs from 100 kHz to 300 GHz.**
**Health Phys. 118(5):483–524; 2020**

## INTRODUCTION

THE GUIDELINES described here are for the protection of humans exposed to radiofrequency electromagnetic fields (EMFs) in the range 100 kHz to 300 GHz (hereafter "radiofrequency"). This publication replaces the 100 kHz to 300 GHz part of the ICNIRP (1998) radiofrequency guidelines, as well as the 100 kHz to 10 MHz part of the ICNIRP (2010) low-frequency guidelines. Although these guidelines are based on the best science currently available, it is recognized that there may be limitations to this knowledge that could have implications for the exposure restrictions. Accordingly, the guidelines will be periodically revised and updated as advances are made in the relevant scientific knowledge. The present document describes the guidelines and their rationale, with Appendix A providing further detail concerning the relevant dosimetry and Appendix B providing further detail regarding the biological and health effects reported in the literature.

## PURPOSE AND SCOPE

The main objective of this publication is to establish guidelines for limiting exposure to EMFs that will provide a high level of protection for all people against substantiated adverse health effects from exposures to both short- and long-term, continuous and discontinuous radiofrequency EMFs. However, some exposure scenarios are defined as outside the scope of these guidelines. Medical procedures may utilize EMFs, and metallic implants may alter or perturb EMFs in the body, which in turn can affect the body both directly (via direct interaction between field and tissue) and indirectly (via an intermediate conducting object). For example, radiofrequency ablation and hyperthermia are both used as medical treatments, and radiofrequency EMFs can indirectly cause harm by unintentionally interfering with active implantable medical devices (see ISO 2012) or altering EMFs due to the presence of conductive implants. As medical procedures rely on medical expertise to weigh potential harm against intended benefits, ICNIRP considers such exposure managed by qualified medical practitioners (i.e., to patients, carers and comforters, including, where relevant, fetuses), as well as the utilization of conducting materials for medical procedures, as beyond the scope of these guidelines (for further information, see UNEP/WHO/IRPA 1993). Similarly, volunteer research participants are deemed to be outside the scope of these guidelines, providing that an institutional ethics committee approves such participation following consideration of potential harms and benefits. However,

[1]ICNIRP, c/o BfS, Ingolstaedter Landstr. 1, 85764, Oberschleissheim, Germany;
The International Commission on Non-Ionizing Radiation Protection (ICNIRP) collaborators are listed in the Acknowledgement section.
ICNIRP declares no conflict of interest.
For correspondence contact: Gunde Ziegelberger, c/o BfS, Ingolstaedter Landstr. 1, 85764 Oberschleissheim, Germany, or email at **info@icnirp.org**.
(*Manuscript accepted* 3 *September* 2019)
0017-9078/20/0

DOI: 10.1097/HP.0000000000001210

occupationally exposed individuals in both the clinical and research scenarios are defined as within the scope of these guidelines. Cosmetic procedures may also utilize radiofrequency EMFs. ICNIRP considers people exposed to radiofrequency EMFs as a result of cosmetic treatments without control by a qualified medical practitioner to be subject to these guidelines; any decisions concerning potential exemptions are the role of national regulatory bodies. Radiofrequency EMFs may also interfere with electrical equipment more generally (i.e., not only implantable medical equipment), which can affect health indirectly by causing equipment to malfunction. This is referred to as electromagnetic compatibility, and is outside the scope of these guidelines (for further information, see IEC 2014).

## PRINCIPLES FOR LIMITING RADIOFREQUENCY EXPOSURE

These guidelines specify quantitative EMF levels for personal exposure. Adherence to these levels is intended to protect people from all substantiated harmful effects of radiofrequency EMF exposure. To determine these levels, ICNIRP first identified published scientific literature concerning effects of radiofrequency EMF exposure on biological systems, and established which of these were both harmful to human health[3] and scientifically substantiated. This latter point is important because ICNIRP considers that, in general, reported adverse effects of radiofrequency EMFs on health need to be independently verified, be of sufficient scientific quality and consistent with current scientific understanding, in order to be taken as "evidence" and used for setting exposure restrictions. Within the guidelines, "evidence" will be used within this context, and "substantiated effect" used to describe reported effects that satisfy this definition of evidence. The reliance on such evidence in determining adverse health effects is to ensure that the exposure restrictions are based on genuine effects, rather than unsupported claims. However, these requirements may be relaxed if there is sufficient additional knowledge (such as understanding of the relevant biological interaction mechanism) to confirm that adverse health effects are reasonably expected to occur.

For each substantiated effect, ICNIRP then identified the "adverse health effect threshold;" the lowest exposure level known to cause the health effect. These thresholds were derived to be strongly conservative for typical exposure situations and populations. Where no such threshold could be explicitly obtained from the radiofrequency health literature, or where evidence that is independent from the radiofrequency health literature has (indirectly) shown that harm could occur at levels lower than the "EMF-derived threshold," ICNIRP set an "operational threshold." These are based on additional knowledge of the relation between the primary effect of exposure (e.g., heating) and health effect (e.g., pain), to provide an operational level with which to derive restriction values in order to attain an appropriate level of protection. Consistent with previous guidelines from ICNIRP, reduction factors were then applied to the resultant thresholds (or operational thresholds) to provide exposure restriction values. Reduction factors account for biological variability in the population (e.g., age, sex), variation in baseline conditions (e.g., tissue temperature), variation in environmental factors (e.g., air temperature, humidity, clothing), dosimetric uncertainty associated with deriving exposure values, uncertainty associated with the health science, and as a conservative measure more generally.

These exposure restriction values are referred to as "basic restrictions." They relate to physical quantities that are closely related to radiofrequency-induced adverse health effects. Some of these are physical quantities inside an exposed body, which cannot be easily measured, so quantities that are more easily evaluated, termed "reference levels," have been derived from the basic restrictions to provide a more-practical means of demonstrating compliance with the guidelines. Reference levels have been derived to provide an equivalent degree of protection to the basic restrictions, and thus an exposure is taken to be compliant with the guidelines if it is shown to be below either the relevant basic restrictions or relevant reference levels. Note that the relative concordance between exposures resulting from basic restrictions and reference levels may vary depending on a range of factors. As a conservative step, reference levels have been derived such that under worst-case exposure conditions (which are highly unlikely to occur in practice) they will result in similar exposures to those specified by the basic restrictions. It follows that in the vast majority of cases, observing the reference levels will result in substantially lower exposures than the corresponding basic restrictions allow. See "Reference Levels" section for further details.

The guidelines differentiate between occupationally-exposed individuals and members of the general public. Occupationally-exposed individuals are defined as adults who are exposed under controlled conditions associated with their occupational duties, trained to be aware of potential radiofrequency EMF risks and to employ appropriate harm-mitigation measures, and who have the sensory

[3]Note that the World Health Organization (1948) definition of "health" is used here. Specifically, "health is a state of complete physical, mental and social well-being and not merely the absence of disease or infirmity."

and behavioral capacity for such awareness and harm-mitigation response. An occupationally-exposed worker must also be subject to an appropriate health and safety program that provides the above information and protection. The general public is defined as individuals of all ages and of differing health statuses, which includes more vulnerable groups or individuals, and who may have no knowledge of or control over their exposure to EMFs. These differences suggest the need to include more stringent restrictions for the general public, as members of the general public would not be suitably trained to mitigate harm, or may not have the capacity to do so. Occupationally-exposed individuals are not deemed to be at greater risk than the general public, providing that appropriate screening and training is provided to account for all known risks. Note that a fetus is here defined as a member of the general public, regardless of exposure scenario, and is subject to the general public restrictions.

As can be seen above, there are a number of steps involved in deriving ICNIRP's guidelines. ICNIRP adopts a conservative approach to each of these steps in order to ensure that its limits would remain protective even if exceeded by a substantial margin. For example, the choice of adverse health effects, presumed exposure scenarios, application of reduction factors and derivation of reference levels are all conducted conservatively. The degree of protection in the exposure levels is thus greater than may be suggested by considering only the reduction factors, which represent only one conservative element of the guidelines. There is no evidence that additional precautionary measures will result in a benefit to the health of the population.

## SCIENTIFIC BASIS FOR LIMITING RADIOFREQUENCY EXPOSURE

### 100 kHz to 10 MHz EMF Frequency Range: Relation Between the Present and Other ICNIRP Guidelines

Although the present guidelines replace the 100 kHz to 10 MHz EMF frequency range of the ICNIRP (2010) guidelines, the science pertaining to direct radiofrequency EMF effects on nerve stimulation and associated restrictions within the ICNIRP (2010) guidelines has not been reconsidered here. Instead, the present process evaluated and set restrictions for adverse health effects *other than* direct effects on nerve stimulation from 100 kHz to 10 MHz, and for all adverse health effects from 10 MHz to 300 GHz. The restrictions relating to direct effects of nerve stimulation from the 2010 guidelines were then added to those derived in the present guidelines to form the final set of restrictions. Health and dosimetry considerations related to direct effects on nerve stimulation are therefore not provided here [see ICNIRP (2010) for further information].

### Quantities, Units and Interaction Mechanisms

A brief overview of the electromagnetic quantities and units employed in this document, as well as the mechanisms of interaction of these with the body, is provided here. A more detailed description of the dosimetry relevant to the guidelines is provided in Appendix A, "Quantities and Units" section.

Radiofrequency EMFs consist of oscillating electric and magnetic fields; the number of oscillations per second is referred to as "frequency," and is described in units of hertz (Hz). As the field propagates away from a source, it transfers power from its source, described in units of watt (W), which is equivalent to joule (J, a measure of energy) per unit of time (*t*). When the field impacts upon material, it interacts with the atoms and molecules in that material. When a biological body is exposed to radiofrequency EMFs, some of the power is reflected away from the body, and some is absorbed by it. This results in complex patterns of electromagnetic fields inside the body that are heavily dependent on the EMF characteristics as well as the physical properties and dimensions of the body. The main component of the radiofrequency EMF that affects the body is the electric field. Electric fields inside the body are referred to as induced electric fields ($E_{ind}$, measured in volt per meter; V $m^{-1}$), and they can affect the body in different ways that are potentially relevant to health.

Firstly, the induced electric field in the body exerts a force on both polar molecules (mainly water molecules) and free moving charged particles such as electrons and ions. In both cases a portion of the EMF energy is converted to kinetic energy, forcing the polar molecules to rotate and charged particles to move as a current. As the polar molecules rotate and charged particles move, they typically interact with other polar molecules and charged particles, causing the kinetic energy to be converted to heat. This heat can adversely affect health in a range of ways. Secondly, if the induced electric field is below about 10 MHz and strong enough, it can exert electrical forces that are sufficient to stimulate nerves, and if the induced electric field is strong and brief enough (as can be the case for pulsed low frequency EMFs), it can exert electrical forces that are sufficient to cause dielectric breakdown of biological membranes, as occurs during direct current (DC) electroporation (Mir 2008).

From a health risk perspective, we are generally interested in how much EMF power is absorbed by biological tissues, as this is largely responsible for the heating effects described above. This is typically described as a function of a relevant dosimetric quantity. For example, below about 6 GHz, where EMFs penetrate deep into tissue (and thus require depth to be considered), it is useful to describe this in terms of "specific energy absorption rate" (SAR), which is the power absorbed per unit mass (W $kg^{-1}$). Conversely, above 6 GHz, where EMFs are absorbed more superficially (making depth less relevant), it is useful to describe exposure in terms of the density of absorbed power over area (W $m^{-2}$), which we refer to as "absorbed power density" ($S_{ab}$). In these guidelines, SAR is specified over different masses to better match particular adverse health effects; $SAR_{10g}$ represents the power absorbed (per kg) over a 10-g cubical mass, and whole-body average SAR represents power absorbed (per kg) over the entire body. Similarly, absorbed power density is specified over different areas as a function of EMF frequency. In some situations, the rate of energy deposition (power) is less relevant than the total energy deposition. This may be the case for brief exposures where there is not sufficient time for heat diffusion to occur. In such situations, specific energy absorption (SA, in J $kg^{-1}$) and absorbed energy density ($U_{ab}$, in J $m^{-2}$) are used, for EMFs below and above 6 GHz, respectively. SAR, $S_{ab}$, SA, $U_{ab}$, and $E_{ind}$ are the quantities used in these guidelines to specify the basic restrictions.

As the quantities used to specify basic restrictions can be difficult to measure, quantities that are more easily evaluated are also specified, as reference levels. The reference level quantities relevant to these guidelines are incident electric field strength ($E_{inc}$) and incident magnetic field strength ($H_{inc}$), incident power density ($S_{inc}$), plane-wave equivalent incident power density ($S_{eq}$), incident energy density ($U_{inc}$), and plane-wave equivalent incident energy density ($U_{eq}$), all measured outside the body, and electric current inside the body, I, described in units of ampere (A). Basic restriction and reference level units are shown in Table 1, and definitions of all relevant terms provided in Appendix A, in the "Quantities and Units" section.

**Radiofrequency EMF Health Research**

In order to set safe exposure levels, ICNIRP first decided whether there was evidence that radiofrequency EMFs impair health, and for each adverse effect that was substantiated, both the mechanism of interaction and the minimum exposure required to cause harm were determined (where available). This information was obtained primarily from major international reviews of the literature on radiofrequency EMFs and health. This included an in-depth review from the World Health Organization on radiofrequency EMF exposure and health that was released as a draft Technical Document (WHO 2014), and reports by the Scientific Committee on Emerging and Newly Identified Health Risks (SCENIHR 2015) and the Swedish Radiation Safety Authority (SSM 2015, 2016, 2018). These reports have reviewed an extensive body of literature, ranging from experimental research to epidemiology, and include consideration of health in children and those individuals thought to be sensitive to radiofrequency EMFs. To complement those reports, ICNIRP also considered research published since those reviews. A brief summary of this literature is provided in Appendix B, with the main conclusions provided below.

As described in Appendix B, in addition to nerve stimulation (described in ICNIRP 2010), radiofrequency EMFs can affect the body via two primary biological effects: changes in the permeability of membranes and temperature rise. Knowledge concerning relations between thermal effects and health, independent of the radiofrequency EMF literature, is also important and is described below. ICNIRP considers this appropriate given that the vast majority of radiofrequency EMF health research has been conducted

**Table 1.** Quantities and corresponding SI units used in these guidelines.

| Quantity | Symbol[a] | Unit |
|---|---|---|
| Absorbed energy density | $U_{ab}$ | joule per square meter (J $m^{-2}$) |
| Incident energy density | $U_{inc}$ | joule per square meter (J $m^{-2}$) |
| Plane-wave equivalent incident energy density | $U_{eq}$ | joule per square meter (J $m^{-2}$) |
| Absorbed power density | $S_{ab}$ | watt per square meter (W $m^{-2}$) |
| Incident power density | $S_{inc}$ | watt per square meter (W $m^{-2}$) |
| Plane-wave equivalent incident power density | $S_{eq}$ | watt per square meter (W $m^{-2}$) |
| Induced electric field strength | $E_{ind}$ | volt per meter (V $m^{-1}$) |
| Incident electric field strength | $E_{inc}$ | volt per meter (V $m^{-1}$) |
| Incident electric field strength | $E_{ind}$ | volt per meter (V $m^{-1}$) |
| Incident magnetic field strength | $H_{inc}$ | ampere per meter (A $m^{-1}$) |
| Specific energy absorption | SA | joule per kilogram (J $kg^{-1}$) |
| Specific energy absorption rate | SAR | watt per kilogram (W $kg^{-1}$) |
| Electric current | I | ampere (A) |
| Frequency | $f$ | hertz (Hz) |
| Time | $t$ | second (s) |

[a]*Italicized* symbols represent variables; quantities are described in scalar form because direction is not used to derive the basic restrictions or reference levels.

using exposures substantially lower than those shown to produce adverse health effects, with relatively little research addressing adverse health effect thresholds from known interaction mechanisms themselves. Thus, it is possible that the radiofrequency health literature may not be sufficiently comprehensive to ascertain precise thresholds. Conversely, where a more extensive literature is available that clarifies the relation between health and the primary biological effects, this can be useful for setting guidelines. For example, if the thermal physiology literature demonstrated that local temperature elevations of a particular magnitude caused harm, but radiofrequency exposure known to produce a similar temperature elevation had not been evaluated for harm, then it would be reasonable to also consider this thermal physiology literature. ICNIRP refers to thresholds derived from such additional literature as *operational* adverse health effect thresholds.

It is important to note that ICNIRP only uses operational thresholds to set restrictions where they are lower (more conservative) than those demonstrated to adversely affect health in the radiofrequency literature, or where the radiofrequency literature does not provide sufficient evidence to deduce an adverse health effect threshold. For the purpose of determining thresholds, evidence of adverse health effects arising from all radiofrequency EMF exposures is considered, including those referred to as 'low-level' and 'non-thermal', and including those where mechanisms have not been elucidated. Similarly, as there is no evidence that continuous (e.g., sinusoidal) and discontinuous (e.g., pulsed) EMFs result in different biological effects (Kowalczuk et al. 2010; Juutilainen et al. 2011), no theoretical distinction has been made between these types of exposure (all exposures have been considered empirically in terms of whether they adversely affect health).

### Thresholds for Radiofrequency EMF-Induced Health Effects

**Nerve stimulation.** Exposure to EMFs can induce electric fields within the body, which for frequencies up to 10 MHz can stimulate nerves (Saunders and Jeffreys 2007). The effect of this stimulation varies as a function of frequency, and it is typically reported as a "tingling" sensation for frequencies around 100 kHz. As frequency increases, heating effects predominate and the likelihood of nerve stimulation decreases; at 10 MHz the effect of the electric field is typically described as "warmth." Nerve stimulation by induced electric fields is detailed in the ICNIRP low frequency guidelines (2010).

**Changes to permeability of cell membranes.** When (low frequency) EMFs are pulsed, the power is distributed across a range of frequencies, which can include radiofrequency EMFs (Joshi and Schoenbach 2010). If the pulse is sufficiently intense and brief, exposure to the resultant EMFs may cause cell membranes to become permeable, which in turn can lead to other cellular changes. However, there is no evidence that the radiofrequency spectral component from an EMF pulse (without the low-frequency component) is sufficient to cause changes in the permeability of cell membranes. The restrictions on nerve stimulation in the ICNIRP (2010) guidelines (and used here) are sufficient to ensure that permeability changes do not occur, so additional protection from the resultant radiofrequency EMFs is not necessary. Membrane permeability changes have also been shown to occur with 18 GHz continuous wave exposure (e.g., Nguyen et al. 2015). This has only been demonstrated in vitro, and the effect requires very high exposure levels (circa 5 kW $kg^{-1}$, over many minutes) that far exceed those required to cause thermally-induced harm (see "Temperature rise" section). Therefore, there is also no need to specifically set restrictions to protect against this effect, as the restrictions designed to protect against smaller temperature rises described in the "Temperature Rise" section will also provide protection against this.

**Temperature rise.** Radiofrequency EMFs can generate heat in the body and it is important that this heat is kept to a safe level. However, as can be seen from Appendix B, there is a dearth of radiofrequency exposure research using sufficient power to cause heat-induced health effects. Of particular note is that although exposures (and resultant temperature rises) have occasionally been shown to cause severe harm, the literature lacks concomitant evidence of the lowest exposures required to cause harm. For very low exposure levels (such as within the ICNIRP (1998) basic restrictions) there is extensive evidence that the amount of heat generated is not sufficient to cause harm, but for exposure levels above those of the ICNIRP (1998) basic restriction levels, there is limited research. Where there is good reason to expect health impairment at temperatures lower than those shown to impair health via radiofrequency EMF exposure, ICNIRP uses those lower temperatures as a basis for its restrictions (see "Radiofrequency EMF health research" section).

It is important to note that these guidelines restrict radiofrequency EMF exposure to limit temperature rise rather than absolute temperature, whereas health effects are primarily related to absolute temperature. This strategy is used because it is not feasible to limit absolute temperature, which is dependent on many factors that are outside the scope of these guidelines, such as environmental temperature, clothing and work rate. This means that if exposure caused a given temperature rise, this could improve, not affect, or impair health depending on a person's initial temperature. For example, mild heating can be pleasant if a person is cold, but unpleasant if they are already very hot. The restrictions are therefore set to avoid significant increase in temperature, where "significant" is considered in light of both potential harm and normal physiological temperature variation. These guidelines differentiate between steady-state temperature rises (where temperature increases slowly, allowing time for heat to dissipate over a larger tissue mass and for thermoregulatory processes to counter temperature rise), and brief temperature rises (where there may not be sufficient time for heat to dissipate, which can result in larger temperature rises in small regions given the same absorbed radiofrequency energy). This distinction suggests the need to account for steady-state and brief exposure durations separately.

*Steady-state temperature rise*

*Body core temperature*. Body core temperature refers to the temperature deep within the body, such as in the abdomen and brain, and varies substantially as a function of such factors as sex, age, time of day, work rate, environmental conditions and thermoregulation. For example, although the mean body core temperature is approximately 37°C (and within the "normothermic" range[4]), this typically varies over a 24-h period to meet physiological needs, with the magnitude of the variation as large as 1°C (Reilly et al. 2007). As thermal load increases, thermoregulatory functions such as vasodilation and sweating can be engaged to restrict body core temperature rise. This is important because a variety of health effects can occur once body core temperature has increased by more than approximately 1°C (termed "hyperthermia"). For example, risk of accident increases with hyperthermia (Ramsey et al. 1983), and at body core temperatures >40°C it can lead to heat stroke, which can be fatal (Cheshire 2016).

Detailed guidelines are available for minimizing adverse health risk associated with hyperthermia within the occupational setting (ACGIH 2017). These aim to modify work environments in order to keep body core temperature within +1°C of normothermia, and require substantial knowledge of each particular situation due to the range of variables that can affect it. As described in Appendix B, body core temperature rise due to radiofrequency EMFs that results in harm is only seen where temperature increases more than +1°C, with no clear evidence of a specific threshold for adverse health effects. Due to the limited literature available, ICNIRP has adopted a conservative temperature rise value as the operational adverse health effect threshold (the 1°C rise of ACGIH 2017). It is important to note that significant physiological changes can occur when body core temperature increases by 1°C. Such changes are part of the body's normal thermoregulatory response (e.g., Van den Heuvel et al. 2017), and thus do not *in themselves* represent an adverse health effect.

Recent theoretical modeling and generalization from experimental research across a range of species predicts that exposures resulting in a whole-body average SAR of approximately 6 W $kg^{-1}$, within the 100 kHz to 6 GHz range, over at least a 1-hour interval under thermoneutral conditions[5] (28°C, naked, at rest), is required to induce a 1°C body core temperature rise in human adults. A higher SAR is required to reach this temperature rise in children due to their more-efficient heat dissipation (Hirata et al. 2013). However, given the limited measurement data available, ICNIRP has adopted a conservative position and uses 4 W $kg^{-1}$ averaged over 30 min as the radiofrequency EMF exposure level corresponding to a body core temperature rise of 1°C. An averaging time of 30 min is used to take into account the time it takes to reach a steady-state temperature (for more details, see Appendix A, "Temporal averaging considerations" section). As a comparison, a human adult generates a total of approximately 1 W $kg^{-1}$ at rest (Weyand et al. 2009), nearly 2 W $kg^{-1}$ standing, and 12 W $kg^{-1}$ running (Teunissen et al. 2007).

As EMF frequency increases, exposure of the body and the resultant heating becomes more superficial, and above about 6 GHz this heating occurs predominantly within the skin. For example, 86% of the power at 6 and 300 GHz is absorbed within 8 and 0.2 mm of the surface respectively (Sasaki et al. 2017). Compared to heat in deep tissues, heat in superficial tissues is more easily removed from the body because it is easier for the thermal energy to transfer to the environment. This is why basic restrictions to protect against body core temperature rise have traditionally been limited to frequencies below 10 GHz (e.g., ICNIRP 1998). However, research has shown that EMF frequencies above 300 GHz (e.g., infrared radiation) can increase body core temperature beyond the 1°C operational adverse health effect threshold described above (Brockow et al. 2007). This is because infrared radiation, as well as lower frequencies within the scope of the present guidelines, cause heating within the dermis, and the extensive vascular network within the dermis can transport this heat deep within the body. It is therefore appropriate to also protect against body core temperature rise above 6 GHz.

ICNIRP is not aware of research that has assessed the effect of 6 to 300 GHz EMFs on body core temperature, nor of research that has demonstrated that it is harmful. However, as a conservative measure, ICNIRP uses the 4 W $kg^{-1}$ corresponding to the operational adverse health effect threshold for frequencies up to 6 GHz, for the >6 to 300 GHz range also. In support of this being a conservative value, it has been shown that 1260 W $m^{-2}$ (incident power density) infrared radiation exposure to one side of the body results in a 1°C body core temperature rise (Brockow et al., 2007). If we related this to the exposure of a 70 kg adult with an exposed surface area of 1 $m^2$ and no skin reflectance, this would result in a whole-body exposure of approximately 18 W $kg^{-1}$; this is far higher than the 4 W $kg^{-1}$ exposure level for EMFs below 6 GHz that is taken to represent a 1°C body

[4]Normothermia refers to the thermal state within the body whereby active thermoregulatory processes are not engaged to either increase or decrease body core temperature.

[5]Thermoneutral refers to environmental conditions that allow body core temperature to be maintained solely by altering skin blood flow.

core temperature rise. This is viewed as additionally conservative given that the Brockow et al. study reduced heat dissipation using a thermal blanket, which would underestimate the exposure required to increase body core temperature under typical conditions.

*Local temperature*. In addition to body core temperature, excessive localized heating can cause pain and thermal damage. There is an extensive literature showing that skin contact with temperatures below 42°C for extended periods will not cause pain or damage cells (e.g., Defrin et al. 2006). As described in Appendix B, this is consistent with the limited data available for radiofrequency EMF heating of the skin [e.g., Walters et al. (2000) reported a pain threshold of 43°C using 94 GHz exposure], but fewer data are available for heat sources that penetrate beyond the protective epidermis and to the heat-sensitive epidermis/dermis interface. However, there is also a substantial body of literature assessing thresholds for tissue damage which shows that damage can occur at tissue temperatures >41–43°C, with damage likelihood and severity increasing as a function of time at such temperatures (e.g., Dewhirst et al. 2003; Yarmolenko et al. 2011; Van Rhoon et al. 2013).

The present guidelines treat radiofrequency EMF exposure that results in local temperatures of 41°C or greater as potentially harmful. As body temperature varies as a function of body region, ICNIRP treats exposure to different regions separately. Corresponding to these regions, the present guidelines define two tissue types which, based on their temperature under normothermal conditions, are assigned different operational adverse health effect thresholds; "Type-1" tissue (all tissues in the upper arm, forearm, hand, thigh, leg, foot, pinna and the cornea, anterior chamber and iris of the eye, epidermal, dermal, fat, muscle, and bone tissue), and "Type-2" tissue (all tissues in the head, eye, abdomen, back, thorax, and pelvis, excluding those defined as Type-1 tissue). The normothermal temperature of Type 1 tissue is typically <33–36 °C, and that of Type-2 tissue <38.5 °C (DuBois 1941; Aschoff and Wever 1958; Arens and Zhang 2006; Shafahi and Vafai 2011). These values were used to define operational thresholds for local heat-induced health effects; adopting 41 °C as potentially harmful, the present guidelines take a conservative approach and treat radiofrequency EMF-induced temperature rises of 5°C and 2°C, within Type-1 and Type-2 tissue, respectively, as operational adverse health effect thresholds for local exposure.

It is difficult to set exposure restrictions as a function of the above tissue-type classification. ICNIRP thus defines two regions and sets separate exposure restrictions, where relevant, for these regions: "Head and Torso," comprising the head, eye, pinna, abdomen, back, thorax and pelvis, which includes both Type-1 and Type-2 tissue, and the "Limbs," comprising the upper arm, forearm, hand, thigh, leg and foot, which only includes Type-1 tissue. Exposure levels have been determined for each of these regions such that they do not result in temperature rises of more than 5°C and 2°C, in Type-1 and Type-2 tissue, respectively. As the Limbs, by definition, do not contain any Type-2 tissue, the operational adverse health effect threshold for the Limbs is always 5°C.

The testes can be viewed as representing a special case, whereby reversible, graded, functional change can occur within normal physiological temperature variation if maintained over extended periods, with no apparent threshold. For example, spermatogenesis is reversibly reduced as a result of the up to 2°C increase caused by normal activities such as sitting (relative to standing; Mieusset and Bujan 1995). Thus, it is possible that the operational adverse health effect threshold for Type-2 tissue may result in reversible changes to sperm function. However, there is currently no evidence that such effects are sufficient to impair health. Accordingly, ICNIRP views the operational adverse health effect threshold of 2°C for Type-2 tissue, which is within the normal physiological range for the testes, as appropriate for them also. Note that the operational adverse health effect threshold for Type-2 tissue, which includes the abdomen and thus potentially the fetus, is also consistent with protecting against the fetal temperature rise threshold of 2°C for teratogenic effects in animals (Edwards et al. 2003; Ziskin and Morrissey 2011).

Within the 100 kHz to 6 GHz EMF range, average SAR over 10 g provides an appropriate measure of the radiofrequency EMF-induced steady-state temperature rise within tissue. A 10-g mass is used because, although there can initially be EMF-induced temperature heterogeneity within that mass, heat diffusion rapidly distributes the thermal energy to a much larger volume that is well-represented by a 10-g cubic mass (Hirata and Fujiwara 2009). In specifying exposures that correspond to the operational adverse health effect thresholds, ICNIRP thus specifies an average exposure over a 10-g cubic mass, such that the exposure will keep the Type-1 and Type-2 tissue temperature rises to below 5 and 2°C respectively. Further, ICNIRP assumes realistic exposures (exposure scenarios that people may encounter in daily life, including occupationally), such as from EMFs from radio-communications sources. This method provides for higher exposures in the Limbs than in the Head and Torso. A $SAR_{10g}$ of at least 20 W $kg^{-1}$ is required to exceed the operational adverse health effect thresholds in the Head and Torso, and 40 W $kg^{-1}$ in the Limbs, over an interval sufficient to produce a steady-state temperature (from a few minutes to 30 min). This time interval is operationalized as a 6-min average as it closely matches the thermal time constant for local exposure.

Within the >6 to 300 GHz range, EMF energy is deposited predominantly in superficial tissues; this makes $SAR_{10g}$, which includes deeper tissues, less relevant to this frequency range. Conversely, absorbed power density ($S_{ab}$) provides a measure of the power absorbed in tissue that closely approximates the superficial temperature rise (Funahashi et al. 2018). From 6 to 10 GHz there may still be significant absorption in the subcutaneous tissue. However, the maximum and thus worst-case temperature rise from 6 to 300 GHz is close to the skin surface, and exposure that will restrict temperature rise to below the operational adverse health effect threshold for Type-1 tissue (5°C) will also restrict temperature rise to below the operational adverse health effect threshold for Type-2 tissue (2°C). Note that there is uncertainty with regard to the precise frequency for the change from SAR to absorbed power density. Six GHz was chosen because at that frequency, most of the absorbed power is within the cutaneous tissue, which is within the upper half of a 10-g SAR cubic volume (that is, it can be represented by the 2.15 cm × 2.15 cm surface of the cube). Recent thermal modeling and analytical solutions suggest that for EMF frequencies between 6 and 30 GHz, the exposure over a square averaging area of 4 $cm^2$ provides a good estimate of local maximum temperature rise (Hashimoto et al. 2017; Foster et al. 2017). As frequency increases further, the averaging area needs to be reduced to account for the possibility of smaller beam diameters, such that it is 1 $cm^2$ from approximately 30 GHz to 300 GHz. Although the averaging area that best corresponds to temperature rise would therefore gradually change from 4 $cm^2$ to 1 $cm^2$ as frequency increases from 6 to 300 GHz, ICNIRP uses a square averaging area of 4 $cm^2$ for >6 to 300 GHz as a practical protection specification. Moreover, from >30 to 300 GHz (where focal beam exposure can occur), an additional spatial average of 1 $cm^2$ is used to ensure that the operational adverse health effect thresholds are not exceeded over smaller regions.

As 6 minutes is an appropriate averaging interval (Morimoto et al. 2017), and as an absorbed power density of approximately 200 W $m^{-2}$ is required to produce the Type-1 tissue operational adverse health effect threshold of a 5°C local temperature rise for frequencies of >6 to 300 GHz (Sasaki et al. 2017), ICNIRP has set the absorbed power density value for local heating, averaged over 6 min and a square 4-$cm^2$ region, at 200 W $m^{-2}$; this will also restrict temperature rise in Type-2 tissue to below the operational adverse health effect threshold of 2°C. An additional specification of 400 W $m^{-2}$ has been set for spatial averages of square 1-$cm^2$ regions, for frequencies >30 GHz.

*Rapid temperature rise*

For some types of exposure, rapid temperature rise can result in "hot spots," heterogeneous temperature distribution over tissue mass (Foster et al. 2016; Morimoto et al. 2017; Laakso et al. 2017; Kodera et al. 2018). This suggests the need to consider averaging over smaller time-intervals for certain types of exposure. Hot spots can occur for short duration exposures because there is not sufficient time for heat to dissipate (or average out) over tissue. This effect is more pronounced as frequency increases due to the smaller penetration depth.

To account for such heterogeneous temperature distributions, an adjustment to the steady-state exposure level is required. This can be achieved by specifying the maximum exposure level allowed, as a function of time, in order to restrict temperature rise to below the operational adverse health effect thresholds.

From 400 MHz to 6 GHz, ICNIRP specifies the restriction in terms of specific energy absorption (SA) of any 10-g cubic mass, where SA is restricted to $7.2[0.05+0.95(t/360)^{0.5}]$ kJ $kg^{-1}$ for Head and Torso, and $14.4[0.025+0.975(t/360)^{0.5}]$ kJ $kg^{-1}$ for Limb exposure, where $t$ is exposure interval in seconds (Kodera et al. 2018). Note that for this specification, exposure from any pulse, group of pulses, or subgroup of pulses in a train, as well as from the total (sum) of exposures (including non-pulsed EMF), delivered in $t$ seconds, must not exceed the below formulae (in order to ensure that the temperature thresholds are not exceeded).

There is no brief-interval exposure level specified below 400 MHz because, due to the large penetration depth, the total SA resulting from the 6-minute local SAR average cannot increase temperature by more than the operational adverse health effect threshold (regardless of the particular pattern of pulses or brief exposures).

Above 6 GHz, ICNIRP specifies the exposure level for both Head and Torso, and Limbs, in terms of absorbed energy density ($U_{ab}$) over any square averaging area of 4 $cm^2$, such that $U_{ab}$ is specified as $72[0.05+0.95(t/360)^{0.5}]$ kJ $m^{-2}$, where $t$ is the exposure interval in seconds (extension of Kodera et al. 2018).

An additional exposure level for square 1-$cm^2$ averaging areas is applicable for EMFs with frequencies of >30 to 300 GHz to account for focused beam exposure and is given by $144[0.025+0.975(t/360)^{0.5}]$ kJ $m^{-2}$.

The SA and $U_{ab}$ values are conservative in that they are not sufficient to raise Type 1 or Type 2 tissue temperatures by 5 or 2°C, respectively.

## GUIDELINES FOR LIMITING RADIOFREQUENCY EMF EXPOSURE

As described in the "Scientific Basis for Limiting Radiofrequency Exposure" section, radiofrequency EMF levels corresponding to operational adverse health effects were identified. Basic restrictions have been derived from these and are described in the "Basic Restrictions" section below. The basic restrictions related to nerve stimulation

**Table 2.** Basic restrictions for electromagnetic field exposure from 100 kHz to 300 GHz, for averaging intervals ≥6 min.[a]

| Exposure scenario | Frequency range | Whole-body average SAR ($W\ kg^{-1}$) | Local Head/Torso SAR ($W\ kg^{-1}$) | Local Limb SAR ($W\ kg^{-1}$) | Local $S_{ab}$ ($W\ m^{-2}$) |
|---|---|---|---|---|---|
| Occupational | 100 kHz to 6 GHz | 0.4 | 10 | 20 | NA |
| | >6 to 300 GHz | 0.4 | NA | NA | 100 |
| General public | 100 kHz to 6 GHz | 0.08 | 2 | 4 | NA |
| | >6 to 300 GHz | 0.08 | NA | NA | 20 |

[a]Note:

1. "NA" signifies "not applicable" and does not need to be taken into account when determining compliance.
2. Whole-body average SAR is to be averaged over 30 min.
3. Local SAR and $S_{ab}$ exposures are to be averaged over 6 min.
4. Local SAR is to be averaged over a 10-g cubic mass.
5. Local $S_{ab}$ is to be averaged over a square 4-$cm^2$ surface area of the body. Above 30 GHz, an additional constraint is imposed, such that exposure averaged over a square 1-$cm^2$ surface area of the body is restricted to two times that of the 4-$cm^2$ restriction.

for EMF frequencies 100 kHz to 10 MHz, from ICNIRP (2010), were then added to the present set of basic restrictions, with the final set of basic restrictions given in Tables 2–4. Reference levels were derived from those final basic restrictions and are described in the "Reference Levels" section, with details of how to treat multiple frequency fields in terms of the restrictions in the "Simultaneous Exposure to Multiple Frequency Fields" section. Contact current guidance is provided in the "Guidance for Contact Currents", and health considerations for occupational exposure are described in the "Risk Mitigations Considerations for Occupational Exposure" section. To be compliant with the present guidelines, for each exposure quantity (e.g., E-field, H-field, SAR), and temporal and spatial averaging condition, either the basic restriction or corresponding reference level must be adhered to; compliance with both is not required. Note that where restrictions specify particular averaging intervals, 'all' such averaging intervals must comply with the restrictions.

### Basic Restrictions

Basic restriction values are provided in Tables 2–4 with an overview of their derivation described below. As described above, the basic restrictions from ICNIRP (2010) for the frequency range 100 kHz to 10 MHz have not been re-evaluated here; these are described in Table 4. A more detailed description of issues pertinent to the basic restrictions is provided in Appendix A, in the "Relevant Biophysical Mechanisms" section. Note that for the basic restrictions described below, a pregnant woman is treated as a member of the general public. This is because recent modeling suggests that for both whole-body and local exposure scenarios, exposure of the mother at the occupational basic restrictions can lead to fetal exposures that exceed the general public basic restrictions.

**Whole-body average SAR (100 kHz to 300 GHz).** As described in the "Body core temperature" section, the guidelines take a whole-body average SAR of 4 $W\ kg^{-1}$,

**Table 3.** Basic restrictions for electromagnetic field exposure from 100 kHz to 300 GHz, for integrating intervals >0 to <6 min.[a]

| Exposure scenario | Frequency range | Local Head/Torso SA ($kJ\ kg^{-1}$) | Local Limb SA ($kJ\ kg^{-1}$) | Local $U_{ab}$ ($kJ\ m^{-2}$) |
|---|---|---|---|---|
| Occupational | 100 kHz to 400 MHz | NA | NA | NA |
| | >400 MHz to 6 GHz | $3.6[0.05+0.95(t/360)^{0.5}]$ | $7.2[0.025+0.975(t/360)^{0.5}]$ | NA |
| | >6 to 300 GHz | NA | NA | $36[0.05+0.95(t/360)^{0.5}]$ |
| General public | 100 kHz to 400 MHz | NA | NA | NA |
| | >400 MHz to 6 GHz | $0.72[0.05+0.95(t/360)^{0.5}]$ | $1.44[0.025+0.975(t/360)^{0.5}]$ | NA |
| | >6 to 300 GHz | NA | NA | $7.2[0.05+0.95(t/360)^{0.5}]$ |

[a]Note:

1. "NA" signifies "not applicable" and does not need to be taken into account when determining compliance.
2. $t$ is time in seconds, and restrictions must be satisfied for all values of $t$ between >0 and <360 s, regardless of the temporal characteristics of the exposure itself.
3. Local SA is to be averaged over a 10-g cubic mass.
4. Local $U_{ab}$ is to be averaged over a square 4-$cm^2$ surface area of the body. Above 30 GHz, an additional constraint is imposed, such that exposure averaged over a square 1-$cm^2$ surface area of the body is restricted to $72[0.025+0.975(t/360)^{0.5}]$ for occupational and $14.4[0.025+0.975(t/360)^{0.5}]$ for general public exposure.
5. Exposure from any pulse, group of pulses, or subgroup of pulses in a train, as well as from the summation of exposures (including non-pulsed EMFs), delivered in $t$ s, must not exceed these levels.

**Table 4.** Basic restrictions for electromagnetic field exposure from 100 kHz to 10 MHz, for peak spatial values.[a]

| Exposure scenario | Frequency range | Induced electric field; $E_{ind}$ (V $m^{-1}$) |
|---|---|---|
| Occupational | 100 kHz to 10 MHz | $2.70 \times 10^{-4} f$ |
| General public | 100 kHz to 10 MHz | $1.35 \times 10^{-4} f$ |

[a]Note:

1. $f$ is frequency in Hz.

2. Restriction values relate to any region of the body, and are to be averaged as root mean square (rms) values over 2 mm × 2 mm × 2 mm contiguous tissue (as specified in ICNIRP 2010).

averaged over the entire body mass and a 30-minute interval, as the exposure level corresponding to the operational adverse health effect threshold for an increase in body core temperature of 1°C. A reduction factor of 10 was applied to this threshold for occupational exposure to account for scientific uncertainty, as well as differences in thermal physiology across the population and variability in environmental conditions and physical activity levels. Variability in an individual's ability to regulate their body core temperature is particularly important as it is dependent on a range of factors that the guidelines cannot control. These include central and peripherally-mediated changes to blood perfusion and sweat rate (which are in turn affected by a range of other factors, including age and certain medical conditions), as well as behavior and environmental conditions.

Thus the basic restriction for occupational exposure becomes a whole-body average SAR of 0.4 W $kg^{-1}$, averaged over 30 min. Although this means that SAR can be larger for smaller time intervals, this will not affect body core temperature rise appreciably because the temperature will be "averaged-out" within the body over the 30-min interval, and it is this time-averaged temperature rise that is relevant here. Further, as both whole-body and local restrictions must be met simultaneously, exposures sufficiently high to be hazardous locally will be protected against by the local restrictions described below.

As the general public cannot be expected to be aware of exposures and thus to mitigate risk, a reduction factor of 50 was applied for the general public, making the whole-body average SAR restriction for the general public 0.08 W $kg^{-1}$, averaged over 30 min.

It is noteworthy that the scientific uncertainty pertaining to both dosimetry and potential health consequences of whole-body radiofrequency exposure have reduced substantially since the ICNIRP (1998) guidelines. This would justify less conservative reduction factors, but as ICNIRP considers that the benefits of maintaining stable basic restrictions outweighs any benefits that subtle changes to them would provide, ICNIRP has retained the same reduction factors as before for the whole-body average basic restrictions. Similarly, although temperature rise is more superficial as frequency increases (and thus it is easier for the resultant heat to be lost to the environment), the whole-body average SAR restrictions above 6 GHz have been conservatively set the same as those ≤6 GHz.

**Local SAR (100 kHz to 6 GHz)**

*Head and Torso*

As described in the "Local temperature" section within the 100 kHz to 6 GHz range, the guidelines take a SAR of 20 W $kg^{-1}$, averaged over a 10-g cubic mass and 6-min interval, as the local exposure level corresponding to the operational adverse health effect threshold for the Head and Torso (5°C in Type-1 tissue and 2°C in Type-2 tissue). A reduction factor of 2 was applied to this for occupational exposure to account for scientific uncertainty, as well as differences in thermal physiology across the population and variability in environmental conditions and physical activity levels. Reduction factors for local exposure are smaller than for whole-body exposure because the associated health effect threshold is less dependent on environmental conditions and the highly variable centrally-mediated thermoregulatory processes, and because the associated health effect is less serious medically. Thus, the basic restriction for occupational exposure becomes a $SAR_{10g}$ of 10 W $kg^{-1}$, averaged over a 6-min interval. As the general public cannot be expected to be aware of exposures and thus to mitigate risk, and also recognizing greater differences in thermal physiology in the general population, a reduction factor of 10 was applied for the general public, reducing the general public basic restriction to a $SAR_{10g}$ of 2 W $kg^{-1}$ averaged over a 6-min interval.

*Limbs*

As described in the "Local temperature" section, within the 100 kHz to 6 GHz range, the guidelines take a SAR of 40 W $kg^{-1}$, averaged over a 10-g cubic mass and 6-min interval, as the local exposure level corresponding to the operational adverse health effect threshold for the Limbs of a 5°C rise in local temperature. As with the Head and Torso restrictions, a reduction factor of 2 was applied to this threshold for occupational exposure to account for scientific uncertainty, as well as differences in thermal physiology across the population and variability in environmental conditions and physical activity levels. This results in a basic restriction for occupational exposure of a $SAR_{10g}$ of 20 W $kg^{-1}$. As the general public cannot be expected to be aware of exposures and thus to mitigate risk, and also to recognize greater differences in thermal physiology in the general population, a reduction factor of 10 was applied for the general public, reducing the general public restriction to 4 W $kg^{-1}$ averaged over a 6-min interval.

**Local SA (400 MHz to 6 GHz).** As described in the "Rapid temperature rise" section, within the >400 MHz to 6 GHz range, an additional constraint is required to ensure that the cumulative energy permitted by the 6-minute average $SAR_{10g}$ basic restriction is not absorbed by tissues too rapidly. Accordingly, ICNIRP sets an SA level for exposure intervals of less than 6 min, as a function of time, to limit temperature rise to below the operational adverse health effect thresholds. This SA level, averaged over a 10-g cubic mass, is given by $7.2[0.05+0.95(t/360)^{0.5}]$ kJ kg$^{-1}$ for the Head and Torso, and $14.4[0.025+0.975(t/360)^{0.5}]$ kJ kg$^{-1}$ for the Limbs, where $t$ is exposure duration in seconds.

As with the $SAR_{10g}$ basic restrictions, a reduction factor of 2 was applied to these exposure levels for occupational exposure to account for scientific uncertainty, as well as differences in thermal physiology across the population and variability in environmental conditions and physical activity levels. This results in a basic restriction for the Head and Torso of $3.6[0.05+0.95(t/360)^{0.5}]$ kJ kg$^{-1}$, and for the Limbs of $7.2[0.025+0.975(t/360)^{0.5}]$ kJ kg$^{-1}$. As the general public cannot be expected to be aware of exposures and thus to mitigate risk, and to recognize greater differences in thermal physiology in the general population, a reduction factor of 10 was applied for the general public. This makes the general public restriction $0.72[0.05+0.95(t/360)^{0.5}]$ kJ kg$^{-1}$ for the Head and Torso, and $1.44[0.025+0.975(t/360)^{0.5}]$ kJ kg$^{-1}$ for the Limbs.

Note that for these brief exposure basic restrictions, the exposure from any pulse, group of pulses, or subgroup of pulses in a train, as well as from the summation of exposures (including non-pulsed EMFs), delivered in $t$ seconds, must not exceed these local SA values.

**Local absorbed power density (>6 GHz to 300 GHz).** As described in the "Local temperature" section, within the >6 to 300 GHz range, the guidelines take an absorbed power density of 200 W m$^{-2}$, averaged over 6 min and a square 4-cm$^2$ surface area of the body, as the local exposure corresponding to the operational adverse health effect threshold for both the Head and Torso, and Limb regions (5 and 2°C local temperature rise in Type-1 and Type-2 tissue, respectively). As with the local SAR restrictions, a reduction factor of 2 was applied to this exposure level for occupational exposure to account for scientific uncertainty, as well as differences in thermal physiology across the population and variability in environmental conditions and physical activity levels. This results in a basic restriction for occupational exposure of 100 W m$^{-2}$, averaged over 6 min and a square 4-cm$^2$ surface area of the body.

As the general public cannot be expected to be aware of these exposures and thus to mitigate risk, and to recognize greater differences in thermal physiology in the general population, a reduction factor of 10 was applied, which reduces the general public basic restriction to 20 W m$^{-2}$, averaged over 6 min and a square 4-cm$^2$ surface area of the body.

Further, to account for focal beam exposure from >30 to 300 GHz, absorbed power density averaged over a square 1-cm$^2$ surface area of the body must not exceed 2 times that of the 4-cm$^2$ basic restrictions for workers or the general public.

**Local absorbed energy density (>6 GHz to 300 GHz).** As described in the "Rapid temperature rise" section, within the >6 to 300 GHz range, an additional constraint is required to ensure that the cumulative energy permitted by the 6-min average absorbed power density basic restriction is not absorbed by tissue too rapidly. Accordingly, for both the Head and Torso, and Limbs, ICNIRP set a maximum absorbed energy density level for exposure intervals of less than 6 minutes, as a function of time, to limit temperature rise to below the operational adverse health effect thresholds for both Type-1 and Type-2 tissues. This absorbed energy density level, averaged over any square 4-cm$^2$ surface area of the body, is given by $72[0.05+0.95(t/360)^{0.5}]$ kJ m$^{-2}$, where $t$ is exposure duration in seconds. To account for focal beam exposure from >30 to 300 GHz, the absorbed energy density level corresponding to the operational adverse health effect threshold, averaged over a square 1-cm$^2$ surface area of the body, is given by $144[0.025+0.975(t/360)^{0.5}]$ kJ m$^{-2}$. Note that for these basic restrictions for brief exposures, the exposure from any pulse, group of pulses, or subgroup of pulses in a train, as well as from the summation of exposures (including non-pulsed EMFs), delivered in $t$ seconds, must be used to satisfy this formula.

As with the absorbed power density basic restrictions, a reduction factor of 2 was applied to this exposure level for occupational exposure to account for scientific uncertainty, as well as differences in thermal physiology across the population and variability in environmental conditions and physical activity levels. This results in a basic restriction for occupational exposure of $36[0.05+0.95(t/360)^{0.5}]$ kJ m$^{-2}$, over any square 4-cm$^2$ surface area of the body. From >30 to 300 GHz, an additional basic restriction for occupational exposure is $72[0.025+0.975(t/360)^{0.5}]$ kJ m$^{-2}$, averaged over any square 1-cm$^2$ surface area of the body. As the general public cannot be expected to be aware of exposures and thus to mitigate risk, and to recognize greater differences in thermal physiology in the general population, a reduction factor of 10 was applied for the general public, reducing the general public restriction to $7.2[0.05+0.95(t/360)^{0.5}]$ kJ m$^{-2}$, averaged over any square 4-cm$^2$ surface area of the body. From >30 to 300 GHz, an additional basic restriction for the general public is $14.4[0.025+0.975(t/360)^{0.5}]$ kJ m$^{-2}$, averaged over any square 1-cm$^2$ surface area of the body.

**Basic restriction tables.** To be compliant with the basic restrictions, radiofrequency EMF exposure must not exceed the restrictions specified for that EMF frequency in Table 2, 3 or 4. That is, for any given radiofrequency EMF frequency, relevant whole-body SAR, local

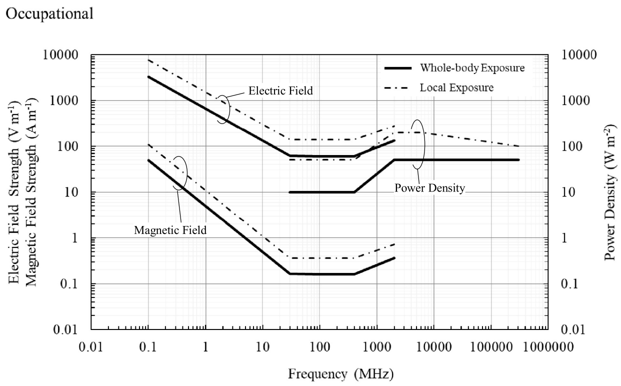


**FIGURE 1.** Reference levels for time averaged occupational exposures of ≥6 min, to electromagnetic fields from 100 kHz to 300 GHz (unperturbed rms values; see Tables 5 and 6 for full specifications).

SAR, $S_{ab}$, SA, $U_{ab}$ and induced E-field[6] restrictions must be met simultaneously.

## Reference Levels

Reference levels have been derived from a combination of computational and measurement studies to provide a means of demonstrating compliance using quantities that are more-easily assessed than basic restrictions, but that provide an equivalent level of protection to the basic restrictions for worst-case exposure scenarios. However, as the derivations rely on conservative assumptions, in most exposure scenarios the reference levels will be more conservative than the corresponding basic restrictions. Further details regarding the reference levels are provided in Appendix A, the "Derivation of Reference Levels" section.

Reference levels are provided in Tables 5–9. Figures 1 and 2 provide graphical representations of the occupational and general public reference level values for extended durations of exposure (≥6 min). Table 5 reference levels are averaged over a 30-min interval, and correspond to the whole-body average basic restrictions. Table 6 (averaged over a 6-min interval), Table 7 (integrated over intervals between >0 and <6 min), and Table 8 (peak instantaneous field strength measures) each relate to basic restrictions that are averaged over smaller body regions. Additional limb current reference levels have been set to account for effects of grounding near human body resonance frequencies (Dimbylow 2001) that might otherwise lead to reference levels underestimating exposures within tissue at certain EMF frequencies (averaged over 6 min; Table 9). Limb current reference levels are only relevant in exposure scenarios where a person is not electrically isolated.

[6]Note that although the term internal is used in place of induced in ICNIRP (2010), induced is used here for consistency within the present document.

Tables 5–9 specify averaging and integrating times of the relevant exposure quantities to determine whether personal exposure level is compliant with the guidelines. These averaging times are not necessarily the same as the measurement times needed to estimate field strengths or other exposure quantities. Depending on input from technical standards bodies, actual measurement times used to provide an appropriate estimate of exposure quantities may be shorter than the intervals specified in these tables.

An important consideration for the application of reference levels is to what degree the quantities used to assess compliance with the reference levels (i.e., $E_{inc}$, $H_{inc}$, $S_{inc}$, $U_{inc}$, $S_{eq}$, $U_{eq}$, I) adequately predict the quantities used to assess compliance with the basic restrictions. In situations where reference level quantities are associated with greater uncertainty, reference levels must be applied more conservatively. For the purposes of the guidelines, the degree of adequacy strongly depends on whether external EMFs can be considered to be within the far-field, radiative near-field or reactive near-field zone. Accordingly, in most cases, different reference level assessment rules have been set for EMFs as a function of whether they are within the far-field, radiative or reactive near-field zone.

A difficulty with this approach is that other factors may also affect the adequacy of estimating basic restriction quantities from reference level quantities. These include the EMF frequency, physical dimensions of the EMF source and its distance from the resultant external EMFs assessed, as well as the degree to which the EMFs vary over the space to be occupied by a person. Taking into account such sources of uncertainty, the guidelines have more conservative rules for exposure in the reactive and radiative near-field than far-field zone. It is noted that there is no simple delineation of the far-field, radiative and reactive near-field zones that is sufficient for ensuring that reference levels will adequately correspond to the basic restrictions. Accordingly, although a definition of these zones is provided in

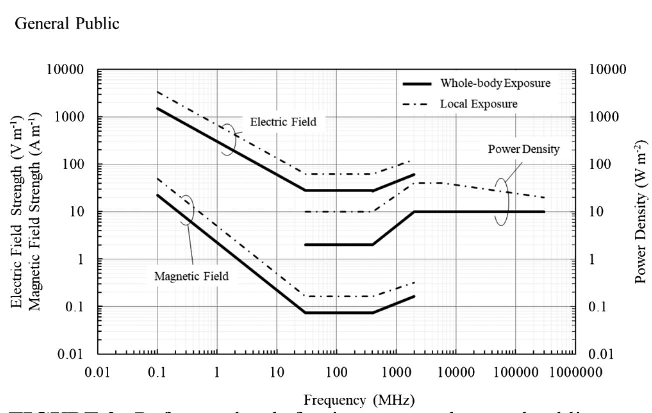


**FIGURE 2.** Reference levels for time averaged general public exposures of ≥6 min, to electromagnetic fields from 100 kHz to 300 GHz (unperturbed rms values; see Tables 5 and 6 for full specifications).

**Table 5.** Reference levels for exposure, averaged over 30 min and the whole body, to electromagnetic fields from 100 kHz to 300 GHz (unperturbed rms values).[a]

| Exposure scenario | Frequency range | Incident E-field strength; $E_{inc}$ (V $m^{-1}$) | Incident H-field strength; $H_{inc}$ (A $m^{-1}$) | Incident power density; $S_{inc}$ (W $m^{-2}$) |
|---|---|---|---|---|
| Occupational | 0.1 – 30 MHz | $660/f_M^{0.7}$ | $4.9/f_M$ | NA |
| | >30 – 400 MHz | 61 | 0.16 | 10 |
| | >400 – 2000 MHz | $3f_M^{0.5}$ | $0.008f_M^{0.5}$ | $f_M/40$ |
| | >2 – 300 GHz | NA | NA | 50 |
| General public | 0.1 – 30 MHz | $300/f_M^{0.7}$ | $2.2/f_M$ | NA |
| | >30 – 400 MHz | 27.7 | 0.073 | 2 |
| | >400 – 2000 MHz | $1.375f_M^{0.5}$ | $0.0037f_M^{0.5}$ | $f_M/200$ |
| | >2 – 300 GHz | NA | NA | 10 |

[a]Note:

1. "NA" signifies "not applicable" and does not need to be taken into account when determining compliance.

2. $f_M$ is frequency in MHz.

3. $S_{inc}$, $E_{inc}$, and $H_{inc}$ are to be averaged over 30 min, over the whole-body space. Temporal and spatial averaging of each of $E_{inc}$ and $H_{inc}$ must be conducted by averaging over the relevant square values (see eqn 8 in Appendix A for details).

4. For frequencies of 100 kHz to 30 MHz, regardless of the far-field/near-field zone distinctions, compliance is demonstrated if neither $E_{inc}$ or $H_{inc}$ exceeds the above reference level values.

5. For frequencies of >30 MHz to 2 GHz: (a) within the far-field zone: compliance is demonstrated if either $S_{inc}$, $E_{inc}$ or $H_{inc}$, does not exceed the above reference level values (only one is required); $S_{eq}$ may be substituted for $S_{inc}$; (b) within the radiative near-field zone, compliance is demonstrated if either $S_{inc}$, or both $E_{inc}$ and $H_{inc}$, does not exceed the above reference level values; and (c) within the reactive near-field zone: compliance is demonstrated if both $E_{inc}$ and $H_{inc}$ do not exceed the above reference level values; $S_{inc}$ cannot be used to demonstrate compliance, and so basic restrictions must be assessed.

6. For frequencies of >2 GHz to 300 GHz: (a) within the far-field zone: compliance is demonstrated if $S_{inc}$ does not exceed the above reference level values; $S_{eq}$ may be substituted for $S_{inc}$; (b) within the radiative near-field zone, compliance is demonstrated if $S_{inc}$ does not exceed the above reference level values; and (c) within the reactive near-field zone, reference levels cannot be used to determine compliance, and so basic restrictions must be assessed.

Appendix A in the "General Considerations for Reference Levels" section this is only intended as a guide, and information from a technical standards body, designed to specify external exposures for each EMF source type to more adequately match the basic restrictions, should be utilized to improve reference level assessment procedures.

Related to the near- and far-field zone distinctions, for some exposure conditions the less onerous plane wave equivalent incident power density ($S_{eq}$) and plane wave equivalent incident energy density ($U_{eq}$) quantities can be used in place of $S_{inc}$ and $U_{inc}$, respectively; where this is permitted, it is specified below. In such cases, the *plane wave equivalent incident energy densities* are to be averaged in the same way as described in Tables 5–7 for the corresponding *incident power densities*.

In terms of electromagnetic fields in the far-field zone, the following rules apply. For EMF frequencies from >30 MHz to 2 GHz, ICNIRP requires compliance to be demonstrated for only one of the E-field, H-field or $S_{inc}$ quantities in order to be compliant with that particular reference level. Further, $S_{eq}$ can be substituted for $S_{inc}$. Similarly, for EMF frequencies >400 MHz where the restrictions are specified in terms of $U_{inc}$, these can be substituted for by $U_{eq}$. EMF frequencies from 100 kHz to 30 MHz are treated as always being within the near-field zone; see next paragraph.

In terms of electromagnetic fields in the near-field zones, the following rules apply. From 100 kHz to 30 MHz, relevant personal exposures from present radiofrequency EMF sources are typically within the near-field zone. The present guidelines treat *all* exposures within this frequency range as near-field, and requires compliance with both the E-field and H-field reference level values in order to be compliant with the reference levels. For EMF frequencies from >30 MHz to 2 GHz, personal exposure within either the radiative or reactive near-field zones is treated as compliant if both the E-field and H-field strengths are below the reference level values described in the tables. For frequencies >30 MHz to 300 GHz, personal exposure within the radiative near-field zone is treated as compliant if $S_{inc}$ (or, where relevant $U_{inc}$) is below the reference level value. However, for exposure within the >2 to 300 GHz range, within the reactive near-field the quantities applied for the reference level values are treated as inadequate to ensure compliance with the basic restrictions. In such cases, compliance with the basic restrictions must be assessed.

ICNIRP is aware that for some exposure scenarios, radiofrequency EMFs at the reference levels specified below could potentially result in exposure that exceeds basic restrictions. Where such scenarios were identified, ICNIRP determined whether the reference levels needed to be reduced by considering the magnitude of the difference between the resultant tissue exposure and corresponding basic restriction (including comparison with the associated dosimetric uncertainty), and whether the violation was likely to adversely affect health (including consideration of the degree of conservativeness in the associated basic

**Table 6.** Reference levels for local exposure, averaged over 6 min, to electromagnetic fields from 100 kHz to 300 GHz (unperturbed rms values).[a]

| Exposure scenario | Frequency range | Incident E-field strength; $E_{inc}$ (V $m^{-1}$) | Incident H-field strength; $H_{inc}$ (A $m^{-1}$) | Incident power density; $S_{inc}$ (W $m^{-2}$) |
|---|---|---|---|---|
| Occupational | 0.1 – 30 MHz | $1504/f_M^{0.7}$ | $10.8/f_M$ | NA |
| | >30 – 400 MHz | 139 | 0.36 | 50 |
| | >400 – 2000 MHz | $10.58 f_M^{0.43}$ | $0.0274 f_M^{0.43}$ | $0.29 f_M^{0.86}$ |
| | >2 – 6 GHz | NA | NA | 200 |
| | >6 – <300 GHz | NA | NA | $275/f_G^{0.177}$ |
| | 300 GHz | NA | NA | 100 |
| General public | 0.1 – 30 MHz | $671/f_M^{0.7}$ | $4.9/f_M$ | NA |
| | >30 – 400 MHz | 62 | 0.163 | 10 |
| | >400 – 2000 MHz | $4.72 f_M^{0.43}$ | $0.0123 f_M^{0.43}$ | $0.058 f_M^{0.86}$ |
| | >2 – 6 GHz | NA | NA | 40 |
| | >6 – 300 GHz | NA | NA | $55/f_G^{0.177}$ |
| | 300 GHz | NA | NA | 20 |

[a] Note:

1. "NA" signifies "not applicable" and does not need to be taken into account when determining compliance.

2. $f_M$ is frequency in MHz; $f_G$ is frequency in GHz.

3. $S_{inc}$, $E_{inc}$, and $H_{inc}$ are to be averaged over 6 min, and where spatial averaging is specified in Notes 6–7, over the relevant projected body space. Temporal and spatial averaging of each of $E_{inc}$ and $H_{inc}$ must be conducted by averaging over the relevant square values (see eqn 8 in Appendix A for details).

4. For frequencies of 100 kHz to 30 MHz, regardless of the far-field/near-field zone distinctions, compliance is demonstrated if neither peak spatial $E_{inc}$ or peak spatial $H_{inc}$, over the projected whole-body space, exceeds the above reference level values.

5. For frequencies of >30 MHz to 6 GHz: (a) within the far-field zone, compliance is demonstrated if one of peak spatial $S_{inc}$, $E_{inc}$ or $H_{inc}$, over the projected whole-body space, does not exceed the above reference level values (only one is required); $S_{eq}$ may be substituted for $S_{inc}$; (b) within the radiative near-field zone, compliance is demonstrated if either peak spatial $S_{inc}$, or both peak spatial $E_{inc}$ and $H_{inc}$, over the projected whole-body space, does not exceed the above reference level values; and (c) within the reactive near-field zone: compliance is demonstrated if both $E_{inc}$ and $H_{inc}$ do not exceed the above reference level values; $S_{inc}$ cannot be used to demonstrate compliance; for frequencies >2 GHz, reference levels cannot be used to determine compliance, and so basic restrictions must be assessed.

6. For frequencies of >6 GHz to 300 GHz: (a) within the far-field zone, compliance is demonstrated if $S_{inc}$, averaged over a square 4-$cm^2$ projected body surface space, does not exceed the above reference level values; $S_{eq}$ may be substituted for $S_{inc}$; (b) within the radiative near-field zone, compliance is demonstrated if $S_{inc}$, averaged over a square 4-$cm^2$ projected body surface space, does not exceed the above reference level values; and (c) within the reactive near-field zone reference levels cannot be used to determine compliance, and so basic restrictions must be assessed.

7. For frequencies of >30 GHz to 300 GHz, exposure averaged over a square 1-$cm^2$ projected body surface space must not exceed twice that of the square 4-$cm^2$ restrictions.

restriction). Where the difference was small, and where it would not adversely affect health, reference levels were retained that can potentially result in exposures that exceed the basic restrictions.

This situation has been shown to occur in terms of the reference levels corresponding to whole-body average SAR basic restrictions, which, in the frequency range of body resonance (up to 100 MHz) and from 1 to 4 GHz, can potentially lead to whole-body average SARs that exceed the basic restrictions (ICNIRP 2009). The exposure scenario where this can potentially occur is very specific, requiring a small stature person (such as a 3-years-old child) to be extended (e.g., standing still and straight with arms above the head) for at least 30 min, while being subject to a plane wave exposure within the above frequency ranges, incident to the child from front to back. The resultant SAR elevation is small relative to the basic restriction (15–40%), which is similar to or smaller than the whole-body average SAR measurement uncertainty (Flintoft et al. 2014; Nagaoka and Watanabe 2019), there are many levels of conservativeness built into the basic restriction derivation itself, and importantly, this will not impact on health. This latter point is important because the basic restriction that this relates to was set to protect against body core temperature rises of greater than 1°C, and being of small stature, the individual in this hypothetical exposure scenario would more easily dissipate heat to the environment than a larger person due to their increased body "surface area-to-mass ratio" (Hirata et al. 2013). Within a small stature person the net effect of this "increased whole-body average SAR" and "increased heat loss" would be a smaller temperature rise than would occur in a person of larger stature who did not exceed the basic restriction, and in both cases would be substantially smaller than 1°C. ICNIRP has thus not altered the reference levels to account for this situation.

**Simultaneous Exposure to Multiple Frequency Fields**

It is important to determine whether, in situations of simultaneous exposure to fields of different frequencies, these

**Table 7.** Reference levels for local exposure, integrated over intervals of between >0 and <6 minutes, to electromagnetic fields from 100 kHz to 300 GHz (unperturbed rms values).[a]

| Exposure scenario | Frequency range | Incident energy density; $U_{inc}$ (kJ $m^{-2}$) |
|---|---|---|
| Occupational | 100 kHz – 400 MHz | NA |
| | >400 – 2000 MHz | $0.29 f_M^{0.86} \times 0.36[0.05+0.95(t/360)^{0.5}]$ |
| | >2 – 6 GHz | $200 \times 0.36[0.05+0.95(t/360)^{0.5}]$ |
| | >6 – <300 GHz | $275/f_G^{0.177} \times 0.36[0.05+0.95(t/360)^{0.5}]$ |
| | 300 GHz | $100 \times 0.36[0.05+0.95(t/360)^{0.5}]$ |
| General public | 100 kHz – 400 MHz | NA |
| | >400 – 2000 MHz | $0.058 f_M^{0.86} \times 0.36[0.05+0.95(t/360)^{0.5}]$ |
| | >2 – 6 GHz | $40 \times 0.36[0.05+0.95(t/360)^{0.5}]$ |
| | >6 – <300 GHz | $55/f_G^{0.177} \times 0.36[0.05+0.95(t/360)^{0.5}]$ |
| | 300 GHz | $20 \times 0.36[0.05+0.95(t/360)^{0.5}]$ |

[a]Note:

1. "NA" signifies "not applicable" and does not need to be taken into account when determining compliance.
2. $f_M$ is frequency in MHz; $f_G$ is frequency in GHz; $t$ is time interval in seconds, such that exposure from any pulse, group of pulses, or subgroup of pulses in a train, as well as from the summation of exposures (including non-pulsed EMFs), delivered in $t$ seconds, must not exceed these reference level values.
3. $U_{inc}$ is to be calculated over time $t$, and where spatial averaging is specified in Notes 5–7, over the relevant projected body space.
4. For frequencies of 100 kHz to 400 MHz, >0 to <6-min restrictions are not required and so reference levels have not been set.
5. For frequencies of >400 MHz to 6 GHz: (a) within the far-field zone: compliance is demonstrated if peak spatial $U_{inc}$, over the projected whole-body space, does not exceed the above reference level values; $U_{eq}$ may be substituted for $U_{inc}$; (b) within the radiative near-field zone, compliance is demonstrated if peak spatial $U_{inc}$, over the projected whole-body space, does not exceed the above reference level values; and (c) within the reactive near-field zone, reference levels cannot be used to determine compliance, and so basic restrictions must be assessed.
6. For frequencies of >6 GHz to 300 GHz: (a) within the far-field or radiative near-field zone, compliance is demonstrated if $U_{inc}$, averaged over a square 4-$cm^2$ projected body surface space, does not exceed the above reference level values; (b) within the reactive near-field zone, reference levels cannot be used to determine compliance, and so basic restrictions must be assessed.
7. For frequencies of >30 GHz to 300 GHz: exposure averaged over a square 1-$cm^2$ projected body surface space must not exceed $275/f_G^{0.177} \times 0.72[0.025+0.975(t/360)^{0.5}]$ kJ $m^{-2}$ for occupational and $55/f_G^{0.177} \times 0.72[0.025+0.975(t/360)^{0.5}]$ kJ $m^{-2}$ for general public exposure.

exposures are additive in their effects. Additivity should be examined separately for the effects of thermal and electrical stimulation, and restrictions met after accounting for such additivity. The formulae below apply to relevant frequencies under practical exposure situations. As the below reference level summation formulae assume worst-case conditions among the fields from multiple sources, typical exposure situations may in practice result in lower exposure levels than indicated by the formulae for the reference levels.

The following issues are noted. In terms of the reference levels, the largest ratio of the E-field strength, H-field strength or power density, relative to the corresponding reference level values, should be evaluated to demonstrate compliance. Reference levels are defined in terms of external physical quantities and have transitions, in terms of quantities, at specific frequencies. For example, field strengths are used below 30 MHz, whereas both field strength and incident power density are applicable from 30 MHz to 2 GHz. Where the exposure includes frequency components below and above the transition, additivity should be used to account for this. The same principle applies for basic restrictions. Field values entering the below equations must be derived using the same spatial and temporal constraints referred to in the basic restriction and reference level tables. The summation equations for basic restrictions and reference levels are presented separately below. However, for practical compliance purposes,

**Table 8.** Reference levels for local exposure to electromagnetic fields from 100 kHz to 10 MHz (unperturbed rms values), for peak values.[a]

| Exposure scenario | Frequency range | Incident E-field strength; $E_{inc}$ (V $m^{-1}$) | Incident H-field strength; $H_{inc}$ (A $m^{-1}$) |
|---|---|---|---|
| Occupational | 100 kHz – 10 MHz | 170 | 80 |
| General public | 100 kHz – 10 MHz | 83 | 21 |

[a]Note:

1. Regardless of the far-field/near-field zone distinction, compliance is demonstrated if neither peak spatial $E_{inc}$ or peak spatial $H_{inc}$, over the projected whole-body space, exceeds the above reference level values.

**Table 9.** Reference levels for current induced in any limb, averaged over 6 min, at frequencies from 100 kHz to 110 MHz. [a]

| Exposure scenario | Frequency range | Electric current; I (mA) |
|---|---|---|
| Occupational | 100 kHz – 110 MHz | 100 |
| General public | 100 kHz – 110 MHz | 45 |

[a]Note

1. Current intensity values must be determined by averaging over the relevant square values (see eqn 8 in Appendix A for details).
2. Limb current intensity must be evaluated separately for each limb.
3. Limb current reference levels are not provided for any other frequency range.
4. Limb current reference levels are only required for cases where the human body is not electrically isolated from a ground plane.

the evaluation by basic restriction and reference level can be combined. For example, the second term in eqn (2) can be replaced by the fourth term in eqn (4) for frequency components above 6 GHz. To be compliant with the guidelines, the summed values in each of Eqn (1) to (7) must be less than 1.

**Basic restrictions for intervals ≥6 min.** For practical application of the whole-body average basic restrictions, SAR should be added according to

$$\sum_{i=100\text{ kHz}}^{300\text{ GHz}} \frac{\mathrm{SAR}_i}{\mathrm{SAR}_{\mathrm{BR}}} \leq 1, \quad (1)$$

where $\mathrm{SAR}_i$ and $\mathrm{SAR}_{\mathrm{BR}}$ are the whole-body average SAR levels at frequency *i* and the whole-body average SAR basic restrictions given in Table 2, respectively.

For practical application of the local SAR and local absorbed power density basic restrictions, values should be added according to

$$\sum_{i=100\text{ kHz}}^{6\text{ GHz}} \frac{\mathrm{SAR}_i}{\mathrm{SAR}_{\mathrm{BR}}} + \sum_{i>6\text{ GHz}}^{30\text{ GHz}} \frac{S_{ab,4cm,i}}{S_{ab,4cm,BR}} + \sum_{i>30\text{ GHz}}^{300\text{ GHz}} \mathrm{MAX}\left\{\left(\frac{S_{ab,4cm,i}}{S_{ab,4cm,BR}}\right), \left(\frac{S_{ab,1cm,i}}{S_{ab,1cm,BR}}\right)\right\} \leq 1, \quad (2)$$

where, $\mathrm{SAR}_i$ and $\mathrm{SAR}_{\mathrm{BR}}$ are the local SAR level at frequency *i* and the local SAR basic restriction given in Table 2, respectively; $S_{ab,4cm,i}$ and $S_{ab,4cm,BR}$ are the 4-cm$^2$ absorbed power density level at frequency *i* and the 4-cm$^2$ absorbed power density basic restriction given in Table 2, respectively; $S_{ab,1cm,i}$ and $S_{ab,1cm,BR}$ are the 1-cm$^2$ absorbed power density level at frequency *i* and the 1-cm$^2$ absorbed power density basic restriction given in Table 2, respectively; inside the body, $S_{ab}$ terms are to be treated as zero; when evaluating the summation of SAR and $S_{ab}$ over the body surface, the center of the SAR averaging space is taken to be x,y,z, such that the x,y plane is parallel to the body surface (z = 0) and z = −1.08 cm (approximately half the length of a 10-g cube), and the center of the $S_{ab}$ averaging area is defined as x,y,0; eqn (2) must be satisfied for every position in the human body.

**Reference levels for intervals ≥6 min.** For practical application of the whole-body average reference levels, incident electric field strength, incident magnetic field strength and incident power density values should be added according to;

$$\sum_{i=100\text{ kHz}}^{30\text{ MHz}} \left\{\left(\frac{E_{inc,i}}{E_{inc,RL,i}}\right)^2 + \left(\frac{H_{inc,i}}{H_{inc,RL,i}}\right)^2\right\} + \sum_{i>30\text{ MHz}}^{2\text{ GHz}} \mathrm{MAX}\left\{\left(\frac{E_{inc,i}}{E_{inc,RL,i}}\right)^2, \left(\frac{H_{inc,i}}{H_{inc,RL,i}}\right)^2, \left(\frac{S_{inc,i}}{S_{inc,RL,i}}\right)\right\} + \sum_{i>2\text{ GHz}}^{300\text{ GHz}} \left(\frac{S_{inc,i}}{S_{inc,RL}}\right) \leq 1, \quad (3)$$

where, $E_{inc,i}$ and $E_{inc,RL,i}$ are the whole-body average incident electric field strength and whole-body average incident electric field strength reference level given in Table 5, at frequency *i*, respectively; $H_{inc,i}$ and $H_{inc,RL,i}$ are the whole-body average incident magnetic field strength and whole-body average incident magnetic field strength reference level given in Table 5, at frequency *i*, respectively; $S_{inc,i}$ and $S_{inc,RL,i}$ are the whole-body average incident power density and whole-body average incident power density reference level given in Table 5, at frequency *i*, respectively. Note that the second term is not appropriate for the reactive near-field zone, and so cannot be used in eqn (3).

For practical application of the local reference levels, incident electric field strength, incident magnetic field strength and incident power density values should be added according to

$$\sum_{i=100\text{ kHz}}^{30\text{ MHz}} \mathrm{MAX}\left\{\left(\frac{E_{inc,i}}{E_{inc,RL,i}}\right)^2, \left(\frac{H_{inc,i}}{H_{inc,RL,i}}\right)^2\right\} + \sum_{i>30\text{ MHz}}^{2\text{ GHz}} \mathrm{MAX}\left\{\left(\frac{E_{inc,i}}{E_{inc,RL,i}}\right)^2, \left(\frac{H_{inc,i}}{H_{inc,RL,i}}\right)^2, \left(\frac{S_{inc,i}}{S_{inc,RL,i}}\right)\right\} + \sum_{i>2\text{ GHz}}^{6\text{ GHz}} \left(\frac{S_{inc,i}}{S_{inc,RL,i}}\right) + \sum_{i>6\text{ GHz}}^{30\text{ GHz}} \left(\frac{S_{inc,4cm,i}}{S_{inc,4cm,RL,i}}\right) + \sum_{i>30\text{ GHz}}^{300\text{ GHz}} \mathrm{MAX}\left\{\left(\frac{S_{inc,4cm,i}}{S_{inc,4cm,RL,i}}\right), \left(\frac{S_{inc,1cm,i}}{S_{inc,1cm,RL,i}}\right)\right\} \leq 1, \quad (4)$$

where, $E_{inc,i}$ and $E_{inc,RL,i}$ are the local incident electric field strength and local incident electric field strength reference level given in Table 6, at frequency *i*, respectively; $H_{inc,i}$ and $H_{inc,RL,i}$ are the local incident magnetic field strength and local incident magnetic field strength reference level given in Table 6, at frequency *i*, respectively; $S_{inc,i}$ and $S_{inc,RL,i}$ are the local incident power density and local incident power density reference level given in Table 6, at frequency $i$, respectively; inside the body above 6 GHz, $S_{inc}$ terms are to be treated as zero; eqn (4) must be satisfied for every position in the human body.

For practical application of the limb current reference levels, limb current values should be added according to

$$\sum_{i=100\ \text{kHz}}^{110\ \text{MHz}} \left(\frac{I_i}{I_{RL}}\right)^2 \leq 1, \quad (5)$$

where $I_i$ is the limb current component at frequency $i$; and $I_{RL}$ is the limb current reference level value from Table 9. If there are non-negligible contributions to the local SAR around limbs over 110 MHz, these need to be considered by combining corresponding terms in eqns (2) or (4).

