Making good things happen

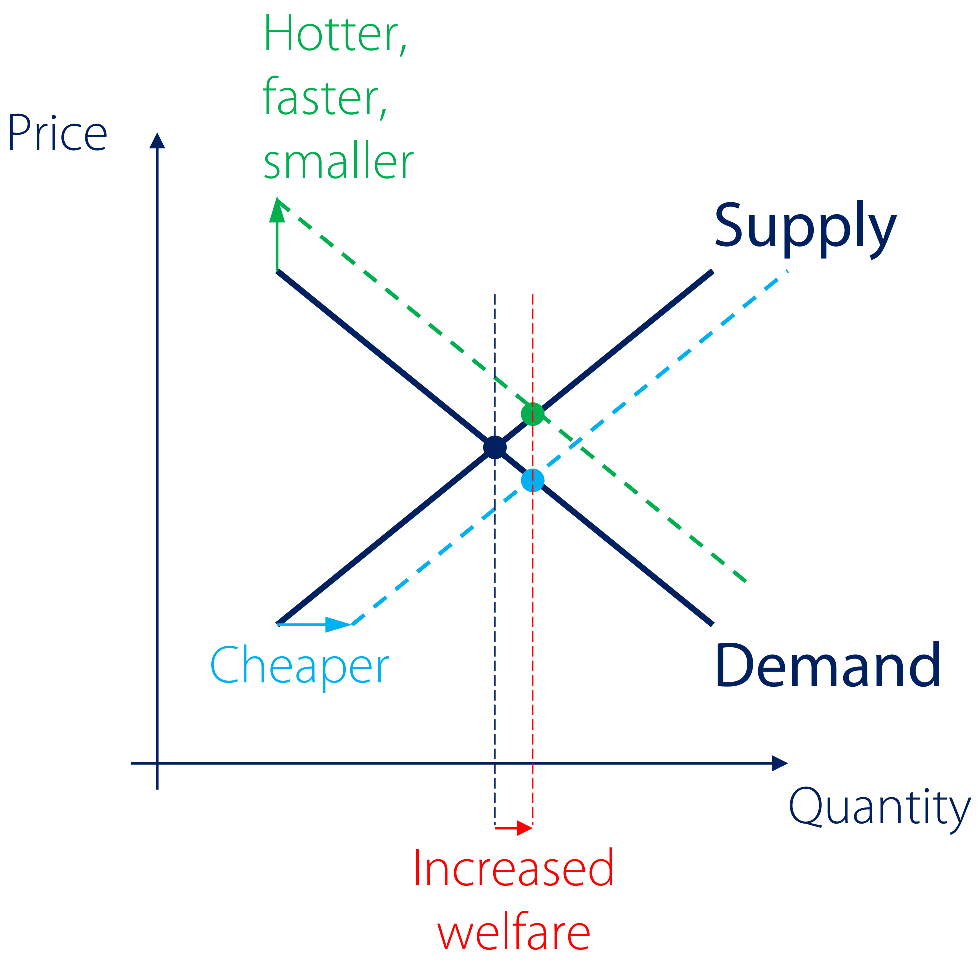
Purdue Engineering Distinguished Lecture Series,
Thursday 30th November, 2023

Professor Julian Allwood FREng

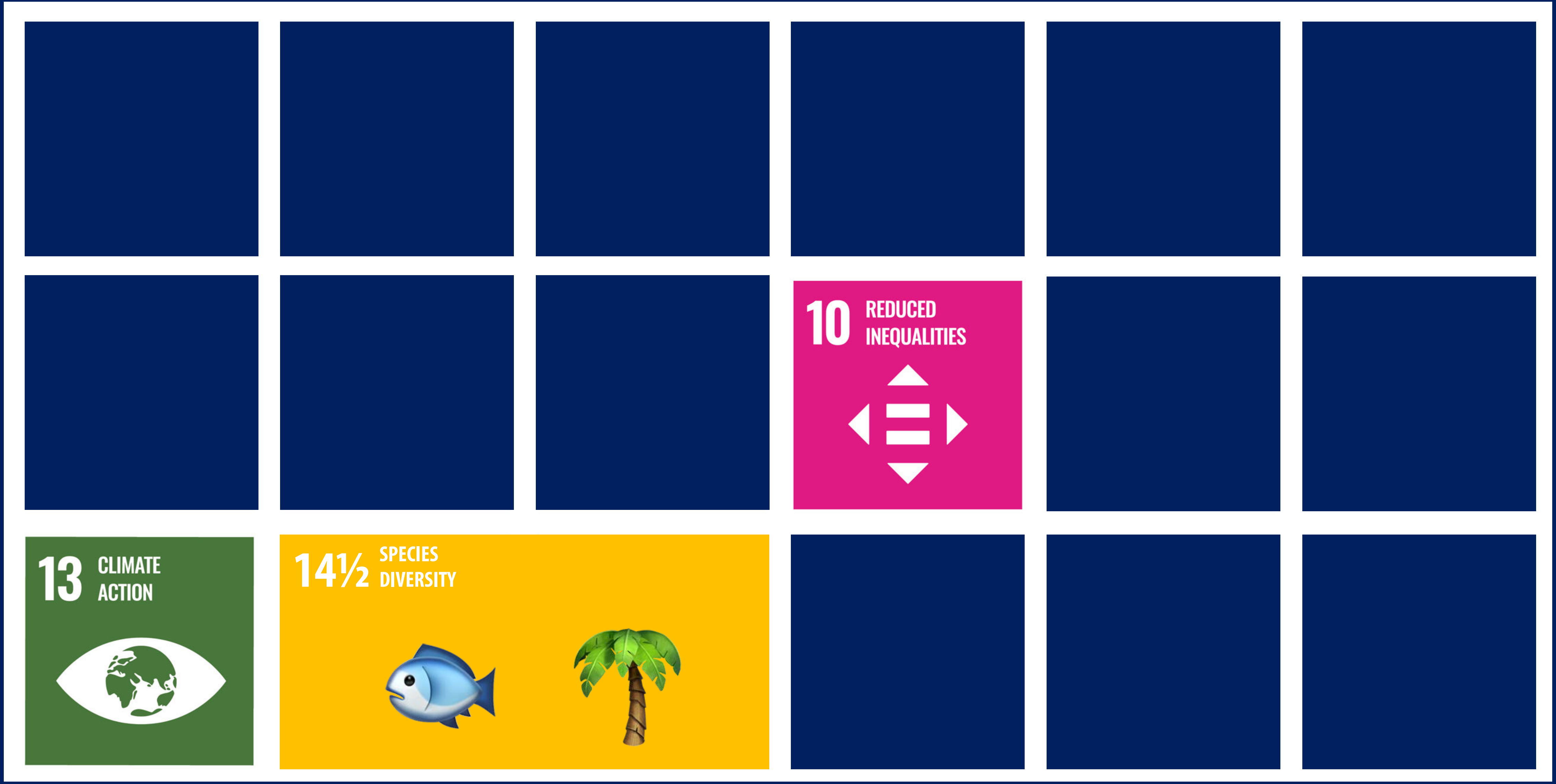
Allwood-office@eng.cam.ac.uk

Making things happen

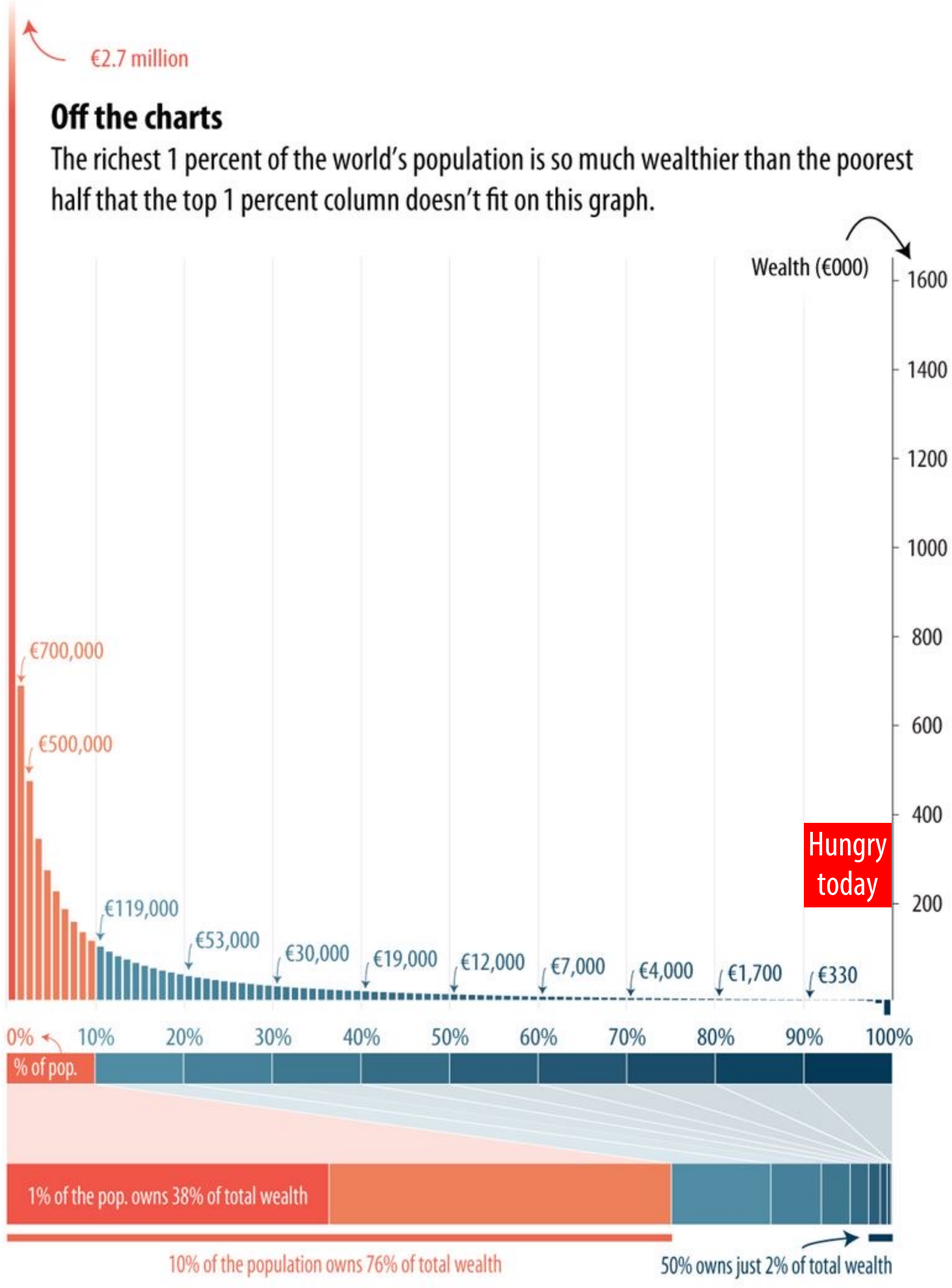
Making things happen: normal engineering practice



Good things

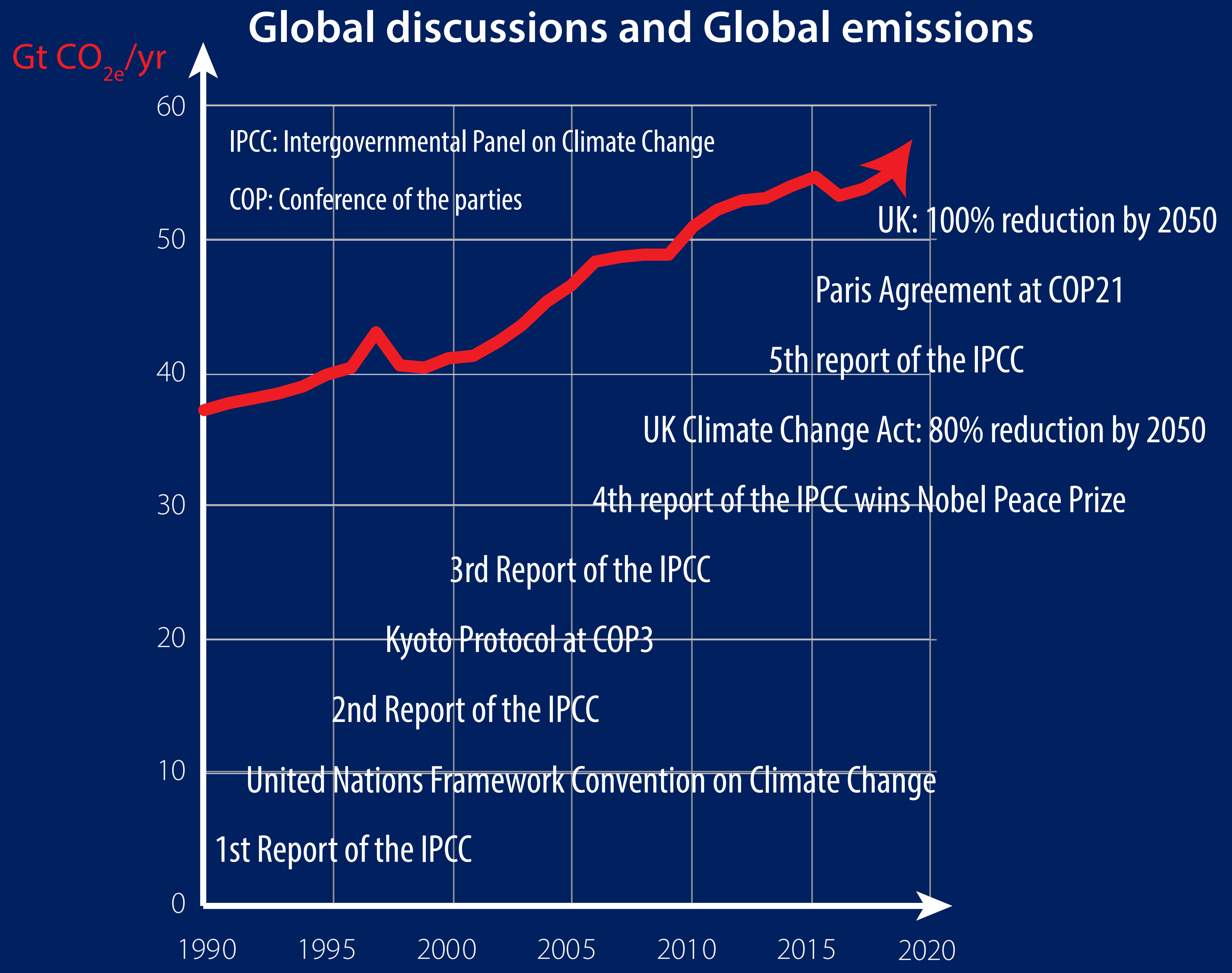

10 REDUCED INEQUALITIES
13 CLIMATE ACTION
14½ SPECIES DIVERSITY

GT1: Equality



Source: World Inequality Report 2022 by the World Inequality Lab.

GT2: Climate safety





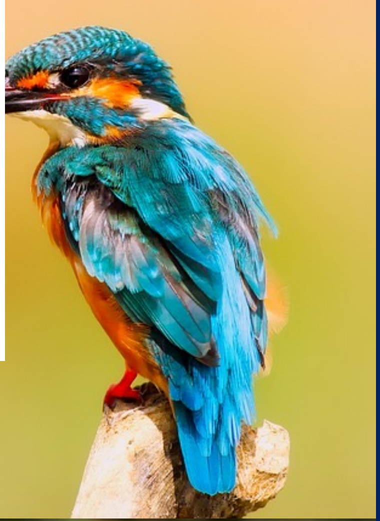


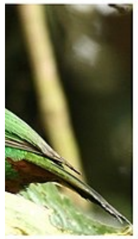




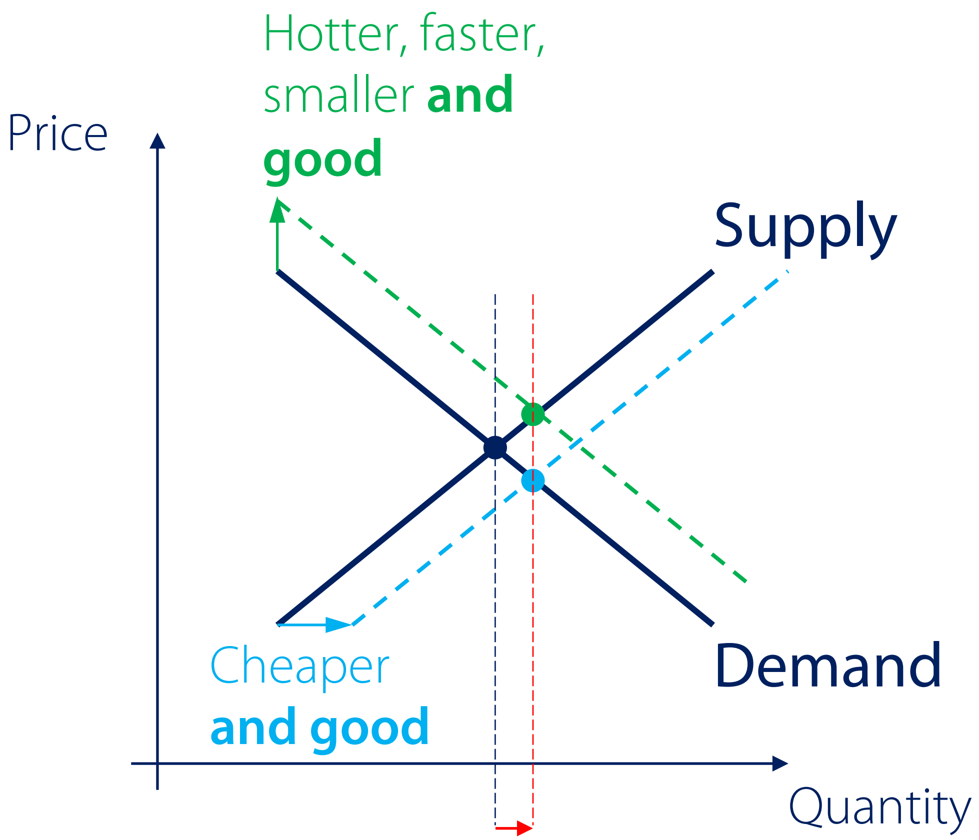




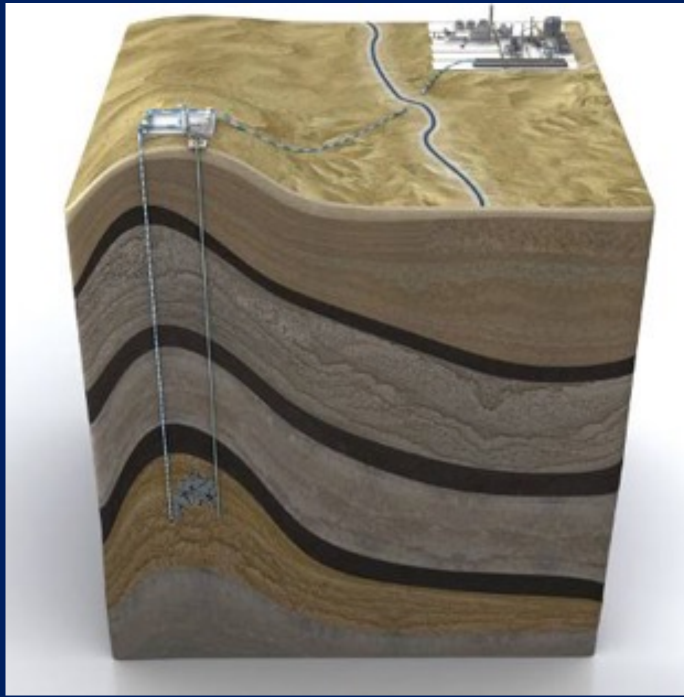
Making good things happen: normal engineering practice