**Basic restrictions for intervals <6 min.** For practical application of the local basic restrictions for time intervals ($t$)<6 min, SAR, SA and absorbed energy density values should be added according to:

$$\sum_{i=100\ \text{kHz}}^{400\ \text{MHz}} \int_t \frac{SAR_i(t)}{360 \times SAR_{BR}} dt + \sum_{i>400\ \text{MHz}}^{6\ \text{GHz}} \frac{SA_i(t)}{SA_{BR}(t)} + \sum_{i>6\ \text{GHz}}^{30\ \text{GHz}} \frac{U_{ab,4cm,i}(t)}{U_{ab,4cm,BR}(t)} + \sum_{i>30\ \text{GHz}}^{300\ \text{GHz}} \text{MAX}\left\{\left(\frac{U_{ab,4cm,i}(t)}{U_{ab,4cm,BR}(t)}\right), \left(\frac{U_{ab,1cm,i}(t)}{U_{ab,1cm,BR}(t)}\right)\right\} \leq 1, \quad (6)$$

where, $SAR_i(t)$ and $SAR_{BR}(t)$ are the local SAR level at frequency $i$ and the local SAR basic restriction given in Table 2, over time $t$, respectively; $SA_i(t)$ and $SA_{BR}(t)$ are the local SA level at frequency $i$ and the local SA basic restriction given in Table 3, over time $t$, respectively; $U_{ab,4cm,i}(t)$ and $U_{ab,4cm,BR}(t)$ are the 4-$cm^2$ absorbed power density level at frequency $i$ and the 4-$cm^2$ absorbed power density basic restriction given in Table 3, over time $t$, respectively; $U_{ab,1cm,i}(t)$ and $U_{ab,1cm,BR}(t)$ are the 1-$cm^2$ absorbed power density level at frequency $i$ and the 1-$cm^2$ absorbed power density basic restriction given in Table 3, over time $t$, respectively; inside the body, $U_{ab}$ terms are to be treated as zero; when evaluating the summation of SAR and/or SA, and $U_{ab}$, over the body surface, the center of the SAR and/or SA averaging space is taken to be x,y,z, such that the x,y plane is parallel to the body surface (z = 0) and z = −1.08 cm (approximately half the length of a 10-g cube), and the center of the $U_{ab}$ averaging area is defined as x,y,0; eqn (6) must be satisfied for every position in the human body; for simultaneous exposure of brief and extended exposures, SAR, SA and $U_{ab}$ must all be accounted for in this equation.

**Reference levels for intervals <6 min.** For practical application of the local reference levels for time intervals ($t$) <6 min, incident electric field strength, incident magnetic field strength, incident power density and incident energy density values should be added according to:

$$\sum_{i>100\ \text{kHz}}^{30\ \text{MHz}} \text{MAX}\left\{\left(\int_t \frac{E^2_{inc,i}(t)}{360^*E^2_{inc,RL,i}} dt\right), \left(\int_t \frac{H^2_{inc,i}(t)}{360^*H^2_{inc,RL,i}} dt\right)\right\}$$

$$+ \sum_{i>30\ \text{MHz}}^{400\ \text{MHz}} \text{MAX}\left\{\left(\int_t \frac{E^2_{inc,i}(t)}{360^*E^2_{inc,RL,i}} dt\right), \left(\int_t \frac{H^2_{inc,i}(t)}{360^*H^2_{inc,RL,i}} dt\right), \left(\int_t \frac{S_{inc,i}(t)}{360^*S_{inc,RL,i}} dt\right)\right\}$$

$$+ \sum_{i>400\ \text{MHz}}^{6\ \text{GHz}} \frac{U_{inc,i}(t)}{U_{inc,RL,i}(t)} + \sum_{i=6\ \text{GHz}}^{30\ \text{GHz}} \frac{U_{inc,4cm,i}(t)}{U_{inc,4cm,RL,i}(t)}$$

$$+ \sum_{i>30\ \text{GHz}}^{300\ \text{GHz}} \text{MAX}\left\{\left(\frac{U_{inc,4cm,i}(t)}{U_{inc,4cm,RL,i}(t)}\right), \left(\frac{U_{inc,1cm,i}(t)}{U_{inc,1cm,RL,i}(t)}\right)\right\} \leq 1, \quad (7)$$

where $E_{inc,i}(t)$ and $E_{inc,RL,i}$ are the local $E_{inc}$ level over time $t$ and the local $E_{inc}$ reference level given in Table 6, at frequency $i$, respectively; $H_{inc,i}(t)$ and $H_{inc,RL,i}$ are the local $H_{inc}$ level over time $t$ and the local $H_{inc}$ reference level given in Table 6, at frequency $i$, respectively; $S_{inc,i}(t)$ and $S_{inc,RL,i}$ are the local $S_{inc}$ level over time $t$ and the local $S_{inc}$ reference level given in Table 6, at frequency $i$, respectively; $U_{inc,i}(t)$ and $U_{inc,RL}(t)$ are the incident energy density level and the incident energy density reference level, over time $t$, at frequency $i$, given in Table 7, respectively; $U_{inc,4cm,i}(t)$ and $U_{inc,4cm,RL}(t)$ are the 4-$cm^2$ incident energy density level and the 4-$cm^2$ incident energy density reference level, over time $t$, at frequency $i$, given in Table 7, respectively; $U_{inc,1cm,i}(t)$ and $U_{inc,1cm,RL}(t)$ are the 1-$cm^2$ incident energy density level and the 1-$cm^2$ incident energy density reference level, over time $t$, at frequency $i$, given in Table 7, respectively; inside the body, $U_{inc}$ terms are to be treated as zero; eqn (7) must be satisfied for every position in the human body.

**Guidance for Contact Currents**

Within approximately the 100 kHz to 110 MHz range, contact currents can occur when a person touches a conducting object that is within an electric or magnetic field, causing current flow between object and person. At high levels these can result in nerve stimulation or pain (and potentially tissue damage), depending on EMF frequency (Kavet et al. 2014; Tell and Tell 2018). This can be a particular concern around large radiofrequency transmitters, such as those that are found near high power antennas used for broadcasting below 30 MHz and at 87.5–108 MHz, where there have been sporadic reports of pain and burn-related accidents. Contact currents occur at the region of contact, with smaller contact regions producing larger biological effects (given the same current). This is due to the larger current density (A $m^{-2}$), and consequently the higher localized SAR in the body.

Exposure due to contact currents is indirect, in that it requires an intermediate conducting object to transduce the field. This makes contact current exposure unpredictable, due to both behavioral factors (e.g., grasping versus touch contact) and environmental conditions (e.g., configuration of conductive objects), and it reduces ICNIRP's ability to protect against them. Of particular importance is the heterogeneity of the current density passing to and being absorbed by the person, which is due not only to the contact area, but also to the conductivity, density and heat capacity of the tissue through which the current passes, and most importantly the resistance between conducting object and contacting tissue (Tell and Tell 2018).

Accordingly, these guidelines do not provide restrictions for contact currents, and instead provide "guidance" to assist those responsible for transmitting high-power radiofrequency fields to understand contact currents, the potential hazards, and how to mitigate such hazards. For the purpose of specification, ICNIRP here defines high-power radiofrequency EMFs as those emitting greater than 100 V $m^{-1}$ within the frequency range 100 kHz to 100 MHz at their source.

There is limited research available on the relation between contact currents and health. In terms of pain, the health effect arising from the lowest contact current level, the main data comes from Chatterjee et al. (1986). In that study sensation and pain were assessed in a large adult cohort as a function of contact current frequency and contact type (grasping versus touch contact). Reversible, painful heat sensations were reported to occur with average (touch contact) induced current thresholds of 46 mA within the 100 kHz to 10 MHz range tested, which required at least 10 s of exposure to be reported as pain. Thresholds were frequency-independent within that range, and thresholds for grasping contact were substantially higher than those for touch contact.

However, given that the threshold value reported was an average across the participants, and given the standard deviation of the thresholds reported, ICNIRP considers that the lowest threshold across the cohort would have been approximately 20 mA. Further, modeling from that data suggests that children would have lower thresholds; extrapolating from Chatterjee et al. (1986) and Chan et al. (2013), the lowest threshold in children would be expected to be within the range of 10 mA. The upper frequency of contact current capable of causing harm is also not known. Although the ICNIRP (1998) guidelines specified reference levels to account for contact currents from 100 kHz to 110 MHz, Chatterjee et al. (1986) only tested up to 10 MHz, and Tell and Tell (2018) reported strong reductions in contact current sensitivities from about 1 MHz to 28 MHz (and did not assess higher frequencies). Thus, it is not clear that contact currents will remain a health hazard across the entire 100 kHz to 110 MHz range.

In determining the likelihood and nature of hazard due to potential contact current scenarios, ICNIRP views the above information as important for the responsible person in managing risk associated with contact currents within the frequency range 100 kHz to 110 MHz. This may also assist in conducting a risk-benefit analysis associated with allowing a person into a radiofrequency EMF environment that may result in contact currents. The above information suggests that risk of contact current hazards can be minimized by training workers to avoid contact with conducting objects, but that where contact is required, the following factors are important. Large metallic objects should be connected to ground (grounding); workers should make contact via insulating materials (e.g., radiofrequency protective gloves); and workers should be made aware of the risks, including the possibility of "surprise," which may impact on safety in ways other than the direct impact of the current on tissue (for example, by causing accidents).

**Risk Mitigation Considerations for Occupational Exposure**

To justify radiofrequency EMF exposure at the occupational level, an appropriate health and safety program is required. Part of such a program requires an understanding of the potential effects of radiofrequency EMF exposure, including consideration of whether biological effects resulting from the exposure may add to other biological effects that are unrelated to radiofrequency EMF. For example, where body core temperature is already elevated due to factors unrelated to EMF, such as through strenuous activity, radiofrequency EMF-induced temperature rise needs to be considered in conjunction with the other sources of heating. Similarly, it is also important to consider whether a person has an illness or condition that might affect their capacity to thermoregulate, or whether environmental impediments to heat dissipation might be present.

The relevant health effects that the whole-body SAR restrictions protect against are increased cardiovascular load (due to the work that the cardiovascular system must perform in order to restrict body core temperature rise), and where temperature rise is not restricted to a safe level, a cascade of functional changes that may lead to both reversible and irreversible effects on tissues (including brain, heart, and kidney). These effects typically require body core temperatures greater than 40°C (or an increase of approximately 3°C relative to normothermia). Large reduction factors have thus been used to make it extremely unlikely that radiofrequency-induced temperature rise would exceed 1°C (occupational restrictions have been set that would, under normothermic conditions, lead to body core temperature rises of <0.1°C), but care must be exercised when other factors are present that may affect body core temperature. These include high environmental temperatures, high physical activity, and impediments to normal thermoregulation (such as the use of thermally insulating clothing or certain medical conditions). Where significant heat is expected from other sources, it is advised that workers have a suitable means

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of verifying their body core temperature (see ACGIH 2017 for further guidance).

The relevant health effects that the localized basic restrictions protect against are pain and thermally-mediated tissue damage. Within Type-1 tissue, such as in the skin and limbs, pain (due to stimulation of nociceptors) and tissue damage (due to denaturation of proteins) typically require temperatures above approximately 41°C. Occupational exposure of the Limbs is unlikely to increase local temperature by more than 2.5°C, and given that Limb temperatures are normally below 31–36°C, it is unlikely that radiofrequency EMF exposure of Limb tissue, in itself, would result in either pain or tissue damage. Within Type-2 tissue, such as within regions of the Head and Torso (excluding superficial tissue), harm is also unlikely to occur at temperatures below 41°C. As occupational exposure of the Head and Torso tissue is unlikely to increase temperature by more than 1°C, and given that body core temperature is normally around 37–38°C, it is unlikely that radiofrequency EMF exposure would lead to temperature rises sufficient to harm Type-2 tissue or tissue function.

However, care must be exercised when a worker is subject to other heat sources that may add to that of the radiofrequency EMF exposure, such as those described above in relation to body core temperature. For superficial exposure scenarios, local thermal discomfort and pain can be important indicators of potential thermal tissue damage. It is thus important, particularly in situations where other thermal stressors are present, that the worker understands that radiofrequency EMF exposure can contribute to their thermal load and is in a position to take appropriate action to mitigate potential harm.

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## APPENDIX A: BACKGROUND DOSIMETRY

### Introduction

This appendix provides additional dosimetry information that is directly relevant to the derivation of the radiofrequency exposure restrictions that form the basis of the present guidelines. As described in the main document, the operational adverse health effects resulting from the lowest radiofrequency exposure levels are due to heating (nerve stimulation is discussed within the low frequency guidelines; ICNIRP 2010). Accordingly, this appendix details the choice of quantities used to restrict temperature rise to the operational adverse health effect thresholds described in the main document, the methods used to derive these restrictions (including, where relevant, the associated uncertainty), the spatial and temporal averaging methods used to represent temperature rise, and the derivation of the basic restrictions and reference levels themselves (including, where relevant, the associated uncertainty). The operational adverse health effect thresholds considered are 1°C body core temperature rise for exposures averaged over the whole body, and 5°C and 2°C local temperature rise over more-localized regions for "Type-1" and "Type-2" body tissue, respectively.[7]

## QUANTITIES AND UNITS

Detailed explanations for the basic quantities, e.g., **E**, **H**, I, T, and $t$ are found elsewhere (see ICNIRP 1985, 2009a, 2009, 2010). In this section, the other quantities used in the guidelines are detailed (i.e., SAR, SA, $S_{inc}$, $S_{ab}$, $S_{eq}$, $U_{inc}$, $U_{ab}$, and $U_{eq}$). Vector quantities are presented in **bold** font.

It is noted that radiofrequency basic restrictions and reference levels are based on the lowest radiofrequency exposure levels that may cause an adverse health effect. Since the health effects are related to the temperature rises caused by the exposure, it is determined by energy or power of the radiofrequency exposure. Therefore, squared values of **E**, **H**, and I are considered for time or spatial integration, or where summation of multiple frequencies is applied. The following equation is an example of the spatial average of **E** over a volume $V$:

$$E_{spatial\_average} = \sqrt{\frac{1}{V}\int_v |\mathbf{E}|^2 dv}, \qquad (8)$$

where $V$ is the volume of the integration ($V = \int_v dv$).

### Specific Energy Absorption Rate (SAR) and Specific Energy Absorption (SA)

SAR is defined as the time derivative of the incremental energy consumption by heat, $\delta W$, absorbed by or dissipated in an incremental mass, $\delta m$, contained in a volume element, $\delta V$, of a given mass density of the tissue (kg m$^{-3}$), $\rho$, and is expressed in watt per kilogram (W kg$^{-1}$):

$$\text{SAR} = \frac{\delta}{\delta t}\left(\frac{\delta W}{\delta m}\right) = \frac{\delta}{\delta t}\left(\frac{\delta W}{\rho \delta V}\right). \qquad (9)$$

Dielectric properties of biological tissues or organs are generally considered as dielectric lossy material and magnetically transparent because the relative magnetic permeability ($\mu_r$) is 1. Therefore, the SAR is usually derived from the following equation:

$$\text{SAR} = \frac{\sigma |\mathbf{E}|^2}{\rho}, \qquad (10)$$

where $\sigma$ is the conductivity (S m$^{-1}$) and **E** is the internal electric-field (root mean square (rms) value).

Temperature rise is strongly correlated with SAR. Under conditions where heat loss due to processes such as conduction is not significant, SAR and temperature rise are directly related as follows;

$$\text{SAR} = C\frac{d\text{T}}{dt}, \qquad (11)$$

where $C$ is specific heat capacity (J kg$^{-1}$ °C$^{-1}$) of the tissue, T is temperature (°C) and $t$ is the duration of exposure (s). For most realistic cases, a large amount of heat energy rapidly diffuses during the exposure. Therefore, eqn (11) cannot be routinely applied to human exposure scenarios. However, eqn (11) is useful for brief exposure scenarios where heat loss is not significant.

SAR is used as a basic restriction in the present guidelines. The SAR basic restrictions are defined as spatially averaged values; that is, whole-body average SAR and $\text{SAR}_{10g}$. The whole-body average SAR is the total power absorbed in the whole body divided by the body mass:

$$\text{Whole-body average SAR} = \frac{(Total\ power)_{WB}}{(Total\ mass)_{WB}} = \frac{\left[\int_{WB}\sigma|\mathbf{E}|^2 dv\right]_{WB}}{\int_{WB}\rho dv}. \qquad (12)$$

$\text{SAR}_{10g}$ is defined as the total power absorbed in a 10-g cubic volume divided by 10 g (see the "Spatial averaging considerations" section):

$$\text{SAR}_{10g} = \frac{(Total\ power)_{V_{10g}}}{(Total\ mass)_{V_{10g}}} = \frac{\left[\int_{V_{10g}}\sigma|\mathbf{E}|^2 dv\right]_{V_{10g}}}{\int_{V_{10g}}\rho dv}. \qquad (13)$$

A 10-g volume ($V_{10g}$) is approximately computed as a 2.15 cm × 2.15 cm × 2.15 cm cube, based on the assumption that the tissue has the same mass density as water, or 1,000 kg m$^{-3}$.

SA (J m$^{-3}$) is derived as the time integral of SAR during the time from $t_1$ to $t_2$:

[7]Type-1 tissue refers to all tissues in the upper arm, forearm, hand, thigh, leg, foot, pinna and the cornea, anterior chamber and iris of the eye, epidermal, dermal, fat, muscle, and bone tissue. Type-2 tissue refers to all tissues in the head, eye, abdomen, back, thorax, and pelvis, excluding those defined as Type-1 tissue.

$$\mathrm{SA} = \int_{t_1}^{t_2} \mathrm{SAR}(t)dt. \quad (14)$$

**Absorbed Power Density ($S_{ab}$) and Absorbed Energy Density ($U_{ab}$)**

$SAR_{10g}$ is no longer an appropriate surrogate for local temperature rise at frequencies above 6 GHz. Therefore, the absorbed power and energy densities are introduced in the guidelines for basic restrictions at such frequencies, where the radiofrequency power or energy absorption is largely confined within very superficial regions of the body. For example, the penetration depths are approximately 8.1 mm and 0.23 mm at 6 GHz and 300 GHz, respectively (see also Table 10). The absorbed power density (W $m^{-2}$) is defined at the body surface:

$$\mathrm{S_{ab}} = \iint_A dxdy \int_0^{Z_{max}} \rho(x,y,z) \cdot \mathrm{SAR}(x,y,z)\, \mathrm{d}z/A, \quad (15)$$

where the body surface is at $z = 0$, $A$ is the averaging area (in $m^2$), and $Z_{max}$ is depth of the body at the corresponding region; where $Z_{max}$ is much larger than the penetration depth, infinity can be substituted for $Z_{max}$. Considering heat diffusion, a square 2 cm × 2 cm region (from 6 to 300 GHz) is used for the averaging area of the absorbed power and energy density basic restrictions.

A more rigorous formula for absorbed power density is based on the Poynting vector (**S**):

$$\mathrm{S_{ab}} = \iint_A \mathrm{Re}[\mathbf{S}] \cdot \boldsymbol{ds}/A = \iint_A \mathrm{Re}[\mathbf{E} \times \mathbf{H}^*] \cdot \boldsymbol{ds}/A, \quad (16)$$

where Re[X] and X* are the real part and the complex conjugate of a complex value "X," respectively, and ***ds*** is the integral variable vector with its direction normal to the integral area $A$ on the body surface.

Similar to the relationship between SAR and SA, the absorbed energy density is derived as the temporal integration of the absorbed power density (J $m^{-2}$):

$$\mathrm{U_{ab}} = \int_{t_1}^{t_2} \mathrm{S_{ab}}(t)dt. \quad (17)$$

**Incident Power Density ($S_{inc}$) and Incident Energy Density ($U_{inc}$)**

The incident power and energy densities are used as reference levels in the guidelines. The incident power density is defined as the modulus of the complex Poynting vector:

$$\mathrm{S_{inc}} = |\mathbf{E} \times \mathbf{H}^*|. \quad (18)$$

In the case of the far-field or transverse electromagnetic (TEM) plane wave, the incident power density is derived as:

$$\mathrm{S_{inc}} = \frac{|\mathbf{E}|^2}{Z_0} = Z_0|\mathbf{H}|^2, \quad (19)$$

where $Z_0$ is the characteristic impedance of free space, i.e., 377 Ω. The above equation is also used for the evaluation of the plane wave equivalent incident power density ($S_{eq}$).

$S_{inc}$ is also related to $S_{ab}$ using the reflection coefficient Γ:

$$\mathrm{S_{ab}} = \left(1 - |\Gamma|^2\right)\mathrm{S_{inc}}. \quad (20)$$

The reflection coefficient (Γ) is derived from the dielectric properties of the tissues, shape of the body surface, incident angle, and polarization.

Similar to the relationship between SAR and SA, the incident energy density is derived as the temporal integration of the incident power density during the time from $t_1$ to $t_2$:

$$\mathrm{U_{inc}} = \int_{t_1}^{t_2} \mathrm{S_{inc}}(t)\, dt. \quad (21)$$

In near-field exposure scenarios, the components of the Poynting vector are not real values but complex ones. In such cases a detailed investigation of the Poynting vector components may be necessary to calculate the incident power density relevant to radiofrequency safety.

## RELEVANT BIOPHYSICAL MECHANISMS

### Whole-Body Average Exposure Specifications

**Relevant quantity.** Health effects due to whole-body exposure are related to body core temperature rise. It is, however, difficult to predict body core temperature rise based on exposure of the human body to radiofrequency EMFs.

Body core temperature depends on the whole-body thermal energy balance. Radiofrequency energy absorbed by the body is transferred to the body core via blood flow, which can activate thermoregulatory responses to maintain the body core temperature (Adair and Black 2003). This means that the time rate of the energy balance is essential for the body core temperature dynamics. Accordingly, whole-body average SAR is used as the physical quantity relating to body core temperature rise.

The relationship between the total energy absorption and the body core temperature is in general independent of frequency. However, at frequencies higher than a few GHz, core temperature does not generally elevate as much as with the same level of whole-body average SAR at lower frequencies because of larger heat transfer from the body surface to air via convection or radiative emission, which

**Table 10.** Penetration depth of human skin tissue (dermis), for frequencies 6 to 300 GHz.

| Frequency (GHz) | Relative permittivity | Conductivity (S/m) | Penetration depth (mm) |
|---|---|---|---|
| 6 | 36 | 4.0 | 8.1 |
| 10 | 33 | 7.9 | 3.9 |
| 30 | 18 | 27 | 0.92 |
| 60 | 10 | 40 | 0.49 |
| 100 | 7.3 | 46 | 0.35 |
| 300 | 5.0 | 55 | 0.23 |

includes the effect of vasodilation in the skin (Hirata et al. 2013). The power absorption is confined primarily within skin surface tissues where localized temperature rise is more significant than the body core temperature rise (Laakso and Hirata 2011). However, it has also been reported that infrared radiation (IR) exposure can cause significant body core temperature rise (Brockow et al. 2007). Infrared radiation refers to electromagnetic waves with frequencies between those of radiofrequency EMF and visible light. This means that despite the penetration depth of infrared radiation being very small or comparable to the high GHz radiofrequency EMFs (or millimeter waves) it is still possible for infrared radiation exposure to raise body core temperature significantly. For conservative reasons, therefore, ICNIRP set equal whole-body average limits for frequencies both above and below 6 GHz. This is especially important for cases of multiple-frequency exposure of both higher and lower frequencies. Thus, the applicable frequency is defined as the entire frequency range considered in the guidelines.

**Temporal averaging considerations.** The definition of the time constant for body core temperature is not clear. However, under simplified conditions that produce a reasonable estimate of the time constant (e.g., assuming a first order lag), temperature dynamics can be described as follows:

$$T(t) = T_0 + (T_\infty - T_0)\left(1 - e^{\frac{-t}{\tau}}\right), \quad (22)$$

where T is the temperature as a function of time $t$, $T_0$ and $T_\infty$ are the initial and steady-state temperatures, respectively, and $\tau$ is the time constant. In this case, the time constant corresponds to the time taken for 63% of the temperature rise, from initial temperature to steady state temperature, to be reached. In the present guidelines, the time to reach a steady-state of 80–90% of the equilibrium temperature, from the initial temperature, is considered for guideline setting; this is almost two times the time constant in eqn (22).

Further, the time needed to reach the steady-state body core temperature depends on the level of heat load, which in this case relates to the whole-body average SAR. Hirata et al. (2007) numerically simulated the body core temperature rise of a naked body exposed to a plane wave at 65 MHz and 2 GHz, and reported that in both cases it takes at least 60 min to reach a 1°C body core temperature rise for whole-body average SARs of 6 to 8 W $kg^{-1}$. This time is also dependent on the sweating rate, with strong sweating increasing this time by 40–100 min (Hirata et al. 2008; Nelson et al. 2013). Consequently, the time to reach the steady state temperature rise due to whole-body exposure to radiofrequency EMFs below 6 GHz is 30 min or longer.

As described above, power absorption is mainly confined within the surface tissues at frequencies above 6 GHz (see Table 10). Thermoregulatory responses are thus initiated by the skin temperature rise rather than body core temperature rise. However, the time needed for the steady state temperature rise is not significantly affected by this, and so is not taken into account. It is thus reasonable to keep the averaging time above 6 GHz the same as that below 6 GHz, because there is no quantitative investigation on the time constant of body core temperature rise above 6 GHz.

**Whole-body average SAR needed to raise body core temperature by 1°C.** Thermoregulatory functions are activated if a human body is exposed to significant heating load, which often results in non-linear relations between whole-body average SAR and body core temperature rise.

Adair and colleagues have experimentally investigated body core temperature (via esophageal temperature measurement) during whole-body exposure. They have reported no or minor increases of the esophageal temperature (<0.1°C) during the whole-body exposure at 100 MHz, 220 MHz, and 2450 MHz, with whole-body average SAR ranging from 0.54 to 1 W $kg^{-1}$ in normal ambient temperature conditions, from 24°C to 28°C (Adair et al. 2001, 2003, 2005).

They also reported a relatively high body core temperature rise (0.35°C) for whole-body average SAR at 220 MHz of 0.675 W $kg^{-1}$ in a hot ambient temperature (31°C) condition, although this was found in only one person and the mean of the body core temperature rises (6 persons) was not appreciable. There is no data on body core temperature rise for whole-body exposure to radiofrequency EMFs above 6 GHz. The only available data are on infrared radiation (Brockow et al. 2007). The conservativeness for whole-body exposure at higher frequencies is discussed in the main text.

There are two main factors affecting body core temperature rise due to radiofrequency exposure: sweating and mass-to-body surface ratio.

Evaporative heat loss due to sweating reduces body core temperature efficiently and needs to be accounted for when estimating body core temperature rise due to EMF. For example, Hirata et al. (2007) reported that 4.5 W $kg^{-1}$ is required to increase the body core temperature by 1°C for a person with a lower sweat rate, such as an elderly person, while 6 W $kg^{-1}$ is required for a person with a normal sweat rate. The decline of sweat rate in elderly people is primarily due to degradation of thermal sensation (Dufour and Candas, 2007).

Similarly, heat exchange between the body surface and external air is also very important. Hirata et al. (2009) found that the steady-state body core temperature rise due to whole-body radiofrequency EMF exposure is proportional to the ratio of the (whole-body) power absorption to the surface area of the body. The ratio of the mass to the surface area is smaller for smaller-dimension bodies such as children, and so greater whole-body average SAR is required to elevate their body core temperature.

This coincides with the finding that smaller persons have a lower body core temperature rise for the same whole-body average SAR. For example, Hirata et al. (2008) numerically evaluated the body core temperature rise in 8-months-old and 3-years-old child models and found that their body core temperature rises were 35% smaller than that of an adult female model for the same whole-body average SAR. They concluded that the higher ratio of a child's surface area to body mass is the reason for more effective cooling resulting from heat loss to the environment. Consequently, the body core temperature rise in the child is smaller than that of the adult at the same whole-body average SAR.

Addressing the issue more broadly, theoretical modeling and generalization from experimental research across a range of species has shown that within the 100 kHz to 6 GHz range, whole-body average SARs of at least 6 W $kg^{-1}$, for exposures of at least 1 h at moderately high ambient temperature (28°C), are necessary to increase body core temperature by 1°C for healthy adults and children (Hirata et al. 2013), and at least 4.5 W for those with lower sweat rates, such as the elderly (Hirata et al. 2007).

**Considerations for fetal exposure.** The primary thermoregulatory mechanism for a fetus is body core heat exchange with the mother via blood flow through the umbilical cord. The fetal temperature is therefore tightly controlled by maternal temperature, and it takes longer to reach thermal equilibrium than in adults (Gowland and De Wilde 2008). The body core temperature of the fetus is typically 0.5°C higher than that of the mother (Asakura 2004). This relationship is not changed significantly by radiofrequency EMF exposure of the mother at 26 weeks gestation, as reported by Hirata et al. (2014). In the frequency range from 40 MHz to 500 MHz, they computed steady-state fetal temperature, taking the thermal exchange between mother and fetus into account, and reported that the fetal temperature rise was only 30% higher than that of the mother, even when the power absorption was focused around the fetus. At lower frequencies, the SAR distribution becomes more homogeneous because of the longer wavelength and penetration depth, which results in more homogeneous temperature rise over the whole-body of the mother and fetus. At higher frequencies, the SAR distribution becomes more superficial because of the shorter penetration depth. This results in a smaller SAR of the young fetus or embryo, as it is generally located in the deep region of the abdomen of the mother, as well as resulting in a smaller whole-body SAR of the older fetus because the size of the fetus is larger than the penetration depth. This suggests that EMF whole-body exposure to the mother will result in a similar body core temperature rise in the fetus relative to that of the mother, even at frequencies outside those investigated in that study.

It follows that an EMF-induced body core temperature rise within the mother will result in a similar rise within the fetus, and thus an exposure at the occupational whole-body average SAR basic restriction would result in a similar body core temperature rise in mother and fetus. Therefore, to maintain fetal temperature to the level required by the general public, a pregnant woman is considered a member of the general public in terms of the whole-body average SAR basic restriction.

ICNIRP's decision on the occupational whole-body average SAR for pregnant women is significantly conservative compared with the established teratogenic fetal temperature threshold (2°C: Edwards et al. 2003; Ziskin and Morrissey 2011). ICNIRP also recognizes that the body core temperature of the fetus, especially during early stage one or embryonic development, is not clearly defined, and that there is no direct evidence that occupational whole-body exposure of the pregnant worker will harm the fetus. It is thus acknowledged that the decision to treat a pregnant worker as a member of the general public is conservative. ICNIRP also notes that there are some mitigating techniques that can be considered in order to allow pregnant workers to enter areas where radiofrequency EMFs are at occupational exposure levels, without exceeding the general public restrictions. For example, within a 30-min averaging interval, a pregnant worker could be within an area at the occupational exposure restriction level for 6 min, providing that the SAR averaged over 30 min (which includes this 6-min interval) does not exceed the general public restrictions. In considering such mitigating techniques, local region exposure restrictions for the pregnant worker are also important, and are described in the "Considerations for fetal exposure" in "Exposure Specifications for Local Regions (100 kHz to 6 GHz)" and in "Exposure Specifications for Local Regions (>6 GHz to 300 GHz)" sections.

### Exposure Specifications for Local Regions (100 kHz to 6 GHz)

**Relevant quantity.** For cases of exposure to radiofrequency EMF over localized body regions, temperature can rise in part of the body without altering body core temperature. Local temperature rise must therefore also be restricted. The maximum local temperature rise generally appears on the surface of the body, and local SAR is a useful surrogate for local temperature rise due to localized radiofrequency EMF exposure. However, other factors, such as clothing, environmental conditions, and physiological states can have more impact on local temperature than SAR itself.

The transition frequency between local SAR and area-averaged absorbed power density is chosen as 6 GHz (Funahashi et al. 2018). This was done as a practical compromise suitable for the conditions relevant to the spatial and temporal averaging described in the following subsections, because no optimal single frequency exists for this transition. For frequencies lower than the transition frequency, the SAR is a metric for simultaneously protecting both the internal tissues (e.g., brain) and the skin, as explained in the "Spatial averaging considerations" section. At higher frequencies (especially above 10 GHz), the absorbed power density is a surrogate for maximum skin temperature rise.

**Spatial averaging considerations.** Different averaging schemes (e.g., cubic, spherical, contiguous single tissue) and masses have been assessed in terms of their ability to predict local temperature rise (Hirata and Fujiwara 2009; McIntosh and Anderson 2011). These suggest that the effect of the size of the averaging mass is more crucial than the shape of the averaging volume, and that SAR varies with different averaging schemes by a factor of approximately 2 (Hirata et al. 2006). It has also been shown that SAR averaged over a single tissue provides somewhat worse correlation with local temperature than that for multiple tissues, because the heat generated in biological tissue can diffuse up to a few centimeters (i.e., across multiple tissue types). Consequently, a cubic averaging mass of 10 g, including all tissues, is used as an appropriate spatial averaging regime for frequencies up to 6 GHz. This metric has been shown to be applicable even for plane wave exposures, in that local temperature rise in the Head and Torso, and Limbs, is correlated with SAR when this averaging mass is used (Razmadze et al. 2009; Bakker et al. 2011; Hirata et al. 2013).

**Temporal averaging considerations.** Time to reach steady-state temperature, given the balance between rate of radiofrequency power deposition on one hand, and heat diffusion and conduction on the other, is characterized by the time constant of temperature rise. The time constant primarily depends on heat convection due to blood flow and thermal conduction. Van Leeuwen et al. (1999), Wang and Fujiwara (1999), and Bernardi et al. (2000) report that the time needed for 80–90% of the steady-state temperature rise, at 800 MHz to 1.9 GHz, is 12–16 min. These guidelines take 6 min as a suitable, conservative averaging time for steady-state temperature rise up to 6 GHz for local exposures.

**Local SAR required to increase local Type-1 and Type-2 tissue temperature by 5 and 2°C, respectively.** Although early research provided useful rabbit eye data concerning the relation between 2.45 GHz exposure and local temperature rise (e.g., Guy et al. 1975; Emery et al. 1975), research with more accurate techniques has demonstrated that the rabbit is an inappropriate model for the human eye (Oizumi et al. 2013). However, given the concern about potential radiofrequency harm to the eye, there are now several studies that provide more-accurate information about radiofrequency-induced heating of the human eye. Expressed as heating factors for the SAR averaged over 10 g of tissue (the °C rise per unit mass, per W of absorbed power), the computed heating factors of a human eye have been relatively consistent [0.11–0.16°C kg $W^{-1}$: Hirata (2005); Buccella et al. (2007); Flyckt et al. (2007); Hirata et al. (2007); Wainwright (2007); Laakso (2009); Diao et al. (2016)]. In most studies, the heating factor was derived for the SAR averaged over the eyeball (contiguous tissue). The SAR averaged over the cubic volume (which includes other tissues) is higher than that value (Diao et al. 2016), resulting in lower heating factors.

There is also a considerable number of studies on the temperature rise in the head exposed to mobile phone handset antennas (Van Leeuwen et al. 1999; Wang and Fujiwara 1999; Bernardi et al. 2000; Gandhi et al. 2001; Hirata and Shiozawa 2003; Ibrahim et al. 2005; Samaras et al. 2007). Hirata and Shiozawa (2003) reported that heating factors are 0.24 or 0.14°C kg $W^{-1}$ for the local SAR averaged over a 10-g contiguous volume, with and without the pinna, respectively. Other studies considering the local SAR averaged over a 10-g cubic volume including the pinna reported heating factors of the head in the range of 0.11–0.27°C kg $W^{-1}$ (Van Leeuwen et al. 1999; Bernardi et al. 2000; Gandhi et al. 2001). Fujimoto et al. (2006) studied the temperature rise in a child head exposed to a dipole antenna and found that it is comparable to that in the adult when the same thermal parameters were used. The heating factor in the brain (the ratio of the temperature rise in the brain to peak SAR in the head) is 0.1°C kg $W^{-1}$ or smaller (Morimoto et al. 2016). Only one study reported the temperature rise in the trunk for body-worn antennas (Hirata et al. 2006). This study showed that the heating factor in the skin is in the range of 0.18–0.26 °C kg $W^{-1}$. Uncertainty factors associated with the heating factors are attributable to the energy absorbed in the pinna (for mobile phones) and other surrounding structures (for example, see Foster et al. 2018) as well as the method for spatial averaging of SAR.

Those studies are consistent with research showing that, within the 100 kHz–6 GHz range, numerical estimations converge to show that the maximum heating factor is lower than 0.25°C kg $W^{-1}$ in the skin and 0.1°C kg $W^{-1}$ in the brain for exposures of at least approximately 30 min. Based on these heating factors, the operational adverse health effect thresholds for the eye and brain (Type 1) and for the skin (Type 2) will not be exceeded for local SARs of up to 20 W $kg^{-1}$.

**Considerations for fetal exposure.** Local SAR heating factors for the fetus, as a function of gestation stage and fetal posture and position, have been determined that take heat exchange between mother and fetus into account (Akimoto et al. 2010; Tateno et al. 2014; Takei et al. 2018). This research used numerical models of 13-week, 18-week, and 26-week pregnant women. The heating factors of the fetus were several times lower than those of the mother in most cases. However, the largest heating factor was observed when the fetal body position is very close to the surface of the abdomen (i.e., middle and later stages of gestation). These provide 0.1°C kg $W^{-1}$ as a conservative heating factor for the fetus.

Based on these findings, exposure of the mother at the occupational basic restriction of 10 W $kg^{-1}$ will result in a temperature rise in the fetus of approximately 1°C, which is lower than the operational adverse health effect threshold for the Head and Torso, but results in a smaller reduction factor (i.e., 2) than that considered appropriate for the general public (i.e., 10). It follows that a localized occupational radiofrequency EMF exposure of the mother would cause the temperature to rise in the fetus to a level higher than that deemed acceptable for the general public. Therefore, to maintain fetal temperature to the level required by the general public local SAR restrictions, a pregnant woman is considered a member of the general public in terms of the local SAR restriction.

It is noted that the above-mentioned case appears only in the middle and late pregnancy stages (18 to 26-week gestation), while the heating factor of the fetus in the early pregnancy stage (12-week gestation) is at most 0.02°C kg $W^{-1}$ (Tateno et al. 2014; Takei et al. 2018). This 12-week gestation fetal temperature rise is 100 times lower than the threshold (2°C) for teratogenic effects in animals (Edwards et al. 2003; Ziskin and Morrissey 2011).

**Exposure Specifications for Local Regions (>6 GHz to 300 GHz)**

**Relevant quantity.** In a human body exposed to radiofrequency EMF, an electromagnetic wave exponentially decays from the surface to deeper regions. This phenomenon is characterized according to penetration depth, as described below:

$$S_{ab} = PD_0 \int_0^{Z_{max}} e^{-\frac{2z}{\delta}}\, dz, \qquad (23)$$

where $S_{ab}$ is the absorbed power density, the body surface is at $z = 0$, $\delta$ is the penetration depth from the body surface in the $z$ direction (defined as the distance from the surface where 86% of the radiofrequency power is absorbed), and $Z_{max}$ is depth of the body at the corresponding region; where $Z_{max}$ is much larger than the penetration depth, infinity can be substituted for $Z_{max}$. $PD_0$ is the specific absorbed power averaged over the area $A$ at $z = 0$, as described below:

$$PD_0 = \iint_A \rho(x, y, 0) \cdot SAR(x, y, 0)\, dxdy/A. \qquad (24)$$

The penetration depth depends on the dielectric properties of the medium, as well as frequency. As frequency increases, the penetration depth decreases, and is predominantly within the surface tissues at frequencies higher than about 6 GHz. Table 10 lists the penetration depths based on the dielectric properties of skin tissue (dermis) measured by Sasaki et al. (2017) and Sasaki et al. (2014).

As a result, the local SAR averaged over a 10-g cubical mass with side lengths of 2.15 cm is no longer a good proxy for local temperature rise; that is, the power deposition is limited to within a few millimeters of the surface tissues. Conversely, the power density absorbed in the skin provides a better approximation of the superficial temperature rise from 6 GHz to 300 GHz (Foster et al. 2016; Funahashi et al. 2018).

**Spatial averaging considerations.** Thermal modeling (Hashimoto et al. 2017) and analytical solutions (Foster et al. 2016) suggest that a square averaging area of 4 $cm^2$ or smaller provides a close approximation to local maximum temperature rise due to radiofrequency heating at frequencies greater than 6 GHz. This is supported by computations for realistic exposure scenarios (He et al. 2018). An important advantage of the 4-$cm^2$ averaging area is the consistency at 6 GHz between local SAR and absorbed power density; the face of an averaging 10-g cube of SAR is approximately 4 $cm^2$.

Because the beam area can usually only be focused to the size of the wavelength, the averaging area of the absorbed power density relevant to the temperature rise depends on frequency; smaller averaging areas are necessary as frequency increases. Therefore, a smaller averaging area is sometimes necessary for extremely focused beams at higher frequencies. An additional criterion is therefore imposed for frequencies above 30 GHz for the spatial peak (maximum) absorbed power density averaged over 1 $cm^2$, such that it must not exceed 2 times the value for the averaging area of 4 $cm^2$ (Foster et al. 2016).

**Temporal averaging considerations.** As well as the cases of localized exposure at frequencies lower than 6 GHz, the temperature rise due to localized exposure to radiofrequency EMF over 6 GHz also achieves an equilibrium state with a particular time constant. Morimoto et al. (2017) demonstrated that the same averaging time as the local SAR (6 min) is appropriate for localized exposure from 6 GHz to 300 GHz. The time needed for steady-state local temperature rise decreases gradually as frequency increases, but no notable change is observed at frequencies higher than 15 GHz (Morimoto et al. 2017). The time needed to reach 80–90% of the maximum temperature rise is approximately 5–10 min at 6 GHz and 3–6 min at 30 GHz. However, it is noted that the time constant becomes shorter if brief or irregular exposure is considered, which is discussed in the "Brief Exposure Specifications for Local Regions (>6 GHz to 300 GHz)" section. In the present guidelines, 6 min is chosen as the averaging time, with additional restrictions for briefer or irregular exposures subjected to additional constraints as a conservative measure.

**Absorbed power density required to increase local Type-1 tissue temperature by 5°C.** Above 6 GHz, power absorption is primarily restricted to superficial tissue and cannot result in tissue temperatures that exceed operational adverse health effect thresholds for Type-2 tissues without also exceeding those for the more superficial Type-1 tissues (e.g., Morimoto et al. 2016). Therefore, exposure level must be chosen to ensure that temperature rise in the more superficial Type-1 tissue does not exceed the operational threshold of 5°C.

Tissue heating, as a function of absorbed power density over 6 GHz, is dependent on a variety of factors, as it is for lower frequencies. A comprehensive investigation of the heating factors for absorbed power density [in terms of the temperature rise (°C) over a unit area ($m^2$), per W of absorbed power] has been conducted in the case of a plane wave incident to a multi-layered slab model as an extreme uniform exposure condition (Sasaki et al. 2017). In that study, Monte Carlo statistical estimation of the heating factor was conducted where it was shown that the maximum heating factor for absorbed power density is 0.025°C $m^2$ $W^{-1}$. This value is more conservative (larger) than results from other studies on the temperature rise in the skin (Alekseev et al. 2005; Foster et al. 2016; Hashimoto et al. 2017) and the eye (Bernardi et al. 1998; Karampatzakis and Samaras 2013). Thus, to increase temperature by 5°C requires an absorbed power density of 200 W $m^{-2}$.

**Considerations for fetal exposure.** As discussed in the "Considerations for fetal exposure" of the "Exposure Specifications for Local Regions (100 kHz to 6 GHz)" section in relation to the frequency characteristics of the SAR distribution, the contribution of surface heating due to radiofrequency EMF exposure above 6 GHz to fetal temperature rise is likely very small (and smaller than that from below 6 GHz). This suggests that the fetus will not receive appreciable heating from localized exposure above 6 GHz. However, there is currently no study that has assessed this. ICNIRP thus takes a conservative approach for exposures above 6 GHz and requires that the pregnant worker is treated as a member of the general public in order to ensure that the fetus will not be exposed above the general public basic restrictions.

### Brief exposure specifications for local regions (100 kHz to 6 GHz)

The 6-min averaging scheme for localized exposure allows greater strength of the local SAR if the exposure duration is shorter than the averaging time. However, if the exposure duration is significantly shorter, heat diffusion mechanisms are inadequate to restrict temperature rise. This means that the 6-min averaged basic restriction can temporarily cause higher temperature rise than the operational adverse health effect thresholds if the exposure period is shorter than 6 min.

A numerical modeling investigation for brief exposure to radiofrequency EMF from 100 MHz to 6 GHz, using a multi-layer model and an anatomical head model, found that the SA corresponding to the allowable temperature rise is greatly variable depending on a range of factors (Kodera et al. 2018). Based on that study and empirical equations of the SA corresponding to the operational adverse health effect threshold for the skin (5°C), the exposure corresponding to this temperature rise is derived from the following equations for Head and Torso:

$$\mathrm{SA}(t) = 7.2\left(0.05 + 0.95\sqrt{t/360}\right) \ \left(\mathrm{kJ\,kg^{-1}}\right), \quad (25)$$

where $t$ is time in seconds and applicable for $t$<360, and SA ($t$) is spatially averaged over any 10-g cubic tissue, considering the continuity of the SAR at 6 min. The averaging procedure of SA is in the same manner as SAR in eqn (13). For Limbs, the following equation should be satisfied:

$$\mathrm{SA}(t) = 14.4\left(0.025 + 0.975\sqrt{t/360}\right) \ \left(\mathrm{kJ\,kg^{-1}}\right). \quad (26)$$

It is noted that the above logic results in slightly different time functions for brief exposure below and above 6 GHz; the resultant time functions below 6 GHz are more conservative than for above 6 GHz (i.e., eqns 27 and 28).

The numerical modeling study by Kodera et al. (2018) also shows that the temperature rise in Type-2 tissue (e.g., brain) is also kept below 1°C by the SA restriction defined in eqn (25). They furthermore reported that the SA corresponding to the allowable temperature rise increases as frequency decreases. At 400 MHz or lower, the SA derived from the local 6-min SAR basic restriction [10 (W $kg^{-1}$) × 360 (s) = 3.6 (kJ $kg^{-1}$)] does not cause the temperature rise corresponding to the operational adverse health effect threshold for the Head and Torso to be exceeded. Accordingly, this SA limit is only required for exposures above 400 MHz.

It should be noted that eqns (25) and (26) must be met for all intervals up to 6 min, regardless of the particular pulse or non-pulsed continuous wave patterns. That is, exposure from any pulse, group of pulses, or subgroup of pulses in a train, as well as from the summation of exposures (including non-pulsed EMFs), delivered in $t$ seconds, must not exceed that specified in eqns (25) to (26), as exposure to a part of the exposure pattern can be more critical than exposure to a single pulse or the exposure averaged over $t$. For example, if two 1-s pulses are separated by 1 s, the levels provided by eqns (25) and (26) must be satisfied for each of the 1-s pulses as well as for the total 3-s interval.

The above discussion on brain temperature rise suggests that the temperature rise in the fetus will also be lower than that assumed for the steady-state (6-min) exposure. That is, as the Type-2 tissue temperature rise will be kept below the operational adverse health effect threshold by applying eqn (25), this will presumably also be the case for temperature rises for the fetus due to brief exposures. However, there is no study available that has considered the effect of brief exposure of pregnant women up to the occupational limit on the fetus. ICNIRP thus maintains the same conservative policy for <6-min exposure as for >6-min exposure (see "Considerations for fetal exposure of Exposure Specifications for Local Regions (100 kHz to 6 GHz)" section), and requires the pregnant worker to be subject to the general public restrictions.

### Brief Exposure Specifications for Local Regions (>6 GHz to 300 GHz)

Similar to the situation for frequencies up to 6 GHz, temperature rise can be enhanced for intense short pulses or discontinuous exposures above 6 GHz, relative to a continuous exposure with the same absorbed power density averaged over a 6-min interval. This becomes significant at frequencies higher than 30 GHz (Foster et al. 2016). Considering the robustness and consistency of simple multilayer models, the basic restrictions for the brief exposures are derived based on investigations using simple models (Foster et al. 2016; Morimoto et al. 2017). Unlike continuous wave exposure, the effect of diffraction, or interference of waves reflected from protruding parts of the body back to the skin, may be apparent for brief pulses. Although the effect of diffraction to the absorbed power density is yet to be fully determined, the resultant temperature rise is estimated to be up to 3 times higher if pulsed than that due to the same absorbed power density spread evenly over a 6-min interval (Laakso et al. 2017).

Considering these factors, absorbed energy density basic restrictions ($U_{ab}$) have been set as a function of the square root of the time interval, to account for heterogeneity of temperature rise (Foster et al. 2016). These have been set to match the operational adverse health effect threshold for Type 1 tissue, as well as to match the absorbed energy density derived from the absorbed power density basic restriction for 360 s. As per the brief interval exposure limits for frequencies up to 6 GHz, the superficial nature of the resultant temperature rise will not result in temperatures that exceed Type-2 tissue operational adverse health effect thresholds, and so only the Type-1 tissue threshold of 5°C needs to be considered here.

Consequently, an extension of the formula from Kodera et al. (2018) for frequencies up to 6 GHz, specifies the maximum absorbed energy density level for brief exposures corresponding to the 5°C temperature rise as follows:

$$U_{ab}(t) = 72\left(0.05 + 0.95\sqrt{t/360}\right)\ \left(\text{kJ m}^{-2}\right) \quad \text{averaged over 2 cm} \times \text{2 cm,} \qquad (27)$$

where $t$ is the time interval in seconds and is applicable for $t$<360s. Above 30 GHz, an additional criterion is given for 1 cm × 1 cm averaging areas, such that absorbed energy density must not exceed the value specified in eqn (28):

$$U_{ab}(t) = 144\left(0.025 + 0.975\sqrt{t/360}\right)\ \left(\text{kJ m}^{-2}\right) \quad \text{averaged over 1 cm} \times \text{1 cm.} \qquad (28)$$

It should be noted that eqns (27) and (28) must both be met for all intervals up to 6 min, regardless of the particular pulse or non-pulsed continuous wave patterns. That is, exposure from any pulse, group of pulses, or subgroup of pulses in a train, as well as from the summation of exposures (including non-pulsed EMFs), delivered in $t$ seconds, must not exceed that specified in eqns (27) and (28), as exposure to a part of the exposure pattern can be more critical than exposure to a single pulse or the exposure averaged over $t$. For example, if two 1-s pulses are separated by 1 s, the levels provided by eqns (27) and (28) must be satisfied for each of the 1-s pulses, as well as for the total 3-s interval.

As discussed above, in relation to the frequency characteristics of the SAR distribution, the contribution of the surface heating due to radiofrequency EMF above 6 GHz to fetal temperature rise is likely smaller than that below 6 GHz. This is the same for cases of brief exposure. However, as there is no study on the fetus relating to exposure of a pregnant woman to radiofrequency EMF above 6 GHz, ICNIRP adopts a conservative approach and treats a pregnant worker as a member of the general public to ensure that the fetal exposure will not exceed that of the general public.

## DERIVATION OF REFERENCE LEVELS

### General Considerations for Reference Levels

As described in the main guidelines document, the reference levels have been derived as a practical means of assessing compliance with the present guidelines. The reference levels for **E**-field strength, **H**-field strength and incident power density have been derived from dosimetric studies assuming whole-body exposure to a uniform field distribution, which is generally the worst-case scenario. Due to the strongly conservative nature of the reference levels in most exposure scenarios, reference levels may often be exceeded without exceeding the corresponding basic restrictions, but this should always be verified to determine compliance.

Different reference level application rules have been set for exposure in the far-field, radiative near-field and reactive near-field zones. The intention of ICNIRP's distinction between these zones is to provide assurance that the reference levels are generally more conservative than the basic restrictions. In so far as the distinction between the zones is concerned, the principle (but not only) determinant of this is the degree to which a field approximates plane wave conditions. A difficulty with this approach is that other factors may also affect the adequacy of estimating reference level quantities from basic restriction quantities. These include the EMF frequency, physical dimensions of the EMF source and its distance from the resultant external EMFs assessed, as well as the degree to which the EMFs vary over the space to be occupied by a person. Taking into account such sources of uncertainty, the guidelines have more conservative rules for exposure in the reactive and radiative near-field than far-field zone. This makes it difficult to specify whether, for the purpose of compliance, an exposure should be considered reactive near-field, radiative near-field or far-field without consideration of a range of factors that cannot be easily specified in advance. As a rough guide, distances $> 2D^2/\lambda$ (m), between $\lambda/(2\pi)$ and $2D^2/\lambda$ (m), and $< \lambda/(2\pi)$ (m) from an antenna correspond approximately to the far-field, radiative near-field and reactive near-field, respectively, where D and λ refer to the longest dimension of the antenna and wavelength, respectively, in meters. However, it is anticipated that input from technical standards bodies should be utilized to better determine which of the far-field/near-field zone reference level rules should be applied so as to provide appropriate concordance between reference levels and basic restrictions.

### E-Field and H-Field Reference Levels up to 30 MHz

In the ICNIRP (1998) guidelines, the reference levels in this frequency region were derived from the whole-body average SAR for whole-body exposure to plane waves. However, Taguchi et al. (2018) demonstrated that whole-body exposure to the decoupled **H**-field results in a whole-body average SAR significantly lower than that calculated for the whole-body exposure to plane-waves with the same **H**-field strength. The whole-body exposure to the decoupled **E**-field was also calculated and it was found that the whole-body average SARs are almost the same as those for the plane wave with the same direction and strength as the **E**-field. The reference levels relevant to the whole-body average SAR basic restrictions below 30 MHz in these guidelines are therefore based on the numerical calculations of the whole-body average SAR for the whole-body exposure to the decoupled uniform **E**-field and **H**-field, separately. Taguchi et al. (2018) also concluded that local SAR basic restrictions, including in the ankle, will also be satisfied when the whole-body SAR basic restrictions are satisfied. This means that compliance with the whole-body average reference levels in this frequency region will result in exposures that do not exceed the whole-body average and local SAR basic restrictions.

In the low frequency guidelines (ICNIRP 2010) where reference levels for frequencies up to 10 MHz are set to protect against nerve cell stimulations, a reduction factor of 3 was applied to account for uncertainty associated with the numerical modeling of the relation between the external fields and the induced (internal) electric fields. The reason for this is that 2-mm cube-averaged values (within a specific tissue) were evaluated in the low frequency guidelines, which are significantly affected by computational artifact.

In the present guidelines, however, the uncertainty of the numerical simulation is not significant because the spatial averaging procedure applied in evaluating the whole-body average and local SAR significantly decreases the uncertainty of the computational artifact. Therefore, additional reduction factors due to computational uncertainty do not need to be considered in deriving the reference levels relevant to the local and whole-body average SAR basic restrictions below 30 MHz in these guidelines.

### E-Field, H-Field and Power Density Reference Levels From >30 MHz to 6 GHz

The ICNIRP (1998) whole-body average SAR for exposure to a field strength equal to the reference level becomes close to the basic restrictions around the whole-body resonant frequency (30–200 MHz) and post resonant frequency region (1,500–4,000 MHz).

The resonance frequency appears at a frequency where half of the wavelength in free space is close to the height (vertical dimension of a person standing) of the human body in free space, or where a quarter of the wavelength in free space is close to the height of a human body standing on the ground plane (Durney et al. 1986), resulting in higher whole-body average SARs. Whole-body resonance appears only for the case of vertically polarized plane wave incidence. If different polarizations are assumed, the resultant whole-body average SAR is significantly (a few orders of magnitude) lower than that of the case of the vertical polarization around the whole-body resonant frequency (Durney et al. 1986). Whole-body resonance has been confirmed by numerical computations (Dimbylow 1997; Nagaoka et al. 2004; Dimbylow 2005; Conil et al. 2008; Kühn et al. 2009; Hirata et al. 2010).

Above the whole-body resonant frequency, especially above a few GHz, the differences in the whole-body average SARs due to polarization are not significant compared with those at the whole-body resonant frequency. Hirata et al. (2009) reported that the whole-body average SAR in child models from 9 months to 7 years old, exposed to horizontally polarized plane wave incidence, is only slightly higher (up to 20%) than the vertically polarized plane wave at frequencies from 2 GHz to 6 GHz. A similar tendency has been reported in other studies (Vermeeren et al. 2008; Kühn et al. 2009).

ICNIRP had concluded that, given the same external field, the child whole-body average SAR can be 40% higher than those of adults (ICNIRP 2009). After that ICNIRP statement, Bakker et al. (2010) reported similar (but slightly higher) enhancements (45%) of the child whole-body average SAR. The effects of age dependence of dielectric properties of the tissues and organs have also been investigated, but no significant effect relevant to whole-body average SAR has been found (Lee and Choi 2012). It is noted that the increased whole-body average SARs have been reported from calculations using very thin child models, which were scaled from adult, and very young (infant) models. Those studies assumed that the child or infant maintains their posture for a substantial time interval so as to match an extreme case condition, in order for their whole-body SAR to exceed the basic restriction. Further, a more recent study using child models that have used the standard dimensions specified by the International Commission on Radiological Protection (ICRP), rather than scaled versions of adults, showed that the increases of the whole-body average SARs in the standard child models are not significant (at most 16%; Nagaoka et al. 2019). Similarly, the relation between whole-body average SAR and whole-body mass has been investigated and it has been found that the whole-body average SAR in low body mass index (BMI) adults can increase in a similar manner to the case of the child (Hirata et al. 2010, 2012; Lee and Choi 2012).

As discussed in the "Considerations for fetal exposure" of the "Whole-body Average Exposure Specifications" section, the temperature of the fetus is similar to the body core temperature of the mother. The whole-body average SAR, which is used to restrict body core temperature rise, is defined as the power absorption in the whole body divided by the whole-body mass. Therefore, the whole-body average SAR of a pregnant woman, whose mass is larger, is generally the same as, or lower than, that of a non-pregnant woman in this frequency region. Nagaoka et al. (2007) reported that the whole-body average SAR of a 26-week pregnant woman model exposed to the vertically polarized plane wave from 10 MHz to 2 GHz was almost the same as, or lower than, the non-pregnant woman model for the same exposure condition.

Dimbylow (2007) reported that, using a simplified pregnant woman model, the whole-body average SAR in both the fetus and mother is highest for ungrounded conditions, at approximately 70 MHz. A similar tendency was found for anatomical fetus models of second and third trimester conditions, with the whole-body average SARs in a fetus of 20, 26, and 29 week gestation periods approximately 80%, 70%, and 60% of those in the mother, respectively (Nagaoka et al. 2014). The whole-body average SARs of the fetus, while still embryonic, are comparable to or lower than the whole-body average SARs in the mother, because the embryo is located deep within the abdomen of the mother (Kawai et al. 2009). The pregnant woman is therefore not considered independently from the fetus in terms of reference levels and is subject to the general public restrictions.

As described above, there are numerous databases relevant to whole-body average SAR for whole-body exposure in this frequency region. These include a considerable number reported since the ICNIRP (1998) guidelines, which are generally consistent with the database used as the basis for the ICNIRP (1998) guidelines. ICNIRP uses a combination of the older and newer databases to derive the reference levels, taking into account some incongruences discussed below.

Since publishing the ICNIRP (1998) guidelines it has been shown that the whole-body average SAR basic restrictions can be exceeded for exposure levels at the reference level for children or small stature people. As reviewed above, the whole-body average SAR is exceeded by no more than 45%, and only for very specific child models, and more recent modeling using realistic, international standardized child models shows only a modest increase of 16% at most (Nagaoka et al. 2019). This deviation is comparable with the uncertainty expected in the numerical calculations. For example, Dimbylow et al. (2008) reported that differences in the procedure or algorithm used for the whole-body averaging results in 15% variation of the whole-body average SARs at 3 GHz, and that the assignment of the dielectric properties of the skin conditions (dry or wet) reported also results in 10% variation in the whole-body average SARs at 1.8 GHz (Gabriel et al. 1996).

As reviewed in the "Considerations for fetal exposure" of the "Whole-body Average Exposure Specifications" section, the heating factor of children is generally lower than that of adults. It follows that the increased SAR will not result in a larger temperature rise than is allowed for adults, and so will not affect health. Given the magnitude of uncertainty and the lack of health benefit in reducing the reference levels to account for small stature people, this has not resulted in ICNIRP altering the reference levels in the frequency range >30 MHz to 6 GHz.

It is also noted that there are other conditions where the whole-body average reference levels can result in whole-body average SARs that exceed the basic restrictions by up to 35%. This occurs in human models with unusual postures that would be difficult to maintain for a sufficient duration in order to cause the elevated SAR (Findlay and

Dimbylow 2005; Findlay et al. 2009). However, the elevated SAR is small compared with the associated uncertainties and the conservative nature of the basic restrictions themselves, the postures are not likely to be routinely encountered, and there is no evidence that this will result in any adverse health effects.

**Reference Levels From >6 GHz to 300 GHz for Whole-Body Exposure**

Above 6 GHz, radiofrequency EMFs generally follow the characteristics of plane wave or far-field exposure conditions; incident power density or equivalent incident power density is used as the reference level in this frequency region. The reactive near-field exists very close to a radiofrequency source in this frequency region. The typical boundary of the reactive near-field and the radiative near-field is defined as $\lambda/(2\pi)$ (e.g., 8 mm at 6 GHz). Because the incident power density used for the reference levels above 6 GHz does not appropriately correlate with the absorbed power density used for the basic restrictions in the reactive near-field region, reference levels cannot be used to determine compliance in the reactive near field; basic restrictions need to be assessed for such cases.

The radiofrequency power absorbed in the body exponentially decays in the direction from the surface to deeper regions (see eqn 23). Therefore, the power absorption is primarily confined within the body surface above 6 GHz, where the total power absorption or the whole-body average SAR is approximately proportional to the exposed area of the body surface (Hirata et al. 2007; Gosselin et al. 2009; Kühn et al. 2009; Uusitupa et al. 2010). For example, an experimental study using a reverberation chamber found a strong correlation between the whole-body average SAR and the surface area of a human body from 1 GHz to 12 GHz (Flintoft et al. 2014).

Because the whole-body average SAR is approximately proportional to the incident power density and body surface area (and is not dependent on EMF frequency), ICNIRP has extended the whole-body reference levels from below 6 GHz, up to 300 GHz. ICNIRP (1998) set whole-body reference levels within this range (up to 10 GHz) at 50 W m$^{-2}$ and 10 W m$^{-2}$ (for occupational and general public exposure, respectively). As there is no evidence that these levels will result in exposures that exceed the whole-body basic restrictions above 6 GHz, or that they will cause harm, these guidelines retain the ICNIRP (1998) reference levels for whole-body exposure conditions.

The same time and spatial average for the whole-body average SAR basic restrictions are applied to these corresponding reference levels. Therefore, the incident power density is to be temporally averaged over 30 min and spatially averaged over the space to be occupied by a human body (whole-body space).

**Reference Levels From >6 GHz to 300 GHz for Local Exposure**

The incident power density ($S_{inc}$) reference levels above 6 GHz for local exposure can be derived from the basic restrictions (i.e., from absorbed power density, $S_{ab}$):

$$S_{inc} = S_{ab}T^{-1}\left(\mathrm{W\ m^{-2}}\right), \quad (29)$$

where T is Transmittance, defined as follows:

$$\mathrm{Transmittance} = 1-|\Gamma|^2. \quad (30)$$

The reflection coefficient $\Gamma$ is derived from the dielectric properties of the tissues, shape of the body surface, incident angle and polarization. For transverse electric (TE)-wave incidence, the angle corresponding to the maximum transmittance is the angle normal to the body surface, whereas for transverse magnetic (TM)-wave incidence this occurs at the Brewster angle (the angle of incidence at which there is no reflection of the TM wave). Furthermore, for cases of oblique incidence of the radiofrequency EMF wave, Li et al. (2019) have shown that the incident power and energy densities of TE waves, averaged over the body or boundary surface, overestimate the absorbed power and energy densities, while the absorbed power and energy densities of TM-waves around the Brewster angle approach the incident power and energy densities. They also found that normal incidence is always the worst case scenario regarding temperature rise (Li et al. 2019).

In the present guidelines, the basic restrictions and reference levels are derived from investigations assuming normal incidence to the multi-layered human model. As this represents worst-case modeling for most cases, the results obtained and used in these guidelines will generally be conservative.

The variation and uncertainty of the transmittance for the normal-angle incident condition have been investigated (Sasaki et al. 2017). The transmittance asymptotically increases from 0.4 to 0.8 as the frequency increases from 10 GHz to 300 GHz. Similar tendencies have also been reported elsewhere (Kanezaki et al. 2009; Foster et al. 2016; Hashimoto et al. 2017).

Considering the frequency characteristics of the transmittance, the reference levels for local exposure have been derived as exponential functions of the frequency linking 200 W m$^{-2}$ at 6 GHz to 100 W m$^{-2}$ at 300 GHz (for occupational exposure). The same method is applied for the derivation of reference levels for the general public. For the same reasons given in the "Reference Levels from >6 GHz to 300 GHz for Whole-body Exposure" section, reference levels cannot be used to determine compliance in the reactive near field; basic restrictions need to be assessed for such cases.

The temporal and spatial characteristics are almost the same for incident power density and absorbed power density at the body surface for the scale considered in the basic restrictions, i.e., 6 min, and either 4 $cm^2$ or 1 $cm^2$ (an additional criteria above 30 GHz). Therefore, the same averaging conditions are applied to the incident power density reference levels, as for the absorbed power density basic restrictions.

**Limb Current Reference Levels**

Limb current is defined as the current flowing through the limbs, such as through an ankle or wrist. High local SAR can appear in these parts of the body because of their anatomical composition. The volume ratio of the high conductivity tissues to the low conductivity tissues is small in the ankle and wrist, resulting in the current concentrating into high conductivity tissues such as muscle, and thus greater SAR. This phenomenon is particularly pronounced for cases of a human body standing on the ground plane in a whole-body resonant condition.

The local SAR in limbs (ankle and wrist) is strongly correlated with the current flowing through the limbs. Although the local SAR is generally difficult to measure directly, the limb SAR can be derived from the limb current (I), which can be relatively easily measured, as follows:

$$\mathrm{SAR} = \frac{\sigma \mathrm{E}^2}{\rho} = \frac{\mathrm{J}^2}{\sigma\rho} = \frac{\mathrm{I}^2}{\sigma\rho A^2}, \qquad (31)$$

where J and $A$ are the current density and effective section area, respectively.

The limb current reference levels are therefore set in order to evaluate the local SAR in the ankle and wrist, especially around the ankle in a grounded human body for the whole-body resonant condition. As the frequency increases above the whole-body resonant frequency for the grounded condition, the efficiency of the localization within the limbs gradually decreases. Thus, at higher frequencies, the maximum local SAR does not generally appear around limbs, and is thus not relevant.

Dimbylow (2002) showed that a limb current of 1 A at 10 MHz to 80 MHz causes 530 W $kg^{-1}$ to 970 W $kg^{-1}$ of local SAR averaged over 10 g in the ankles of an adult male model standing on a grounded plane. It is noted that the shape of the averaging region of the 10-g tissue was not cubic, but contiguous, which results in higher SAR values than those of a cube. Based on that study, ICNIRP sets the limb current reference levels at 100 mA and 45 mA for occupational and general public exposures, respectively, to conservatively ensure compliance with the local SAR basic restrictions in the limbs (e.g., the maximum local SAR in the limbs for a 100 mA current would only be 10 W $kg^{-1}$). Taguchi et al. (2018) confirmed this relation between SAR and ankle current from 10 MHz to 100 MHz in different anatomical models.

Similarly, Dimbylow (2001) computed the 10-g local SAR (with contiguous tissue) for a 100-mA wrist current, which resulted in 27 W $kg^{-1}$ at 100 kHz, decreasing to 13 W $kg^{-1}$ at 10 MHz. Considering the reduction of SAR for the cubic compared to contiguous shape, the 100-mA limb current at the wrist will also conservatively ensure compliance with the local SAR basic restrictions in the wrist. Based on this, ICNIRP has revised the lower frequency range to 100 kHz, from 10 MHz in ICNIRP (1998).

As shown in eqn (31), the local SAR is proportional to the squared value of the limb current. In eqn (31), however, the effective area is a constant to relate the limb current to the 10-g averaged local SAR and depends on not only the actual section area but also tissue distribution/ratio and conductivity. Because the conductivity asymptotically increases as the frequency increases from 100 kHz to 110 MHz, the relationship between local SAR and limb current is not constant across this frequency range. For example, Dimbylow (2002) demonstrated that the local SAR due to a constant limb current halved as frequency increased from 10 MHz to 80 MHz. This suggests that the upper frequency limit for limb current reference levels could potentially be lowered, relative to the upper limit of the 10 MHz to 110 MHz range of ICNIRP (1998). However, due to the lack of research addressing this issue, ICNIRP has kept the same upper frequency range as in ICNIRP (1998).

Because the limb current reference levels are relevant to the local SAR basic restrictions, the same temporal averaging is applied (i.e., 6 min). Further, as the squared value of the limb current is proportional to the local SAR, the squared value of the limb current must be used for time averaging (as described in the "Quantities and Units" section). Note that temperature rise for exposures of less than 6 min is only of concern for frequencies above 400 MHz, which is higher than the upper frequency limit for limb currents. Limb current reference levels are therefore not required for exposures of less than 6 min.

**Reference Levels for Brief Exposure (<6 min)**

The reference levels for brief exposure are derived to match the brief exposure basic restrictions, which have been set in terms of SA and absorbed energy density, up to and above 6 GHz, respectively.

The reference levels have been derived from numerical computations with the multi-layered human model exposed to a plane wave, or to typical sources used close to the body, such as a dipole antenna.

The reference levels vary as a function of time interval to match the absorbed energy density basic restrictions (above 6 GHz), with a similar function used below 6 GHz to match the SA basic restrictions. It is noted that the time function of the absorbed energy density basic restrictions and corresponding incident energy density reference levels are more conservative than those for the SA basic restrictions and corresponding incident energy density reference levels. This means that the reference levels are more conservative above than below 6 GHz.

Because the reference levels are based on the multi-layered model, the uncertainty included in the dosimetry is not significant. Conversely, this simple modeling is likely overly conservative for a realistic human body shape and structure. This overestimation decreases as the frequency increases because the penetration depth is short relative to the body-part dimensions. Morphological variations are also not significant.

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## APPENDIX B: HEALTH RISK ASSESSMENT LITERATURE

### Introduction

The World Health Organization (WHO) has undertaken an in-depth review of the literature on radiofrequency electromagnetic fields (EMFs) and health, which was released as a Public Consultation Environmental Health Criteria Document in 2014. This independent review is the most comprehensive and thorough appraisal of the adverse effects of radiofrequency EMFs on health. Further, the Scientific Committee on Emerging and Newly Identified Health Risks (SCENIHR), a European Commission initiative, also produced a report on potential health effects of exposure to electromagnetic fields (SCENIHR 2015), and the Swedish Radiation Safety Authority (SSM) have produced several international reports regarding this issue (SSM 2015, 2016, 2018). Accordingly, the present guidelines have used these literature reviews as the basis for the health risk assessment associated with exposure to radiofrequency EMFs rather than providing another review of the individual studies. However, for completeness, ICNIRP considered more recent research published after the reviews from WHO, SCENIHR and SSM in the development of the current guidelines (cut-off date September 1st, 2019). The discussion of ICNIRP's appraisal of the radiofrequency health literature below provides a brief overview of the literature, a limited number of examples to help explain the overview, and the conclusions reached by ICNIRP.

The summary of the research on biological and health effects of radiofrequency EMFs presented below considers effects on body systems, processes or specific diseases. This research feeds into the determination of thresholds for adverse human health effects. Research domains considered are experimental tests on cells, animals and humans, and human observational studies assessing relationships between radiofrequency EMFs and a range of potentially health-related outcomes. The experimental studies have the advantages of being able to control a large number of potential confounders and to manipulate radiofrequency EMF exposure. However, they are also limited in terms of making comparisons to realistic exposure environments, employing exposure durations sufficient to assess many disease processes, and, in the case of in vitro and animal research, relating the results to humans can also be difficult. Epidemiological research more closely relates to actual health within the community, but it is mostly observational and, thus, depending on the type of studies, various types of error and bias are of concern. These include confounding, selection bias, information bias, reverse causality, and exposure misclassification; in general, prospective cohort studies are least affected by bias but large sample sizes are needed for rare diseases. Therefore, it is important to consider research across a range of study types in order to arrive at useful conclusions concerning the relation between radiofrequency EMF exposure and adverse health effects.

It is important to note that ICNIRP bases its guidelines on substantiated[8] adverse health effects. This makes the difference between a biological and an adverse health effect an important distinction, where only adverse health effects require restrictions for the protection of humans. Research on the health effects of radiofrequency EMFs has tended to concentrate on a few areas of particular interest and concern, with some other areas receiving little or no attention. There is not sufficient research addressing potential relations between radiofrequency EMFs and the skeletal, muscular, respiratory, digestive, and excretory systems, and so these are not considered further. This review considers the potential for different types of radiofrequency EMF exposure to adversely affect health, including sinusoidal (e.g., continuous wave) and non-sinusoidal (e.g., pulsed) EMFs, and both acute and chronic exposures.

## BRAIN PHYSIOLOGY AND FUNCTION

### Brain Electrical Activity and Cognitive Performance

Human research addressing higher cognitive function has primarily been conducted within the ICNIRP (1998) basic restriction values. This has mainly been assessed via performance measures and derivations of the electroencephalogram (EEG) and cerebral blood flow (CBF) measures (sensitive measures of brain electrical activity and blood flow/metabolism, respectively). Most double-blind human experimental studies on cognitive performance, CBF or event-related potential (a derivative of the EEG) measures of cognitive function, did not report an association with radiofrequency EMF exposure. A number of sporadic findings have been reported, but these do not show a consistent or meaningful pattern. This may be a result of the large number of statistical comparisons and occasional chance findings. There are therefore no substantiated reports of radiofrequency EMFs adversely affecting performance, CBF, or event-related potential measures of cognitive function. Studies analyzing frequency components of the EEG have reliably shown that the 8–13 Hz alpha band in waking EEG and the 10–14 Hz "sleep spindle" frequency range in sleep EEG, are affected by radiofrequency EMF exposure with specific energy absorption rates (SAR) <2 W $kg^{-1}$, but there is no evidence that these relate to adverse health effects (e.g., Loughran et al. 2012).

Both rodents and non-human primates have shown a decrease in food-reinforced memory performance with exposures to radiofrequency EMFs at a whole-body average SAR >5 W $kg^{-1}$ for rats, and a whole-body average SAR >4 W $kg^{-1}$ for non-human primates, exposures which correspond to increases in body core temperatures of approximately 1°C. However, there is no indication that these changes were due to reduced cognitive ability, rather than the normal temperature-induced reduction of motivation (hunger). Such changes in motivation are considered normal and reversible thermoregulatory responses, and do not in themselves represent adverse health effects. Similarly, although not considered an adverse health effect, behavioral changes to reduce body temperature have also been observed in non-human primates at whole-body average SARs of 1 W $kg^{-1}$, with the threshold the same for acute, repeated exposures and for long-term exposures.

There is limited epidemiological research on higher cognitive function. There have been reports of subtle changes to performance measures with radiofrequency EMFs, but findings have been contradictory, as there is no evidence that the reported changes are related to radiofrequency EMF exposure and alternative explanations for observed effects are plausible.

In summary, there is no substantiated experimental or epidemiological evidence that exposure to radiofrequency EMFs affects higher cognitive functions relevant to health.

### Symptoms and Wellbeing

There is research addressing the potential for radiofrequency EMFs to influence mood, behavior characteristics, and symptoms.

A number of human experimental studies testing for acute changes to wellbeing or symptoms are available, and these have failed to identify any substantiated effects of exposure. A small portion of the population attributes non-specific symptoms to various types of radiofrequency EMF exposure; this is referred to as Idiopathic Environmental Intolerance attributed to EMF (IEI-EMF). Double-blind experimental

[8]Further details concerning the term substantiated can be found in the main guidelines document.

studies have consistently failed to identify a relation between radiofrequency EMF exposure and such symptoms in the IEI-EMF population, as well as in healthy population samples. These experimental studies provide evidence that "belief about exposure" (e.g., the so-called "nocebo" effect), and not exposure itself, is the relevant symptom determinant (e.g., Eltiti et al. 2018; Verrender et al. 2018).

Epidemiological research has addressed potential long-term effects of radiofrequency EMF exposure from fixed-site transmitters and devices used close to the body on both symptoms and well-being, but with a few exceptions these are cross-sectional studies with self-reported information about symptoms and exposure. Selection bias, reporting bias, poor exposure assessment, and nocebo effects are of concern in these studies. In studies on transmitters, no consistent associations between exposure and symptoms or well-being have been observed when objective measurements of exposure were made or when exposure information was collected prospectively. In studies on mobile phone use, associations with symptoms and problematic behavior have been observed. However, these studies can generally not differentiate between potential effects from radiofrequency EMF exposure and other consequences of mobile phone use, such as sleep deprivation when using the mobile phone at night. Overall, the epidemiological research does not provide evidence of a causal effect of radiofrequency EMF exposure on symptoms or well-being.

However, there is evidence that radiofrequency EMFs, at sufficiently high levels, can cause pain. Walters et al. (2000) reported a pain threshold of 12.5 kW $m^{-2}$ for 94 GHz, 3-s exposure to the back, which raised temperature from 34°C to 43.9°C (at a rate of 3.3°C per second). This absolute temperature threshold is consistent with Torbjork et al. (1984), who observed a median threshold for pain at 43°C, which was in compliance with simultaneously measured response thresholds of nociceptors (41°C and 43°C).

Another instance of pain induced by radiofrequency EMFs is due to *indirect* exposure via contact currents, where radiofrequency EMFs in the environment are redirected via a conducting object to a person, and the resultant current flow, dependent on frequency, can stimulate nerves, cause pain, and/or damage tissue. Induced current thresholds resulting from contact currents are very difficult to determine, with the best estimates of thresholds for health effects being for pain, which is approximately 10 and 20 mA for children and adults, respectively (extrapolated from Chatterjee et al. 1986).

In summary, no reports of adverse effects of radiofrequency EMF exposures on symptoms and wellbeing have been substantiated, except for pain, which is related to elevated temperature at high exposure levels (from both direct and indirect radiofrequency EMF exposure). Thresholds for direct effects on pain are in the vicinity of 12.5 kW $m^{-2}$ for 94 GHz exposures to the back, which is consistent with thermal physiology knowledge. Thresholds for indirect effects (contact currents) are within the vicinity of 10 and 20 mA, for EMFs between 100 kHz and 110 MHz, for children and adults respectively.

### Other Brain Physiology and Related Functions

A number of studies of potential adverse effects of radiofrequency EMFs on physiological functions that could adversely affect health have been conducted, primarily using in vitro techniques. These have included multiple cell lines and assessed functions such as intra- and intercellular signaling, membrane ion channel currents and input resistance, $Ca^{2+}$ dynamics, signal transduction pathways, cytokine expression, biomarkers of neurodegeneration, heat shock proteins, and oxidative stress-related processes. There have been some reports of morphological changes to cells, but these have not been verified, and their relevance to health has also not been demonstrated. There have also been reports of radiofrequency EMFs inducing leakage of albumin across the blood-brain barrier in rats (e.g., Nittby et al., 2009), but due to methodological limitations of the studies and failed attempts to independently verify the results, there remains no evidence of an effect. Some studies also tested for effects of co-exposure of radiofrequency EMFs with known toxins, but there is currently no demonstration that this affects the above conclusions.

Intense pulsed low frequency electric fields (with radiofrequency components) can cause cell membranes to become permeable, allowing exchange of intra- and extra-cellular materials (Joshi and Schoenbach 2010); this is referred to as electroporation. Exposure to an unmodulated 18 GHz field has also been reported to cause a similar effect (Nguyen et al. 2017). Both exposures require very high field strengths [e.g., 10 kV $m^{-1}$ (peak) in tissue in the case of low frequency electric fields, and 5 kW $kg^{-1}$ at 18 GHz]. These levels have not been shown to adversely affect health in realistic exposure scenarios in humans and, given their very high thresholds, are protected against by restrictions based on effects with lower thresholds. Accordingly, electroporation is not discussed further.

In summary, there is no evidence of effects of radiofrequency EMFs on physiological processes that impair human health.

## AUDITORY, VESTIBULAR, AND OCULAR FUNCTION

A number of animal and some human studies have tested for potential effects of radiofrequency EMFs on function and pathology of the auditory, vestibular, and ocular systems.

Sub-millisecond pulses of radiofrequency EMF can result in audible sound. Specifically, within the 200–3000

MHz EMF range, *microwave hearing* can result from brief (approximately 35–100 μs) radiofrequency pulses to the head, which cause thermoelastic expansion that is detected by sensory cells in the cochlea via the same processes involved in normal hearing. This phenomenon is perceived as a brief low-level noise, often described as a "click" or "buzzing." For example, Röschmann (1991) applied 10- and 20-μs pulses at 2.45 GHz that caused a specific energy absorption (SA) of 4.5 mJ $kg^{-1}$ per pulse, and which was estimated to result in a temperature rise of approximately 0.00001°C per pulse. These pulses were barely audible, suggesting that this corresponded to a sound at the hearing threshold. Although higher intensity SA pulses may result in more pronounced effects, there is no evidence that microwave hearing in any realistic exposure scenarios can affect health, and so the present Guidelines do not provide a restriction to specifically account for microwave hearing.

Experimental and observational studies have also been conducted to test for adverse effects of EMF exposure from mobile phones. A few studies have investigated effects on auditory function and cellular structure in animal models. However, these results are inconsistent.

Beyond the behavioral and electrophysiological indices of sensory processing described above, a number of studies have tested for acute effects of radiofrequency EMF exposure on auditory, vestibular and ocular functioning in humans. These have largely been conducted using mobile phone-like signals at exposure levels below the ICNIRP (1998) basic restriction levels. Although there are some reports of effects, the results are highly variable with the larger and more methodologically rigorous studies failing to find such effects.

There is very little epidemiological research addressing sensory effects of devices that emit radiofrequency EMFs. The available research has focused on mobile phone use and does not provide evidence that this is associated with increased risk of tinnitus, hearing impairment, or vestibular or ocular function.

Animal studies have also reported that the heating that results from radiofrequency EMF exposure may lead to the formation of cataracts in rabbits. In order for this to occur, very high local SAR levels (100–140 W $kg^{-1}$) at low frequencies (< 6 GHz) are needed with temperature increases of several °C maintained for several hours. However, the rabbit model is more susceptible to cataract formation than in primates (with primates more relevant to human health), and cataracts have not been found in primates exposed to radiofrequency fields. No substantiated effects on other deep structures of the eye have been found (e.g., retina or iris). However, rabbits can be a good model for damage to superficial structures of the eye (e.g., the cornea) at higher frequencies (30–300 GHz). The baseline temperature of the cornea is relatively low compared with the posterior portion of the eye, and so very high exposure levels are required to cause harm superficially. For example, Kojima et al. (2018) reported that adverse health effects to the cornea can occur at incident power densities higher than 1.4 kW $m^{-2}$ across frequencies from 40 to 95 GHz; no effects were found below 500 W $m^{-2}$. The authors concluded that the blink rates in humans (ranging from once every 3 to 10 s, as opposed to once every 5 to 20 min in rabbits) would preclude such effects in humans.

In summary, no reported effects on auditory, vestibular, or ocular function or pathology relevant to human health have been substantiated. Some evidence of superficial eye damage has been shown in rabbits at exposures of at least 1.4 kW $m^{-2}$, although the relevance of this to humans has not been demonstrated.

## NEUROENDOCRINE SYSTEM

A small number of human studies have tested whether indices of endocrine system function are affected by radiofrequency EMF exposure. Several hormones, including melatonin, growth hormone, luteinizing hormone, cortisol, epinephrine, and norepinephrine have been assessed, but no consistent evidence of effects of exposure has been observed.

In animal studies, substantiated changes have only been reported from acute exposures with whole-body SARs in the order of 4 W $kg^{-1}$, which result in core temperature rises of 1°C or more. However, there is no evidence that this corresponds to an impact on health. Although there have been a few studies reporting field-dependent changes in some neuroendocrine measures, these have also not been substantiated. The literature, as a whole, reports that repeated, daily exposure to mobile phone signals does not impact on plasma levels of melatonin or on melatonin metabolism, oestrogen or testosterone, or on corticosterone or adrenocorticotropin in rodents under a variety of conditions.

Epidemiological studies on potential effects of exposure to radiofrequency EMFs on melatonin levels have reported conflicting results and suffer methodological limitations. For other hormonal endpoints, no epidemiological studies of sufficient scientific quality have been identified.

In summary, the lowest level at which an effect of radiofrequency EMFs on the neuroendocrine system has been observed is 4 W $kg^{-1}$ (in rodents and primates), but there is no evidence that this translates to humans or is relevant to human health. No other reported effects have been substantiated.

## NEURODEGENERATIVE DISEASES

No human experimental studies exist for adverse effects on neurodegenerative diseases.

Although it has been reported that exposure to pulsed radiofrequency EMFs increased neuronal death in rats, which could potentially contribute to an increased risk of neurodegenerative disease, other studies have failed to confirm these results. Some other effects have been reported (e.g., changes to neurotransmitter release in the cortex of the brain, protein expression in the hippocampus, and autophagy in the absence of apoptosis in neurons), but such changes have not been shown to lead to neurodegenerative disease. Other studies investigating effects on neurodegeneration are not informative due to methodological or other shortcomings.

A Danish epidemiological cohort study has investigated potential effects of mobile phone use on neurodegenerative disorders and reported reduced risk estimates for Alzheimer disease, vascular and other dementia, and Parkinson disease (Schüz et al. 2009). These findings are likely to be the result of reverse causation, as prodromal symptoms of the disease may prevent persons with early symptoms to start using a mobile phone. Results from studies on multiple sclerosis are inconsistent, with no effect observed among men, and a borderline increased risk in women, but with no consistent exposure-response pattern.

In summary, no adverse effects on neurodegenerative diseases have been substantiated.

## CARDIOVASCULAR SYSTEM, AUTONOMIC NERVOUS SYSTEM, AND THERMOREGULATION

As described above, radiofrequency EMFs can induce heating in the body. Although humans have a very efficient thermoregulatory system, too much heating puts the cardiovascular system under stress and may lead to adverse health effects.

Numerous human studies have investigated indices of cardiovascular, autonomic nervous system, and thermoregulatory function, including measures of heart rate and heart rate variability, blood pressure, body, skin and finger temperatures, and skin conductance. Most studies indicate that there are no effects on endpoints regulated by the autonomic nervous system. The relatively few reported effects of exposure were small and would not have an impact on health. The reported changes were also inconsistent and may be due to methodological limitations or chance. With exposures at higher intensities, up to a whole-body SAR of about 1 W $kg^{-1}$ (Adair et al. 2001), sweating and cardiovascular responses have been reported that are similar to that observed under increased heat load from other sources. The body core temperature increase was generally less than 0.2°C.

The situation is different for animal research, in that far higher exposure levels have been used, often to the point where thermoregulation is overwhelmed, and temperature increases to the point where death occurs. For example, Frei et al. (1995) exposed rats to 35 GHz fields at 13 W $kg^{-1}$ whole-body exposure, which raised body core temperature by 8°C (to 45°C), resulting in death. Similarly, Jauchem and Frei (1997) exposed rats to 350 MHz fields at 13.2 W $kg^{-1}$ whole-body exposure and reported that thermal breakdown (i.e., where the thermoregulatory system can no longer cope with the increased body core temperature) occurred at approximately 42°C. It is difficult to relate these animal findings directly to humans, as humans are more-efficient thermoregulators than rodents. Taberski et al. (2014) reported that in Djungarian hamsters no body core temperature elevation was seen after whole-body exposure to 900 MHz fields at 4 W $kg^{-1}$ with the only detectable effect a reduction of food intake (which is consistent with reduced eating in humans when body core temperature is elevated).

Few epidemiological studies on cardiovascular, autonomic nervous system, or thermoregulation outcomes are available. Those that are have not demonstrated a link between radiofrequency EMF exposure and measures of cardiovascular health.

In summary, no effects on the cardiovascular system, autonomic nervous system, or thermoregulation that compromise human health have been substantiated for exposures with whole-body average SARs below approximately 4 W $kg^{-1}$, with harm only found in animals exposed to whole-body average SARs substantially higher than 4 W $kg^{-1}$.

## IMMUNE SYSTEM AND HAEMATOLOGY

There have been inconsistent reports of transient changes in immune function and haematology following radiofrequency EMF exposures. These have primarily been from in vitro studies, although some animal studies have also been conducted. These reports have not been substantiated.

The few human studies that have been conducted have not provided any evidence that radiofrequency EMFs affect health in humans via the immune system or haematology.

## FERTILITY, REPRODUCTION, AND CHILDHOOD DEVELOPMENT

There is very little human experimental research addressing possible effects of radiofrequency EMF exposure on reproduction and development. What is available has focused on hormones that are relevant to reproduction and development, and as described in the Neuroendocrine System section above, there is no evidence that they are affected by radiofrequency EMF exposure. Other research has addressed this issue by looking at different stages of development (for endpoints such as cognition and brain electrical activity), in order to determine whether there may be greater sensitivity to radiofrequency fields as a function of age. There is currently no evidence that developmental phase is relevant to this issue.

Numerous animal studies have shown that exposure to radiofrequency EMFs associated with a significant temperature increase can cause effects on reproduction and development. These include increased embryo and fetal losses, increased fetal malformations and anomalies, and reduced fetal weight at term. Such exposures can also cause a reduction in male fertility. However, extensive, well-performed studies have failed to identify developmental effects at whole-body average SAR levels up to 4 W $kg^{-1}$. In particular, a large four-generation study in mice on fertility and development using whole-body SAR levels up to 2.34 W $kg^{-1}$ found no evidence of adverse effects (Sommer et al. 2009). Some studies have reported effects on male fertility at exposure levels below this value, but these studies have had methodological limitations and reported effects have not been substantiated.

Epidemiological studies have investigated various aspects of male and female infertility and pregnancy outcomes in relation to radiofrequency EMF exposure. Some epidemiological studies reported associations between radiofrequency EMFs and sperm quality or male infertility, but, taken together, the available studies do not provide evidence for an association with radiofrequency EMF exposure as they all suffer from limitations in study design or exposure assessment. A few epidemiological studies are available on maternal mobile phone use during pregnancy and potential effects on child neurodevelopment. There is no substantiated evidence that radiofrequency EMF exposure from maternal mobile phone use affects child cognitive or psychomotor development, or causes developmental milestone delays.

In summary, no adverse effects of radiofrequency EMF exposure on fertility, reproduction, or development relevant to human health have been substantiated.

## CANCER

There is a large body of literature concerning cellular and molecular processes that are of particular relevance to cancer. This includes studies of cell proliferation, differentiation and apoptosis-related processes, proto-oncogene expression, genotoxicity, increased oxidative stress, and DNA strand breaks. Although there are reports of effects of radiofrequency EMFs on a number of these endpoints, there is no substantiated evidence of health-relevant effects (Vijayalaxmi and Prihoda 2019).

A few animal studies on the effect of radiofrequency EMF exposure on carcinogenesis have reported positive effects, but, in general, these studies either have shortcomings in methodology or dosimetry, or the results have not been verified in independent studies. Indeed, the great majority of studies have reported a lack of carcinogenic effects in a variety of animal models. A replication of a study in which exposure to radiofrequency EMFs increased the incidence of liver and lung tumors in an animal model with prenatal exposure to the carcinogen ENU (ethylnitrosourea) indicates a possible promoting effect (Lerchl et al. 2015; Tillmann et al. 2010). The lack of a dose-response relationship, as well as the use of an untested mouse model for liver and lung tumors whose relevance to humans is uncertain (Nesslany et al. 2015), makes interpretation of these results and their applicability to human health difficult, and, therefore, there is a need for further research to better understand these results.

Two recent animal studies investigating the carcinogenic potential of long-term exposure to radiofrequency EMFs associated with mobile phones and mobile phone base stations have also been released: one by the U.S. National Toxicology Program (NTP 2018a and b) and the other from the Ramazzini Institute (Falcioni et al. 2018). Although both studies used large numbers of animals, best laboratory practice, and exposed animals for the whole of their lives, they also have inconsistencies and important limitations that affect the usefulness of their results for setting exposure guidelines. Of particular importance is that the statistical methods employed were not sufficient to differentiate between radiofrequency-related and chance differences between treatment conditions; interpretation of the data is difficult due to the high body core temperature changes that resulted from the very high exposure levels used; and no consistency was seen across these two studies. Thus, when considered either in isolation (e.g., ICNIRP 2019) or within the context of other animal and human carcinogenicity research (HCN 2014, 2016), their findings do not provide evidence that radiofrequency EMFs are carcinogenic.

A large number of epidemiological studies of mobile phone use and cancer risk have also been performed. Most have focused on brain tumors, acoustic neuroma and parotid gland tumors, as these occur in close proximity to the typical exposure source from mobile phones (Röösli et al. 2019). However, some studies have also been conducted on other types of tumors, such as leukaemia, lymphoma, uveal melanoma, pituitary gland tumors, testicular cancer, and malignant melanoma. With a few exceptions, the studies have used a case-control design and have relied on retrospectively collected self-reported information about mobile phone use history. Only two cohort studies with prospective exposure information are available. Several studies have had follow-ups that were too short to allow assessment of a potential effect of long-term exposure, and results from case-control studies with longer follow-up are not consistent.

The large Interphone study, coordinated by the International Association for Research on Cancer, did not provide evidence of a raised risk of brain tumors, acoustic neuroma, or parotid gland tumors among regular mobile phone users, and the risk estimates did not increase with longer time since first mobile phone use (Interphone 2010, 2011). It should be noted that although somewhat elevated odds ratios were observed at the highest level of cumulative call time for acoustic neuroma and glioma, there were no trends observed for any of the lower cumulative call

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time groups, with among the lowest risk estimates in the penultimate exposure category. This, combined with the inherent recall bias of such studies, does not provide evidence of an increased risk. Similar results were observed in a Swedish case-control study of acoustic neuroma (Pettersson et al. 2014). Contrary to this, a set of case-control studies from the Hardell group in Sweden report significantly increased risks of both acoustic neuroma and malignant brain tumors already after less than five years since the start of mobile phone use, and at quite low levels of cumulative call time. However, they are not consistent with trends in brain cancer incidence rates from a large number of countries or regions, which have not found any increase in the incidence since mobile phones were introduced.

Furthermore, no cohort studies (which unlike case-control studies are not affected by recall or selection bias) report a higher risk of glioma, meningioma, or acoustic neuroma among mobile phone subscribers or when estimating mobile phone use through prospectively collected questionnaires. Studies of other types of tumors have also not provided evidence of an increased tumor risk in relation to mobile phone use. Only one study is available on mobile phone use in children and brain tumor risk (Aydin et al. 2011). No increased risk of brain tumors was observed.

Studies of exposure to environmental radiofrequency EMFs, for example from radio and television transmitters, have not provided evidence of an increased cancer risk either in children or in adults. Studies of cancer in relation to occupational radiofrequency EMF exposure have suffered substantial methodological limitations and do not provide sufficient information for the assessment of carcinogenicity of radiofrequency EMFs. Taken together, the epidemiological studies do not provide evidence of a carcinogenic effect of radiofrequency EMF exposure at levels encountered in the general population.

In summary, no effects of radiofrequency EMFs on the induction or development of cancer have been substantiated.

## SUMMARY

The only substantiated adverse health effects caused by exposure to radiofrequency EMFs are nerve stimulation, changes in the permeability of cell membranes, and effects due to temperature elevation. There is no evidence of adverse health effects at exposure levels below the restriction levels in the ICNIRP (1998) guidelines and no evidence of an interaction mechanism that would predict that adverse health effects could occur due to radiofrequency EMF exposure below those restriction levels.

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# Scientists warn of potential serious health effects of 5G

**September 11, 2017**

***We the undersigned, more than 170 scientists from 37 countries, recommend a moratorium on the roll-out of the fifth generation, 5G, for telecommunication until potential hazards for human health and the environment have been fully investigated by scientists independent from industry. 5G will substantially increase exposure to radiofrequency electromagnetic fields (RF-EMF) on top of the 2G, 3G, 4G, Wi-Fi, etc. for telecommunications already in place. RF-EMF has been proven to be harmful for humans and the environment.***

(Note: Blue links below are references.)

## 5G leads to massive increase of mandatory exposure to wireless radiation

5G technology is effective only over short distance. It is poorly transmitted through solid material. Many new antennas will be required and full-scale implementation will result in antennas every 10 to 12 houses in urban areas, **thus massively increasing mandatory exposure.**

With ”the ever more extensive use of wireless technologies,” nobody can avoid to be exposed. Because on top of the increased number of 5G-transmitters (even within housing, shops and in hospitals) according to estimates, ”10 to 20 billion connections” (to refrigerators, washing machines, surveillance cameras, self-driving cars and buses, etc.) will be parts of the Internet of Things. All these together can cause a substantial increase in the total, long term RF-EMF exposure to all EU citizens.

## Harmful effects of RF-EMF exposure are already proven

Over 220 scientists from more than 40 countries have expressed their “serious concerns” regarding the ubiquitous and increasing exposure to EMF generated by electric and wireless devices already before the additional 5G roll-out. They refer to the fact that ”numerous recent scientific publications have shown that *EMF affects living organisms at levels well below most international and national guidelines*”. Effects include increased cancer risk, cellular stress, increase in harmful free radicals, genetic damages, structural and functional changes of the reproductive system, learning and memory deficits, neurological disorders, and negative impacts on general well-being in humans. Damage goes well beyond the human race, as there is growing evidence of harmful effects to both plants and animals.

After the scientists’ appeal was written in 2015 additional research has convincingly confirmed serious health risks from RF-EMF fields from wireless technology. The world’s largest study (25 million US dollar) National Toxicology Program (NTP), shows statistically significant increase in the incidence of *brain and heart cancer* in animals exposed to EMF below the ICNIRP (International Commission on Non-Ionizing Radiation Protection) guidelines followed by most countries. These results support results in human epidemiological studies on RF radiation and brain tumour risk. A large number of peer-reviewed scientific reports demonstrate harm to human health from EMFs.

The International Agency for Research on Cancer (IARC), the cancer agency of the World Health Organization (WHO), in 2011 concluded that EMFs of frequencies 30 KHz – 300 GHz are possibly carcinogenic to humans (Group 2B). However, new studies like the NTP study mentioned above and several epidemiological investigations including the latest studies on mobile phone use and brain cancer risks confirm that RF-EMF radiation is carcinogenic to humans.

The EUROPA EM-EMF Guideline 2016 states that ”there is strong evidence that *long-term exposure to certain EMFs is a risk factor for diseases* such as certain cancers, Alzheimer's disease, and male infertility…Common EHS (electromagnetic hypersensitivity) symptoms include headaches, concentration difficulties, sleep problems, depression, lack of energy, fatigue, and flu-like symptoms.”

An increasing part of the European population is affected by ill health symptoms that have for many years been linked to exposure to EMF and wireless radiation in the scientific literature. The International Scientific Declaration on EHS & multiple chemical sensitivity (MCS), Brussels 2015, declares that: "In view of our present scientific knowledge, we thereby stress all national and international bodies and institutions...to recognize EHS and MCS as true medical conditions which acting as sentinel diseases may create a *major public health concern in years to come worldwide* i.e. in all the countries implementing unrestricted use of electromagnetic field-based wireless technologies and marketed chemical substances… ***Inaction is a cost to society*** and is not an option anymore… we unanimously acknowledge this serious hazard to public health…that major primary *prevention measures are adopted and prioritized, to face this* ***worldwide pan-epidemic*** *in perspective."*

## Precautions

The **Precautionary Principle** (UNESCO) was adopted by EU 2005: ”*When human activities may lead to morally unacceptable harm that is scientifically plausible but uncertain,* actions shall be taken to *avoid or diminish that harm.*”

**Resolution 1815** (Council of Europe, 2011): ”*Take all reasonable measures to reduce exposure to electromagnetic fields,* especially to radio frequencies from mobile phones, and particularly the exposure to children and young people who seem to be most at risk from head tumours…Assembly strongly recommends that the ALARA (as low as reasonably achievable) principle is applied, covering both the so-called thermal effects and the athermic [non-thermal] or biological effects of electromagnetic emissions or radiation” and to ”improve risk-assessment standards and quality”.

The **Nuremberg code** (1949) applies to all experiments on humans, thus including the roll-out of 5G with new, higher RF-EMF exposure. All such experiments: ”should be based on previous knowledge (e.g., an expectation derived from animal experiments) that justifies the experiment. No experiment should be conducted, *where there is an a priori reason to believe that death or disabling injury will occur*; except, perhaps, in those experiments where the experimental physicians also serve as subjects.” (Nuremberg code pts 3-5). Already published scientific studies show that there is ”a priori reason to believe” in real health hazards.

The **European Environment Agency** (EEA) is warning for ”Radiation risk from everyday devices" in spite of the radiation being below the WHO/ICNIRP standards. EEA also concludes: ”There are many examples of the failure to use the precautionary principle in the past, which have *resulted in serious and often irreversible damage to health and environments*…harmful exposures can be widespread before there is both 'convincing' evidence of harm from long-term exposures, and biological understanding [mechanism] of how that harm is caused.”

## “Safety guidelines” protect industry — not health

The current ICNIRP ”safety guidelines” are obsolete. All proofs of harm mentioned above arise although the radiation is below the ICNIRP "safety guidelines". Therefore new safety standards are necessary. The reason for the misleading guidelines is that “conflict of interest of ICNIRP members due to their *relationships with telecommunications or electric companies* undermine the impartiality that should govern the regulation of Public Exposure Standards for non-ionizing radiation…To evaluate cancer risks it is necessary to include scientists with competence in medicine, especially oncology.”

The current ICNIRP/WHO guidelines for EMF are based on the obsolete hypothesis that *”*The critical effect of RF-EMF exposure relevant to human health and safety is heating of exposed tissue.” However, scientists have proven that many different kinds of *illnesses and harms are* caused without heating (”non-thermal effect”) at radiation levels well below ICNIRP guidelines.

**We urge EU:**

1) To take all reasonable measures to halt the 5G RF-EMF expansion until independent scientists can assure that 5G and the total radiation levels caused by RF-EMF (5G together with 2G, 3G, 4G, and WiFi) will not be harmful for EU-citizens, especially infants, children and pregnant women, as well as the environment.

2) To recommend that all EU countries, especially their radiation safety agencies, follow Resolution 1815 and inform citizens, including, teachers and physicians, about health risks from RF-EMF radiation, how and why to avoid wireless communication, particularly in/near e.g., daycare centers, schools, homes, workplaces, hospitals and elderly care.

3) To appoint immediately, without industry influence, an EU task force of independent, truly impartial EMF-and-health scientists with no conflicts of interest[1] to re-evaluate the health risks and:

a) To decide about new, safe "maximum total exposure standards" for all wireless communication within EU.

b) To study the total and cumulative exposure affecting EU-citizens.

c) To create rules that will be prescribed/enforced within the EU about how to avoid exposure exceeding new EU "maximum total exposure standards" concerning all kinds of EMFs in order to protect citizens, especially infants, children and pregnant women.

4) To prevent the wireless/telecom industry through its lobbying organizations from persuading EU-officials to make decisions about further propagation of RF radiation including 5G in Europe.

5) To favor and implement wired digital telecommunication instead of wireless.

***We expect an answer*** *from you no later than* ***October 31, 2017*** *to the two first mentioned signatories about what measures you will take to protect the EU-inhabitants against RF-EMF and especially 5G radiation. This appeal and your response will be publicly available.*

## *Respectfully submitted,*

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[1] Avoid similar mistakes as when the Commission (2008/721/EC) appointed industry supportive members for SCENIHR, who submitted to EU a misleading SCENIHR report on health risks, giving telecom industry a clean bill to irradiate EU-citizens. The report is now quoted by radiation safety agencies in EU.

## Signatories to Scientists' 5G Appeal
**(As of September 8, 2017)**

**Note:** The endorsements are personal and not necessarily supported by the affiliated universities or organizations.

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***Signatories: 171 scientists from 36 nations: 99** scientists from EU and **72** from other nations.*

World Climate Declaration

# THERE IS NO CLIMATE EMERGENCY

1944 SIGNATORIES

GLOBAL CLIMATE INTELLIGENCE GROUP

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World Climate Declaration

# THERE IS NO CLIMATE EMERGENCY

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# There is no climate emergency

*Climate science should be less political, while climate policies should be more scientific. Scientists should openly address uncertainties and exaggerations in their predictions of global warming, while politicians should dispassionately count the real costs as well as the imagined benefits of their policy measures*

## Natural as well as anthropogenic factors cause warming

The geological archive reveals that Earth's climate has varied as long as the planet has existed, with natural cold and warm phases. The Little Ice Age ended as recently as 1850. Therefore, it is no surprise that we now are experiencing a period of warming.

## Warming is far slower than predicted

The world has warmed significantly less than predicted by IPCC on the basis of modeled anthropogenic forcing. The gap between the real world and the modeled world tells us that we are far from understanding climate change.

## Climate policy relies on inadequate models

Climate models have many shortcomings and are not remotely plausible as policy tools. They do not only exaggerate the effect of greenhouse gases, they also ignore the fact that enriching the atmosphere with $CO_2$ is beneficial.

## $CO_2$ is plant food, the basis of all life on Earth

$CO_2$ is not a pollutant. It is essential to all life on Earth. More $CO_2$ is favorable for nature, greening our planet. Additional $CO_2$ in the air has promoted growth in global plant biomass. It is also profitable for agriculture, increasing the yields of crops worldwide.

## Global warming has not increased natural disasters

There is no statistical evidence that global warming is intensifying hurricanes, floods, droughts and suchlike natural disasters, or making them more frequent. However, there is ample evidence that $CO_2$-mitigation measures are as damaging as they are costly.

## Climate policy must respect scientific and economic realities

There is no climate emergency. Therefore, there is no cause for panic and alarm. We strongly oppose the harmful and unrealistic net-zero $CO_2$ policy proposed for 2050. Go for adaptation instead of mitigation; adaptation works whatever the causes are.

> OUR ADVICE TO THE WORLD LEADERS IS THAT SCIENCE SHOULD STRIVE FOR A SIGNIFICANTLY BETTER UNDERSTANDING OF THE CLIMATE SYSTEM, WHILE POLITICS SHOULD FOCUS ON MINIMIZING POTENTIAL CLIMATE DAMAGE BY PRIORITIZING ADAPTATION STRATEGIES BASED ON PROVEN AND AFFORDABLE TECHNOLOGIES.

To believe the outcome of a climate model is to believe what the model makers have put in. This is precisely the problem of today’s climate discussion to which climate models are central. Climate science has degenerated into a discussion based on beliefs, not on sound self-critical science. Should not we free ourselves from the naive belief in immature climate models?

photo: Simon Skafar

# The undersigned:

WCD AMBASSADORS

NOBEL LAUREATE PROFESSOR JOHN F. CLAUSER / USA
NOBEL LAUREATE PROFESSOR IVAR GIAEVER NORWAY/USA
PROFESSOR GUUS BERKHOUT / THE NETHERLANDS
DR. CORNELIS LE PAIR / THE NETHERLANDS
PROFESSOR REYNALD DU BERGER / FRENCH SPEAKING CANADA
BARRY BRILL / NEW ZEALAND
VIV FORBES / AUSTRALIA
DR. PATRICK MOORE / ENGLISH SPEAKING CANADA
JENS MORTON HANSEN / DENMARK
PROFESSOR LÁSZIÓ SZARKA / HUNGARY
PROFESSOR SEOK SOON PARK / SOUTH KOREA
PROFESSOR JAN-ERIK SOLHEIM / NORWAY
PROFESSOR STAVROS ALEXANDRIS / GREECE
FERDINAND MEEUS / DUTCH SPEAKING BELGIUM
PROFESSOR RICHARD LINDZEN / USA
HENRI A. MASSON / FRENCH SPEAKING BELGIUM
PROFESSOR INGEMAR NORDIN / SWEDEN
JIM O'BRIEN / REPUBLIC OF IRELAND
PROFESSOR IAN PLIMER / AUSTRALIA
DOUGLAS POLLOCK / CHILE
DR. BLANCA PARGA LANDA / SPAIN
DR. PETER STALLINGA / PORTUGAL
PROFESSOR ALBERTO PRESTININZI / ITALY
PROFESSOR BENOÎT RITTAUD / FRANCE
DR. THIAGO MAIA / BRAZIL
PROFESSOR FRITZ VAHRENHOLT / GERMANY
THE VISCOUNT MONCKTON OF BRENCHLEY / UNITED KINGDOM
DUŠAN BIŽIĆ / CROATIA, BOSNIA AND HERZEGOVINA, SERBIA AND MONTE NEGRO

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# TOTAL SIGNATORIES 1944

## 5 SIGNATORIES FROM ARGENTINA

**5 Signatories**

- Dr. Cristián Antiba — Research professor at national universities and educational institutes
- Mauro Borsella — Environmental Consultant & Auditor
- Aldo Brandani — Coastal Specialist and Environmental Scientist
- Rosa Compagnucci — PhD in Meteorological Sciences, Climate Researcher, Full-time Professor at the University of Buenos Aires and Principal Researcher at CONICET
- Sergio Heguilén — MSc, Director of Ecoativo Environmental Consulting, specialized in regenerative agriculture and livestock and energy revaluation of wastes

## 179 SIGNATORIES FROM AUSTRALIA

**2 WCD Ambassadors**

- Viv Forbes — Geologist with Special Interest in Climate, Founder of www.carbon-sense.com, Queensland, Australia
- Ian Plimer — Professor Earth Sciences, The University of Melbourne

**177 Signatories**

- D.Weston Allen — Physician and Medical Director of Kingscliff Health, New South Wales, Author of a number of Climate-related papers
- Don Andersen — Retired Teacher, Programmer
- David Archibald — Research Scientist
- Rick Armstrong — retired metallurgist and strategic planner
- Michael Asten — Retired Professor in Geophysics and Continuing Senior Research Fellow at the Monash University, Melbourne
- József Balla — retired teacher and manager of a small business
- Stuart Ballantyne — PhD, Senior Ship Designer, Sea Transport Corp.
- Dr. Priyanka Bandara — PhD, former academic medical researcher operating as a freelance researcher in environmental health since 2012.
- Jim Bannister — industry researcher for many years but recently a high school educator.
- Jeremy Barlow — Energy and Mining professional, Director and CEO
- Dr. Colin M. Barton — Geologist, Retired Civil Engineer with Experience in Project Control, Research and Professional Training, Honorary Fellow RMIT University, Australia
- Gordon Batt — Director GCB Investments Pty Ltd.
- Maxwell Charles S. Beck — lifetime of international experience in law, retired Magistrate and Coroner on the bench
- Robert M. Bell — Retired Geologist, Victoria
- Karen Benn — PhD, Biologist and Environmental Scientist, Educator and University Lecturer in Sciences, Biology, Environmental Sciences, Water Quality and Water Resource Management
- Richard Blayden — Professional Engineer
- Colin Boyce — Engineer, Member of Parliament, Queensland State Parliament, Engineer, Farmer and Entrepreneur
- Howard Thomas Brady — Member Explorers Club of New York, Member of the Australian Academy of Forensic Sciences
- Geoff Brown — Organizer of a Critical Climate Group
- Andrew Browne — Exploration Geoscientist, Fellow AusIMM (CP), 50 Years Global Experience

Australia continued

| | |
|---|---|
| • Frank Brus | holds a B. Comm from UNSW, spent most of his working life with the Electricity Commission of NSW |
| • Ernest Buchan | Chartered Engineer MIET, Kardinya, W. Australia |
| • Alan Douglas Buerger | Fellow Australasian Institute of Mining and Metallurgy, Member of Australian Institute of Comapany Directors |
| • Mike Bugler | Retired Environmental Consultant |
| • Paul Buncle | Medical Practitioner |
| • Tony Burns | PhD in Chemical Engineering |
| • Paul Callander | Retired Geologist BSc Melbourne, Extensive experience in energy economics |
| • Charles Camenzuli | Structural Engineer specializing in Remedial Work, Catcam Group, Sydney |
| • Ray Carman | Organic Chemist, Honorary Fellow University of Queensland |
| • Dr. Larry Cashion | PhD in Psychology, Consultant Psychologist, Special interest in cognition and language of climate science |
| • Peter Champness | Radiologist |
| • Andrew E. Chapman | Expert on Rainfall and Flood Events |
| • Michael F. Clancy | Retired Civil Engineer, Brisbane |
| • Martin Clark | Expert in Building Design, Planning and Landscaping, Townsville NQ |
| • Richard Corbett | Member Royal Australian Chemical Institute, Member of The Clean Air Society of Australia and New Zealand |
| • Dr. Michael Creech | lifetime active as Geologist; Dr. Creech informs the public by giving presentations on Climate Change |
| • Matt Crisanti | BSc, UniSA, Science Faculty Coordinator at St. Columba College in 2008 |
| • Majorie Curtis | Retired Geologist, Stratigrapher and Palaeoclimatic Studies, Canberra |
| • Eric Daniel | Retired IT Consultant |
| • Arthur Day | Earth Scientist, Specialist in Geochemical Modelling of Volcanic Processes |
| • Dr. Geoff Deacon | PhD., MSc., BSc (hons), geologist, palaeontologist, advocate for geological truth in Climate Science |
| • David H. Denham | lifetime experience as Architect (B Arch), active in giving talks and writing opinion articles on climate change |
| • Geoff Derrick | Geologist |
| • Trish Dewhirst | Retired Geologist, Queensland |
| • Bevan Dockery | BSc (UWA), Grad.Dip.Computing (Curtin U), Exploration Geophysicist in minerals world-wide |
| • Aert Driessen | Geologist, Fellow Australian Institute of Geoscientists |
| • John A. Earthrowl | Retired Geologist, Brisbane |
| • Mike Elliott | Dux of School in Mathematics, Co-Founder of Climate Realists of Five Dock |
| • Jeremy K. Ellis | Retired Chairman of BHP, now Chairman of the Saltbush Club in Australia |
| • Dr. Stephen David English | PhD in Crop Physiology from University of New England, Retired Agricultural Scientist |
| • Matthew J. Fagan | Founder and President of FastCAM Inc. |
| • Michael Foley | BSc Microbiology, PhD Biochemistry, Professor of Biochemistry, La Trobe University Austra |
| • Paul S. Forbes | Financial Advice Specialist |
| • Nick Franey | MSc Mineral Exploration, NJFconsulting Pty Ltd (founder, MD), Director Australian Institute of Geoscientists |
| • Dr. Rodney Fripp | Mining Geologist and Chemist by education, lifetime experience in the fields of Mining and Exploration Geology, Analytical Chemistry and Physics of the Earth |
| • Michael Fry | PhD, retired Professor, ex Head of School and Dean of IT |
| • Christopher J.S. Game | Retired Neurophysiologist |
| • Robin George | Geologist, Canterbury |
| • David Gibson | Experimental Physicist |
| • Andrew Gillies | Geologist |

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| • Gavin Gillman | Former Senior Principal Research Scientist with SCIRO Australia, Founding Director of the IITA Ecoregional Research Centre in Cameroon |
| • Paul R.C. Goard | BSc Sydney University, Physics & Maths, + Two years geology, one year Chemistry, member of the Australian Meteorological & Oceanographic Society |
| • Brendan Godwin | Weather Observations and General Meteorology, Radio (EMR and Radar) Technical Officer, Retired from Bureau of Meteorology |
| • Hamish Grant | MR Spectroscopy & Imaging Consultant, Victoria |
| • Dr. Kesten C. Green | Leading Researcher on forecasting Methods and Applications, University of South Australia, author of "Validity of Climate Change forecasting for public policy decision making" |
| • Jeffrey R. Grimshaw | MSc Information Technology, Author of Trigger Warming, Everything You Wanted To Know About Global Warming But Were Afraid To Ask |
| • Guy Grocott | MSc Engineering Geology, Retired Consulting Engineering Geologist/ Geotechnical Engineer |
| • Lindsay Hackett | BSc, Author of the paper "Global Warming Misunderstood" and the paper "The Impact of Greenhouse Gases on Earth's Spectral Radiance" |
| • Maureen Hanisch | PhD Biochemistry, Medical Research 1997, Australian National University, Retired |
| • Erl Happ | Managing Director at Happs |
| • John Happs | Geoscientist, Retired University Lecturer |
| • Peter J.F. Harris | Retired Engineer (Electronic), now Climate Researcher |
| • Paul Leonard Harrison | Geophysicist with an M.Sc in Geology and Geophysics, over 45 years experience in research and exploration for the geo-energy industry |
| • Jarvis Hayman | Retired Surgeon, Recently retired Archaeologist and Visiting Fellow at the Australian National University |
| • Mark Henschke | Retired Geologist in Mining, Oil and Gas |
| • Frederick Stewart Hespe | Consulting Civil and Forensic Engineer, Critic of Government Policy on Climate Related Matters |
| • Gerhard Hofmann | Geologist and Palaeontologist, Former Director of the Geological Survey of Queensland |
| • Robert Ian Holmes | PhD in Climate Science/Mitigation, University Lecturer (retired) and Climate Scientist |
| • Selwyn Hopley | MSSSI, Retired Land and Engineering Surveyor |
| • Antonia Howarth-Wass | Mathematician, Author on Local Climate Articles |
| • Geraint Hughes | Climate Researcher, Mechanical Building Engineer, Climate Researcher |
| • Douglas Hutchison | BSc and MSc degrees in geology, consulting geologist in the mining industry, member of the Australian Institute of Geoscientists |
| • David Hyde | MEnvSt, Environmental Biology, Former Scientific Chairman of Australian Underwater Federation (NSW) |
| • Paul Ingram | Qualified Geologist, Member of the Australian Institute of Mining and Metallurgy, studying Palaeoanthropology and Human Evolution |
| • Mr. Anthony Jackson | Bachelor of Arts degree, Bachelor of Laws degree, retired |
| • Ian Johnson | Bachelor of Engineering, consultant |
| • Mike Jonas | IT consultant, retired, frequent contributor to Watts Up With That? |
| • Prof. Aynsley Kellow | Professor emeritus of Government, College of Arts, Law and Education, University of Tasmania |
| • Alison Kelsey | PhD, Palaeoclimatogist and Archaeologist, University of Queensland |
| • Kevin Kemmis | Climate Researcher, Expert in Information Technology |
| • Neil Killion | Occupational Psychologist, author and Chairman and Co-Founder of Climate and Energy Realists Queensland |
| • Bill Kininmonth | BSc (UWA), MSc (CSU) M. Admin. (Monash), Former Superintendent of the Bureau of Meteorology National Climate Center |
| • David Knox | IT professional, bachelors in business (Uni of South Australia) and a Masters degree in business administration (Charles Sturt University) |
| • Rosemarie Kryger | PhD, Biochemistry, Retired, University of Queensland, Brisbane |
| • Hugh H. Laird | Retired Tropical Agriculture Executive |
| • John Leisten | OBE, Expert in Physical Chemistry |
| • Brian Levitan | Worked for NASA, now Technology Consultant to Multinationals |
| • Ian Levy | CEO Australian Bauxite Ltd. |

Australia continued

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|---|---|
| • Matthew David Linn | Fellow of the Institution of Engineers of Australia |
| • Ian Longley | Geologist, Bsc (Hons) Petroleum Geologist, Fellow of the Geological Society |
| • Kevin A. Loughrey | LtCol(Ret'd) BAppSc, BE Mech(hons), psc, jssc, Grad Dip Strategic Studies |
| • David Z. Lubowski | Conjoint Professor in Surgery, University of New South Wales |
| • Finlay MacRitchie | Professor Emeritus in the Department of Grain Science and Industry at Kansas State University USA |
| • John Ross May | Bsc, Adip, Cres., Management of Forests and National parks in Victoria |
| • Sandy McClintock | BA(Science)TCD, MSc, PhD, Lifetime experience in modeling and data analysis; in retirement, 20 years of interest in climate data analysis |
| • Gerard McGann | Technical Director Eon NRG |
| • Jim McGregor-Dawson | Geologist and informed scientist on the subject of Climate Science |
| • Rodney McKellar | Retired Geologist, Queensland |
| • John McLean | Author of First Major Review of HadCRUT 4 Climate Temperature Data, Member of New Zealand Climate Science Coalition |
| • Toby McLeay | General Medical Practitioner AM, MBBS, FRACGP, FACRRM |
| • Ross McLeod | Retired Environmental Health Officer |
| • Peter R. Meadows | Agricultural Scientist |
| • Paul Messenger | PhD, Earth Science |
| • John Michelmore | Retired Industrial Chemist |
| • Des Moore | Former Deputy Secretary of the Federal Treasury, Founder and Leader of the Institute for Private Enterprise |
| • Alan Moran | Contributor and Editor of the Mark Steyn Compilation: "Climate Change, the Facts", Author of Climate Change: "Treaties and Policies in the Trump Era" |
| • Hugh M. Morgan | Prominent Australian Mining Executive, Fellow of the Australian Academy of Technology, Science and Engineering (FTSE) |
| • Peter Murphy | PhD, Adjunct Professor, Social Sciences, La Trobe University (Melbourne) and the Cairns Institute, James Cook University |
| • John Edward Nethery | BSc in Geology, DipEd in Geology, Physics, Chemistry, Biology, Consultant Geologist |
| • John Nicol | PhD, Retired Senior Lecturer Physics and one time Dean of Science, James Cook University, North Queensland |
| • Paul John O'Keeffe | MB, BS, FRCS, FRACS, Retired Surgeon |
| • Clifford David Ollier | DSc, Geologist, Emeritus Professor of Geology and Honorary Research Fellow |
| • David Parsons | B.E Mech. FIE Aust CPEng NER, Principal Design Engineer, specialised in boiler design and gas radiation analysis |
| • M. Louise Petrick | MSc Applied Science, Materials and Welding Engineer |
| • Suzana Podreka | Environmental Scientist |
| • Alistair Pope | PSc, CM, Sceptical Scientific Contrarian in the Climate Debate |
| • Robert Pyper | Geologist and Director of Minnelex Pty Ltd. |
| • Tom Quirk | Nuclear Physicist |
| • Art Raiche | PhD, Mathematical Geophysics, Retired CSIRO Chief Research Scientist |
| • Geoff Rankin | BVSc (Hons), MVSc, Veterinarian, retired, A long-time interest in Meteorology, Climate, and Geology |
| • Campbell Rankine | Barrister and Solicitor |
| • Peter Ridd | Oceanographer and Geophysicist |
| • Tim Riley | Mining Geologist |
| • John Cameron Robertson | Author of CO2 Feeds the World and The Climate Change Delusion |
| • Philip Lance Robinson | Chemical Engineer, lifetime experience in the aluminium and steel industry |
| • Nigel Rowlands | Retired from Mining and Exploration Industry |
| • George (Rob) Ryan | Professional Geologist |
| • Judy Ryan | Editor Principia Scientific Institution Australia |
| • Tony Schreck | Managing Director, 35 yrs experienced geologist, Member of the Australian Institute of Geoscientists, Member of the Australian Institute of Company Directors |
| • Pasquale Seizis | Mechanical Engineer, climate critic |

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| • Geoffrey Sherrington | Geoffrey Sherrington, Retired Chief Geochemist, Geopeko Limited |
| • Jim Simpson | Retired from Managing Positions in different International Telecommunications Firms, nowadays Convenor of 'The Climate Realists of Five Dock', Sydney Australia." |
| • Case Smit | Physicist, Expert in Environmental Protection, Cofounder of the Galileo Movement |
| • Edward Smith | Charted Chemist, member of the Royal Australian Institute of Chemistry (RACI), lifetime of experience in the Pharmaceutical industry |
| • Lee Smith | University Lecturer in Spatial Technology, Responsible for State Government Precise Monitoring of Sea Level and International Sea Boundaries |
| • Peter Smith | Geologist (Retired), New South Wales |
| • Mark Sonter | MSc(Hons)(Physics - Space Resources), Consultant & Principal, Asteriod Enterprises Pty Ltd at Asteroid Enterprise |
| • Dr. Libor Spacek | PhD in Computer Science, Modelling & AI |
| • Darren Speirs | Independent Business Owner, Rangeland NRM Consultants |
| • Geoffrey Stocker | Professor and Head of Department of Forestry, PNG University of Technology, Director of PNG Forest Research Institute |
| • Dr. Nancy Enid Stone | BSc (Hons), University of Western Australia (1950), PhD Cantab. (1956), Retired Research Biochemist |
| • John Stone | Former Head of the Australian Treasury and Executive Director of both the IMF and the World Bank |
| • Rodney R. Stuart | Retired Expert in Energy Industry, Tasmania |
| • Roger Symons | Professional Engineer, Expert in Temperature Control of Industrial Buildings |
| • James Taylor | Electrical Aerospace and Astrophysics Engineer, Computer Modelling Researcher |
| • Tony Thomas | MA, B.Ec, journalist and author for more than 60 years |
| • Rustyn Wesley Thomas | Retired Aircraft Engineer |
| • Baki M. Top | Senior Agricultural Scientist, Freelance Consultant Agricultural and Food Production & Agribusiness |
| • John W. Turner | Science Educator, Noosa Heads |
| • Ralph J. Tyler | Retired Senior Principal Research Chemist, CSIRO, expert in conversion of coal and natural gas to liquid fuel |
| • Peter Tyrer | Project Controls Engineer in Mining Industry |
| • Dr. Julian Vearncombe | PhD, Geologist, Fellow Australian Institute of Geoscientists |
| • Terrence Vincent | Security Engineer, Small Business Adviser AIST, ASIAL, SMBE |
| • John Vucko | Bachelor of Electrical Engineering (Hons) |
| • James Walter | Medical Doctor |
| • John Warnock | Astro Economist |
| • Chris Warren | Retired Engineer, Design and Construction of Dams and feasibility of Coal Mines |
| • Colleen J. Watts | Retired Environmental Scientist with specialization in Aquatic Chemistry and Environmental Consequences of Renewable Energy |
| • Alan C. Watts | Medical Practitioner specialized in Effects of Infrasound on Human Health |
| • Glyn Weatherall | Energy Resources Advisor |
| • Neil Wilkins | Retired Geologist |
| • Richard Willoughby | retired electrical engineer with thirty years experience in the Australian mining and mineral processing industry |
| • P.C. Wilson | Former Journalist with the A.B.C. Queensland |
| • Lawrence A. Wilson | Professional Chemical Engineer, Melbourne |
| • Michael Wilson | PhD, DSc, Emeritus Professor, former Executive Dean UWS, Former Chief Research Scientists CSIRO, Low Emissions Transport Fuels Leader |
| • Philip Wood | Qualified Lawyer in four Jurisdictions (Australia, New York, UK and Hong Kong), CEO of two ASX-listed Companies operating in the Mining and Minerals Processing Fields |

Australia continued

- Michael Wort — BSc Geology, MSc Mineral Process Design, PhD Mineral Technology, Geologist interested in impact of high levels of atmospheric CO2 as trigger for formation of limestone deposits

## 10 SIGNATORIES FROM AUSTRIA

**10 Signatories**

- Dr. Wolf Bertling — PD in Medicine,and pharmacist and entrepreneur
- Dr. Ernst Hammel — Career in Physics and Nanotechnology, patent holder and author in multiple scientific publications
- Dr. Gerhard Kirchner — Berg Ingenieur, Climate Realist
- Dipl Ing, Dr rer techn Heribert Martinides — European Space Agency, retired
- Rudolf Posch — PhD, Retired Software Engineer of a Technical Multinational, Expert in Nonlinearities and Feedbacks
- Dr. Eike Roth — PhD in Physics, Lifetime career in Nuclear Energy
- Helmut M. Sauseng — MSc Physical Chemistry, entrepreneur, activist in civil society
- Hans Dirk Struve — Dipl. Ing., Mechanical Engineer with large experience in business
- Dr. Joseph Laszlo Szekeres — MD, PhD, Associate Professor at Medical University of Vienna, President of Vienna Medical Association
- Konrad Falko Wutscher — Doctor of Engineering Sciences, specialist in treatment of water and wastewater

## 1 SIGNATORY FROM BANGLADESH

**1 Signatory**

- Prof. Dr. Aftab Alam Khan — PhD, Active Professor Geological Oceanography, BSMR Maritime University, Retired Professor of Geology and Geophysics of Dhaka University

## 1 SIGNATORY FROM BARBADOS

**1 Signatory**

- Fred Corbin — Director of CSW Engineering 2000, Co-founder of The FREEWINDS organization

## 38 SIGNATORIES FROM BELGIUM

**2 WCD Ambassadors**

- Henri A. Masson — Professor Emeritus Dynamic System Analysis and Data Mining, University of Antwerp, French speaking Belgium
- Ferdinand Meeus — Retired Dr. Sc (Chemistry, Photopfysics, Photochemistry), IPCC expert Reviewer AR6

**36 Signatories**

- Rudy Berkvens — Information Security and Quality Management Auditor in ICT and Aviation, Commercial Pilot, Flight Instructor
- Eric Blondeel — Retired Civil Engineer
- Emiel van Broekhoven† — Emeritus Professor of Economics, University of Antwerp
- Christophe de Brouwer — MD, Honorary Professor of Environmental and Industrial Toxicology, Former President of the School of Public Health at the Université Libre de Bruxelles
- Jan-Paul Buijs — Biologist, Computer scientist, experienced business consultant and change manager, director of two NGOs around awareness for, and protection and restauration of fragile ecosystems
- Alexandre G. Clauwaert — Brussels Polytechnic, Civil Engineer
- Alain Colignon — Surgeon, Brussels University (ULB), Professor of Laser Physics at Paris V René Descartes, Specialist in medical Ultrasound.
- Rudi Creemers — Eur. Ing. MSc Electronics-ICT, Network engineer/manager
- Benjamin Damien — Docteur en Biologie et Entrepreneur en Biotechnologie
- Ferdinand Engelbeen — Former Chemical Process Automation Engineer, Akzo Nobel Chemicals
- Samuel Furfari — Professor of Energy Geopolitics at the Free University of Brussels

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|---|---|
| • Georges Geuskens | Emertitus Professor of Chemistry, Free University of Brussels and Expert Publicist on Climate Science |
| • Drieu Godefridi | PhD, Law, Author of several books |
| • Jan Goffa | Civil Engineer Applied Mechanics, Retired lecturer in thermo- and aerodynamics |
| • Dr. Volkmar Hierner | degree in business administration and economy, retired coach of companies in increasing the effectiveness of their organization |
| • Jan Jacobs | Science Journalist Specializing in Climate and Energy Transition |
| • Guy Janssen | MSc Applied Sciences (civil engineer electromechanics), MSc Nuclear Engineering, Reactor Sciences, experienced conventional electric power expert |
| • Raymond Koch | Retired Research Director at Lab. Plasma Physics, RMA Brussels and Fellow Lecturer at UMons |
| • Rob Lemeire | Publicist on Environmental and Climate Issues |
| • Jean Meeus | Retired Meteorologist, Brussels Airport, Author of the Best Seller Astronomical Algorithms |
| • Ernest Mund | Honorary Research Scientist, Honorary Research Director, FNRS, Nuclear Engineering |
| • Bart Ooghe | Geologist & Geophysicist, Independent Scientist |
| • Luc Opdecamp | “The agronomist-philosopher” (independent researcher), Agronmist (Soil science) |
| • Jaak Peeters | Psychologist and Writer |
| • Eric Perpète | Microcomputed Tomography Scientist, FNRS Senior Research Associate in Chemical Physics |
| • Michel Pollyn | MSc in Energy Science, Retrired engineer. Lifetime career in industrial process water treatment and energy projects |
| • Dr. Hugo Poppe | Emeritus hoogleraar, Weer- en Klimaatkunde, KU-Leuven, 1966-2002 |
| • Alain R. Préat | PhD in Geology, Emeritus Professor at Université Libre de Bruxelles |
| • Danie Roettger | MSc. Engineering, lifetime career in energy conversion system development |
| • Phil Salmon | Computer Tomography Scientist, Kontich |
| • Paul Scheers | MSc Engineer in Chemistry and Nuclear Physics |
| • Rémy Sproelants | Civil EngineerRetired CEO ‘RESPRO Languages & Consultancy’, Team H2 SALK/ ThinkTank/Engineering |
| • Jozef Verhulst | PhD, Chemistry, Author |
| • Jean van Vliet | Retired Specialist in Space Weather |
| • Dr. Marc Wathelet | PhD in Molecular Biology, Free University of Brussels |
| • Appo van der Wiel | Senior Development Engineer |

## 1 SIGNATORY FROM BOLIVIA

**1 Signatory**

| | |
|---|---|
| • Ambassador José Brechner | retired Congressman and Ambassador for the Bolivian Government, Chair of the Foreign Affairs Committee, currently Syndicated Columnist and Senior Political Analyst |

## 22 SIGNATORIES FROM BRAZIL

**1 WCD Ambassador**

| | |
|---|---|
| • Dr. Thiago Maia | Nuclear Physicist, PhD in Astrophysics |

**21 Signatories**

| | |
|---|---|
| • Jorge Luis Balino | PhD in Nuclear Engineering, Career in R&D and Education in topics related to Nuclear and Petroleum Engineering |
| • Dr. Peter Brian Bayley | PhD, lifetime experience in Aquatic Ecology and Fisheries, retired from Dep. Fisheries & Wildlife, Oregon State University |
| • Jose Nestor Cardoso | Professor on first oceanography course in Latin America, Pioneer on Brazilian expedition to Antartic, First scientific diver for Brazil from CMAS |
| • Mario de Carvalho Fontes Neto | Agronomist, Editor of ‘The Great Global Warming Swindle’ |

Brazil continued

| | |
|---|---|
| • José Bueno Conti | Geographer and Professor of Climatology, Full Professor of the Geography Department at the University of Sao Paulo (USP) |
| • Dr. Johnson Delibero Angelo | Master and Ph.D. in Material Science, Industrial Chemist, Emeritus Collaborating Professor of Postgraduate Studies in Mechanical Engineering at UFABC |
| • Prof. Dr. Ricardo Augusto Felicio | BSc Meteorology - USP, MSc Antarctic Meteorology and Satellites - INPE, PhD in Climatology - Physical Geography - USP |
| • Richard Jakubazsko | Executive Editor of Agro DBO Magazine and Co-Author of the Book ‘CO2, Warming and Climate Change: Are you kidding us?’ |
| • Dr. George Lentz Cesar Fruehauf | BSc. Doctor of Sciences – USP, MSc. Meteorology – SJSU, expert in environmental engineering |
| • Agnaldo Martins | professor and researcher at the Department of Oceanography and Ecology at the Federal University of Espírito Santo |
| • Luiz Carlos Badicero Molion | Emeritus Professor of the Federal University of Alagoas (UFAL), Formerly of the National Institute of Space research (INPE) |
| • Prof. Marcos José de Oliveira | Environmental Engineer, Master in Climatology, Author of research articles about climate cycles and natural causes of climate change |
| • Fernando Paiva | PhD Animal Science, Full professor at the Federal University of Mato Grosso do Sul |
| • José Carlos Parente de Oliviera | Physicist, Professor at the Federal Institute of Education, Science and Technology of Cearà (IFCE), Retired Associate Professor of the Federal University of Cearà (UFC) |
| • Paulo Pimenta | PhD in Aerospace Engineering, Professor for Solid and Structural Mechanics, University of São Paulo |
| • Guilherme Polli Rodrigues | Geographer, Master in Climatology, Environmental Consultant |
| • Adelino de Santi | BSc Biology and Ecology, MSc Applied Ecology, Biologist, works with environmental education, licensing, restoration, sustainability management and staff supervision |
| • Geraldo Luis Saraiva Lino | Geologist, Author of ‘How a Natural Phenomenon Was Converted into a False Global Emergency |
| • Marcello Silva Sader | Graduated in Veterinary Medicine and Computer Sciences |
| • Daniela de Souza Onca | Professor of the Geography Department of the State University of Santa Catarina (UDESC) |
| • Igor Vaz Maquieira | Biologist, Specialist in Environmental Management |

## 2 SIGNATORIES FROM BULGARIA

**2 Signatories**

| | |
|---|---|
| • Ivan Daraktchiev | MSc of Applied Science (Electronics engineering, Chemistry, Physics), Independent Researcher |
| • Fabrice Toussaint | lifetime of experience in the geo-energy industry, expert in complex numerical modelling |

## 148 SIGNATORIES FROM CANADA

**2 WCD Ambassadors**

| | |
|---|---|
| • Reynald du Berger | Retired Professor of Geophysics, Université du Québec a Chicoutimi, French Canada |
| • Patrick Moore | Ecologist, Chair CO2 Coalition, Co-Founder Green Peace |

**146 Signatories**

| | |
|---|---|
| • Steven Ambler | PhD, Full Professor University of Quebec, Dept. of Economics |
| • John Andersen | BSc, Honours, University of Alberta |
| • Peter Andreadis | Satellite Systems Engineer |
| • Dr. Grant Armstrong | Leadership development and coaching |
| • Russ Babcock | retired biochemist, lifetime experience in the mining and smelting industry with emphasis on pollution abatement |
| • Tim Ball† | Emeritus Professor Geography, University of Winnipeg and Advisor of the International Science Coalition |
| • Ron Barmby | M.Eng in Engineering with major in Geoscience, Author of ‘Sunlight in Climate Change: A Heretic’s Guide to Global Climate Hysteria’ |
| • Timothy J. Barrett | PhD, Geochemical Researcher, Ore Systems Consulting |

| | |
|---|---|
| • Robert Douglas Bebb | Professional Engineer (Mechanical), MBA |
| • Callum Beck | PhD in Religious Studies, Sessional Professor in Religious and University Studies |
| • Rick Beingessner | BSc, BA and LLB University of Alberta, lifetime experience in the Geo-Energy Industry, recently involved in researching Climate Change Matters |
| • Jean du Berger | Ingénieur Retraité, Bell |
| • Mario Blais | Science and Mathematics Teacher |
| • Alain Bonnier | PhD, Physique, INRS-Centre de Recherche en Énergie, Montréal |
| • Andrew Bonvicini | Professional Geophysicist, President of Friends of Science Society |
| • Dr. Don Bowen | PhD population ecology, Emeritus Research Scientist, Bedford Institute of Oceanography |
| • Jacques Brassard | Minister of Recreation (1984), Minister of Environment (1994), Minister of Transport and Intergovernmental Affairs of Canada (1996), Minister of Natural Resources and House Leader |
| • Kevin Burke | MSc in Marine Biology, author/co-author of 2 technical report with the Departement of Fisheries and Oceans and 2 scientific article published in the Journal of Shellfish Research |
| • Chris Carr | BSc (Hons) Engineering Geology and Geotechnics, retired Geoscientist |
| • Michel Chapdelaine | MSc, Géologie, Montréal |
| • Michel Chossudovsky | PhD of Economics, Professor of Economics, Emeritus, University of Ottawa |
| • Henry Clark | Thermal/Power Engineer |
| • Ian Clark | Professor of Earth and Environmental Sciences, University of Ottawa |
| • Edmond (Ted) Clarke | MSc, Engineering, Member of Friends on Science Society |
| • Paulo N. Correa | Biophysicist and Oncologist, Inventor, Author of numerous books and research papers, Director of Research at Aurora Biophysics Research Institute |
| • Hortense Côté | Ingénieur Géologue, Goldminds |
| • Susan Crockford | Zoologist and Polar Bear Expert, Former Adjunct Professor University of Victoria |
| • Norman Curry | Technical College, Design Engineering-Mechanical Engineering, President of National Zephyr Research |
| • Charles Danten | former veterinarian, scientific translator, author, and free-lance journalist. |
| • John Bruce Davies | BSc Pysics and Mathematics, MSc Geoscience, PhD Geophysics and Astrophysics, awards for research on cosmology and fundamental physics. |
| • Ronald Davison | Professional Chemical Engineer |
| • Dr. E. David Day | BSc, PhD, Chemistry |
| • A.E. Dixon | PhD, Emeritus Professor of Physics, University of Waterloo |
| • Eric Ducharme | MSc, Géologie, Abitibi |
| • Michel Dumais | Ingénieur Civil Retraité, Université d'Ottawa |
| • Dr. George Duncan | PhD, Retired environmental consultant from A &A Environmental Consultants Inc. |
| • Claude Duplessis | BcSc, Géologie, Ingénieur Géologue, Goldminds |
| • Craig A. Elliott | MSc Mechanical Engineering, Design Consultant, President at CAElliott Inc |
| • Ashton Embry | Research Geologist, Embry Holdings |
| • Christopher Essex | Emeritus Professor of Mathematics and Emeritus Professor of Physics, University of Western Ontario |
| • David Fermor | Anaesthesiologist, B.A., M.D., FRCPC |
| • Chris Fleming | PhD, Senior Metallurgical Consultant |
| • Len Flint | Ph.D, P.Eng. (Life Member). A 54 year career in oil and gas and renewable energies. Advisor on GHG footprints for several companies in Canada. Follower of the broad science. |
| • André Forgues | Meteorologist/Aerologist |
| • Jeffrey Foss† | Professor of Philosophy of Science, University of Victoria; Former WCD Ambassador |
| • Joseph Fournier | PhD, Expert in Physical Chemistry |
| • Anita Frayne | farmer and firm adherent of science realism-based decision making. |

Canada continued

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|---|---|
| • Paul M. Gagnon | Professional Engineer |
| • George Gale | PhD Geology, Mineral Deposit Geoscience |
| • Thomas P. Gallagher | Earth Scientists, life-long career in the study of paleoclimate, geology and earth ocean systems, see https://www.youtube.com/watch?v=pj-Iu1i317E |
| • J. Claude Gobeil | BSc, Geology |
| • Douglas Goodman | Engineer, life of time experience in the geo-energy industry |
| • Kenneth B. Gregory | Professional Engineer, Director Friends of Science Society |
| • Jean-Francois Guay | PhD in Environmental Science and Decision System, Regional Planner and Associate Professor |
| • Dr. Paul Hamblin | Retired Research Scientist Environment Canada, Advisor to the Georgian Bay Association |
| • John Hastie | MSc Soil Physics, Reclamation and Soil Scientist |
| • Mark T. Hohm | Professional Engineer registered with the Association of Professional Engineers and Geoscientists of Alberta (APEGA) |
| • R.G. Holtby | profesional agrologist |
| • Patrick Hunt | former member of the Royal Canadian Navy, former member of the Legislative Assembly of Nova Scotia, retired entrepreneur in the high-tech field (35 Years) |
| • Rick Ironside | Director Fortress ESG, provides specialized expertise to help clients map out their journey to attempt to achieve the goal of net zero by 2050 |
| • Eric Jelinski | M. Eng. P. Eng., Alumni and Contract Lecturer, University of Toronto, Department of Chemical Engineering and Applied Chemistry, CHE568 Lecturer, Nuclear Plant Engineering |
| • Paul A. Johnston | Associate Professor, Paleontology, Paleoecology, Department of Earth and Environmental Sciences, Mount Royal University, Calgary, Alberta |
| • Richard T. Jones | experimental physicist, researched in the field of fission energy |
| • E. Craig Jowett | Geologist and Environmental Researcher PhD University of Toronto |
| • Andre Julien | MSc Mechanical Engineering, Thermodynamics Expert, over 40 patents published |
| • Klaus L.E. Kaiser | Retired Research Scientist, National Water Research Institute, Author of Numerous Press Articles |
| • Bogdan Kasprzak | Professional Geoscientist, life time experience in data modelling, data analysing and data interpretation |
| • Madhav Khandekar | Expert Reviewer IPCC 2007 AR4 Report |
| • David Koop | BSc,Analytical Chemist |
| • Kees van Kooten | Professor of Economics and Canada Research Chair in Environmental Studies and Climate, University of Victoria |
| • Emil Koteles | PhD in Solid State Physics, Max Planck Institute in Stuttgart, National Research Council of Canada, visiting professor at Zhejiang University in Hangzhou, retired |
| • Jean Laberge | Professeur Retraité de Philosophie, CEGEP du Vieux Montréal |
| • Sherri Lange | CEO North American Platform Against Wind Power, Great Lakes Wind Truth |
| • M.J. Lavigne | MSc, Professional Geologist |
| • Douglas Leahey | PhD, Meteorology, past President of Friends of Science |
| • Professor Denis Leahy | PhD in Astrophysics, Full Professor in the Department of Physics and Astronomy, University of Calgary |
| • Dr. Catherine Lebrun | PhD, Management, HEC Montreal |
| • Robert Ledoux | PhD, Professeur Retraité en Géologie, Université Laval |
| • Dick Leppky | Retired businessman and Independent Truth Seeker |
| • Richard Lewanski | BsC (Hons) in Geophysics from the university of Manitoba, Exploration Geophysicist, Founder and CEO of several exploration and production companies in the oil industry |
| • H. Douglas Lightfoot | Research Engineer in the Chemical Industry, Co-Founder of the Lightfoot Institute, papers on Alternative Energy and Atmospheric CO2 |
| • Gerald Machnee | Retired Meteorologist, Environment Canada |
| • Allan M.R. MacRae | Retired Engineer |
| • Paul MacRae | Independent Climate Researcher |

- Joanne Marcotte — Bachelor's Degree in Computer Engineering and Author of "Inconvenient Doubts - Climate Change Apocalypse: Really?"
- Michael Martinz — Radio Podcast Host, Climate Realist, Activist, former Industrial Consulting Forester
- J. David Mason — Applied Geologist, BASc, Applied Geology, MEng., Mining
- Stuart McDonald — Retired Canadian Insurance Broker
- Dwight McIntosh — degree in physics and geology at the University of Alberta, lifetime of experience in the geo-energy industry, advisor on how to cope with financial penalties for GHG emissions
- Norman Miller — Former P.Eng, now Retired
- Ron Mills — Geologist/geochemist Emeritus NS Geological Survey
- Randall S. Morley — veterinary epidemiologist, retired
- Dr. Thomas F. Moslow — PhD, P. Geol., President Moslow Geoscience Consulting Ltd., Adjunct Professor Department of Geoscience, University of Calgary
- Roland Moutal — Teacher Physics and Chemistry at Vancouver Community College
- Prof. Frank Mucciardi — retired Professor in the Department of Mining and Materials Engineering at McGill University Montreal, research focus on energy, heat transfer, fluid mechanics and modeling
- Eiichiro Ochiai — Emeritus Professor, Juniata College (USA)
- Christian Olivier — former Postdoc @ UC Berkeley
- Robert Orr — Historical Linguist
- Scott Patterson — Professional Geologist
- Andy Pattullo — Associate Professor of Medicine at the University of Calgary
- Steven Pearce — PhD, Lecturer
- Prof. David A. Penny — PhD, Former Associate Professor, Dept. of Computer Science, University of Toronto, currently CTO at BlueCat Networks
- Gregory Phillips — Retired Agrifood Industry Professional, with research background in biology, economics and policy formulation.
- Jozinus Ploeg — retired Vice-President, Engineering and Technology, National Research Council, Canada. Field of expertise: Energy transfer from atmosphere to surface of ocean, wave mechanics
- Joe Postma — Research Analyst, Physics & Astronomy, University of Calgary
- Brian R. Pratt — Professor of Geological Sciences, University of Saskatchewan
- Michael Priaro — BSc Chem. Eng, P.Eng, Member of Association of Professional Engineers and Geoscientists of Alberta
- Gerald Ratzer — Professor Emeritus, Computer Science McGill University, Montreal
- John Angus Raw — aerospace engineer, specialised in aerodynamics, life time career in the international aerospace industry
- Dr. Michael Raw — PhD in Mechanical Engineering, specialization in computer modelling of fluid flow and heat transfer, current field of work in technology management
- Robert James Reid — BSF degree, Registered Professional Forester, lifetime experience in the forestry industry
- Norman Reilly — Professor Emeritus of Mathematics, Simon Fraser University, British Columbia
- Gérald Riverin — PhD, Géologie, Géologue Retraité
- John Robson — Historian, Journalist, Documentary Filmmaker
- Peter Salonius — Retired Research Scientist, Natural Resources
- Marcelo C. Santos — Professor of Geodesy, University of New Brunswick
- Paul R. Schmidt — BSc, Professional Engineer Ontario, Research Scientist, Author/ Lecturer 'Review & Analysis of Climate Change', Member Friends of Science
- Ian de W. Semple — Retired Exploration Geologist and Mining Investment Analyst of McGill University
- Afshin Shahzamani — Retired professional (Medical Science Liaison) pharmaceutical industry
- Élie Shama — Ingénieur Retraité en Électromécanique, Président d'Éconoden, Montréal
- Wayne Shepheard — MSc Geology, Retired oil and gas explorer
- H.F. (Gus) Shurvell — Emeritus Professor of Chemistry, Queen's University

Canada continued

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|---|---|
| • Brian Slack | Distinguished Professor Emeritus, Concordia University Montreal, Department of Geography, Planning and Environment |
| • Aize Smit | MSc Climatology on Global Warming, retired high school science and A.P. environmental science teacher |
| • Nigel Southway | Business and Manufacturing Engineering Consultant, Educator, and Author |
| • Rodolfo (Rudy) Spatzner | graduated from Environmental/Civil Engineering Technology, Humber College, Ontario, lifetime experience in wireless networks across North America |
| • Robert Sproule | PhD, Professor of Economics, Bishop's University, Quebec, Canada |
| • Michelle Stirling | Writer/Researcher with focus on 'consensus' social proofs, Top 10% downloaded author on SSRN, Communications Manager, Friends of Science Society |
| • Mary Taitt | PhD Zoology, MSc Ecology, retired |
| • Mario Thomas | B.Sc., Ph.D. Chemistry, CEO and Chairman of Precision Biomonitoring Inc. |
| • Graydon Tranquilla | BScEE, Electrical Power, Senior Electrical Engineer (retired), now an energy advisory consultant |
| • V Ismet Ugursal | Professor of Mechanical Engineering, Dalhousie University |
| • Marc Vallée | PhD, Geophysicien |
| • Petr Vaníček | Dr. Sc, Professor Emeritus of Geodesy, University of New Brunswick |
| • Duncan Veasey | psychiatrist with a particular interest in mass hysteria, authoritarianism and social compliance |
| • Prof. Dr. Ir. Frank C.J.M. van Veggel | Full Professor at the University of Victoria, M.Eng and PhD in Chemical Technology, University of Twente, The Netherlands, Since 2015 Fellow of the Royal Society of Canada |
| • Jean-Joel Vonarburg | PhD, Professeur Ingénieur, Université du Québec à Chicoutimi |
| • Dr. Ronald Voss | PhD Chemistry, lifetime career in the environment department of a research consortium |
| • Robert Wager | BSc and MSc, Microbiological Sciences and Immunology, Biochemistry and Molecular Biology, Retired |
| • Dr. Helen Warn | PhD in Fluid Dynamics from McGill University |
| • Dr. Thorpe W. Watson | material science, lifetime career in the mining industry with focus on intellectual property protection |
| • Larry Weiers | energy engineer, retired, author of "Sustainability of the Modern Human Economy" |
| • William van Wijngaarden | Professor of Physics, York University |
| • Kenneth W. Wilson | Professional Engineer (retired) |
| • Daryl Youck | MSc, PEng, Oil Sands Pioneer |
| • AL ZEEPER | Physicist, Mathematically discovered the Unification of Gravity with Electricity and Magnetism |

## 4 SIGNATORIES FROM CHILE

**1 WCD Ambassador**

| | |
|---|---|
| • Douglas Pollock | Civil Industrial Engineer, University of Chile |

**3 Signatories**

| | |
|---|---|
| • Juan Luis Edwards Velasco | Civil engineer in hydraulics, Universidad Católica de Chile, Master in hydraulic engineering, Universidad de Santander, Spain |
| • Rafael Muñoz Canessa | Part time Academic University of Talca, Economics and strategic management |
| • Carlos Varea | Energy Engineer |

## 4 SIGNATORIES FROM CHINA

**4 Signatories**

| | |
|---|---|
| • Dr. Robert Hanson | PhD, BA (Hons), MA, LL.M, PGCE, CPE, Barrister |
| • Guang Bao Liu | BSc and MSc in Atmospheric Physics, Author of "The Principle of Periodic Changes in Earth's Climate" |

| | |
|---|---|
| • Wyss Yim | Retired Professor, Dpt of Earth Sciences, University of Hong Kong, Dept Chairman Climate Change Science Implementation Team UNESCO year for Planet Earth, Expert Reviewer IPCC AR2 |
| • NG Young | Principal Geoscientist, Danxiashan Global Geopark of China |

## 2 SIGNATORIES FROM COLOMBIA

**2 Signatories**

| | |
|---|---|
| • William Antonio Lozano Rivas | full Professor of Water Management, Water Engineering, Climate and Meteorology, Simulation and Modeling; Piloto de Colombia University |
| • Felipe Villegas | MSc Civil engineer. MBA, Consultant for Energy, Policy and Regulation |

## 1 SIGNATORY FROM COSTA RICA

**1 Signatory**

| | |
|---|---|
| • Eugenio G. Araya | Theoretical Physicist, Researcher, former scientist at University of Costa Rica |

## 2 SIGNATORIES FROM CROATIA

**1 WCD Ambassador**

| | |
|---|---|
| • Dušan Bižić | MSc, Meteorologist, Head of Radar Centre of the Croation Meteorological and Hydrological Service |

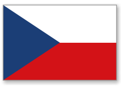
**1 Signatory**

| | |
|---|---|
| • Zorislav Gerber | MSc, Head of Hail Prevention Support Department, Croatian Meteorological and Hydrological Service |

## 1 SIGNATORY FROM CYPRUS

**1 Signatory**

| | |
|---|---|
| • Darko Krstic | editor of https://philosophyofgoodnews.com/ |



## 15 SIGNATORIES FROM CZECH REPUBLIC

**15 Signatories**

| | |
|---|---|
| • Ladislav Bocak | PhD, Professor of Entomology, Czech Advanced Technology and Research Institute |
| • Pavel Dudr | Ing, Independent publicist and climatologist / Pravy prostor, EP Shark/ |
| • Marek Eiderna | Agricultural Engineer and graduated in General Biology |
| • Tomas Furst | PhD, teacher of mathematics at Palacky University in Olomouc and a proponent of correct, i.e. Bayesian inference |
| • Vaclav Hubiner | Retired Ambassador, Anthropologist, Climate Policy Commentator for www.forum24.cz |
| • Pavel Kalenda | PhD, CSc., Coal Expert |
| • Václav Klaus | Former President of the Czech Republic, Professor of Economics, Founder of the Václav Klaus Institute |
| • Peter Kopa | Lawyer, Writer, Publisher, Founder of thinktanklatam.org |
| • Lubos Motl | PhD, former Harvard faculty, high energy theoretical physicist, co-author of the 2009 NIPCC report |
| • Václav Procházka | participates in paleoclimatic research of sediments in central Europe and in the exogenous model of global tectonics showing that the Earth crust cannot be ignored in climatic models. |
| • Dr. Milan Salek | PhD, Freelance Meteorologist and Consultant |
| • Ivan Spicka | Professor of Internal Medicine at Charles University with speciality in Hemato-Oncology, Prague |
| • Dalibor Štys | professor of Applied physics, Faculty of Fisheries and Protection of Waters, University of South Bohemia in ?eské Bud?jovice |
| • Gary M. Vasey | PhD, Geology, Managing Partner and Analyst in Commodity Technology Advisory llc |

Czech Republic continued

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|---|---|
| • Ing. Miroslav Žáček | PhD., aplied geochemistry, been working on the climate for more than 10 years as a geochemist |

## 15 SIGNATORIES FROM DENMARK

**1 WCD Ambassador**

| | |
|---|---|
| • Jens Morten Hansen | PhD, Geology, Professor at Copenhagen University, Former Director General for the Danish National Research Agency and National Research Councils |

**14 Signatories**

| | |
|---|---|
| • Bjarne Andresen | Professor of Physics, Niels Bohr Institute, University of Copenhagen |
| • Claus Beyer | Geologist, gen.manager for CB-Magneto, possessing palaeomagnetic laboratory |
| • Steffen Frederiksen | MSc Economics, Climate Economics, Cost benefit analysis of CO2 |
| • Dr. Hans Götzsche | Emeritus Associate Professor, Linguistics and Philosophy of Science, President Nordic Associaton of Linguists (NAL), Director, Center for Linguistics, Aalborg University |
| • Frank Hansen | Emeritus Professor, Department of Mathematics, University of Copenhagen |
| • Niels Harrit | PhD, Emeritus Associate Professor of Chemistry, Dept. Chemistry, University of Copenhagen |
| • Sören Kjärsgaard | Professional Chemical Engineer |
| • Johannes Krüger | Emeritus Professor, Dr. Scient, Department of Geosciences and Natural Resource Management, University of Copenhagen |
| • Knud Larsen | PhD, Natural Sciences |
| • Peter Locht | Senior Lecturer, Business Academy Aarhus (statistics) |
| • Peter Kjær Poulsen | Metering Engineer |
| • Steen Rasmussen | Bsc in Electrical Engineering from Denmark Technical University, lifetime career at IBM Denmark Aps |
| • Niels Schrøder | Geophysist/Geologist, Associate Professor Institute of Nature and Environment, Roskilde University |
| • Pavel Svennerberg | Master of engineering, Technology of oil and gas processing |

## 1 SIGNATORY FROM ECUADOR

**1 Signatory**

| | |
|---|---|
| • Fernando Villon | MSc, Industrial Engineer, Lifetime Experience in the Geo-Energy Industry |

## 1 SIGNATORY FROM ESTONIA

**1 Signatory**

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| • Andres Saukas | Diploma Electrical Engineer, Estonian Society of Moritz Hermann Jacobi |

## 7 SIGNATORIES FROM FINLAND

**7 Signatories**

| | |
|---|---|
| • Merit Enckell | PhD, MSc, former KTH, Royal Institute of Technology, freelance researcher, specialist in Structural Health Monitoring, sustainable development |
| • Christer Kald | Engineer with academic studies in Physics, Chemistry and Mathematics |
| • Simo Mykkanen | Ba Econ, small business owner, retired |
| • Ari Okkonen | MSc EE, Finland, Climate data analysis enthusiast |
| • Dr. Antero Ollila | Emeritus Adj. Ass. Professor Aalto University, expert in atmospheric modeling |
| • Simo Ruoho | President Ilmastofoorumi ry Finland, Signature of association https://ilmastofoorumi.fi including its scientists and professional members |
| • Boris Winterhalter | Retired Marine Geology, Geological Survey of Finland |

## 111 SIGNATORIES FROM FRANCE

### 1 WCD Ambassador

| | |
|---|---|
| • Benoît Rittaud | Assistant professor of Mathematics at University of Paris-Nord, President of the French Association des climato-réalistes |