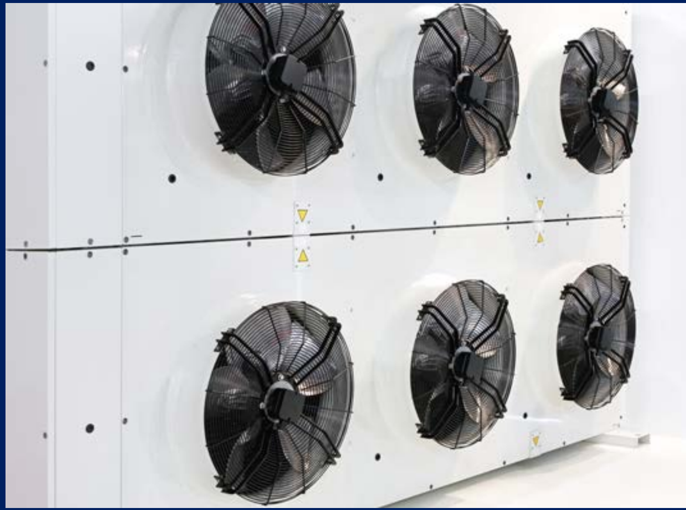


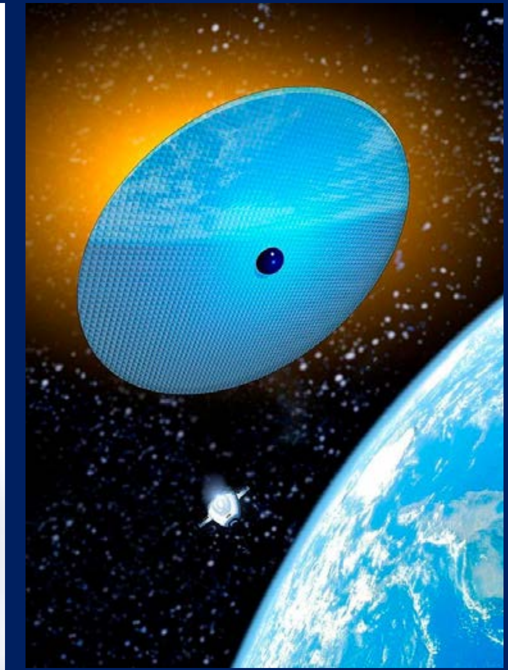
We don't mind trying to make good things happen provided that economic growth carries on as if we weren't doing anything different

GT1 Innovation…

GT2 Innovation…



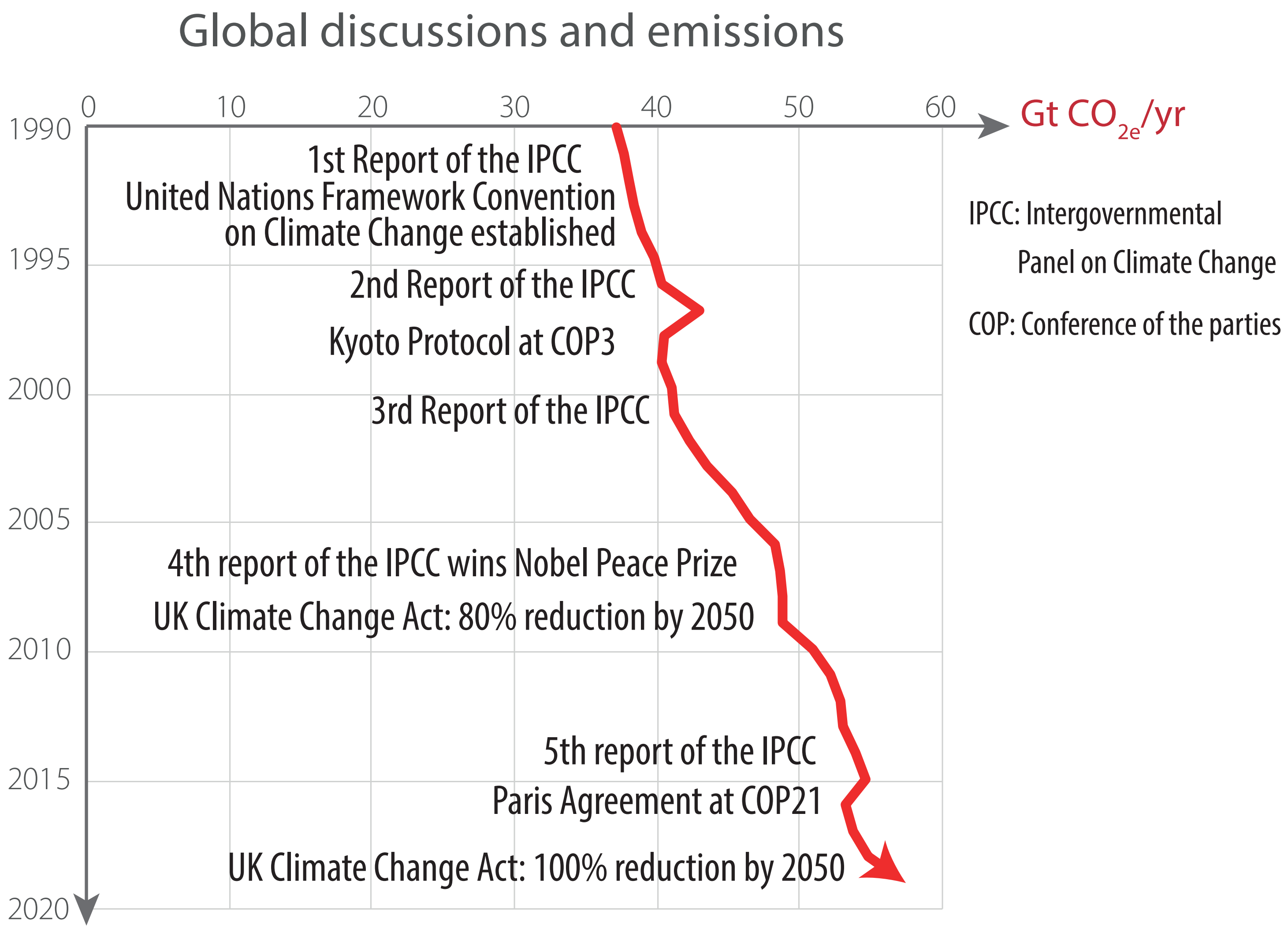




GT3 Innovation…

Climate policy evaluation: are good things happening?

Rising emissions and pledges



Legally committed to zero emissions by 2035:

- **Finland**

Legally committed to zero emissions by 2040:

- **Austria, Iceland**

Legally committed to zero emissions by 2045:

- **Germany, Sweden**

Legally committed to zero emissions by 2050:

- **EU, USA, UK, S Korea, Australia, Canada**

Policy document for zero emissions by 2050:

- **Most South American countries**

Policy document for zero emissions by 2060:

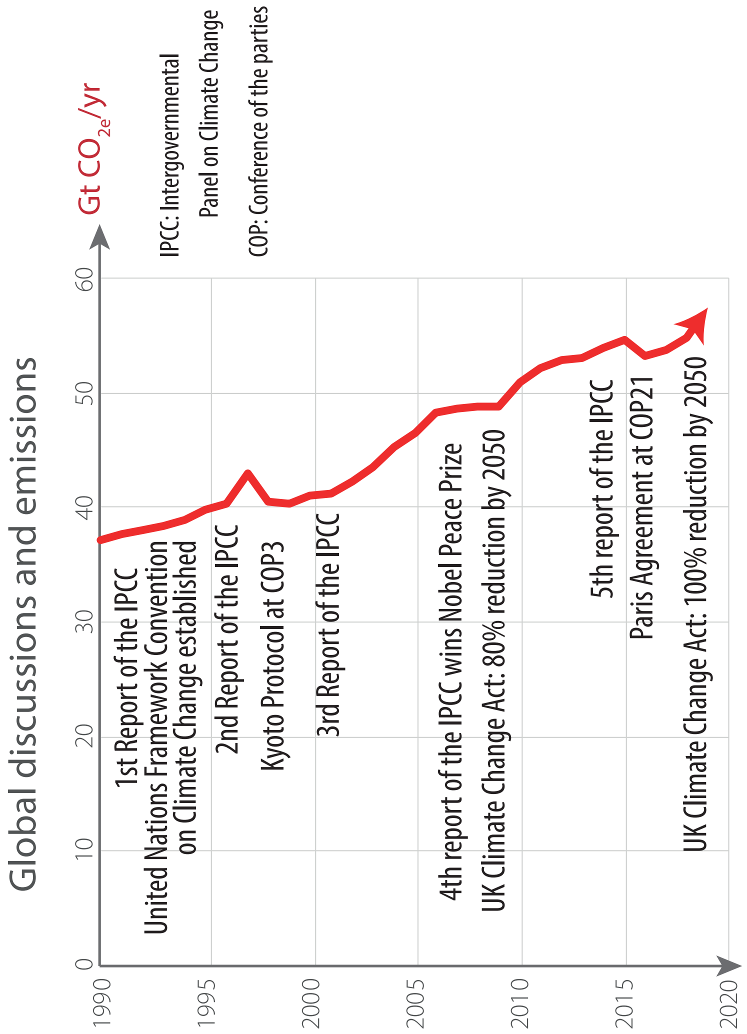
- **China**

Policy document for zero emissions by 2070:

- **India**

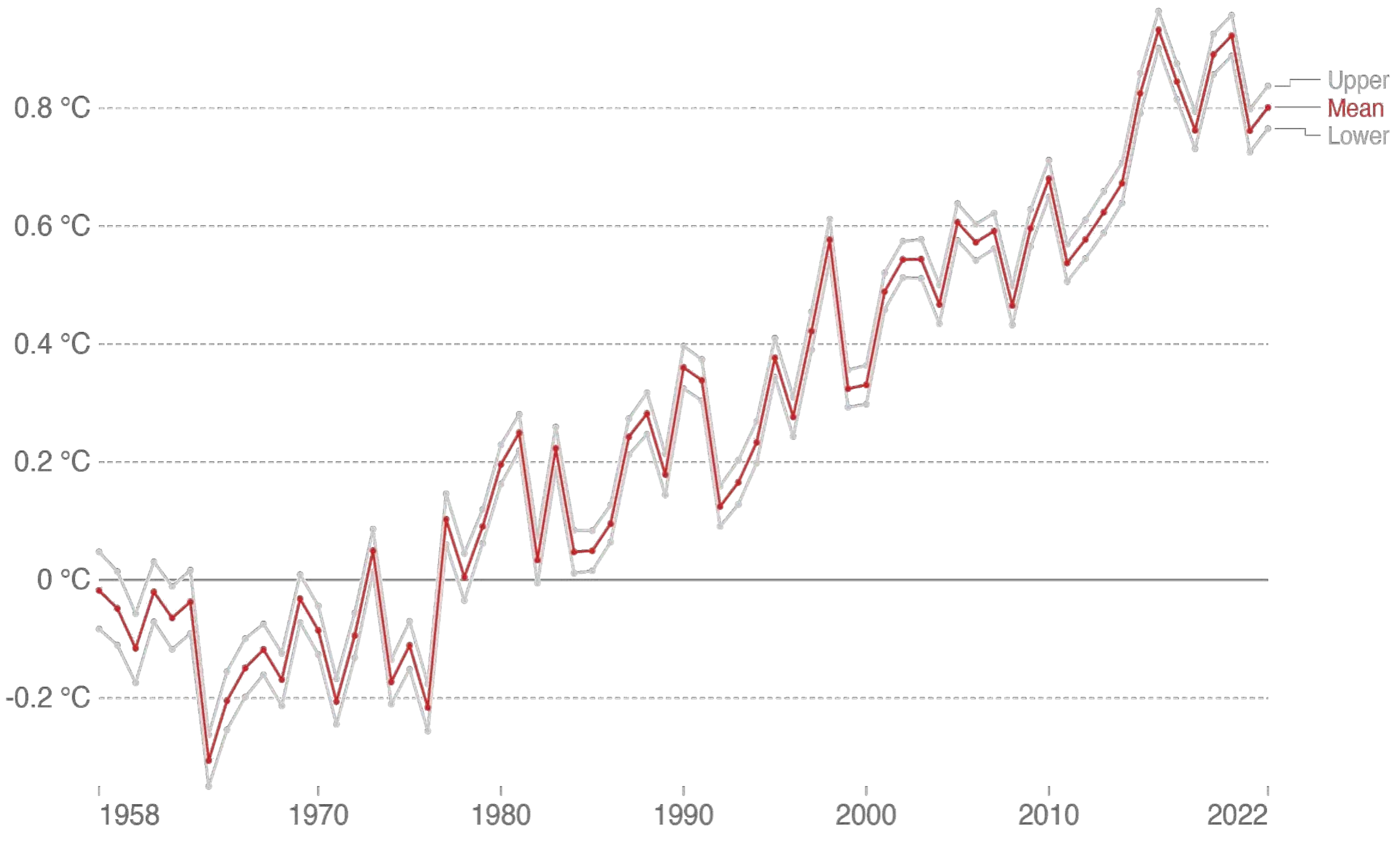
Data from https://eciu.net/netzerotracker

Rising temperature and risk



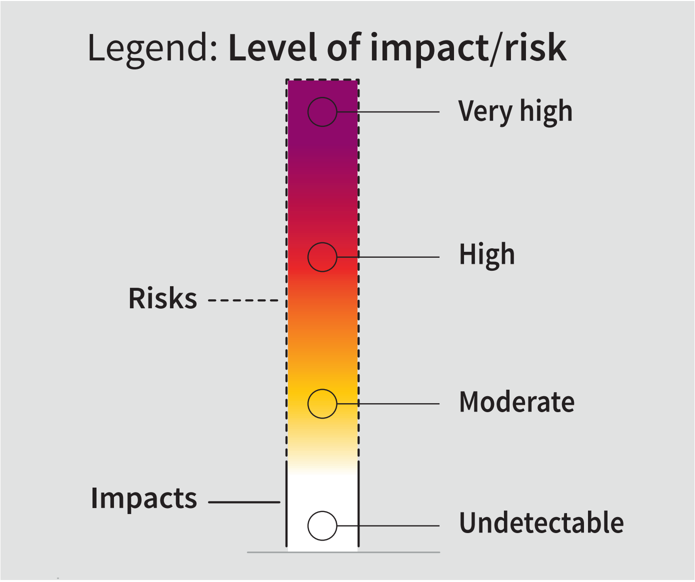
Average temperature anomaly, Global

Global average land-sea temperature anomaly relative to the 1961-1990 average temperature.