### 110 Signatories

| | |
|---|---|
| • Jean-Charles Abbé | Former Research Director at CNRS, Labs Director (Strasbourg, Nantes) in Radiochemistry, Expert at NATO and IAEA |
| • Pascal Acot | Centre National de la Recherche Scientific, Paris |
| • Bertrand Alliot | Environmentalist |
| • Yacine Amara | PhD of Applied Physics, Professor of Electrical Engineering |
| • Frédéric Antoine | graduated from Sciences Politiques in France |
| • Charles Aubourg | Full Professor at the University of Pau, Geophysicist |
| • Hervé Azoulay | Engineer (CNAM), Specialist of Networks and Systemics, CEO and President of several Associations |
| • Guy Barbey | Alumnus of Harvard Business School, Retired Investment Banker, Founder and President of 'Climate et Vérité' |
| • Jean-Pierre Bardinet | Ingénieur ENSEM, Publicist on Climate Issues |
| • Yorik Baunay | Geographer (Master 2) specialized in the natural risk and crisis management, CEO of Ubyrisk Consultants (firm specialized on natural hazard mitigation) |
| • Bernard Beauzamy | University Professor (Ret.), Chairman and CEO, Société de Calcul Mathématique SA (Paris) |
| • Serge Bellotto | PhD, Geology |
| • Guy Bensimon | Retired Associate Professor of Economics at Institute of Political Studies of Grenoble (SciencesPo Grenoble) |
| • Jean-Claude Bernier | Emeritus Professor (University of Strasbourg), Former Director of the Institute of Chemistry of the CNRS |
| • Pierre Beslu | Former Researcher and Head of Department in the French Nuclear Energy Commission (CEA) |
| • Michel Bouillet | PhD, Human Geography, Emeritus Professor, Former Associate Researcher at the MMSH (Aix-en-Provence) |
| • Christian Buson | PhD, Agronomy, Director of Research in a Company (impact studies in Environmental Issues, Sewage Treatment) |
| • Jean-Louis Butré | Head of Laboratory at Grenoble Nuclear Research Center, President of the Fédération Environnement Durable and the European Platform Against Windfarms |
| • Emmanuel Camhi | Msc in Physics, life time experience in Complex Systems Modeling and Data Analysis in the Aerospace industry |
| • Bernard Capai | Retired Chemistry Engineer, Specialist of Industrial Processes avoiding the use of Carcinogenic Solvents |
| • John Carr | PhD in Physics, Directeur de Recherche CNRS (retired), Particle Physics and Astroparticle Physics |
| • Patrick de Casanove | Doctor of Medicine, Chairman of the Cercle Frédéric Bastiat |
| • Philippe Catier | Medical Doctor |
| • Vincent Chaplot | PhD Soil Science, Senior Research Scientist |
| • Bruno Chaumontet | Engineer ENSEA, specialized in Feedback Systems |
| • Pascal Chondroyannis | Forest Engineer, Retired Director of the National Alpine Botanical Conservatory (2008-2013) |
| • Jean Michel Colin | PhD, Retired Chemist Engineer, Expert for the French Academic Evaluation Agency (AERES) |
| • Philippe Colomban | CNRS Research Emeritus Professor, Former Head of Laboratory at Université Piere-et-Marie Curie, Expert in Hydrogen-based Energy Storage |
| • Jacques Colombani | Former Research Director ORSTOM-IRD, numerous Studies in Hydrology and Climatology and Specialist in Fluid Mechanics, Member of the Board of ORSTOM for twenty years |
| • Christian Coppe | PhD, Organic & Analytical Chemistry |
| • Philippe Costa | Energy Engineer at ENSEM Nancy, specialist in Industrial Process and Energy Saving |

France continued

| | |
|---|---|
| • Vincent Courtillot | Geophysicist, Member of the French Academy of Sciences, Former Director of the Institute de Physique du Globe de Paris |
| • Pierre Darriulat | Professor of Physics, Member of the French Academy of Sciences |
| • Jean Davy | Engineer (ENSAM), Digital Modeling Software Developer |
| • Dr. Stephen John Dearden | Retired Research Chemist, lifetime R&D experience in the general chemical, pharmaceutical and photographic industries |
| • Pierre Delarboulas | CEO of a Robotics Company, Former R&D Director at Partnering Robotics, Silver Medal at the 2016 Lépine contest of the Ministry of Foreign Affairs and International Development |
| • Jean-Pierre Desmoulins | Retired Professor of Thermal and Energy Engineering at the "Institut Universitaire de Technologie, Université-Grenobles-Alpes" |
| • Gérard Douhet | PhD, Nuclear Physics, Retired Engineer at CERN, Technical Manager on Digital Transmission and Video Encoding |
| • Hubert Dulieu | Emeritus Professor Applied Ecology, Formerly Senior Researcher in the CNRS, President of the National Scientific Research Committee, Vegetal Biology Section (XXVII) |
| • Dr. Denis Dupuy | Urologist, climate realist |
| • Bruno Durieux | Economist, Former Minister of Health and of Foreign Trade, Ancient Administrator of the French National Institute of Statistics and Economic Studies (INSEE) |
| • Ralph Ellis | Bsc in Aviation, ATPL |
| • Max Falque | International Consultant in Environmental Policy |
| • Serge Ferry | PhD, Retired Teacher-Researcher (MCF), University of Lyon |
| • Patrick Fischer | Associate Professor in Applied Mathematics, University of Bordeaux |
| • Michel Frenkiel | Engineer (Arts et Métiers), Former Researcher with NCAR at Boulder |
| • Francis le Gaillard | PhD, Natural Sciences and Pharmaceutical Sciences, Emeritus Professor of Biochemistry at the Faculty of Pharmaceutical Sciences of Toulouse |
| • François Gauchenot | Governance Specialist, Founder of Saint George Institute |
| • Jean Gergelé | Engineer Graduate from the Ecole Centrale de Lyon, R&D Director, Freelance Consultant, mainly in the Li-ion battery development |
| • Christian Gérondeau | Former Advisor of several French Prime Ministers, Formerly responsible for the Road Traffic Safety Policy for France and the European Union |
| • Francois Gervais | Emeritus Professor of Physics and Material Sciences, University of Tours |
| • Philippe Giraudin | Ecole Polytechnique Paris, Geographic Sciences |
| • Bernard Grandchamp | Agronomic Engineer and Environment & Plant Defense Expert, Managing Director of Famoux Chateaux Viticoles in Bordeaux |
| • Gilles Granereau | Former Meteorologist, currently Project Manager Environment and Tourism, Worked on Coastal Risks, Marine Erosion, Sand Dune Fixation, Hydraulics, Forest Management, Botany |
| • Maximilian Hasler | Associate Professor in Mathematics, University of French West Indies |
| • Charles Hazan | Retired Chemist (ENSCP) and Chemical Engineer (UMIST) Former Technical Director Nosolor |
| • Manfred Horst | MD, PhD, MBA, lifetime career in healthcare and pharmaceuticals |
| • Ed Hoskins | MSc, Founder of Applied Research of Cambridge |
| • Julien Iapichella | PhD in Chemistry |
| • Yvon Jarny | Emeritus Professor in Thermal and Energy Sciences, Nantes University |
| • Claude Jobin | Retired A&M Engineer specialized in Microwave Communication |
| • Alan Kennedy | Emeritus Professor of Psychology, University of Dundee, Fellow of Royal Society of Edinburgh |
| • Vladimir Klein | lifetime career in renewable energy projects, patent holder in aerobic composting of organic waste |
| • Alexandre Krivitzky | Psychoanalyst, Member of the International Psychoanalytical Association |
| • Roger Lainé | Retired Geological Engineer |
| • Philippe de Larminat | Professor at École Centrale de Nantes, specialist of Business Process Modeling |
| • Jacques Laurentie | Aeronautical Engineer, and CEO of a software publishing company |
| • René Laversanne | Researcher at the CNRS, 16 patents |

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|---|---|
| • Christian Liegeois | PhD Physics, patent holder in photonics |
| • Jean-Marie Longin | Engineer (Saint-Cyr), Chief of the Pole Operations of Security Inventory Management |
| • Guy Lucazeau | Emeritus Professor (Institut Polytechnique de Grenobel) in Material Sciences and Spectroscopy |
| • Philippe Malburet | Emeritus Associated Professor of Mathematics, Founder of the Planetarium of Aix-en-Provence, Member of the Academy of Aix-en-Provence |
| • Christian Marchal | Astronomer and Mathematician, Former Research Director at the French National Office for Aerospace Studies and Research |
| • Dr. Yves G. Maria-Sube | PhD in Geosciences Montpellier University, lifetime career in the geo-energy industry |
| • Paolo Martinengo | Applied Physicist, Senior Staff Member in the Experimental Physics Department, Detector Technologies Group, CERN |
| • Patrick Mellett | Architect and CEO |
| • Marc le Menn | PhD, Head of Metrology-Chemistry Oceanography Lab, Brest |
| • Henri Mertz | Ingénieur Civil de l'école de la Métallurgie et des Mines de Nancy, Chef d'Entreprises |
| • Serge Monier | former manager of various multinational companies, at present Co-founder and Treasurer of 'Climat et Vérité' |
| • Jean-Laurent Monnier | Emeritus Research Director, CNRS-Université de Rennes, Research Worker at the CNRS from 1973 to 2013, speciality in Pleistocene Geology in Western Europe |
| • Jacques-Marie Moranne | Retired Engineer (Ecole Centrale de Lille), Specialist in Air and Water Purification, Chemical and Nuclear Engineering |
| • Serge Morin | Emeritus Professor Geography at Université Michel de Montaigne, Bordeaux, Honorary Mayer of Branne |
| • Cédric Moro | Geographer on Natural Hazards Management, Co-Founder of Visov, a NGO in Civil Defense |
| • Philippe Morvan | Engineer ENSTA and Génie Maritime, specialist in Software Development |
| • Dr. Arnaud Muller-Feuga | former researcher in biological oceanography, agronomy engineer, founder of Microphyt SA. Now retired. |
| • Charles Naville | R&D Exploration Geophysicist, IFP Energies Nouvelles |
| • Massimo Nespolo | PhD, Distinguished Professor of Mineralogy and Crystallography, Université de Lorraine, France |
| • Michel le Normand | Emeritus Professor of Botany and Plant Pathology and Chairman of Plant Production Department, National Superior School of Agronomy, Rennes |
| • Ludovic Penin | former Senior Executive, Chief Information Officer, former Entrepreneur/Investor, Co-founder and Vice-president of 'Climat et Vérité', member of "Association des Climato-réalistes' |
| • Dr. Patrice Poyet | Graduated at Ecole des Mines de Paris as a geochemist and defended a D.Sc. (1986) at Nice University / INRIA, author of 'The Rational Climate e-Book' |
| • Rémy Prud'homme | Emeritus Professor in Economics at University of Paris-Est, Former Deputy-Director, Environment Directorate, OECD |
| • Jean Marie Ravier | Engineer of ECOLE CENTRALE DE PARIS, and diplomed SCIENCES POLITIQUES PARIS, recently retired MD of small industrial company |
| • Pierre Richard | Engineer ESPCI Paris, Former Research Geochemist at Institut de Physique du Globe de Paris (IPGP) |
| • Pierre Ripoche | Engineer INSA in Chemistry, Retired Project Manager in R&D, Expert in High Temperature Plasma for Optical Fiber Process |
| • Isabell Rivals | Associate Professor in Statistics at ESPCI Paris |
| • Betrand Rouffiange | Doctor of Medicine, specialized in Radiology |
| • Jean Rouquerol | Emeritus Research Director at CNRS Marseille, Expert in Gas Adsorption and Calorimetry |
| • Georges de Sablet | Retired Associate Professor at University of Paris Descartes, formerly in charge of Operating Systems and Networks at IUT Paris |
| • François Simonet | PhD, Biology, Former Director for Planning and Forsight in a State Agency for Water and Aquatic Ecosystems Management |

France continued

| | |
|---|---|
| • Zakaria Tarif | Scientific engineer specialized in electrical energy and telecommunications |
| • Luc C. Tartar | Mathematician, corresponding member of Académie des Sciences in Paris, University Professor of Mathematics emeritus at Carnegie Mellon University, Pittsburgh, PA |
| • Marcel Terrier | Ex Engineers in Industry, Former Teacher at the Douai School of Mines |
| • Michel Thizon | Chemical engineer, ACR (Association des Climato-Réalistes, France) member, former researcher at the Ecole Polytechnique, consultant, retired |
| • David Uzal | PhD philosophy of technics and PhD of practical philosophy |
| • Etienne Vernaz | Former Director of Research of CEA (Commissariat à l'Énergie Atomique) in France, Professor at INSTN (Institut National des Sciences et Techniques Nucléaires) |
| • Camille Veyres | Retired Engineer at École des Mines, specialist in Telecommunications and Broadband Networks |
| • Werner de Ville Vreden | writer ("Afrika"), developper and author |
| • Brigitte van Vliet-Lanoë | Geoscientist, Emeritus Research Director (CNRS, Université de Bretagne Occidentale), Stratigraphy and Paleoenvironments, Quaternary and Holocene |
| • Théa Vogt | Retired CNRS Searcher, Géomorphology, Quaternary Palaeoenvironments, Soil and Desertification Remote Sensing |
| • Henry Voron | Retired Civil Chief Engineer, specialized in Water Management |

## 119 SIGNATORIES FROM GERMANY

**1 WCD Ambassador**

| | |
|---|---|
| • Fritz Vahrenholt | Professor (i.R.) am Institut für Technische und Makromolekulare Chemie der Universität Hamburg |

**118 Signatories**

| | |
|---|---|
| • Detlef Ahlborn | PhD, Expert on German Energy Transition (Energiewende) |
| • Prof. Dr. Peter Altmiks | Professor of Economics, FOM Hochschule für Oekonomie und Management Hannover |
| • Patrick A. Baeuerle | Serial entrepreneur, co-founder of eight biopharmaceutical companies, cancer drug developer, inventor, molecular biologist, and a member of the CO2 Coalition |
| • Hans-Jürgen Bandelt | Emeritus Professor of Mathematics, University of Hamburg |
| • Dietrich Bannert | Professor Honoris Causa, University of Marburg |
| • Graham George Baumber | former agronomist &irrigation crop specialist, business man & investor |
| • Dr. Lars Birlenbach | Dr. in Chemistry, University of Siegen |
| • Michael Bockisch | Emeritus Professor Chemistry at the Technical University of Berlin |
| • Klaus-Dieter Böhme | Dipl. Physicist, professional experience in X-ray spectroscopy |
| • Thomas Brey | PhD in Natural Sciences (Dr. rer. nat), Marine Ecological Researcher |
| • Stephan Bujnoch | Wirtschaftsingenieur (i.e. a combination of economics and engineering), retired manager with the automotive industry |
| • Martin Bülow | Emeritus Professor of Physical Chemistry at the Leibniz Sozität der Wissenschaften zu Berlin, e.V. |
| • Eike-Mattias Bultmann | Geoscientist |
| • Prof. (i.R.) Dr.rer.nat Eberhard Burkel | Prof. (i.R.) Dr.rer.nat , Physics of New Materials, University of Rostock |
| • Dr. Arthur Chudy | Agricultural Chemist, OT Warsaw |
| • Günter Dedié | Dipl. Physiker |
| • Prof. Dr. Hans Demanowski | Engineer, Professor of Packaging Technology, BHT, Berlin, expert in Counterfeit Protection, holder of several Patents in this field |
| • Dr. Joachim Dengler | Physicist retired, PhD, patent holder in fingerprint analysis, work on relation between CO2 emissions and concentration |
| • Dr. Ing. Rolf Diederichs | Studie Eisenhüttenkunde in Clausthal-Zellerfeld, climate realist |
| • Prof. Dr. Klaus D. Döhler | Professor of Pharma Sciences, University of Hannover |
| • Wolf Doleys | Retired teacher (high school, college) and writer (essay, poetry, novel) |
| • Joerg Dornemann | Msc in Geology, lifetime career in the Geo-Energy Industry |
| • Jörg Eichner | Specialist in situational awareness in crises and risk management |

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| • Friedrich-Karl Ewert | Emeritus Professor Geology, University of Paderborn |
| • Ludwig E. Feinendegen | Emeritus Professor Medicine |
| • Dr. Dieter Freundlieb | retired senior lecturer Griffith University, School of Humanities, Brisbane, Australia |
| • Gerhard Gerlich | Emeritus Professor of Mathematical Physics, TU Braunschweig |
| • Axel Robert Göhring | Doctor of Natural Sciences, EIKE e.V. |
| • Dr. Klaus-Jürgen Goldmann | worldwide experienced petroleum geologist |
| • Dr. Christian Habermann | Dr. in Economics, Investment Manager |
| • Eberhard Happe | Eisenbahningenieur |
| • Hermann Harde | Emeritus Professor of Experimental Physics and Materials Science, Helmut Schmidt-University, Hamburg |
| • Prof. Dr. Bernd Hartke | Professor in Theoretical Chemistry, Expert Knowledge in Computer Modelling, University of Kiel |
| • Manfred Hauptreif | Natural Scientist |
| • Dr. Fleck Helmut | langjährige berufliche Tätigkeit als Projektkoordinator in einer Großforschungseinrichtung |
| • Dennis J. Hendricks | Graduated Engineer of Environmental Technologies, Technischen Hochschule Ostwestfalen-Lippe, University of Applied Sciences and Arts |
| • Dietmar Hildebrand | PhD Biophysics and Nuclear Physics, patent holder in fuzzy logic based suveillance, IT expert and development manager |
| • Dr. Jens Hofele | Chemist, developer of low-carbon cement compositions |
| • Dr. Andreas Hoppe | Systems biologist, Institute for Bee Research |
| • Heinz Hug | Chemistry, Master (Diplom Chemiker), PhD (Dr. rer. nat.), lecturer at Paul-Ehrlich-Schule (Frankfurt, Germany), Technical College affiliated to the former Hoechst AG |
| • Prof. Axel Janke | PhD, professor of evolutionary genomics |
| • Jörg Jensen | Dipl.-Ing. Interested and committed to environmental issues |
| • André Karutz | Chemist, Dr. rer. nat. expert in environmental matters |
| • Professor Dr. Gerhard Kehrer | Retired Physician, Internist and Physiologist |
| • Dr. Udo Kienle | Agricultural Scientist at University of Hohenheim |
| • Werner Kirstein | Emeritus Professor of Climatology, University of Leipzig |
| • Prof. Dr. Knut Kleesiek | Emeritus Professor for Clinical Chemistry and Clinical Biochemistry Ruhr University Bochum |
| • Gunther Klessinger | Physicist, University at Regensburg Germany and Boulder Colorado |
| • Dr. André Knoth | PhD in Economics and Organizational Science |
| • Dr. Torsten Kreer | PhD in physics, 20 years experience in academic research and education, condensed matter physics |
| • Stefan Kröpelin | Dr. in Geosciences, Free University of Berlin and University of Cologne (Retired), specialized in Climate Change of the Sahara |
| • Dr. rer. nat Gunter Kümel | lifetime career in virus research in the natural siences |
| • Max Kupillas | Dipl.-Ing. Masch.-Bau, retired Prod.Ltr. |
| • Ulrich Kutschera | Professor of Plant Physiology & Evolutionary Biology at the University of Kassel and Visiting Scientist in Stanford USA |
| • Jobst Landgrebe | Scientist and Entrepreneur specialised in Artificial Intelligence and Theory of Science |
| • Wolfgang Laub | Physics (J.W.Goethe University, 1977-1986), Medicine (Physiology-Biomechanics, Max-Planck Institute, 1980-1986), patent holder in different areas |
| • Michael Limburg | Vice-President EIKE (Europäisches Institute für Klima und Energie) |
| • Martin Lindner | PhD in Chemistry, Dipl. in Chemistry, President of the Bürger für Technik |
| • Dr. rer. nat. Rolf Lindner | Chemist |
| • Dr. Alf Loeffler | PhD in Theoretical Physics |
| • Prof. Dr. Kai van de Loo | Dr. rer. oec. Honorarprofessor der THGA und Senior Consultant im Forschungszentrum Nachbergbau |
| • Dr. Stephan Lorenzen | PhD Theoretical Biology, Bioinformatician, worked with nonlinear modelling |

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|---|---|
| • Professor Dr. Knut Löschke | studied crystallography, chemistry, physics, mathematics and computer science. Honorary professor at the University of Leipzig, dealed with the energy industry and climate change |
| • Horst-Joachim Lüdecke | Professor of Operations Research (i.R.) HTW of Saarland, Saarbrücken |
| • Hermann Luyken | MSc Chemical Engineering |
| • Wolfgang Merbach | Professor Dr. Agrar. Habil. at Institut für Agrar Ernährungswissenschaften |
| • Prof. Lothar W. Meyer | Emeritus Professor of Material Engineering, Chemnitz University of Technology, Saxony Entrepreneur 'Nordmetall GmbH', Member of the Board of 'Vernunftkraft Niedersachsen' |
| • Marcus Moller | MD, PhD, University Professor of translational Nephrology, RWTH Aachen University, Germany |
| • Jens Möller | graduate economist, climate realist |
| • Wolfgang Monninger | PhD, lifetime career in Petroleum Geology (Exploration, Petrophysics) |
| • Klaus Morawetz | PhD Physics, Professor in Theoretical Physics, Quantum Kinetic Theory, Quantum Statistics |
| • Werner Mormann | Emeritus Professor of Macromolecular Chemistry, Universität Siegen |
| • Dipl. Phys. Raimund Müller | education in physics and thermodynamics, climate realist |
| • Holger Neulen | retired mechanical engineer |
| • Prof. Dr.rer.nat Dr.med Peter Nielsen | retired Biochemist and Physician from the Universital Hospital Hamburg-Eppendorf, medical faculty of the University of Hamburg |
| • Rainer Olzem | Diplom-Geologe, Aachen |
| • Flo Osrainik | Bestselling Author & Journalist |
| • Hans Penner | PhD, Dipl.-Chem. Dr. rer. nat., Linkenheim-Hochstetten |
| • Dr. Dr. Wätzold Plaum | Physicist and YouTuber |
| • Michael Principato | MSc. in Electrical Engineering, specialised in control engineering and modeling |
| • Dieter Ramcke | retired geophysicist |
| • Siegfried Reiprich | Dipl.-Ing, Geoscientist and Oceanography |
| • Mathias Ricking | Dr. rer.nat Geoscience, Environmental Geoscientist |
| • Andreas Salzman | Dr. rer. nat. , Diplom Chemiker |
| • Prof. Dr. Dieter Schildknecht | Professor of theoretical Physics, University of Bielefeld |
| • Dr. Hendrik Schlesing | Environmental Expert and Consultant |
| • Christoph Schmidt | MSc Mathematics, JWG-University Frankfurt |
| • Stefan Schmidt | Scientist in the field of Energy |
| • Dr. Martin Schmidt | PhD Physics, industrial career of research, development and production of hightec products and subequently 22 years CEO of Möller-Wedel, a German medical company |
| • Hans Joerg Schmidt | Chemical Engineer and Autor of certain books, explaining atmospheric energy exchange and providing arguments against global warming caused by mankind |
| • Dr. Jens-Christoph Schneider | PhD in Isotope Chemistry, life time career in palaeoclimate and atmospheric geochemistry |
| • Dr. rer. nat. Michael Schnell | Retired Chemist |
| • Prof. Dr. Dr. Karl-Heinz Schulz | University Hospital Hamburg-Eppendorf, interdisciplinary research in Medicine, Psychology and exercise science (https://www.researchgate.net/profile/Karl-Heinz-Schulz-2) |
| • Thomas Schulze | Thomas Schulze, Dr. phil., Selbständiger Berater und Dozent |
| • Dipl. Psych. Ulrike Schwan | Professional psychotherapist, psychotherapist look at the IPCC organization |
| • W.H. Eugen Schwartz | Emeritus Professor of Theoretical Chemistry, Universitaet Siegen |
| • Dr.-Ing. Christian Singewald | Dipl.-Geologist, PhD Mining Engineering |
| • Attila Sonal | Dipl.-Ing. der Elektrotechnik, Retired am Technischen Universität Kaiserslautern, Stadtratsmitglied Kaiserslautern, Preisträger Ansaldo Ricerche Price |
| • Dr. Fritz Sontheimer | Retired Physicist, PhD in Condensed Matter Physics |
| • Dr. Gerhard Stehlik | PhD Natural Science Physico-Chemiste |
| • Dr. Wolfgang Strehlau | Phys. Chemist, Technology Fellow in Johnson Matthey Plc, UK |
| • Lothar Strenge | strategy and concept developer, full time writing on a large SF project |
| • Manuel Tacanho | founder and president of the Afrindependent Institute |

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| Matthias Thiermann | Parliamentary adviser in the Bavarian Parliament |
| Dr. Holger Thuss | President EIKE Institute |
| Dr. Martin Treiber | PhD in Physics, Professorship of Econometrics and Statistics |
| Jost Trier | PhD, Retired Experimental Physicist at the Federal Institute in Braunschweig, Dept. of Atomic Physics |
| Ralf D. Tscheuschner | PhD in Physics |
| Dr. Stefan Uhlig | Geologist |
| Helmut Waniczek | Dr. Dipl. Ing., Scientist, working 40 years in chemical industry |
| Ulrich O. Weber | Exploration Geophysicist with lifetime interest in Paleoclimate |
| Silvio Weeren | Diplom in Physics, former IBM environmental affairs Germany, former chairs of EMI3 and ECMA TC38 |
| Thomas Weimer | Process Engineer (Dr.-Ing.), worked on CO2 capture from atmosphere and during hydrogen generation |
| Toon Weisenborn | PhD in Theoretical Physics, Emeritus scientist |
| Carl-Otto Weiss | Emeritus Professor in Non-linear Physics, Advisor to the European Institute for Climate and Energy, Former President of the German Meteorological Institute, Braunschweig |
| Roland Wiesendanger | Professor of Experimental Physics, University of Hamburg, Germany |
| Dr. Peter Willingmann | Dr. rer.nat |
| Lutz Wimmer | MSc Climate- and Environmental Change (Geography) |

## 18 SIGNATORIES FROM GREECE

**1 WCD Ambassador**

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|---|---|
| Prof. Stavros Alexandris | Professor of Agricultural Meteorology & Crop Water Requirements, at the Agricultural University of Athens, Dept. of Natural Resources & Agricultural Engineering. |

**17 Signatories**

| | |
|---|---|
| Ioannis Benekos | PhD in Civil and Environmental Engineering, Senior Researcher, Head of the Laboratory on Risk Management and Resilience at the Centre for Research and Technology Hellas |
| Costas Fasseas | Emeritus Professor of Plant Anatomy & Electron Microscopy, Department of Crop Science, Agricultural University of Athens |
| Anthony Foscolos | Emeritus Professor of Mineral Resources at the Technical University of Crete, Energy Consultant for the United Nations Development Program (UNDP) |
| Chris Fytas | PhD, MSC in Chemistry, Chemist, Lyophilization Scientist |
| Christos Georgiou | MSc (with Honors) in Biochemistry, PhD in Biology-Biochemistry, Emeritus Professor of Biochemistry |
| Dr. Vassilios C. Kelessidis | former Professor at Khalifa University, Texas A&M at Qatar and Technical University of Crete Greece, Lifetime of Experience in Petroleum Engineering |
| Christos J. Kolovos | PhD, Mining & Metallurgy Engineer, Former Director of Mine Planning & Contractor Works Dept., Public Power Corporation of Greece |
| Emmanouil Kopanakis | Mechanical Engineer, Teacher at the Environmental Education Center of Karpenisi |
| Prof. Demetris Koutsoyiannis | Professor Emeritus of Hydrology and Analysis of Hydrosystems at the National Technical University of Athens |
| Aristotelis Liakatas | Emeritus Professor of the Agricultural University of Athens on Agrometeorology, Member of the Greek Agricultural Academy |
| Prof. Nikos Mamassis | Professor of Engineering Hydrology and Hydrometeorology at the National Technical University of Athens |
| Charilaos Markopoulos | MSc in Waste Management |
| Spyridon Nikiforos | Economist, MBA |
| Dr Miltiadis Nimfopoulos | PhD in Earth, Atmospheric and Environmental Sciences, lifrtime career in Applied and Environmental Geochemistry |
| Sonia Perez† | PhD, Biology/Immunology, Scientific Coordinator Cancer Immunology and Immunotherapy Center Saint Savas Cancer Hospital, Athens |
| Dr. G.-Fivos Sargentis | Dr Engineer-Sculptor, Dept. of Water Resources; School of Civil Engineering, National Technical University of Athens |

Greece continued

| | |
|---|---|
| • Michael Sidiropoulos | Principal Engineer, FortisBC |

## 2 SIGNATORIES FROM GUATEMALA

**2 Signatories**

| | |
|---|---|
| • Jorge Chapas | agronomist, environmental economics specialist, writter, spokesman of climate realism and conservative politician. |
| • Christopher Lingle | PhD Economics Universidad Francisco Marroquín |

## 9 SIGNATORIES FROM HUNGARY

**1 WCD Ambassador**

| | |
|---|---|
| • Laszlo Szarka | Geophysicist, O.M. |

**8 Signatories**

| | |
|---|---|
| • Dr. Dezso Csejtei | retired professor of philosophy at the University of Szeged |
| • Dr. Endre Fuggerth | lifelong experience in gas-chromatography |
| • Istvàn Héjjas | PhD, Retired R&D Electrical Engineering |
| • Tom Kauko | PhD Geography, Independent Researcher based in Budapest |
| • József Király | Chemical Engineer and one of the Authors of the Hungarian site www.klimarealista.hu |
| • Dr. József Majer | Senior Professor of Ecology and Environment Protection at University of Pecs |
| • Gábor Simon | MSc Chemical Engineering, University teacher General, Anorganic, Environmental and Analytic Chemistry |
| • Dr. Gábor Szász | Professor Emeritus, College Professor Dennis Gabor College Department of Economics and Engineering |

## 1 SIGNATORY FROM ICELAND

**1 Signatory**

| | |
|---|---|
| • Dr. Helgi Tomasson | PhD in Econometrics/statistics, Estimation and Computation in time-series models |

## 5 SIGNATORIES FROM INDIA

**5 Signatories**

| | |
|---|---|
| • Dr. M.M. Ali | MSc in Meteorology and Oceanography with a PhD in Meteorology, Center for Ocean-Atmospheric Prediction Studies, Florida State University, USA |
| • Dornadula Chandrasekharam | retired professor from Indian Institute of Technology Bombay, currently working in Izmir Institute of Technology as TUBITAK Professor working on geothermal energy systems |
| • Vijay Jayaraj | Research Associate at CO2 Coalition, Contributor to Cornwall Alliance |
| • Prem raj Pushpakaran | PhD in BioTechnology, Professor |
| • Sanjeev Sabhlok | Economist with focus on Climate and Energy Policy |

## 2 SIGNATORIES FROM INDONESIA

**2 Signatories**

| | |
|---|---|
| • Dr. Dr Paul D Giammalvo | PhD, CDT, CCE (#1240), MScPM, MRICS, Senior Technical Advisor, retired |
| • Purwono Wahyudi | Entrepreneur and informed climate realist |

## 20 SIGNATORIES FROM IRELAND

**1 WCD Ambassador**

| | |
|---|---|
| • Jim O'Brien | Founder of the Irish Climate Science Forum, Expert Reviewer of IPCC AR6 |

**19 Signatories**

| | |
|---|---|
| • Tom Baldwin | Electrical Engineer, Specialist in Power System Security |
| • dr. Dr Timothy Dunne | PhD Psychology, Consultant Clinical Psychologist working in private practice in Dublin |
| • Gerald Fitzgibbon | Physical Chemist specializing in Electrochemistry and Thermodynamics |
| • David Horgan | MA (Cambridge), MBA (Harvard), Resource Company Director |
| • Seamus Hughes | BAgricSc, Specialist in Genetics |
| • Mark Gerard Keenan | Former Science Advisor, Department of Energy and Climate Change, U.K., Former Environmental Affairs Officer, United Nations Environment Division, Geneva, Switzerland |
| • Ultan Murphy | BSc (Hons) Chemistry, Industry Science Professional |
| • Donal O'Callaghan | electrical engineer, retired food industry research scientist |
| • Patrick L. O'Brien | MSc, MPhil, Senior International Environmental Consultant |
| • Owen O'Brien | Business Founder and Entrepreneur, MBA, DBA |
| • J. Philip O'Kane | Emeritus Professor, School of Engineering, University College Cork |
| • Peter O'Neill | Retired, School of Engineering, University College Dublin, Expert Reviewer of IPCC AR6 |
| • Fintan Ryan | Retired Senior Airline Captain, Fellow Royal Aeronautical Society |
| • Christian Schaffalitzky | FIMMM, Founder Institute of Geologists of Ireland, EurGeol |
| • Dr. Norman Stewart | PhD, former astrophysicist and meteorologist |
| • Brian N. Sweeney | Founding Chairman of Science Foundation Ireland |
| • Pat Swords | BE, CEng, FIChemE, PPSE, CEnv, MIEA, Challenger of Over-Reach in Environmental Legislation |
| • Sean Tangney | Business Entrepreneur, Former Technical Director, CRH plc |
| • David Thompson | BAgricSc, MA, Animal Nutritionist |

## 7 SIGNATORIES FROM ISRAEL

**7 Signatories**

| | |
|---|---|
| • Dr. Gaby Avital | PhD in Aerospace, member of the Israeli forum for rational environmentalism |
| • Uriel Cohen | MSc in Computer Science from Technion - Israel Institute of Technology |
| • Prof. Yonatan Dubi | PhD, Professor of Theoretical Physics and Chemistry at Ben-Gurion University, co-founder of the Israeli Forum For Rational Environmentalism |
| • Yakov Itenberg | BSc of Meteorology and Climatology, MSc of Physics Education, 25 years reserve meteorological officer of Israeli Defense Forces Home Front Command |
| • Micha Klein | PhD, Emeritus Professor, The Department of Geography and Environmental Studies |
| • Avner Niv | PhD of Solid State Physics, Research scholarship awarded by Ministry of National Infrastructures, Energy and Water Resources. Industrial multidisciplinary experimental researcher |
| • Nir J. Shaviv | PhD in Physics at the Israel Institute of Technology, Professor of Physics at the Racah Institute at the The Hebrew University of Jerusalem |

## 206 SIGNATORIES FROM ITALY

**1 WCD Ambassador**

| | |
|---|---|
| • Alberto Prestininzi | Professor of Geological Risks at Sapienza University of Rome, former Scientific Editor in Chief of the International Journal IJEGE, Director Research Centre CERI |

**205 Signatories**

| | |
|---|---|
| • Pietro Agostini | Ingegnere, Associazione Scienziati e Tecnologi per la Ricerca Italiana |
| • Aldo Aluigi | Nuclear Engineer, Consultant in Power Plants, Cogeneration end District Heating |
| • Piero Baldecchi | Lettore |

Italy continued

| | |
|---|---|
| • Achille Balduzzi | Geologo, Agip-Eni |
| • Antonio Ballarin | Fisico, "Chief Artificial Intelligence Officer" della Pubblica amministrazione |
| • Cesare Barbieri | Professore Emerito di Astronomia, Università di Padova |
| • Donato Barone | Ingegnere |
| • Sergio Bartalucci | Fisico, Presidente Associazione Scienziati e Tecnologi per la Ricerca Italiana |
| • Giuseppe Basini | Astrofisico, Deputato, Già dirigente di ricerca dell'INFN |
| • Francesco Battaglia | Professore di Chimica Fisica, Università di Modena, Movimento Galileo 2001 |
| • Marco Benini | Ingegnere idraulico, libero professionista |
| • Eliseo Bertolasi | Dottore di Ricerca in Antropologia Culturale |
| • Giorgio Bertucelli | Ingegnere, già Dirigente Industriale, ALDAI |
| • Alessandro Bettini | Professore Emerito (Fisica) Università di Padova |
| • Antonio Bianchini | Professore di Astronomia, Università di Padova |
| • Luciano Biasini | Emeritus Professor of Numerical and Graphic Calculations, Director of the Faculty of Mathematical, Physical and Natural Sciences of the University of Ferrara |
| • Mariano Bizzarri | PhD, M.D., is Professor of Clinical Pathology in the Department of Experimental Medicine at University Sapienza, Rome |
| • Paolo Blasi | Professore Emerito (Fisica) e già Rettore dell'Università di Firenze; già Presidente della Conferenza dei Rettori delle Università Italiane |
| • Enrico Bongiovanni | Dottore Commercialista |
| • Paolo Bonifazi | Ex Direttore dell'Istituto di Fisica dello Spazio Interplanetario (IFSI) dell'Istituto Nazionale Astrofisica (INAF) |
| • Roberto Bonucchi | Insegnante in Pensione |
| • Giampiero Borrielli | Ingegnere |
| • Francesca Bozzano | Professore di Geologia Applicata, Università di Roma La Sapienza, Direttore del Centro di Ricerca Previsione, Prevenzione e Controllo Rischi Geologici (CERI) |
| • Antonio Brambati | Professore di Sedimentologia, Università di Trieste, Responsabile Progetto Paleoclima-mare del PNRA, già Presidente Commissione Nazionale di Oceanografia |
| • Gianfranco Brignoli | Geologo |
| • Marcello Buccolini | Professore di Geomorfologia, Università di Chieti-Pescara |
| • Paolo Budetta | Professore di Geologia Applicata, Università di Napoli |
| • Antonio Maria Calabrò | Ingegnere, Ricercatore, Consulente |
| • Monia Calista | Ricercatore di Geologia Applicata, Università di Chieti-Pescara |
| • Massimo Canali | Associate Professor of Agricultural Economics and Policy, Department of Agriculture and Food Sciences, University of Bologna |
| • Dr. Andrea Capodaglio | PhD, Professor, Environmental Engineering, University of Pavia |
| • Cristiano Carabella | Geologo, Borsista presso l'Università di Chieti |
| • Peppe Caridi | |
| • Franco Casali | Professore di Fisica, Università di Bologna e Accademia delle Scienze di Bologna |
| • Andrea Casini | Lifetime career in electronic engineering and radiocommunications, patent holder in wideband radio signals transmission over fiber optics, Member of The Climate Reality Project |
| • Giuseppe Cautero | MSc in Physics, head of the Instrumentation & Detectors Laboratory, Elettra Synchrotron radiation Source |
| • Dr. Fausto Cavalli | Agronomist, specialisation in meteorology |
| • Giuliano Ceradelli | Ingegnere e Climatologo, ALDAI |
| • Augusta Vittoria Cerutti | Membro del Comitato Glaciologico Italiano |
| • Franco di Cesare | Dirigente, Agip-Eni |
| • Alessandro Chiaudani | PhD, Agronomo, Università di Chieti-Pescara |
| • Luigi Chilin | Dirigente in Pensione |
| • Claudio Ciani | Relazioni Internazionali, Scienza Politica, Università di Roma La Sapienza |

| | |
|---|---|
| • Edoardo Cicali | Member of the C.I.R.N (Italian Nuclear Relaunch Committee) and of the "Atoms for peace" association, former employee of a Radiological Medical Center.Currently in the IT sector |
| • Pino Cippitelli | Geologo Agip-Eni |
| • Carlo Colomba | |
| • Enrico Colombo | Chimico, Dirigente Industriale |
| • Vito Comencini | Onorevole, Membro della Camera dei Deputati italiana dal 2018 |
| • Enrico Conti | Physicist, Istituto Nazionale di Fisica Nucleare (INFN) |
| • Ferruccio Cornicello | Fotografo e Lettore di Studi sul Clima |
| • Domenico Corradini | Professore di Geologia Storica, Università di Modena |
| • Carlo del Corso | Ingegnere Chimico |
| • Uberto Crescenti | Professore Emerito di Geologia Applicata, Università di Chieti-Pescara, già Magnifico Rettore e Presidente della Società Geologica Italiana |
| • Fulvio Crisciani | Professore di Fluidodinamica Geofisica, Università di Trieste e Istituto Scienze Marine, Cnr, Trieste |
| • Salvatore Custodero | |
| • Roberto d'Arielli | Geologo, Borsista presso l'Università di Chieti |
| • Francesco Dellacasa | Ingegnere, Amministratore di Società nel Settore Energetico |
| • Alessandro Demontis | Perito Chimico Industriale, Tecnico per la Gestione delle Acque e delle Risorse Ambientali, Pomezia |
| • Gandolfo Dominici | PhD in Business Management, , Associate Professor of Business Management and Marketing, University of Palermo, Italy |
| • Serena Doria | Ricercatore di Probabilità e Statistica Matematica, Università di Chieti-Pescara |
| • Gianluca Esposito | Geologo |
| • Carlo Esposito | Professore di Rischi Geologici, Università di Roma La Sapienza |
| • Prof. Stefano Falcinelli | PhD, Professor of Chemistry and Materials Technology, Department of Civil and Environmental Engineering, University of Perugia |
| • Antonio Mario Federico | Professore di Geotecnica, Politecnico di Bari |
| • Aureliano Ferri | Vicepresidente Associazione Piceno Tecnologie |
| • Maurizio Fiorelli | Sommelier Professionale, Studioso dell'evoluzione nella Coltivazione delle Vigne |
| • Mario Floris | Professore di Telerilevamento, Università di Padova |
| • Gianni Fochi | Chimico, Ricercatore in Pensione della Scuola Normale Superiore, Giornalista Scientifico |
| • Sergio Fontanot | Ingegnere |
| • Luigi Fressoia | Architetto Urbanista, Perugia |
| • Mario Gaeta | Professore di Vulcanologia, Università di Roma La Sapienza |
| • Stefano Galli | MSc. In Chemical Engineering, retired researcher |
| • Sabino Gallo | Ingegnere Nucleare e Scrittore Scientifico |
| • Stefano Gallozzi | Degree in Physics, Researcher at the INAF, Italian Institute for Astrophysics, Astronomical Observatory of Rome and presidente of the Safegarding Astronomical Sky Foundation |
| • Giuseppe Gambolati | Fellow della American Geophysical Union, Professore di Metodi Numerici, Università di Padova |
| • Alessio del Gatto | Liceo Scientifico, Collaboratore Attivita Solare.it |
| • Rinaldo Genevois | Professore di Geologia Applicata, Università di Padova |
| • Umberto Gentili | Fisico dell'ENEA, Climatologo per il Progetto Antartide, ora in pensione |
| • Enrico Ghinato | Perito Fisico |
| • Mario Giaccio | Professore di Tecnologia ed Economia delle Fonti di Energia, Università di Chieti-Pescara, già Preside della Facoltà di Economia |
| • Daniela Giannessi | Primo Ricercatore, IPCF-CNR, Pisa |
| • Roberto Grassi | Ingegnere, Amministratore G&G, Roma |
| • Roberto Graziano | Ricercatore di Geologia Stratigrafica e Paleoclimatologia/ Paleoceanografia, Università di Napoli, già Geologo presso il Servizio Geologico d'Italia |
| • Alberto Guidorzi | Agronomo |
| • Roberto Habel | Professore di Fisica Medica, Università di Cagliari |
| • Nicola Iacovone | Physicist |

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| • Thomas Kukovec | Tropical Agronomist and Subtropical Field Biologist, Scientific adviser and consultant in research-projects and learned societies |
| • Alberto Lagi | Ingegnere, Presidente di Società Ripristino Impianti Complessi Danneggiati |
| • Dr. Francesco Lamberti | PhD in Material Science of the University of Padova, working on next generation PV |
| • Luciano Lepori | Ricercatore IPCF-CNR, Pisa |
| • Carlo Lombardi | Professore di Impianti Nucleari, Politecnico di Milano |
| • Walter Luini | Geometra |
| • Roberto Madrigali | Meteorologo |
| • Angelo Maggiora | PhD, INFN Senior Researcher, more than 40 years Experience in Research at CERN, Saclay, Dubna and Frascati |
| • Franco Maloberti | Emeritus Professor, expert on microelectronics and modelling |
| • Ettore Malpezzi | Ingegnere |
| • Vania Mancinelli | Geologo, Borsista presso l'Università di Chieti |
| • Ludovica Manusardi | Fisico Nucleare e Giornalista Scientifico, UGIS |
| • Luigi Marino | Geologo, Centro Ricerca Previsione, Prevenzione e Controllo Rischi Geologici (CERI), Università di Roma La Sapienza |
| • Maurizio Marsigli | Graduated in Geological Sciences and science author on the Sun and Space Meteorology |
| • Francesco Martelli | Professor Emeritus of University of Florence, Former President of European Turbomachinery Society |
| • Alessandro Martelli | Ingegnere, già Dirigente ENEA |
| • Paolo Martini | consultant petroleum geologist with 30+ years of experience |
| • Salvatore Martino | Professore di Geologia Applicata all'Ingegneria al Territorio ed ai Rischi, Università di Roma "Sapienza" |
| • Maria Massullo | Tecnologa, ENEA-Casaccia, Roma |
| • Enrico Matteoli | Primo Ricercatore, IPCF-CNR, Pisa |
| • Paul P.A. Mazza | Associate Professor of Quaternary Geology and Paleontology and of Archeozoology, University of Florence |
| • Daniele Mazza | Former Professor of Applied Chemistry at Politecnico di Torino, Current research: climate issues, ocean chemistry, CO2 dynamic equilibria in seawater and climate cyclic variations. |
| • Paolo Mazzanti | Professore di Interferometria Satellitare, Università di Roma La Sapienza |
| • Adriano Mazzarella | Professore di Meteorologia e Climatologia, Università di Napoli |
| • Marcello Mazzoleni | Teacher and entrepreneur in the training sector, Fondatore del Website MeteoSincero |
| • Carlo Merli | Professore di Tecnologie Ambientali, Università di Roma La Sapienza |
| • Enrico Miccadei | Professore di Geografia Fisica e Geomorfologia, Università di Chieti-Pescara |
| • Gabriella Mincione | Professore di Scienze e Tecniche di Medicina di Laboratorio, Università di Chieti-Pescara |
| • Umberto Minopoli | Presidente dell'Associazione Italiana Nucleare |
| • Diego Minuto | MSc Geology, Engineering Geologist, Italy |
| • Alberto Mirandola | Professore di Energetica Applicata e Presidente Dottorato di Ricerca in Energetica, Università di Padova |
| • Aurelio Misiti | Professore di Ingegneria sanitaria-Ambientale, Università di Roma La Sapienza, già Preside della Facoltà di Ingegneria, già Presidente del Consiglio Superiore ai Lavori Pubblici |
| • Maurizio Montuoro | Medico |
| • Maria Luisa Moriconi | CNR researcher at Institute of Atmospheric Physics (retired) and associate to INAF until 2020 |
| • Renzo Mosetti | Professore di Oceanografia, Università di Trieste, già Direttore del Dipartimento di Oceanografia, Istituto OGS, Trieste |
| • Prof. Federico A. Nazar | Researcher at Scientific Progress Fund, former Professor at the Pontifical Catholic University of Argentina |
| • Prof. Rinaldo Nicolich | Emeritus Professor of Applied Geophysics, University of Trieste |
| • Daniela Novembre | Ricercatore in Georisorse Minerarie e Applicazioni Mineralogichepetrografiche, Università di Chieti-Pescara |
| • Francesco Oriolo | Professore di Impianti Nucleari, Università di Pisa |

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| • Paolo Emmanuele Orrù | Professore di Geografia Fisica e Geomorfologia, Università di Cagliari |
| • Sergio Ortolani | Professore di Astronomia e Astrofisica, Università di Padova |
| • Roberto Pagani | Freelance Geologist |
| • Alessandro Pagano | Geologist |
| • Giorgio Paglia | Geologo, Borsista presso l'Università di Chieti |
| • Massimo Pallotta | Primo Tecnologo, Istituto Nazionale Fisica Nucleare |
| • Antonio Panebianco | Ingegnere |
| • Giuliano Panza | Professor of Seismology, University of Trieste, Beno Gutenberg medal 2000, International Award of the American Geophysical Union in 2018 |
| • Emanuele Paone | BSc.(HONS) Geology, M.Sc Geology, Geologist |
| • Prof. Andrea Pardini | PhD, University of Florence |
| • Antonio Pasculli | Ricercatore di Geologia Applicata, Università di Chieti-Pescara |
| • Ernesto Pedrocchi | Professore Emerito di Energetica, Politecnico di Milano |
| • Davide Peluzzi | Ambasciatore del Parco Nazionale del Gran Sasso e dei Monti della Laga nel Mondo nel 2017 |
| • Corrado Penna | Docente di Matematica |
| • Enzo Pennetta | Professore di Scienze Naturali e Divulgatore Scientifico |
| • Gianni Pettinari | Impiegato Amministrativo, Fondatore del gruppo Facebook: "Falsi allarmismi sul riscaldamento globale" |
| • Alessandro Pezzoli | Ricercatore universitario e Professore aggregato in Weather Risk Management, Politecnico di Torino e Università di Torino |
| • Tommaso Piacentini | Professore di Geografia Fisica e Geomorfologia, Università di Chieti-Pescara |
| • Stefano de Pieri | Ingegnere Energetico e Nucleare |
| • Paolo M.J. Pilli | Pensionato |
| • Massimo Pilolli | PhD Physics, Physicist, Meteorologist, Teacher |
| • Stefano Piotto | PhD in Chemistry, Associate professor in Chemistry at the University of Salerno |
| • Mirco Poletto | Geologo libero professionista, registered at 'Ordine dei geologi del Veneto' |
| • Andrea Pomozzi | Presidente Associazione Piceno Tecnologie |
| • Guido Possa | Ingegnere nucleare, già Viceministro del Ministero dell'Istruzione, Università e Ricerca con delega alla ricerca |
| • Alfonso Pozio | PhD, Senior Researcher, ENEA CR Casaccia, Rome |
| • Giorgio Prinzi | Ingegnere, Direttore responsabile della Rivista "21mo Secolo Scienza e tecnologia" |
| • Franco Prodi | Professore di Fisica dell'Atmosfera, Università di Ferrara |
| • Franco Puglia | Ingegnere, Presidente CCC, Milano |
| • Francesca Quercia | Geologo, Dirigente di Ricerca, Ispra |
| • Nunzia Radatti | Chimico, Sogin |
| • Arnaldo Radovix | Geologo, Risk Manager in Derivati Finanziari |
| • Maurizio Rainisio | Mathematician, Lifetime career in Clinical Development and Epidemiology |
| • Mario Luigi Rainone | Professore di Geologia Applicata, Università di Chieti-Pescara |
| • Mario Rampichini | Chimico, Dirigente Industriale in pensione, Consulente |
| • Arturo Raspini | Geologo, Ricercatore, Istituto di Geoscienze e Georisorse (IGG), Consiglio Nazionale delle Ricerche, Firenze |
| • Enzo Reali | MSc, Agricultural and Rural Development Expert |
| • Tucci Riccardo | agroecology and rigenerative expert |
| • Marco Ricci | Fisico, Primo Ricercatore, Istituto Nazionale di Fisica Nucleare |
| • Renato Angelo Ricci | Professore Emerito di Fisica, Università di Padova, già Presidente della Società Italiana di Fisica e della Società Europea di Fisica, Movimento Galileo 2001 |
| • Renzo Riva | Comitato Italiano Rilancio Nucleare (C.I.R.N.), Buja |
| • PierMarco Romagnoli | Ingegnere, Milano |
| • Vincenzo Romanello | Ingegnere nucleare, Ricercatore presso il Centro di Ricerca Nucleare di Rez, Repubblica Ceca |
| • Piergiorgio Rosso | Ingegnere Chimico |
| • Stefano Rosso | Insegnante di Geografia, Storia e Italiano, Scuola Secondaria, Modena |

Italy continued

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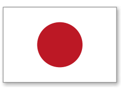
|---|---|
| • Alberto Rota | Ingegnere, Ricercatore presso CISE ed ENEL, Esperto di Energie Rinnovabili |
| • Ettore Ruberti | Ricercatore ENEA, Docente di Biologia Generale e Molecolare |
| • Giancarlo Ruocco | Professore di Struttura della Materia, Università di Roma La Sapienza |
| • Sergio Rusi | Professore di Idrogeologia, Università di Chieti-Pescara |
| • Massimo Salleolini | Professore di Idrogeologia Applicata e Idrogeologia Ambientale, Università di Siena |
| • Nicola Scafetta | Professore di Fisica dell'Atmosfera e Oceanografia, Università di Napoli |
| • Emanuele Scalcione | Responsabile Servizio Agrometeorologico Regionale ALSIA, Basilicata |
| • Nicola Sciarra | Professore di Geologia Applicata, Università di Chieti-Pescara |
| • Francesco Sensi | Generale di Divisione Aerea (R) |
| • Massimo Sepielli | Direttore di Ricerca, ENEA, Roma |
| • Leonello Serva | Geologo, Accademia Europa delle Scienze e delle Arti, Classe V, Scienze Tecnologiche e Ambientali, già Direttore Servizio Geologico d'Italia |
| • Roberto Simonetti | Geologo, R&D c/o Azienda S.I.I. |
| • Elio Sindoni | Professore Emerito dell'Università di Milano Bicocca |
| • Enzo Siviero | Professore di Ponti, Università di Venezia, Rettore dell'Università e-Campus |
| • Rinaldo Sorgenti | Deputy Chairman of ASSOCARBONI |
| • Ugo Spezia | Ingegnere, Responsabile Sicurezza Industriale, Sogin, Movimento Galileo 2001 |
| • Luigi Stedile | Geologo, Centro di Ricerca Previsione, Prevenzione e Controllo Rischi Geologici (CERI), Università di Roma La Sapienza |
| • Emilio Stefani | Professore di Patologia Vegetale, Università di Modena |
| • Flavio Tabanelli | Fisico |
| • Maria Grazia Tenti | Geologo |
| • Umberto Tirelli | Visiting Senior Scientist, Istituto Tumori d'Aviano, Movimento Galileo 2001 |
| • Francesco Torre | Former Associate Professor of Geomorphology at the University of Bologna |
| • Giorgio Trenta | Fisico e Medico, Presidente Emerito dell'Associazione Italiana di Radioprotezione Medica, Movimento Galileo 2001 |
| • Roberto Vacca | Ingegnere e Scrittore Scientifico |
| • Gianluca Valensise | Dirigente di Ricerca, Istituto Nazionale di Geofisica e Vulcanologia, Roma |
| • Prof. Paolo Sebastiano Valvo | PhD - Associate Professor of Solid and Structural Mechanics, University of Pisa |
| • Corrado Venturini | Professore di Geologia Strutturale, Università di Bologna |
| • Flavio Vetrano | Honorary Professor of General Physics, DiSPeA, University Carlo Bo , Urbino |
| • Mario Visaggio | founder of the scientific Facebook page of Klima and science (Klima e scienza) |
| • Benedetto de Vivo | Professore di Geochimica in Pensione dall'Università di Napoli; ora Professore Straordinario presso Università Telematica Pegaso, Napoli |
| • Mario Voltaggio | MSc in Geology, former first researcher CNR IGAG, retired |
| • Andrea Zaccone | Geologo, Dirigente Protezione Civile Regione Lombardia |
| • Luigi Zanotto | Docente in Pensione |
| • Franco Zavatti | Ricercatore di Astronomia, Università di Bologna |
| • Antonino Zichichi | Professore Emerito di Fisica, Università di Bologna, Fondatore e Presidente del Centro di Cultura Scientifica Ettore Majorana di Erice |



## 6 SIGNATORIES FROM JAPAN

**6 Signatories**

| | |
|---|---|
| • Takahiko Ban | Ph. D. Chemical Engineering, Associate Professor at Osaka University |
| • Masayuki Hyodo | Professor of Earth Science, Kobe University, Japan |
| • Yoshihiro Muronaka | Professional Engineer, studied Chemical Engineering, has been working in the areas of Environment, Energy, CVD and EHS |
| • Mototaka Nakamura | Atmospheric and Oceanic Scientist (ScD in Meteorology, MIT) |

- Dr. Hiroshi L. Tanaka — Professor in Atmospheric Science, Centre for Computational Sciences, University of Tsukuba
- Junji Yamamoto — PhD, Professor of Earth and Planetary Sciences, Kyushu University

## 1 SIGNATORY FROM KUWAIT

**1 Signatory**

- Mohammad A. AlKhamis — DVM, MPVM, PhD, Assistant Professor of Epidemiology, Department of Epidemiology and Biostatistics, Faculty of Public Health, Health Sciences Center, Kuwait University

## 1 SIGNATORY FROM MALAYSIA

**1 Signatory**

- Christoffel Schoneveld — Earth Scientist and Retired Shell Exploration Geophysicist

## 1 SIGNATORY FROM MALTA

**1 Signatory**

- Joseph Attard — Retired Scientist, PhD chemical engineering MSc Electronics Communication

## 5 SIGNATORIES FROM MEXICO

**5 Signatories**

- Rubén Coronal Méndez — Master degree in Applied Economics, Industrial Engineer
- Luis Frausto — Chemical Engineer
- Armando Páez — PhD, Urbanism, Expert in Sustainability and Energy Transitions
- prof. dr. Rumen Tsonchev — PhD in Physics, Professor at Faculty of Physics, University of Zacatecas
- Victor Manuel Velasco Herrera — PhD, Space Engineer

## 1 SIGNATORY FROM NAMIBIA

**1 Signatory**

- Dr. Simon Idris Beshir — Cardiologist, currently involved in Green Project in Kalahari Desert

## 158 SIGNATORIES FROM NETHERLANDS

**2 WCD Ambassadors**

- Prof.Dr.Ir. Guus Berkhout — Emeritus Professor of Geophysics, Delft University of Technology, Member of the Royal Netherlands Academy of Arts and Sciences
- Dr. Kees Lepair — Physicist, Former CEO Physics & Technology Research Organisations

**156 Signatories**

- Drs. Jan H. Akkerman — MSc, Structural Geology, worked 19 years with Billiton in Mining and Geology and the last 20 years with DGA van Akkerman Exploration BV
- Maarten van Andel — Author of the 'Groene Illusie'
- Tjeerd Andringa — MSc in Physics, PhD in Signal Processing, former Associate Professor of Sensory Cognition, Epistemologist
- Jan Asselbergs — Mechanical Engineer who started his career with IHC. Since 1990 he is active in revitalizing medium sized companies
- Dries Ausems — MSc, Earth Sciences, Lifetime Experience as Geologist in the Geo-Energy Industry
- René Bakers — Former Lawyer and Attorney Liability and Insurance
- Dr. Thomas W. Bakker — Lifetime Experience in the Geo-energy Industry, Founder and former (or retired) CEO of Well Engineering Partners BV
- Nanda Josina Sofia Bakker -Ait Arrami — MSc, MBA
- Robert Becht — Lifetime R&D Experience in Water Management with emphasis on water management in East Africa
- Frans van den Beemt — Nuclear Physicist, Former Program Director Technology Foundation STW

Netherlands continued

| | |
|---|---|
| • Jan Bernard | Geologist dredging- and offshore industry and Royal Netherlands Navy Reserve (hydrography) |
| • Drs. A (Toine) J. A. Beukering | Bgen (b.d.), Member of the Provincial Council of Zuid Holland, Member of the Senate (Eerste Kamer) of the Dutch Parliament (the States General) |
| • Jim van Beusekom | Retired Captain B747-400 with KLM, 35 years observational knowledge of the Earth's atmosphere |
| • Maarten Biesheuvel | MSc and PhD Chemical Technology, University of Twente, Senior Scientist Chemical Engineering and Water Technology, Wetsus |
| • André Bijkerk | Retired Officer Royal Dutch Air Force, now Climate Researcher |
| • Dr. Frans Bijlaard | Professor-Emeritus steel constructions, TU Delft |
| • Dr. Ruud Binnekamp | Msc Integral Design and Management, teacher and researcher in design and decision systems at TU Delft |
| • Harold J. Blaauw | PhD in Physics, Secretary of the former Netherlands Energy Research Council, independent consultant (retired) |
| • Peter Bloemers | Emeritus Professor of Biochemistry, Radbout University, Nijmegen |
| • Albert F.T. de Booij† | Founder Speakers Academy Int. BV, Founder and CEO World of Consciousness.com, Co-Founder with Pim Fortuyn of the political party LPF. |
| • Hans Bouman | MSc, Chemistry, Professional in Production Technology and Asset Management |
| • Dr. Ir. Arnold Bovy | retired, former Director Energy Transmission Company MEGALIMBURG |
| • Ben Braam | Msc in Physics, lifetime career in space instrumentation |
| • Paul M.C. Braat | Emeritus Professor of Pulmonary Physics, University of Amsterdam |
| • Solke Bruin | Emeritus Professor of Product-driven Process Technology, University of Eindhoven and Former Member Management Committee Unilever Research, Vlaardingen |
| • Dr. T.H.L. Claassen | Aquatic Ecologist |
| • Prof.Dr. Paul Cliteur | Professor of Legal Sciences, Member of the Senate of The Netherlands |
| • Albert J.H.G. Cloosterman | Retired Chemical Engineer, Publicist on Climate and Cosmological Matters |
| • Charles Coleman | former executive Olivetti Group International |
| • Marcel Crok | Climate Researcher and Science Journalist |
| • Gerhard Diephuis | MSc, Geosciences, specialized in Geophysics, Lifetime Experience in the Geo-Energy Industry, Guest Lecturer TU Delft |
| • Henck van Dijck | Sculptor, designer and innovator |
| • Hessel van Dijk | Organic Chemist |
| • David E. Dirkse | Former Computer Engineer and Teacher Mathematics |
| • Dr. Tjibbe Dokter | MBA, Expert in Scenario Analysis and Risk Assessment, retired from AkzoNobel |
| • Marco Draaisma | ICT Process Coördinator |
| • Vincent van Driel | MSc Mechenical Engineering TU Delft, Design and Construction of gas / oil processsing plants, Retired |
| • Dr. Jan W. Drukker† | Emeritus Professor Industrial Design Delft University of Technology, University of Twente and (Visiting Professor) Tsinghua University Beijing, |
| • Arjan Duiker | Process Technologist at Tata Steel, specialist on Thermodynamics and Fluid Mechanics |
| • Louw Feenstra | Emeritus Professor Erasmus University and Philosopher, Rotterdam |
| • Arnold Fellendans | Physics at TU Delft, 40 years at Unilever (retired), www.omdeaarde.nl |
| • Frans Galjee | Mechanical Engineer, Retired Researcher at ECN |
| • Harold van Garderen | PhD in complexity science/chemistry (TU Eindhoven) and social complexity/narrative scientist (self-employed) |
| • Jan van Gils | Teacher in Physics |
| • Ir. Henk Goemans | MSc, Geosciences, specialized in Reservoir Engineering |
| • Frans H Gortemaker | Former Vice President Unilever Global R&D |
| • Drs. W.J. Evert van de Graaff | Consulting Geologist, 50+ years Global Experience |
| • Ton J.T. Grimberg | Oil & Gas Professional, Finance Adviser |
| • Katharina Grimm | Msc Agroecology and Sustainable Food Systems, Project Leader energy transition at the municipality of Epe |

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| • Ir. Kees de Groot | Former Director Upstream Research Lab. Shell |
| • Paul de Groot | PhD, Geoscience, Manager dGB Earth Sciences |
| • Lex A. van Gunsteren | Marine propulsion expert, former director of Corporate Planning and R&D of the Royal Boskalis Westminster Group, former professor of Technology at TU Delft and Erasmus University |
| • Leo Halvers | Former Director Billiton Research Arnhem and Former Director Technology Foundation STW |
| • Hans Hamaker | University Degree in Phonetic Sciences, expert in biomechanics of speech, supporter of plasma cosmology, former wireless communication officer |
| • Maarten Hardon | BSc, Civil Engineering, Lifetime Experience in Offshore Industry, Director Venty BV |
| • Eduard Harinck | Former Logistics Expert, Nedlloyd Group/KPMG Consulting |
| • Drs. Godard Hazeu | MSc, Geoscciences, specialized in Geology, past Technical Director of the Dutch State Oil and Gas Company EBN |
| • Edward Heerema | Msc in Civil Engineering TU Delft, President of Allseas, worldwide active in offshore pipelaying and platform lifting |
| • J.R. Hetzler† | Retired WUR Engineer Forestry Economics |
| • Dr. Tom van der Hoeven | Energy Transport Modeling Expert |
| • Jan Holtrop† | Emeritus Professor of Petroleum Engineering, Delft University of Technology |
| • J.A.R. Hombroek | MSc, Geoscience, Lifetime Experience in the International Geo-Energy Industry |
| • Tom Hoornstra | Air-Conditioning Engineer |
| • Jan Horstink | Earth Scientist, Exploration Projects Oil & Gas ME & FE |
| • A. Huijser | Physicist and Former CTO Royal Philips Electronics |
| • Jan de Jager | emeritus professor Geology (VU University Amsterdam, University of Utrecht) |
| • Jan J.C. de Jong | Msc Process Engineering TU Delft, expert in energy-and thermal process engineering, lifetime career in the oil and gas industry |
| • Jan de Jong | former director Sampo Industrial Insurance NV. Benelux and Electrorisk Verzekeringsmaatschappij N.V. |
| • Wouter J. Keller | Emeritus Professor of Statistical Methods, Former Member Board of Directors, Central Bureau of Statistics (CBS) |
| • Jacques van Kerchove | Economist and Marketeer, Former CFO Rabobank, now Climate and Environment Researcher |
| • Henri G. Kerkdijk-Otten | Msc History, University of Nijmegen, Founder and Chairman of Restoring Africa's Wildlife Foundation, Founder and former chairman of True Nature Foundation |
| • Rob de Kok | Principal Geophysicist, researching Influence of CO2 on Atmospheric Temperatures |
| • Hans Kolmschate | Chemical Engineer, University of Twente |
| • Henk de Koning | MSc, former Principal Management Consultant Atos Consulting with specialisation Logistics, IT and Information Security |
| • Rob Kouffeld† | Emeritus Professor of Energy Conversion, Delft University of Technology |
| • Hans H.J. Labohm | Former Expert Reviewer IPCC |
| • Prof. dr. Cornelis A. de Lange | Emeritus Professor of Atmospheric Chemistry and Physics, and Complex Modelling, Former Senator in the Dutch Senate |
| • Arjan Lenoir | MSc Industrial Sciences |
| • Dr. ir. B.G. Linsen | Former Director Unilever Research Vlaardingen |
| • Jaap M. van Luijk | Msc. Petroleum Engineering, lifetime experience in the international geo-energy industry |
| • PROF. DR. Pieter Lukkes | Emeritus Professor of Economic and Human Geography, University of Groningen |
| • Ronald Luttikhuizen | Studied Physical Geography, retired economist and statistician |
| • Hugo Matthijssen | Former Teacher Meteorology, now Publicist on Climate Matters |
| • Leo D. Minnigh | retired scientist in structural geology, lecturer/speaker for non-professionals |

Netherlands continued

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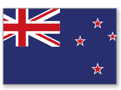
|---|---|
| • Dr. Rob Mooij | PhD in Nuclear Physics at University of Utrecht, MS Computer Science at Drexel University, Philadelphia, Retired as Medical Physicist from University of Pennsylvania |
| • Ir. J.M. Mulderink | Former General Director Akzo-Nobel |
| • Rob Nijssen | Radar Engineer and Publicist on Climate Matters |
| • Rutger van den Noort | PhD, advisor in Innovation Processes, CEO Newcalf |
| • Dr. Chris Oldenhof | PhD in Photochemistry, Retired from the Dutch chemical company DSM |
| • Ir. Peter Oosterling | Former Scientist E & P Shell, now active as Climate Researcher |
| • Daan Osinga | Geologist |
| • Kees Pieters | Mathematician, Former Operational Research and ICT manager at Shell |
| • Robert J. van der Plas | MSc Applied Physics, MSc Development Studies, Sustainable Energy Management and Development Specialist |
| • Reynier Pronk | Former IT Manager, Accredited Project Management Consultant and Trainer |
| • Paul Ras | Msc Geophysics TU Delft, Geophysical Consultant, climate realist |
| • Ir. B. Peter Rauwerda | Msc in nuclear engineering, TU Delft |
| • Louis M.P.T. van den Reek | PharmD, Member of 'De Groene Rekenkamer' |
| • Jan C. Reinoud | retired CEO Dutch chain of Supermarkets |
| • A.G. Reitsma | MSc in Social technology, planned change (University of Groningen 1978) Social Technician |
| • Kees Remi | Electrical Engineer, lifetime experience in Energy Distribution and Industrial Automation |
| • Joseph Reynen | Finite Element Modeling Expert, Retired from EU Joint Research Centre in Ispra, Emeritus Associate professor TU Delft |
| • George T. Robillard | Emeritus Professor of Biochemistry and Biophysics |
| • Jaap Romijn | Msc in Civil Engineering TU Delft, lifetime experience in water management projects |
| • Kees Roos | Emeritus Professor of Optimization Technology, Delft University of Technology |
| • Albertus F. Rooze | MSc in Chemistry, mathematics and natural sciences, retired |
| • Robert Sambell | PhD, Physics, Professional Geophysicist |
| • Rutger van Santen | Emeritus Professor of Anorganic Chemistry and Catalysis, Former Rector Magnificus, Eindhoven University |
| • Don Schäfer | Former Director Shell Exploration & Production and New Business, Shell |
| • Juleon Schins | PhD in Molecular Physics, specialist in near infrared spectroscopy |
| • Dr. Rob Schoevaart | Biocatalist, Co-founder and Managing Director of ChiralVision, being specialised in making chemical processes greener |
| • Frans Schrijver | Strategy Consultant and Climate Publicist |
| • Bert Sigmond | Geologist, Founder of EuGeNe Company in Geothermal Energy |
| • Hendrick Smit | Chemical Engineer, specialised in Environmental Instrumentation |
| • Prof.Dr.Ir. Jos de Smit | Emeritus Professor of Stochastic Operations Research and Former Rector Magnificus of the University of Twente |
| • Barend-Jan Smits | Geologist, Former Director of Wintershall Nederland, BASF Group |
| • Jack van Soest | BSc, Geography teacher (retired) |
| • Dr. Engel van Spronsen | PhD in Physics, Lifetime career in Shell as researcher, reservoir engineer, and technical manager. After Shell he also worked for Maersk OiI, IMPaC Engineering, and Eneco |
| • Chris Stenger | PhD in inorganic chemistry and materials engineering. Lifetime research and development career in Billiton and Shell. . |
| • Albert Stienstra† | Emeritus Professor of Computer Simulation and Micro-Electronics, Delft University of Technology. |
| • P.J. Strijkert | Former Member Board of Directors of DSM, Delft |
| • Dr Hans van Suijdam | Former Executive Vice President Research and Development DSM |
| • Dick Swart | MSC, worldwide drilling expert, lifetime of experience in the geo-energy industry |
| • Dr. Harry C. M. de Swart | Emeritus Professor of Logic and Language Analysis, University of Tilburg, Author of the book 'Philosophical and Mathematical Logic' |

| | |
|---|---|
| • Peter van Toorn | Former Research Geophysicist Shell |
| • Fred Udo | Emeritus Professor of Nuclear Physics, Vrije Universiteit Brussels |
| • Ir. Arnold Uijlenhoet | retired Electrical Engineer, TU Delft, Postgraduate at University of Pittsburgh, Lifetime international experience in power generation, transmission, and distribution |
| • prof. dr. ir. Jan Dirk van Elsas | PhD, Em. Prof .Microbial Ecology, RUG |
| • Maarten Vasbinder | MD, specialized in prion theories and practice |
| • J.F. van de Vate | Former Director ECN, Petten, The Netherlands. Former UN Delegate IPCC |
| • prof. dr. ir. Jan Verheij | Retired Scientist Applied Physics at TNO Delft, Emeritus Professor of Noise Control Engineering at Eindhoven University of Technology |
| • Hans Verschuur | MSc, Geosciences, specialized in Mining |
| • Henk Verveer | Msc Civil Engineering TU Delft, lifetime experience in maritime infrastructure and building services |
| • Jannes. J. Verwer | Former Director ECN and Former Chairman Supervisory Board State Owned Radio Active Waste Storage Facilities |
| • Koen Vogel | Geologist and Geostatistician, lifetime experience in numerical modelling, proficient in evaluating and developing global energy projects |
| • Henk van der Vorst | Emeritus Professor of Numerical Mathematics, University of Utrecht |
| • Bart Vos | Msc Petroleum Engineering, Lifetime of Experience in the Geo-energy Industry |
| • Rob de Vos | Geographer and Editor of “Klimaatgek” |
| • Henk de Vries | lifetime experience in organised crime, expert in digital forensics |
| • Jaap van der Vuurst de Vries | Emeritus Professor of Petroleum Engineering, Former Dean Faculty of Applied Earth Sciences, Delft University of Technology |
| • Dr. Jules de Waart | PhD Physical Geography, Exploration Geologist in Africa, Past member of the Dutch Parliament, author of the book on Climate Change and Energy Transition “Don’t believe everything” |
| • Dr. André Wakker | energy expert, lifetime experience in nuclear energy, speaker and writer on energy transition |
| • Karel Wakker | Emeritus Professor of Astrodynamics & Geodynamics, Delft University of Technology |
| • Robert N. Walter | MSc E.E., member Advisory Board ‘De Groene Rekenkamer’ |
| • Cyril Wentzel | Multi-Physics Engineer and Chairman of Environmental Think Tank ‘Groene Rekenkamer’ |
| • Frans A. van der Werf | Master of Law, Owner of an International Business for Management, Consultancy and Finance |
| • Bert Weteringe | Author, independent research journalist on energy transition and wind energy. |
| • Dolf van Wijk | Formerly AkzoNobel Environmental Research Laboratory and Former Executive Director Cefic-Euro Chlor, Brussels |
| • Jaap Wijsman | Mechanical Engineer, active in the offshore industry |
| • Jan Winkel | MSc, Chemical Engineering, specialization in Natural Gas Projects, Lifetime Experience in the Geo-Energy Industry |
| • Theo te Winkel | Geo Scientist and International Health Care Specialist |
| • Wim Witteman | Professor of Applied Physics and CO2 lasers, University of Twente |
| • Dr. Hans Wolkers | PhD in Animal Physiology and Environment, Over 20 years of research experience, incl. Arctic ecotoxicology, Science journalist and university lecturer in ‘Writing about Science’ |
| • Theo Wolters | Chairman Environment, Science & Policy Foundation, Co-founder ‘Groene Rekenkamer’ and ‘Climategate.nl’ |
| • Govert Zijderveld | MSc Mining Engineering, Consultant for all Drilling, Mining and Naval Engineering activities |
| • Dr. E.J. (Ed) Zuiderwijk | Retired Astrophysicist and Data Manager |
| • Diederik Zwager | MSc Petroleum Engineering, CEO Air Drilling Associates |



## 26 SIGNATORIES FROM NEW ZEALAND

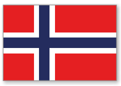
**1 WCD Ambassador**

| | |
|---|---|
| • Barry Edward Brill | OBE, Previously Minister of Science and Techology |

New Zealand continued

**25 Signatories**

| | |
|---|---|
| • Deborah Alexander | Agricultural Scientist |
| • Jock Allison | Retired Agricultural Scientist, Ministry of Agriculture |
| • Mario Barbafiera | MSc Palaeoclimatology, Teacher |
| • Paul A. Catchpole | Qualified Land Surveyor & Fellow of New Zealand Institute of Surveyors, Retired Ex Commissioner of the New Zealand Environment Court |
| • Roger High Dewhurst | Retired, Geologist/Hydrogeologist |
| • Geoffrey. G. Duffy | Professor Emeritus, University of Auckland |
| • Terry Dunleavy† | MBE, Co-Founder (2006) and Honorary Secretary New Zealand Climate Science Coalition; Former WCD Ambassador |
| • Doug Edmeades | Managing Director agKnowledge Ltd. |
| • Joe Fone | CAD Engineer, Enatel Ltd. |
| • Professor Michael J Kelly | MA, PhD, SCD, MAE, Emeritus Prince Philip Professor of Technology at the University of Cambridge |
| • Gary Kerkin | Retired Chemical Engineer, Upper Hutt. Executive Member New Zealand Climate Science Coalition |
| • Roman Leslie | Research specialist in geochemistry of arc-magmatism, magma-wallrock interactions, mineralogy, melt inclusions, SW Pacific tectonics and geodynamics. |
| • Brian Leyland | Power Systems Engineer and Experienced Renewable Energy Specialist |
| • Gerrit J. van der Lingen | Geologist and Paleoclimatologist, New Zealand, Author of the Book The Fable of Stable Climate |
| • Nima Maleki | MD specialist in family health, Bachelor in science |
| • Dr. John Maunder | Climate Scientist, President of the WMO Commission for Climatology 1989-1996 |
| • Dr Richard Reaney | Climate Researcher, Post Graduate Qualification in Antarctic Studies, University of Canterbury New Zealand |
| • Darag S. Rennie | MBChB, Lifetime explorer of truth |
| • John Scarry | ME (Civil), Structural Engineer, Member of the New Zealand Climate Science Coalition |
| • John Sexton | Member of the New Zealand Climate Coalition |
| • David Shelley | Emeritus Associate Professor Geology and latterly Dean of Postgraduate Studies, University of Canterbury, Christchurch |
| • David Steward | Electronic Engineer, Supporter of truth seeking in climate change |
| • Philip Strong | Science Research Leader & Member of the New Zealand Climate Coalition |
| • Richard Treadgold | Executive Member NZ Climate Scienc Coalition, Convenor Climate Conversation Group |
| • Ian Wright | Professional Geologist |



## 32 SIGNATORIES FROM NORWAY

**2 WCD Ambassadors**

| | |
|---|---|
| • Ivar Giaever | Nobel Laureate Professor, Nobel Prize Winner in Physics, Emeritus Professor of the Rensselaer Polytechnic Institute, Chief Technology Officer of Applied Biophysics Inc., Fellow of the American Physical Society |
| • Jan-Erik Solheim | Professor Emeritus Astrophysics, University of Tromsø – The Arctic University of Norway |

**30 Signatories**

| | |
|---|---|
| • Gunnar Abrahamsen | Professor Emeritus Soil Science, University of Life Sciences |
| • Knut Åm | Retired Geoscientist, adjunct Professor of Geophysics at the University of Bergen, Norway, Honorary member of The Norwegian Academy of Technological Sciences |
| • Egil Bergsager | MSc of UCLA and University of Oslo, Petroleum Geologist, Direc-tor Norwegian Petroleum Directorate, President Rogaland Science Park. Board member of advanced technology companies |

Norway continued

| | |
|---|---|
| • Stein Sorlie Bergsmark | Phycisist, Former Head of Renewable Energy Studies Program-mes, University of Agder |
| • Einar R. Bordewich | multidiscipline Engineering |
| • Dr. Hans Borge | Associate Professor in Mathematics, University of Stavanger |
| • Reidar Borgstrøm | Professor Emeritus in Fishbiology and Nature Conservation, University of Life Sciences |
| • Dr. Erik Bye | Retired Senior Scientist in Physical Chemistry, Crystallography, Chemometrics and Occupational Hygiene |
| • Ole Henrik Ellestad | Physical Chemist. Former Research Director and Professor in Petrochemistry at the Centre for Industrial Research and University of Oslo |
| • Jon Gulbrandsen | PhD, Biologist, Associate Professor NOFIMA and NOAA (USA) |
| • Arve Gleissner Gustavsen | Msc in Cybernetics, Lifelong Experience in Design and Engineering |
| • Rögnvaldur Hannesson | Professor Emeritus, Norwegian School of Economics |
| • Geir Hasnes | Adjunct Associate Professor, Department of Engineering Cyber-netics, Norwegian University of Science and Technology |
| • Martin Torvald Hovland | Geophysical and Geological Advisor, Former Lecturer at Universi-ty of Tromsø |
| • Ole Humlum | Professor Emeritus in Physical Geography, University of Oslo |
| • Morten Jødal† | Biologist, Former Employee of the Norwegian Research Council and the Centre for the Development and Environment at the University of Oslo. Passed away |
| • Dr. Ing. Hans Konrad Johnsen | |
| • Olav Martin Kvalheim | Emeritus Professor, Chemistry, Bergen University |
| • Arnfinn Langeland | Professor Emeritus Biology, Norwegian University of Science and Technology |
| • Mikael Lindgren | MS Applied Phyics and electronics, PhD Chemical Physics, Prof Applied Physics (Optics) and Biophysics (spectroscopy) |
| • Willy Nerdal | Professor of Chemistry, University of Bergen |
| • Johannes Oraug | Landscape Architect, Researcher for 11 years at the Norwegian Institute for Urban and Regional Research |
| • Egil Pedersen | Dr. Eng. and Professor of Technology at UiT The Arctic University of Norway |
| • Elen Roaldset | Emertitus Professor in Geology, University of Oslo, Former Direc-tor of Natural History Museum Oslo, Professor at Norwegian University of Science and Technology |
| • Ulf Torgny Rock | Master of Chemical Engineering, Norsk Hydro |
| • Gjertrud Røyland | Meteorologist with experience in operational forcasting (1997-2007) from the Norwegian Meteorological Institute. |
| • Håkon Gunnar Rueslåtten | Geological Researcher, Trondhheim |
| • Tom V. Segalstad | Associate Professor Emeritus of Geochemistry, University of Oslo |
| • Einar Sletten | PhD, Professor in the Dept of Chemistry, University of Bergen |
| • Jørgen Stenersen | Professor Emeritus Eco-Toxicology, University of Oslo |

## 1 SIGNATORY FROM PARAGUAY

**1 Signatory**

| | |
|---|---|
| • Albrecht Glatzle | Retired Director Research of INTTAS (Iniciativa para la Inverstigación y Transferencia de Tecnología Agraria Sostenible) |

## 2 SIGNATORIES FROM PHILIPPINES

**2 Signatories**

| | |
|---|---|
| • Melanchthon Bernil | Professional Chemical Engineer |
| • Herman Bognot | MA in Philosophy, Assistant Professor, Department of European Languages, University of the Philippines Diliman |

## 4 SIGNATORIES FROM POLAND

**4 Signatories**

| | |
|---|---|
| • Marek Boinski | Chairman of the National Section of Energy Workers' Union NSZZ |

Poland continued

| | |
|---|---|
| • Zbigniew Gidzinski | Advisor to the Chairman of the Silesian Region of the Solidarity Union for climate policy, former Secretary of the National Energy Security Team of the Chancellery of the President |
| • Jaroslaw Grzesik | Chairman of the National Secretariat of Mine and Energy Workers' Union NSZZ |
| • Dominik Kolorz | Chairman of the Slasko-Dabrowski Region of NSZZ |

## 10 SIGNATORIES FROM PORTUGAL

**1 WCD Ambassador**

| | |
|---|---|
| • Dr. Peter Stallinga | Professor Associado com Agregação, Universidade do Algarve, Portugal, Faculty of Sciences and Technology, Department of Electronic Engineering and Informatics |

**9 Signatories**

| | |
|---|---|
| • Demétrio Carlos Alves | Chemical Engineer, specialized in Processes and Systems, Postgraduate in Legal Issues of Urban Planning, University of Lisbon |
| • José Araújo | Environmental Engineer, Airline Pilot. |
| • Rui Cruz | Pharmaceutical Development Scientist, PhD In Chemical and Biological Engineering (Material Science Focus for Solar Energy Applications) |
| • Pieter IJzerman | entrepreneur in modern energy solutions and electric mobility |
| • Prof. Dr. Igor Khmelinskii | Aggregate Professor of Physical Chemistry, University of Algarve, discoverer of long-range energy transfer in biological systems |
| • Joao Manuel Silva Martins | retired agrarian researcher |
| • Pamela Matlack-Klein | Member of Portuguese Sea Level Project, USA |
| • José Pinto de Sá | PhD in Electrical and Computers Engineering, Professor of Power Systems (Electrical and Computers Engineering), Instituto Superior Técnico, Lisbon |
| • João José Rodrigues Tilly | Mechanical Engineer and Maths teacher |

## 8 SIGNATORIES FROM RUSSIA

**8 Signatories**

| | |
|---|---|
| • Habibullo Abdussamatov | Head of the Space Research Sector of the Sun, Pulkova Observatory RAS and Head of the Lunar Observatory Project on Monitoring of the Climate |
| • Prof. Vladimir N. Bashkin | Professor in Biogeochemistry, Principal Researcher of the Institute of Physicochemical and Biological problems of Soil Science of RAS, Moscow |
| • Pavel Bizyukov | PhD in Metallurgical Engineering, faculty member at Moscow State Institute of Steel and Alloys |
| • Gleb I. Evgenev | Professor of Environment, Moscow State Technical University (MADI) |
| • Vladimir G. Kossobokov | Chief Scientist, Professor Expert, Russian Academy of Sciences |
| • Eugene Nagibin | MA in Economics, CIR, Territorial Development and Management Consultant |
| • Henni Ouerdane | PhD in Physics, Associate Professor with extensive experience in the physics of energy conversion and the related technologies |
| • Dr. Michael Petelin | Professor of the University of Nizhny Novgorod, head researcher of the Institute of Applied Physics, Nizhny Novgorod |

## 1 SIGNATORY FROM SAUDI ARABIA

**1 Signatory**

| | |
|---|---|
| • Christopher M. Fellows | Phd, physical chemist |

## 1 SIGNATORY FROM SERBIA

**1 Signatory**

| | |
|---|---|
| • Ivan Stefanovic | Curator of collection, Faculty of Mining and Geology, University of Belgrade |

## 2 SIGNATORIES FROM SINGAPORE

**2 Signatories**

| | |
|---|---|
| • Andrew Frazer | offshore drilling, earth sciences and renewables |
| • Dr. Lars Schernikau | Energy Economist, Entrepreneur & Author |

## 1 SIGNATORY FROM SLOVAKIA

**1 Signatory**

| | |
|---|---|
| • Boris Divinsky | MSc, freelance researcher in geography, demography, and migration issues |

## 4 SIGNATORIES FROM SLOVENIA

**4 Signatories**

| | |
|---|---|
| • Borut Bohanec | Emeritus Professor of Biotechnology, active to explain major missinterpretations of scientific discoveries |
| • Tadej Ian | MA, owner of a green-roof business, political publicist/columnist, and expert in international relations |
| • Ján Lakota | MD, PhD molecular biology |
| • Rafael Mihalič | Professor of Electrical Engineering, University of Ljubljana |

## 13 SIGNATORIES FROM SOUTH AFRICA

**13 Signatories**

| | |
|---|---|
| • Dr. Henrique J.S. de Barros Pinheiro | Geologist, Invited Associate Professor, Universidade Fernando Pessoa, Porto, Portugal |
| • Rosemary Falcon | Emeritus Professor Clean Coal Technology Research Group at the University of Witwatersrand, Director Fossil Fuel Foundation |
| • Dennis Shaun Garisch | BSc (Civil) Eng, Professional Engineer registered with Engineering Council of South Africa (ECSA), over 30 years of practice, inclusive of many storm water management designs |
| • Dr. Hans Hofmann-Reinecke | nuclear physicist, author of several books “Grün und Dumm”, articles an videos on global warming and alternative energies for the general public |
| • Rob Jeffrey | Economic Risk Consultant: Senior Economist and Managing Consultant, leading expert in energy and electricity |
| • Kelvin Kemm | PhD, Nuclear Physicist, CEO Nuclear Africa, Pretoria |
| • Dr. John Ledger | Visiting Associate Professor at the University of the Witwatersrand, Energy and Environmental Consultant, Consulting Editor, Freelance Writer, Editor and Lecturer |
| • Prof. Richard Meissner | Associate Professor, Department of Political Sciences, University of South Africa |
| • Don Mingay | Retired Professor of Nuclear Physics |
| • Professor Martin R. Sharpe | PhD from University of Exeter, retired Geologist, Geochemist, Analyst and Field Mapper at University of Pretoria, Founder of geological consulting and exploration companies |
| • Grant Son | PhD in Natural Science |
| • Jacques Theron | Retired Veterinarian |
| • Geert F de Vries | Retired physicist / nuclear engineer |

## 2 SIGNATORIES FROM SOUTH KOREA

**1 WCD Ambassador**

| | |
|---|---|
| • Dr. Seok Soon Park | Professor of Environmental Science and Engineering, Ewha Womans University, Seoul, Founder of the Climate Truth Forum |

**1 Signatory**

| | |
|---|---|
| • Zonghie Han | economist at Daegu University |

## 22 SIGNATORIES FROM SPAIN

**1 WCD Ambassador**

| | |
|---|---|
| • Blanca Parga Landa | PhD, Modelling Expert, specialist in Environmental Law |

**21 Signatories**

| | |
|---|---|
| • Bernardo Armero | Engineer and Project Leader within Clean Aviation |
| • Raquel Barquero | PhD, lifetime career as nuclear engineer and medical physicist in Valladolid University Clinical Hospital |
| • Dr. Saúl Blanco | Associate Professor of Ecology at the University of León |
| • Ferran Brunet | Professor on the European Economy, Unniversitat Autònoma de Barcelona |
| • Antonio de la Hoz | BSc in in Business and International Economics, activist and expert in economics and political implications of causes and consequences of climate change |
| • Aitor Ercilla | climate historian and computer scientist. Researches the importance of climate change in social processes |
| • Maria Teresa Estevan Bolea | Engineering award 2019 Royal Spanish Academy of Engineering, World Award 2018 In Engineering WFEO, National Prize in Industrial Engineering 2019 |
| • José-Ramón Ferrandis | Analyst, Writer, Communicator |
| • Juan Miguel Gómez Menor Robles | PhD in Biology (Botany), High School Head of Department. |
| • Antonio J. Huertas | Engineer with 35 years experience in Energy Politics and Operation, and Environmental Care |
| • Isabel López García | PhD on Chemical Engineering, Assistant Professor of Physical Chemistry and applied Thermodynamics , University of Córdoba |
| • Alexander Keith Martin | PhD Geology and Geophysics, Consultant geologist |
| • Jose Manuel Miranda Lopez | PhD, Professor at the University Santiago de Compostela , Department of Analytical Chemistry, Nutrition and Bromatology |
| • Antonio Jesús Muñoz Cobo | PhD in Environmental Sciences from the University of Jaén, member of the research group Environmental Technologies of the Dept of Chemical, Environmental and Materials Engineering |
| • Luis Pomar | Emeritus Professor of the University of the Balearic Islands, Sedimentologist specialized in the study of Carbonate Rocks which the Impact of CO2 and Paleoclimate |
| • Alejandro Rodríguez-Gómez | Associate Professor, Universitat Politècnica de Catalunya, Barcelona, Spain |
| • Manuel Jesús Romero Rincón | PhD Civil Engineering, Professor at Miguel Hernández University of Elche, Spain CEO at ETRES Consultores |
| • Manuel M. Sánchez del Pino | PhD, Department of Biochemistry and Molecular Biology, University of Valencia |
| • Javier del Valle Melendo | Doctor in Climatology, Professor a Centro Universitario de la Defensa |
| • Javier Vinós | PhD, Scientist and independent climate researcher |
| • Wynn Williamson | co-founder and managing partner of real estate developer BWRE |

## 48 SIGNATORIES FROM SWEDEN

**1 WCD Ambassador**

| | |
|---|---|
| • Ingemar Nordin | Emeritus Professor Philosophy of Science, Linköping University |

**47 Signatories**

| | |
|---|---|
| • Michael Andersson | Bsc in biology, medical doctor, retired Chief Medical Officer at a battalion of the Swedish Airforce |
| • Leif Åsbrink | PhD, Technology at KTH in Molecular Physics, Stockholm |
| • Sture Åström | MSc, Technology, Professional in Climate Issues, Secretary of the Swedish Network Klimatsans |
| • Erik Axelkrans | MSc in physics and physical oceanography, University of Gothenburg |
| • Rolf Bergman | Emeritus Professor of Physical Chemistry, Uppsala University |
| • Dr. Lars Bern | Member of The Royal Swedish Academy of Sciences, Retired CEO in Incentive AB |

- Joakim Blomqvist — Sr. Design Manager for design and energy solutions within a larger construction company
- Magnus Cederlöf — Software Specialist, Stockholm
- Tore Dalväg — Msc, Physics, Research Engineer in Hydrodynamics and Thermodynamics, Senior Advisor in Environmental Standards, Author of 'CO2 a source of life or a threat'
- Hans Eklund — PhD, Technology, Acting Professor at the Department of Laser-and Electro-optics, Chalmers University of Technology, Gothenburg
- Per-Olof Eriksson — Physicist, Former CEO of Sandvik Group
- Dr. Anders Flodin — PhD, Mechanical Engineering, NC, USA
- Mats Freding — MSc Mechatronics Test team leader, environmental and software test.
- David D. Gee — Professor Emeritus Orogen Dynamics, Uppsala University
- Anders Grufman — MSE, MA, Economics, Industrial and Environmental Economics
- Jan Hagberg — PhD, Statistics, Stockholm
- Björn Hammarskjöld — MD, PhD in Biochemistry, Assistant Professor in Pediatrics
- Lars Hässler — PhD, Rock and Soil Mechanics, Bsc Chemistry and Biology, Msc Civil Engineering
- Eilif Hensvold — PhD, Mathematics, Associate Professor of Mathematics (Retired), Simulation of Large-scale Industrial Systems, Uppsala University, Luleå Technical University
- Gunnar Holmgren — PhD, Space Physics, Retired Head of Dept. of Engineering Sciences, Uppsala University
- Mats Janson — MSc, Electrical Engineering, KTH Royal Institute of Technology, Stockholm
- Hans Jelbring — Climate Researcher
- Göran Johansson — specialist in Energy Systems
- Claes Johnson — Emeritus Professor of Mathematics at Royal Institute of Technology, Stockholm
- Gunnar Juliusson — Professor of Hematology, Lund University, Senior Consultant, Skåne, University Hospital, Lund
- Sten Kaijser — Emeritus Professor of Mathematics, Uppsala University
- Johnny Kronvall Mah — Emeritus Professor in Building Physics, Malmö University and Lund University
- Lars E. Linder — Associate Professor of Medicine, Gothenburg
- Jan Lindström — Senior Medical Physicist, PhD, Former Head of Department of Medical Physics Karolinska, Worked and published in Environmental Science (Harwell UK). Long climate interest.
- Rune Lundgren — MSc, Helsinki University of Technology, Energy System Expert
- Toomas Mathiesen — MD, Retired
- Johan Montelius — Associate Professor of Computer Science at the Royal Institute of Technology, Stockholm
- Jacob Nordangård — PhD, Technology and Social Change at the University of Linköping, Researcher on Climate Change History
- Gabriel Oxenstierna — PhD, retired, currently author for Klimatupplysningen.se
- Gösta Pettersson — Emeritus Professor in Biochemistry, University of Lund
- Marian Radetzki — Emeritus Professor of Economics, Luleå University of Technology
- Mats Rosengren — Mathematics, Space Flight Trajectory Specialist
- Torsten Sandström — Professor Emeritus, Department of Law, University of Lund
- Rabbe Sjöberg — PhD, Geology, Member of Paleogeophysics & Geodynamics Institute
- Peter Stilbs — Emeritus Professor of Physical Chemistry, Royal Institute of Technology (KTH), Stockholm
- Prof. Jan-Olov Strömberg — Emeritus Professor of Mathematics at Royal Institute of Technology, Stockholm
- Lars H. Thylen — Professor Emeritus in Photonics, Dept. of Theoretical Chemistry and Biology, Royal Institute of Technology, Stockholm, specializing in Low Power Nanophotonics Technology
- Tege Tornvall — Member of Klimatrealisterna and of its election committee, active in network Klimatsans
- Gösta Walin — Proffessor Emeritus in Oceanography at Univerity of Gothenburg
- Elsa Widding — Consultant, Author on Climate Change, Stockholm

Sweden continued

| | |
|---|---|
| • Lech Wosinski | Researcher Emeritus, Associate Professor, Royal Institute of Technology, Stockholm |
| • Orjan Wrange | PhD, Emeritus Professor in molecular Genetics Karolinska Institutet, Stockholm, Sweden |

## 22 SIGNATORIES FROM SWITZERLAND

**22 Signatories**

| | |
|---|---|
| • Dr. Denis Bednyagin | researcher specialised in integrated (Energy-Economy-Environment) assessment modelling |
| • Thomas Binder | Cardiologist and Internist |
| • Majed Chergui | Emeritus Professor of Chemistry and Physics |
| • Helmut Elben | PhD in Physics, working as Strategy, Technology and IT Consultant |
| • Dr. Michael Esfeld | full professor of philosophy of science, University of Lausanne |
| • Ferruccio Ferroni | Dipl.Ing. ETH, Energy Consultant |
| • René Funk | Software Engineer, specialized in Analysing Satellite, Sea and Land Temperature |
| • Werner Furrer | MSc, Mathematics and Physics, President of the Climate Realistic Group in Switzerland |
| • Christian Jacot | Pharmacist |
| • Fabrizio Jauch | PhD Earth Sciences, Expert for the Swiss Accreditation Service for geotechnical laboratory analysis |
| • Markus D. Knecht | chemist, 15 years reserach on climate change |
| • Dr. Johannis Nöggerath | 40 years experience in Nuclear Power Engineering, Passionate amateur researcher in realistic climate science for more than 10 years |
| • Joseph Ongena | Member of the Permanent Monitoring Panel for World Energy, World Federation of Scientists, Geneva |
| • Dr. Jean-Claude Pont | Dr. Math., Emeritus Professor of The History of Philosophy of Sciences, University of Genève |
| • Dr. Franz-Karl Reinhart | Emeritus Professor of Physics, Lausanne |
| • Claude Roessiger | Entrepreneur and Author of several Books on Organizational Management and Public Policy, Organiser and Chairman of the Portsmouth Conference 2018 on Climate Policies |
| • Beat Dominic Roth | Owner Filmcompany |
| • Heinz Schmid | Dipl. Ing. Agr ETH, more than 10 years involement in climate science and climate communication |
| • Dr. Ralf Lorenz Schmitt | PhD in Chemistry, Product Manager |
| • Thomas Stadler | MSc in Physics, ETH Zürich, Geophysics, Specialty in Geothermics |
| • Prof. Dr. Eric P. Verrecchia | Professor at the University of Lausanne, Chair of Biogeochemistry at the Institute of Earth Surface Dynamics, expert in terrestrial carbon cycle of the tropical and temperate zones |
| • Dr. Eric Vieira | (retired), Ph.D (organic chemistry), 27 years at Roche Pharmaceuticals (Principal Scientist) |

## 3 SIGNATORIES FROM TURKEY

**3 Signatories**

| | |
|---|---|
| • Prof. Kerem Cankocak | Professor in Particle Physics at Istanbul Technical University, author of more than 200 books in different scientific areas |
| • Ufuk Coscun | columnist at Milat Newspaper |
| • Andrew Cullen | Ph.D Geography |

## 2 SIGNATORIES FROM UKRAINE

**2 Signatories**

| | |
|---|---|
| • Vsevolod Lozitsky | DrSci, Astronomical Observatory of Taras Shevchenko National University of Kyiv, expert in solar physics, solar activity and magnetic field, and solar-terrestrial connections |
| • Irina Vasiljeva | CSc, Research Fellow at the Main Astronomical Observatory of National Academy of Science of Ukraine, research interests include solar physics |

## 165 SIGNATORIES FROM UNITED KINGDOM

### 1 WCD Ambassador

| | |
|---|---|
| Christopher The Viscount Monckton of Brenchley | Peer of the Realm and Author of several reviewed papers on Climate |

### 164 Signatories

| | |
|---|---|
| Tom Agbabi | PhD, Professional engineer in the energy industry |
| Colin Andress | BSc Physics, MSc Astrophysics, MA (Oxon) Classics & Philosophy, Barrister, Fellow of the Royal Astronomical Society |
| Neils C. Arveschoug | Geophysicist, Private start-up Oil E&P Company |
| Nigel Banks | PhD Geology, Petroleum Geologist |
| Andrew P. Barker | Biological Chemist |
| John Anthony Barney | Retired Scientist and Technologist |
| Nik Bartley | Mechanical Engineer |
| Nigel Beckwith | professional graduate Podiatrist, Post Grad. in Sports Science, Post Grad. in Science Education |
| Alan Richard Belk | retired Mechanical Engineer with a 40+ year international career in energy, industrial gas and chemical industries |
| Roshan Bhunnoo | Mathematics and Statistics, former Climate Data Analyst at the Meteorological Office |
| Paul Binns | Former Research Geoscientist and Climate Researcher |
| David Blake | BSc Applied Chemistry, Chair of East College Group & CME Futures Trader |
| David Bodecott | Geologist/Geophysicist, Fellow of the Geological Society of London |
| Dr. Richard Booth | retired Special Merit mathematician in the UK Civil Service |
| D.Q. Bowen | Emeritus Professor of Earth and Ocean Sciences, Fellow International Union for Quaternary Research, Cardiff University |
| Dr Phillip A. W. Bratby | Physicist, Member of the Institute of Nuclear Engineers, retired energy consultant |
| Michael Brown | Expert in Large Scale Thermal Fluid Dynamic Models |
| Paul Burgess | BSc, MSc, C. Eng (retired) Hydro Climate Specialist |
| Derrick Byford | BSc (Hons) holder of 10 patents, previously Deputy Director Research & Statistics Inner London Education Authority |
| Gerry Byron | BSc in Physics, MBA which included modules on statistical anylysis |
| Peter Cale | Solicitor, co founder and fund raiser for wave energy research project as Director of Staithe Energy Products (1988 1995) |
| George Carey | BSc Hons. Physics and Geology, Lifetime Physics teacher and amateur astronomer |
| Brian R. Catt | Electrical Engineer, Retired, publishing papers on Energy and Climate Change |
| Richard Ceen | BSc Physical Oceanography with Physics, entrepreneur / engineer in Marine LNG Safety and Weather forecast dependent Optimising Voyage Control Systems |
| Arthur Champion | retired European Environmental Coordinator and CofE Diocesan Environmental Adviser |
| John Church | Earth Science Professional, Retired from Energy Sector |
| David Coe | MA(Oxon) in Physics, lifetime working on gaseous absorption spectroscopy, Lead author of "The Impact of CO2, H2O and Other Greenhouse Gases on Equilibrium Earth Temperatures" |
| Professor John C.W. Cope | Professor of Geology, National Museum Wales, Cardiff |
| Dr. Douglas Cormack | BSc in Chemistry, Maths, Physics and Microbiologyy, PhD in Physical Chemistry, Chief at Scientific Civil Service, Founder of the website "The campaign against belief consensus" |
| Richard Courtney | Retired Material Scientist, Expert Peer Reviewer of the IPCC |
| Chas Cowie | GDE Mining Engineering, Wits University, Retired IT Professional worked primarily in Mining and Logistics Industries |
| Dr. David Critchley | Senior Clinical Pharmacologist, mathematical modelling of complex systems |
| Michael Cross | Chemical Engineer |
| Peter Cunningham | Expert in Mathematical Modelling of Complex Physical Phenoma |

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| • Robert Davies | BSc Airline pilot |
| • Dr Philip George Davies | Principal Lecturer in the Department of Computing and Informatics at Bournemouth University |
| • Isabel Davies | Geophysicist and Entrepreneur |
| • Dr. Keith P. Dawson | Environmental and Agricultural Researcher |
| • Jeremy Dawson | retired Chartered Engineer with a career in the oil and gas industries |
| • John Dewey | Emeritus Professor of Geology at the University College Oxford, Distinguished Emeritus Professor University of California, |
| • Howard Dewhirst | FGS, Geologist, Initiator Open Letter to the Geological Society of London |
| • James Dillon | BSc Physics, DPhil Nuclear Physics, Former research physicist |
| • Gregor Dixon | FGS, Geologist, Former Member Geological Society of London |
| • Peter Dorey | BSc Physics, Senior Project Manager, (and unpaid educator & Climate Scientist) |
| • Timothy (Tim) C. Duckworth | Retired Mechanical Engineer in the Oil & Gas industry, Senior Auditor in Management/Facility/HSE |
| • Dr. Michael Earle | international earth scientist, energy professional, author |
| • Dr. John S. Easterby | Retired Senior Lecturer in Biochemistry University of Liverpool, Research area: Protein chemistry, Enzymology, Metabolic Modelling |
| • Roderick Paul Eaton | MBA FIET MCMI, Retired Consultant Energy Industry Analyst/ Management Consultant |
| • Debra Eddy | Entrepreneur and Guest Lecturer in Business Management |
| • Dr. Andrew Edmonds | data scientist with a strong background in AI, past CTO of a publicly traded US tech company, currently CEO of a private US company, ThinkBase LLC |
| • Peter Etherington-Smith | Geologist/Oceanographer, Coral Reef Researcher, MSc Petroleum Engineering (Imperial), life-time international experience in developing countries, retired from BG |
| • Kevin Foo | MSc, DIC, Dip. Met, AusIMM, IOM3, SME, Ch.Eng., President Tianshan Jade (UK) Ltd |
| • Ashley Francis | BSc, FRAS, Geophysicist with expertise in forward and inverse modelling, stochastic modelling and resolution/scale change impacts |
| • Sean Galbally | Project Manager Water and Wastewater Systems |
| • Kalghatgi Gauram | PhD Aeronautical Engineering, Consultant Professor, 50 Years' experience in R&D in combustion, fuels and energy |
| • Gil Gilchrist | Geophysicist |
| • Peter Gill | Physicist, Ex Chair Institute of Physics Energy Group, Ex London Branch Chair & Fellow of EI |
| • Alan Gill | Retired Engineer in South Wales |
| • Paul R. Goddard | retired Professor of Radiology, University of the West of England |
| • John D. Goss-Custard | PhD Ecology, University of Aberdeen, Visiting Professor in the Department of Life and Environmental Sciences, Bournemouth University |
| • Alastair Gray | retired geologist, 50 years in oil exploration, production and asset evaluation |
| • Delphine Gray-Fisk | Former airline pilot, and parliamentary candidate for both the UK Independence Party and Brexit Party |
| • Mick Greenway | Research and Development of Flight Control Systems for Modern Civil and Military Aircraft, Retired Head of Research and Development within a Multi-Million-Dollar Company |
| • David P. Gregg | retired Unilever Research group leader and scientist, Author of studies of historical climate time series based on modern spectral analysis techniques |
| • Brian Gregory | MA. in Natural Sciences, MSc. in Business Studies, Lifetime Career in the UK Chemical Industry, currently Policy Director of the Alliance of British Drivers |
| • Jimmy Haigh | Independent Geological Consultant |
| • Stephen Hardcastle | Retired Electronics Engineer, 10 years experience in the design of NDIR gas detectors, for gases including CFC's CO2, CH4 and N2O |

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| • David Hardy | Business Owner, Director and Experienced Chemical Engineer. 20+ years in Energy technology development including removal of pollution from conventional fossil fuel power sources |
| • Tim Harper | Geomechanics Consultant and Researcher, previous Recipient of the Royal Academy of Engineering MacRobert Award for Engineering Innovation |
| • Ken Harrison | Retired Chartered Physicist |
| • John Harrison | Former Chartered Physicist and Chartered Engineer |
| • Peter Harvey | Project Manager – Renewable offshore wind industry |
| • Raymond Hayes | BA (Lond) M.Litt (Oxon) FRGS Solicitor Hong Kong and England and Wales |
| • Robert Heath | Retired Geophysicist, Honorary member of the Indian Society of Petroleum Geologists |
| • Alex Henney | Formerly London Electricity Board, Consultant on Electricity Matters |
| • Roger Higgs | DPhil (Oxon), Independent Geological Consultant, Geoclastica Ltd. |
| • Tatiane Melchior Stefanello Hodson | Oceanographer, author, undertaking a Master's degree in International Public Policy at Queen Mary University of London |
| • Dr. Sinclair Holland | MBChB(Edin) Medical Doctor |
| • Paul Homewood | Climate & Energy Policy Analyst |
| • Keith H. James | PhD, Consultant Geologist |
| • James Barry Jamieson | Retired Aeronautical Engineer, Co-author IPCC report 1999 |
| • Anthony Janio | PhD in Physics, Independent Elected Councillor in Brighton and Hove |
| • David A.L. Jenkins | Geologist, Director Hurricane Energy plc |
| • Dr. Chris Jesshope | Emeritus Professor University of Amsterdam, Director Techne Consulting Ltd. |
| • David Jessop | C.Eng., M.I.C.E., lifetime career in the water industry |
| • Robert Jones | BSc and PhD Mining Engineering, Director at Warwick Energy |
| • Stephen Latimer Jones | BA Chemistry, IT professional |
| • Zana Juppenlatz | Consultant in environment, environmental law and sustainability, including renewable energy projects |
| • Gavin Kenny | Emeritus Professor of Anaesthesia, Intensive Care and Pain Medicine University of Glasgow |
| • John L.D. Kerr | B.A. (Hons) in Environmental Science & Technology; B.Sc. (Hons) in Chemistry, active as Environmental Consultant |
| • Stephen King | Experienced technically trained chenical engineer with experience in environmental consideration of major petrochemical projects, including technical and economic aspects |
| • David A. Kirkwood | MSc MIET,Professional engineer working in IT, Deputy Chairman of Reform UK Scotland |
| • Geoffrey W. Lane | retired Marine Engineer and Technical Author |
| • Eur.Ing Colin Leci | CO2 and Environmental Specialist |
| • Roger Longstaff | Experimental Space Physicist and Company Director |
| • Anthony Lowe | BSc Hons Polymer Chemistry and Physics, Consultant Polymer Solutions |
| • Peter Justin Lunt | MSc Geology London, adjunct lecturer in geology (stratigraphy) at Universiti Teknologi Petronas and Shandong University of Science and Technology (SDUST) Qiangdao |
| • Tom Mackay | BSc, Geologist, Fellow of the Geological Society (FGS) of London |
| • Chris MacKenzie | MSc, Director and Geological & Environmental Consultant at Peak Minerals Ltd |
| • Ian Magness | Geologist turned treasurer, Since retirement actively involved in the analysis of all aspects of climate change from a sceptical viewpoint |
| • Stephen Martin | retired exploration geophysicist |
| • Chris Matchette-Downes | Geologist and Geochemist, particularly involved in studies about past climates including glaciation |
| • William James McAuley | M.Sc. from Imperial College and an M.B.A. from Lehigh University, retired Chemical Engineer with a 40+ year international career in energy, industrial gas and chemical industries |
| • Dr. Niall McCrae | PhD in Mental Health |
| • Angela McKay | retd Mechanical Engineer in Turbine Generator Industry. Retd Head of Physics St Mary's 6th Form College, Lancashire |

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| • Dr. Euan Mearns | retired, freelance consultant, researcher, blogger and author |
| • Krov Menuhin | Expert on ocean life, underwater filmmaker, professional diver, pilot and writer, explored the Earth's extremities, experiencing the oceans and the atmosphere first-hand |
| • Geoffrey Middleton | Chartered Architect, Socal Science |
| • Terence Mordaunt | Accomplished businessman, Self taught climate scientist mentored by Professor David Bellamy |
| • Dr. William Morgan | Retired Clinician |
| • Dr. Ian Mortimore | BSc, Phd, MB, BS, FRCP, retired Consultant Respiratory Physician in the NHS with research affiliations to Edinburgh and Newcastle Universities |
| • Philip Mulholland | Geoscientist, Life time experience in the Geo-Energy Industry, co-author of the DAET climate model |
| • Stuart Munro | Exploration Geologist and Geophysicist |
| • Edward Nealon | Geologist, Member of the Australian Institute of Mining & Metallurgy |
| • Alex Nichols | BSc Geography, MSc Environmental Assessment, 27 years in sustainability consultancy, programmes and projects |
| • Blair Nimmo | Electronic Engineer, working in Computer Networking and Optical Surface Metrology and Fibre Optics |
| • Michael John Oates | Geologist, Lifetime Experience in the Geo-Energy Industry, Fellow of the Geological Society of London |
| • Gerard O'Donovan | Entrepreneur, Business Owner, career in building international and multinational organisations |
| • Andrew O'Rourke | journalist climate change |
| • Peter Owen | FGS, Fellow of the Geological Society of London |
| • Jonathan R. Partington | Emeritus Professor of Mathematics, University of Leeds |
| • Dennis Paterson | Retired Geologist |
| • Dr. James Petch | Physical Geographer, formerly Reader in Environmental Science at MMU and Head of Distributed Learning at the University of Manchester |
| • Peter Phillips | BSc Hons Mechanical Engineering, lifetime experience in the geo-energy industry |
| • Graeme Phipps | geologist and geophysicist, Jersey Channel Islands |
| • Dr. James Pindell | Geologist, specialised in plate tectonics and palaeographic evolution, Director of Tectonic Analysis Ltd (UK), Adjunct Professor at Rice University (USA) |
| • Gerry A. Quinn | Research Scientist, Ulster University, lifetime career in microbiology, biochemistry and environmentalism |
| • Clive Randle | Geologist, Fellow of the Geological Society of London |
| • Jonathan Charles Read | Honours degree in Physics from the University of Durham, member of the Institute of Physics (MInstP), Fellow of the Chartered Association of Certified Accountants (FCCA) |
| • Dr. Colin Richard Reeves | Emeritus Professor of Operational Research, Expert in Mathematical Modelling |
| • Ceri Reid | PhD Electrical and Electronic Engineering, Sonar Specialist |
| • Chris Rice | BEng(Hons) Engineering & Environmental Science |
| • Steven Andrew Richards | MSc, Retired Chartered Engineer, Retired Lecturer from Portsmouth University and Southampton Solent University |
| • Michael F. Ridd | Geologist, Fellow of the Geological Society of London |
| • Philip Risby | BSc Engineering, Retired environmental consultant, patent holder |
| • Anthony Robb | PhD, Retired Chemist |
| • Salmaan Saleem | Family Medicine Doctor |
| • Dr. José Sánchez-Morales | Doctor in Geology, analysing paleoclimate cycles and software expert |
| • Richard Saumarez | Biomedical Engineer from Imperial College |
| • Charles Savage | BA, BSc, MA (Oxon.) in Chemistry, CEO of CP Pharmaceuticals (Retired) |
| • Robert M. Schneider | MSCE, retired Civil Engineer |
| • Michael Seymour | Geologist, Fellow of the Geological Society of London |
| • Stephen Silverstein | BSc Graduate of Queen Mary University, London, in chemistry with geology |
| • Mike Sluman | Retired teacher with an honours Degree in Environmental Biology |

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|---|---|
| • Dr. Ian Smith | MSc Maritime Archaeology, PhD Chemistry |
| • Mike Stigwood | Environmental Researcher |
| • Leslie Thomson | Retired Vice President Operations, BP Exploration, Aberdeen |
| • Edwin Thwaites | Retired Principal Lecturer in Organisational Analysis and Crisis Management, University of Central Lancashire, Predton |
| • Derek Tipp | BSc honours degree in chemistry, former research chemist and retired science teacher, currently councillor on New Forest District Council |
| • David Todd | retired Associate Member of the Institute of Bankers, Post Graduate Certificate in Business and Management |
| • Paolo Emilio Trevisanutto | PhD in Physics, Senior Computational Scientist |
| • Mark Tucker | BSc of Science Geophysics, Serial Entrepreneur and Scientific Advisor to APPG for Industrial Hemp |
| • Neil Upton | Retired GP UK |
| • prof. Anton van der Merwe | MD, PhD, Professor in Molecular Immunology |
| • Matthew David Waggener | Financial professional, strategic consultant on business investments |
| • Dr. Glenn K. Wakley | Emeritus Associate Professor Biological Science, Fellow of the Royal Society of Biology and member of The Anatomical Society |
| • Professor David Wastell | Emeritus Professor of Information Systems at the University of Nottingham |
| • Paul White | B.Sc. Physics, Durham University, Retired, Former Higher Scientific Officer Marine Climatology |
| • Philip Linden Wilkes | Life time Experience in Marine Biology |
| • Jay Willis | Marine Scientist, Associate of the OxNav Group of Oxford University. |
| • Matt Wood | BSc in Metallurgy & Materials Science, Retired Airline Pilot, Patent holder |
| • Alison Wright | BSc MSc. Systems Engineer, Energy Policy, Sustainable Development policy. |
| • Valentina Zharkova | Professor of Mathematics and Astrophysics, Northumbria University, Newcastle upon Tyne |
| • Ivor Zoeftig | International communications coach specialised in chaodynamics and NLP LP |

## 441 SIGNATORIES FROM UNITED STATES OF AMERICA

**2 WCD Ambassadors**

| | |
|---|---|
| • Dr. John F. Clauser | Nobel Laureate Physicist |
| • Richard Lindzen | Emeritus Professor Atmospheres, Oceans and Climate, MIT, USA |

**439 Signatories**

| | |
|---|---|
| • Edward Abbott | MD, Retired obstetrician, BSc in math and chemistry |
| • Paul Berrick Abramson | PhD. in Theoretical (Solid State) Physics, Juris Doctor, Registered Professional Nuclear Engineer |
| • Dr. Syun-Ichi Akasofu | Professor of Geophysics, Founding Director of the International Arctic Research Center of the University of Alaska Fairbanks from 1998 until 2007 |
| • Ralph B. Alexander | Emeritus Professor of Physics, Science Writer |
| • Chapel Allen | Geophysical Engineer with 49 years experience in earth science |
| • Lincoln Anderson | Macroeconomist and Econometric Model Development |
| • Michael Anderson | BS Chemical Engineering, PhD Information Science, writes about contemporary American politics, including global warming |
| • Michael Antonetti | P.G., Professional geologist for 35+ years in Pennsylvania with Ms in glacial geomorphology |
| • Anthony J. Armini | Retired Founder and CEO Implant Sciences Corp. |
| • Bob Armstrong | MS , mathematical psychophysics |
| • Nicholas Ashcraft | Materials Science and Engineering, Wright State University. Lifetime career in the oil and gas industry |
| • Dr. Malgorzata Askanas | Senior R&D Associate at the Aurora Biophysics Research Institute |
| • Hans-Peter Bähr | Emeritus Professor of Pharmacology, Canada and Former Dean of Basic Medical Sciences, American University of Barbados, Barbados |
| • George Baker | Emeritus Professor, Applied Science, James Madison University |

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|---|---|
| • Jeffrey Baldwin | petrophysicist and rock physicist specialist |
| • Lynne Balzer | certification in Biology, Chemistry and Physics, founder of Faraday Science Institute, retired high school teacher (chemistry, physics, biology), adjunct college science professor |
| • Donna Barr | lifetime career as investigative journalist worldwide |
| • Dr. Bryan Barrilleaux | MD, Physician of Internal Medicine |
| • Joe Bastardi | Chief Meteorologist Weatherbell.com, Author: The Climate Chronicles: Inconvenient Revelations you won't hear from Al Gore and others; The Weaponization of Weather in the Phony Climate War |
| • Captain Walter Bates | Former pilot at United Airline |
| • Charles G. Battig | Climate Adviser, Heartland Institute |
| • Eric Baum | PhD in Theoretical Physics, Princeton University |
| • Trenin Bayless | PhD in Materials Science, Post-doctoral research in metallurgy, Masters degree in Biomedical Engineering |
| • Scott Beattie | Juris Doctor Degree (Law), studied history of science for 25 years and climate science for ten years |
| • James Beilman | ASBOG Licensed Environmental Geologist |
| • Dr. Ernest Calvin Beisner | Expert on the Ethics and Economics of Climate and Energy Policy, Founder and Spokesman of The Cornwall Alliance for the Stewardship of Creation |
| • Larry Bell | Endowed Professor of Space Architecture, University of Houston |
| • Frank X. Bellini | Retired Geologist and Environmental Scientist, 45 years experience in earth science research including flooding studies |
| • David J. Benard | Chemical Physicist & Co-inventor of the Oxygen-iodine Chemical Laser |
| • Haym Benaroya | Distinguished Professor of Mechanical and Aerospace Engineering, Rutgers University |
| • Dr. Shmuel Ben-Shmuel | PhD in Aerospace & Mechanical Engineering, retired aerospace engineer, worked on the Space Shuttle, doing Computational Fluid Dynamics simulations |
| • Dr. Peter R. Bergethon | retired Professor of Biochemistry, Anatomy & Neurobiology, Biomedical Engineering and Neurology, Boston and Tufts Universities. Inventor of bioelectrochemical energy systems. |
| • Robin Bernhoft | MD, FACS, FAAEM, retired liver and pancreatic surgeon, retired clinical toxicologist, author of 3 books, 28 peer-reviewed papers |
| • Edward X. Berry | PhD, Atmospheric Physicist, American Meteorological Society, Author, Climate Physics LLC |
| • Ronald Berti | lifetime career in the semiconductor industry |
| • Brent J. Bielema | studied Economics at Northern Illinois University, professional nutritional counseler |
| • Dr. David L. Black | Clinical and Forensic Toxicologist (Microbiology, Immunology, Pathology, Pharmacology), Vanderbilt University Nashville, adjunct of Department of Medicine Board of Visitors |
| • Jared L. Black | Numerical Analysis Consultant, ScD |
| • Thomas Lindsay Blanton | PhD in Tectonophysics, Texas A&M University, Consultant in geomechanics specializing in compaction, subsidence, and lithospheric stress determination |
| • Elliott D. Bloom | Emeritus Professor of Particle Physics and Astrophysics, KIPAC-SLAG, Stanford University |
| • David Boleneus | Professional Geologist |
| • Daniel Botkin | Emeritus Professor of Biology, Climate Researcher, Author of the Book: Twenty-five Myths That Are Destroying the Environment |
| • Dr. Walter Bradley | PhD, Emeritus Professor Mechanical Engineering, Texas A&M University, Baylor University |
| • Robert L. Bradley jr. | CEO and Founder of the Institute for Energy Research |
| • David Brand | PhD Biology, Immunology and Biochemistry Scientist since the early 1990's |
| • Donald Bretches | PhD Physical Organic Chemistry |
| • Dr. William Briggs | Alumnus Cornell University, Writer and Philosopher |
| • Daniel Brimhall | MS Extractive Metallurgy, University of Utah, retired Vice President Operations, American Chemet, East Helena, MT, now active as consultant |

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|---|---|
| • Clare Livingston (Bud) Bromley III | BS Natural Sciences, scientific instruments |
| • Dr. Larry Frank Brown | PhD in Range Plant Ecology (Ecophysiology) from Colorado State University (1974), President of L.F. Brown & Assoc. Inc. |
| • Joel M.G. Brown | retired petroleum engineer |
| • James Brucher | technology and business consultant for over 30-years in the telecommunications, transportation, aerospace, software, defense, manufacturing, and biotechnology industries. |
| • Gerald Brunetto | Retired after lifetime career in engineering & building nuclear & fossil fuel fired steam power plants |
| • Clifford Brust | Director of Engineering at Defense Engineering Corporation |
| • James W. Buell | PhD, Aquatic Biologist, Consultant |
| • Robert Bugiada | Senior Process Engineer at R.C. Costello & Assoc. Inc |
| • Frits Buningh | Data Research Specialist |
| • Lior Burko | PhD, Theoretical Physicist |
| • Dr. H. Sterling Burnett | PhD, Applied Philosophy with a specialization in Environmental Ethics, past Senior Fellow of the National Center for Policy Analysis, now Senior Fellow Heartland Institute |
| • David Burton | System and Computer Scientist, Expert Reviewer of AR5 and AR6, Member of the CO2 Coalition and Creator of the SeaLevel.info website |
| • Mark Shane Butler | MA in mathematics, lifetime career in data science |
| • Barry Butterfield | Civil Engineer Retired |
| • George Buzel | BS and MS Engineering, Physics and Optics |
| • Roger Caiazza | Pollution Meteorologist, life time experience in the electric generating business, retired Director of the Environmental Energy Alliance of New York |
| • Ron Cakebread | mechanical engineer with 35 years in the industrial automation business; experience in modeling, simulation, and analysis of very complex systems |
| • Sharon R. Camp | PhD, Retired Analytical Chemist and Environmental Scientist |
| • Nick Capaldi | PhD, Author Books on Logic, the Scientific Method and the Philosophy of Science |
| • John M. Cape | P.E. former military officer and economics instructor at West Point, Licensed Professional Engineer, Energy Consultant - Upstream Oil and Gas, now writing Net Zero themed novels |
| • John Carr | Electronic Engineer, specialised in antenna and satellite installations |
| • Marion G. Ceruti | PhD Chemistry, Retired Research Scientist, Space and Naval Warfare Systems Center Pacific |
| • Dr. Francis Cheng | Professor of Chemistry with specialties in carbon materials, batteries and energy conversion, University of Idaho |
| • Mitchell R. Childress | Archaeologist and Cultural Resource Environmental Compliance Specialist, Commonwealth Heritage Group |
| • Prof. Krishnan Chittur | emeritus-professor in chemical engineering and biotech, Univ of ALabama Huntsville, cofounder of medical diagnostics startup (genecapture) |
| • Terigi Ciccone | Engineer, author of “A Hitchhiker’s Journey Through Climate Change,” and a proud former Sierra Club member |
| • Prof. Claudio Cioffi-Revilla | PhD, DSc Pol, University Professor Emeritus at George Mason University |
| • Roy Clark | Climate Researcher, Retired Engineer, California |
| • Bob Cohen | Certified Consulting Meteorologist (CCM), MS in physical oceanography from Texas A&M University and a BS in meteorology from Penn State University |
| • Dr. Richard Collingham | PhD in Engineering, Professor for 16 years teaching Graduate Level Heat Transfer and Fluid flow courses |
| • David Collum | PhD in Chemistry, Professor of Chemistry (organic/organometallic chemistry) |
| • Sabin W. Colton | PhD, Biochemist and Marine Biologist |
| • Michael Combs | Major, US Air Force, Retired; Retired Lockheed Missiles and Space Company Environmental Protection Auditor |
| • Gary Cooke | MSc. Geophysical Sciences, Laboratory analyst and manager, studied sea level curves since the 1980s |

United States of America continued

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|---|---|
| • George Copeland | PhD, Electrical Engineering, Computer Architect, Software Architect, Physicist, retired |
| • Martin Cornell | Retired Senior Scientist, Dow Chemical Company |
| • David T. Cramer | MS, Instructor of Sociology and Psychology, Pratt Community College |
| • Daniel Clyde Cummings | M.D. University of Utah School of Medicine, B.A. mathematics, political advocate against all treaties and most legislative proposals to limit use of fossil fuels |
| • John Curtin | Msc in Economics, lifetime experience in strategic planning and forecasting |
| • Joseph S. D'aleo | Professor of Meteorology and Climatology at Lyndon Stage College, Founder of Icecap.us, First Director of meteorology of the Weather Channel |
| • Raphael D'Alonzo | Analytical Chemist, Retired Associate Director, the Proctor & Gamble Company |
| • Stephen Dartt | Retired from 19 years of Chemical Engineering and from 24 years of Teaching Mathematics, Physics, Chemistry & Applied Statistics. |
| • George Davey | Physicist, University of Iowa |
| • Donn Dears | GE Company Engineer, and Senior Executive, Retired, Author of 'Net-zero Carbon, The Climate Policy Destroying America' |
| • Ken DeGraaf | MSc Engineering Mechanics, Structural Dynamics, Colorado House of Representatives, USAF pilot, Instructor: USAFA AP Calc; weather for pilots, Environmental Manager, Michigan ANG |
| • James DeMeo | PhD, Retired Expert in Earth and Atmospheric Science, Oregon |
| • David Deming | Professor of Arts & Sciences, University of Oklahoma |
| • Maaneli Derakhshani | Ph.D in theoretical physics and philosophy of physics, Postdoctoral researcher in theoretical physics and philosophy of physics at Rutgers University--New Brunswick |
| • William Robert Detzner | retired special education teacher, fighter agains the continuing reduction of personal freedom |
| • David Dilley | MSc, Meteorologist-Climatologist-Paleoclimatologist, CEO Global Weather Oscillations Inc. |
| • M.D. Robert G. Dillon | retired physician and astronomist |
| • Robert G. Dodge | Attorney |
| • Pedro Domingos | Emeritus Professor of Computer Science and Engineering, leading AI researcher |
| • Terry Donze | BS-Geological Engineering, Lifetime Career in Geophysical Consulting |
| • Michael Down | Petroleum Engineer, lifetime experience in the geo-energy industry |
| • Jack D. Downing | Geologist and Geophysicist |
| • Gordon A. Dressler | MSc, 36-year professional career as a rocket and spacecraft propulsion engineer, awarded six patents in the field of rocket propulsion |
| • Paul Driessen | Senior Policy Advisor, Committee for a Constructive Tomorrow (CFACT) and Congress of Racial Equality (CORE) |
| • John Droz jr. | Physicist, Founder of AWED Alliance |
| • Dr. William DuBroff | PhD Metallurgy, Former Director of Research Inland Steel, Former Asst. Professor Clemson University |
| • John Dueker | MBA University of Houston, BSEE University of Notre Dame, 45 years of experience in environmental permit compliance |
| • Murray Duffin | BScEE, MBA, former Corporate Vice President for Total Quality and Environmental Management, Retired |
| • John Dale Dunn | MD, JD, Lecturer Carl R. Darnall Army Medical Center, Fort Hood, Texas |
| • Jack Edwards | AI research and development (Retired) |
| • Stephen Einhorn | MSc in Chemistry, author of Climate Change: What they Rarely Teach In College |
| • Guy Ellison | Second generation oil and gas explorationist |
| • Prof. James E. Enstrom | PhD, MPH, FFACE, Retired UCLA Research Professor in Epidemiology, President of the Scientific Integrity Institute, Los Angeles |
| • Kenneth Epperson | Nuclear Engineer |
| • Richard G. Eramian | BA in mathematics and physics |
| • Willis Eschenbach | Generalist and Author of many (peer-reviewed) critical Climate Articles with numerous Citations |

- Vincent Esposito — Adjunct Professor University of Pittsburg, PA, Doctor of Science in Nuclear Engineering (Un. Fo Viginia), Retired Manager from Westinghouse Electric Company
- Douglas Fairobent — Retired Physicist trained in Condensed Matter Theory, PhD (Physics), University of Michigan, 1978
- Dennis Falgout — BS chemistry, MSE air pollution measurement, PhD Photochemistry, Consulting environmental engineer
- Peter Farrell — Fellow of the US National Academy of Engineering
- Ralph English Fisler — professional aerospace engineer
- Edward Patrick Flaherty — American lawyer based in Geneva, litigating against the UN, WMO, WIPO and other IOs on behalf of staff members, whistleblowers and injured third parties
- Rex Fleming — Research Scientist, Author of Book on Carbon Dioxide Fallacy, Retired President Global Aerospace
- Jim Folcik — Geosciences Manager Extraction Oil & Gas
- William Foley — BS and MS in Geology, University of Kentucky, 30 plus years in the energy industry, including experience in uncertainty and probability analysis.
- James Forensky — B.S.E.E. , M.D. Retired Engineer and Physician
- John Fortier — Vice President of Geology/Geophysics
- Dr. Geoffrey Q. Fox — Geoffrey Q. Fox, Retired Neuroscientist, PhD in Anatomy and Physiology from the University of California, Berkeley
- Dr. Neil Frank — Lifetime of Experience in Research and Forecasting in Tropical Meteorology, Former Director National Hurricane Center
- Patrick Frank — PhD, SLAC National Accelerator Laboratory, Stanford University
- Gary Freeman — PhD, Water Resources, President, River Research & Design, Inc
- Robert S. (Steve) Friberg — Trend Resources LLC, Resources Exploration Geologist with +55 years of experience in the geological sciences field
- Gordon J. Fulks — Astrophysicist, Board of Directors CO2 Coalition, Co-founder Global Warming Realists
- S. Fuller Hunt — Biology Teacher at Preparatory High School of Mathematics, Science, Technology and Careers, Calabash, North Carolina
- Lynn Warren Funk — accelerator physicist, climate realist
- Terry Gannon — Physicist, Retired Semiconductor Executive
- Dr. Philip Garrou — PhD Chemistry 1974 Indiama Univ. Retired Director of Technology at Dow Chemical’s electronics division. Serves DARPA and the DoD as a microelectronics subject matter expert (SME)
- Louis Genevie — PhD, Epidemiologist, www.LitStrat.com
- Nicholas de Gennaro — PhD, PE, Coastal Engineer, Southport North Carolina
- Prof. Lee C. Gerhard — PhD. in Geology, Retired Getty Professor of Geological Engineering from the Colorado School of Mines and Retired Director and State Geologist of the Kansas Geological Survey
- Ulrich H. Gerlach — Professor of Mathematics, Ohio State University
- Thomas A. Gilliam — PhD, Professor of Accounting, Retired
- Alan Glabe — PhD Organic Chemistry, University of California, Retired
- Dr. William Glassco — PhD in Medicinal Chemistry, former researcher, currently Instructor
- Curtis Fred Goddard — Retired Geologist
- Dr. Indur M. Goklany — Science policy advisor in the US Dept of Interior, Co-developed the work plan for the IPCC’s 1st, 2nd, 4th Assm. Reports, Expert Reviewer for several IPCC reports
- Dr. J.D. Gold — lifetime experience in Clinical Psychology; worked in the frontlines of the war against the madness of terrifying people
- Leo Goldstein — MSc in Mathematics, lifetime experience in computer software, computer networks and cyber security. He is also a successful author and start-up founder
- Timothy W. Gordon — Retired USAF/USN Veteran, Independent Researcher
- Derek Gordon — CEO HTS Engineering
- Steve Goreham — Executive Director, Climate Science Coalition of America
- Laurence I. Gould — Professor of Physics, University of Hartford, Past Chair, New England Section of the American Physical Society
- Ronald Graham — Retired Scientist in Physics, Chemistry and Complex Modeling

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|---|---|
| • Jim Granato | Dean of the Hobby School of Public Affairs, University of Houston, lifetime career in research methodology |
| • William Griffin | Staff Oceanographer US Naval Forces Korea |
| • Charles F. Gritzner | PhD, Professor Emeritus of Geography, author of the book “Changing Climates” (2010) |
| • Mike Gruntman | Professor of Astronautics, Space Physics and Space Technology, Space and Rocket History, University of Southern California |
| • Thomas Gyorog | P.E., Project Manager and Designer of transportation infrastructure projects |
| • Kenneth Haapala | President of the Science and Environmental Policy Project (SEPP), Contributor to the NPCC reports. Energy and Economics Modeler |
| • Kent Halac | BS Mechanical Engineering, Masters Nuclear Engineering, Executive Masters of Technology Management, Commercial Nuclear Power (Carbon Free Energy) |
| • Stephen Hallin | Retired from Atmospheric Science (BA 81 MS 91) |
| • Dale B. Halling | BSEE, MS Physics, JD, Retire Patent Attorney |
| • Lyle W. Hancock | Professional Mathematician |
| • Kip Hansen | Independent Science Research Journalist |
| • Dr. William Happer | Professor Emeritus in the Department of Physics at Princeton University |
| • Brett T. Harding | Materials Scientist in Sustainable Technology, over 20 granted patents in nanoceramics, OLED, photocatalyst, optical devices, and related materials |
| • Steven Harford | PhD chemistry and lifetime career in renewable energy and aerospace research |
| • Richard Harris | PhD, atmospheric physics and chemistry as applied to radiation transport modeling, laser propagation, high power microwave propagation |
| • Ilana Harrus | PhD Physics, MS In Information Systems, Former Senior Research ScientistSenior Research Scientist NASA Goddard Space Flight Center |
| • Korbi Hart | Marketing Director Inland Crude Purchasing |
| • Peter J. Hatgelakas | Masters in Petroleum Engineering, petroleum geologist, geophysicist, and petroleum engineer at Hatgelakas Consulting |
| • Bryan Haycock | PhD, Adjunct Faculty at a University in the state of Utah |
| • Howard C. Hayden | Emeritus Professor of Physics, University of Connecticut |
| • David Heald | Retired Electrical Engineer |
| • Donald R. Healy | BS, Degree in Forest Management from Oregon State University, Participated in Anthony Watts’ first Surface Station Project |
| • Dennis E. Hedke | CEO-Hedke Geoscience Consulting, LLC, presented the 2018 testimony on Seal Level Rise before the Committee on Environmental Protection of the New York City Counsil |
| • Tony Heller | Geologist, electrical engineer, climate communicator at realclimatescience.com |
| • Edward G. Helmig | Environmental Engineering Professional in the field of Industrial Water Treatment and Environmental Protection |
| • Oliver Hemmers | Retired Executive Director of the Harry Reid Center at the University of Nevada, Las Vegas |
| • James D. Henry | Consulting Geologist, BS Geology, U Texas Austin, 1970, founder of Old Aulacogen, L.P. in 1991 |
| • Glenn C. Hillam | Big Data Architect/Scientist |
| • Gary L. Hoe | PE, Retired Colonel USAF, Technical Director of several Nuclear Weapon Effects Tests at the Nevada Test Site, Member Scientists for Accurate Radiation Information (SARI) |
| • Aaron Hogue | PhD, Associate Professor, Department of Biological Sciences, Salisbury University |
| • Jim Hollingworth | Social Scientist, Book: ‘Climate Change: A Convenient Truth’ |
| • Dr. Gary M. Hoover | Geophysicist, Lifetime Experience in the Geo-Energy Industry, Retired Member Board of Directors Geo-Service Company |
| • Christopher Paul Horger | lifetime experience in optical network design |
| • Jerry C Hornbuckle | Retired Rocket Scientist |

- Walter Horsting — Energy Expert, CEO of Global Village Utilities, Large Technology Projects Developer for 4th generation Thorium applications.
- Captain Thomas C. Houghton — USNR (Rtd), Qualfied Nuclear Engineering Officer; Sr. Director, Reactor Programs, Nuclear Energy Institute
- J. Stephen Huebner — PhD, Retired Research Geologist, U.S. Geological Survey
- Edward Huff — PhD, Retired NASA Senior Scientist
- John Hunt — MD, pediatrician, former tenured Associate Professor of Pediatrics, medical missionary, patent holder, and writer about contamination of science by politics
- Richard W Hurst — PhD, Emeritus Professor of Forensic Environmental Geochemistry and Planetary Sciences, California State University, Los Angeles
- Kanzan Inoue — MS & PhD in Physics, President & Physicist of Exponential Future LLC
- Gamaliel Isaac — PhD, Retired senior software engineer of the Department of Radiology of the Hospital of the University of Pennsylvania
- William Ivers — PhD Scripps Oceanography, ocean current computer modeler, software designer, entrepreneur, economist, artificial intelligence innovator
- Jim Janota — Developing and improving petroleum based Chemicals, Plastics and applications
- James Jaskie — Career in renewable energy, over 50 patents in solar cells and other solid-state devices.
- Laurence N. Johnson — Lt Col, USAF (Ret), MS in meteorology, MSE in aerospace engineering
- Randy Johnson — Retired VP of Engineering and Geoscience Technology at two Fortune 500 independent oil companies
- Stephen Albert Johnston — BS Molecular Biology, Phd Genetics, Phd Plant Breeding/Genetics, Postdoc Biochemistry, CEO, CSO Inventor
- John Joyce — Climate Narrative Challenger
- Walter Kailey — BA Physics with Honors, PhD Astronomy, Physicist, Inventor and high performance Computing Specialist
- Dr. Thomas J. Karr — PhD physicist, Retired Principal Director in the U.S. Office of the Undersecretary of Defense for Research & Engineering
- James Kelly — PhD Physics, data science executive
- Kerry Kelly — Geology degree, Energy and Environment Professional
- Kathryn E. Kelly — President Delta Toxicology
- Michael L. Kelly — US Navy, BS, Tool Design Engineer (retired)
- Hugh Kendrick — PhD, Retired Director Plans and Analysis, Office of Nuclear Reactor Research, US Dept. of Energy, Fellow American Physical Society
- Robert Kernodle — independent researcher in public health issues.
- Kevin T. Kilty — Adjunct Prof. Mechanical Engineering at University of Wyoming
- Fred Kinsley — Retired Geologist (MSc)
- Kevin Kirchman — Editor of the Climate Science Journal, more than a decade in renewable energy engineering
- Floyd Lee Knapp — BSc Portland State University, 300 level Geography and Climatology
- Stephen C. Knowles — Marine Scientist and Geologist, Beacon, New York
- Kenneth D. Kok — retired Nuclear Engineer, ASME Fellow, Past Chair of the ASME Nuclear Engineering Division and the ASME Energy Committee
- Mark Konya — B.S. Ed. Mathematics, B.S. Physics, M.S. Nuclear Engineering, M.A. Physics
- Alex Kozinski — Retired Judge on the US Court of Appeals
- Wayne P. Kraus — Member American Institute of Chemical Engineers (AIChE)
- Kirk Laird — retired Oceanographer and Meteorologist (US Navy), Geologist with US Bureau of Land Management
- Richard Lambert — Retired Program Director for the Physical Oceanography Program at NSF: Tropical Ocean/Global Atmosphere (TOGA), and World Ocean Circulation Experiment (WOCE).
- Richard Lang — MSc Geophysics
- Prof. Donald Langmuir — PhD, Emeritus Professor of Geochemistry, Depts. of Chemistry, Geochemistry, and Environmental Sciences, Colorado School of Mines. Consultant and President of Hydrochem Systems Corp
- Dirk van Leenen — Doctorate in Horticulture, Author of 5 books latest title: The Nonsense of Global Warming and Climate Change

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| • David R. Legates | PhD, Retired Professor of Climatology in the Department of Geography and Spatial Sciences at the University of Delaware, Cornwall Alliance for the Stewardship of Creation |
| • Jay Lehr† | PhD, Senior Policy Analyst for the International Climate Science Coalition, Former Science Director of the Heartland Institute |
| • David P. Lentini | Chemist and Patent Attorney, New Hampshire |
| • Dr. David H. Lester | PhD in Chemical Engineering, Advisor to allaboutenergy.net |
| • James M. Leverentz | Instructor UCI, Manager, California |
| • Ulf Lindqwister | PhD theoretical particle physics, Princeton University, Business executive with 30+ years of industry experience |
| • Harry Lins | PhD, U.S. Geological Survey (Retired), Past-President, Commission for Hydrology, World Meteorological Organization |
| • Ramon Lopez | PhD, Distinguished Professor of Physics, expert in space physics and space weather modeling, |
| • Howard R. Lowe | Prof. Eng., Geologist |
| • Ronald J. Lukas | BS-Physics, PhD-Biophysics; Founder and CEO, Molecular Matters AZ |
| • Anthony Lupo | PhD Atmospheric Science, Professor of Atmospheric Science, University of Missouri |
| • Dean Lusby | IT professional, business owner, Pennsylvania |
| • James MacNeal | Specialty Gases Chemist |
| • Frank Madarasz | Ph.D. (Ret) Condensed Matter Theoretical Physics |
| • Michael Maguire | Meteorologist/Scientist/Trader at MarketForum |
| • Jeffrey Mahn | Retired Nuclear Engineer Sandia National Laboratories (New Mexico), Member Scientists for Accurate Radiation Information (SARI), Member Nuclear Society (ANS) |
| • Matt Malkan | PhD, Distinguished Professor of Physics and Astronomy, UCLA |
| • Michael Maller | Professor Emeritus of Mathematics, Queens College, CUNY |
| • John Maney | Doctorate in Analytical Chemistry, career in environmental sampling, analysis and data quality |
| • Wally Manheimer | Retired from the US Naval Research Lab and life fellow of APS and IEEE, Author of “Mass Delusions, how they harm sustainable energy, climate policy, fusion and fusion breeding” |
| • Prof. Paul Manner | MD FRCSC, Joint Replacement/Hip and Knee Arthritis, Department of Orthopaedics and Sports Medicine, University of Washington |
| • James A. Marsh | Emeritus Professor of Immunology, Cornell University, Dept. of Microbiology and Immunology |
| • David Martinovich | General Science Teacher, grades K-12, United States, China, and Belize |
| • David Matthews | BS Meteorology and Oceanography, MS PhD Atmospheric Sciences, Manager, River Systems and Meteorology Group, Bureau of Reclamation, US Department of the Interor (Retired) |
| • John Mauer | PhD in Atomic and Molecular Physics, 20 years experience as a physicist, currently business owner in statistical analysis and software |
| • Kirk Maxey | BS Organic Chemistry, MD, President and Founder of Cayman Chemical Inc |
| • Donald May | BS, PhD Chemistry, Research Fellow. (Retired) |
| • Andy May | Writer and Retired Petrophysicist |
| • Gene McCall | Consultant to the Defense Science Board, Former consultant to the Department of Energy on Issues related to Inertial Fusion |
| • William McCann | PhD Seismology, lifetime career in Earthquake Hazard modeling and analysis |
| • Dr. Neil J. McCarthy Jr. | Financial Consultant at N J Mc Carthy & Assoc, PhD in Organic Chemistry Cornell University |
| • Craig McCluskey | PhD, Physics |
| • Richard McFarland | Retired NASA Physicist |
| • Sean McGrew | Analytical Chemist, lifetime career in Chromatography/Mass Spectrometry, applications to semi-volatile organic compounds in the environment |
| • Edward P. McMahon | PhD, career in remote sensing from spacecraft, and super computing analyses of physical phenomena |
| • Dr. Michael Meichle | PhD in Physics, Research Imaging Scientist |
| • Mark Meier | PhD, Professor of Physics, University of Houston |

- Samuel H. Melfi — Emeritus Professor of Physics, UMBC, Retired NASA Scientist
- Kenneth Melvin — MD, Retired Professor of Medicine, Portland, Oregon
- Dr. Daniel M. Merfeld — BSME U Wisconsin-Madison, MSE Princeton, PhD MIT, neuroscientist/neuroengineer, former Professor at the Harvard Medical School, Professor at the Ohio State University
- Dr. Peter B. Merkle — Associate Professor in environmental science and engineering at the School of Engineering at Benedictine College
- Rodney Michael — COL, US Army Medical Corps, Retired
- Patrick J. Michaels† — Competitive Enterprise Institute, Washington DC
- Michelle Michot Foss — PhD, fellow in energy, minerals and materials at Rice University's Baker Institute
- Miodrag Micic — PhD Chemistry, Professor of Engineering Design Technology at Cerritos College in Norwalk, California and Life Sciences Marketing Executive
- Edward Mickelson — Ph.D., Technology Transfer Professional, Oil & Gas Industry
- Christopher Miller — PE, CEM, CBCP, Registered Professional Engineer for the Power and Energy Industry
- Steven Milloy — MHS, JD, LLM, Publisher
- Ference M. Miskolczi — Retired NASA/AS&M Senior Scientist, Foreign Associate Member of the Hungarian Academy of Sciences
- Michael J Mitchell — Mechanical Engineer
- Guy K. Mitchell Jr. — graduate mechanical engineer and physicist with extensive research in the field of anthropogenic global warming
- Josh Mitteldorf — PhD, theoretical astrophysics, Independent scientist in computer modeling, Visiting scholar at MIT's Department of Earth, Atmospheric, and Planetary Sciences
- Matthias Mixon — BBA Degree, University of Mississippi
- MIchael Monce — PhD in Physics, Emeritus Professor of Physics, Astronomy, and Geophysics, Connecticut College
- Brian Moody — Former GET Specialist for SMS Equipment in Ft McMurray
- David Moore — PhD Physical Chemistry, Los Alamos Laboratory Fellow, lifetime career in molecular spectroscopy of materials at extreme conditions as well as trace detection of illicit materials
- James Moore — Commercial Fisherman, President Alaska Trawlers Association, Executive Committee Northern Southeast Regional Aquaculture Association, Board member Amstrong Keta Inc.
- James R. Morris — Geophysical Exploration Oil & Natural Gas
- Thomas L. Moser — Retired NASA Senior Executive, Program Manager of the Space Station and Space Shuttle, Founder of the "Right Climate Stuff", a group of former NASA Engineers & Scientists
- Steven Mosher — first American social scientist to conduct field research in China, exposed human rights abuses in China's one-child policy.
- David R. Motes — Chemical Engineer, lifelong experience in the geo-energy industry
- Steve Mroczkiewicz — PhD in entomology, Crop Protection Field Research Scientist, student of climate change and climate policy
- James F. Mundy — Retired Meteorologist
- Daniel W Nebert — Emeritus Professor of Gene-Environment Science, University of Cincinnati College of Medicine and Cincinnati Children's Hospital, Ohio
- Prof. Eric L. Nelson — PhD, Assistant Clinical Professor, Department of Public Health Sciences, University of California
- Gregg Neuendorf — Retired Chemical Engineer, Cleveland
- Danny L. Newton — Retired from Federal Aviation Administration (FAA), Experience in Working with NOAA with respect to Experimental Weather Data Collection
- Richard Nicholson — MD University Of South Alabama 1988, Family Medicine
- Ned Nikolov — PhD, Physical Scientist at the USFS Rocky Mountain Research Station in Fort Collins, CO, Managing a Fire-Weather Intelligence Project
- Paul Noel — Research Scientist (retired)
- Jesús Ochoa — MSc Earth Sciences
- Thomas O'Connor — Member American Association of Petroleum Geologists, Washington
- Sidney Oldberg — BME, MSE, MSEE

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| • Kenton Oma | Retired PE Chemical Engineer, Environmental Engineering, Environmental Consultant, R&D at DOE Nuclear Facility |
| • Jane M. Orient | President of Doctors for Disaster Preparedness |
| • Tench C. Page | MSc & BSc in Geology including study of causes and effects of earth's climatic history |
| • Steven Palmieri, Ph.D., D.O. | MSc & PhD in Chemistry, Doctor of Osteopathic Medicine, Former Chemist & Virologist, Medical Doctor - Retired |
| • Charlie Pappis | retired Semiconductor Industry Executive |
| • Trueman D. Parish | Retired Director of Engineering Research Eastman Chemical Company |
| • Arvid Pasto | PhD in Ceramics, Retired from the Oak Ridge National Laboratory, TN |
| • Chad M. Paton | PhD, Associate Professor at University of Georgia |
| • Bill Pekny | MSc Physics, Retired Atmospheric Physicist, former U.S. Navy Meteorologist and Hurricane Hunter, Author of the book: A Tale of Two Climates—One Real, One Imaginary |
| • Pawel Penczek | PhD in Physics, Retired Profesor of Biochemistry and Molecular Biology |
| • Charles W. Pennington | Senior Vice President of Engineering NAC International (Retired), Secretary, XLNT Foundation, Board of Directors |
| • Morgan Perry | MS, MBA, Founder and CEO of Stratus Aero, LLC an aviation technology company focusing on aerial directed energy for human betterment, patents in aerial directed energy. |
| • Jeffrey S. Philbin | Retired Nuclear Engineer Sandia National Laboratories, Independent Consultant in Nuclear Facility Design and Safety Analysis, Nuclear Criticality Safety and Weapon Response |
| • Dr. Robert B. Phillips | retired from radio astrophysics, specialised in calibration and validation of orbital IR and visible sensors (GOESS, STSS-1 and -2) |
| • Nina Pierpont | MD, PhD. Ecology and medicine. Author, Wind Turbine Syndrome: A Report on a Natural Experiment. |
| • James Richard Poirier | BS degree in Meteorology, Lifetime Career in Atmospheric Science |
| • James M. Policelli | Registered Professional Engineer |
| • Herman A. Pope | Retired Aerospace Engineer NASA-JSC |
| • Willem Post | Independent Researcher regarding Energy and Environment |
| • Darrell Potter | Retired Geologist/Environmental Hydrogeologist |
| • Dr. William H. Pound | PhD Major in Industrial Engineering with Minor in Materials Science |
| • Dr. Victor Privalsky | PhD in math, PhD in physics, lifetime career in applications of theory of random processes for analysis and extrapolation of scalar and multivariate time series |
| • Kenneth L. Purdy | Management Consultant, Retired Naval Officer in Operational Intelligence |
| • Dr. Marisol Quintanilla | PhD, Assistant Professor of Nematology, Michigan State University |
| • Jilong Rao | PhD in Geochemistry from Yale University… A retiree in Virginia. |
| • Michael Rath | BS in Forest Management, Michael Rath, 55 years in Forest Management |
| • Brian D. Ray | PhD in science education from Oregon State University, Salem |
| • Dr. George Rebane | Scientist with degrees from UCLA in Physics (BS) and Engineering (MSE and PhD), lectured at UCLA and California State University as an Adjunct Professor |
| • Edward A. Reid | lifetime experience in the US energy industry in technical research and development, market development, marketing and consulting |
| • Fred A. Reitman | professional career as a petroleum and petrochemical toxicologist. |
| • Forrest J. Remick | Commissioner (Retired), US Nuclear Regulatory Commission |
| • Dr. Douglas Rigby | Ph.D. in Geomechanics, B.S. in Hydrology, expertise in modeling complex phenomena under uncertainty |
| • Anthony Robledo IV | MSc, Environmental Scientist, United States Environmental Protection Agency |
| • David K. Rogers | PE, CEG MS, Geological Engineering, Member of the Boards of Consultants for the Federal Energy Regulatory Commission |
| • Dr. Jennifer Runquist | PhD from Northwestern Unv, Evanston IL related to photosynthesis |
| • Marius Russo | IT expert |
| • James H. Rust | Emeritus Professor of Nuclear Engineering, Georgia Institute of Technology |

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| • Ralph Sacrison | MSc, lifetime career in earth sciences and engineering |
| • Charles L. Sanders | Retired Radiobiologist, Author of Radiobiology and Radiation Hormesis: New Evidence and Its Implications for Medicine and Society (Springer) |
| • Rick Sanders | MA, Scientists for Accuracy in Radiation Information (SARI), Associate Editor, 21st Century Science and Technology Magazine |
| • Dr. Steven Saterlie | PhD in Physics, Chief Engineer with major corporation and author of numerous technical papers. |
| • Jeffrey Satinover | MD, PhD, research theorical physicist in unpredictability of complex systems; director of a Sterling Institute neuropsychiatric facility. |
| • Kent Satterlee | Executive Director at Gulf Offshore Research Institute (GORI) |
| • Dana H. Saylor Sr. | a lifelong agriculturalist, retired, article “Living a lifetime of climate change” |
| • Hans Schantz | PhD Physics, Principal Scientist, Geeks and Nerds Corporation, physicist, author, and inventor on over forty patents |
| • John Schell | BS Marine Biology, PhD Toxicology, Toxicologist who has participated in the assessment of environmental impacts of chemical releases |
| • Jesse Schilling | Certified Management Accountant |
| • Mike Schimmelpfennig | Degreed Mining Engineer with more than 40 years of experience |
| • Brian Schmidt | Co-Founder and Chief Visionary Officer of Primary Ocean Aquaculture division and Primary Bio Agriculture - Agriculture division |
| • Harold Grant Scoggins | retired IT professional |
| • John Seater | PhD, Emeritus Professor of Economics, North Carolina State University |
| • Mark W. Sellers | PhD Systems Science, Modeling and Analysis of Complex Systems |
| • Edwin T. Sewall | Retired BS Electrical Engineering, Southern MethodistUniversity 1960 Dallas Texas |
| • John A. Shanahan | Civil Engineer with Career in Nuclear Power, Public Education about Fossil Fuels including question of man-made Global Warming and Nuclear Power through Website: allaboutenergy.net |
| • William Sharp | PhD Applied Science, Retired. |
| • Roscoe M. Shaw | meteorologist and portfolio manager |
| • Dr. Thomas P. Sheahen | PhD in Physics at MIT, Chairman, Science & Environmental Policy Project, involved in energy-related research for 45 years |
| • Dr. Roger Sheley | Ecologist, USDA-Agricultural Research Service; Editor-in-Chief of the international journal-Rangeland Ecology and Management |
| • John D. Sheppard | MD, MMSc, FACS, Professor of Ophthalmology, Microbiology & Immunology, Eastern Virginia Medical School |
| • John Shewchuk | Meteorologist (CCM) and Atmospheric Researcher |
| • Stephen W. Shipman | Institutional Investor |
| • Ryan Shrout | Environmental Attorney with a Masters of Law in Environmental Law practicing in the air emissions field |
| • Dr. Matthew Eric Shultz | University of Delaware, Dept. of Physics & Astronomy, specialised in Stellar Astrophysics, Annie Jump Cannon Fellow |
| • David Siegel | author, entrepreneur, critical thinker, communicator |
| • Hal Simeroth | PhD in Ethics, Graduate Engineer, 45 years of research science and engineering with patents in geological logging instrumentation and geophysical exploration methodologies |
| • Benjamin Slivka | Retired, MSc Computer Science, “Angel” Investor with 20 start-ups in 56 countries |
| • Elliot Smith | airline pilot, climate realist, 30+ years of studying AGW data |
| • Robert P. Smith | PhD, PE, Environmental Scientist and Professional Engineer |
| • Robert J. Smith | Bachelor of Physics, Aircraft test and evaluation engineer |
| • Professor William H. Smith | Professor of Earth & Planetary Sciences, Astronomer and Planetary & Atmospheric Scientist, involved in the Analysis of the Earth’s Climate and Renewable Energy Systems |
| • Nicholas Smith-Sebasto | PhD, Retired Professor of Environmental and Sustainability Studies |
| • Willie Soon | Independent Scientist |
| • Prof. George Sowers | PhD, Space Resources, Colorado School of Mines |
| • Prof. Rick Bernard Spielman | Senior Scientist & Professor of Physics, University of Rochester, Laboratory for Laser Energetics |
| • Robert M. St. Louis | MSc in geology, owner of Mine Water Consulting LLC |

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|---|---|
| • Kirk Douglas Stahnke | MS Educ. Prof of Design Tech (Retired), Independent Climate Researcher |
| • Walter Starck | PhD, Marine Science, Pioneer in Coral Reef Studies, Policy Advisor to The Heartland Institute |
| • Jess L. Stark | Founder and CEO of Stark Industries, Houston, Texas |
| • Doug Stearns | PE, Natural Gas Consultant |
| • Jim Steele | Emeritus Director Sierra Nevada Field Campus, San Francisco State University |
| • Phil Stegemoeller | Professional Forester, Partnership with the Quinault Indian Nation, a BS in forest management at the University of Minnesota, 1979 |
| • Ronald Stein | Professional Engineer, Policy Adviser to Heartland Institute on Energy, and Co-Author of the Amazon 5-Star rated books “Energy Made Easy” and “Just GREEN Electricity” |
| • Kenneth S. Stevens | PhD, Professor, University of Utah, Electrical and Computer Engineering Dept |
| • Brent K. Stewart | PhD, Professor Emeritus, Radiology, University of Washington School of Medicine |
| • Jonathan Stigant | BSc Engineering Science |
| • Kenneth Stoller | MD - Lifetime Fellow, American College of Hyperbaric Medicine, author of Incurable Me (Skyhorse 2016) |
| • David Stubbs | MSc Physics, Sr. Research Scientist, Aerospace Materials and Nondestructive Testing, Retired |
| • Gerald M. Sulzer | MS Chemical Engineer, Retired Director of Technology, Albemarle Corporation |
| • Soames Summerhays | Marine Biologist, Film Maker |
| • Dr. Daniel P. Taggart | PhD in Experimental Plasma Physics, life time career in Controlled Thermonuclear Research and Radiation Protection at Los Alamos National Laboratory |
| • Tomer D. Tamarkin | Physicist, Founder and President/CEO of Energycite Inc., President and Chairman of ClimateCite Inc. |
| • Paul Taylor | Energy Economist, Recipient Rossitor Raymond Award, Golden Colorado |
| • Bradley Thomas | M.A. Air Pollution Meteorology |
| • Francis Thompson | Space Vehicle Engineer, Masters in General Relativity |
| • Edward Thompson | PhD, DIC, Mechanical Engineering , retired |
| • David E. Thompson | Professor Emeritus Mechanical Engineering and Computer Science, Dean Emeritus College of Engineering, University of Idaho |
| • Roane Thorpe | BSME California Polytechnic, MBA University of California, lifetime career in global energy projects |
| • Gordon Tomb | Energy and climate writer, communications consultant, primary editor of Inconvenient Facts and Senior Advisor for the CO2 Coalition |
| • Cecil Joe Tomlinson | Retired Boeing Senior Principle Engineer |
| • Frank Trask | BS Degree in Mechanical Engineering, University of Maine |
| • Kip Trout | Lecturer in Physics, The Pennsylvania State University – York Campus |
| • Karl Michael Frederick Truitt | BSEE, IEEE, US Veteran, 6 US Patents, Climate Data Researcher, Host of the The Climate Change Hoax Podcast |
| • Richard Trzupek | Chemist and Air Quality Expert |
| • Mark Twaalfhoven | Executive CEO Technology Companies |
| • Mark Ulmer | Esq., Mayor of Miami Shores, Florida, 1999-2001 |
| • Peter Villucci | MSc. Organic Chemistry, Lifetime science and communications professional |
| • Arthur Viterito | PhD, Physical Geography, Policy Adviser to the Heartland Institute |
| • Dariusz Vogelsinger | Psychologist |
| • Brian Volkman | PhD, Professor of Biochemistry, Medical College of Wisconsin |
| • Whitson G. Waldo | Scientist and Engineer with MS Chemical Engineering from Clemson Univ, lifetime career in the semiconductor industry, owner of 13 awarded patents |
| • William B. Walters | Guggenheim Fellow, Professor of Atmospheric, Nuclear and Environmental Chemistry, University of Maryland |
| • James Wanliss | Professor of Physics, Presbyterian College |
| • R. Peter Weaver | lifetime career in energy, energy policy and sustainable operations |

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|---|---|
| Robert Webster | More than 65 years of interest in Meteorology and Climatology, Author of "Looking Out the Window", an evidence based defense of CO2 charged with being a climate change force |
| Steven E. Weismantel | Retired Engineer and Climate Researcher |
| Isaac William Wells | Lawyer in International Law and Foreign Affaires |
| Dr. Steven C. Wendelken | EPA, OGWDW/TSC, climate realist |
| Gary S. Westerman | PhD, physical geography with specializations in climate science and remote sensing |
| Stephen H. Westing | PhD, Director Medical Affairs, Regeneron Pharmaceuticals, Inc. |
| Jim Whiting | MD from McGill U, Montreal, Fellow of the American College of Radiology |
| Dr. Matthew Wielicki | PhD in Geochemistry from UCLA, Assistant Professor of Geological Sciences at the University of Alabama |
| Chuck F. Wiese | Professional Meteorologist |
| David Williams | PhD, University Distinguished Professor Emeritus, Oregon State University |
| Brock Williams | PhD, Lifetime research scientist with subjects from molecular to population pathology with a special interest in immunopathology and atopic disease |
| Jeff Wilmer | B.Sc. Physics, Post Undergrad Studies: Atmospheric Physics & Chemistry, Industrial Capitalist and Innovator |
| Steven Wilmoth | Certified Petroleum Geologist |
| Kevin Wilson | PhD in Geological Sciences, Retired, former Professor and Researcher on Plate Tectonics, Paleoclimate and Paleoceanography |
| Terry Winters | PhD in Chemistry, Writer, Member of CO2Coalition |
| David Wojick | Cognitive Scientist |
| Dr. Calvin M. Wolff | Adjunct Professor University of Houston at Clear Lake, Expertise in Energy Management |
| Michael Wood | BSChE, MBA; former lead technical engineer in development of space station and space launch vehicles |
| Peter Wood | PhD, President, National Association of Scholars |
| Gregory R. Wrightstone | Expert Reviewer IPCC, Geologist, Author, Executive Director CO2 Coalition |
| Walter Yarbrough | PhD, retired from Penn State |
| Frank Yates Jr | Past President of Yates Petroleum Corporation |
| Dan Youra | publisher Youra media, creator and editor of Carbon Tax News |
| Ronald B. Zelt | Hydrologist, retired PH-WQ., U.S. Geological Survey (retired). |
| Matthew Ziska | PhD, Director of Environmental Health and Safety at Elevation Labs |
| Hannes Zuercher | PhD Geophysics, Independent Geophysicist |
| Bob Zybach | Program Manager, Oregon Websites and Watersheds Project Inc. |

## 1 SIGNATORY FROM VIETNAM

**1 Signatory**

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|---|---|
| Dr. Thi Thuy Van Dinh | PhD in Law, Master in environmental law, University of Limoges, former official of the UN Secretariat |

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# OPEN LETTER SENT TO LEEDS CITY COUNCIL – CLIMATE EMERGENCY

Dear Councillor,

**OPEN LETTER - "CLIMATE EMERGENCY" and NET ZERO POLICIES**

## 1. Background

As you will no doubt be aware, on 27th March 2019, Leeds City Council passed a motion to declare a *"climate emergency"* in Leeds. In the said motion, Leeds City Council resolved, inter alia, to *"Sign up to a science-based carbon reduction target that is consistent with achieving the Paris Agreement of no more than 1.5°C global temperature rise."* (https://democracy.leeds.gov.uk/documents/b20549/Supplement%20for%20White%20Paper%20motion%20in%20the%20name%20of%20Councillor%20Judith%20Blake%2027th-Mar-2019%2013.00%20Counc.pdf?T=9

On 24th March, 2023, a Freedom of Information Request ("FOIR") (which was later deemed to be an Environmental Information Regulations Request ("EIRR")) was sent to Leeds City Council requesting, inter alia, the following:

1. Leeds City Council's definition of *"climate emergency"*; and
2. The evidence, data, correspondence or other documents in support of Leeds City Council's decision to declare a "climate emergency".