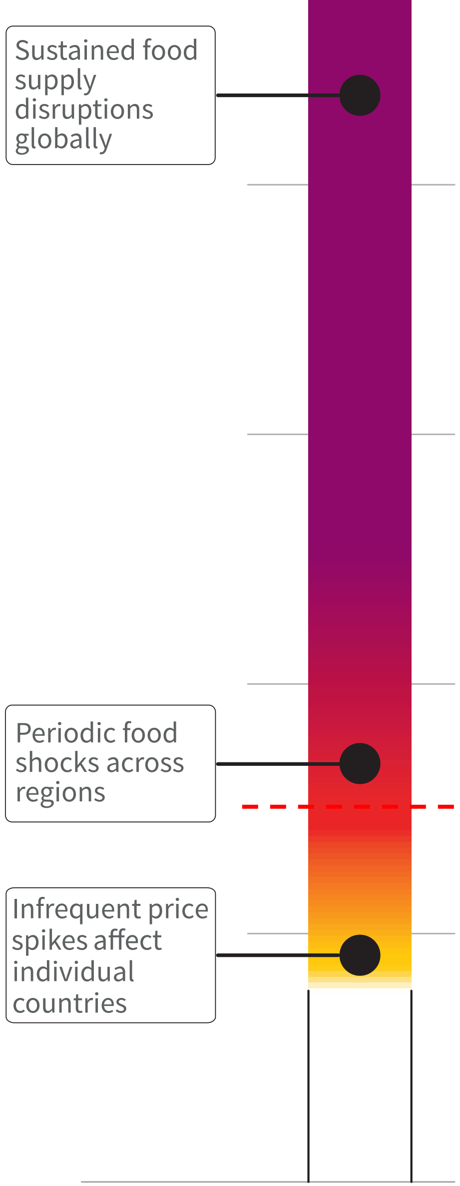


Source: Met Office Hadley Centre (HadCRUT5)

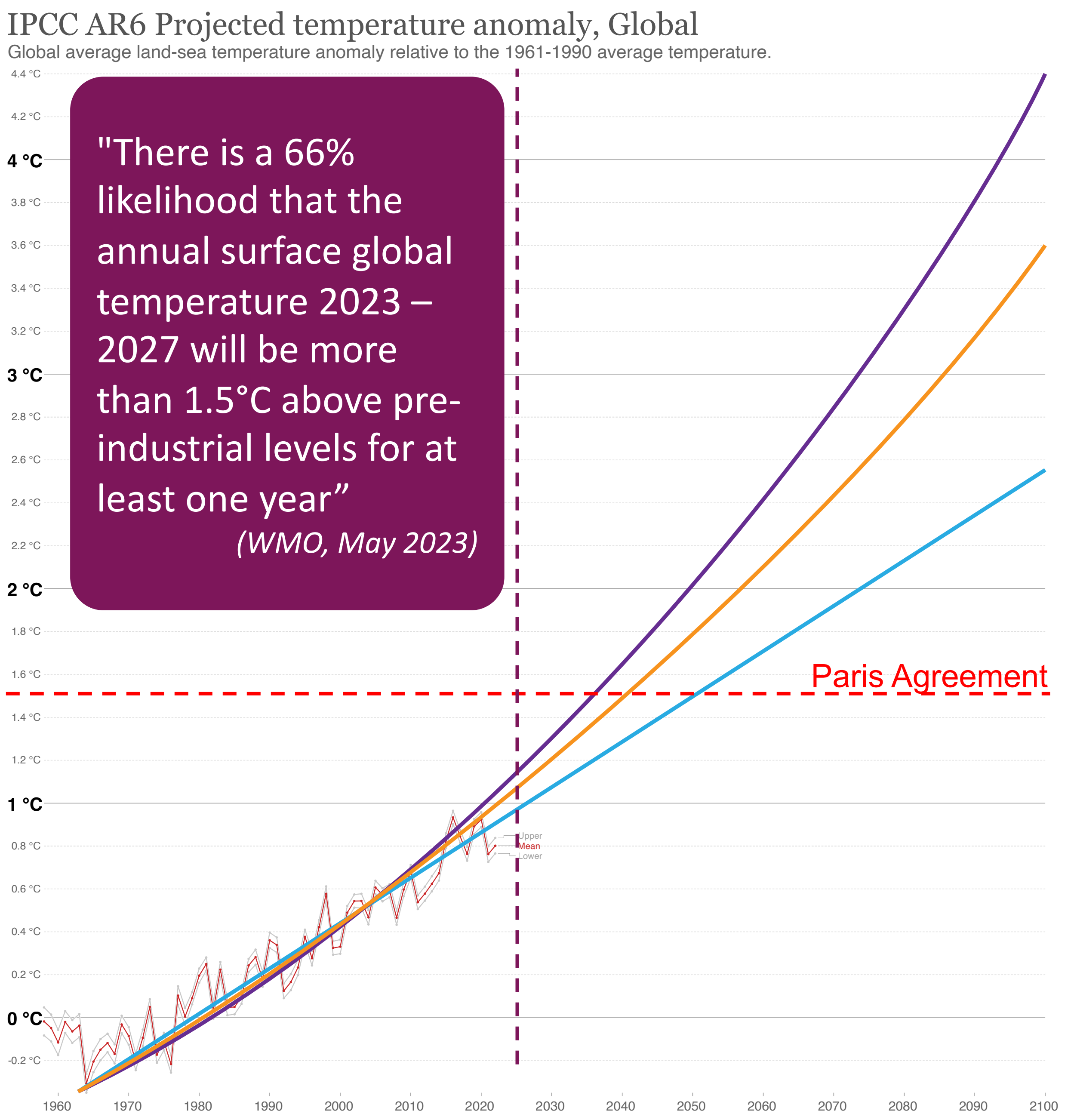
Rising temperature and risk



Source IPCC SRCCL (2019)

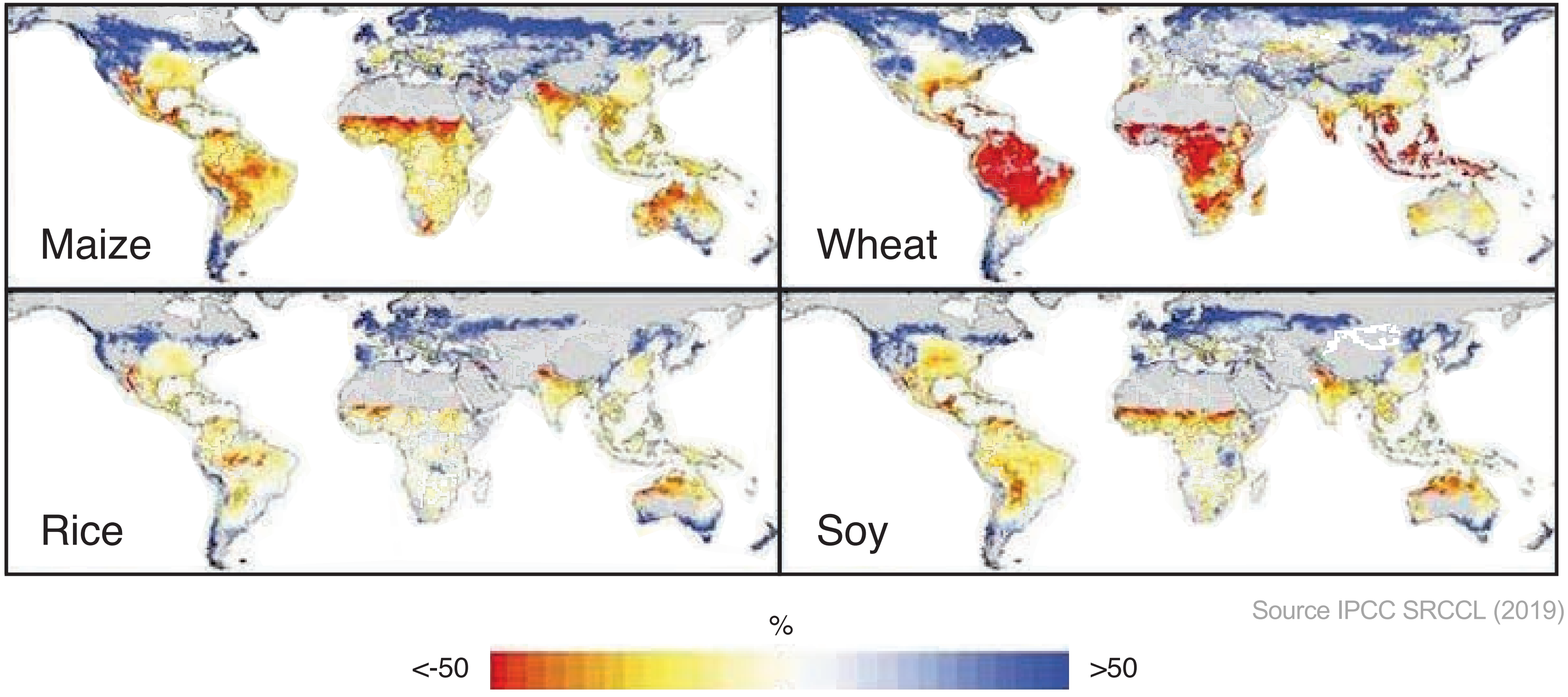


Food supply instabilities



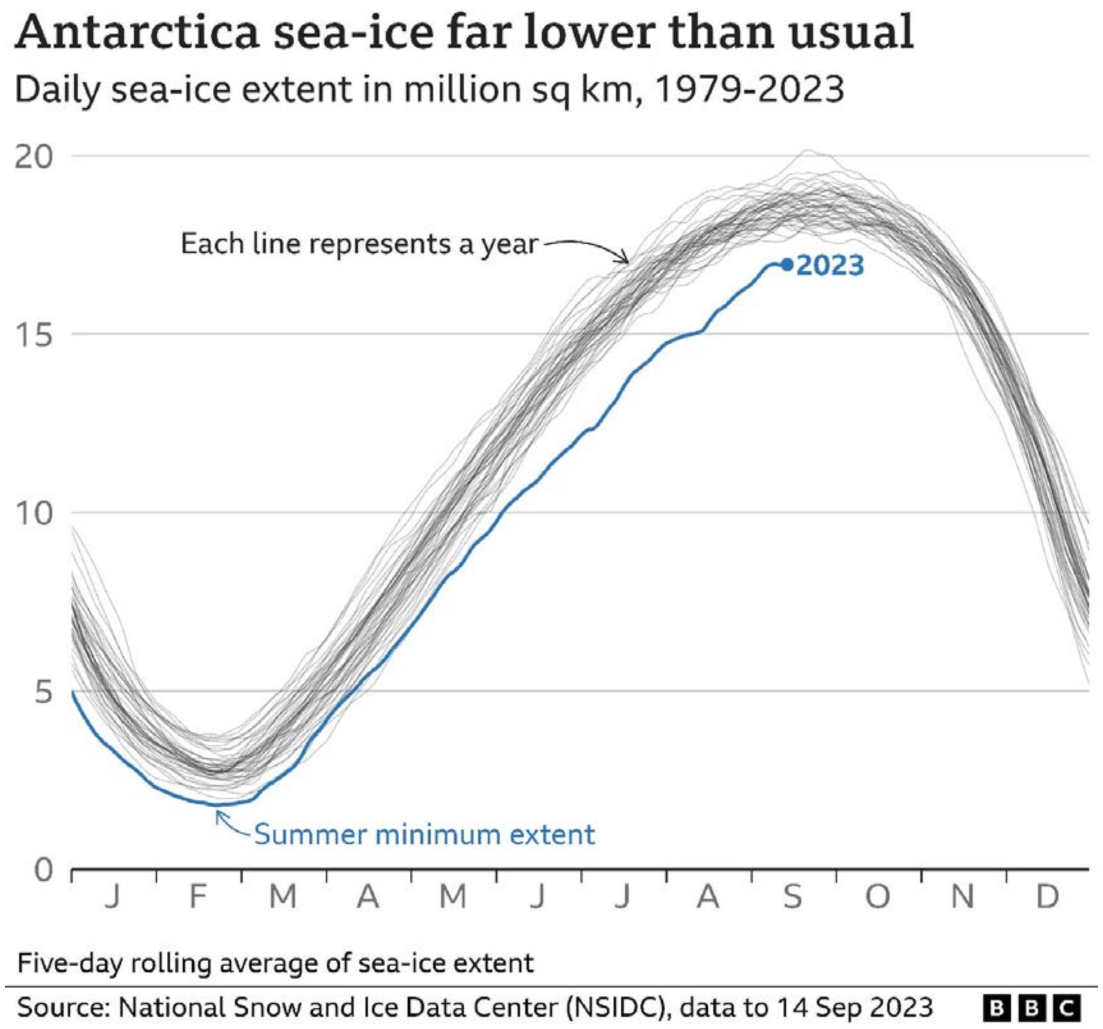
Rising temperature and risk

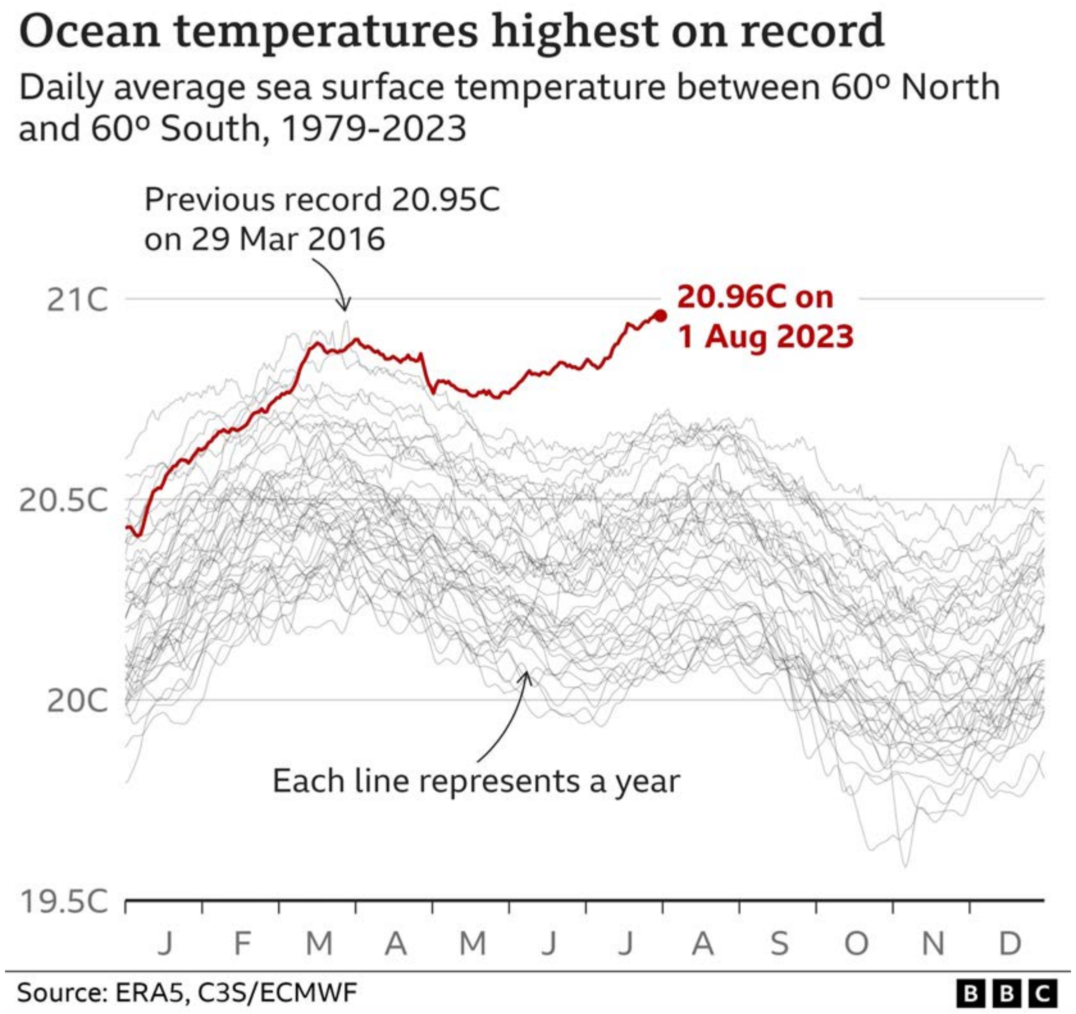
Crop yield changes 1990-2090 averaged over Global Gridded Crop Models



Source IPCC SRCCL (2019)

Rising temperature and risk: tipping points

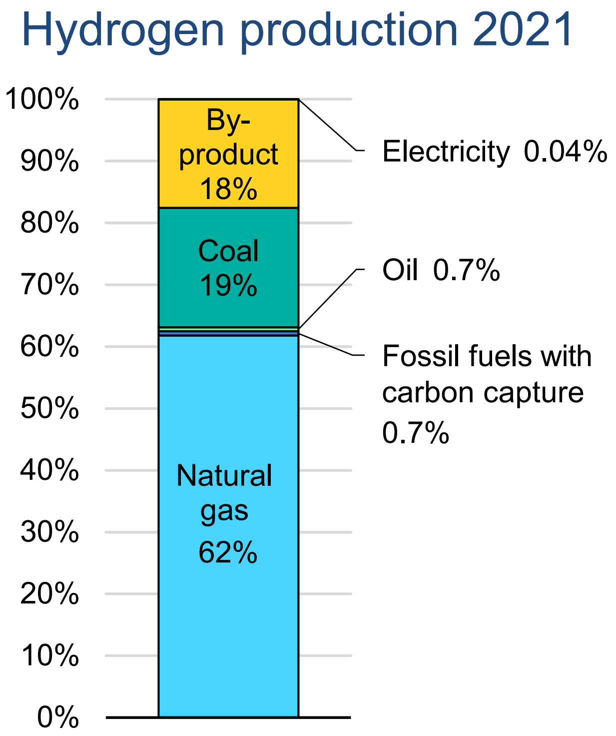




Why isn’t it working?

Unpacking burden-shifting via aggregation & deployment rates

“I’m making good things happen!”

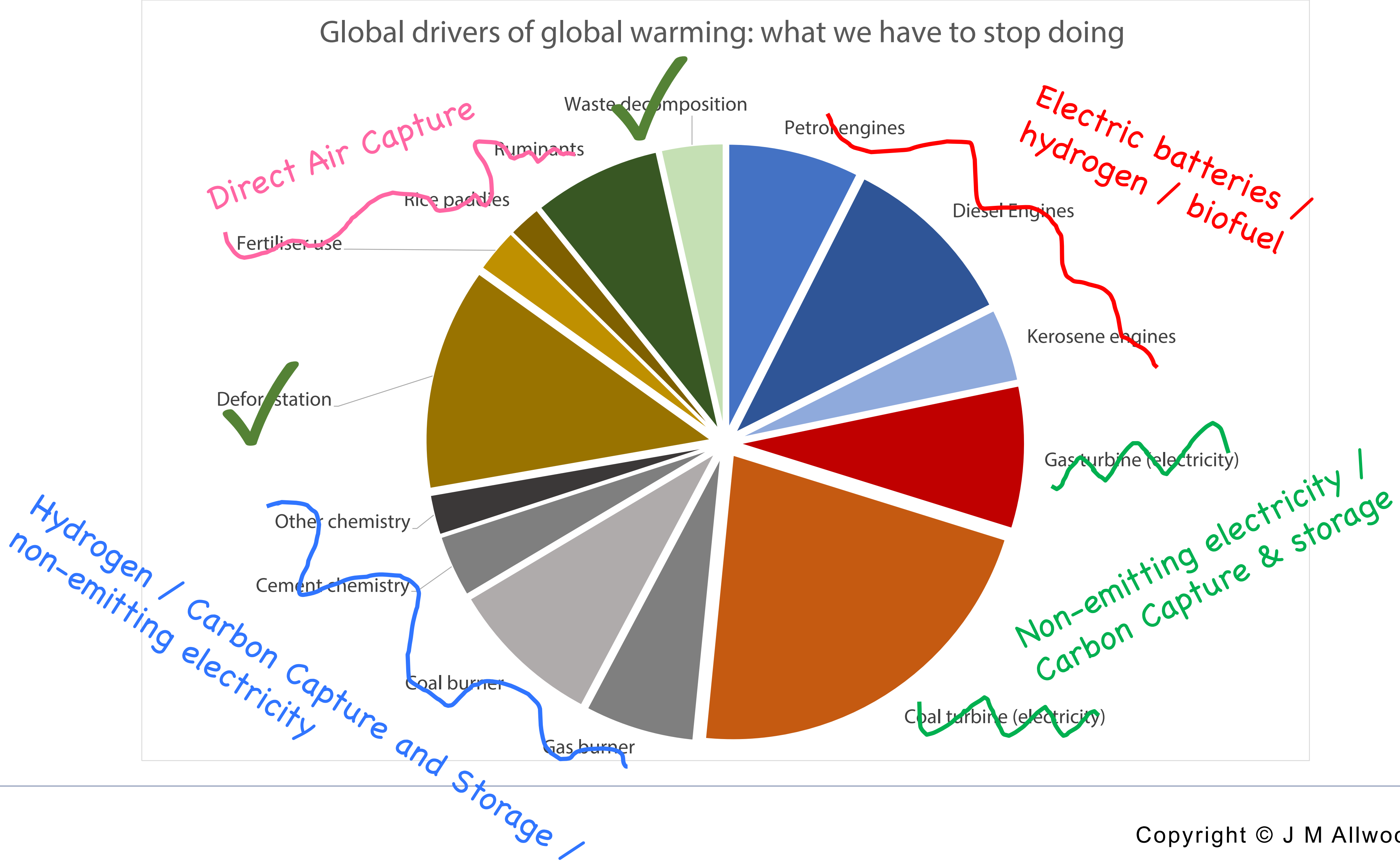


Source: International Energy Agency (2022)

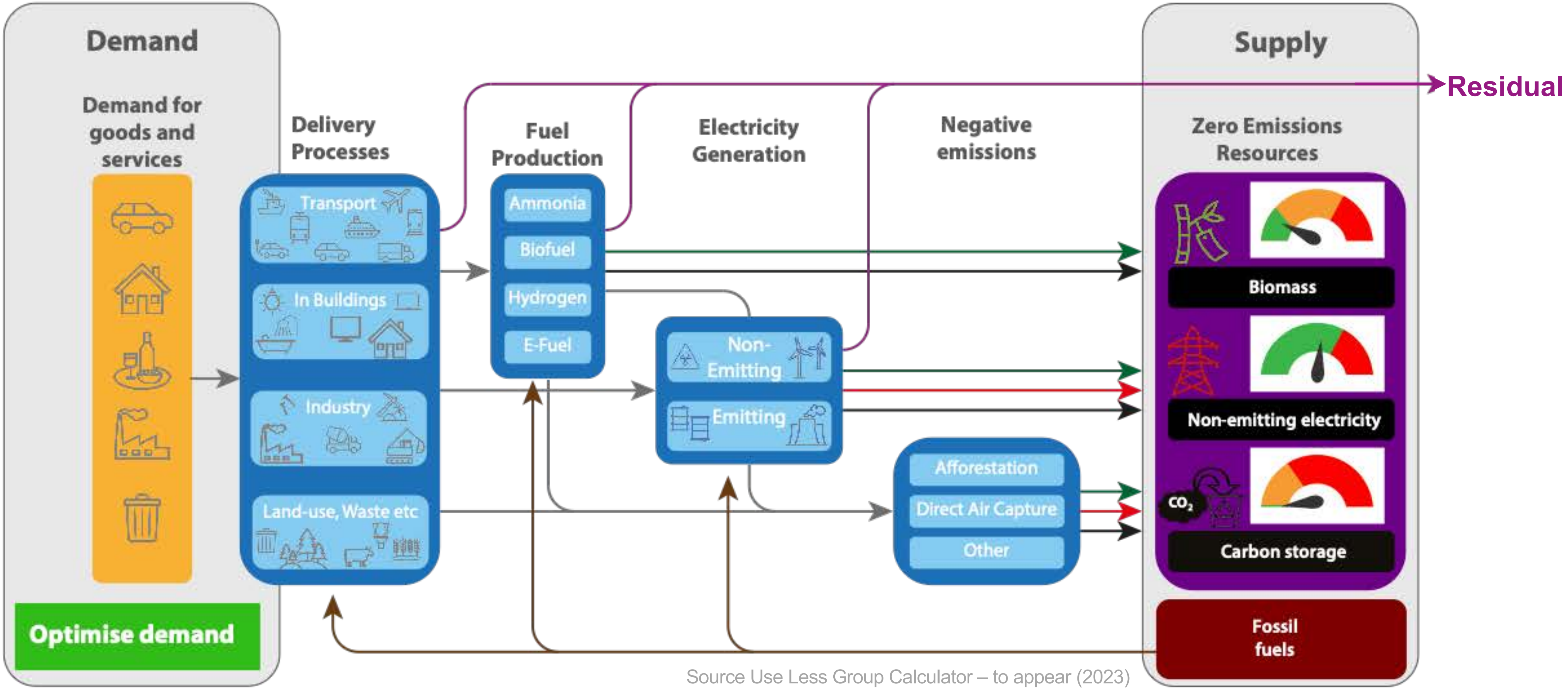
- Hydrogen
- Trade
- Carbon offsets
- “Negative emissions technologies”
- Bio-fuels
- Synthetic fuels
- …

Burden-shifting is endemic to climate policy at present

Incumbent thinking on how to reach zero emissions



Aggregating demand for three “zero-emissions resources”



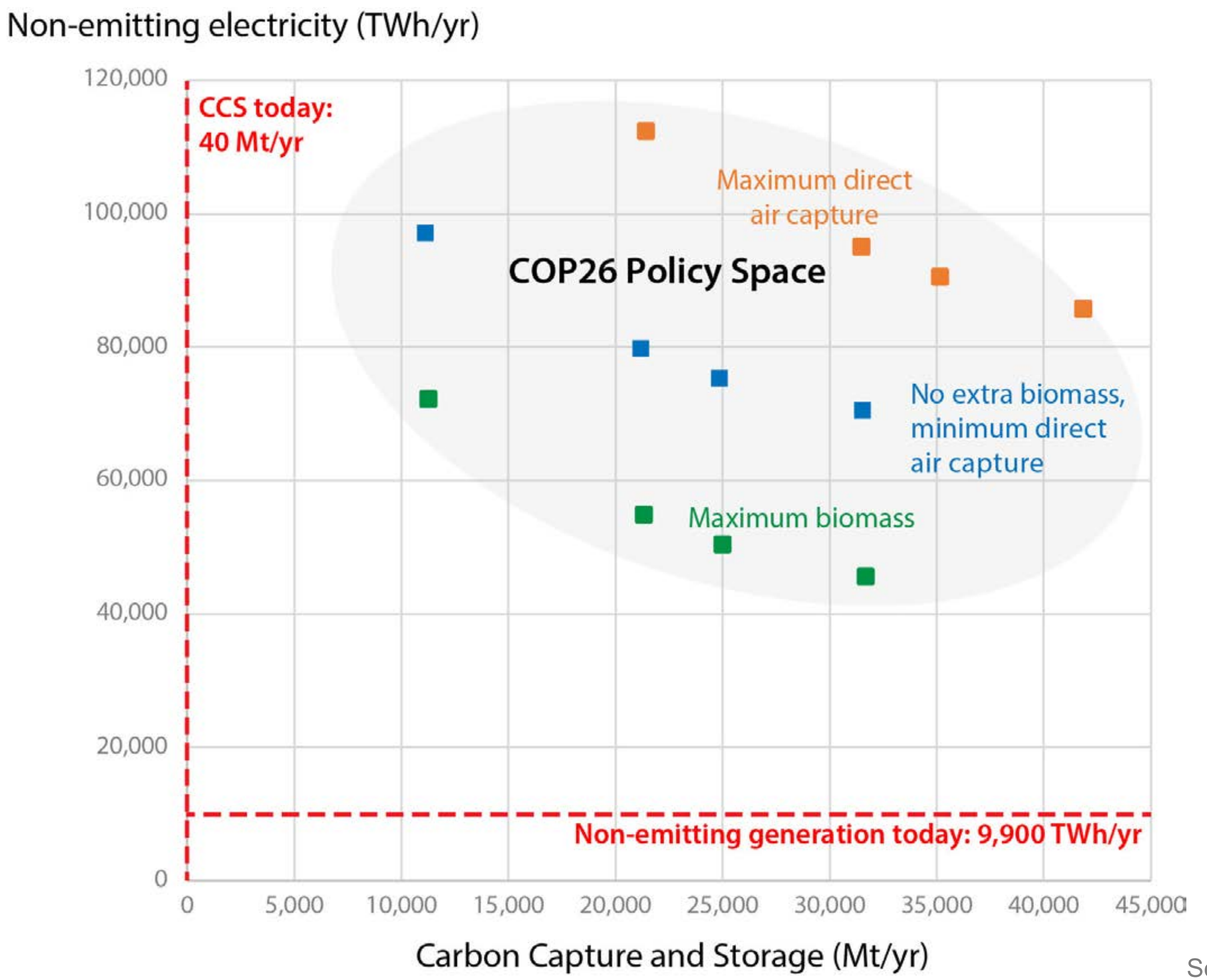
Source Use Less Group Calculator – to appear (2023)

Aggregation analysis

Sector	2020 GHGs (MtCO2/yr)	Physical units	Option 1	Option 2
Road vehicles	6,100	2,700 G litres petrol/diesel	140-320 litres biofuel per tonne biomass	6 litres petrol equivalent to 20kWh electric power
Train	200	40 G litres diesel	As above	As above
Shipping	900	370 G litres diesel	As above	19kWh per litre synthetic fuel
Aviation	2,900	470 G litres kerosene	As above	As above
Electricity (emitting)	10,000	17,000 TWh	10,000 Mt CCS	17,000 TWh non-emitting generation
Electricity (non-emitting)		9,900 TWh		
Space heating	6,700	8,800 TWh gas boiler output	6,700 Mt CCS	1kWh heat pump = 3.1kWh gas boiler
Blast furnace Steel	3,700	1,400 Mt Steel	3,700 Mt CCS	3.5MWh/tonne steel via green hydrogen
Cement	3,100	4,100 Mt Cement	3,100 Mt CCS	
Other industry	6,700		6,700 Mt CCS	Same total electricity as steel
Deforestation	1,100	Assumed to stop		
Fertiliser/rice/soil/crop	5,300	Un-changed	Direct Air Capture	
Ruminants	3,000	Un-changed	Direct Air Capture	
Waste	1,600	Assumed to stop		
Direct Air Capture		Applicable to all emissions	4MWh/t capture and store plus 1 t CCS per t DAC	

Data from multiple sources: https://ukfires.org/blog-cop26/

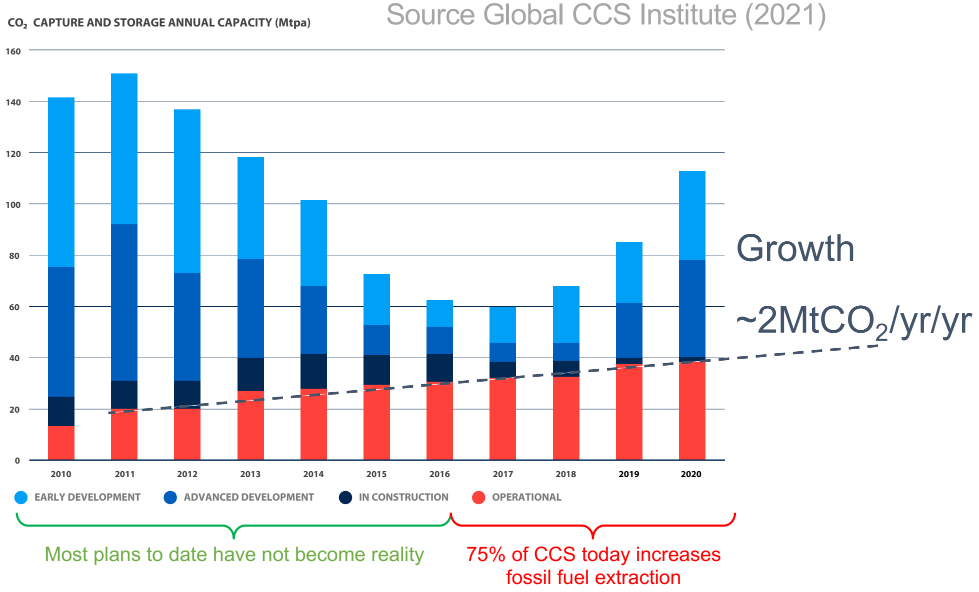
Aggregation of plans discussed at COP26

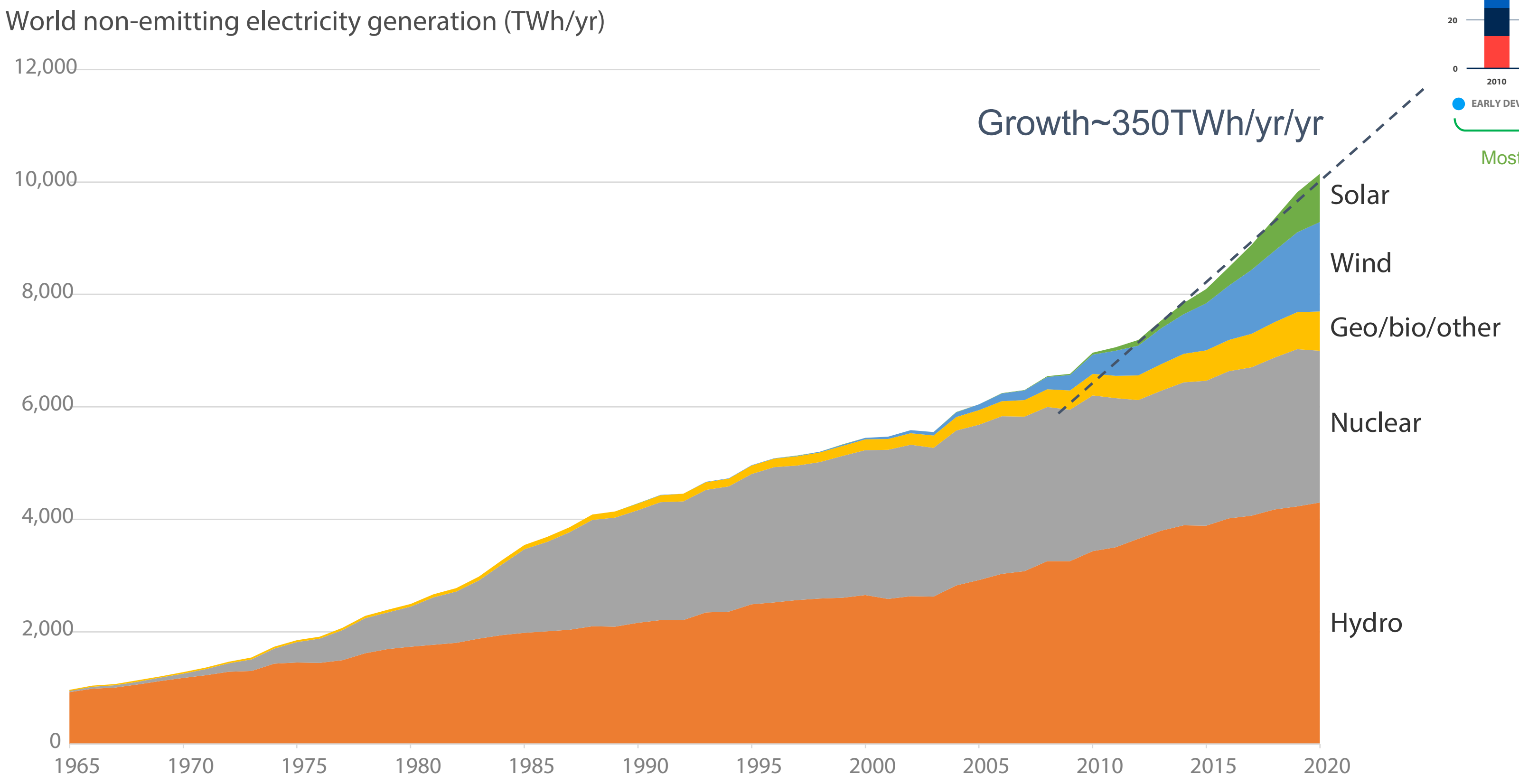


Source: https://ukfires.org/blog-cop26/

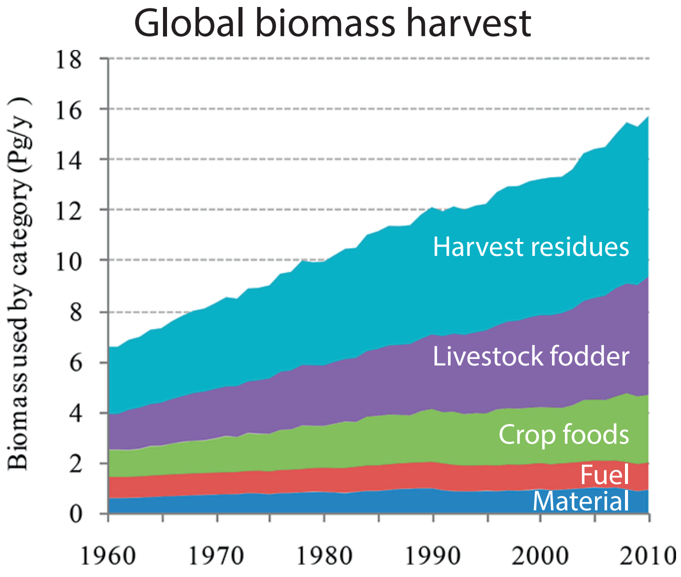
Deployment rates

Source Global CCS Institute (2021)