Leeds City Council, in their response to this FOIR, were unable to provide the definition of *"climate emergency"* as requested pursuant to 1) above; and with respect to 2) above referred me to *"A Net-Zero Carbon Roadmap for Leeds"*. (https://leedsclimate.org.uk/sites/default/files/Net-Zero Carbon Roadmap for Leeds.pdf) https://www.leedsclimate.org.uk/sites/default/files/Net-Zero%20Carbon%20Roadmap%20for%20Leeds_0.pdf

## 2. Leeds City Council evidence in support of the declared "climate emergency"

In the document, *"A Net-Zero Carbon Roadmap for Leeds"* (the "Roadmap"), which you are relying upon to support your motion to declare a hitherto undefined *"climate emergency"*, the claims below are made (emphasis my own).

2.1 *"Climate science has proven the connection between the concentration of greenhouse gases in the atmosphere and the extent to which the atmosphere traps heat and so leads to global warming. The science tells us –* ***with a very high level of confidence*** *– that such warming will lead to increasingly severe disruption to our weather patterns and water and food systems, and to ecosystems and biodiversity. Perhaps most worryingly, the science predicts that there* ***may*** *be a point where this process becomes self-fuelling, for example where warming leads to the thawing of permafrost such that significant quantities of greenhouse gases are released, leading to further warming. Beyond this point or threshold, the evidence* ***suggests*** *that we* ***may*** *lose control of our future climate and become subject to what has been referred to as dangerous or "runaway" climate change."*

2.2 *"Until recently, scientists* ***felt*** *that this threshold existed at around 2ºC of global warming, measured as a global average of surface temperatures. However, more recent scientific assessments (especially by the IPCC in 2018) have suggested that the threshold should instead be set at 1.5ºC. This change in the suggested threshold from 2ºC to 1.5ºC has led to calls for targets for decarbonisation to be made both stricter (e.g. for the UK to move from an 80% decarbonisation target to a net-zero target, which it did in 2019) and to be brought forward (e.g. from 2050 to 2030), which the UK has not done, although many local authorities, particularly C40 cities, and other places have set themselves this ambitious goal."*

**3. Flawed Science: the CO2 Myth**

I will address each of the claims detailed in Section 2 above in turn.

At 2.1 the claim is made that *"Climate science has proven the connection between the concentration of greenhouse gases in the atmosphere and the extent to which the atmosphere traps heat and so leads to global warming."*

To the contrary, climate science **does not** support the connection between the concentration of greenhouse gases in the atmosphere and continued warming. In fact, it clearly shows us that, for example, greenhouse gases such as CO2 and methane are already saturated and thus not capable of continuing to warm the planet as claimed (as explained in this video: https://vimeo.com/934299121#t=0).

The work presented in the video is from two world leading scientists, one of whom has been a scientific adviser to three US Presidents. However, that appeal to authority is not evidence in and of itself rather the evidence comes from their work, which has been proven to be correct by direct observation.

At 2.1 the claim is also made that "*The science tells us – **with a very high level of confidence** – that such warming will lead to increasingly severe disruption to our weather patterns...".*

Again, climate science **does not** support such a claim. In fact, to the contrary, extreme weather has lessened as the planet warmed. The Intergovernmental Panel on Climate Change ("IPCC"), the National Aeronautics and Space Administration ("NASA"), the National Oceanic and Atmospheric Administration ("NOAA") and the UK Meteorological Office are all in agreement and conclude the same.

Indeed, Chapter 12, table 12.12, page 1856, of the IPCC Report linked here: https://www.ipcc.ch/report/ar6/wg1/downloads/report/IPCC_AR6_WGI_Chapter12.pdf *(see Footnote 1)* shows no changes, beyond naturally occurring variations, in the following: frost, mean precipitation, river flood, heavy precipitation and pluvial floods, landslide, aridity, hydrological drought, agricultural and ecological drought, fire weather, mean wind speed, severe wind storms, tropical cyclones, sand and dust storms, snow, glacier and ice sheets, heavy snow fall and ice storm, hail, snow avalanche, coastal sea level, coastal flood, coastal erosion, marine heat wave, ocean acidity, air pollution weather, and radiation at surface.

Focusing on the UK, and by way of example only, Volume 43 of The Royal Meteorological Society Journal of Climate Science Figure 51, page 42 (https://rmets.onlinelibrary.wiley.com/doi/epdf/10.1002/joc.8167) counts the number of days each year in which at least twenty UK stations recorded gusts exceeding 46/58/69 mph and notes:

*"The most recent two decades have seen fewer occurrences of max gust speeds above the thresholds than during previous decades, particularly comparing the period before and after 2000."*

The report goes on to note:

*"This earlier period [before 2000] also included among the most severe storms experienced in the UK in the observational records including the 'Burns Day Storm' of 25 January 1990, the 'Boxing Day Storm' of 26 December 1998 and the 'Great Storm' of 16 October 1987, while in the last decade the most significant major winter storms have been on 5 December 2013, 3 January 2012 and 8 December 2011 (for the latter three the strongest winds being across Scotland). Any comparison of storms is complex as it depends on severity, spatial extent and duration. Storm Eunice was the most severe storm to affect England and Wales since February 2014 but, even so, these storms of the 1980s and 1990s were very much more severe."*

There exists a significant amount of evidence illustrating that extreme weather has decreased over the last 150 years. I can provide you with a detailed evidence-based response to any claim you wish to make with regard to extreme weather eve

At 2.2, you make the claim that the threshold to avoid out of control climate change is 1.5°C yet, to date, the increase in temperature of circa 1.2°C, since the Little Ice Age, has been wholly beneficial to humanity and the planet. Are you suggesting that the people of Leeds would be better off living in the Little Ice Age with the accompanying extreme weather and famines? (It is perhaps worth noting here that with the same amount of land the world has been producing record crop yields year on year substantially helped along by the increase in plant food - $CO_2$).

It is critical to understand the distinction between modelling and observation. In science, models are nothing more than opinions - they are not evidence. For example, there are almost one hundred different climate models none of which amount to evidence. All that matters in science is evidence derived from observation.

Dangerously, climate models are being confused with evidence with respect to $CO_2$. The resulting Net Zero policies will be disastrous for the people of Leeds. Every single climate alarmist prediction, to date, has been proven to be wrong when its time came. For example, islands did not sink, they grew; polar bear numbers did not fall, they increased; the barrier reef is the healthiest it has ever been in recorded history and the Arctic ice is standing at its highest level, for this time of year, for twenty years. All of this can be evidenced by observation.

The theory of the climate alarmists, as represented by the IPCC modelling, is disproven by the observational data which proves the theory of the climate realists.

As Professor Richard Feynman said *"It doesn't matter how beautiful your theory is, it doesn't matter how smart you are. If it doesn't agree with experiment, it's wrong."*

**<u>4. Conclusion</u>**

You were unable to define *"climate emergency"* when asked. Do you not think it odd that you resolve to provide a solution to a problem you are unable to define? I'll give you a helping hand - I think what you meant when declaring a *"climate emergency"* is this: *"the earth is experiencing planet-wide increases in atmospheric temperature as a direct result of greenhouse gas emissions, in particular $CO_2$, caused by the activities and habits of humans resulting in an existential threat to the world and human life."* However, the climate science relied upon, by you, does not support the *"climate emergency"* you declared. The climate science modelling, upon which you rely, is demonstrably flawed.

Decarbonisation is evidently at the heart of your policies to reach Net Zero by 2030 so you must believe, beyond any doubt, that $CO_2$ is the cause of increased temperatures yet the Roadmap, as drafted by Leeds Climate Commission, is peppered with "may", "suggests" and "felt" which would seem to indicate that they are far from forming a conclusive position. Are you sure that the Leeds Climate Commission are the "independent voice" they claim to be? Is it possible that bias, leading to pre-determination, is built into the system?

In pursuing a "*Net Zero Carbon Roadmap for Leeds*", you are responsible for enacting policies based on modelling rather than observation i.e. flawed science with the resulting waste of hundreds of millions of pounds of financial resources; intrusion into the private lives of the people of Leeds; and, in the process, the impoverishment of the people of Leeds.

Your resolution to *"Sign up to a science-based carbon reduction target that is consistent with achieving the Paris Agreement of no more than 1.5°C global temperature rise"* has no grounding in science as has been illustrated in this letter. Your monomaniacal focus on Net Zero polices forgoes any and all considerations of costs and benefits to the people of Leeds and is thus both absurd and dangerous.

You are accountable to the people of Leeds for the policy decisions you make and you therefore have a responsibility, to the peo[illegible] fully consider the position of those scientists who provide evidence for their theories through observations. You have a duty to listen to the climate realists as well as the climate alarmists - the future well-being of the people of Leeds depends upon you doing so.

I welcome the opportunity to meet in person, accompanied by a scientist, to discuss the climate science upon the condition that the meeting be recorded.

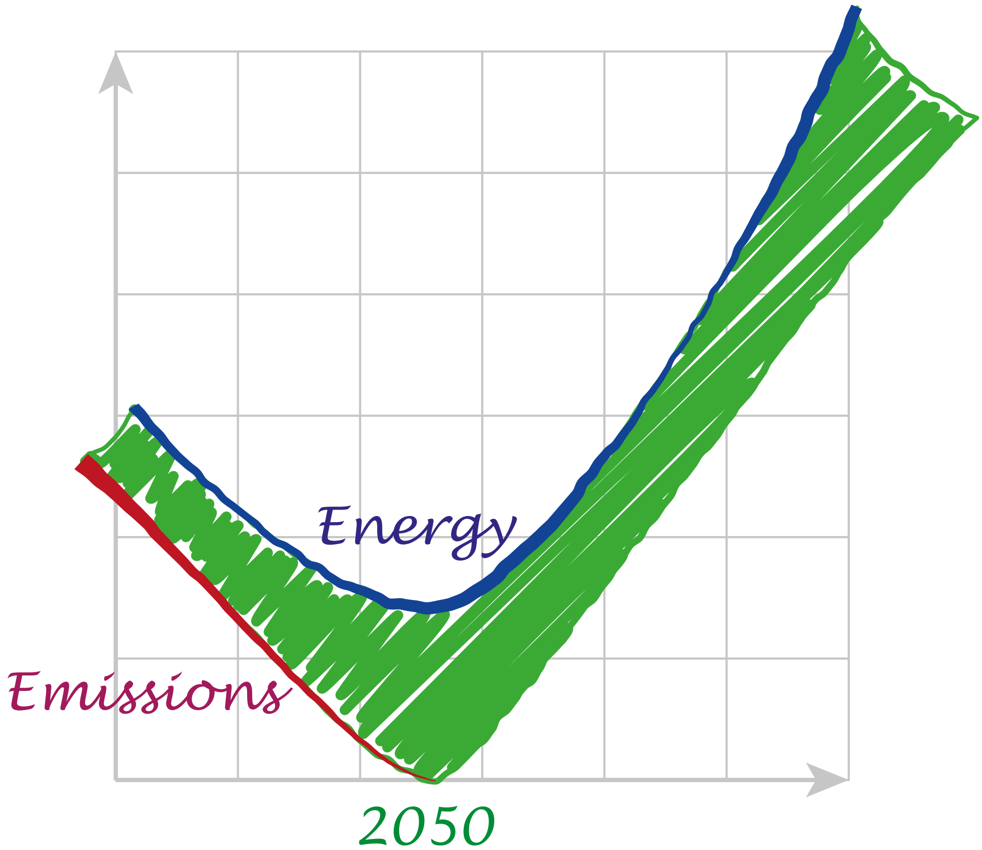
I look forward to receiving your response – you have my email address.

Your sincerely,

A very concerned citizen of Leeds.

***Footnote 1:*** Chapter 12 forms a part of the report entitled "Climate Change 2021 The Physical Science Basis" (https://report.ipcc.ch/ar6/wg1/IPCC_AR6_WGI_FullReport.pdf) which represents Working Group I's contribution to the Sixth Assessment Report of the IPCC. The Sixth Assessment Report can be reviewed in its entirety here: https://www.ipcc.ch/assessment-report/ar6/

# Absolute Zero




Delivering the UK's climate change commitment with incremental changes to today's technologies

UK FIRES

# Absolute Zero

UK demand for energy-intensive materials is growing, driving increased emissions in the UK and abroad. UK FIRES is a research programme sponsored by the UK Government, aiming to support a 20% cut in the UK's true emissions by 2050 by placing Resource Efficiency at the heart of the UK's Future Industrial Strategy.

Industry is the most challenging sector for climate mitigation – it's energy efficient and there are no substitutes available at scale for the energy-intensive bulk materials - steel, cement, plastic, paper and aluminium. UK FIRES is therefore working towards an industrial renaissance in the UK, with high-value climate-safe UK businesses delivering goods and services compatible with the UK's legal commitment to zero emissions and with much less new material production.

UK FIRES

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# Executive Summary

We can't wait for breakthrough technologies to deliver net-zero emissions by 2050. Instead, we can plan to respond to climate change using today's technologies with incremental change. This will reveal many opportunities for growth but requires a public discussion about future lifestyles.

We have to cut our greenhouse gas emissions to zero by 2050: that's what climate scientists tell us, it's what social protesters are asking for and it's now the law in the UK. But we aren't on track. For twenty years we've been trying to solve the problem with new or **breakthrough** technologies that supply energy and allow industry to keep growing, so we don't have to change our lifestyles. But although some exciting new technology options are being developed, it will take a long time to deploy them, and they won't be operating at scale within thirty years.

Meanwhile, our cars are getting heavier, we're flying more each year and we heat our homes to higher temperatures. We all know that this makes no sense, but it's difficult to start discussing how we really want to address climate change while we keep hoping that new technologies will take the problem away.

In response, this report starts from **today's technologies**: if we really want to reach zero emissions in thirty years time, what does that involve? Most of what we most enjoy - spending time together as families or communities, leisure, sport, creativity - can continue and grow unhindered. We need to switch to using electricity as our only form of energy and if we continue today's impressive rates of growth in non-emitting generation, we'll only have to cut our use of energy to 60% of today's levels. We can easily achieve this with **incremental** changes to the way we use energy: we can drive smaller cars and take the train when possible, use efficient electric heat-pumps to keep warm and buy buildings, vehicles and equipment that are better designed and last much longer.

The two big challenges we face with an all electric future are **flying** and **shipping**. Although there are lots of new ideas about electric planes, they won't be operating at commercial scales within 30 years, so zero emissions means that for some period, we'll all stop using aeroplanes. Shipping is more challenging: although there are a few military ships run by nuclear reactors, we currently don't have any large electric merchant ships, but we depend strongly on shipping for imported food and goods.

In addition, obeying the law of our Climate Change Act requires that we stop doing anything that causes emissions regardless of its energy source. This requires that we stop eating **beef and lamb** - ruminants who release methane as they digest grass - and already many people have started to switch to more vegetarian diets. However the most difficult problem is **cement**: making cement releases emissions regardless of how its powered, there are currently no alternative options available at scale and we don't know how to install new renewables or make new energy efficient buildings without it.

We need to discuss these challenges as a society. Making progress on climate change requires that the three key groups of players - government, businesses and individuals - work together, rather than waiting for the other two to act first. But until we face up to the fact that breakthrough technologies won't arrive fast enough, we can't even begin having the right discussion.

Committing to zero emissions creates tremendous **opportunities**: there will be huge growth in the use and conversion of electricity for travel, warmth and in industry, growth in new zero emissions diets, growth in materials production, manufacturing and construction compatible with zero emissions, growth in leisure and domestic travel, growth in businesses that help us to use energy efficiently and to conserve the value in materials.

Bringing about this change, and exploring the opportunities it creates requires three things to happen together: as individuals we need to be part of the process, exploring the changes in lifestyle we prefer in order to make zero emission a reality. **Protest is no longer enough** - we must together discuss the way we want the solution to develop; the government needs to treat this as **a delivery challenge** - just like we did with the London Olympics, on-time and on-budget; the emitting businesses that must close cannot be allowed to delay action, but meanwhile the authors of this report are funded by the government to work across industry to support the **transition to growth compatible with zero emissions**.

Breakthrough technologies will be important in future but we cannot depend on them to reach our zero emissions target in 2050. Instead this report sets an agenda for a long-overdue public conversation across the whole of UK society about how we really want to achieve Absolute Zero within thirty years.

# Key messages for industrial sectors

**Key Message:** Absolute Zero creates a driver for tremendous growth in industries related to electrification, from material supply, through generation and storage to end-use. The fossil fuel, cement, shipping and aviation industries face rapid contraction, while construction and many manufacturing sectors can continue at today's scales, with appropriate transformations.

**Leisure, sports, creative arts and voluntary work**: These sectors can expand greatly and should have a central position in national definitions of welfare targets.

**Electricity sector and infrastructure**: Absolute Zero requires a 3x expansion in non-emitting electricity generation, storage, distribution and load-balancing.

**Construction sector**: All new build should be to zero-energy standards of use. The impacts of construction are primarily about the use of materials, primarily steel and cement. By 2050, we will have only very limited cementitious material and will use only recycled steel, but there are myriad opportunities for radical reductions in the amount of material used in each construction.

**Steel sector**: All exsiting forms of blast furnace production, which are already under great pressure due to global over-capacity, are not compatible with zero-emissions. However, recycling powered by renewables, has tremedous opportunities for growth exploiting the fact that steel scrap supply will treble in the next 30 years. There are short term innovation opportuniteis related to delivering the highest quality of steel from recycling, and longer-term opportunities for technologies for zero-carbon steel making from ore that could be deployed after 2050.

**Cement sector**: All existing forms of cement production are incompatible with zero emissions. However, there are some opportunities for expanded use of clay an urgent need to develop alternative processes and materials. Using microwaves processes to recycle used cement appears promising.

**Mining and material supply**: Zero emissions will drive a rapid transition in material requirements. Significant reduction in demand for some ores and minerals, particularly those associated with steel and cement, are likely along with a rapid expansion of demand for materials associated with electrification. It seems likely that theire will be opportunities for conslidation in the currently diffuse businesses of secondary material collection, processing, inventory and supply.

**Rail**: The great efficiency of electric rail travel suggests a significant expansion of electric rail travel, domestically and internationally, is likely and would see high demand. The most efficient electric trains are aerodynamically efficient, like those designed for the highest speed operation today, but travelling at lower speeds.

**Road vehicles**: The transition to electric cars is already well under-way, and with increasing demand, costs will presumably fall. We already have targets for phasing out non electric vehicles, but by 2050 will have only 60% of the electricity required to power a fleet equivalent to that in use today. Therefore we will either use 60% fewer cars or they will be 60% the size. Development of auto-grade steels from recycling is a priority, and the need to control recycled metal quality may require changed models of ownership. The rapid expansion of lithium battery production may hit short-term supply constraints and create environmental concerns at end-of-life unless efficient recycling can be developed.

**International freight**: We currently have no non-emitting freight ships, so there is an urgent need for exploration of means to electrify ship power, and options to transfer to electric rail. This would require an enormous expansion in international rail capacity.

**Aviation**: There are no options for zero-emissions flight in the time available for action, so the industry faces a rapid contraction. Developments in electric flight may be relevant beyond 2050.

**Fossil fuel industries**: All coal, gas, and oil-fuel supply from extraction through the supply chain to retail must close within 30 years, although carbon capture and storage may allow some activity later.

**Travel and tourism**: Without flying, there will be growth in domestic and train-reach tourism and leisure.

**Food and agriculture**: Beef and lamb phased out by 2050 and replaced by greatly expanded demand for vegetarian food. Electricity supply for food processing and storage will be cut by 50%.

**Building maintenance and retrofit**: Rapid growth in demand for conversion to electric heat-pump based heating matched to improvements in insulation and air-tightness for building envelopes.

# Key messages for individuals

**Key Message:** The big actions are: travel less distance by train or in small (or full) electric cars and stop flying; use the heating less and electrify the boiler when next upgrading; lobby for construction with half the material for twice as long; stop eating beef and lamb. Each action we take to reduce emissions, at home or at work, creates a positive ripple effect.

As individuals we can all work towards Absolute Zero through our purchasing and our influence. Each positive action we take has a double effect: it reduces emissions directly and encourages governments and businesses to be bolder in response. Where we cause emissions directly we can have a big effect by purchasing differently. Where they are released by organisations rather than individuals, we can lobby for change.

The actions stated as absolutes below are those which will be illegal in 2050 due to the Climate Change Act.

## Living well

The activities we most enjoy, according to the UK's comprehensive time-use survey, are sports, social-life, eating, hobbies, games, computing, reading, tv, music, radio, volunteering (and sleeping!) We can all do more of these without any impact on emissions.

## Travelling

The impact of our travelling depends on how far we travel and how we do it. The most efficient way to travel is with a large number of people travelling in a vehicle with a small front and we can all reduce our total annual mileage.

1. Stop using aeroplanes
2. Take the train not the car when possible.
3. Use all the seats in the car or get a smaller one
4. Choose an electric car next time, if possible, which will become easier as prices fall and charging infrastructure expands.
5. Lobby for more trains, no new roads, airport closure and more renewable electricity.

## Heating and appliances:

Our energy bills are mainly driven by our heating and hot water.

1. Use the boiler for less time, if possible, staying warm by only heating rooms if people are sitting in them, sealing up air gaps and adding insulation.
2. Wear warmer clothes in winter.
3. Next time you replace the boiler, choose an electric air or ground-source heat pump if possible
4. Buy smaller more efficient appliances that last longer
5. Lobby for zero-carbon building standards, means-tested support for housing retrofit and more renewable electricity

## Purchasing:

Most industrial emissions relate to producing materials, which are made efficiently but used wastefully so we need to reduce the weight of material made. The highest volumes of material are used not by households, but to make commercial and public buildings and infrastructure, industrial equipment and vehicles.

1. Lobby businesses and the government to build buildings and infrastructure with half the material guaranteed for twice as long.
2. When extending or modifying your home, try to choose recycled or re-used materials and avoid cement.
3. Aim to reduce the total weight of material you purchase each year.
4. Lobby for border controls on emissions in materials (like we have with food standards) to allow businesses fit for Absolute Zero to grow and prosper in the UK

## Eating:

Small changes in diet can have a big effect.

1. Reduce consumption of beef and lamb as these have far higher emissions than any other common food.
2. Choose more locally sourced food if possible, to reduce food miles, particularly aiming to cut out air-freighted foods.
3. Aim to use less frozen and processed meals as these dominate the energy use of food manufacturers.
4. Lobby supermarkets to support farmers in using less fertiliser - it has a high impact, but much of it is wasted as it's spread too far away from the plants.

# Why this report matters

**Key Message:** We are legally committed to reducing the UK's emissions to zero by 2050, and there isn't time to do this by deploying technologies that don't yet operate at scale. We need a public discussion about the changes required and how to convert them into a great Industrial Strategy.

## Timelines:

In her last significant act as Prime Minister, Theresa May changed the UK's Climate Change Act to commit us to eliminating all greenhouse gas emissions in the UK by 2050. This decision is based on good climate-science, was a response to a great wave of social protest and has been replicated in 60 other countries already.

However, 30 years is a short time for such a big change. Politicians in the UK and internationally talk about climate change as if it can be solved by new energy technologies alone, and UK government reports are over-confident about how much progress has been achieved; in reality most UK cuts in emissions have been as a result of Mrs Thatcher's decision to switch from coal to gas fired electricity and to allow UK heavy industry to close. The UK has been successul in reducing methane emissions - by separating our organic waste and using it in anaerobic digesters to make gas for energy, but new energy technologies are developing slowly.

There are no invisible solutions to climate change so we urgently need to engage everyone in the process of delivering the changes that will lead to zero emissions.

## Confusion about technologies

In this report we're using three different descriptions of the technologies which cause emissions:

- **Today's technologies** are the mass-market products of today - such as typical petrol or diesel cars.
- **Incremental technologies** could be delivered today if customers asked for them - for example smaller cars.
- **Breakthrough technologies** such as cars powered by hydrogen fuel cells, may already exist, but haven't yet captured even 5% of the world market.

Incremental technologies can be deployed rapidly, but breakthrough technologies can't. We're concerned that most plans for dealing with climate change depend on breakthrough technologies - so won't deliver in time.

## Why we've written this report now

The authors of this report are funded by the UK government to support businesses and governments (national and regional) to develop a future Industrial Strategy that's compatible with Zero Emissions. To do that, we have to anticipate how we'll make future goods and buildings, and also think about what performance we want from them.

## What we mean by "Absolute Zero"

The UK's Climate Change Act contains two "escape" words: it discusses "net" emissions and targets on those that occur on our "territory." However, in reality, apart from planting more trees, we don't have any short-term options to remove emissions from the atmosphere, and even a massive expansion in forestry would have only a small effect compared to today's emissions. Furthermore, shutting factories in the UK doesn't make any change to global emissions, and may make them worse if we import goods from countries with less efficient processes.

Public concern about the Climate is too well informed to be side-lined by political trickery on definitions. In writing this report, we have therefore assumed that:

- the target of zero emissions is absolute - there are no negative emissions options or meaningful "carbon offsets." Absolute Zero means zero emissions;
- the UK is responsible for all emissions caused by its purchasing, including imported goods, international flights and shipping.

## Invitation to participate

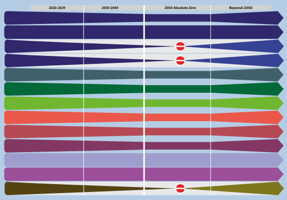
This report presents our best estimate of Absolute Zero, based on publicly reported data and peer-reviewed evidence. Undoubtedly there are more opportunities that we don't know of, and if this report proves useful, there will be other aspects of the journey to Absolute Zero that we can help to inform. We welcome contributions and comment and will provide an edited summary of any discussion on www.ukfires.org. If there is demand, we will update and re-issue the report in response.

Please contact us via info@ukfires.org and if you found this report useful, please share it through your networks.

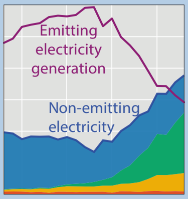
# Guide to the report

**Opening material**

What actions can we take - as individuals and in the key sectors to reduce emissions now and to develop future choices to deliver Absolute Zero?



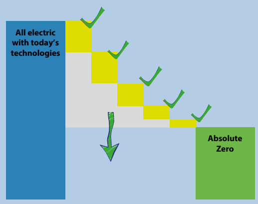
**1. Absolute Zero with today's technologies**



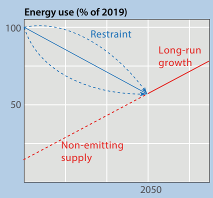

The UK Climate Change Act commits us to zero emissions in 30 years time - based on good climate science. The lowest risk way to get there is to change the way we use today's technologies.

**2. Options for incremental and breakthrough innovations**

The goods we buy will of course change over the next 30 years, but it takes decades for breakthrough technologies to reach full scale, so we focus on likely incremental innovations.



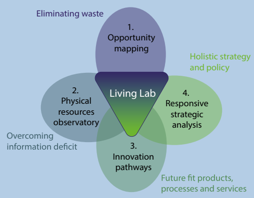

**3. The process of change towards Absolute Zero**




Reaching Absolute Zero requires a collaboration between individuals, government and businesses. None of them can act unilaterally, so reaching the target will be a process.

**4. Opportunities created by Absolute Zero**

One of the benefits of considering Absolute Zero is that it allows us to recognise how many opportunities are created by pursuing the strict emissions target.




**Notes to the figures**

Notes to the figures

**Figure 1.2**: Data from the International Energy Agency (IEA, 2018) with data on CCS installations at power-stations from the Oil and Gas funded pro-CCS lobby, Global CCS Institute.

**Figure 1.3**: This analysis by Vaclav Smil (2014) looks at global deployments of the three major fossil fuels, relative to total world energy demand at the time. Some faster transitions have occurred in individual countires, as shown in the box story on page 3.

We've tried to make this report as easy to read as possible, but all our analysis is firmly rooted in data. These notes show how we've sourced and used the evidence

**References**

These references point to the sources we used for data or other evidence.

References

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Haerl, H., Erb, K.H., Krausmann, F. Human Appropriation of Net Primary Production: Patterns, Trends, and Planetary Boundaries. Annual Review of Environment and Resources, 2014, 39 (1): pp. 363-391.

HM Government, 2018. Our waste, our resources ...

Agenda Item 5

| | 2020-2029 | 2030-2049 |
|---|---|---|
| **Road vehicles** | Development of petrol/diesel engines ends; Any new vehicle introduced from now on must be compatible with Absolute Zero | All new vehicles electric, average size of cars reduces to ~1000kg. |
| **Rail** | Growth in domenstic and international rail as substitute for flights and low-occupancy car travel | Further growth with expanded network and all electric trains; rail becomes dominant mode for freight as shipping declines |
| **Flying** | All airports except Heathrow, Glasgow and Belfast close with transfers by rail | All remaining airports close |
| **Shipping** | There are currently no freight ships operating without emissions, so shipping must contract | All shipping declines to zero. |
| **Heating** | Electric heat pumps replace gas boilers. and building retrofits (air tightness, insulation and external shading) expand rapidly | Programme to provide all interior heat with heat pumps and energy retroifts for all buildings |
| **Appliances** | Gas cookers phased out rapidly in favour of electric hobs and ovens. Fridges, freezers and washing machines become smaller. | Electrification of all appliances and reduction in size to cut power requirement. |
| **Food** | National consumption of beef and lamb drops by 50%, along with reduction in frozen ready meals and air-freighted food imports | Beef and lamb phased out, along with all imports not transported by train; fertiliser use greatly reduced |
| **Mining material sourcing** | Reduced demand for iron ore and limestone as blast furnace iron and cement reduces. Increased demand for materials for electrification | Iron ore and Limestone phased out while metal scrap supply chain expands greatly and develops with very high precision sorting |
| **Materials production** | Steel recycling grows while cement and blast furnace iron reduce; some plastics with process emissions reduce. | Cement and new steel phased out along with emitting plastics . Steel recycling grows. Aluminium, paper reduced with energy supply. |
| **Construction** | Reduced cement supply compensated by improved material efficiency, new steel replaced by recycled steel | All conventional mortar and concrete phased out, all steel recycled. Focus on retrofit and adaption of existing buildings. |
| **Manufacturing** | Material efficiency becomes promiment as material supply contracts | Most goods made with 50% as much material, many now used for twice as long |
| **Electricity** | Wind and solar supplies grow as rapidly as possible, with associated storage and distribution. Rapid expansion in electrificiation of end-uses. | Four-fold increase in renewable generation from 2020, all non-electrical motors and heaters phased out. |
| **Fossil fuels** | Rapid reduction in supply and use of all fossil fuels, except for oil for plastic production | Fossil fuels completed phased out |

| 2050 Absolute Zero | Beyond 2050 |
|---|---|
| Road use at 60% of 2020 levels - through reducing distance travelled or reducing vehicle weight | New options for energy storage linked to expanding non-emitting electricity may allow demand growth |
| Electric trains the preferred mode of travel for people and freight over all significant distances, | Train speeds increase with increasing availability of zero emissions electricity |
| | Electric planes may fly with synthetic fuel once there are excess non-emitting electricity supplies |
| | Some naval ships operate with onboard nuclear power and new storage options may allow electric power |
| Heating powered on for 60% of today's use. | Option to increase use of heating and cooling as supply of non-emitting electricity expands |
| All appliances meet stringent efficiency standards, to use 60% of today's energy. | Use , number and size of appliances may increase with increasing zero-emnis-sions electricity supply |
| Total energy required to cook or transport food reduced by 60%. | Energy available for fertilising, transporting and cooking increases with zero-emissions electricity |
| Demand for scrap steel and ores for electrification much higher, no iron ore or limestone. | Demand for iron ore and limestone may develop again if CCS applied to cement and iron production |
| All materials production electric with total 60% power availability compared to 2020 | Material production may expand with electricity and CCS, CCU, hydrogen may enable new cement and steel. |
| Any cement must be produced in closed-loop, new builds highly optimised for material saving. | Growth in cement replacements to allow more architectural freedom; new steel may become available. |
| Manufacturing inputs reduced by 50% compen-sated by new designs and manufacturing practices. No necessary reduction output. | Restoration of reduced material supplies allows expansion in output, although some goods will in future be smaller and used for longer than previously. |
| All energy supply is now non-emitting electricity. | Demand for non-emitting electricity drives ongoing expansion in supply. |
| | Development of Carbon Capture and Storage (CCS) may allow resumption of use of gas and coal for electricity |

# 1. Zero emissions in 2050 with today's technologies

**Key Message:** Apart from flying and shipping, all of our current uses of energy could be electrified. With tremendous commitment the UK could generate enough non-emitting electricity to deliver about 60% of our current final energy-demand, but we could make better use of that through incremental changes in the technologies that convert energy into transport, heating and products.

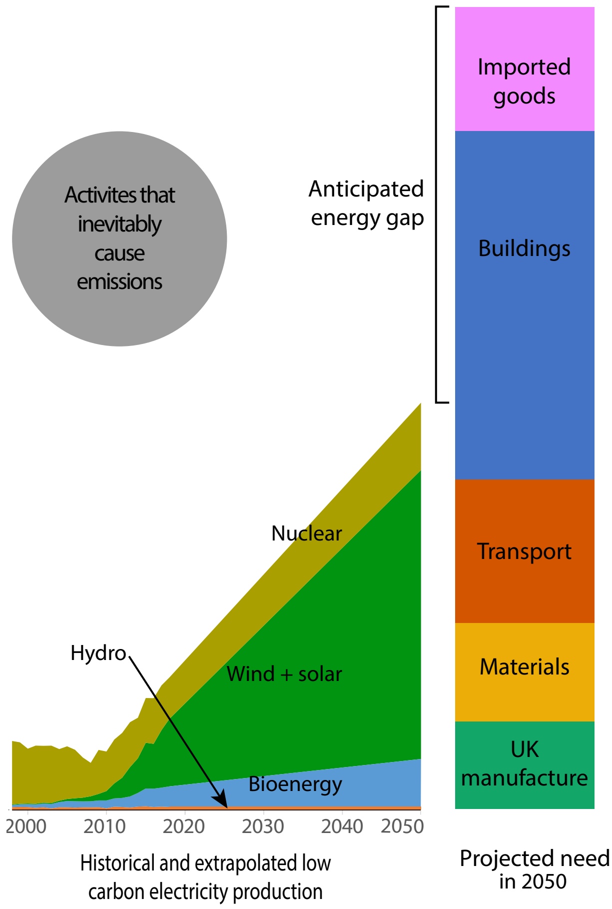
About three quarters of the greenhouse gas emissions caused by humans are emitted when we burn the fossil fuels - coal, gas and oil - and the rest arise from our agriculture (particularly cows and sheep), our conversion of land from forestry to pasture, the way we allow organic waste to decompose, and our industrial processes. Using today's technologies, all of these sources un-related to energy have no alternative, so reducing our emissions to zero means phasing out these activities.

Our emissions related to energy come from our use of oil (as diesel, petrol or kerosene) for transport, our use of gas for heating our homes and industrial processes, and our use of coal and gas to generate electricity. Some of our electricity is also generated without burning fossil fuels - for instance by nuclear power stations, wind turbines or solar cells - and in a zero emissions future these will be our only source of energy. Most of our current uses of energy could be electrified - as is becoming familiar with electric cars - but there are currently no options for electric flying or shipping. With today's technologies, these modes of transport must therefore be phased out also.

Over the past 10 years in the UK, we have made a significant change to the way we generate electricity and about half of our generation is now from non-emitting sources. If we continue developing the generation system at the same rate, then by 2050 we will have around 50% more electric power than we have today. Data on the efficiencies of today's motors and heaters allows us to estimate that this will be enough to power about 60% of today's energy-using activities (apart from flying and shipping). However, because energy has been so cheap and abundant in the past 100 years, in many cases we could make small changes to existing technologies to make much better use of less energy.

Figure 1.1 summarises this overview of Absolute Zero with today's technologies: the left side of the figure shows the recent history of the UK's non-emitting electricity generaton extrapolated forwards to 2050. The right side shows the amount of electricity we'd need if we electrified everything we do today, apart from those activities that inevitably cause emissions, which we'll have to phase out.

**Figure 1.1: Gap between today and Absolute Zero**

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## 1.1 Energy Supply Today

The science is clear: we must stop adding to the stock of greenhouse gases in the atmosphere to control global warming. In response, the best estimates of science today predict that annual global emissions from human activities must be reduced rapidly and should be eliminated by 2050 – in thirty years' time. This target, which requires extraordinarily rapid change, is now law in the UK, and several other countries. However, despite the science and the laws, global emissions are still rising.

The critical choice in planning to cut emissions is about the balance between technology innovation and social choice. Is it possible to develop a new technology that will cut emissions while allowing people in developed economies to continue to live as we do today and to allow developing economies to develop the same behaviours? Or should we first modify our behaviour to reach the emissions target, with different aspirations for development, and then take the benefits of technology innovation when they become available later? To date, as illustrated in fig 1.2, every national and international every national and international government plan for responding to climate change has chosen to prioritise technology innovation, yet global emissions are still rising.

For twenty years, two technologies have dominated policy discussions about mitigating climate change: renewable energy generation and carbon capture and storage (CCS). The two renewable technologies now being deployed widely are wind-turbines and solar-cells. These critical forms of electricity generation are essential, and should be deployed as fast as possible, but fig. 1.3 shows that they combined with nuclear power and hydro-electricity still contribute only a small fraction of total global energy demand. Meanwhile, although CCS has been used to increase rates of oil extraction, its total contribution to reducing global emissions is too small to be seen. The technological elements of CCS have all been proven at some scale, but until a first fleet of full-scale power-plants are operating, the risks and costs of further expansion will remain high and uncertain. To illustrate the current importance of CCS in global power generation, the total

**Figure 1.2: Acting now or waiting for new technologies**

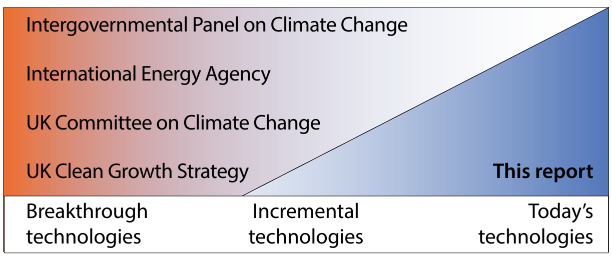
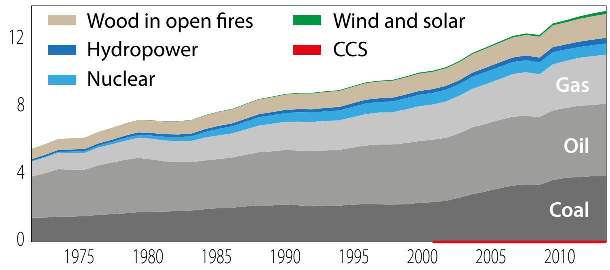



**Figure 1.3: World primary energy supply ('000 Mtoe)**

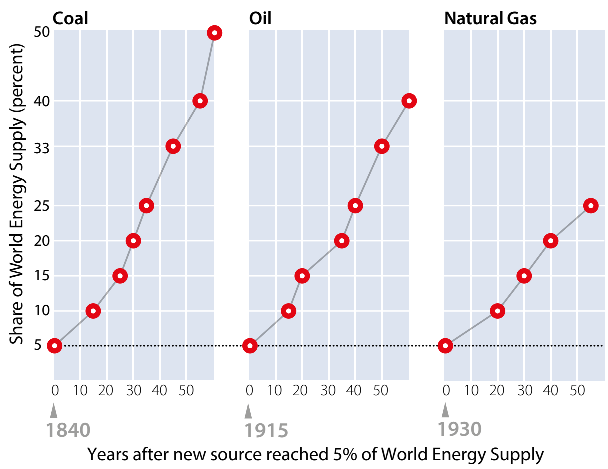



output of all CCS enabled power-generation is shown on fig. 1.3 - still very definitely on top of the y-axis.

All previous transitions in the energy system, for example in figure 1.4, have occurred relatively slowly. Early installations experience problems due to human error, and the installation of large generation requires lengthy public consultation on land-rights, environmental protection, safety and financing. Despite this, CCS looks very attractive to policy makers. Twenty years ago, the International Energy Agency stated that "within 10 years we need 10 demonstrators of CCS power stations" but none are operating at full-scale today. Yet in 2019 the UK's Climate Change Committee published its plans to deliver zero emissions, requiring deployment of CCS in six of thirteen sectors within thirty years. However, the UK has no current plans for even a first installation and although CCS may be important in future, it is not yet operating at meaningful scale, but meanwhile global emissions are still rising.

The hope of an invisible, technology-led, solution to climate change is obviously attractive to politicians and incumbent businesses. However, a result of their focus on this approach has been to inhibit examination of our patterns of energy demand. Figure 1.6a shows that the UK's demand for energy is only falling in industry. This is because in the absence of a meaningful industrial strategy, we have closed our own industry in favour of increased imports. As a result, this apparent reduction in energy

**Figure 1.4: Major transitions in global energy supply**

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## Technology Transitions in the Energy System

New computers, clothes and magazines can be put on sale soon after the are invented. However new energy technologies have typically required much longer time to reach full scale: even if the technology is well-established, building a power station requires public consultation about finance, safety, land-rights, connectivity and other environmental impacts all of which take time. For new technologies, it takes much longer, as investors, operators and regulators all need to build confidence in the safety and perfomance of the system. Figure 1.5 summarises the rates of introduction of various new energy technologies in the countries where they grew most rapidly. The green arrow corresponds to the start points of the linear periods of growth shown in figure 1.4.

**Figure 1.5: Years to deploy energy technologies**

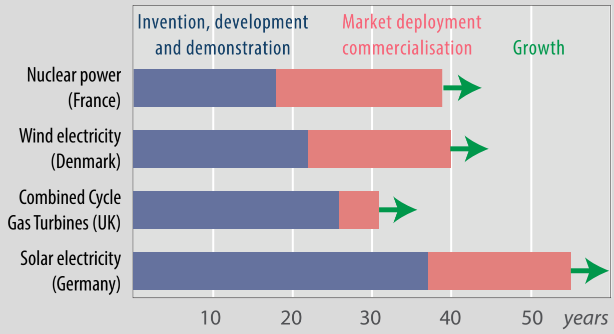
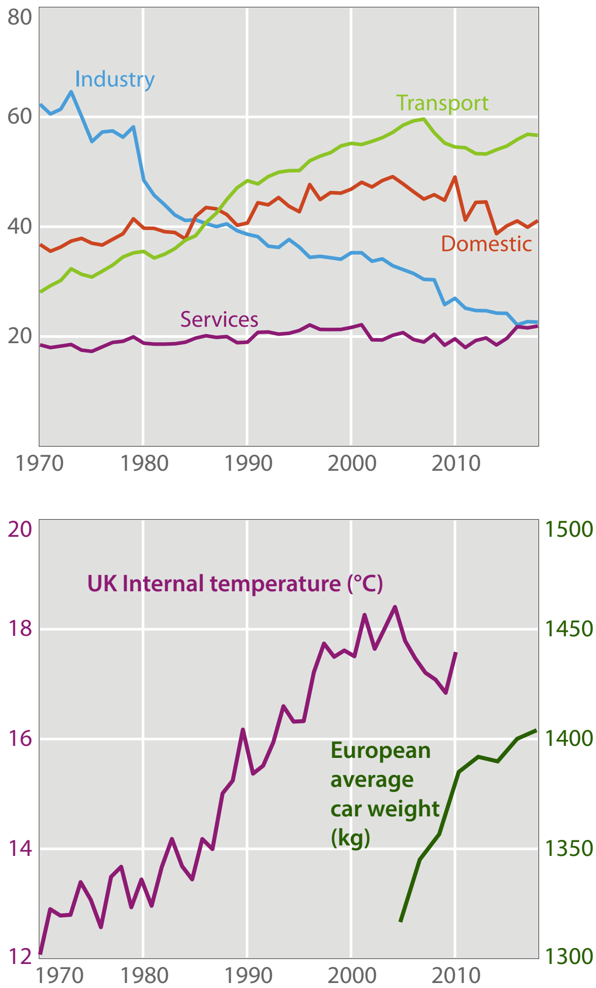



**Figure 1.6: Energy demand (a) by sector (Mtoe) influenced by (b) car weight & internal temperature**




use is compensated by an increase in other countries. Meanwhile, demand in other sectors is rising, driven, for example, by an increase in the weight of our cars and increased use of heating to raise internal temperatures in winter (fig. 1.6b). With thirty years remaining to deliver zero emissions, we cannot risk waiting for a different energy system, so must have an inclusive public discussion about how we use energy, because global emissions are still rising.

2019 has seen a great rise in public concern about climate change, driven by science and growing evidence of changes occurring. So far, the social protesters have called for "someone to do something" without engaging in discussion about solutions, but the only solutions available in the time remaining require some change of lifestyle. This report therefore aims to trigger that critical discussion. The report starts with a plan to reach zero emissions by 2050 using only technologies that are already mature today, to minimise the risk that we continue emitting beyond 2050. This is possible but requires some specific restraint in our lifestyles. Innovation can relieve this restraint so the report then presents an overview of the range of options for innovation in the way we use energy as well as how we generate it.

Global emissions are still rising and the need for action is urgent. This report aims to allow us to start an informed discussion about the options that really will deliver zero emissions by 2050.

**Key Message:** Global demand for energy is rising. In the UK our demand has fallen, but only because we have closed industry and now import goods elsewhere. Policy discussions have prioritised breakthrough technologies in the energy system, particularly carbon capture and storage, but it is at such an early stage of development that it won't reduce emissions significantly by 2050.

## 1.2 UK Energy System now and in 2050

Climate change is driven by greenhouse gas Emissions. Most emissions arise from burning fossil fuels to create Energy; some of our energy use is in the form of Electricity. These three words beginning with "E" are often confused in public dialogue, but figure 1.7 separates them. Three quarters of global emissions (slightly more in the UK because we import 50% of our food) arise from the combustion of fossil-fuels (coal, gas and oil). Most coal and one third of gas is used in power stations to generate electricity. However, we also generate electricity by nuclear power and from renewable sources. The third column of the figure shows that nearly a half of the UK's current electricity supply is from non-emitting sources, of which nuclear power and the use of imported bio-energy pellets are most important.

Figure 1.8 shows how the UK's energy supply has developed over the past twenty years. Total demand has fallen, due to the loss of industry shown in fig. 1.6, but our use of oil and nuclear power has been relatively constant. (The figures in both figures disguise the fact that over this period the UK's population has grown by 16% so we have improved the efficiency of our energy use by around 0.5% per year.) The other major change in the figure is the switch from coal to gas powered electricity generation which has reduced UK emissions significantly.

Figure 1.9 extracts from fig 1.8 our generation of electricity – the numbers in this figure for 2018 correspond to those shown in fig 1.7c – and divides them into emitting and non-emitting sources. This figure shows the UK making good progress in de-carbonising its current levels of electricity supply, and if the linear-trends in the figure continue, then

**Figure 1.7: Emissions, Energy and Electricity in the UK**

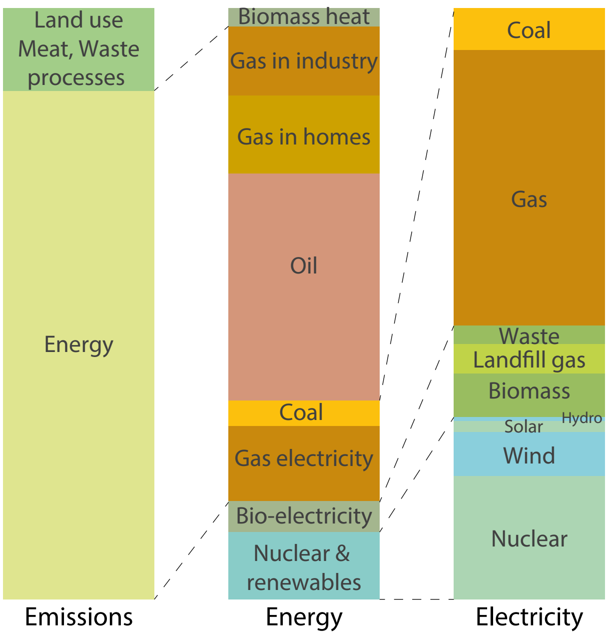
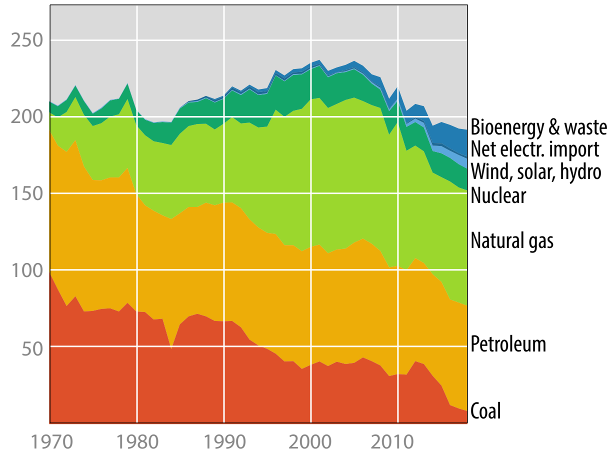



**Figure 1.8: UK Primary Energy supply (Mtoe/yr)**




by 2050, the UK can be expected to generate around 580 TWh of electricity without emissions. This is the figure shown on figure 1.1 at the beginning of this chapter.

If we can manage our electricity distribution system and find ways to store electricity from windy/sunny times to be available at still/dull times this suggests that by 2050 we will have around 60% more electricity available than today, all from non-emitting sources. Physically, although the Hinckley C Nuclear Plant will probably by completed by 2030, delivering this increase will largely come from increasing wind-generation. To meet this growth from offshore wind would require an addition of around 4.5 GW of generation capacity each year of the next 2 decades (allowing time for them to be fully operational by 2050). By comparison, the Crown Estate have just launched a process to award 7-8.5 GW of new seabed leases over the next 2 years, but the Offshore Wind Sector Deal expects Government support for the delivery of only 2 GW/year through the 2020s.

**Figure 1.9: UK Electricity generation (TWh/year)**

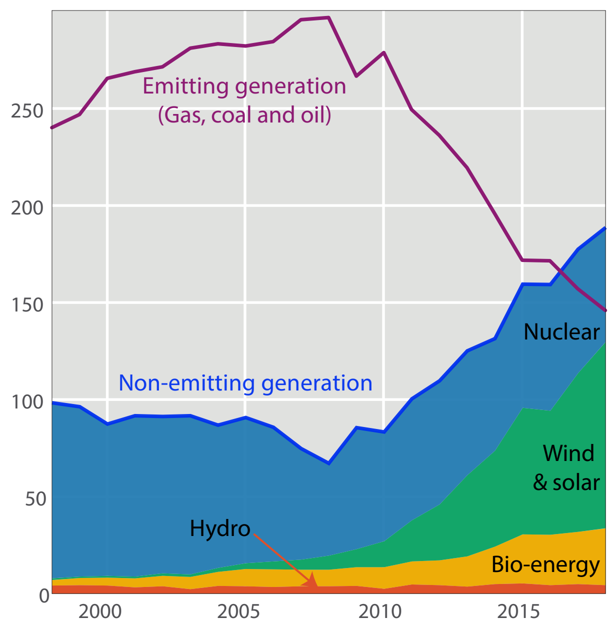
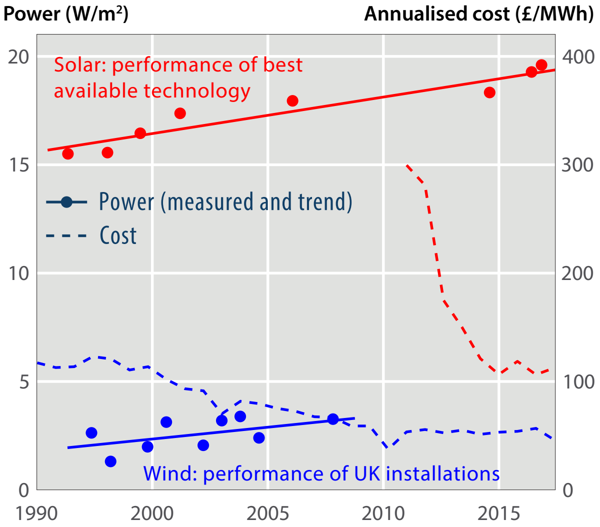


Figure 1.10: Development of wind and solar power




Meanwhile fig 1.10 shows how the two options for on-shore generation, wind-turbines and solar power, are developing. Both technologies are becoming cheaper, although the amount of power generated from each unit of land is increasing only slowly. Replacing existing on-shore wind turbines with much taller models could increase total generation by 50%. Increasing solar generation depends on the commitment of area, but is plausible: if every south-facing roof in the UK were entirely covered in high-grade solar cells, this would contribute around 80TWh per year

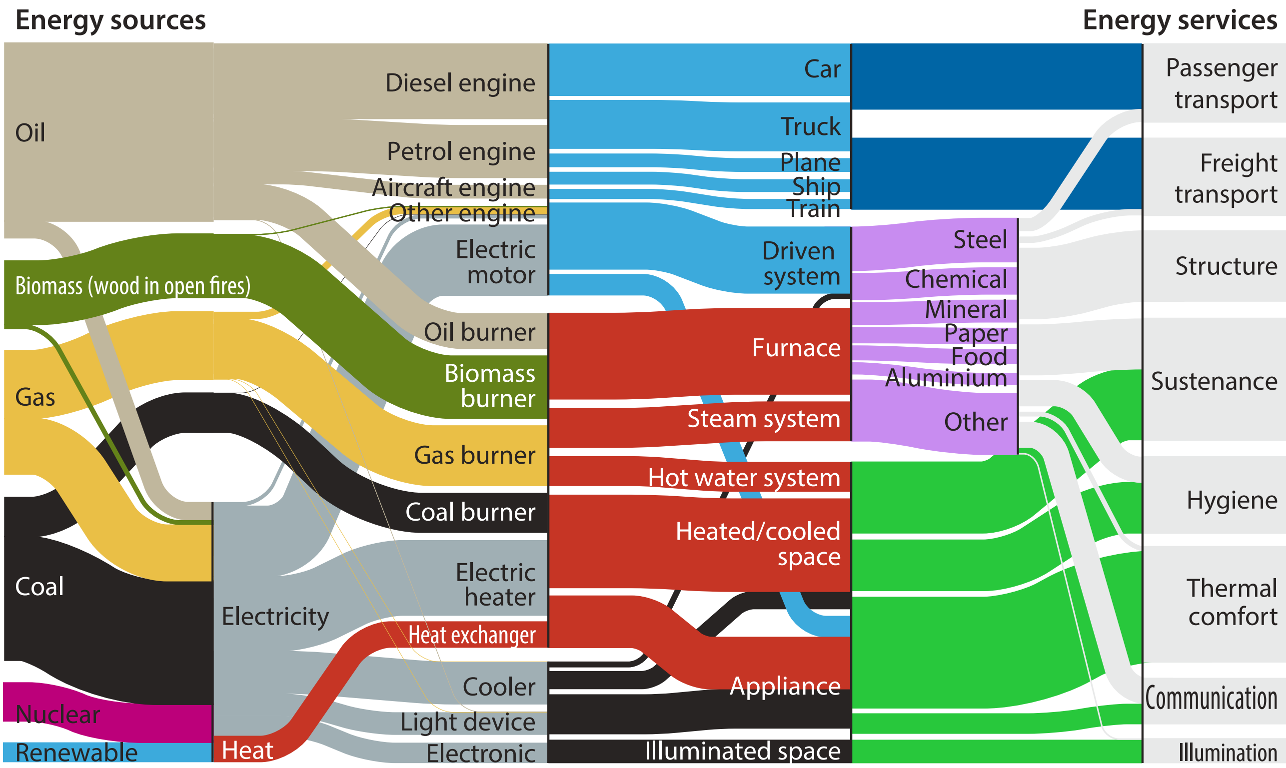
Figure 1.7 also shows a range of bio-energy sources contributing to the UK's energy supply. All these supplies are combusted, leading to the release of $CO_2$, but because the fuel derives from plants, these releases form part of the normal cycle so do not accelerate climate change. Waste policy has been a success in UK mitigation since 1990, with organic waste separated and largely processed in anaerobic digestors to produce methane for electricity. However, this source is unlikely to increase further. Meanwhile, bio-energy derived directly from new plant growth is in competition with the use of biomass for food so unlikely to increase (see box story on p13).

This discussion suggests that, using today's technologies and with plausible rates of expansion, the UK will in a zero-emissions 2050 have an energy supply entirely comprising electricity with about 60% more than generated that we have today.

How much of the benefit of all of today's use of energy will we be able to enjoy without any fossil fuels, but with 60% more electricity? At first sight, this sounds like a significant reduction - fig. 1.7 showed that today, electricity provides only about one third of our total energy needs, so apparently we would need a 200% increase in electricity output? In fact this isn't the case, because the final conversion of electricity into heat or rotation is very efficient compared to the fossil fuel equivalents.

If the UK is to run entirely on electricity, then all devices currently powered with fossil-fuels must be replaced by electrical equivalents. Figure 1.11 presents a view of how energy is used globally. (We don't currently have an equivalent of this for the UK, but the UK is likely to be similar, although with less industrial use, due to our

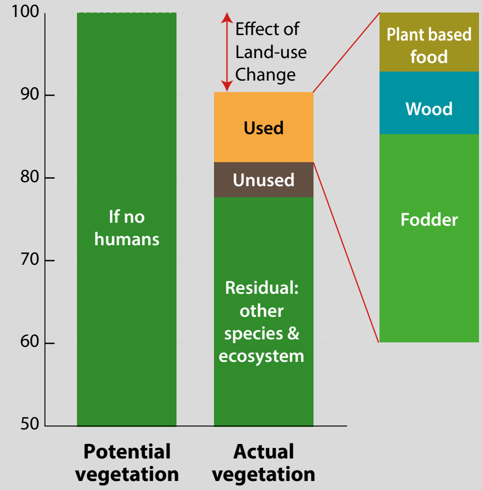
Figure 1.11: Global transformation of energy to services



## What's the problem with bio-energy?

The world's poorest people stay warm and cook with wood burnt on open furnaces, and this energy source shows up significantly in the global energy supplies of fig. 1.11. Could we use modern technology to harness even more biomass to make other fuels, such as biodiesel or kerosene? Fig 1.12 reveals that more than 20% of the world's total annual harvest of new biomass is already 'appropriated' by humans for wood, food and fodder. This annual harvest is the fundamental source of habitat and food for all non-aquatic species. Any further appropriation by humans is likely to be dangerously harmful to other species and the effect of deforestation rates is already a major contributor to the emissions in fig. 2.10. This evidence suggests that modern bio-fuels are incompatible with any wider sustainability of life on earth.

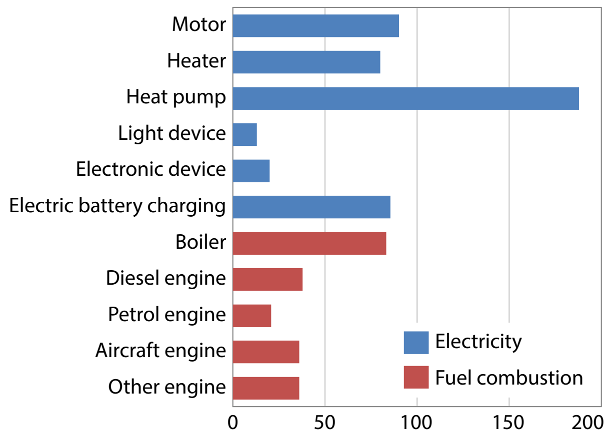
**Figure 1.12: Human appropriation of biomass**




dependence on imports.) The widths of the lines in the figure are proportional to energy use, and any vertical cut through the diagram could be converted into a pie-chart of all the world's energy use. In effect fig. 1.11 shows six connected pie-charts, each breaking out the statistics of all the world's energy use into different categories.

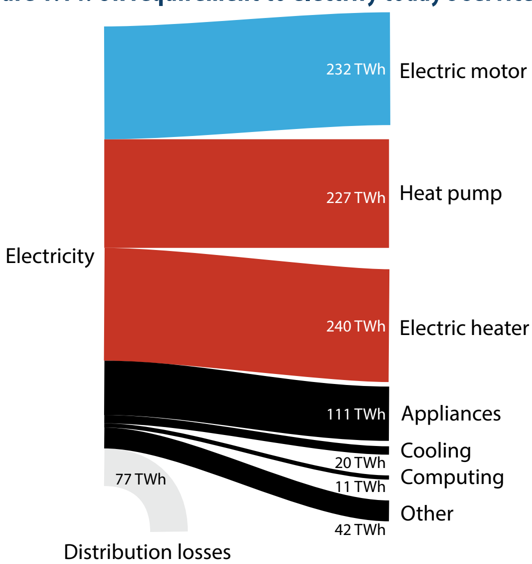
The figure shows that most energy is used in engines, motors, burners and heaters to create motion or heat. To estimate the electricity required if all of these devices are replaced, we use the average efficiencies presented in fig. 1.13: for example, we know how much power is currently delivered in the UK's cars by petrol engines, so can use fig. 1.13 to predict how much electricity would be required to provide the same power from electric motors. Combining this conversion with an estimated 11% population growth, leads to our prediction that we would need 960 TWh of electricity by 2050. (A terawatt hour, Twh, is a thousand million kilowatt hours - the unit normally used in UK energy bills.) The final requirement for electricity is split between motion, heating and appliances as shown in Fig 1.14.

**Figure 1.13: Efficiency of enegy conversion devices (%)**




If the UK is fully electrified by 2050, and we used the same final services as today, our demand for energy as electricity will be 960 TWh. However, based on a linear projection of the rate at which we have expanded our non-emitting electricity supply in the past 10 years, we estimate that we will have just 580 TWh available. Therefore, our commitment to absolute zero emissions in 2050 requires a restraint in our use of energy to around 60% of today's levels.

**Figure 1.14: UK requirement to electrify today's services**




**Key Message:** If we only used electricity, delivering all the transport, heat and goods we use in the UK would require 3x more electricity than we use today. If we expand renewables as fast as we can, we could deliver about 60% of this requirement with zero emissions in 2050. Therefore in 2050 we must plan to use 40% less energy than we use today, and all of it must be electric.

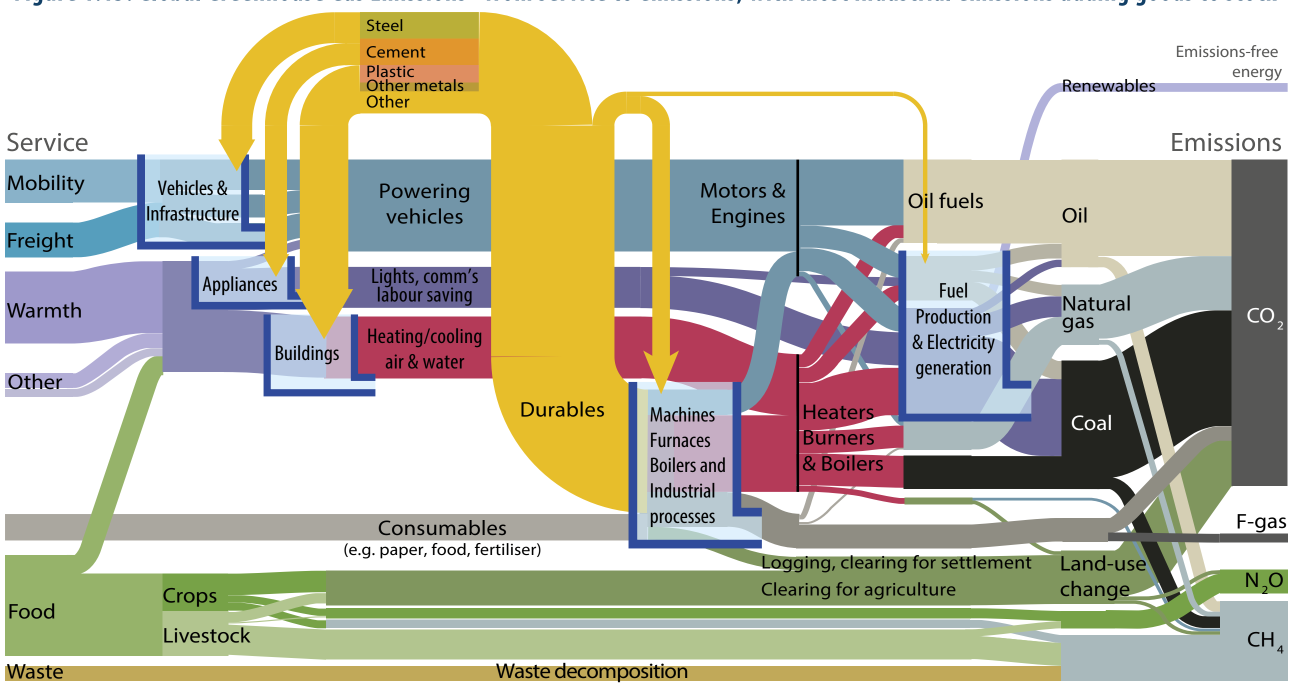
## 1.3 Zero emissions in the UK in 2050

In addition to restraining our energy demand to 60% of current levels, meeting our legal commitment to zero emissions will require that we phase out any energy using activities that cannot be electrified and any sources of emissions beyond fossil-fuel combustion. Planning for this requires that we make a collective decision about the scope of our responsibility. The UK's Climate Change Act was written to make commitments based solely on emissions that occur on UK territory. However, this excludes international aviation and shipping and our net imports of goods. As a result, it appears to be a success for UK climate policy when we shut UK industry and instead import goods – even though this will not reduce global emissions, and may often increase them if the closed UK processes were more efficient. Although these limitations were helpful in passing the Climate Change Act into law, they now look morally questionable, and they also fail to create the stimulus to innovation and growth in UK businesses and industries fit for a zero emissions future. This report therefore assumes that the UK should be responsible for the emissions of all its consumption.

Figure 1.15 shows an analysis of all global greenhouse gas emissions, using a format similar to fig. 1.11. In this case, the final services that drive the activities that cause emissions are shown at the left of the diagram, leading to the greenhouse gasses on the right side of the diagram which cause global warming. The yellow-loop in the middle of the figure demonstrates that most industrial emissions are associated with producing the buildings, vehicles and other equipment which provide final services from energy, but which themselves require energy in production. This is important because most of this year's industrial output is to produce equipment (durables) that will last for several years. The services provided in one year therefore depend on the accumulation of a stock of goods made in previous years - and this long-lasting stock limits the rate at which change can be made to our total emissions. For example, if cars last on average for 15 years, then to ensure that all cars are electric in 2050, the last non-electric car must be sold no later than 2034. As with fig. 1.11, fig. 1.15 is based on global data - again to reflect the consequences of UK consumption, rather than its "territorial" emissions.

The top three quarters of this figure demonstrate the emissions consequences of our use of energy. The two critical forms of equipment that cannot be electrified with known technology are aeroplanes and ships. Although Solar-Impulse 2, a single-seater solar-powered electric aeroplane circumnavigated the Earth in 2016, it is difficult to scale up solar-powered aeroplanes due to the slow rates of improvement in of solar cell output put unit of area shown in fig. 1.10. Meanwhile battery-powered flight is inhibited by the high weight of batteries, bio-fuel substitutes for Kerosene face the same competition for land with food as described in section 1.2 and there are no other ready and appropriate technologies for energy storage. As a result, under the constraint of planning for zero emissions with known technologies, all flying must be phased out by 2050 until new forms of energy storage can be created. At present we also have no electric merchant ships. There isn't space to have enough solar cells on a ship to generate enough energy to propel it, and as yet there has been no attempt to build a battery powered container

**Figure 1.15: Global Greenhouse Gas Emissions - from service to emissions, with most industrial emissions adding goods to stock**



ship. Nuclear powered naval ships operate, but without any experience of their use for freight, we cannot safely assume that nuclear shipping will operate at any scale in 2050. This is a serious challenge: with today's technologies, all ship-based trade must be phased out by 2050.

Figure 1.15 further reveals that the two key sources of non-energy related emissions are in agriculture and industrial processes. Agricultural emissions arise primarily from ruminant animals – in particular cows and sheep – which digest grass in the first of their two stomachs in a process that releases methane and from land-use change. Converting forestry to agricultural land leads to the release of the carbon stored in the forest and the loss of future carbon storage as the trees grow. In addition, ploughing the land releases carbon stored in the soil, and using Nitrogen based fertilisers to stimulate plant growth leads to further emissions. The motivation for this conversion of forestry land is to increase food production, but is greatly exacerbated by the demand for meat eating. Growing grain and other feed for cows, pigs and sheep is exceptionally inefficient, as up to 80 times more grain is required to create the same calories for a meal of meat as for a meal made from the original grain. As a result, our commitment to zero emissions in 2050 requires that we refrain from eating beef and lamb.

Three industrial processes contribute significant emissions beyond those related to energy. Blast furnaces making steel from iron ore and coke release carbon dioxide and half of the emissions from current cement production come from the chemical reaction as limestone is calcined to become clinker. There are no alternative processes available to deliver these materials, and although old steel can be recycled efficiently in electric arc furnaces, there are no emissions-free alternatives to cement being produced at any scale. As a result, a zero-emissions economy in 2050 will have no cement-based mortar or concrete, and no new steel. The absence of cement is the greatest single challenge in delivering Absolute Zero, as it is currently essential to delivering infrastructure, buildings and new energy technologies.

The final source of direct industrial emissions is the group of "F-gases" which have diverse uses, including as refrigerants, solvents, sealants and in creating foams. It may be possible to continue some of these applications beyond 2050 if the gases are contained during use and at the end of product life.

Delivering Absolute Zero in thirty years with today's technologies is possible. Our energy supply will be 60% less than today, and solely in the form of electricity, but apart from flight and shipping, all other energy applications can be electrified. Socially motivated action is leading some change in both travel and diet. The most challenging restraint is on the bulk materials used in construction, in particular in the absence of cement, which will constrain the deployment of new energy supplies and economic development which depends on building.

However, despite these restraints, the most striking feature of this analysis is how many features of today's lifestyles are unaffected. Many of the leisure and social activities we most enjoy can continue with little change, many forms of work in service sectors will flourish, and the transition required will also lead to substantial opportunities for growth, for example in renewable electricity supply and distribution, in building retrofit, in electric power and heat, in domestic travel, material conservation, plant-based diets and electrified transport. Delivering Absolute Zero within thirty years with today's technologies requires restraint but not despair and of course any innovation that expands service delivery without emissions will relieve the required restraint. That's the theme of the second chapter of this report.

**Key Message:** In addition to reducing our energy demand, delivering zero emissions with today's technologies requires the phasing out of flying, shipping, lamb and beef, blast-furnace steel and cement. Of these, shipping is currently crucial to our well-being - we import 50% of our food - and we don't know how to build new buildings or install renewables without cement. The need for this restraint will be relieved as innovation is deployed but many of our most valued activities can continue and expand, and Absolute Zero creates opportunities for growth in many areas.

# 2. Innovations to make more use of less energy

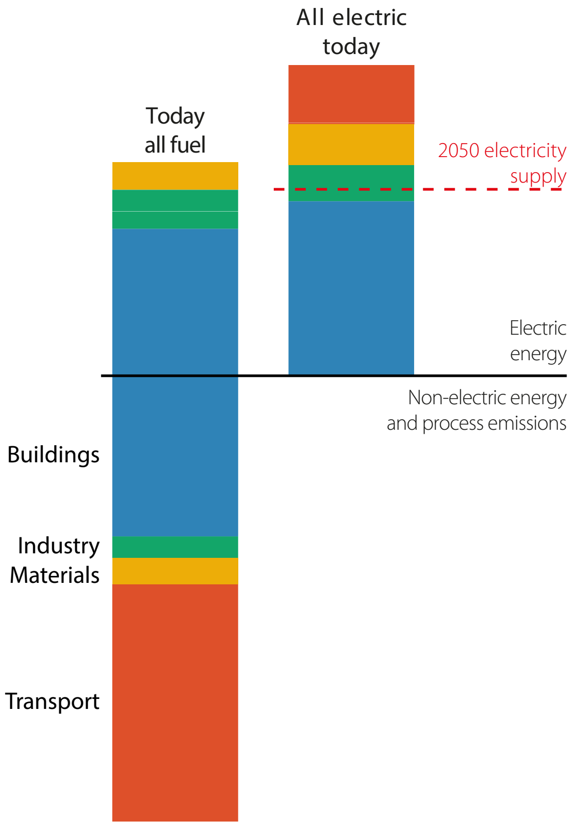
**Key Message:** With incremental changes to our habits and technologies, there are multiple options for living just as well as we do today, with 60% of the energy. With electric heat pumps and better insulation we can stay just as warm. With smaller electric cars we can keep moving, and by using materials better, we can make buildings and goods compatible with our zero emissions law.

This chapter starts from the analysis of electricification in chapter 1, summarised in fig. 2.1: below the line, all of today's non-electric uses of energy must be electrified. Any activities that lead to emissions regardless of energy source or that cannot be electrified must be phased out. If we electrify all remaining activities with today's technologies, we require the amount of electricity shown in the second column - but we'll only have 60% of that amount available. For each of the sectors in fig. 2.1, we therefore look at all the options for a more efficient future.

Section 2.1. focuses on the way we use energy directly - in buildings and vehicles - and on the way we source our food. Sections 2.2-2.4 explore how we make things - firstly looking at how we produce materials, which is what drives most of today's industrial emissions, and then in how we use them in construction and manufacturing. It turns out that we are already very efficient in our use of energy when making materials, but wasteful in the way we use the materials - so there are plenty of options for living well while using half as much material for twice as long.

For completeness, in section 2.5 we survey the "breakthrough technologies" that are unlikely to be significant by 2050, but could expand afterwards.

**Figure 2.1: Absolute Zero overview**




## 2.1 Products in-use and consumables

In the UK, the use of final products and consumables accounts for almost three quarters of current annual emissions. 12% of UK emissions come from domestic food production, waste disposal and land use changes, but two thirds are produced by our use of vehicles and buildings. These mostly come from road transport and heating in buildings, but to what extent can innovation help reduce these emissions to zero?

### Using energy in buildings

Figure 2.2 shows that most energy uses in buildings are for heating air (space) and water, mostly by combustion of gas in individual boilers in each building. Absolute zero emissions requires a complete electrification of energy uses in buildings. Although appliances and lighting are already electric, space and water heating must change.

Heat pumps, based on principles similar to the familiar domestic fridge - but in reverse, offer a viable alternative to gas boilers. Since heat pumps are around four times more efficient than direct heat of combustion, complete deployment of best-practice heat pumps could save approximately 80% of current energy demand for heating. Heat pumps can be used in two forms: as a direct replacement for a gas-boiler they can provide hot water for a conventional radiator system. However, the best use of heat pumps is with ducted air heating - which requires a more intrusive modification of a building, but saves more energy. Deploying heat pumps would almost double the demand for electricity in buildings from current levels, so further interventions to reduce the demand for heating are also important.

New buildings are much more efficient than old Victorian houses still in use today — better insulation and design result in much smaller heating requirements. However, the turnover of the UK's building stock is very slow - we like old buildings - so refurbishment of old houses is important. Already, we have made substantial efforts to retrofit double glazed windows and to install high quality insulation in roofs and attics, and this could be completed to ever higher-standards to reduce national energy demand for heating.

For new build homes, Passive designs which only use the sun for heating, and need electricity only for ventilation, lighting and appliances are now well established. Until 2015, the UK's zero-carbon homes standards promoted this form of design, which is applied rigorously in Sweden, and at current rates of building, would affect 20% of the UK's housing if enforced now. The cost of houses built to the Passive standard is approximately 8-10% more than standard construction, and the thick walls required slightly reduce the available internal space, in return for zero energy bills.

Figure 2.3 summarises the options for operating buildings under the conditions of Absolute Zero: whatever happens we must electrify all heating. We could then either use the heating for 60% of the time we use it today, or apply other incremental changes in building design to maintain today's comfort with 60% of the energy input.