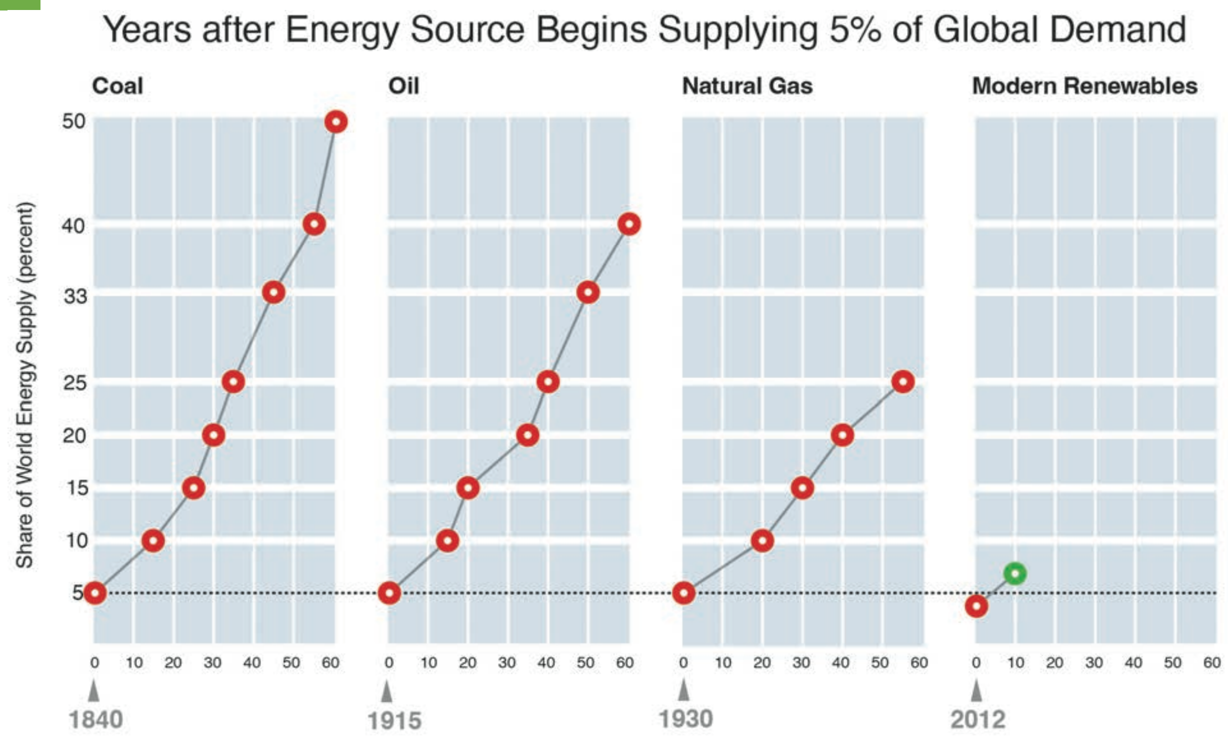


Source BP Statistical Review of World Energy (BP, 2021)

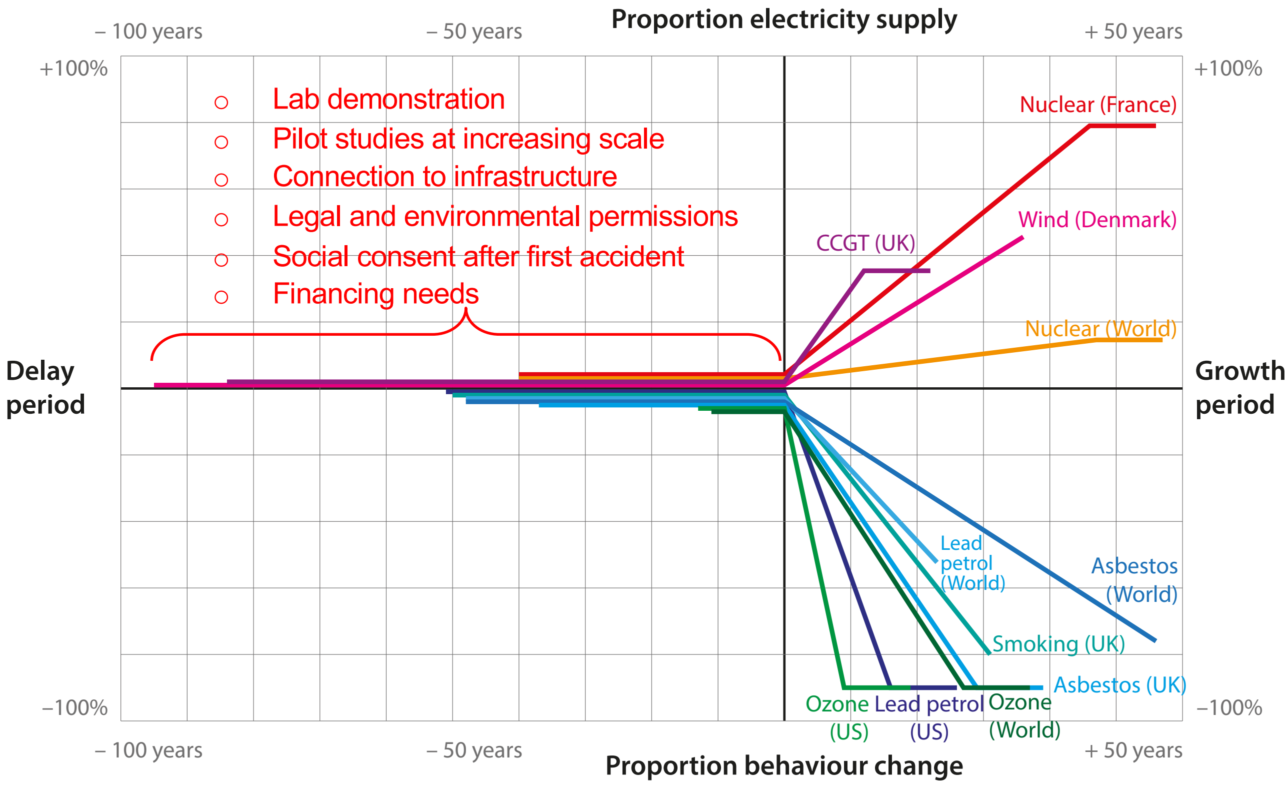


Source Zhou et al. (2018)

Deployment rates



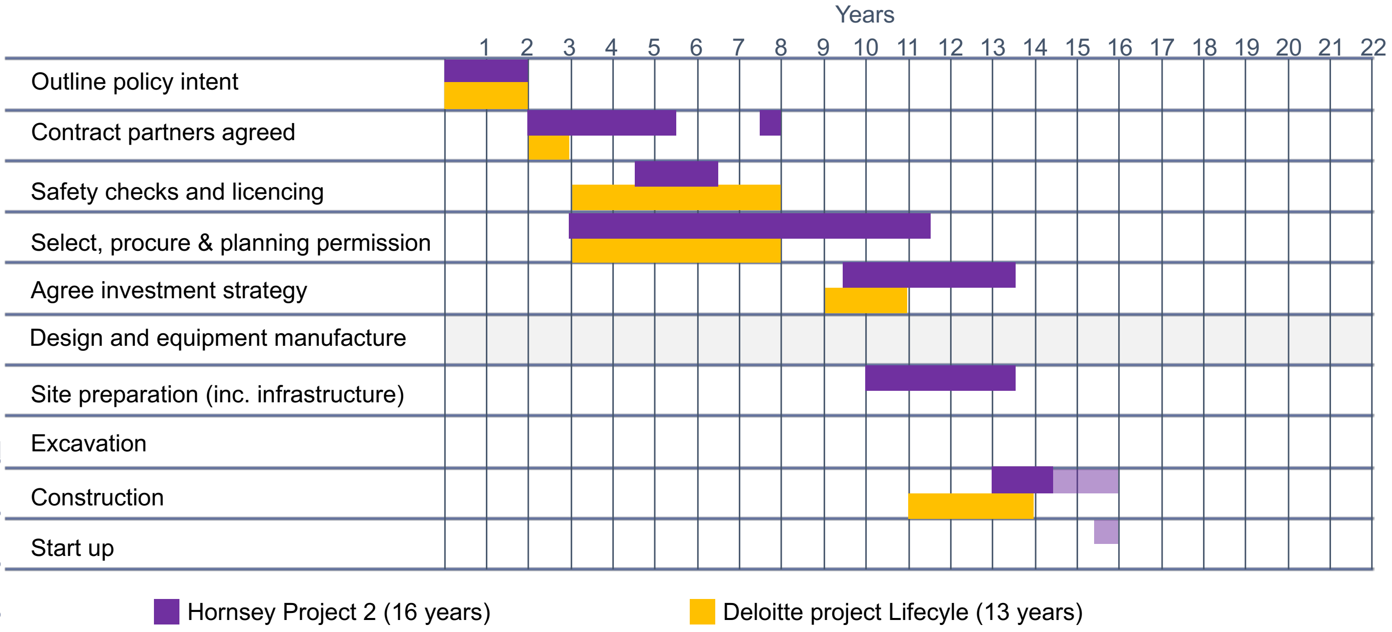
Sources: Smil (2014), update BP World energy statistics (2022)



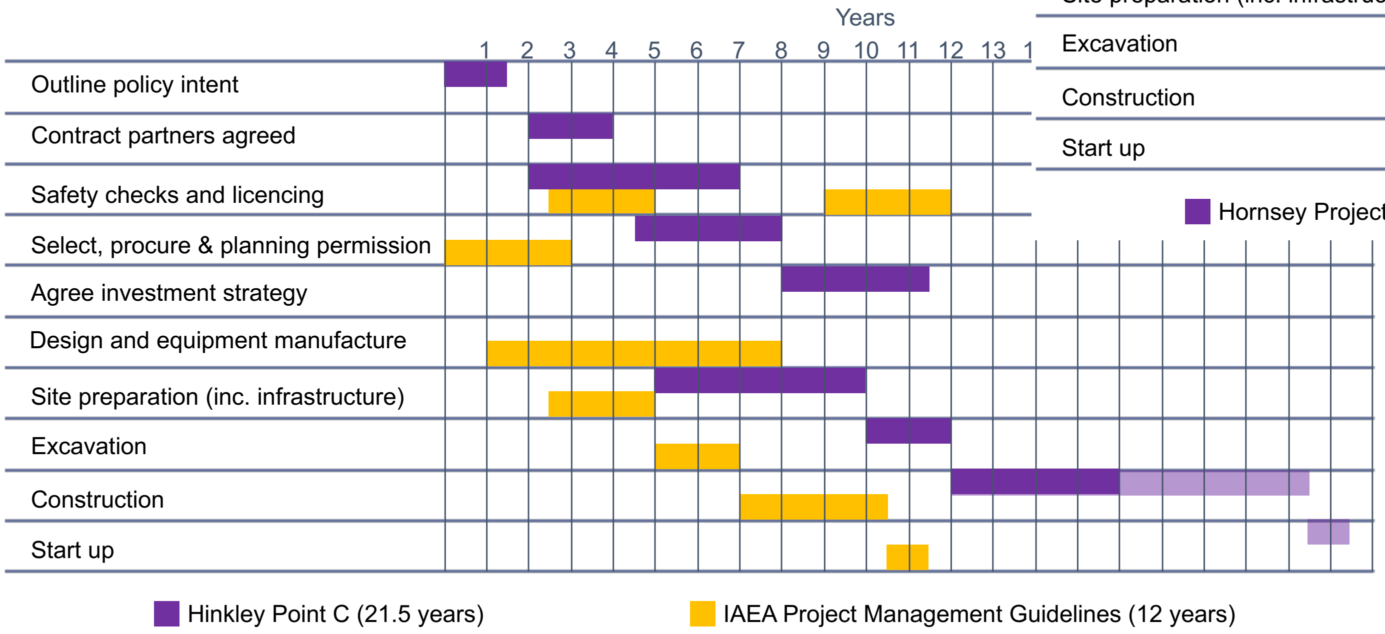
Source: Nelson & Allwood (2021)

Project examples

Offshore Wind Power Timeline

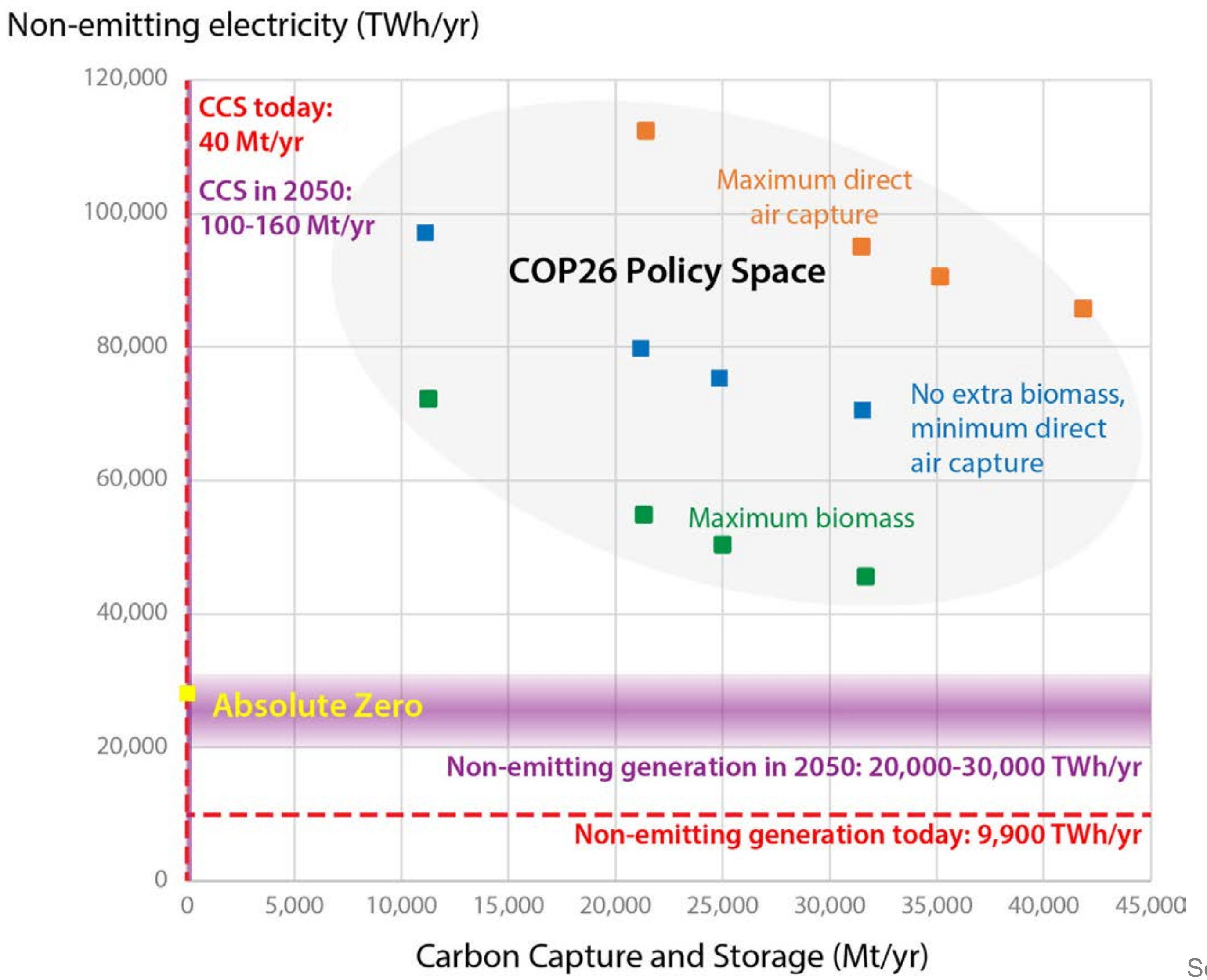


Nuclear Power Timeline



Source: Use Less Group analysis

Preliminary result: policy will be constrained by resources

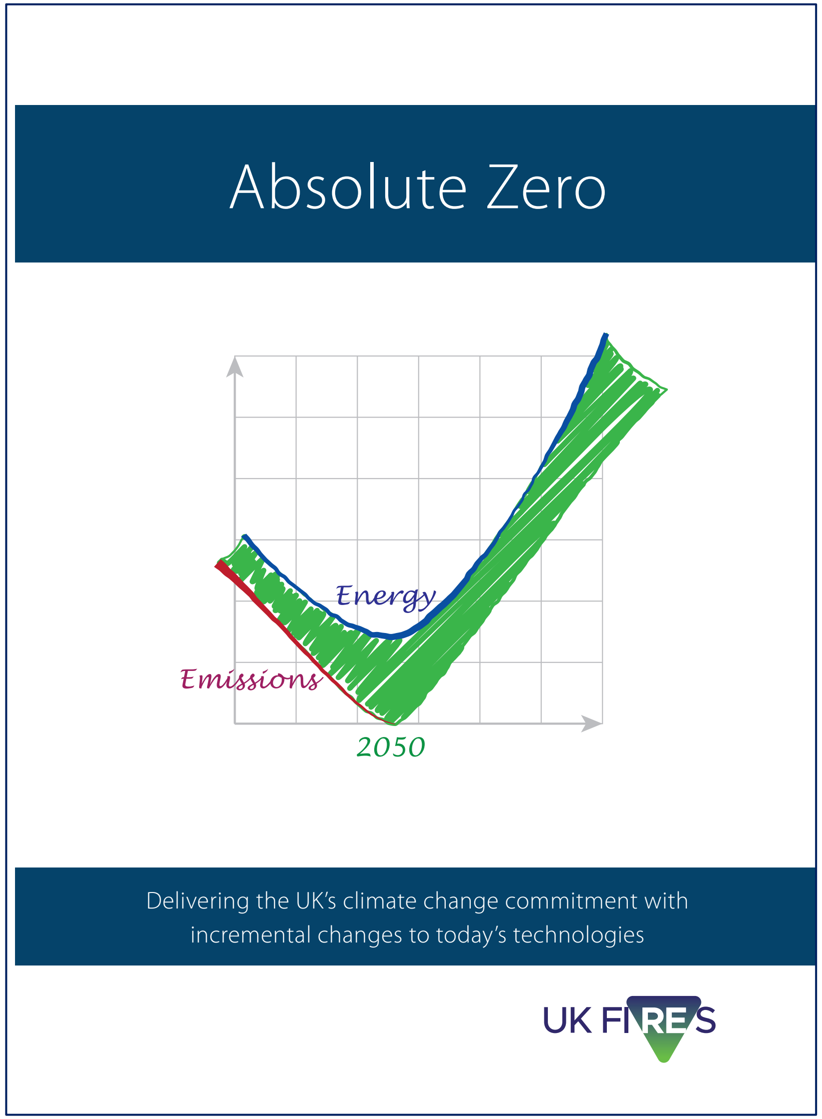


Source: https://ukfires.org/blog-cop26/

Resource-constrained climate policy

The big picture in the UK:

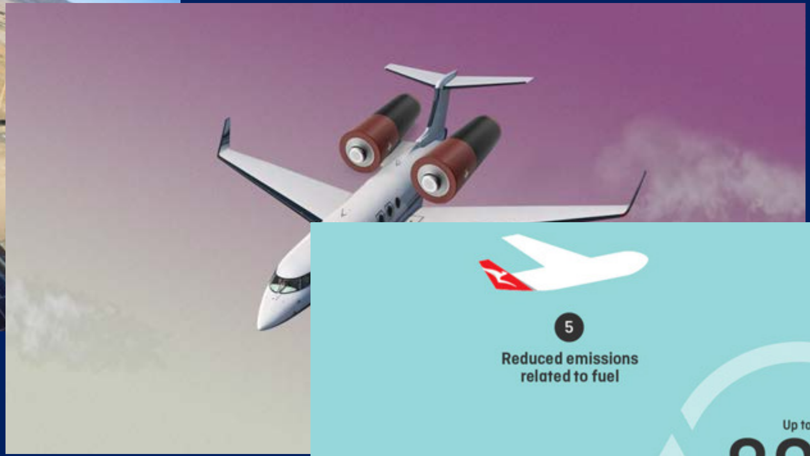
- By 2050 we will have ~ 2.5x as much emissions-free electricity as today
- We will have no significant carbon storage, surplus biomass, hydrogen or negative emissions technologies
- We have to electrify everything possible, close anything else, and use ~60% as much electricity as we'd otherwise like
- For householders only 4 actions matter - stop using:
  - fossil boilers,
  - fossil cars,
  - fossil planes,
  - ruminants.

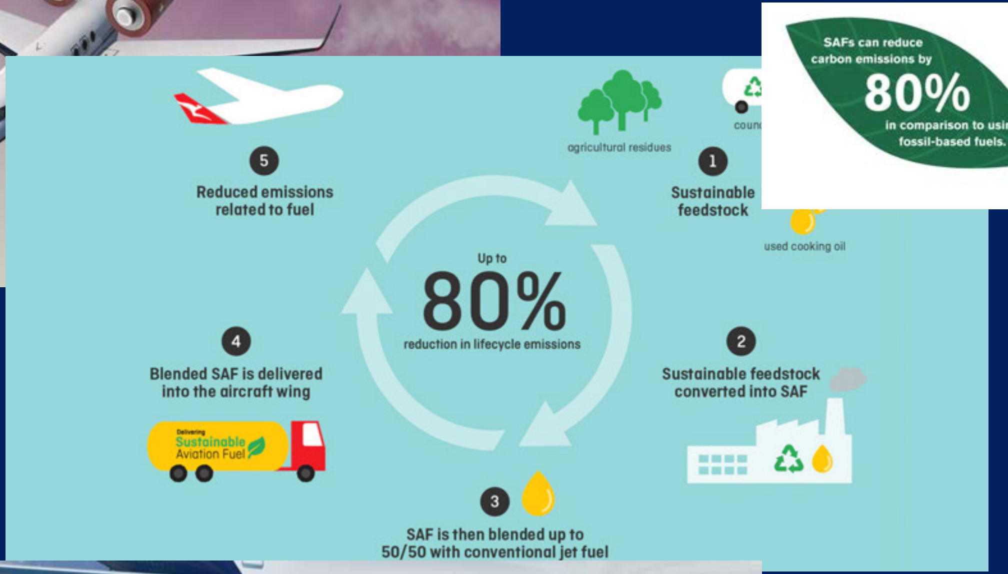


https://ukfires.org/absolute-zero/

“We’ll just have to go a bit faster then…”


SUNSEEKER

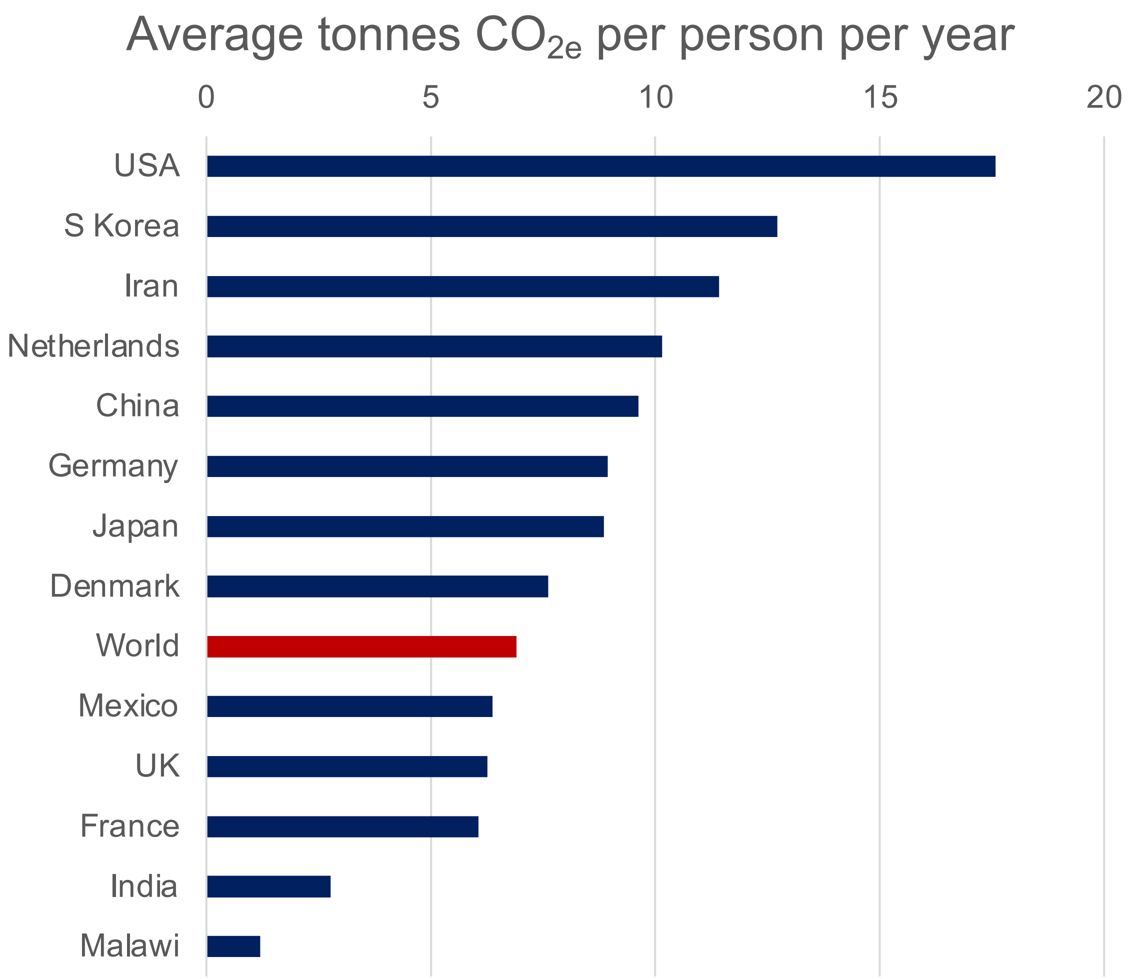


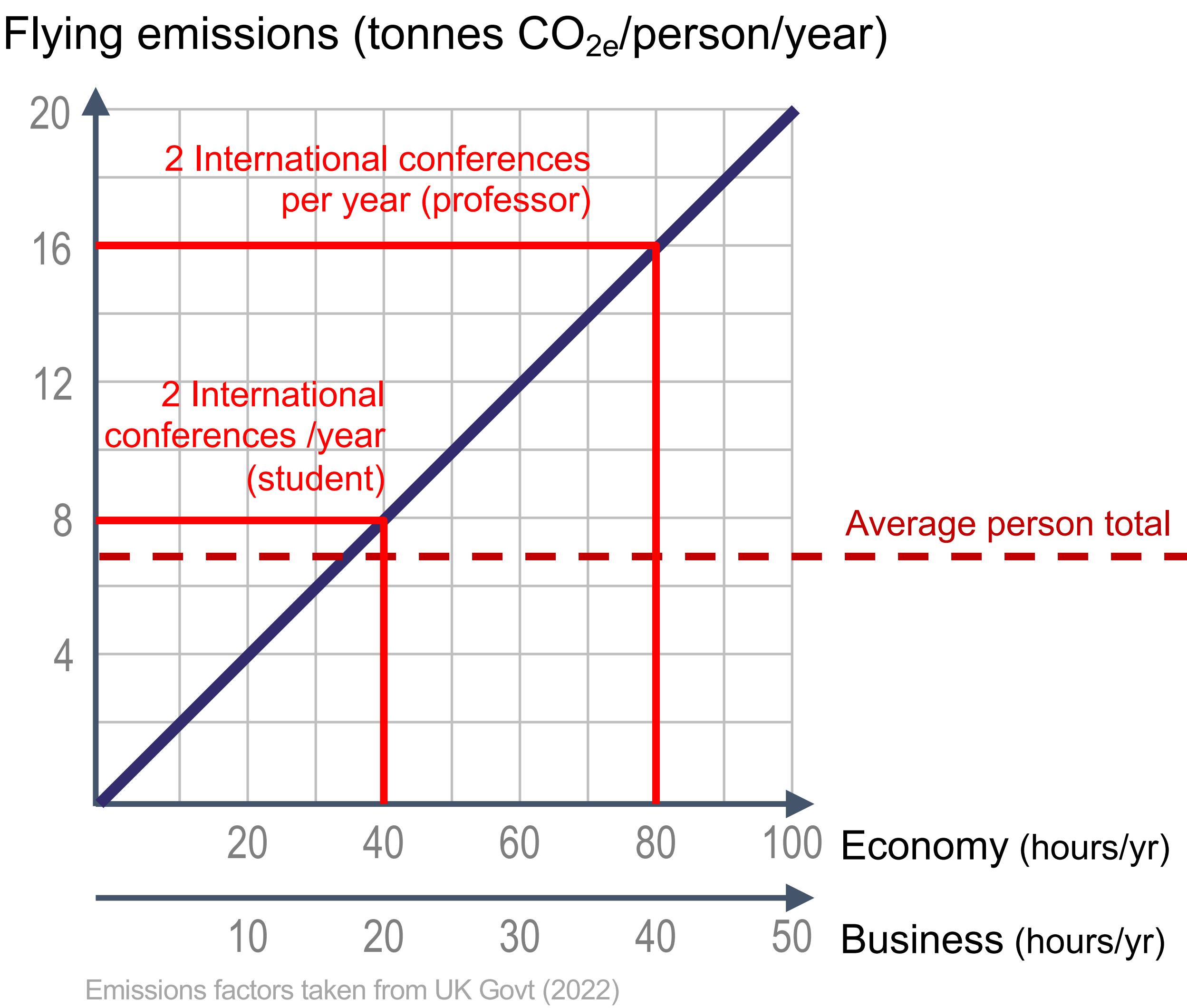

5
Reduced emissions related to fuel
agricultural residues
1
Sustainable feedstock
used cooking oil
Up to
80%
reduction in lifecycle emissions
4
Blended SAF is delivered into the aircraft wing
Delivering Sustainable Aviation Fuel
2
Sustainable feedstock converted into SAF
3
SAF is then blended up to 50/50 with conventional jet fuel
SAFs can reduce carbon emissions by
80%
fossil-based fuels.


H2 powered


339
933 BERLIN-TEGEL
8260 FRANKFURT
5525 BUDAPEST
1508 ISTANBUL
3248 HURGHADA
939 IZMIR
2378

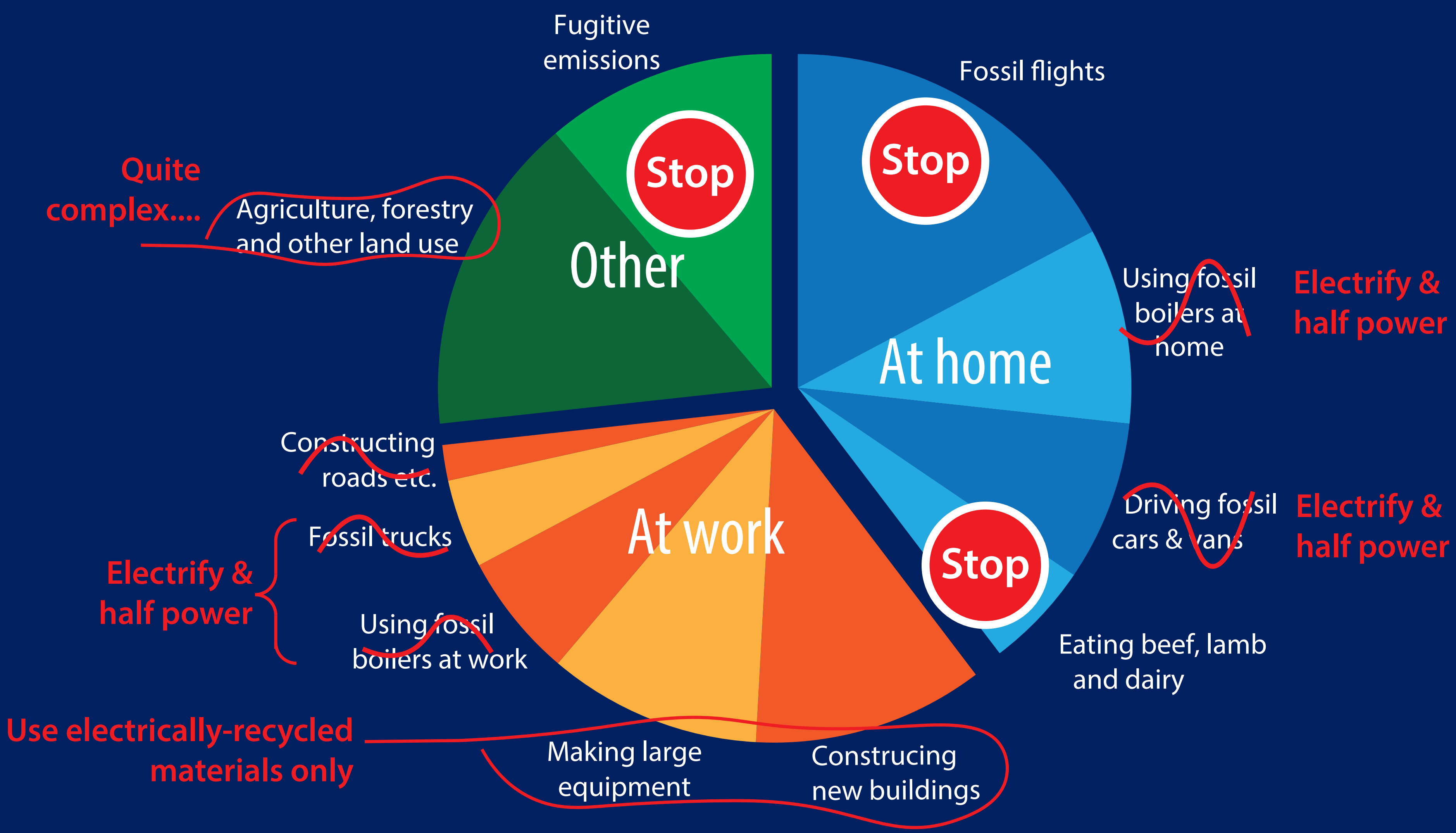
Academic responsibility



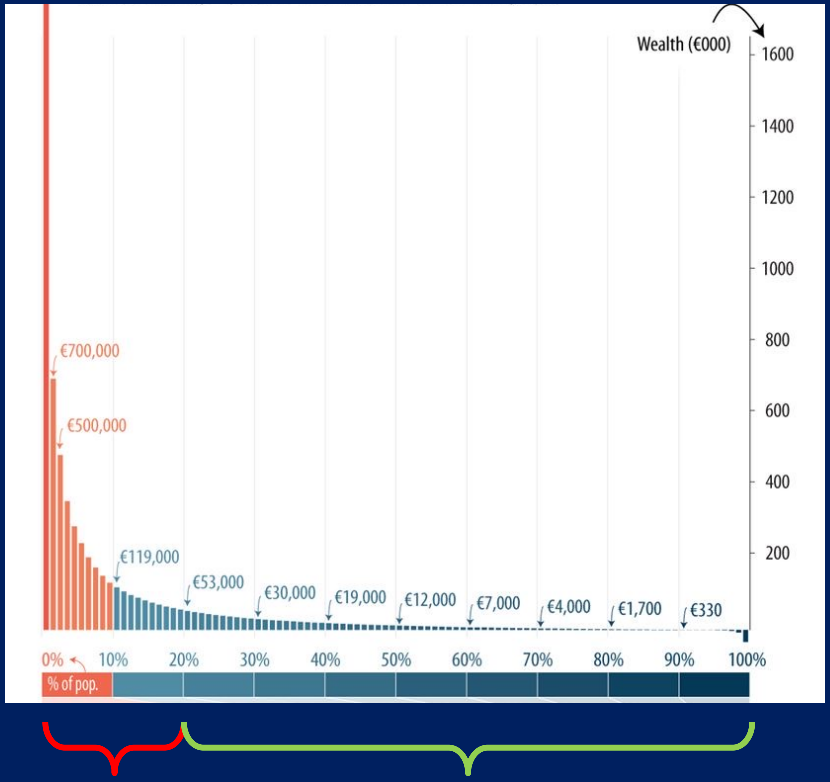


Source: https://ourworldindata.org/grapher/per-capita-ghg-emissions
(The page at this link then gives all the primary data sources)

Does restraint mean misery?