**Figure 2.2: Energy use in buildings**

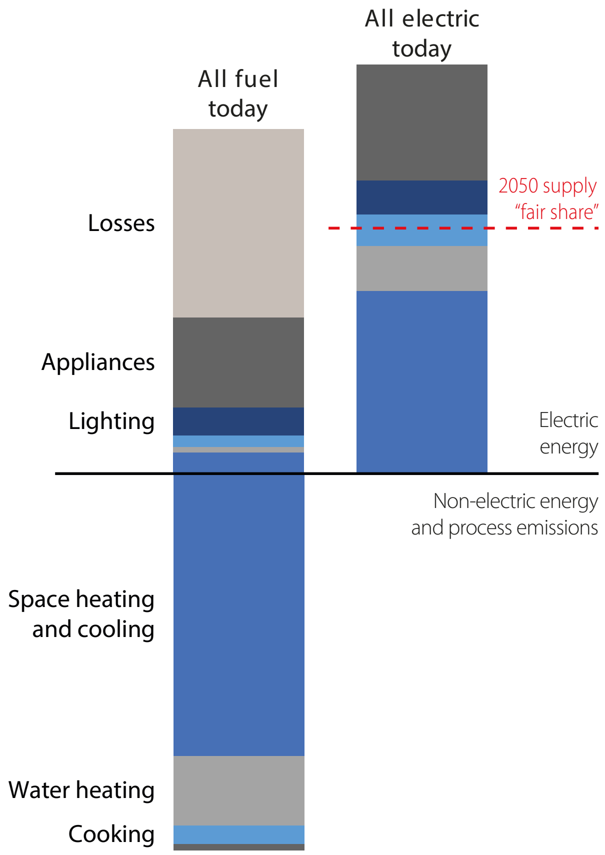
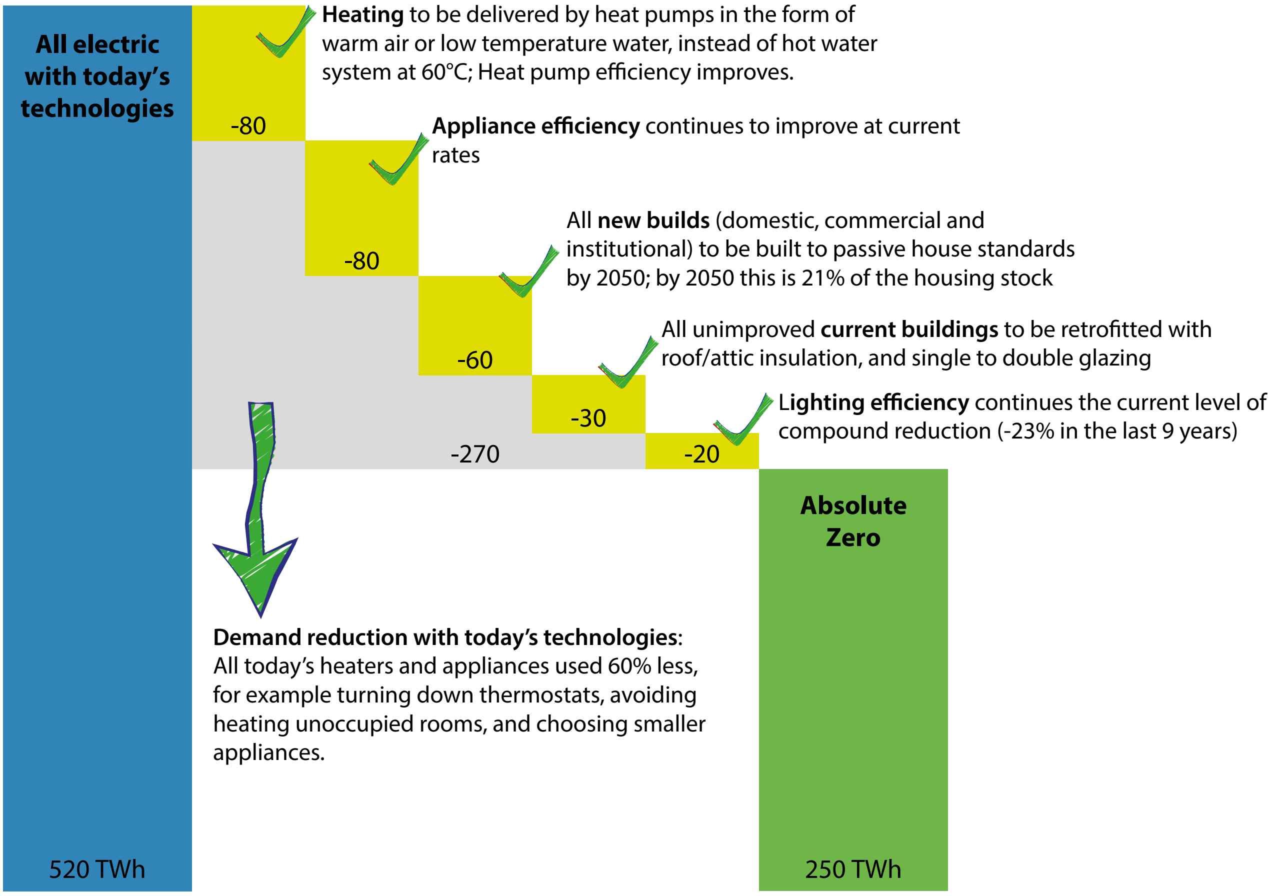



**Figure 2.3: Reducing energy use in buildings with incremental technologies or reducing demand with today's technology**



## Using energy in transport

Figure 2.4 shows that almost all of today's transport involves the direct combustion of fossil fuels in the vehicle, with only 1% of transport powered by electricity, in electric trains. Without technology options to replace aeroplanes and ships with electric equivalents, the second column of the figure assumes that these modes have been phased out in thirty years, so the electricity available for transport can be divided between rail and road vehicles.

Figure 2.5 demonstrates the opportunity for energy saving through adjusting the way we travel. The figure shows both the energy and emissions consequences of a person travelling a kilometre by different modes: these two figures are closely correlated except for flight, where the emissions at high altitude cause additional warming effects. The figure underlines how important it is to stop flying - its' the most emitting form of transport and we use planes to travel the longest distances. A typical international plane travels at around 900km/hour, so flying in economy class equates to 180kg$CO_{2e}$ per person per hour (double in business class, quadruple in first class, due to the floor area occupied.) Flying for ~30 hours per year is thus equal to a typical UK citizen's annual emissions.

The key strategies to reduce energy use in transport depend on the form of journey. Short distance travelling involves frequent stops and restarts, so a substantial

**Figure 2.4: Energy use in transport**

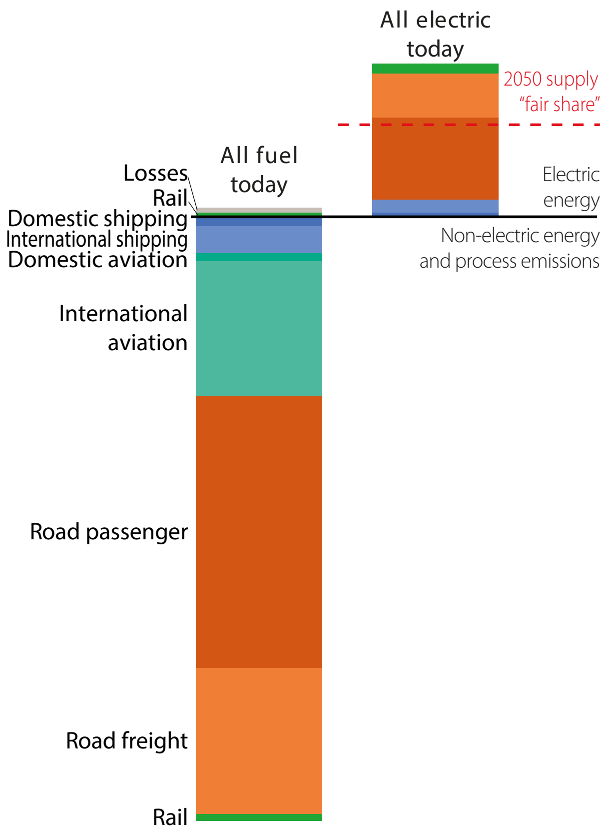
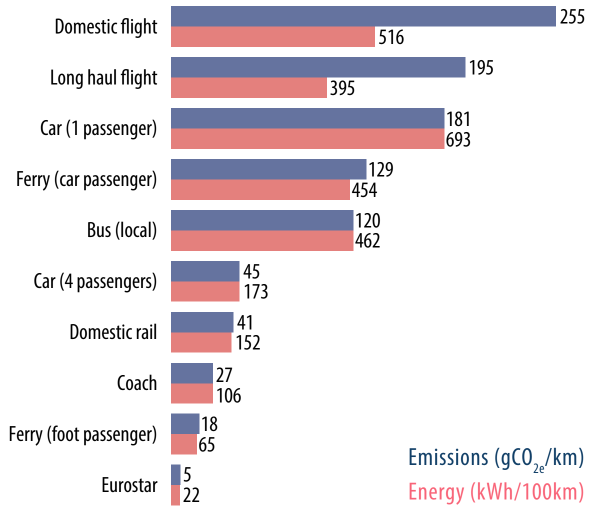



**Figure 2.5: "Mode shift" for personal transport**




share of energy is used to accelerate a vehicle and its contents. As a result, reducing the weight of the vehicle and travelling less become key strategies to reduce energy demand. At present UK cars are on average used with 1.8 people inside, but weigh around 1,400 kg, which is ~12 times more than the passengers, so almost all petrol is used to move the car not the people. Figure 2.6 illustrates how reducing the ratio of the weight of the vehicle to the weight of the passengers trades off with distance travelled and energy used. Regenerative braking offers a technological opportunity to recapture some of the energy used in accelerating vehicles, and is under active development.

For long-distance travelling most energy is used to overcome air resistance, so the key to reducing energy demand is to reduce top speeds (aerodynamic forces increase with speed squared) and drag by using long and thin vehicles — trains. Rail transport is thus the most efficient transport mode for long-distance travelling, and if a higher share of trips is made by train rather than car,

**Figure 2.6: Car travel - trading weight and distance**

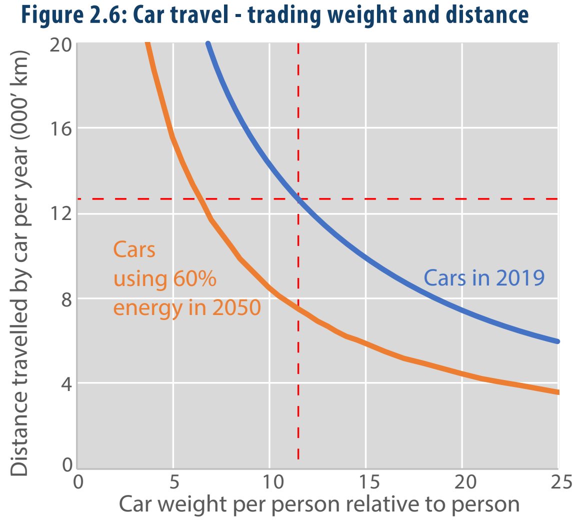
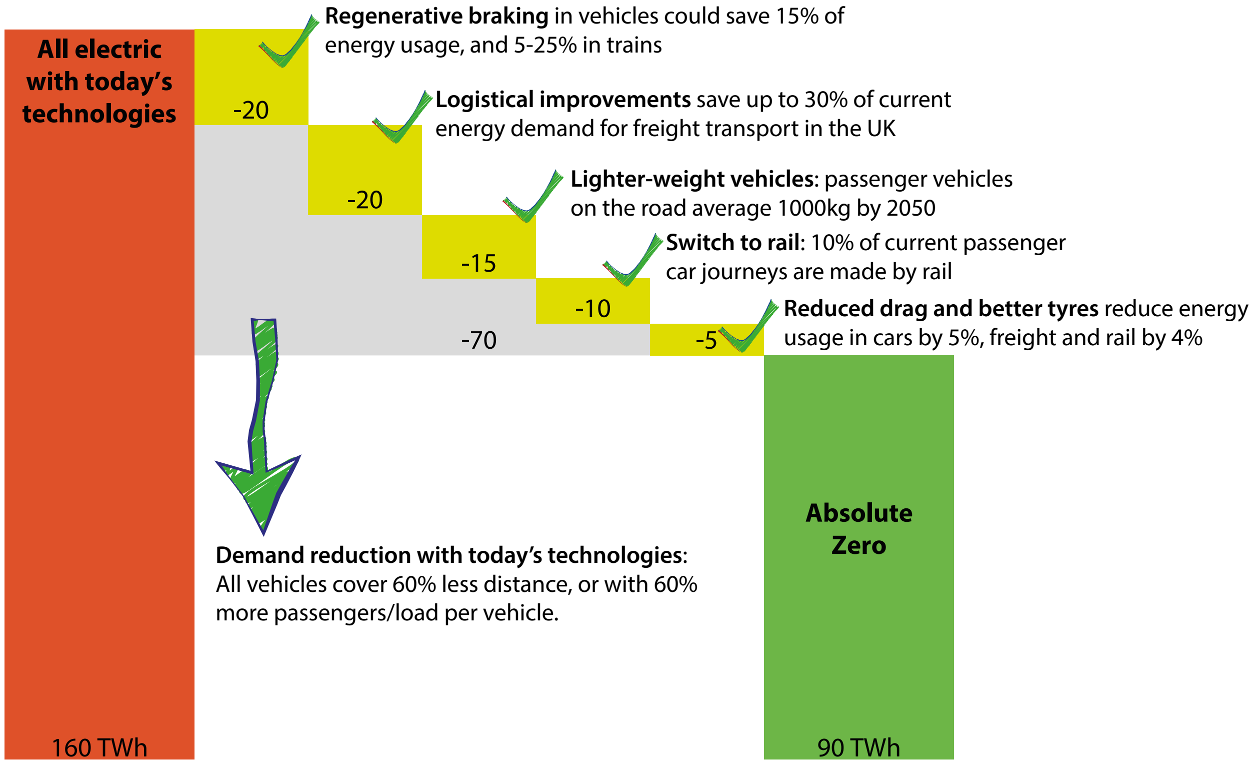


**Figure 2.7: Reducing energy use in transport with incremental technologies or reducing demand with today's technology**




substantial energy savings can be achieved without loss of mileage. A full electric train can move people using 40 times less energy per passenger than a single-user car.

Other modes of transport can also reduce energy demand in transport. For example, in the Netherlands, approximately 20% of all distance travelled is by bicycle, compared to only 1% in the UK.

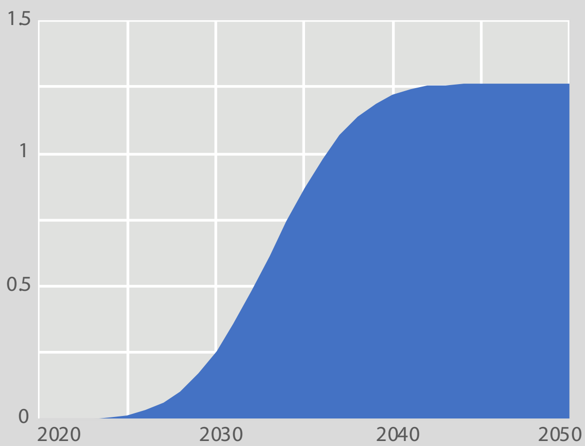
Although there are opportunities to reduce energy demand by mode shift in freight transport, substantial savings could also be achieved by logistical improvements. Up to 30% of energy demand in freight could be saved with an optimised location of distribution centres and with the creation of new collaborative networks to promote co-loading. Technology to facilitate the implementation of these logistical strategies already exists or is expected to become available over the next five years, although this also requires new corporate partnerships.

Figure 2.7 summarises the options for electrifying UK transport and using 60% of the energy. Either vehicles are modified - with regenerative braking, reduced drag and rolling resistance (better tyres), and weight reductions, or we can choose to use them less - through ride-sharing, better freight management, or an overall reduction in distance travelled.

## Can we make & recycle enough batteries?

Lithium battery manufacturing requires a wide range of metals, most of which only exist in nature at very low concentrations. Cobalt is one of the most valuable and is currently essential to the stability and lifetime of batteries. If new car sales are to be completely electric within 5 years, we will need to make 50 million batteries by 2050, just in the UK. Most cobalt production is obtained as a by-product of nickel and copper mining, so could only expand if demand for these materials expand in proportion. Batteries can be recycled, but separating the materials in them is difficult and mining new metals is tehrefore currently cheaper than recycling. There is no simple route to recycle lithium batteries at present, but the surge in old batteries shown in Figure 2.8 should trigger innovation to address this.

**Figure 2.8: Estimated volumes of electric car batteries reaching their end-of-life in the UK (millions/yr)**



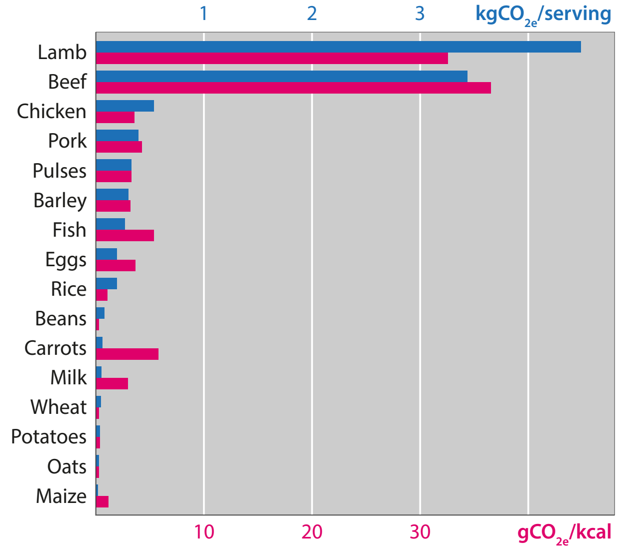
## Land-use, food and waste

Figure 1.15 demonstrated that around a quarter of global emissions arise from good production and the decomposition of organic wastes. The UK figures in fig. 1.7 show this fraction being closer to one sixth, which reflects the fact that the UK imports around half of its food. Figure 2.10 provides more detail on these non-energy and non-industrial emissions.

As waste biomass breaks down to compost, it releases either carbon dioxide (if the biomass is in contact with air) or methane, which is a much more potent greenhouse gas and is the main driver of the emissions from waste decomposition. However, methane is the gas we use in cooking or in gas fired electricity generation, and the greatest success of recent UK climate policy has been to reduce these emissions significantly. Households across the UK now expect to discard organic wastes in their green bins, which are collected as the feedstock for anaerobic digesters which generate methane for energy production as shown in figure 1.7. As a result, UK landfill methane emissions have reduced by more than 50% since 1990 and will be close to zero by 2050.

The other major sources of emissions in figure 2.10 are largely related to ruminant animals – cows and sheep – grown for meat and dairy consumption. Ruminants digest grass in their first stomach, leading to methane emissions (enteric fermentation) while also releasing methane with their manure. In parallel, rising global demand for food is driving demand for increased biomass production, around half of which is to feed animals and in turn this drives forestry clearance. Trees are a substantial store of carbon, so clearance increases emissions either as $CO_2$ if the wood is burnt, or more damagingly, as methane if left to rot. The clear implication of fig 2.10 is that eating lamb and beef will be incompatible with Absolute Zero.

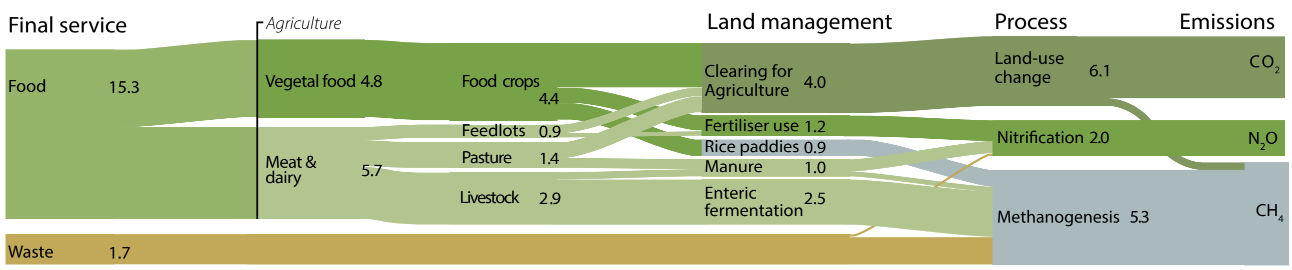
**Figure 2.9: Emissions intensities of food**




This message is underlined in fig. 2.9 which gives an estimate of the emissions associated with a meal with typical portions of different diets. The figure demonstrates that a vegetarian meal isn't emissions free, and a meat-based meal (with pork or chicken) may not have much more impact than one based on pulses. However, the ruminant meats stand out so are a priority action in moving towards Absolute Zero.

The market for vegetarian food is currently growing rapidly, as rising social concern about emissions has motivated many individuals to switch to a more plant-based diet. There is significant potential for innovation in extending and developing new manufactured meat substitutes. Research has also begun to examine whether alternative feeds could eliminate ruminant emissions, but this is not yet mature.

**Figure 2.10: Global emissions from agriculture, and organic waste (total in 2010: 17 Gt $CO_{2e}$)**



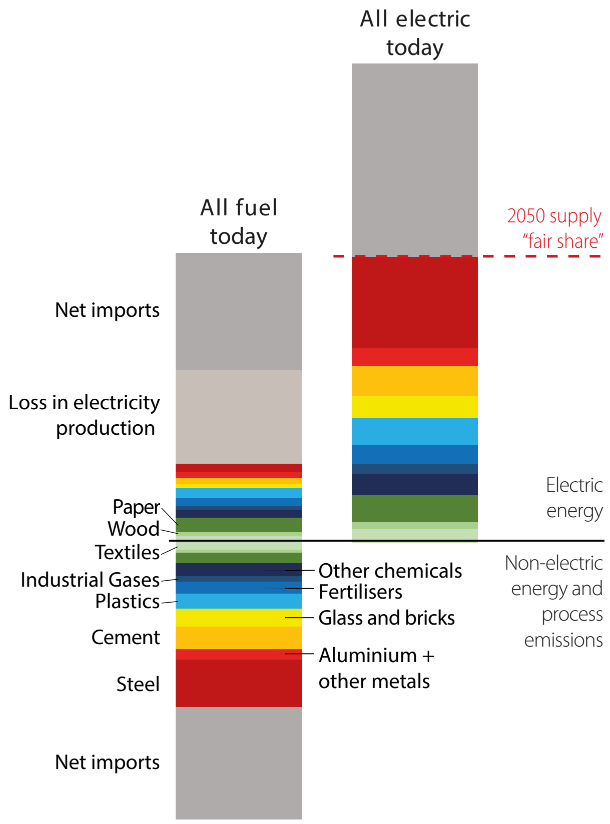

**Key Message:** Most of today's UK lifestyles can continue and grow within the target of Absolute Zero. Changing the way we travel (in particular not flying, and making better use of wheeled vehicles), stay warm (using electric heat pumps instead of gas boilers) and eat (cutting out lamb and beef) are the most important changes that we would notice. In parallel, small changes in the design of buildings and vehicles can make them more efficient. However the biggest challenge revealed in this section is the use of shipping for freight: at the moment we have no alternatives.

## 2.2 Materials and Resources

The implications of the analysis of chapter 1 for material production are summarised in figure 2.11. The UK imports much of our material requirement - either as materials, components or finished goods - so around half of the impact of our consumption today leads to the release of greenhouse gas emissions in other countries. Of the bulk materials that drive most industrial emissions, paper and aluminium production are the only two for which electricity is the dominant energy source. The processes that make materials can nearly all be electrified, but the challenge to Absolute Zero is to deal with the production processes that inevitably lead to emissions. Blast furnace steel can be replaced by steel recycled in electric furnaces, and this leads to the expansion of electricity for steel production shown in the figure. However, we currently have no means to avoid the emissions of cement production - even if the process were electrified - because the chemical reaction that converts limestone into cement inevitably releases carbon dioxide. Without innovation, we will be unable to use concrete or mortar - the two forms in which we generally use cement - but because this is so difficult to envisage, we have allowed some electric supply for the production of cement alternatives.

Starting from cement, this section explores the opportunity for innovation to expand the available supply of materials within absolute zero emissions.

**Figure 2.11: Energy use in producing materials**




## Cement

Cement hardens when mixed with water because the solid products of the reaction (called hydrates) have a higher volume than the cement powder and thus form a solid skeleton. Only a few elements in the periodic table have this property and are also widely found in the Earth's crust. The elements available in the earth's continental crust with an abundance higher than 1% are silica (60.6%), Alumina (16.9%), iron oxide (6.7%), lime (6.4%), magnesia (4.7%), sodium oxide (3.1%) and potassium oxide (1.10%). Of these, Portland cement mainly uses calcium and silica, with aluminium, iron, calcium and sulphur also playing a minor role. Calcium and aluminium together can form a heat-resistant cement used in refractory applications. Magnesium, sulphur and aluminate can also work together as a cement, but attempts at making a reliable product from them have proven unsatisfactory. Iron does not form hydrates with a high volume. Thus, the key ingredient to Portland cement is calcium, which is found mostly in the form of limestone (or calcium carbonate), as the fossilised remains of micro-organisms which have combined $CO_2$ and calcium to form shells for billions of years.

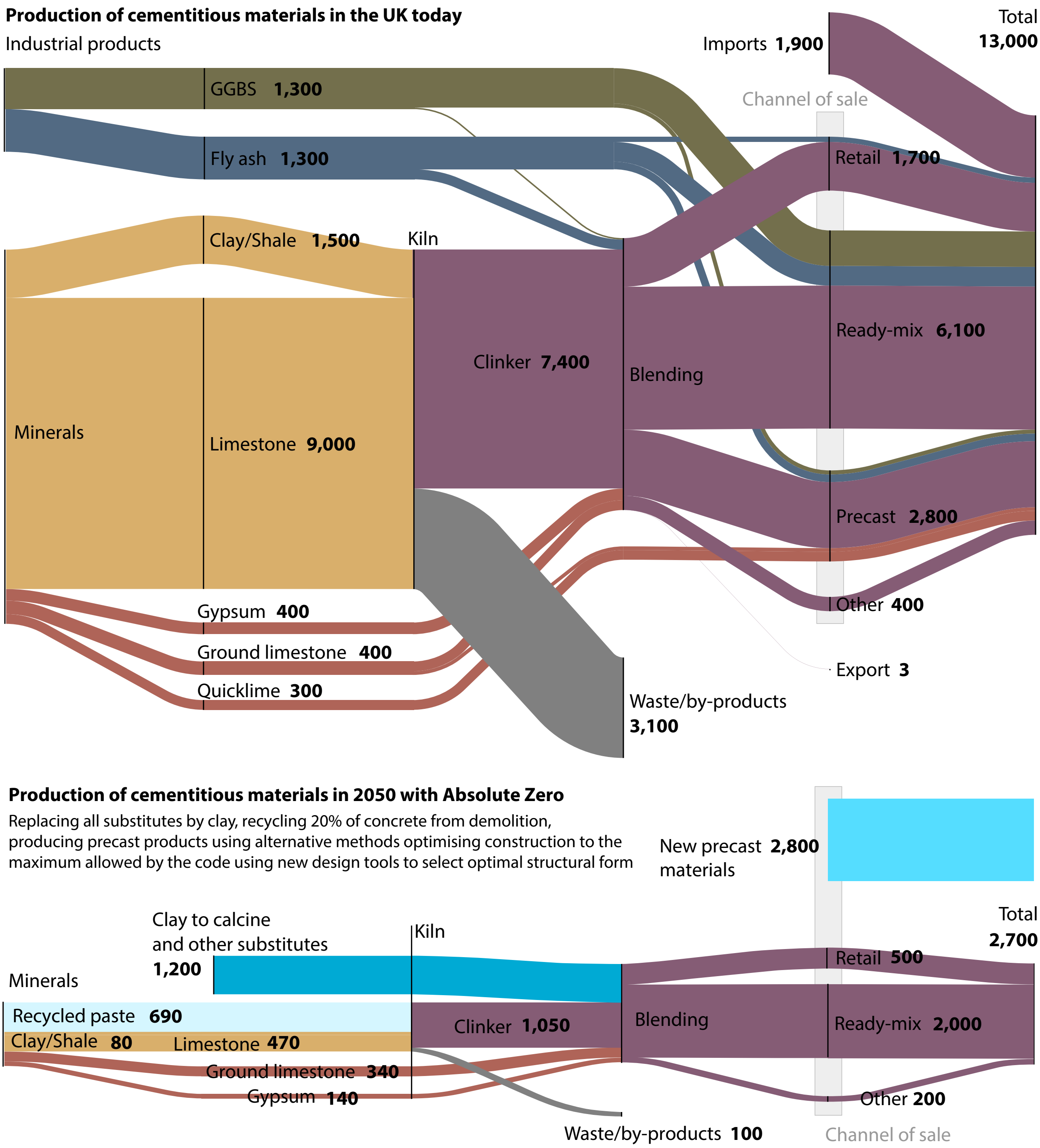
60% of emissions from cement production arise from the chemical reaction of calcination in which limestone is converted to clinker - the precursor of cement. The remaining emissions are due to the combustion of fossil fuels (and waste materials) in kilns. Although heating processes may be electrified in the future, process emissions from calcination would be unavoidable, unless alternative sources of calcium oxide are found to replace limestone in cement production. Currently it appears to be impossible to produce cement with absolute zero emissions. Technology innovation on the alternatives to calcination and reconfiguration of the cement industry could enable zero emissions in cement production. However, any innovation in these processes would probably require a substantial reduction in cement demand from current levels.

Currently, the construction industry makes use of many substitute materials to reduce the total demand for cement: both fly ash a by-product of burning coal, and ground granulated blast furnace slag, a by-product of the steel industry are used. Together, they reduce the need for pure Portland cement by about 20%. However, in a zero-carbon world, neither of these products would be available - as coal combustion and blast furnaces would not be possible - which leads to an increase in the need for new cement.

It is possible to produce pre-cast products (bricks, blocks, or slabs) with zero or even negative emissions, whether using micro-organisms which transform $CO_2$ to calcite or through bubbling $CO_2$ through magnesium sulfo-aluminate cement-based mixes. These could satisfy some of the construction industry's needs, but we have no alternative binders to replace Portland cement on construction sites. It is often claimed that geopolymers (fly ash or slag which react to form hydrates in the presence of alkalis) could replace Portland cement. However, this is not an option in a zero-carbon world because the base materials for geopolymer come from highly emitting industrial processes (burning coal and coking steel) which will not continue.

Pre-cast products could replace at most 14% of current uses of cement, but without binders, they could not be used for foundations or repairs even of critical infrastructure. One of the most common structural elements in today's commercial buildings, the flat slab which is cast in place from liquid concrete brought to site in mixer trucks and used to build floors, would disappear: the only available option would be pre-cast elements, but these could not be finished as they are now with a thin layer of concrete (called a screed). A currently popular construction method, composite construction using thin concrete slabs poured over corrugated steel sheets and beams, would also be

**Figure 2.12: Production of cementitious materials in the UK and with innovation for zero emissions in 2050 (kT/yr)**



impossible, despite being more materially efficient than the reinforced concrete flat slab.

There are two complementary paths that might lead to reducing the emissions from cement production.

Firstly, there may be new sources of cement replacement, and new low-carbon feeds for the production. A promising source of cement replacement is kaolinite-rich clay. Kaolinite is an oxide of aluminium and silicium, which when calcined at 850 C transforms into metakaolin which is an amorphous, reactive product. Because of the lower calcination temperature, this material is about half as energy intensive as Portland cement. It has the interesting property that it can react with raw limestone to form hydrates, as well as substitute cement. Thus substitution levels of up to 65% can be achieved without lowering strength. In the UK, waste from kaolinite mining in Wales can provide a good source of clay to calcine. London clay is of a poorer quality but could still be used if the strength requirements of new construction were lowered.

The second path to producing zero-carbon cement is to eliminate limestone from the feed of cement. An abundant source of calcium which is not carbonated is concrete demolition waste. Current best practice suggests that approximately 30% of the limestone feed of a cement kiln can be replaced by concrete demolition waste. This limit is due to the presence of the concrete aggregates, but if a separation process was established, and only the cement paste from concrete demolition waste was used, then it could be possible to produce cement without chemical process emissions.

The amount of demolition waste available yearly in the UK could cover an important fraction of our yearly needs, provided heroic efforts were made to make good use of this available source of materials. 30 Mt of demolition waste is produced yearly (2007 value from the National Federation of Demolition Contractors), 59% of which is concrete of which 20% is cement paste. An 80% yield in separating aggregates from paste would then provide 3 Mt of low carbon feed for the kilns to produce new cement.

Figure 2.12 illustrates a summary of this narrative, comparing today's UK requirements for cement (or more generally, "cementitious material") in the upper picture, and the maximum possible supply we can envisage within the constraints of Absolute Zero in the lower picture. Section 2.3 will consider the opportunities to deliver construction with the 75% reduction in cement production implied by this figure.

Finally, there are many possible options for structural elements not using concrete and steel, including rammed earth, straw-bale (ModCell), hemp-lime, engineered bamboo and timber (natural or engineered). Often, these materials claim superior carbon credentials, which may be exaggerated, but they also come with enhanced building-physics attributes, including insulation, hygrothermal and indoor air quality benefits. These could be used to substitute concrete in some applications, but would require different design processes and choices of architectural forms.

## Steel

Recycling steel in electric arc furnaces powered by renewably generated electricity could supply most of our needs for steel, as it already does in the US. Almost all steel is recycled already (the exception is where steel is used underground, in foundations or pipework) and as figure 2.13 shows, the average life of steel-intensive goods is around 35-40 years. The amount of scrap steel available globally for recycling in 2050 will therefore be approximately equal to what was produced in 2010. Fig. 2.14 shows how the balance of global steel production can evolve in the next 30 years to be compatible with Absolute Zero: blast furnace steel making, which inevitably leads to the emissions of greenhouse gas due to the chemical reaction involved in extracting pure iron from iron ore using the carbon in coal, must reduce to zero. Meanwhile, recycling which happens in electric arc furnaces could be powered by renewable electricity to be (virtually) emissions free, and can expand with the growing availability of steel for recycling. Even without action on climate change, the amount of scrap steel available globally for recycling will treble by 2050. In order to meet the requirements of Absolute Zero, this valuable resource can be the only feedstock, as there is currently no alternative technology for producing steel from iron ore without emissions.

**Figure 2.13: Life expectancy of steel by application**

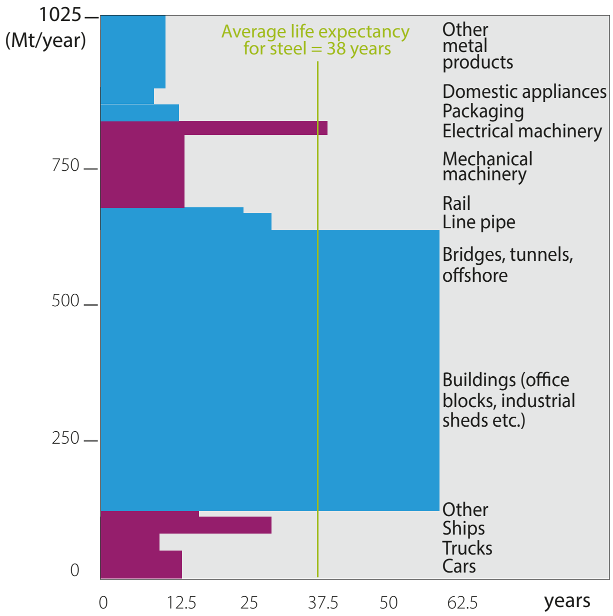
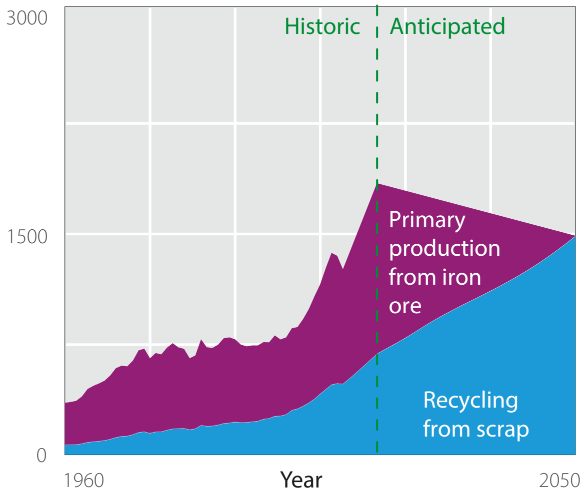


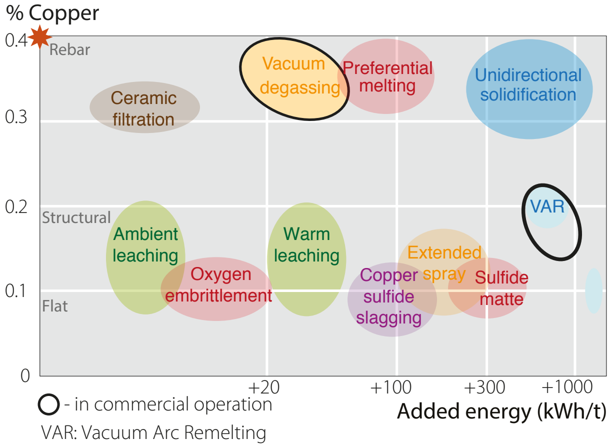
**Figure 2.14: Global steel output in Absolute Zero (Mt/yr)**




Recycled steel can have the same quality as blast furnace steel. In fact, some of the highest quality aerospace grades of steel used in the UK are made in Rotherham by recycling. However, the quality depends on the mix of metals supplied to the electric arc furnace, and is degraded in the presence of any significant quantity of tin or copper. Tin enters the steel recycling stream because of the use of tin-plate to make food cans, but this is relatively easily managed: these cans can be separated from other end-of-life steel and a mature process already operates at scale to separate the tin from the steel.

Copper is more of a problem in steel recycling, because current waste management involves shredding used cars and domestic appliances to separate metal from other materials, and these products contain many electric motors and associated wiring made from copper. There is a rich field of opportunity in responding to this problem, which could include: removing motors and wiring prior to shredding; improved separation of metals after shredding; metallurgical processes to remove copper from the liquid metal created by the electric arc furnace; developing new downstream processes to cope with

**Figure 2.15: Options to reduce copper concentration**




copper contamination in the steel; eliminating copper for example by substituting it with aluminium. Fig. 2.15 presents a survey of metallurgical processes for reducing copper concentrations in liquid steel, from 0.4% (a typical value today for average UK steel scrap recycling) to around 0.1% (the threshold for higher quality applications such as car bodies) as a function of energy input. The high grade steels made in Rotherham are purified with vacuum arc remelting, with high energy (and therefore financial) cost, but the figure demonstrates how many other opportunities could be developed given the motivation provided by Absolute Zero.

Steel production is extraordinarily energy-efficient, and consequently steel is remarkably cheap. As a result, it is used wastefully, and in most applications we could deliver the same end-user service from half the amount of steel used for twice as long – i.e. requiring only 25% of annual steel production. This strategy of material efficiency depends on practices in construction and manufacturing so is discussed further in sections 2.3 and 2.4.

## Non-ferrous metals

The production of non-ferrous metals is already almost completely electrified. The most notable example is aluminium production, which alone uses 3.5% of global electricity and the demand for this metal is currently growing rapidly. In theory, Aluminium recycling requires only 5% of the energy used to produce primary aluminium, although in reality with additional processing for cleaning scrap aluminium prior to melting it, diluting it with primary metal to control quality, and with inevitable downstream processing, a more accurate figure is around 30%. However, as demand for aluminium is growing rapidly, there is currently not enough scrap available to supply current demand, so within Absolute Zero future, primary production must continue - with output reduced in proportion to the supply of non-emitting electricity. Problems of contaminations which undermine the quality of recycled aluminium, could be a basis for innovation in improved processes to separate aluminium in end-of-life waste streams or modify composition in its liquid state.

## Critical metals

Critical metals are so called, because of their growing demand and risks associated to their supply. There are no problems of scarcity for these metals, but their global availability is very unequal — most reserves are concentrated in very few locations, often in countries with volatile political environments, and several critical metals are produced as by-products of other larger-volume metals. Most of the production processes for critical metals are already electrified, but these are very energy-intensive due to the need to concentrate these metals from ores in which they naturally have very low concentrations. Unfortunately, recycling critical metals may require even more energy than primary production, because they are typically used as alloys and it is more difficult to separate them from the complex mix of metals in recycling than from the more controlled compositions in which they are found in nature. Absolute Zero, which requires a significant expansion of electrification, is likely to increase demand for critical metals which enhance the performance of motors, but this demand will come at the cost of an unavoidable growth in demand for electric power.

## Ceramics

Ceramics and bricks are mostly produced from clays. These need to be vitrified at high temperatures in a kiln. Currently, heat is obtained from fossil fuel or waste combustions, but electric alternatives exist for all temperatures of kiln. Some colours in ceramics require reduction firing, which requires a stage in the kiln with a reducing atmosphere. This is currently obtained by fuel combustion, and thus alternatives to this practice will required. The 60% constraint on available electricity implies a 60% constraint on ceramics production in 2050.

## Mining

Mining uses energy for two main purposes: shifting rocks and mined products in heavy "yellow" vehicles, and crushing them to allow the chemical processes of extraction. Both uses can be electrified but at present, yellow vehicles largely run on diesel while the power for crushing and grinding depends on local conditions. Potentially, there may be more energy efficient technologies for crushing and grinding, but already there is a competitive market looking for these, so breakthroughs are unlikely. However, within the constraints of Absolute Zero, the elimination of coal and iron ore mining will significantly reduce the total energy demand of the sector, providing "head-room" in the non-emitting electrical-energy budget for the expansion of mining associated with wide-scale electrification.

## Glass

Most current glass production uses natural gas-fired furnaces. These could be electrified, but a reduction in production would be required in proportion with the available supply of emissions-free electricity.

## Fertilisers

$CO_2$ from ammonia production is currently captured and used for urea production. Urea is then used as a fertiliser, delivering nitrogen to the roots of plants and crops, but as urea decomposes in the soil it releases the embedded $CO_2$ to the atmosphere. Overall, 2 tonnes of $CO_2$ are produced per tonne of urea used. Ammonium nitrate is an alternative fertiliser to urea, but it is produced from ammonia, thus leading to the same emissions, although all occurring in the chemical plant.

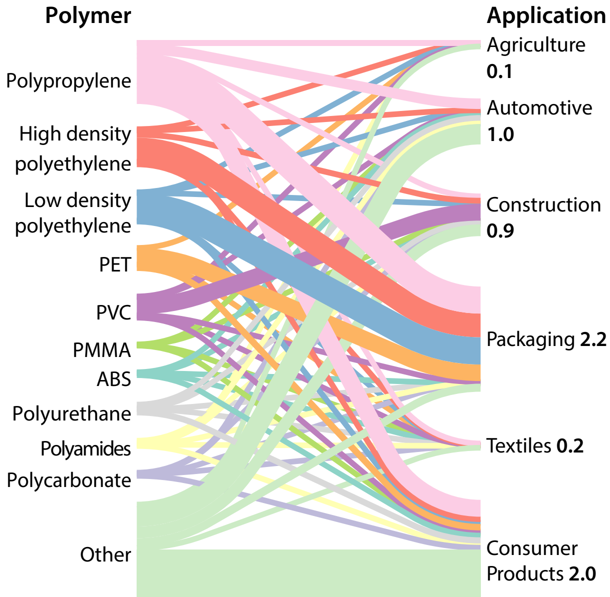
Carbon capture technologies could eventually be deployed, but this would only be compatible with a substantial reduction from current production. However, there are substantial opportunities to reduce energy use by reducing demand for fertilisers. Existing evidence suggests that more fertilisers are used than the nitrogen requirements to grow crops. For example, a study for the Netherlands shows that the use of fertilisers could be halved without loss in productivity, if used more efficiently.

## Plastics

Approximately 1 tonne of $CO_2$ is emitted per tonne of plastic produced, but more than double this $CO_2$ is produced when plastic waste is incinerated. Plastics are made from oil - and they are therefore the most valuable component of existing waste streams, if the waste is burnt for energy. However, if plastic is combusted, it is in effect a fossil-fuel. As a result, plastic incineration is not compatible with the goal of Absolute Zero.

Plastic can be recycled, rather than incinerated, either by mechanical or chemical means. Mechanical recycling preserves the chemical structure and composition of polymers, and is normal practice within existing manufacturing processes: scrap at the exit of a plastic extrusion machine, for example, can be fed directly back into the machine for re-extrusion. However, this is possible only when the composition is known and under control. The great attraction of plastics is that they can be tailored to every application - with different colours, densities, textures, strengths and other characteristics according to each design specification. However, this tremendous variation is a curse for recycling: in current mechanical recycling of end-of-life plastics, the composition of the resulting product is uncontrolled and therefore of little

Figure 2.16: UK polymer applications (Mt/ year)




value. Furthermore, plastic waste is often mixed with other materials, hence the levels of purity of new plastics cannot be achieved by recycling, which therefore leads inevitably to down-cycling. A frequent example is packaging PET, which cannot be recycled back to food-grade standards and is thus used in lower-value applications.

In contrast, in chemical recycling, polymers are broken down into their constituent monomers which are then recovered to synthesise new plastics. At present, it is only economically attractive to recycle plastics mechanically, requiring less than half of the energy for new production. However, in future, chemical recycling by pyrolysis and gasification may allow plastic waste recovery for high-value applications. As yet, it has proved difficult to operate pyrolysis processes at scale, they require high temperatures, and have yield losses of up to 40%, partly due to use of part of the feedstock to generate heat.

Recyclability is also dependent on the type of polymers available in waste streams. Figure 2.16 shows the annual flows of plastics in end-use products purchased in the UK by type of polymer and application. Although approximately 40% of annual plastics demand is used in packaging, these have short service lives and are quickly returned to waste streams. A great variety of polymers is used for each application, which hinders the identification and separation of polymers in waste streams, thus limiting the recyclability of plastics. Currently, land-filling plastics leads to almost no emissions. Plastics are stable when landfilled so do not generate methane. However, land-filling neither saves the production of new primary plastics, nor does it contribute to the future availability of material for recycling, unless it is cleaned and separated prior to landfill for storage.

## Other chemicals

The chemicals industry produces a wide variety of products. Methanol, olefins and aromatics are produced in much smaller quantities than most plastics and fertilisers, but are important precursors to a variety of chemical products. Emissions arise from energy uses and chemical processes. Although most energy uses can be electrified, it may be very difficult to continue producing many of today's chemicals without releasing process emissions.

## Paper

The paper industry globally uses a third of its energy from its own biomass feedstock. Yet, in Europe biomass accounts for half of its total energy requirements, suggesting a global potential for improvement. Absolute zero emissions would require a conversion of existing fossil fuel-based combined heat and power systems to electrical power processes. Given the constraint on non-emitting electricity availability required by chapter 1, then after complete electrification, paper production would be reduced by approximately 80% of current volumes, to be consistent with UK targets.

## Textiles

Most energy uses in the textile industry have already been electrified. However, leather production (which depends on cows) would not be compatible with Absolute Zero for the same reasons given for beef earlier. As washing, drying and ironing account for more than half of the energy uses for most clothing textiles, the industry could promote fabrics that need no ironing and support a reduction in the frequencies of washing and drying.

## Engineering composites

Novel nano-materials offer promising properties, which could enable the substitution of some metals across different applications. However, the current total volume of these materials could probably fit into a water bottle. For this reason, it seems unlikely that these materials will have any value in reducing demand for the bulk materials by 2050.

**Key Message:** Because of the emissions associated with their production, cement and new steel cannot be produced with zero emissions. Steel can be recycled effectively, but we need urgent innovation to find a cement supply. Under the conditions of Absolute Zero, the availability of most other materials will be proportion to the amount of non-emitting electricity available to the sector.

## 2.3 Resource Efficiency in Construction

Most emissions associated with the construction arise due to the use of materials: the process of erecting buildings and infrastructure requires little energy compared with making the required materials, which are predominantly steel and cement. Under the conditions of Absolute Zero, all steel used in construction will be from recycling - which is largely the case already in the USA, and poses no significant challenge. However, as discussed in the previous section, the industry must learn to make use of considerably less cement. A parsimonious use will make the transition to Absolute Zero possible without putting the material industry under impossible strain. Furthermore, all efficiency gains in one material usually cause reduction in the use of the other, because lower loads always translate to lower structural needs. Figure 2.17 shows the current uses of cement in the UK as a guide to the search for material efficiencies.

The causes of material *in*efficiency in construction are relatively well understood. The most common is over-specification. The amount of steel in a typical floor of a steel-framed building is about twice what the structural requirements would dictate. This is because the choice of steel beams or steel reinforcement in concrete slabs is not fully optimised and because the decking (the thickness and type of floor slab) is typically oversized.

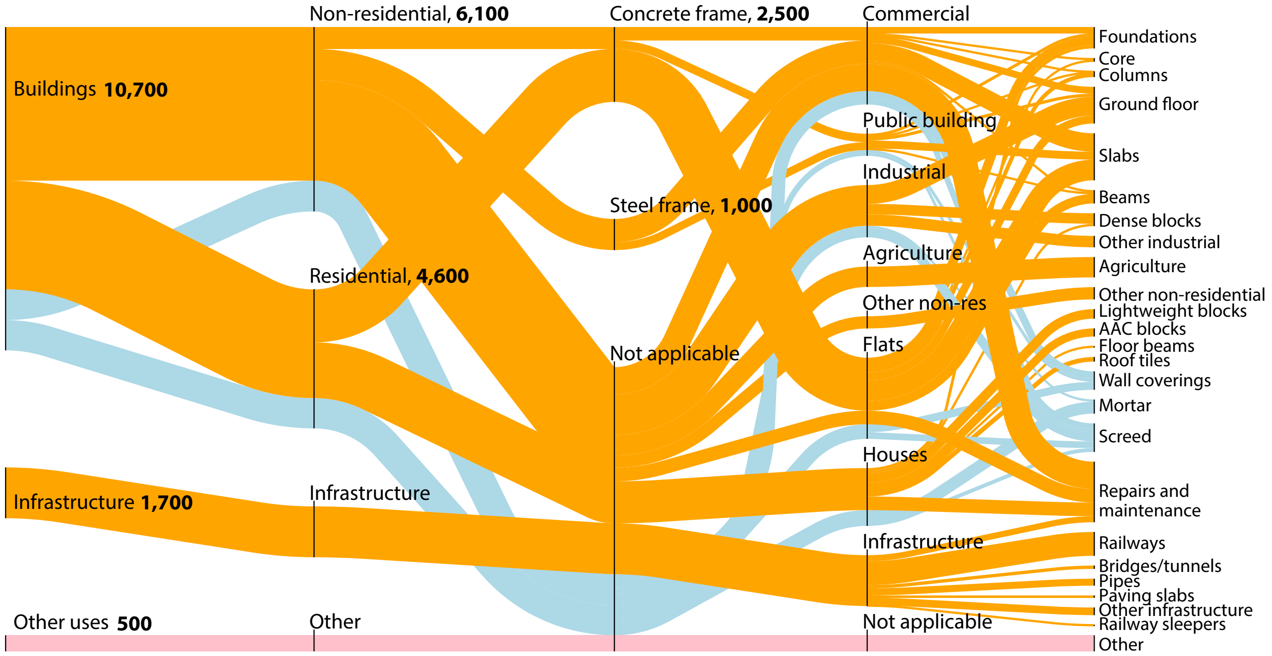
In current UK construction of steel-framed buildings, on average the steel is over-specified by a factor of two, even after accounting for our conservative safety factors. This does not mean that it would be possible to half the amount of steel, be we estimated that it was possible to save at least 15% of the mass of steel with no loss in service or safety. The deckings, are also oversized: the thickness of the concrete layer is larger than required, and the steel plate supporting the concrete in composite construction is frequently double the required thickness.

The building codes currently only specify the minimum amount of material to be used (including the margin of safety). But they could also enforce an upper limit, adding an "and no more" clause. There is also no existing benchmark to compare the embodied energy of the materials in a building per square metre of but this would help drive the efficiency of structural design.

In addition to these sources of over-specification, buildings are often designed for much higher loads than they will ever bear: gravity loading in buildings, predominantly from people, is specified to a far higher level than the physical proximity of groups of people could allow or that ventilation systems could sustain for life in the building. An overestimate of design loading leads directly to material being wasted in buildings. We do not routinely measure loading in buildings, and therefore a research effort is needed. Measuring loading in our buildings, would provide lessons from our existing buildings to transform structural design efficiency.

When specifying the vibration behaviour of buildings, which governs their "feel," engineers usually exceed the requirements of our building codes. However, in use this feel is usually governed by the choice of flooring and the location of partitions, but designers usually ignore those factors, which are not set when the structural frame is

**Figure 2.17: Current patterns of cement use in the UK (kT/yr)**



chosen. Therefore, a lot of effort goes into making stiff buildings, which require more material and which may be entirely wasted. Better methods of predicting the feel of buildings would help guide design towards more efficient outcomes.

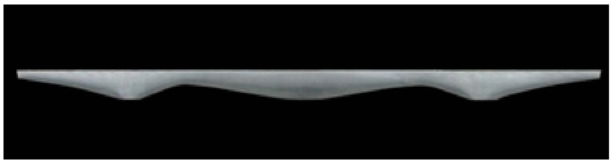
A further driver of inefficiency in our use of materials in construction, independent of over-specification, is the choice of structural form. The choice of the grid (the spacing between columns) is the most important factor in the $CO_2$ intensity of construction, yet there is little awareness of its importance. The carbon intensity of a building could double if very long spans are specified in preference to shorter ones, even when the users of such buildings frequently install partitions to sub-divide over-large rooms.

Scheming tools, which help guide early design towards a suitable architectural form are being developed. Currently, a designer is faced with a staggering array of options, not obviously different from each other, and will be naturally inclined to choose one with which they have experience. This is probably the cause of the over-design of decking. As the number of options grows – for example with growing enthusiasm for timber construction – the number of options in design will keep expanding, and designers may not be able to realise the promise of new constructions methods New scheming tools to support their decisions can halve the material requirements in construction.

The regularity of structures is also a currently underestimated source of in-efficiency: regular grids can be up to 20% more efficient than more complicated layouts. Novel tools can help structural designer make the right choices early in their projects, and link the choice of architectural form to the best currently available technology, as well as giving a context which may support architects to choose more efficient forms.

Resource efficiency can also be improved by using optimised structural members (slabs, beams, columns). Prismatic structural members in either concrete or steel are highly wasteful, because maximum stress in such members will only occur at one location along the entire length. Modern manufacturing processes can be used to specify appropriate structural shapes (e.g. fig. 2.18.) Even when designing flat concrete slabs, the pattern of reinforcement is rarely optimised, in part because a complex reinforcement pattern would increase the odds

**Figure 2.18: Concrete beam made with fabric formwork**



of errors on the construction site. New products such as reinforcement mats which have been tailored for specific site and can be simply unrolled have appeared, but they are not yet fully integrated in the design process of the structural design firms.

Finally using alternative construction material at scale will require considerable changes in design habits. Engineered timber, if it lives up to its promise, will probably take its place besides steel and concrete as a standard frame material. However, engineers are only now being trained to design with timber, and it will take time before it can be used broadly. The trade-off between building tall (probably using high-carbon materials) with low transport requirements, and building low-rise (using low-carbon materials) but with higher transport requirements in a more sprawling approach, needs to be explored.

Steel production, even using a fully recycled route is energy intensive. It would require less energy to re-use beams rather than recycling them by melting. Currently, steel reuse is only a marginal practice, mostly because steel fabrication is an efficient, streamlined process which relies on beams being standardised products. It would be possible to increase the rate of reuse if legislation was adapted to help the recertification of steel beams, but more importantly the construction value chain must develop to accommodate the collection and reconditioning of beams to make them ready for re-fabrication.

Together, these material efficiency techniques can considerably reduce the need for materials in construction. This is vital to reduce the requirement for cement production to manageable levels. Putting into place all of the material efficiency techniques described here would allow us to keep meeting the needs in fig. 2.17 with the cement supply implied by the second of fig. 2.12a and thus to meet the challenge of Absolute Zero.

**Key Message:** Construction uses half of all steel and all cement, but has developed to use them inefficiently. The requirements for materials in construction could be reduced to achieve Absolute Zero by avoiding over-specification and over-design, by structural otpimisation and with re-use.

## 2.4 Resource efficiency in manufacturing

The manufacturing of basic materials into products and goods is a major source of greenhouse gas emissions. For most products, manufacturing processes themselves cause a relatively small fraction of a product's total embodied emissions, compared to the material input – see Fig 2.19. However, constraints caused by manufacturing practices strongly influence both the material input, and emissions caused by the product during its use. Therefore, under the conditions of Absolute Zero, major changes in manufacturing are needed; driven not just by changes up and downstream of the sector, but also by the need for greater resource efficiency within it.

These changes have some impact on all products, but a critical priority in planning the delivery of Absolute Zero is to focus effort on the sectors with most impact. Having recognised that material production drives most current industrial emissions, figure 2.20 allocates the energy use in the first column of fig. 2.19 to applications to reveal the specific target sectors where material demand reduction is essential. Section 2.2 focused on construction, the single biggest user, and the strategies described there are relevant also to the non-cement components of infrastructure. But the figure clearly prioritises vehicles, industrial equipment and packaging for most attention.

**Figure 2.19: Energy use in Manufacturing & Construction**

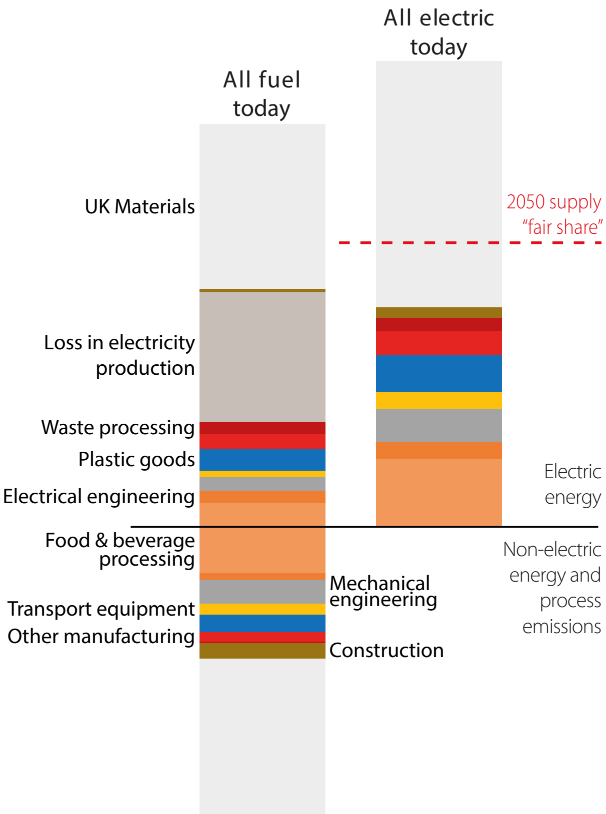
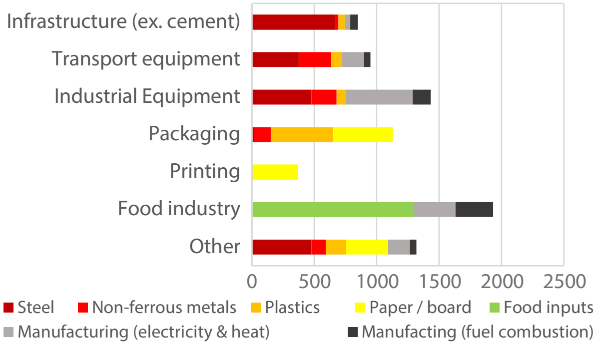



**Figure 2.20: Emissions of key product categories ($MtCO_{2e}$)**




## Responding to changed material availability

In section 2.2 we saw that the availability of materials which today directly emit greenhouse gases in their production will be reduced by 2050. This includes major raw materials such as steel from iron ore and cement, and multiple products of the chemical industry including F-gases, solvents, lubricants, and certain types of plastics. The knock-on effects for manufacturing are huge:

Lubrication is critical for much of manufacturing; from metal forming, to motors, pumps and compressors; but almost all current commercial lubricants are derived from fossil fuels and directly emit greenhouse gases by oxidation either in production or use and so – by a strict definition of absolute zero – are ruled out.

Similarly, solvents which emit Volatile Organic Compounds cannot be used. Yet these play a significant role in many industries, including paper coating, degreasing, printing and textiles, but also in coating or painting manufactured goods. Alternatives will be prized and their use widely expanded by 2050. Currently most steel used in manufacturing derives from iron ore; recycled steel is used almost exclusively in construction. New methods will be needed to shape, certify and steel derived from recycled sources. Processes will need greater tolerance to input variation.

Whilst cement and concrete are not widely used in manufactured goods, they are of course ubiquitous in industrial floors, machine foundations and the like: placing a significant constraint on future factories at a time when flexibility and adaptability is key.

## Meeting changed product requirements

By 2050 and beyond the product and composition of many manufacturing industries will be significantly different. For example, Chapter 1 anticipated a 3-fold increase in non-emitting electricity generation over the next 30 years which means that the need for energy storage will sky-rocket. Section 2.1 predicted major shifts in demand for transport equipment: large uptake in electric vehicles and an end to plane or ship building. Similarly, widespread electrification of domestic and industrial heating will require a massive increase associated equipment such as heat pumps. A shift to vegetarian diets would change the food industry significantly. Increased consumption of processed meat substitutes with lower emissions embodied in the food inputs, would require new processing capability and could need more energy in processing.

The scale of material and resource input to enable these changes is significant; looking at wind electricity generation alone, increasing capacity at the rate predicted creates the opportunity for a substantial increase UK industrial output. On the other hand, Section 2.1 anticipates that by 2050 consumers will require products that live for longer and can be used more intensively. This will present manufacturers with the challenge of producing higher quality, higher value products. These may be individually more materially intensive but, with a reduction in total volume of sales, manufacturers will see a reduction in their total throughput.

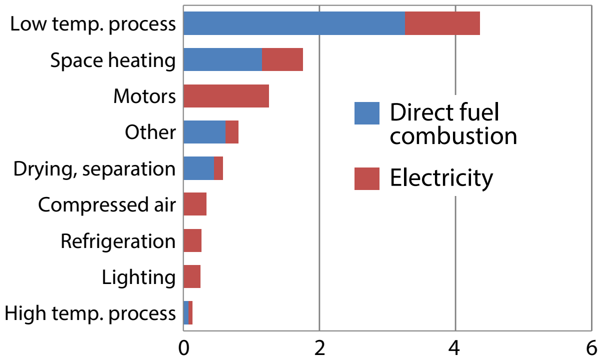
## Improving resource efficiency

In a world with much-reduced primary energy availability manufacturers will need to make a step change in resource efficiency; both in material and energy input.

## Material efficiency

Various material efficiency measures are technically possible in the manufacturing of goods, components and equipment, including the reduction of process scrap, optimised component design and re-use or re-purposing of components. Large emission savings are possible by reducing process scrap. In machining up to 90% of material can be wasted. For example, machining of aerospace fan blades from solid titanium can produce 90% waste in the form of machining chips. The paper industry produces pulp residue as waste containing high cellulose fibre and high calcium oxide, both of which can be used in fired clay brick production. Other uses are for land-filling, incineration, use in cement plants and brickworks, agricultural use and compost, anaerobic treatment and recycling.

**Figure 2.21: Annual energy use (MToe) of key processes**




The automotive industry in the UK generated 0.5% of the total commercial and industrial waste in the UK, at 1.85 million tonnes, 41% of which is metallic, 28% is mixed ordinary waste, 8% chemical and medical waste, and the remainder mineral, paper, wood and plastic. Many nascent technologies have been proposed that could reduce process scrap such as additive manufacturing, precision casting or forging and so on. However, the significant variation in performance between companies illustrated in fig. 2.22 suggests that the problem is just as much in the management of component and manufacturing design processes.

Shape optimisation of components could further reduce the material requirements of manufacturing. Whereas a given component - whether it is food or beverage can, drive shaft, or a structural beam – would often ideally have variable thickness along its length, or a hollow interior, current manufacturing process are not set up to produce such features. Material savings could be achieved by the development of new manufacturing processes: the economies of scale promote production of components with uniform cross-sections, but optimising material use would require a distribution, and new computer-controlled

**Figure 2.22: Material utilisation rates for selected cars**

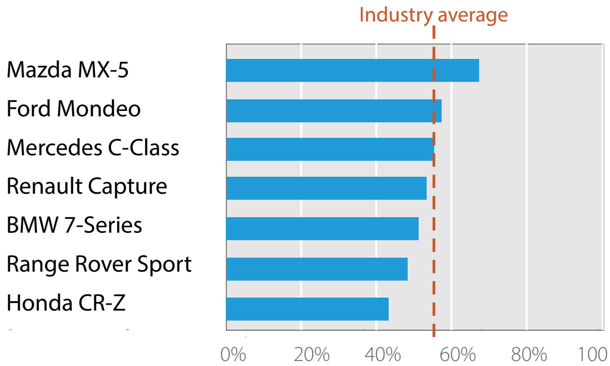
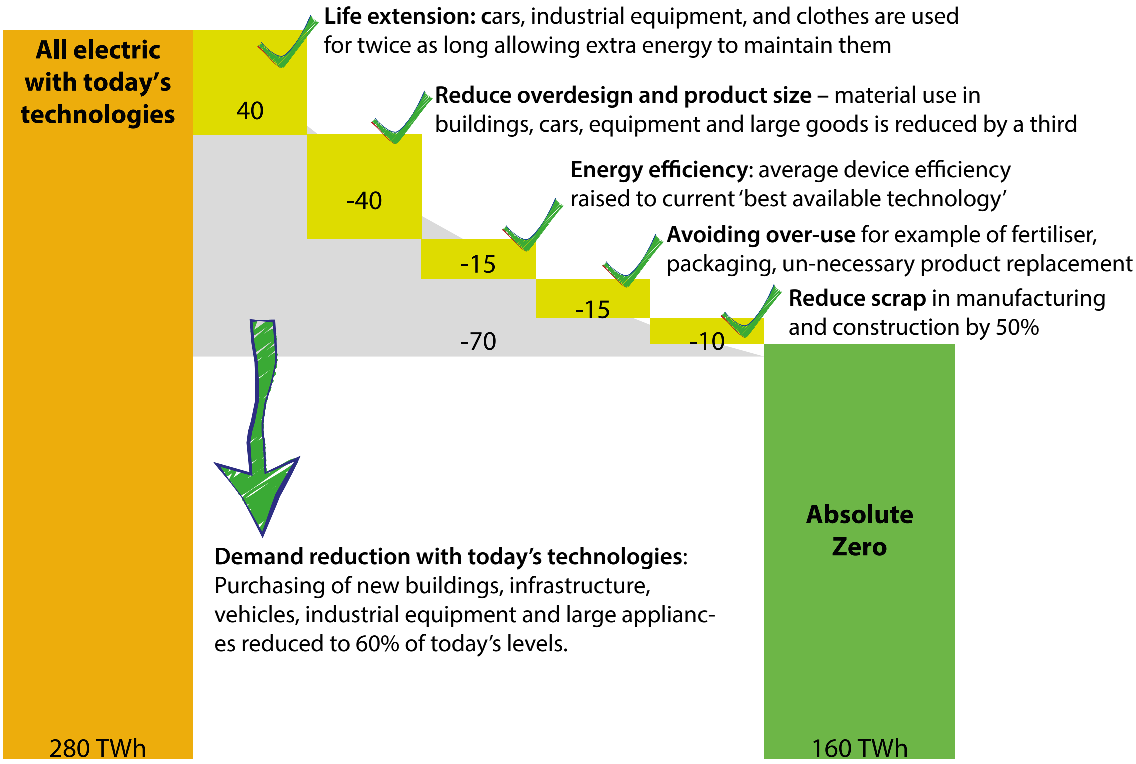


**Figure 2.23: Reducing energy use in manufacturing and construction with incremental technologies or reducing demand**




equipment can facilitate this change. Functional grading – generating different mechanical properties in different parts of the component - or using higher strength or lighter materials can also contribute.

Changes of the nature described have all been demonstrated at differing technical 'readiness' but their deployment requires large disruptive changes in management practices, skills and manufacturing processes.

## Energy efficiency

Direct energy use in manufacturing will need to reduce if electricity supply is restricted to zero-carbon sources by 2050. Some of this reduction could be achieved by energy efficiency. In the UK, the use of energy in downstream industries is dominated by low temperature process heating, space heating and motors, with a long tail of other uses as shown in fig 2.21. Recent estimates suggest that it may be possible to quarter electricity consumption over the next 10-15 years with the appropriate deployment of conventional technology such as motor drives, pump and compressed air efficiency measures, and the use of heat pumps.

## Product standards

Many positive changes are already occurring and many others seem both technically feasible and cost-saving in the long run. To deliver the rapid pace of improvement needed we propose that stretching and imaginative embodied emissions standards are phased in for almost all manufactured product and imposed equally on UK manufacturers and imported goods. Such standards are already widely familiar within manufacturing, whether for safety, inter-operability or use-phase energy efficiency. These must now be extended to embodied emissions and – as matter of urgency - be attached to the major programmes of industrial product development delivering the widespread changes in energy, transport equipment, food infrastructure. If these are imposed fairly on traded goods, it would create a great incentive for UK manufacturers to develop and benefit from the novel products and processes compatible with Absolute Zero.

Fig. 2.23 summarises the analysis of this and the previous section: the energy required to power UK manufacturing and construction, once electrified, can be reduced by a combination of changes to product specification and design, product longevity and process efficiency.

**Key Message:** Driven by inventive new embodied emissions standards, manufacturing will adapt to three major changes: 1) reduced availability of current inputs, 2) radically different product composition and requirements, and 3) the existential need for improved resource efficiency.

## 2.5 Breakthrough Technologies

The purpose of this report is to focus attention on how we can really deliver zero emissions by 2050, using today's technologies and incremental changes from them. This is because breakthrough technologies take a long time to deploy - as shown in the box story on page 10 - and we don't have enough time left. However, beyond 2050, new technologies will emerge to transform the energy and industrial landscape, and some of them will be those under development today.

The options surveyed on this page are therefore post-mitigation technologies: after we have met Absolute Zero through complete electrification, a 60% cut in energy demand and the elimination of emitting activities without substitutes, these technologies may later grow to be significant.

## Generation

Of the non-emitting technologies in current use, hydro-electricity is difficult to expand, due to geography, and as discussed earlier, the use of biomass for food will exclude its use at scale for energy generation. However, nuclear power could expand. Following the Fukushima disaster in 2011, Japan closed its nuclear reactors and Germany decided to move permanently away from them. However, France continues to generate much of its power from nuclear power, and in the UK, Hinckley Point C is under construction although this is a big, costly project with uncertain completion date. New "small" modular reactors are also under discussion. At present, none are operating world-wide, with two under construction, but potentially beyond 2050, these could make a significant addition to generation. More remotely, nuclear fusion which has been under development since the 1940's is still decades away from generating any energy even at laboratory scale, so cannot be included in planning.

Beyond wind and solar power, the other renewable generation technologies under development are geothermal, tidal and wave power. Geothermal generation which operates at scale in Iceland, New Zealand and Costa Rica is unlikely to be significant in the UK and is operated only at very small scale. Two large tidal power stations operate world-wide, in France and Korea, at a scale of about a quarter of a gigawatt, but although the Severn Estuary has been explored as an attractive site, the UK has no current plans for a first installation. World-wide there is no significant generation based on wave-power. As a result, while these are important areas for development, it is not possible to anticipate any significant new generation from these new renewable technologies.

## Energy storage and transfer

Wind and solar power are intermittent, so create a challenge of matching the availability of electricity supply to demand for its use. This can be addressed by storage (for example by batteries or the pumped hydro-station at Dinorwig) or by controlling demand to match availability, for example by allowing network operators to decide when domestic appliances and industrial processes can operate. There are already many developments in this area in the UK, and we assume that they can operate at sufficient scale in 2050 to prevent the need for excess generation.

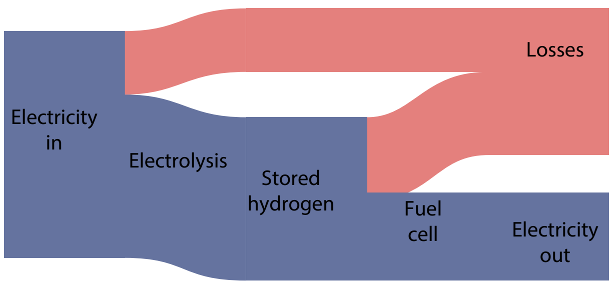
Batteries can operate at large scale, but remain heavy. For static applications this is not a problem but for transport it is constraining: the battery accounts for around one quarter of the weight of a two-tonne Tesla Model S. Technology developers have therefore looked for alternative forms of energy storage to use in transport, and found two important options: hydrogen and ammonia.

Hydrogen is currently produced mainly (95%) from fossil fuels by steam reforming methane, which leads to the release of a significant quantity of greenhouse gases offering no benefit as a form of energy storage. However, it can also be made from water by electrolysis, although as Figure 2.24 shows, this involves losses which depend on the application, but may be higher than those in the figure depending on the form of storage used. If, in future, we have an excess supply of electricity from non-emitting sources, we could use it to make hydrogen, which could then be used to power vehicles.

Ammonia combustion for shipping may be available in the future, but it currently leads to the production of NOx, which is a powerful air pollutant. Additionally, ammonia is currently produced from fossil fuels, which results in emissions. Although it is possible to use fuel cells to produce ammonia using renewable electricity, there is currently no such process in commercial operation, and its implementation at scale would again be an additional burden to the decarbonisation of the power grid.

One further opportunity for energy storage and transfer is through heat networks which capture "waste heat" from

**Figure 2.24: "Round-trip" efficiency of hydrogen storage**



industrial processes and use it, for example, for domestic heating. Around 1% of the UK's homes are heated by heat networks, but expanding this number has proved difficult due to the high cost of the required infrastructure.

## Emissions capture

Although not all related to the energy system, several novel approaches have been proposed to capture carbon emissions. Carbon Capture and Storage (CCS) is used to a very small extent by the oil industry to increase production through the process called "Enhanced Oil Recovery": compressed $CO_2$ is pumped into the rocks in which oil is stored to drive more of it to the well.

For over twenty years CCS has been proposed as the key technology to allow continued generation of electricity from gas and coal. However, the only power plant operating with CCS – the Boundary Dam project at Saskatchewan in Canada, a very small 0.1GW power station – does not produce transparent figures on performance, and when last reported on by researchers at MIT, was capturing but then releasing its emissions. This technology, despite the very well-funded lobby supported by the incumbent oil and gas industry, is far from mature or ready to be included in meaningful mitigation plans.

Plans for "Bio-energy CCS" or "BECCS" claim to be carbon negative – burning biomass and storing carbon permanently underground – are entirely implausible, due to the shortage of biomass, and should not be considered seriously.

Carbon Capture and Utilisation (CCU) has become a key technology promoted by the industrial operators of conventional plant, particularly the steel and cement industry, but it requires significant additional electrical input, which clearly will not be available before 2050. In future CCU allow conventional steel and cement production to re-start, but only when we have excess non-emitting electricity.

In fact, the idea of carbon capture and storage requires no new technology, as it could be developed by increasing the area of land committed to forestry or "afforestation". We aren't short of tree-seeds, and instead the world is experiencing deforestation under the pressure of needing land for agriculture to provide food. Planting new trees is the most important technology on this page, and does not require any technological innovation.

## Industrial processes

In addition to its potential application in energy storage, hydrogen creates a further opportunity in industrial processes because it is sufficiently reactive that it could be used to reduce iron ore to pig iron without releasing carbon emissions in the reaction. Steel has been produced at laboratory scale by hydrogen, and pilot plants are now being developed to demonstrate higher scale production. However, it will only be consistent with a zero-emissions future when the hydrogen is produced with non-emitting electricity, and we have no spare non-emitting electricity to allow this to happen.

Beyond 2050, the incumbent operators of blast furnace steel making, have several process concepts for making new steel from iron ore without emissions. The three main areas being discussed are: separating $CO_2$ from other blast furnace gases, and applying CCS to it; using hydrogen instead of coke to convert iron ore to steel; separating $CO_2$ from other blast furnace gases, and using it for other purposes via CCU. All three routes show rich technological opportunities, but will not be operating at scale before 2050.

## Flight and shipping

Electric planes are under development, but difficult: the limited rate of improvement in solar cell efficiency shown in fig. 1.10 suggests that solar power will be never be sufficient for multi-passenger commercial flight. Meanwhile, we have yet to find a sufficient breakthrough in battery development to anticipate sufficient light-weight storage. The most promising route appears to be synthetic jet-fuel - which, inevitably, will be important only after a substantial increase in non-emitting electricity generation.

The decarbonisation of shipping is difficult with current technologies. Although short-distance shipping can be electrified using battery-powered engines, long-distance shipping requires a combustion process. Nuclear propulsion of ships offers a viable alternative to current long-distance shipping and it is already used, although almost only in military vessels. Some commercial operators are currently exploring the opportunity to add sails to conventional ships to reduce their diesel requirements.

**Key Message:** The problem with breakthrough technologies is not our shortage of ideas, but the very long time required to take a laboratory-scale idea through the technical and commercial development cycle before it can begin to capture a substantial share of the world market.

# 3. Transitions:

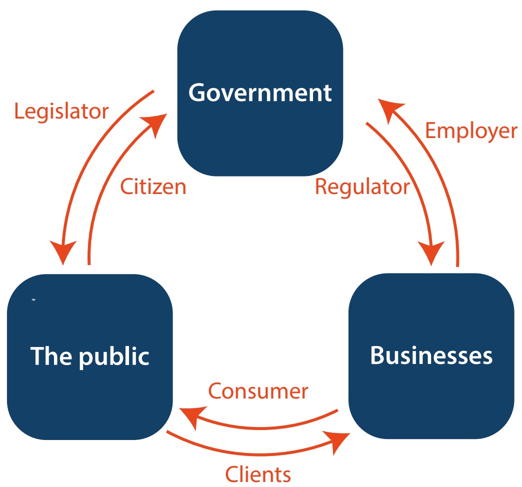
**Key Message:** No one actor can bring about Absolute Zero. Delivering it is a journey depending on co-operative action by individuals, businesses and governments acting on good information

## Absolute Zero is a journey

Action on climate change depends on the co-operation of three "players" illustrated in fig. 3.1. The public, the government and businesses must act jointly to transform the way we produce, consume and live. Large sections of the public are increasingly concerned with climate change, and some take individual actions such as eating less meat, looking for locally sourced products or taking the plane less often. Politically, this has translated to a growth in the support for Green parties across Europe. Businesses, driven by the demands of the public and driven to efficiency are seeking more efficient production methods and developing products consistent with a zero-emissions future. Governments embrace the drives of the public and businesses to grow the economy and gain votes.

Despite this goodwill towards change, the important transformations outlined in this report do not seem to be happening, or at least not at a sufficient pace. A key reason for this is that these transformations are attempted without the required trust building between the actors which can make them successful. The actors of change are in effect locked in a prisoners' dilemma, and the changes proposed make it seem like a static version of the game. The prisoner's dilemma is a theoretical game where the best outcome for the players cannot be achieved if the players only follow their own best interests. There are many variants to the story but in substance it runs like this: two bandits just successfully robbed a bank and were caught soon after for some minor offence. They are kept in separate cells, and each is told their accomplice has also been caught. They can defect and accuse their accomplice of the robbery, in which case they'll get at least a reduced sentence, or they can cooperate and refuse to accuse each other. Should they both defect, they'll both have a reduced sentence. Should they both cooperate, they'll both have a small fine, should one cooperate and the other defect, the defector will go out free and the cooperator will get a full sentence.

**Figure 3.1: The three "players" of climate mitigation**




Game theory predicts they should both defect: indeed, there is no outcome from cooperating which cannot be improved by defecting… Every day, all of us are faced with many such dilemmas – but every day we cooperate rather than defect! This is because the prisoner's dilemma when played over and over is a completely different game which is won by achieving cooperation. When considering the so-called iterated prisoner's dilemma, it's not single moves but strategies which matter. This is a well-studied problem, and the winning strategies which achieve cooperation share a number of basic characteristics: they punish defectors, they reward cooperators, they are simple enough that they can be understood by observers. Other research looking at how humans play in games compared to the predictions of game theory suggests another crucial quality of winning strategies: the cooperative strategies must also be fair. Marginally cooperative moves will be treated as defections.