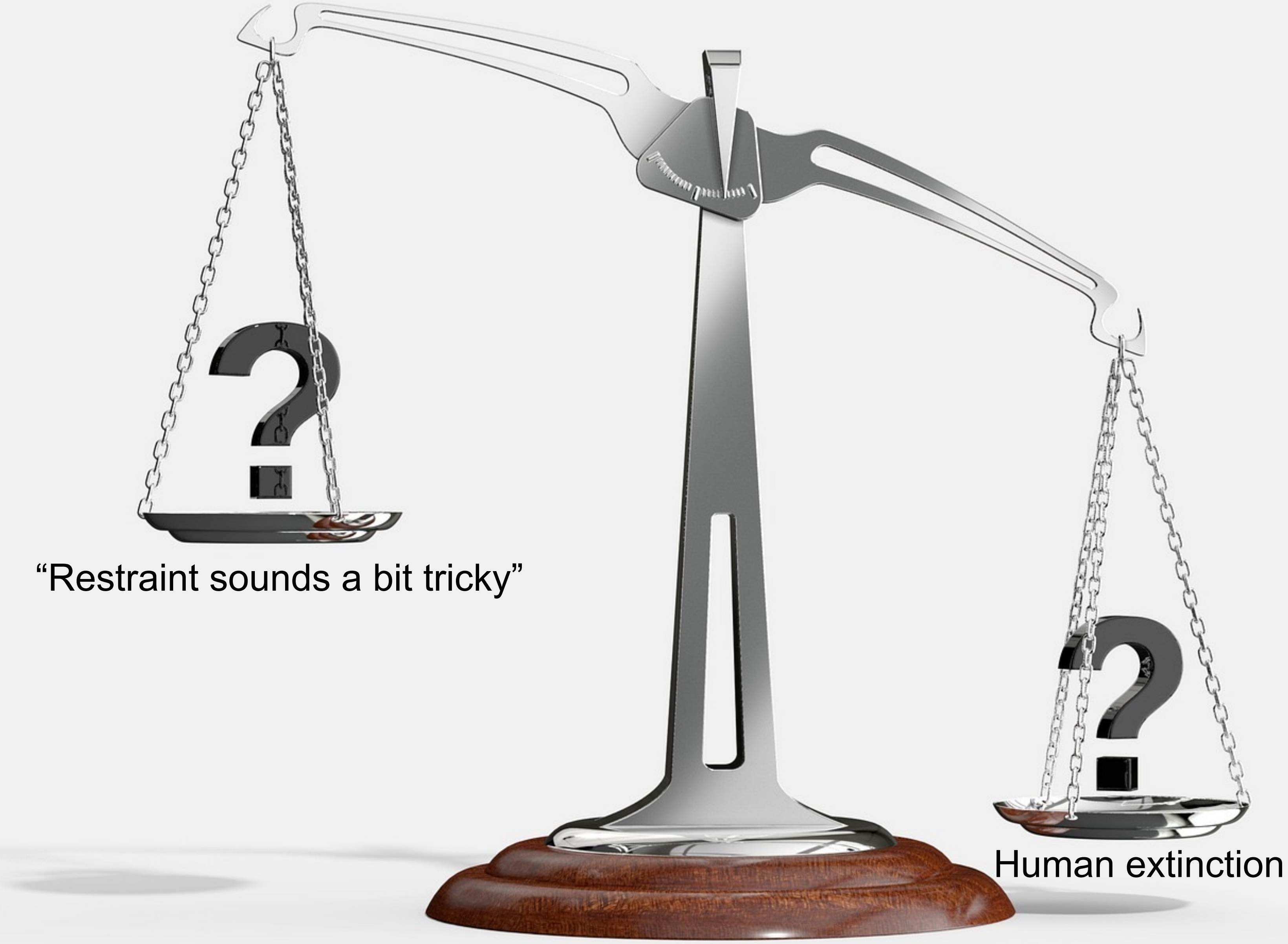


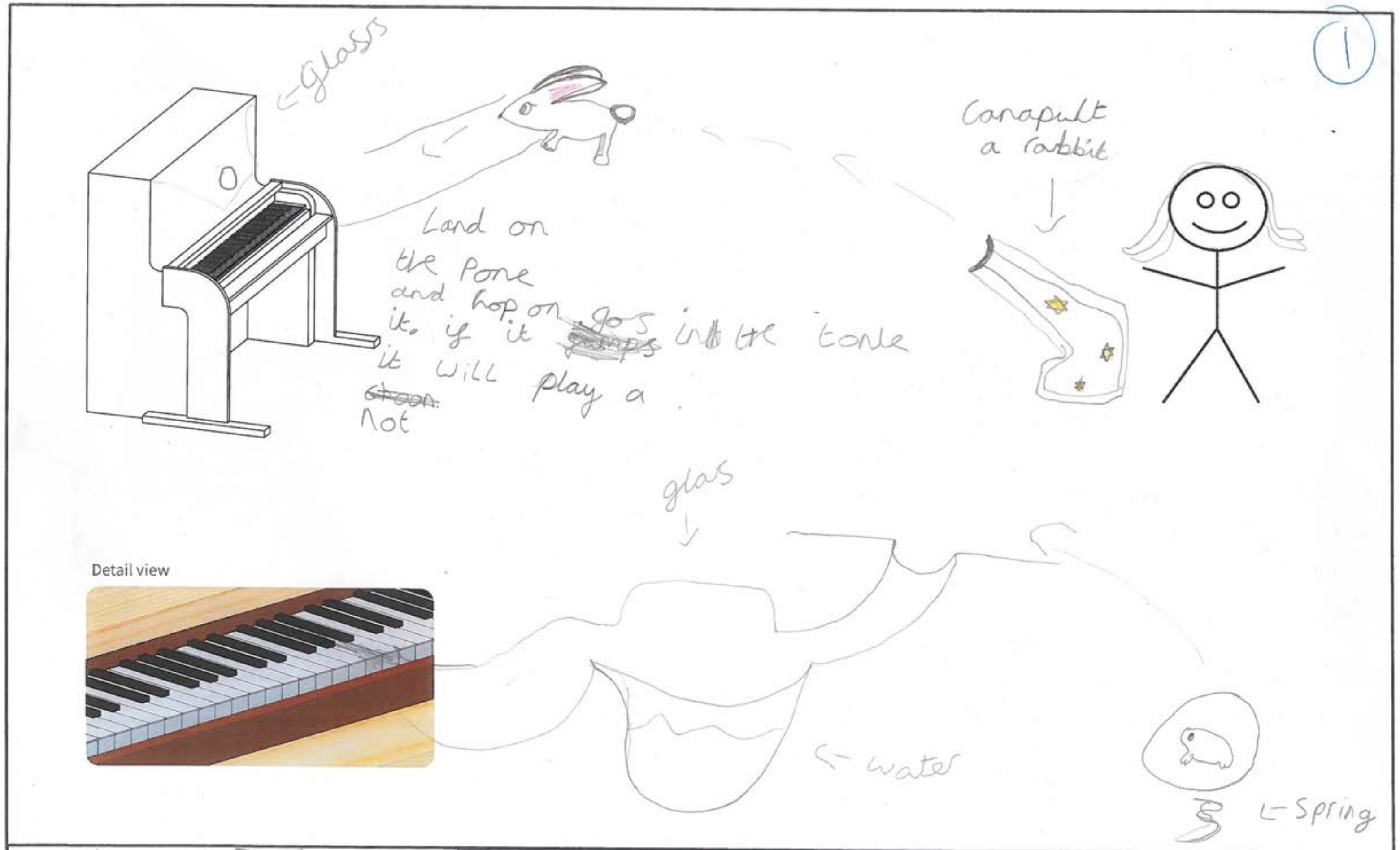
Fugitive emissions
Fossil flights
Stop
Stop
Stop
Other
At home
At work
Quite complex....
Agriculture, forestry and other land use
Using fossil boilers at home
Electrify & half power
Constructing roads etc.
Driving fossil cars & vans
Electrify & half power
Fossil trucks
Electrify & half power
Using fossil boilers at work
Eating beef, lamb and dairy
Use electrically-recycled materials only
Making large equipment
Construcing new buildings



Restraint

Development


“Restraint sounds a bit tricky”
Human extinction



Name: Dolores 2

Date: 10.12.18

School: Junior schoole

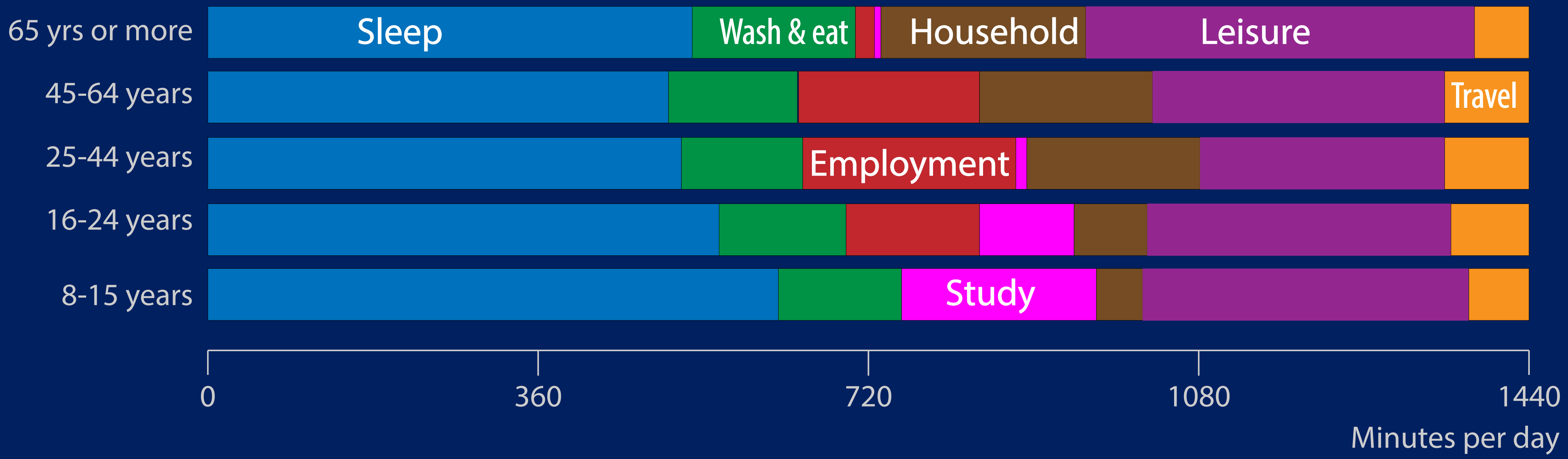
Lydgate

Eighty eight pianists

Invention Title:

The fliemg animuls


new balance



65 yrs or more
45-64 years
25-44 years
16-24 years
8-15 years
Sleep
Wash & eat
Household
Leisure
Travel
Employment
Study
0
360
720
1080
1440
Minutes per day

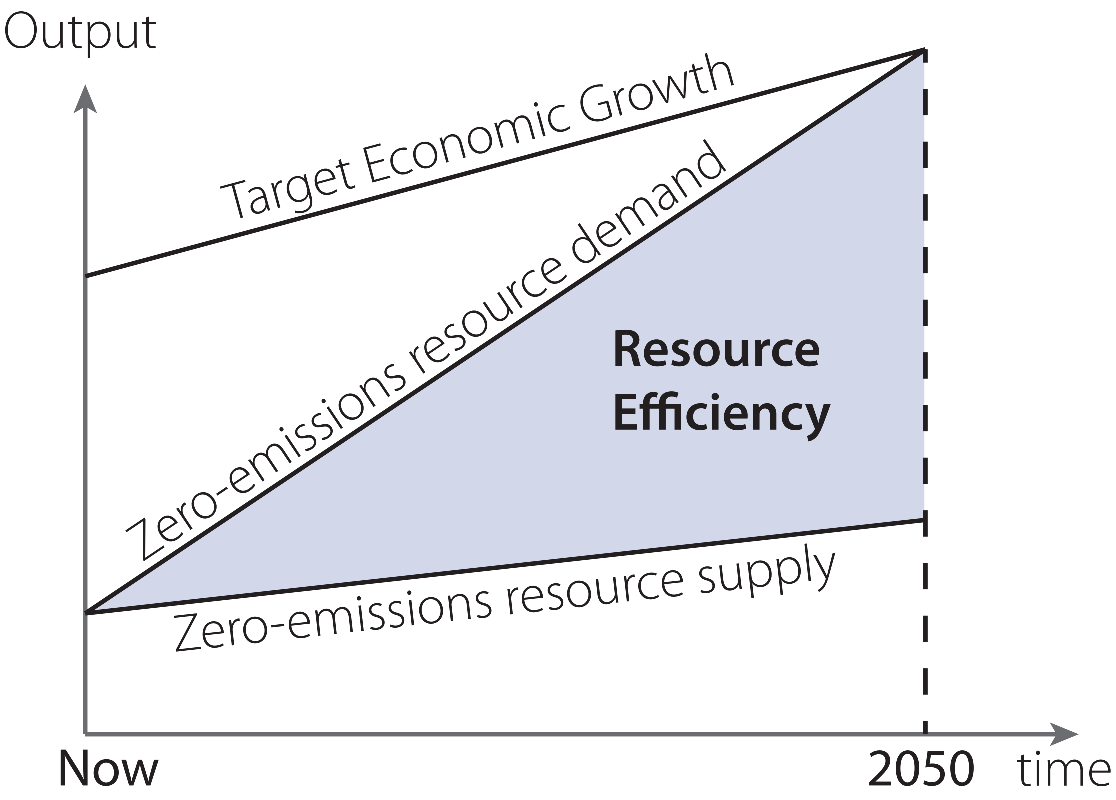
Welfare =

- Imagination
- Fascination
- Diversity of activity
- Endeavour
- Appreciation
- A “balanced life”
- Fulfilment
- Wonder
- Virtue
- …

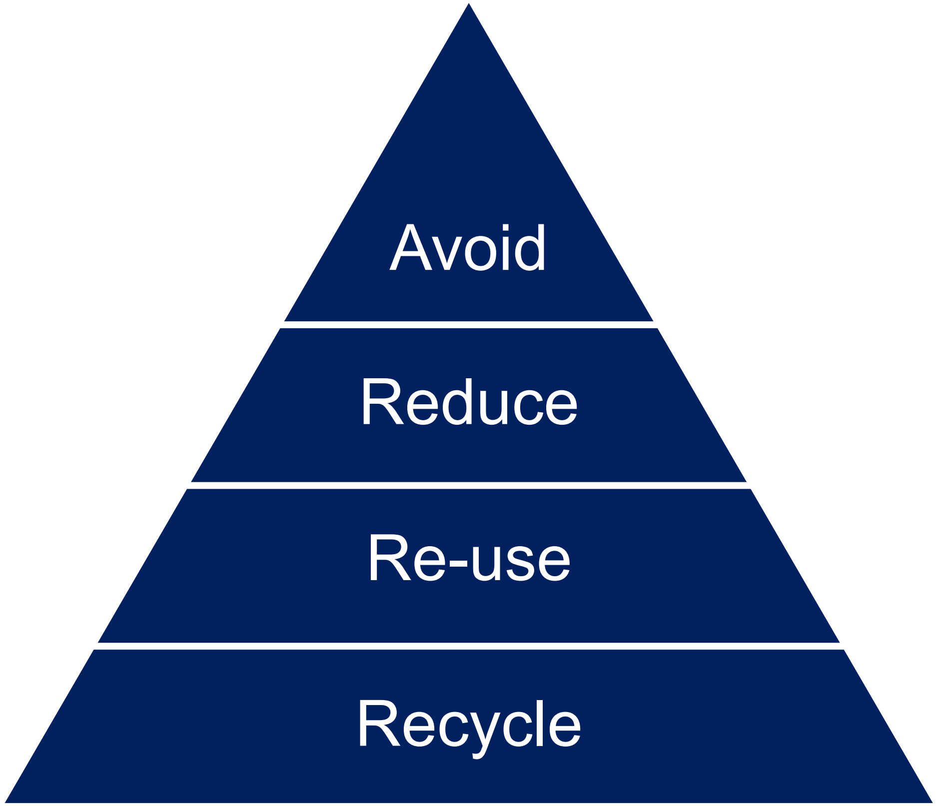
… which allows restraint

Engineering reality

Facing up to the supply-demand gap



Excitement in Resource Efficiency innovation

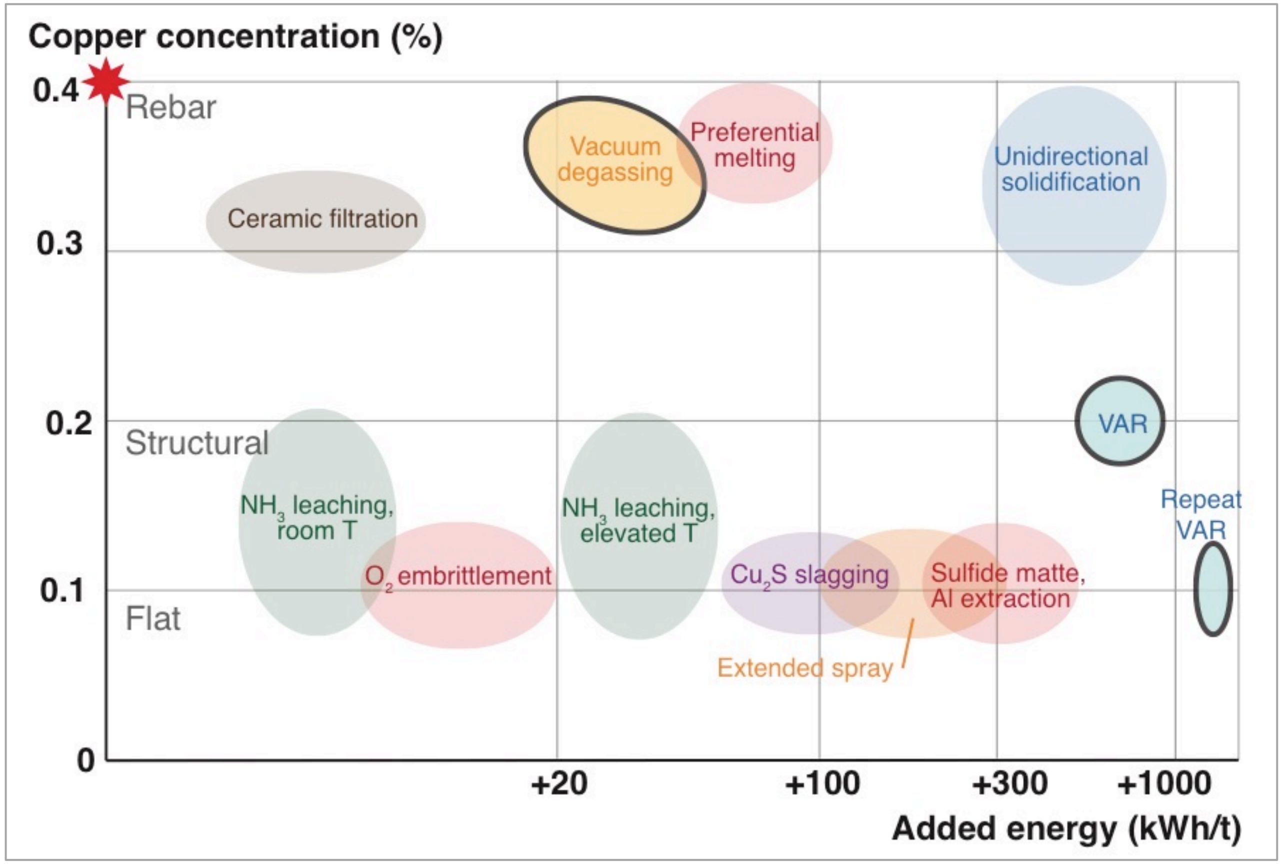


Drawing green circles doesn't help

Avoid
Reduce
Re-use
Recycle

Resource inputs → Lots of lovely economic growth → 'By-products' / Hardly anything

Recycling and quality



Source Daehn et al. (2019)

- To date, copper contamination has not been a problem because it can be absorbed in rebar
- It will become a global problem ~2040-50
- There is a technology opportunity for innovation in removing copper from recycled steel or coping with it

Sustainable metals: science and systems

Scientific discussion meeting
Part of the Royal Society scientific programme

Organised by Professor Julian M Allwood FREng
and Professor Dierk Raabe.