Similarly, the transformation required for climate change mitigation needs to be played out like the repeated game, and not seen as a single huge step which will most likely be resisted and fail. Fortunately, three-player games favour cooperation somewhat, unlike the two-player variant. Unfortunately, having more players may drive each one individually to try and delay making changes. To achieve the scale of transformation required, small incremental changes are the immediately necessary steps to build and reinforce trust between the actors.

## Case study: re-using steel

Currently, most of the steel from demolitions is recycled. There is nothing else which can be done with the reinforcing steel of concrete, but steel beams having standard sections and not being damaged from their service as structural elements could be reused. If not directly, after some sand-blasting and the fitting of new connexions the beams are as good as new. Most of the research on the barriers to steel reuse focuses on the certification problem: steel to be used in construction needs to be certified, but the process of obtaining certification assumes the beam is coming out of a mill and is not transposable to already used beams. However, is is possible for a small price premium to test the beams and guarantee that they have all the appropriate properties.

What we found is that the key obstacle in the supply chain was that steel reuse puts the buyer of the building wanting to use steel from reuse and the fabricator responsible for the conditioning of beams in a prisoner's dilemma. Reconditioning the steel takes approximately twice the amount of time to condition a new steel beam direct from the foundry. Although the fabricator can charge for this time, a project being abandoned – always a risk in construction – will translate to large losses. Therefore, all projects that we could study where the fabricator was not part of the planning, failed. Our proposed solution is for steel stockist to take on the job of reconditioning and re-certifying steel so that the fabricators need never know whether the steel is from reuse or not. Acting as a trusted intermediary, this would avoid the project failures due to fabricators not wanting to shoulder all the risk. The upfront investment could be helped by government grants, and we showed that this would be overall profitable.

## Case study: Cycling in the Netherlands

After the second world war, the Netherlands had, like the rest of Europe embraced cars as a symbol of freedom and mobility and had built highways and roads to accommodate this new transport mode. In 1971 alone, 300 children died in the Netherlands from accidents involving cars, leading to widespread protests. In 1973-74 the oil crisis caused oil shortages, leading the Dutch government to look for strategies which would lower the oil dependency. The protesters were demanding a return to the biking culture which had been an important part of Dutch habits until the war, and the government took this occasion to launch a number of bike-friendly initiatives: a number of car-less Sundays in the years. Some city centres were made car-free. These moves proved popular and were followed by the construction of bike-specific infrastructure.

From the mid-70s onwards, bikes were integrated in urban planning decisions, meaning not only cycles paths being built, but traffic-calmed streets would be favoured, and bike parking be available at convenient locations, and bike traffic be integrated in the general public transport infrastructure. As the bicycle is seen as a symbol of the Netherlands, it was possible to pass more stringent legislation: for example since 1992, in an accident, it is always the motorist's insurance which is liable for the costs in the Netherlands. Safe interaction with bikes is part of passing one's driving license. As the popularity of bikes grow in the 90s and 2000, larger investments in bike infrastructure became possible with the support of the public, leading to even more bikes being ridden.

Overall, the current Dutch biking culture is the result of a long process where multiple changes to legislation, habits and infrastructure were self-reinforcing, leading to today's situation where the Netherlands is Europe's leader in km cycled.

## 3.1 Individuals – at home and at work

Protesters and school strikers have increased our awareness of the need to address climate change. An individual wanting to reduce their personal emissions can find a wealth of information on social media, websites and podcasts detailing actions they could take. Behavioural changes required to deliver zero emissions by 2050 are already being practised by some people in some places: some people already choose not to fly, to be vegan, to car share, to lower the temperatures in their homes and offices. If large scale social amplification could occur, as it did with the 'Me Too' movement, surely a cultural change could occur to enable zero emissions by 2050?

Although public awareness of the need to act has increased, the UK has not meaningfully reduced its resource use in recent decades, with the International Energy Agency reporting total final energy consumption has reduced by only 7% since 1990 levels. Individuals continue to use nearly as much energy as they did 30 years ago, suggesting that existing strategies to motivate individuals to use less energy are not generating the scale of impact required.

### Social norms and individual behaviours

There is a misalignment between the scale of actions recommended by government (e.g. energy conservation) and those most commonly performed by individuals (e.g. recycling) . Actions which can have a big effect, such as better insulation in houses and not flying, are being ignored in favour of small, high profile actions, such as not using plastic straws. This is enabling individuals to feel satisfied that they are 'doing their bit' without actually making the lifestyle changes required to meet the zero emissions target. If large scale social change is to be successful a new approach is needed.

Whilst the thought of society taking radical, meaningful steps to meet zero emission targets could be criticised for being idealistic, we can learn from historical cultural changes. Not long ago, smoking cigarettes was encouraged and considered to be acceptable in public spaces that children frequented, drink-driving was practiced with such regularity that it killed 1000 people per year in the UK, and discrimination based on sexual orientation was written into law. These behaviours now seem reprehensible, showing society is capable acknowledging the negative consequences of certain behaviours and socially outlawing their practice. Focus should therefore be centred on expediting the evolution of new social norms with confidence that change can happen.

Evidence from behavioural science, and the long experience in public health of changing behaviours around smoking and alcohol, shows that information alone is not enough to change behaviour. To make the types of changes described in this report, we will have to think more broadly on the economic and physical contexts in which designers, engineers and members of the public make decisions that determine carbon emissions. At the same time, clear, accurate and transparent information on problems and the efficacy of proposed solutions is essential for maintaining public support for policy interventions.

The phrasing of communication is also important. Messages framed about fear and climate crisis have been found to be ineffective at motivating change. The longevity of the challenge of reducing emissions, and the lack of immediate or even apparent consequences of small individual actions mean it is challenging to link to them to the large-scale climate crisis. This allows individuals to make decisions which contrast with their desire to reduce emissions. Scientific description is not always the most effective means of communication, and language used to promote zero emissions should no longer focus on an 'eco-friendly' and 'green' lexicon, but rather candid descriptions of actions that appeal to human fulfilment. Evidence from time-use studies shows that human fulfilment does not strictly depend on using energy – the activities we enjoy the most are the ones with the lowest energy requirements. Consumers can be satisfied in a zero emissions landscape.

### Individuals and industry

If net-zero targets are to be met, all of society needs to change, not just those motivated by the environment. Therefore, as well as persuading and supporting individuals to change with environmental campaigning and one-off sustainability projects, industry should embed a net-zero emissions strategy into business-as-usual, only offering products and services which meet their consumers' welfare needs without emissions.

This change will be driven by individuals acting in their professional capacity, as managers, designers, engineers, cost consultants, and so on. A structural engineer designing a concrete-framed building has vastly more influence over carbon emissions through their design decisions at work than through their personal lifestyle. Therefore, as well as the transitions in businesses discussed in the following section, this section applies also to individuals at work.

**Key Message:** Changes to social norms and individual behaviours can be positively framed to appeal to human fulfilment. Motivated individuals can be as effective at work as at home.

## 3.2 Transitions in businesses

Many of the opportunities and changes identified in the first sections of this report will involve businesses making changes to the types of technologies they use, or the way they use them. But this type of change can be difficult to motivate. This section examines why this is, and discusses the role of incentives, market pull, standardisation and collaboration in achieving the change required.

### Challenges in changing technologies for zero emissions

We are surrounded by a constant stream of innovation in technology in some areas – but in others, some industries have been slow to respond and to integrate relevant innovations into their operating models. In general, the introduction of new generations of products set the cadence of technology insertion. When new manufacturing technologies and processes are introduced, they are generally second-order technology insertions: that is, they are often not central to the functionality of the next product but are driven instead by improvements in cost, quality and logistics.

In such cases thorough assessment of technology merits, maturity and readiness are carried out, especially where change represents some form of risk. Without the driver of a new product launch, and associated new revenue stream, firms have displayed a risk-averse attitude towards significant technology-stack transformation. This is particularly true in instances of low product launch cadence and safety critically. In such cases, novel technologies have had to pass the test of time before being considered for full deployment.

Another reason behind gradual technology adoption is the lack of propensity to invest, especially in highly established industries where the cost of new capital would be prohibitive.

### Incentives for technology innovation

Using the "carrot and stick" analogy, it is easy to understand that innovation can have a difficult time permeating into an organisation without the right type of leverage and motivation. Governments can impose additional taxes, policies and regulations to achieve the desired changes but this could be short lived with the next batch of policy changes. Emissions and energy caps can be seen as a "stick" but financial rewards and customer-valued green credentials will be perceived as a "carrot".

Ideally there should be a market pull that is driven by the end customer. Organisations are more likely to adopt innovation and technology when there is a direct correlation to increased revenue and returns. They are also more likely to pursue targets that result in products and services that use less resources but still valued equally or greater by the customer.

Consumers are more aware of the macro effects of their purchasing choices and there is a move towards companies that have the same brand values. For a business, this can be hard to benefit from, as these qualities are not easily visible to the end customer. As well as changing the manufacturing process and business practises towards a less carbon intensive model, they also have to spend money on advertising and branding so potential customer are informed of these less visible changes and benefits.

The achievement of absolute zero almost certainly requires life extension and better utilisation of certain categories of product, but with progressive insertion of more sustainable manufacturing and through-life engineering technologies throughout life in service. This position is contrary to the situation described above, and requires a new mechanism to establish a cadence of positive technological changes. The most obvious means of establishing such a cadence via public intervention would be the establishment, and acceptance, of some form of 'roadmap' which sets out progress, time bound improvement targets.

### The role of standardisation

Standardisation can play a significant role in reducing industrial and domestic energy use and CO2 production. In many industries, standardisation and sharing best practice have paved the way to less resource duplication and greater customer experience. An example that is often mentioned is the light bulb but a more modern example would be the phone charger. In the early days of the mobile phone industry, not only did every manufacturer have their own chargers but every model had its own connector type. Once customer habits were analysed, it was found that customers wanted to upgrade to a new phone every few years, therefore very quickly there would be a build-up of useless chargers and connectors ending up in landfills. Several of the major manufactures developed a standard charger and connector that would be used for all models going forward. This had 4 main benefits:

- Reduction in unnecessary charger variation and legacy part production.
- Increased customer experience as phones could be charged with any charger and no longer limited to one connector.
- Phone manufacturers diverting funds and resources away from charger and connector design into other parts of the product that were more valued by the

customer.

- Users investing in higher quality chargers that could be used for years without needing replacement and a reduction in E-waste.

In other industries current practice often requires specialised components and parts that are designed specifically for their intended use. With standardisation comes the reduction in design flexibility. In an already saturated market place, businesses are trying to differentiate their products and services form one another. Customisation currently allows them to achieve these goals, but as discussed above, in future the environmental benefits of standardisation could provide an alternative source of differentiation.

It is possible that the progressive roll-out of standards over time could form a central and tangible element of any roadmap for achieving absolute zero. The development of standards which drive positive change would however be entirely reliant on some key principals of backward compatibility, such that the implementation of each new standard avoids immediate obsolescence of existing assets.

## Making collaboration work

The achievement of absolute zero seems to be beyond the ability of individual firms, and even nations, to enact. It requires a level of cooperation which has perhaps only been seen during times of war.

Moving beyond the purely competition model and integrating some learning from the collaboration model can be beneficial to competitors as well as the environment. As well as eliminating obvious duplication of resources, a new level of cooperation would be needed so that the benefits of shared learning can rapidly permeate through supply chains, and horizontally across sectors. This presents a more complex legal and organisational challenge to the traditional manufacturing and business model, but one which could create new opportunities for early adopters.

The necessary transition will incorporate the current move beyond the traditional manufacturing line to more flexible manufacturing for increased agility while taking a balanced and holistic planning approach to enable through life considerations to be made. The role of analysis in this model based on increased computing power, but also the carbon impact of data storage and transfer is a complex one. Gathering information on the whole manufacturing process from all participants in the supply chain and then analysing the results to produce the holistic resource usage is one of the ways to truly understand what goes into the final product. Insights from this information will allow for the development of a valid roadmap to absolute zero, but there are challenges to obtaining and using this information that will be discussed later, in section 3.4.

## A look to the future

Technology innovation and change readiness is becoming a desirable quality. With shortening product life cycles, organisations need to adopt a more agile approach to respond to market needs. Catering to this consumer mentality has led to the production of lower quality products that fail in the time the consumer would be looking to upgrade or replace the product. An extension of through-life engineering approaches beyond ultra-high capital value assets into more mainstream consumer products is needed. Essentially this means producing much higher quality products with parts that can be dismantled, retrieved and reused. Products could either be disassembled and reassembled with some modifications and resold or they could be cascaded down into a completely new product. This would require forward planning, standardisation and modular design thinking.

Organisational and inter-organisational culture will need to match the aspiration of absolute zero over time to become, itself the great incentive and driver of a positive cadence of change. No organisation can outrun their legacy, therefore a roadmap that commits them to real change while keeping the business profitable now and in the future is desirable.

This section has focused on technology transitions in existing businesses, but successful disruptive transformations often come from outsiders and new players. Therefore, support mechanisms also need to exist for new businesses bringing zero-carbon-compatible business models and production processes as an alternative to the status quo.

**Key Message:** Agreed roadmaps, new forms of market pull and collaboration are needed to spread the required technological innovation through industry.

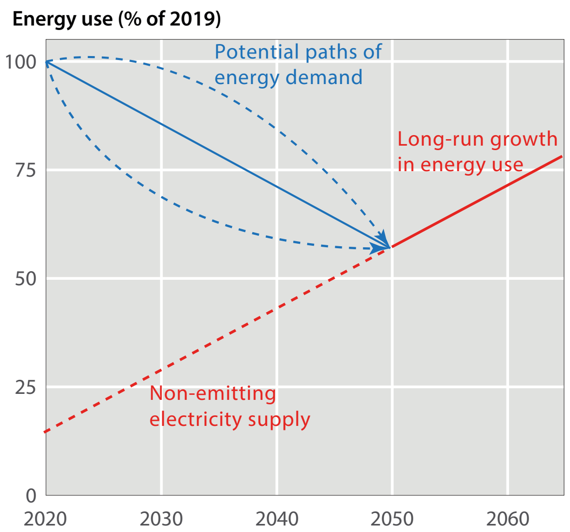
## 3.3 Action by Government

The government will need to act to create the context in which the individual and supply-chain changes described in the previous sections can develop. There is also a strategic choice about the speed of transition which should be pursued.

Figure 3.2 shows three potential paths for energy reduction to reach Absolute Zero in 2050. This is predicated on growth in the supply of energy from renewables growing at the rate indicated in figure 1.1. This means that demand has to reduce to 60% of its current level by 2050. Growth in energy use beyond 2050 will be driven by ongoing renewable and other carbon-free technologies. The distinction between the pre-2050 and post-2050 analysis is that the steps taken to meet the 2050 target must rely on technologies which are already in existence, and have the clear mechanisms to be scaled, whereas post-2050 growth can reflect new technologies. The three potential paths for energy reduction reflect three different approaches, depending on the extent of delay. What these three paths do not show is that the cost or sacrifice needed for an extra percentage point reduction is not constant: initial reductions are likely to be much easier. This in turn implies that if the desire is to spread the cost of reduction equally over the 30 years to Absolute Zero, then the actual path needs to reflect a sharp early decline, as in the dashed red line.

Absolute zero means two things: first, that no carbon can be produced by any industry or household; second, averaged across the economy, energy consumption must fall to 30% of its current level. This distinction between the carbon reduction, which is an obligation on all industries, and an energy reduction which is on the average, leads to very different substitution possibilities: there are no substitutes for the reduction of carbon to zero, but there needs to be a mechanism for allocating scarce energy resources. Ensuring carbon is at zero is a regulation issue, with prohibitions on the use of carbon similar to prohibitions on the use of asbestos. Ensuring energy is cut in the aggregate requires an allocation mechanism, and the price of energy to reflect its scarcity. In such a scenario, the owners of the means of production of renewable energy will make very large profits. This in turn raises both efficiency and distributional issues.

**Figure 3.2: Pathways of restraint and growth**




We break the discussion into four components: first, on the possibilities for substitution away from Carbon and energy use across different sectors; second, on the impact on the types of job and the location of jobs; third, on the overall impact on output; and finally, on the implementation.

## Production Substitution

At the heart of understanding the impact on the economy of Absolute Zero is an understanding of the substitution possibilities away from Carbon and energy in different industries and production processes.

Section 2.3 discusses the options for the construction sector: the production of cement involves the emission of carbon and so cement in its current form cannot be used in construction. At present there is no alternative to the use of cement and so the construction industry has to radically change its production process or close. In this case, radically change means either reverting to using wood or other natural products (but this in turn limits the size of buildings and so the sector cannot continue as it is), or successfully developing the alternatives to current cement production described in Section 2.2, but this in turn limits the size of buildings and the sector cannot continue as it is. This has implications for the way in which businesses and households operate. Buildings need to be reused rather than rebuilt. On the other hand, it is not clear how the existing stock of buildings will be maintained, and the conclusion is that building space (residential and commercial) will have an ever increasing premium

The difficulty of the construction industry highlights the impact on any assets being used in an industry where there are no substitutes for carbon – such as planes, or industrial plants. The value of these assets will be zero in 2050 and this should directly affect the desire to invest in those assets now. This points to the implementation issue: realising the value will be zero in 2050 may encourage greater use in the run up to 2050 – for example, putting up new buildings at a much faster rate for the next 30 years, knowing that construction must then halt. On the other hand, Figure 1.1 makes clear that the value of investment in processes of carbon-neutral energy production will increase sharply.

## Jobs and Location

There are two key implications for how we live our lives: first, buildings will become much more expensive because the restrictions on building which generate substantial scarcities; second, transport will become much more expensive because the limits on air travel will generate excess demand for other forms of transport. By expensive, we mean the direct costs to an individual or firm, but also indirect costs in terms of reduced quality. We would expect these two substantial changes to lead to pressure on the amount of space any one individual uses, and also where people choose to live and work. This points to increased centralisation, with growth in cities.

The wider problem with the changes in labour is knowing what type of labour or jobs will be in demand. Those who are starting secondary school now, in 2019, will be 43 in 2050. Thinking about what education is appropriate for a very different set of industries is a key question. Should we still be training airplane pilots? Or aeronautical engineers? How are we training architects, civil engineers? Education decisions are far more persistent than capital investments. This in turn highlights the needs to take decisions on investments now where the lead times are very long or depreciation rates very low.

## Overall Impact on Output

Economic growth in the industrialised world has been associated with increasing energy use. Long-term growth rates will also be constrained by the rate at which energy production can grow which depends on the growth rate of renewables. The key question in the transition is how much will output decline to reach a level where only 30% of current energy is being used and no carbon is being produced. We have discussed the direct impact of this on the construction and transport sectors. What this misses is the inter-dependence of the non-emitting and emitting sectors. Specialisation in production and the substitution of energy for labour have been key drivers for growth and increased productivity. The open question is whether specialisation can still be achieved without the reliance on energy.

These impacts on output will not be felt equally across the country. Industries are typically geographically concentrated – such as steel production – and this means that large shifts in production will have concentrated impacts. Rural or more isolated communities are likely to be disproportionately affected. The largest distributional impact, however, is intergenerational: the cost of hitting Absolute Zero will be borne by the current generation.

## Implementation

The changes in behaviour to achieve Absolute Zero are clearly substantial. In principle, these changes could be induced through changing prices and thus providing clear incentives for behaviour to change. The alternative is that the government prohibits certain types of behaviour and regulates on production processes. Given the difficulty for the government of knowing what production process to change or what options for innovation are available to companies, the natural decentralised solution is for the government to either put a price on carbon or to restrict its use directly. The push for Absolute Zero means the distinction between these two approaches is irrelevant: the price of carbon must be prohibitively large by 2050 to stop all demand. In the run-up to 2050, the question is how fast must the price of carbon be increased, or equivalently, how fast must restrictions on the use of carbon be put in place. It is understanding this time-line for the price increase (or time-line for the strictness of restrictions on use) which is the key issue for the implementation.

The underlying point is that any asset which uses carbon will have essentially zero value in 2050. This in turn may encourage greater use in the run up to 2050 – for example, putting up new buildings at a much faster rate for the next 30 years, knowing that construction must then halt. This sort of response is clearly counter-productive: the climate problem is about the stock of carbon, rather than the flow.

A natural question in considering implementation of the 2050 is how to evaluate the cost to the economy of various measures. For example, how to compare the cost of installing solar panels to the cost of driving smaller cars. Individuals' willingness to pay gives a measure of the value of installing solar panels (rather than take electricity from the grid) or the value of driving a small car (rather than a larger one with the same functionality).

**Key Message:** The effective price of carbon must be prohibitively large by 2050. A key issue for how to implement this is the timeline for how the price must grow (or restrictions must become more strict) from now to 2050.

## 3.4 Information

Information has a critical role to play in guiding transition to absolute zero emissions. Data about our present situation is needed to prioritise change and innovation, to monitor progress, and to identify 'bright spots' of good practice. We also need to understand how the future might develop and how we can make choices now that are robust to future uncertainty. However, information alone is not sufficient to cause actual changes in behaviour, and we should be aware of lessons from behavioural science to maximise the effectiveness of information.

### Information on the present

Understanding the current scale of our different activities that drive emissions is key to prioritising the behaviour changes and technical innovations that would most effectively lead to emissions reductions at the scale required. Put simply, the impact of a change (whether behavioural or technical) can be represented as:

$$\text{Impact of change} = \text{Scale} \times \text{Change in flow} \times \text{Impact of flow}$$

For example, in construction it is possible to use post-tensioned floor slabs in place of the standard slab types, to achieve a 20% reduction in cement use (the 'change in flow' of cement entering construction). However, this technique is only applicable to a fraction of all the floor slabs that are constructed (the 'scale'), and the overall impact depends on the impact factor of the flow (in this case, GHG emissions per tonne of cement). Clearly, the overall impact of a change depends on all of these factors. An understanding of all three is critical to formulating a roadmap for change (Section 3.2) that can really reach absolute zero emissions. The same applies to research agendas, where there has been more research and policy interest in reducing food waste than on reducing meat consumption, despite the former contributing an estimated 1–2% to emissions and the latter an estimated 50% . Data on how things are currently happening can also support change through identifying 'bright spots' where good practice is already happening .

### Looking to the future

However, understanding the present is not enough. Many of the decisions that will influence emissions in 2050 must be made far in advance, such as designing buildings, investing in energy infrastructure and car manufacturing plants (Section 1). These decisions should ideally be robust to a wide range of possible future outcomes, such as faster- or slower-than- expected deployment of zero-carbon energy supplies, or higher or lower loading requirements for buildings in use. When this is not done

well, the result is the situation described in Section 2.3, where structural designs are routinely excessively sized, leading to proportionally excessive carbon emissions. In contrast, it has been shown that an initially-smaller design that allows for reinforcement to be added to beams in future, if needed, would lead to lower lifetime emissions .

There are many possible pathways to zero emissions in 2050, and different reports can reach very different conclusions from by focusing on different scenarios. To provide clarity on our options to reaching Absolute Zero, we need to compare different proposals on a common basis and highlight the different starting assumptions that lead to different conclusions (see box story for an example).

### Getting better information

Despite these important roles that information about our use of resources plays, the data we have is patchy and disconnected. There are two basic ways the situation can be improved: collecting better data, and making smarter use of the limited data we do have.

The UK Government's Resources and Waste Strategy has recognised that 'lack of reliable data on the availability of secondary materials is cited by industry as a barrier to their use', and proposes a National Materials Datahub to address this issue by providing 'comprehensive data on the availability of raw and secondary materials, including chemicals, across the economy to industry and the public sector, and by modelling scenarios around material availability'. The Office for National Statistics is leading the initial development of such a Datahub. As well as official statistics such as these, there is a large body of evidence contained in academic work which is currently difficult to access. Efforts towards Open Science practices ins fields such as Industrial Ecology are starting to improve the discoverability and reusability of this knowledge.

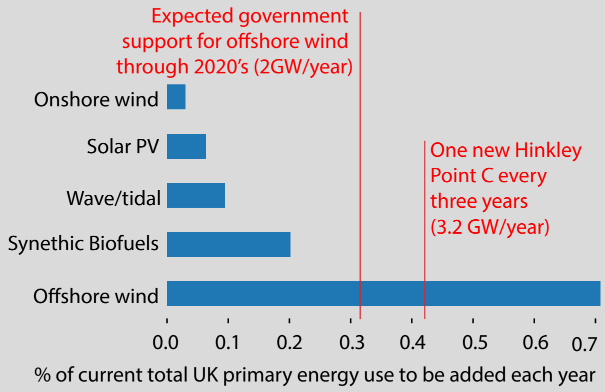
Better information will also be needed within and across supply chains, but there are challenges that will have to be overcome before this can be achieved. The first

## Why aren't all plans for zero emissions the same?

Several reports have presented scenarios for how we could achieve net-zero emissions in 2050, such as the Centre for Alternative Technology's "Zero Carbon Britain" report. Unlike the need to reduce absolute energy use described in this report, they find instead that "industrial energy use is expected to remain similar to current levels". How is it possible to reach such a different conclusion on the same question?

It is easier to see the differences by looking at the different assumptions made about the energy system. The figure on the right shows the deployment rates implied by their scenario, together with some reference points to provide context. The Zero Carbon Britain report has much more optimistic assumptions about the deployment rates of renewable generation technologies, especially very early-stage technologies such as producing liquid fuels from biomass – which has not yet been proven at commercial scale – and wave & tidal generation. Assumed deployment rates for offshore wind are also high, requiring a doubling in the speed of installation envisaged in the Governments plans for support through the 2020s.

**Figure 3.3: Rates of increase in "Zero Carbon Britain"**




is information gathering: it is still not normal practice by suppliers to gather information on all facets of their manufacturing process. Secondly, for business to share collected data with rest of the chain rather than storing in silos. Current corporate practices mean information is often not shared even with different groups within the same organisation let alone with "outsiders". In the information age, industry has remained closed to information out-flow. This may be attributed to good reasons, but the achievement of absolute zero requires, possibly above all else, the will to cooperate. The final challenge is analysis of the data and making sense of it. Gathering, storing, processing and presenting data is an energy intensive and expensive task, therefore currently most organisations do not have the appetite to undertake this without proven returns.

Digital tools can potentially help to enable this position. A universal and global approach to IP law and the tracking of information using technologies such as blockchain can greatly increase the confidence of organisations into opening their doors and sharing more of their information. By doing so it is possible to dramatic reduce resource duplication whilst enhancing visibility of resource usage. This could allow businesses to make long-term strategical decisions that lead to higher profitability whilst reducing energy usage and $CO_2$ production.

**Key Message:** Good information is critical to transitions in individual behaviour, business operations and in supporting government action, but there are challenges to overcome in collecting and communicating the required information effectively to support decisions and influence behaviour.

# 4. Opportunity

**Key Message:** Absolute zero requires societal change. This will provide opportunities for growth in business, education and research, governance and industrial strategy. To achieve zero emissions we must only pursue the right opportunities and restrain activities which are no longer compatible with a zero emission society.

## 4.1 Opportunities in business:

This report has revealed an overwhelming wealth of innovation potential for businesses – but not in the area that dominates current discussion about mitigating climate change. Carbon Capture and Storage or Utilisation and "the Hydrogen economy" are important development opportunities and may be significant beyond 2050, but won't play any significant part in national or global emissions reductions by 2050, because implementation at meaningful scale will take too long. Instead, taking the target of Absolute Zero seriously requires a massive expansion of wind and solar power generation, along with the infrastructure required to install, manage and deliver this power and the fertile supply chains of material extraction, production, construction and manufacturing.

The key innovation opportunities revealed in this report are not about how we generate energy, but how we use it. Meeting the target of Absolute Zero requires adapting to using around 60% of the energy we consume today, which without innovation will require restraint. However, section 2 of the report has revealed a tremendous space for business innovation and growth in expanding the benefit we receive from energy use. For the past century, our economy has grown based on an assumption of virtually unlimited energy supply without consequences. Unsurprisingly, this has led to extremely inefficient use – for example with cars weighing around 12 times more than the people within them. The more rapidly the UK commits to delivering its legally binding target, the greater the benefit it will extract from business innovation opportunities. Without question, some incumbent businesses such as the fossil fuel industries, will decline and inevitably they currently spend the most money on lobbying the government to claim that they are part of the solution. This is unlikely.

Instead, future UK growth depends on exploiting the opportunities created by the restraint of Absolute Zero. For example:

- All current aviation activity will be phased out within 30 years, which creates an extraordinary opportunity for other forms of international communication (for example using the technologies of today's gaming industry to transform today's backwards-looking video-conferencing), for the travel and leisure industry to expand more localised vacations and for developments in non-emitting mid-range transport such as electric trains and buses
- The markets for electric cars, electric heating at all scales and temperatures, electric motors at all scales, building retrofit and thermal control are certain to grow at rates far ahead of the recent past. Electric cars comprise a small fraction of new sales today, but under current regulation will, by 2040, have captured 100% of the market. Given the total energy supply constraint of Absolute Zero, the clear evidence of figure 2.6 is that the total market will either contract or shift rapidly towards smaller vehicles – this is a fertile and under-populated space.
- Cement and blast furnace steel production will be illegal within 30 years, yet our demand for construction and manufacturing will continue. To meet this demand our supply of bulk materials must transform and there is high-volume innovation potential for non-emitting cement substitutes, for technologies to support high-quality steel recycling, and in the open space of "material efficiency": using half the material per product and keeping the products in use for twice as long.

Beyond the 2050 target of Absolute Zero, technologies that exist at early development stages today may expand into valuable business streams. These include:

- Carbon Capture and Storage or Utilisation applied to fossil fuel power stations, steel or cement production.
- The "hydrogen economy" once there is spare capacity in the supply of non-emitting electricity
- Other forms of electrical transport, including shipping and aviation

The 100% target of the Climate Change Act creates an extraordinary opportunity for UK business to develop the goods and services that will be the basis of a future global economy. However, the biggest commercial opportunities are not breakthrough but incremental developments from today's technologies.

## 4.2 Opportunities in welfare and education

Today's secondary school entrants will be 43 in 2050. At that age, they will be in leadership positions, so the obvious question is what skills they should be developing now and in their subsequent higher-education years to underpin their decision-making abilities in a very different future world? The legacy of education is surely to know that it is the quality of the questions which one is able to ask which will lead to success. Asking the right questions is a sign of deep education, while answering these questions is an altogether easier proposition even if research is needed.

How do we move from answering questions as the staple of education to asking questions as the hallmark of a necessary education for future uncertainty? Climate change provides us with exactly this opportunity. Some of the current syllabi in secondary schools will be irrelevant in future, and there will be new skills that school children will require. The same is true in universities, both in teaching and in research, where a clear distinction must be made between mitigation actions that can be deployed today through chosen restraint and innovations that might ease the challenge of restraint in future. The former implies hard decision-making, while the latter implies real opportunity.

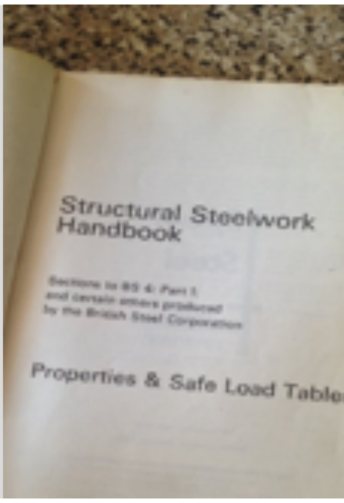
Starting with the difficult decisions, an educational setting should provide a timeline for actions to be taken by humanity in order to ensure that we hit our carbon-reduction targets by 2050. Plans cannot merely relate to actions. They must also relate to the timings of such actions, as any Gantt Chart does. By working backwards from 2050, and sequentially working out the order and timing in which key mitigation actions need to be taken, a roadmap for the necessary restraint can be established. Across the secondary school system, this roadmap is essential in eliciting the questions which will inevitably come from the school children. This will enable an exploration of real change in the mind sets of those who will need to embrace change more than ever before later in their lives. Huge questions will emerge, such as: will internal-combustion engines disappear, will aeroplanes disappear, will meat-and-dairy agriculture disappear and will we need to stop building things? By empowering school children to realise that asking the huge questions is appropriate, we will enable change to be embraced through education. The timing of the change should lead to questions of transition towards electrification, or the trade-offs between energy and labour in delivering services across a whole range of economic activities, for instance. What are the implications for consumption or ownership in a changing society, and how can we ensure that material use down to the finest granularity is all encapsulated in circularity?

Across the education system, we should be seizing the opportunity for the next generation to grow up with 'best practice': from the food available in schools, the way

## Changing Building Design Practices through Education in the 1970's

In the 1970's, British Steel saw an opportunity to expand their market for structural steel sections, by persuading UK clients and the construction supply chain to switch from concrete framed buildings (which remain more common in many European countries even today) to steel framed buildings, like the one illustrated on page 35. Instead of seeking Government support to subsidise or legislate to support this change, they instead developed high quality teaching material and supported the development of new courses in all major civil engineering degree courses about design with steel. As a result, the next generation of graduate civil engineers entering the profession were equipped to use more steel, and expected it to be more normal practice.

This suggests an opportunity to develop teaching material that reconfigures society to adopt new approaches to thriving in a zero carbon economy, by changing the way we live and work.




children get to school, to the way school buildings are used. All schools could immediately switch to providing meat-free meals – reducing emissions and promoting healthy eating. Existing efforts to change travel habits aimed at avoiding local air pollution around school gates can be extended to support parents and children in low-carbon travel to school wherever possible. Many schools already feel the need to keep heating temperatures low in an effort to make severely constrained budgets balance, which is a side-effect that could be standardised across the system to help establish the normality of lower-energy, lower-temperature heating setpoints.

Looking beyond the need for this kind of restraint in the short term, there are enormous opportunities in education which we could be embracing now to ensure that when the painful period of mitigation nears an end, we have an educated population ready to take advantage of the zero-carbon era. We do not have the luxury of time to wait for graduates to emerge who know something about future possibilities. We need to exploit the creativity, intelligence and ideas of our students before they have graduated. But what are the innovations which we should be teaching? We are still researching them, and research takes time.

A potential solution to this unwanted time dependency is Vertically Integrated Projects (VIP), a concept developed by Georgia Tech, and which is now also operating successfully at the University of Strathclyde in the UK. In essence, undergraduate students across all years of study are involved in major inter-disciplinary research projects, each of which is aimed at a long-term complex research question. Strathclyde ensures that the 17 UN Sustainable Development Goals are central to their VIPs. In this way, undergraduate students not only learn key skills for the future, but they are indeed themselves creating knowledge for all simultaneously. It is the combination of empowerment, inter-disciplinarity, huge research questions, confidence and space to explore without fear of failure which brings this concept alive. In an era of extraordinary change and equally extraordinary opportunity, it feels right and proper that the most fertile brains are exploited and enriched in such a manner.

There are questions which the era of restraint begs concerning research and its funding in universities and companies. Is it right, for instance, to be funding research using public funds which includes technology-developments which we know are not aligned with the 17 UNSDGs? Examples might include trying to squeeze out efficiency gains in 20th century technologies or researching products which rely on scarce materials.

Bold decisions are needed by schools, universities and funding bodies if we are to galvanise education and action towards rapid mitigation, followed by innovative opportunity. Across the span of education and research, areas of importance highlighted by this report include:

- Technologies and their constraints in efficient use of electric motors and electric heating
- The trade-offs between energy and labour in delivering services across the range of all economic activities
- Understanding of welfare dependent on self-actualisation rather than consumption or ownership
- Maximising the value of secondary materials and the realities of reduce/re-use/recycling/ "circularity" etc.
- Renewable generation and the system of its efficient use.

The opportunity in education spans from preparing for the restraint required to achieve Absolute Zero to preparing for the longer-term transformation of prosperity beyond 2050. What could a world look like without cement, internal combustion engines or aeroplanes? We need to educate students for this new reality, and embrace the opportunity, rather than the threat, which this reality offers.

## 4.3 Opportunities in governance

The Olympic Games is one of the biggest government projects which has been delivered on time and to budget. It was a great success and a source of national pride. There are parallels between hosting the 2012 Olympic Games and delivering Absolute Zero. Both commitments were made on a world stage where failure to deliver would result in national embarrassment; both projects require collaboration of multiple government departments, industry and the general public; and both require delivery processes and structures to be built from scratch. We managed to overcome these challenges for the Olympics, but delivering Absolute Zero has additional challenges.

To achieve our emissions goal we have to sustain momentum over a longer timespan than for the Olympics. We also have to consider life beyond 2050, what is the legacy of the net-zero emissions project? The Olympic legacy has been criticised for under delivering, so we must do better this time to ensure society can thrive in a zero emissions world beyond 2050. When we hosted the 2012 Olympics we could draw on the experiences of historical Olympic Games to inform decisions being made, but no country has met a zero-emissions target before, there is no precedent for us to follow. Finally the 2012 Olympic developments generated growth in the delivery of new and improved infrastructure and services. Meeting the net-zero emission targets will generate growth in some industries, but will also require the decline of others, this is likely to be met with resistance as those who benefit from the status quo resist change.

The London Olympics highlighted the following key lessons that could be transferred to emissions targets:

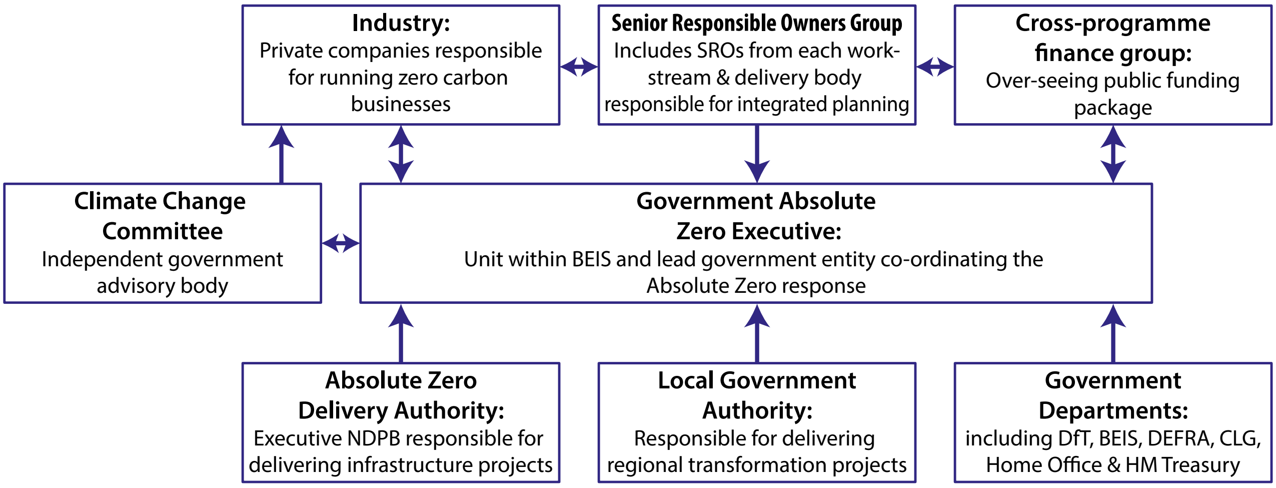
- Form a responsible body in government
- Limit innovation to knowledge gaps to reduce risk
- Maintain a unified cross party vision
- Have a protected and realistic budget
- Invest in programme management & delivery with discipline on time and scope change
- Empower people, with the right skills and track record to deliver against clear responsibilities
- Ensure accountability, with scrutiny and assurance given when risk is identified.

This section attempts to explore the first three of these lessons, the most relevant to Absolute Zero commitment.

### Responsible body in government:

For the 2012 Olympics an executive non-departmental public body (NDPB) called the Olympic Delivery Authority (ODA) was established to deliver the infrastructure and venues required for the Olympics. In parallel the London Organising Committee of the Olympic and Paralympic Games (LOCOG) was established as a private company limited by guarantee to fund and stage the Games. The government set up the Government Olympic Executive (GOE) within the Department for Culture, Media & Sport. The GOE was responsible for other elements of the games, such as transport and security, as well as overseeing the ODA and LOCOG. Although the governance structures were considered to be complex, it has been reported that they allowed quick decision making and ensured people remained engaged throughout the delivery process. Figure

**Figure 4.1: Olympic-style governance structure for UK Climate Emergency Response:**




4.1 gives an example of how this structure could be applied to delivering Absolute Zero. The proposed Government Absolute Zero Executive would be even more critical since it would be required to coordinate multiple industries and organisations, rather than just two delivery bodies as was the case in the 2012 Olympics. The governance structure proposed in figure 4.1 would enable fast decision making and accountability to meeting interim goals, which is essential if we are going to meet the 2050 zero emission targets.

## Limit innovation:

The Government Olympic Executive deliberately limited innovation to fill knowledge gaps. This move was considered to be counter-intuitive, but successful. Relying only on proven technologies reduced the risk of failure and avoided the temptation to use the Games to showcase risky innovation. Although the Olympics did not innovate new ways of doing things, it did require existing activities to be scaled up to meet unprecedented demand. As Jeremy Beeton, Director General of the Government Olympic Executive explains "It was a whole new business model for London." This scaling up of proven technologies and systems was seen as a risk in itself. This lesson should be transferred to the task of meeting the 2050 zero-emission targets. We have identified in this report 'bright spots' where best practice exists and could be scaled up, if we apply the Olympic approach, this is enough of a risk, and further innovation should be limited. That said, we don't currently have all the answers to transition to a net-zero society and some innovation will be necessary, but approached with caution.

## Cross party vision:

The delivery of the 2012 Olympic Games was supported by a unified cross party vision which was maintained through regular progress reports. This enabled stability throughout government changes which allowed the project to maintain momentum. The UK's approach to climate change does not currently have a unified cross party vision. For example the Labour party proposes moving the zero-emissions targets to 2030. Whilst parties argue over goals and targets, actions are not being taken and we fall further behind on the journey to zero-emissions. It is essential that government generate a unified cross party vision to emulate the success of the 2012 Olympics which was able to create clear roles and responsibilities which fostered collaborative problem solving, not blame shifting.

If we are to learn from our previous successes, the net-zero target is more likely to be achieved through the establishment of the Government Absolute Zero Executive and the associated Delivery Authority with cross party support. The Executive should set a strategy which is realistic and risk averse, without over-reliance of innovation.

## 4.4 Opportunities for Industrial Strategy in the UK

With a legal target, now set by the UK government, to achieve net-zero emissions by 2050, UK business are developing organisational strategies to ensure they will prosper in a zero emissions business landscape. This report has shown how placing resource efficiency at the heart of industrial strategy can enable businesses to prosper, but this requires significant changes in the products, production processes and supply chain systems which currently make up the industrial sector.

The UK government has invested £5m in the UK FIRES research programme, bringing together the academics from six universities who have written this report with businesses across the supply-chain in a 'Living Lab'. The subscribing industrial partners pose strategic challenges to the academic research team and test emerging solutions in practice.

UK FIRES research will support businesses in developing industrial strategies to achieve zero emissions in key four areas illustrated in fig. 4.2:.

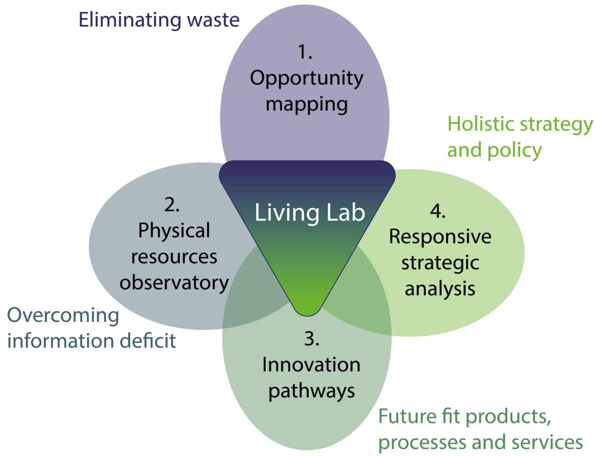
1. Opportunity mapping will identify new methods of design and manufacture which improve on existing best practices. Software tools to enumerate all options for design and delivery of resource intensive goods with today's technologies will be developed and commercialised.

2. The tools of recent advances in data science will be applied in a new Resource Observatory, to provide the highest-resolution insights into the UK's use of resources, with new metrics, scenarios and search tools used to identify opportunities for valuable innovation and efficiency gains. These tools will give UK FIRES industry partners foresight in decision making.

3. Through specific case studies of process, product and service innovation, the UK FIRES consortium will seek to define the innovation pathways by which the new practices of resource efficiency can be the basis of thriving UK businesses. The Living Lab industrial partners will be supported to exploit these opportunities in practice.

4. To support holistic industrial strategies and supply chains UK FIRES researchers will create responsive strategic analysis tools. Living Lab industrial partners can then apply these findings through the generation of new business models in collaboration with the UK FIRES Policy Champion.

**Figure 4.2: UK FIRES programme structure**




The output of the UK FIRES Living Lab collaboration will be published in quarterly reports, made available for government and industry, to provide reliable information to inform the development of their net zero industrial strategies. Focus themes for future Living Lab reports are now outlined.

## UK FIRES connections

UK FIRES aims to provide data, tools, experience and analysis to support its partner companies in specifying new business models, diffusing innovation, giving holistic foresight to new opportunities and improving best practice as they pursue Resource Efficiency for a net-zero industrial strategy.

UK FIRES members can access the resources of the £5m programme through:

- Quarterly meetings of the Living Lab, in which members across the bulk materials supply chains specify target challenges for future work, support current activity and provide feedback on the application of programme insights in practice.
- Early access to emerging analysis of strategic opportunities
- Shared or dedicated PhD students applying the collective insights of the UK FIRES team to specific commercial contexts
- Pilot testing of new tools developed in the research programme
- Shaping the agenda and participating in the Annual UK FIRES Resource Efficiency Forum.

For more information contact info@ukfires.org.uk

# Notes to the figures

**Figure 1.1:** Assuming an additional 400 TWh/year is needed by 2050, to be supplied by offshore wind, we need to have 115 GW of offshore wind capacity operational by 2050 (assuming an approximate capacity factor of 40% for offshore wind). The Crown Estate estimates that projects with seabed rights being awarded in 2021 would become operational by 2030, so all projects needed for 2050 would need to be started by 2040. Although current capacity is 9 GW, there is an additional 25 GW already in the pipeline. Therefore new projects need to be established and built at a rate of 4.5 GW/year for the next two decades.

**Figure 1.3:** Data from the International Energy Agency (IEA, 2018) with data on CCS installations at power-stations from the Oil and Gas funded pro-CCS lobby, Global CCS Institute.

**Figure 1.4:** This analysis by Vaclav Smil (2014) looks at global deployments of the three major fossil fuels, relative to total world energy demand at the time. Some faster transitions have occurred in individual countries, as shown in the box story on page 3.

**Figure 1.5:** The data in this figure come from a survey of academic reports by Gross et al. (2018) on the introductions of a range of new technologies - which generally showed that energy technology changes are among the slowest to reach full deployment.

**Figure 1.6:** Sectoral breakdown of UK energy demand from DUKES (2019); UK domestic internal temperature history from Official Statistics (2014); European car weight (and similar trends for all other regions) from the Global Fuel Economy Initiative a partnership with the International Energy Agency and others.

**Figures 1.7–1.8:** All constructed using data from DUKES (2019). n.b. there are many ways of calculating the equivalence of fuels - typically, the units of "Mega-tonnes of oil equivalent" are used, but this is not obvious when comparing primary electricity (nuclear or renewably powered electricity) which is not the result of conversion in a power station. We have attempted to be consistent in reporting the Mtoe equivalence of total UK energy demand.

**Figure 1.9**: Constructed with yearly data on electricity supplied in the UK from DUKES (2019). Electricity generated via non-emitting sources is shown as stacked lines whereas electricity generated from coal, gas and oil is plotted in a separate line.

**Figure 1.10:** The cost figures represent the weighted average of the levelized cost of electricity of commissioned solar and onshore wind projects in the United Kingdom and were obtained from IRENA (2018). For solar photovoltaic generation only cost figures after 2010 were reported. The figures were converted from US dollars to Pound sterling using yearly average exchange rates. The power density points for onshore wind were obtained using the power density of 61 wind farms commissioned between 1992 and 2007 compiled by Mackay (2009). These data-points were averaged by year of commissioning using installed capacity as averaging weight. The installed capacity and commissioning dates were obtained from Department for Business, Energy & Industrial Strategy (2019). The power density points for solar photovoltaic were estimated using best available cell efficiency data provided by National Renewable Energy Laboratory (2019) for multi-crystalline Si Cells in conjunction with the UK's annual insolation data from Photovoltaic Geographical Information System (2017) and a performance ratio of 84 % obtained from National Renewable Energy Laboratory (2013).

**Figure 1.11:** This chart was constructed using 2005 global energy data supplied by the International Energy Agency, and multiple sources to estimate the allocation of energy to devices and "passive systems" - the equipment (such as a car or house) in which the final form of energy (typically mechanical work or heat) is exchanged for a service. The chart is from Cullen et al. (2010), which has a lengthy Supplementary Information file giving every detail of the estimations. It is currently arduous to update this form of analysis - and a target of the UK FIRES research programme is to use the emerging techniques of Data Science to make this easier - but we assume that the proportions of energy use have remained approximately similar from 2005 to today.

**Figure 1.12:** Data taken from Haberl et al. (2007), subject to uncertainty due to definitions and the need for estimation of un-measurable data.

**Figure 1.13:** all the values represent "real world" efficiencies of conversion devices. The efficiency of electric heater, light and electronic devices was obtained by Cullen and Allwood (2010). The efficiency of electric battery charging applies to charging road vehicles and was obtained from Apostolaki-Iosifidou et al. (2017). The efficiency of heat pumps is the average of all the values reported by Shapiro and Puttagunta (2016) who quantified the coefficient of performance of these devices during use in residential buildings. The remaining values were obtained by Paoli and Cullen (2019).

**Figure 1.14:** Figure 1.14: This Sankey diagram was obtained using UK energy consumption data for 2018 from National Statistics (2018) and the conversion factors of figure 1.13. The data is disaggregated by energy type and sector. The total electricity demand was scaled to account for population growth using the predictions from National Statistics (2019) and the distribution losses from OECD/IEA (2018). In addition to the efficiencies of figure 1.13, the efficiency of charging electric car batteries was taken from Apostolaki-Iosifidou et al. (2017).

**Figure 1.15:** This analysis, building on the energy diagram of fig. 1.11 was developed in order to provide clarity for the IPCC's 5th Assessment Report, and based on global emissions data for 2010 taken from the EU's EDGAR database of global emissions. The original analysis was published as Bajzelj et al (2013) but has been modified here to clarify the difference between emissions that occur as equipment (cars, boilers, lights) are used, and those that occur in industry when making equipment that lasts for more than one year. The UK FIRES programme is largely concerned with these industrial emissions, so clarifying the way that stock of goods in service (and therefore their requirements for energy inputs) evolve over time, is of critical importance to understanding how to develop an Industrial Strategy compatible with Absolute Zero.

**Figure 2.1:** This figure is a summary of the analysis leading to figs. 2.2, 2.4, 2.11 and 2.19.

**Figure 2.2:** Today's values on energy use in buildings were obtained from UK energy statistics (HM Government, 2019). The values in the second column were calculated using the method described in the notes for Figure 1.13 and the efficiency values estimated by Cullen et al. (2010). The values in the third column were calculated considering the efficiency improvements of better insulation of roofs and attics, and the installation of double-glazed windows estimated by the IEA (2013), considering the number of surviving buildings in 2050 estimated by Cabrera Serrenho et al. (2019).

**Figure 2.3:** Impact of new buildings and retrofit from Cabrera Serrenho et al. (2019) and IEA (2013), use of heat pumps for space heating (MacKay, 2008), Appliance efficiency improvements (ECUK, 2019, table A1).

**Fig 2.4**: Today's values on energy use in transport were obtained from UK energy statistics (HM Government, 2019) and IEA energy balances (IEA, 2019). The values in the second column were calculated using the method described in the notes for Figure 1.13 and the efficiency values estimated by Cullen et al. (2010). The values in the third column were calculated considering no international aviation, the substitution of domestic shipping and aviation by rail, a reduction of energy use in passenger road transport to 60% of current levels (as demonstrated in Figure 2.6) and a reduction of 30% in road freight energy demand (Dadhich et al., 2014).

**Figure 2.5:** Emissions factors from the BEIS Greenhouse gas reporting conversion factors 2019. Equivalent energy intensities calculated using the BEIS values for fuel CO2e intensities, apart from rail which was calculated using the CO2e intensity factor for electric traction. Radiative forcing corrections are included in the emissions intensities for flying. Data for cars are for the current average fleet of petrol cars.

**Figure 2.6:** Developed assuming a linear correlation between vehicle weight and fuel consumption (there is reasonable empirical support for this) and with current vehicle weight taken from fig. 1.6.

**Figure 2.7:** Effect of vehicle weight reduction (Cullen et al., 2011), logistical improvements (Dadhich et al, 2014), regenerative braking (Gonzalez-Gil et al, 2014), drag and rolling resistance (Cullen et al, 2011).

**Figure 2.8:** developed considering the number of cars purchased and discarded in the UK estimated by Serrenho et al. (2017), with full adoption of electric cars in new sales from 2025.

**Figure 2.9:** This is constructed from emissions intensities reported by Scarborough et al. (2014) combined with data on portion sizes and calories per portion from the UK's National Health Service (www.nhs.uk/live-well/healthy-weight/calorie-checker/). There is significant uncertainty behind the numbers in this figure - due to the difficulty of defining the boundaries of analysis for the emissions calculation, and the arbitrary size of portions - but the scale of difference between the two foods is significant.

**Figure 2.10:** Is taken from Bajzelj et al. (2014) as used for fig. 1.15

**Figure 2.11:** Current energy consumption data from ECUK: End uses data tables, 2018, split by 2 digit SIC. Where further disaggregation was needed e.g. chemicals sector, consumption was split by the according proportions in 2007, where data is provided at 4 digit SIC level. Energy embodied in net imports for steel, cement, plastics and textiles by multiplying the energy intensity of UK production by the net imports of each material; tonnage data from Allwood et al. (2019), Shanks et al. (2019), ImpEE project and Allwood et al. (2006) respectively. Energy loss in electricity production is from DUKES aggregate energy balances, 2018. Energy for direct fuel combustion was converted to electricity using the relevant efficiency

values provided in Figure 1.11. Demand reduction interventions: 1) reduce scrap in metal processing to half of the current level, i.e. half of the savings identified in Milford et al. (2011); 2) reduce metal consumption by 20% by avoiding over-design of metal products, consistent with Section 2.3, Section 2.1 and Allwood and Cullen (2012); 3) A 75% cut in cement output based as described in Section 2.2; 4) Life extension of cars, clothes and industrial goods, reducing output of these products by 40%, 45% and 40% respectively. Proportions of steel and aluminium usage as per the global data provided in Allwood and Cullen (2012). 5) Reduction in plastic packaging by 25%; in the UK plastics packaging is 2.2Mt out of 6.3Mt total consumption estimated from the ProdCom database; 6) A 25% cut in fertiliser use, half of the reduction identified for Netherlands in Section 2.2; 7) Reduction of food waste leading to a 3% cut in output in the food processing industry as per the WRAP Courthald Commitment; 8) More efficient use of electricity in industry by improving efficiency of motors, heat pumps for space heating, process heating and lighting from 60% to 80%, 104% to 400%, 80% to 90% and 13% to 15% respectively, consistent with Cullen and Allwood (2010).

**Figure 2.12:** Original analysis for this report developed by C.F.Dunant

**Figure 2.13:** Developed from Cooper et al. (2014).

**Figure 2.14:** Original version of this figure published in Allwood et al. (2012) modified here to show primary production from blast furnaces declining to zero in-line with the zero emissions target.

**Figure 2.15:** Developed from Daehn et al. (2019)

**Figure 2.16:** The flows of plastics in the UK were estimated from the UK trade statistics (Eurostat, 2018), using a systematic allocation of trade product codes into the various stages of the supply chain, and by estimating the plastic content and application for each produce code.

**Figure 2.17:** Developed from Shanks et al. (2019

**Figure 2.18:** A survey of structural engineers, MEICON showed that, in general, structural engineers are prepared to over-design structures routinely in order to pre-empt any possible later changes to the brief, to deal with design risk and to cover for the possibility of construction error. Material efficient design, for example using fabric form-work, could allow substantial reduction in over-use without any increase in risk.

**Figure 2.19:** Current energy consumption data from ECUK: End uses data tables, 2018, split by 2 digit SIC, and where further disaggregation needed (e.g. separating primary and secondary wood processing) 2007 data at 4 digit SIC level. Energy loss in electricity production, conversion of direct fuel combustion to electricity and demand reduction interventions are all as described in Figure 2.23.

**Figure 2.20:** Allocation of emissions from global materials production to the six key sectors based on material flow analysis of steel (Cullen et al., 2012), cement (Shanks et al, 2019), Aluminium (Cullen and Allwood, 2013), plastic (Allwood et al, 2012), Paper (Counsell and Allwood, 2007), food (Bajzelj et al. 2014)

**Figure 2.22:** This data is made publicly available by the car industry. Horton and Allwood (2017) review the data, and explore several options by which this form of material inefficiency could be addressed.

**Figure 2.23:** Manufacturing energy efficiency imporvements (Paoli and Cullen, 2019), scrap metal reduction (Milford et al, 2011), reducing over-design and ilfe-extension (Allwood & Cullen, 2012), plastic packaging (Lavery et al, 2013), food waste (WRAP, 2018)

**Figure 2.24:** The proportions of losses here are indicative and based on data in Li et al (2016). The actually losses vary according to the way the hydrogen is stored and the precise pattern of demand by which electricity is extracted from the fuel cell.

**Figure 3.3**: The Zero Carbon Britain (Allen et al, 2013) report sets out a scenario for energy supply in 2050. We have calculated the amount that energy generation from each source would have to increase in every year from now to 2050 to achieve the target. Increases are presented as a percentage of current UK primary energy demand of about 2200 TWh (BEIS, 2019). Expectations for Government support for offshore wind in the 2020s are from the Crown Estate (2019), converted into generation values with a representative capacity factor for offshore wind of 40%. A review of Biomass to Liquid systems for transport fuel production reports that no commercial scale plants are yet operating (Dimitriou, 2018).

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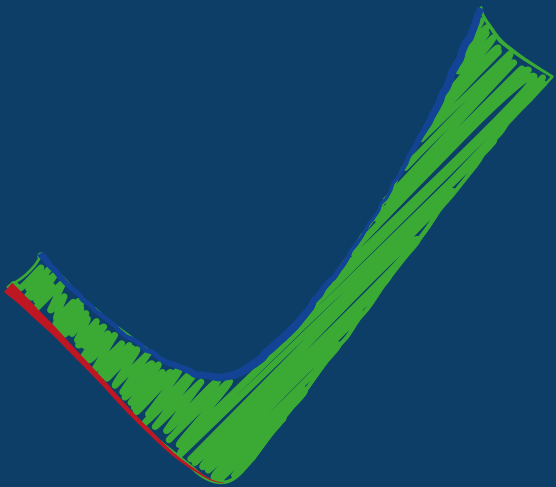

Absolute Zero: some short-term restraint in our use of energy, but no restraint whatsoever in what we most enjoy...









**COUNCIL – 12TH SEPTEMBER 2024**

**QUESTIONS RAISED BY MEMBERS OF THE COUNCIL**

1 **<u>Question submitted by Councillor Prendergast to the Leader of the Council (Councillor Atkinson)</u>**

**Subject: Children's Services**

"A further monitoring visit from OFSTED, has revealed that there are still ongoing problems with Leadership within Sefton Children's Services Department.

There are also still ongoing criticisms about the pace of improvement, both of which are very concerning given that we are now more than two and a half years on from when the Service was first graded as 'Inadequate'.

In light of the further and ongoing problems identified by OFSTED, can the Leader of the Council answer the following questions:

**a.** What steps has she taken, since becoming Leader of the Council to tackle the ongoing issues around Leadership that are continually raised by OFSTED?

**b.** What steps has she taken since becoming Leader of the Council to quicken the pace of improvement within the Department and how does this differ from what the previous Leader of the Council did?

**c.** Since being graded as Inadequate by OFSTED, how much funding has been spent (as opposed to allocated) on financing the Department?

**d.** When, in her opinion, will the recurring issues in relation to Leadership and the pace of improvement be resolved"?

**Response:**

a. As Leader I have initiated and undertaken regular challenge and review meetings with the Department of Education Commissioner, Chief Executive and the Director of Children's Services.

"I have also amalgamated the roles of Cabinet Member for Education and Cabinet Member for Children's Social Care into a new Lead Member role for Children, Schools and Families to giving better oversight over all services for children and families.

Most recent OSFTED visits had highlighted the stable improvement in children services and had identified new leadership as an effective mechanism for this improvement. The OFSTED monitoring letter from March 2024 stated, "More recently, there has been a positive step change at a strategic level. A new chief executive officer brings a clear understanding of the council's corporate responsibilities and a determination to meet these for children and young people. A new resolute and child-focused leader of the council is supporting this approach. A change in Director of Children's Services, and two new interim Assistant Directors, has brought new ideas, a clarity of vision and greater ambition for Sefton's care leavers."

The new DCS continually pus pportive yet challenging culture within

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| | the senior leadership team which recognises the need to individual capability and where necessary development plans for these critical roles”.<br><br>b. “I have recognised that improvement to children services require systemic transformation change.<br><br>I am directly involved in critical progress and improvement meetings across all of children services. Ranging from my role on the Corporate Parenting board, input into the Children’s Social Care improvement board and regular meetings with critical figures in our improvement journey including the DFE commissioner”.<br><br>c. “By the end of 2024/25 (from April 2022) the Council will have spent £256m on the Children’s Social Care service”.<br><br>d. “The new DCS has recognised that the previous staff structure was not appropriate for the pace of improvement that was necessary across children services. This was agreed at Cabinet and is being implemented and will bring improved oversight, challenge and support to front line practitioners, enabling us to improve the pace of improvement.<br><br>There is still more to be done, but there is close working and clear alignment across political and officer leadership in the council, and with the DfE Commissioner, about the scale of the challenge, the key issues and the work we need to do continue and complete the improvement journey. |
| 2 | **Question submitted by Councillor Prendergast to the Cabinet Member for Regeneration, Economy and Skills (Councillor Lappin)** |
| | **Subject: Southport Marine Lake** |
| | “The marine lake in Southport is one of the largest in the region and hosts a range of water sports and activities available to the general public and the many organisations that use the lake and it forms an integral part of the works being undertaken as part of the Town Deal funding.<br><br>At present though, there are no changing facilities or toilets available to those who use the lake. The launch area is also in a poor state of repair with large amounts of bird excrement, litter/broken glass, damaged wood edgings and slippery wooden surfaces.<br><br>All of this presents a barrier to those who might want to take part in activities on the lake and does not present the town in the best possible light.<br><br>Taking into account the above, can the Cabinet Member set out what measures, if any, that Sefton Council are proposing to take in order to:<br><br>**a.** Provide appropriate changing/toilet facilities for those who use the lake, including providing suitable facilities for those with disabilities?<br><br>**b.** Tackle the litter/broken glass and bird excrement, on a regular basis, that not only detracts from the appearance of the launch area but also presents a hazard to those who use the lake?<br><br>**c.** The damaged wood edgir[...]unch area and the slippery surfaces that, |

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| | again, detract from the appearance and presents a barrier to those who might want to use the lake?" |
| | **Response:** |
| | a. "Marine Lake is leased out to a concession who has overall lake management responsibility while utilising the lake for leisure facilities. There are several clubs around the lake who have separate agreements and leases. These clubs provide changing and toilet facilities for their users. To ensure safe usage of the Lake and due to the lease in place, members of the public cannot turn up and use the lake for their own purposes if not part of one of the clubs or have a licence to do so from the lake concessionaire.<br><br>b. The revetment edge has recently been jet washed and cleaned at considerable cost. Unfortunately, we cannot communicate with the swans to ask them to defecate elsewhere.<br><br>c. Work is undertaken all year around to repair damage edgings, this is done on a priority basis working with the lake users' group. Work has also been done to install matting where appropriate at entry points again in consultation with the lake users. The Seafront budget covers multiple areas and has to be managed efficiently". |
| 3 | **<u>Question submitted by Councillor Prendergast to the Cabinet Member for Cleansing and Street Scene (Councillor Harvey)</u>** |
| | **Subject: Household Bin Collections** |
| | Over the last few months many residents across Sefton have seen a deterioration in the regularity and reliability of household waste collections by Sefton Council. Issues with staffing and resource shortfalls have been highlighted on council social media channels as reasons for this.<br><br>Can the Cabinet Member highlight in greater detail what these issues are for members and also set out what steps are being taken to tackle these issues and when it is expected that the service will return to a level of normality? |
| | **Response:**<br><br>"The service is currently under significant pressure from a staff resource perspective, in addition to the challenge of managing the seasonal increase in holiday requests.<br><br>However, backlogs of collections have now been successfully addressed through weekend deployments. I recognise the impact to residents across the borough, and their patience and understanding has been appreciated. Affected neighbourhoods have been kept informed via social media channels.<br><br>To address resource challenges, arrangements have been put in place for an enhanced occupational health offer that is specific to Operational In-House Services. This will be for a three-month trial and is based at the Hawthorne Road depot in Bootle. This service will feature a medical professional and a physiotherapist. The additional support is to ensure that staff are assessed swiftly, and appropriate support is fast-tracked to minimise absence. The new service is expected to start imminently". |

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| 4 | **<u>Question submitted by Councillor Sammon to the Leader of the Council (Councillor Atkinson)</u>** |
| | **Subject: Support for Local Businesses in Southport** |
| | “I am hearing from the local business community in Southport that many have had a tough month with a stark drop in footfall and bookings since the tragic incident of 29th July in Hart Street. Can you tell me what Sefton Council is doing to support local businesses to help them recover and are you speaking with the Government to gain further support?” |
| | **Response:** |
| | As you will no doubt be aware, discussions with Government commenced in the immediate aftermath of the tragic events, the Prime Minister visited twice during that week (and other members of his Cabinet, senior civil servants, and the MetroMayor visited) and engaged with the Leader of Sefton Council and the Executive Team. This dialogue continues. The families affected remain our priority, but the impact upon the economy and upon businesses has also featured in these discussions, reflecting the impacts on the wider town.<br><br>The Council’s Invest Sefton team has been out speaking to businesses in Hart Street and St Lukes Rd to establish the immediate needs of those specific business communities, and on the back of this have devised a package of support measures. These support measures include financial assistance for businesses affected by these events, via the introduction of a Southport Business Recovery Fund (which is to be considered on tonight’s agenda). While business and economic considerations may be wider and longer-term as well, the immediate focus of this fund is proposed to be on businesses and organisations located in the Hart Street and St Lukes Road areas. The Council will distribute resources to businesses over two rounds of funding: firstly, to businesses directly affected by closure on Hart Street, St Luke’s Road and Sussex Road, followed by businesses in the wider immediate area that were otherwise affected.<br><br>At the same time the Council, the Combined Authority and Southport BID have worked together to send out an online questionnaire to the wider business community to establish the immediate and projected impacts, support needs and business intelligence. This has been sent initially to over 750 BID businesses/levy payers, over 100 responding within a week. Initial results have been collated and reported, a further survey will be sent to other businesses (outside of the BID boundary), and the Council has also had teams across the Economic Growth and Housing Service holding detailed discussions with particularly impacted sectors and specific businesses. The combination of which provides invaluable intelligence to progress ‘evidence-led’ discussions about the ongoing priority actions, resources and investments needed to support businesses and the wider economy in the short, medium and longer term.<br><br>The Marketing Southport campaign has been adapted and refocussed, sensitive to the impacts of the events.” |
| 5 | **<u>Question submitted by Councillor Prendergast to the Leader of the Council (Councillor Atkinson)</u>** |
| | **Subject: Council Tax Discount** |
| | Can the Leader of the Council confirm that there are no plans to abolish or reduce |

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| | the amount of Council Tax discount that is currently available for single person households and can she also confirm that there are no plans to reduce or abolish any of the other Council Tax exemptions/discounts that are currently available? |
| | **Response:** |
| | "The council does not set the amount of council tax discount for single person households and has no plans to reduce or abolish any other exemptions or discounts". |
| 6 | **<u>Question submitted by Councillor Shaw to the Spokesperson for Merseytravel (Councillor Carragher)</u>** |
| | **Subject: Train times in September** |
| | 1) Would the spokesperson please advise me of the normal fastest times for trains on the northern line:<br>1. Southport to Liverpool Central in September 2023<br>2. Southport to Liverpool Central in September 2024<br>3. Southport to Hunts Cross in September 2023<br>4. Southport to Hunts Cross in September 2024<br><br>2) Would the spokesperson please advise me what plans, if any, there are to address the issue raised in 1 above? |
| | **Response:** |
| | 1)<br>1. Southport to Liverpool Central in September 2023 - 46 min<br>2. Southport to Liverpool Central in September 2024 - 50 min<br>3. Southport to Hunts Cross in September 2023 - 64 min<br>4. Southport to Hunts Cross in September 2024 - 73 min with 5 min change at Liverpool Central<br><br>Section time is slower due to a number of factors, these are:<br>• Temporary Timetable adjustments to allow work on installing beacons to prepare for the 8 cart service on Southport to Hunts Cross. 8 cars cannot currently work South of Liverpool central. The beacons will allow automatic selective door operation which is required for certain platforms.<br><br>• Without these adjustments there would be capacity issues between Southport and Liverpool Central. The introduction of the 8 cart services will alleviate the capacity issues.<br><br>• 777 are still working on the 50 percent Timetable. Once the optimal conditions are in place the Timetable will be reset and trains will operate to a faster Timetable than the 50 percent.<br><br>• Temporary infrastructure fault in Hall Road area means units are not currently able to draw full power. Working is ongoing with Network Rail to resolve this problem.<br><br>• Every Autumn the timetable is adjusted to give the trains more resilience in poor railhead conditions. The Autumn Timetable has been brought forward a month early to avoid multiple changes. |

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| | • Journey time from Ormskirk Hunts Cross is now 55min down from 57 with 4 min change.<br><br>2) The above is a necessary temporary adjustment for the next phase rollout of 8 carts. Once the beacons have been installed and the testing and training has been completed the previous timetable will be introduced.<br><br>During this period of adjustment, the performance of the 8 cart operation will be monitored to assist in the performance of 8 cart operation. This is necessary to help build a robust and reliable 8 cart 777 timetable.<br><br>Autumn Timetable adjustments are built into this development period. Once the autumn period is over, the risk to services because of railhead conditions reduces and faster Timetables can be reintroduced". |
| 7 | **Question submitted by Councillor Doolin to the Cabinet Member for Public Health and Wellbeing (Councillor Doyle)** |
| | **Subject: Crosby Coastal Pathway** |
| | Given the Crosby Coastal Pathway between South Road and the Radar Station (known locally as (The Prom) is unusable for pedestrians, cyclists and others due to a build-up of sand over several years, can the Cabinet Member update me on Sefton's current plans for the pathway, to ensure it is again suitable for public use? |
| | **Response:** |
| | "Sand clearance at Crosby involves 'excavating' the coast footpath, which was formerly on top of the seawall. The majority of which is now buried under the sand dunes that have naturally formed (accreted) over time. The volume of build-up is beyond any real practical reality of returning to a clear seawall footpath, as the level of the beach would need to be lowered. Cleared sand has to be relocated within the dune system and is typically dumped within close proximity to the work area as access allows. The cleared material combined with the accretion increases the volume of blown sand exponentially.<br><br>The Council has tried to keep these pathways clear of blown sand, but this has become increasingly difficult primarily due to the beach level rise. Several of the paths have been abandoned in terms of clearance as excavating some would leave very steep sided and unsecured sand hills, which would simply collapse back onto the path under unrestricted use and recover the cleared paths in no time, destabilisation causing a significant risk.<br><br>The natural processes at work are extremely powerful and we will continue to do the best we can and we have recently received some new equipment and allocated some additional staffing resource for Winter 2024/25.<br><br>Our main priority is maintaining Mariners Road as an access point to the foreshore, the path nearest the Peel Port boundary - which are essential access for our colleagues in the emergency services attending beach related incidents.<br><br>Signs have been placed recently to direct people to an alternative route, should they need wheeled access". |

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| 8 | **Question submitted by Councillor Doolin to the Cabinet Member for Communities and Partnership Engagement (Councillor Dowd)** |
| | **Subject: Crosby Library** |
| | In 2023 Sefton Council agreed a plan to demolish Crosby Library in Waterloo and move library services to a new HUB in Crosby Village. However, due to a popular campaign and petitions signed by thousands of local residents, Sefton Council cancelled the library's demolition and guaranteed its future. Can I ask the Cabinet Member how plans are progressing to upgrade the physical structure of Crosby Library and ensure it is able to serve the local community for decades to come? |
| | **Response:** |
| | "Crosby Library is a fantastic facility providing not only books and reading materials, but also access to the internet, information, printing facilities, a warm friendly space and a range of community groups and activities for people of all ages and abilities. We know that access to such facilities is greatly valued by the community and can support children and young people by encouraging a lifelong love of reading.<br><br>It should also be noted that Crosby Library is a large, ageing building that needs investment. To understand the scale of investment needed, a series of detailed condition surveys have been commissioned, the findings of which will help the council to decide what is needed to support the longer-term provision of this valuable service in the community". |
| 9 | **Question submitted by Councillor Pugh (Leader of the Liberal Democrat Group) to the Cabinet Member for Cleansing and Street Scene (Councillor Harvey)** |
| | **Subject: Sefton Cemeteries** |
| | What percentage of Sefton cemeteries have been given over to wildlife and fall outside the maintenance contract? |
| | **Response:** |
| | "We recognise that cemeteries can be a sanctuary for wildlife, and we support and encourage biodiversity across our sites. Our cemeteries attract visits from deer, red squirrels, foxes, hedgehogs, and other animals.<br><br>Small sections of two of our cemeteries are utilised as wildlife/wildflower areas with low-level maintenance. These are at Duke Street, Southport, and Liverpool Road, Birkdale. In percentage terms, the areas would cover no more than an estimated 10% of either cemetery. There are no designated areas at Southport Crematorium, Thornton Garden of Rest or Bootle Cemetery.<br><br>While older areas of a graveyard are more suitable for the suspension of grass-mowing to encourage wildflowers, the overall tidiness of a cemetery, especially for regular visitors to more recent graves, is a priority. Pathways to war graves are always maintained, even if they are within a meadow.<br><br>This balancing act between supporting biodiversity and maintaining a tidy, safe, and respectful cemetery is managed by staff. I would welcome any suggestions about how we can further encourage l[illegible]n our council-run cemeteries while |

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| | maintaining this balance.” |
| 10 | **Question submitted by Councillor Brodie-Brown to the Cabinet Member for Housing and Highways (Councillor Veidman)** |
| | **Subject: EV Charging** |
| | Government grants have been available to Local Authorities to assist with the installation of EV charging. Please list the dates when Sefton MBC has applied for these grants. |
| | **Response:** |
| | • “In 2014 the Council, through the Liverpool City Region Combined Authority, bid for and secured funds for the delivery of a limited number of public and private charging points.<br><br>• For 2022-2025, through the Combined Authority, capability funding has been secured to fund Liverpool City Region staff to allow capacity building for EV charging infrastructure.<br><br>• In 2023 the Combined Authority secured £9.647m of capital funding, to be distributed between the Local Authorities for the delivery of public charging points”. |
| 11 | **Question submitted by Councillor Brodie-Brown to the Cabinet Member for Regeneration, Economy and Skills/Deputy Leader (Councillor Lappin)** |
| | **Subject: Sir Ian McKellen Visit to Southport** |
| | Sir Ian has let it be known in an interview in The Times that he wants to bring his present production of Henry IV part 1 and 2 with its message of "hope and belief" to Southport. What action has the Council taken to ensure that his generous offer is accepted. |
| | **Response:** |
| | “We have reached out to Sir Ian McKellen’s promoters seeking a discussion, and look forward to hearing from his team at the earliest opportunity”. |
| 12 | **Question submitted by Councillor Lloyd Johnson to the Cabinet Member for Housing and Highways (Councillor Veidman)** |
| | **Subject: Planning Comments Being Publish on Planning Portal** |
| | 'We have been told that it is now the policy of the Planning Department not to publish comments made by members of the public on the Planning Portal. Can the member tell me;<br><br>a. On what date did this become the department's policy?<br>b. Who was consulted before this decision was made?<br>c. What was the rationale behind this decision?' |
| | **Response:** |
| | a. “We stopped publishing neighbour comments on line in April 2024. |

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| | b. The decision to stop publishing neighbour comments on line was taken by the Chief Planning Officer, in consultation with the Cabinet Member. The reasons for the decision are set out below.<br><br>c. Publishing comments made by members of the public is not a statutory requirement in the processing and determination of planning applications. The concept was introduced at Sefton Council in February 2021 on a trial basis. However, since its introduction it has caused significant problems for the Council. There is a substantial amount of redacting required to comply with the GDPR, which is compounded by the need to further redact inappropriate comments and statements made by the public of a derogatory and libellous nature, which if not redacted could create significant community unrest. The portal is also being used by some individuals to lobby support for their views and opinions, often based on inaccurate and unfounded statements, which is unhelpful. It is clear that the costs and time involved in supporting this platform is unsustainable, particularly at a time of significant budget restraint and cannot continue to be supported.<br><br>Comments from statutory consultees, based on professional judgement and expertise, will continue to be posted on-line, and these should form a reliable basis for members of the public to form their own responses. It is a statutory requirement to keep all comments made on planning applications in hard copy format on the Part 2 register, which is kept by the Local Planning Authority at Magdalen House. This can be inspected by appointment, by any member of the public, where all documentation is available to view. In addition to this, all comments made by the public, where material to planning, are summarised on all reports for each application, which brings such comments into the public domain". |
| 13 | **Question submitted by Councillor Sammon to the Cabinet Member for Regeneration and Skills/Deputy Leader (Councillor Lappin)** |
| | **Subject: 'The White House' at Southport Municipal Golf Links** |
| | On 18th July 'The White House' at Southport Municipal Golf Links posted on their Facebook page that due to essential maintenance works in their kitchen, they will be closed for a few weeks. I understand they are now back open, but the restaurant is still not serving cooked food. What exactly are these kitchen works and when will the restaurant be back to a full menu? |
| | **Response:** |
| | "The maintenance works related to minor plumbing issues that have now been resolved. The strategy (including any menu changes) for the future of the venue is under review and will be communicated to customers in due course". |
| 14 | **Question submitted by Councillor Sammon to the Cabinet Member for Public Health and Wellbeing (Councillor Doyle)** |
| | **Subject: Swans on Southport Marine Lake** |
| | A resident has informed me that this year no swan cygnets have survived at Southport Marine Lake. Can you confirm if this is true and what the reason might be? |

| | **Response:** |
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| | "Management of the Marine Lake is not something we influence or are directly involved in, although I must add tourism operations manager Steve Irwin and his team, plus concessionaires, have been most understanding about keeping craft and disturbance away from the northern-most island which is now an important site for rare breeding and wintering species of birds including egrets.<br><br>Mute Swan cygnets are often the subject of high mortality for a variety of reasons including disturbance, food supply, predation, weather conditions and avian flu (which is unfortunately endemic in the bird population of the UK now). Some amount of mortality is natural amongst all young wild birds.<br><br>Sometimes diet can play a part even when food appears to be abundant - if visitors feed the birds bread for example, the swans will happily eat it, but it is extremely bad for them.<br><br>That said, it would be hard to ascribe a cause without knowing the full details of the factors affecting the lake this summer." |