5 – 6 February 2024

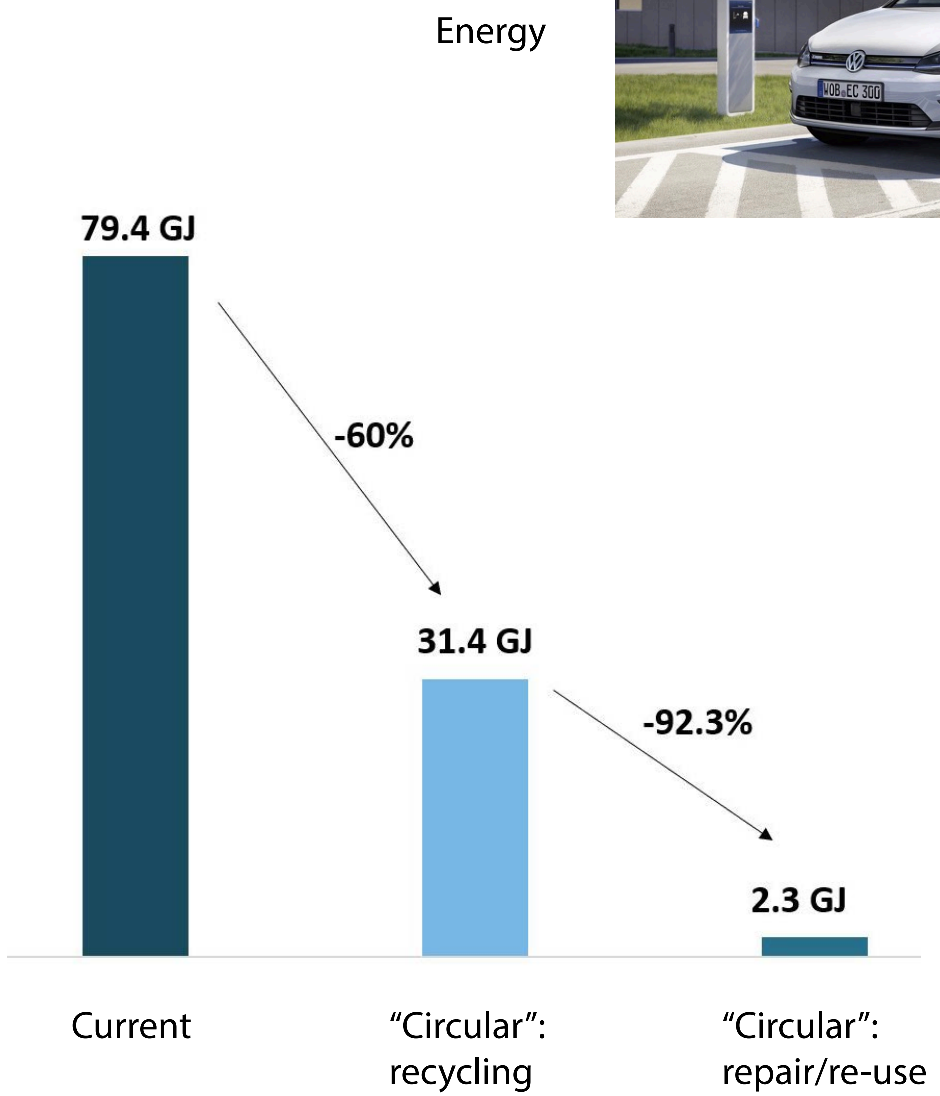
The Royal Society
6 – 9 Carlton House Terrace, London, SW1Y 5AG

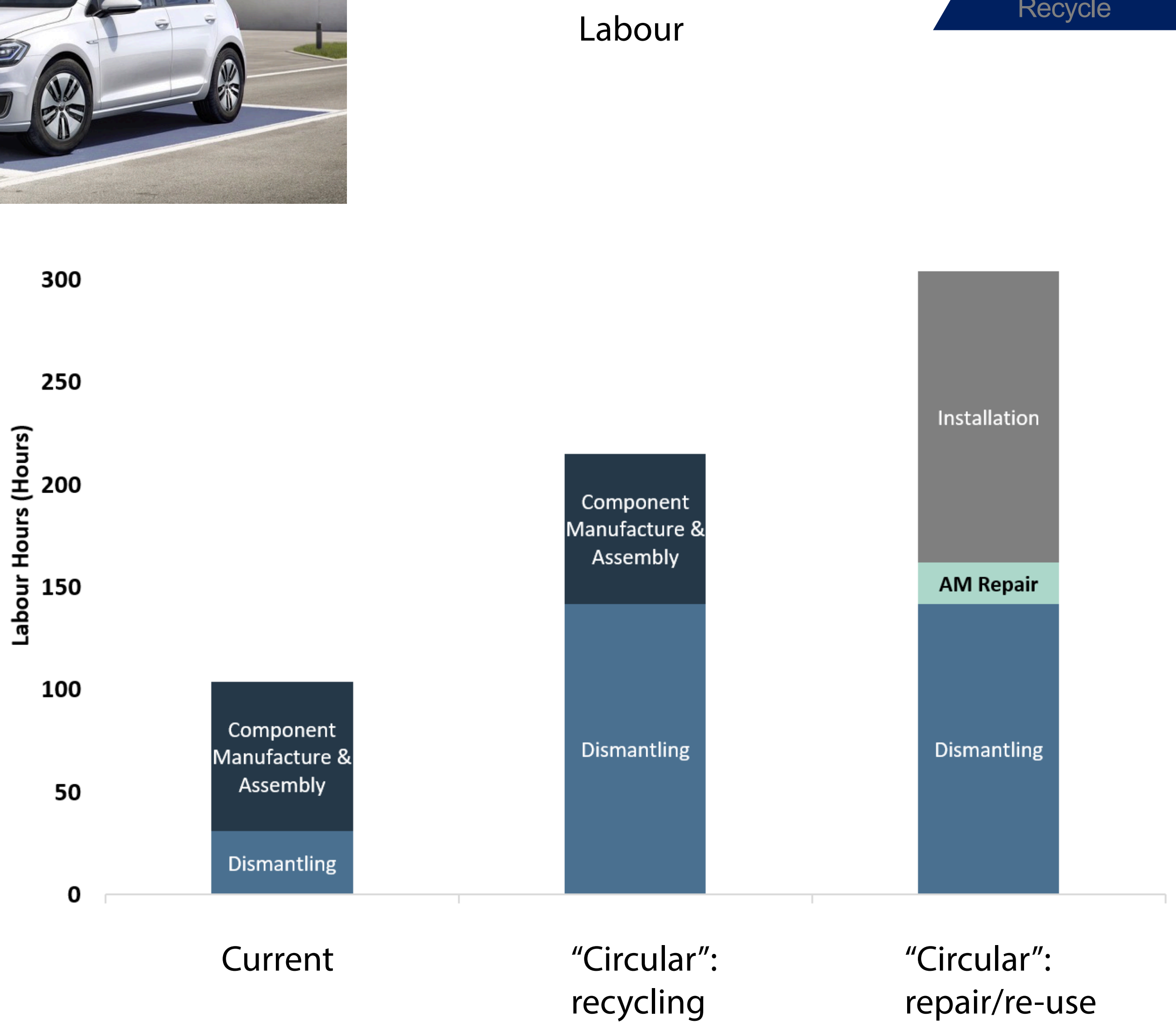
Find out more at **royalsociety.org/events/for-scientists**

THE
ROYAL
SOCIETY

Image: © zephylwer0 from Pixabay.

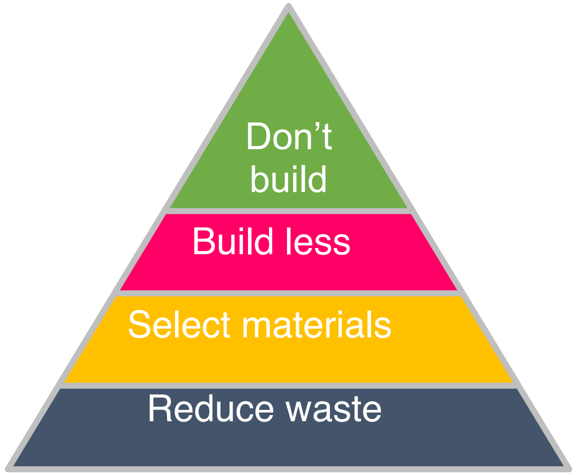
Re-use





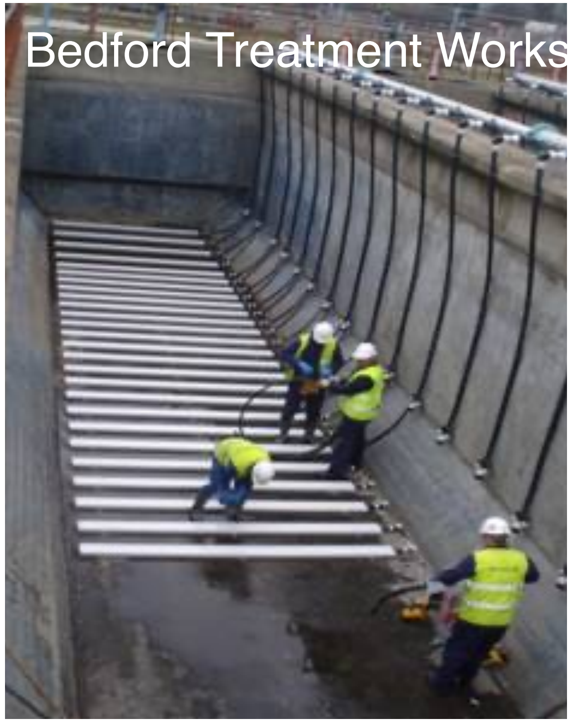
Source Keh (2021)

Avoid

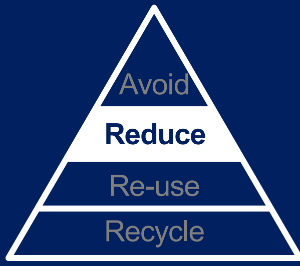


Reconfiguring existing facility and intelligent design gave 66% saving in embodied carbon, 40% cost saving.

love every drop
anglianwater

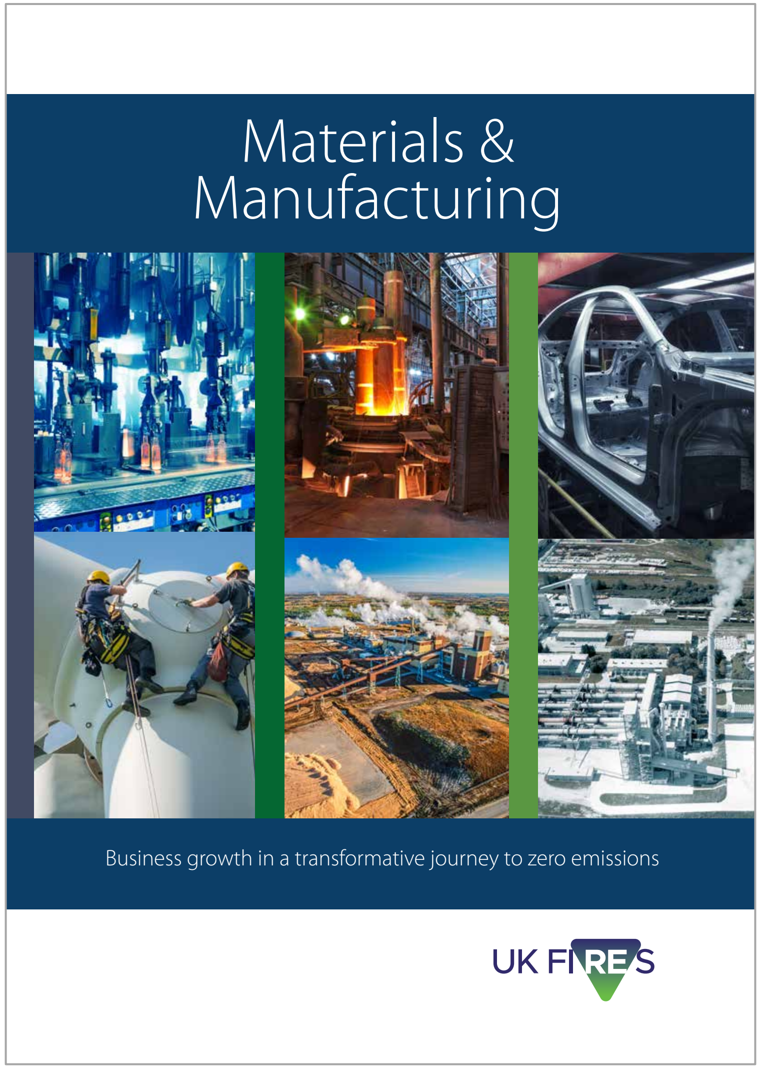


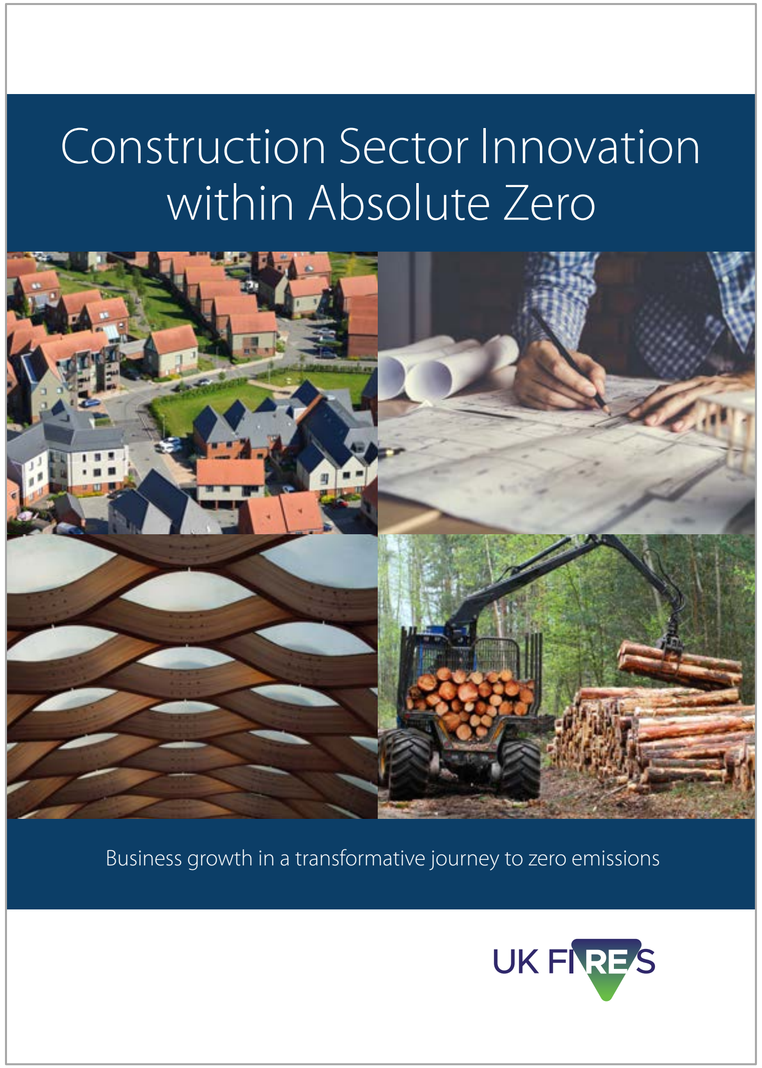
- Longer life
- More intense use
- Material substitution
- Product substitution



Reduce – examples of research into practice

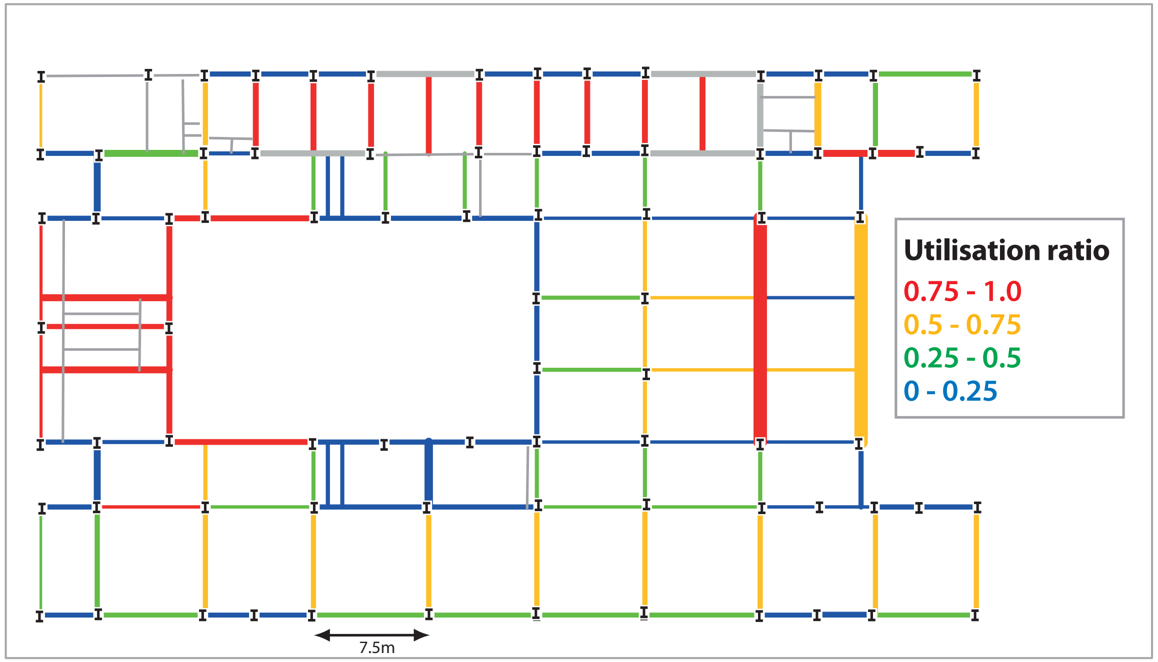
Innovation opportunities



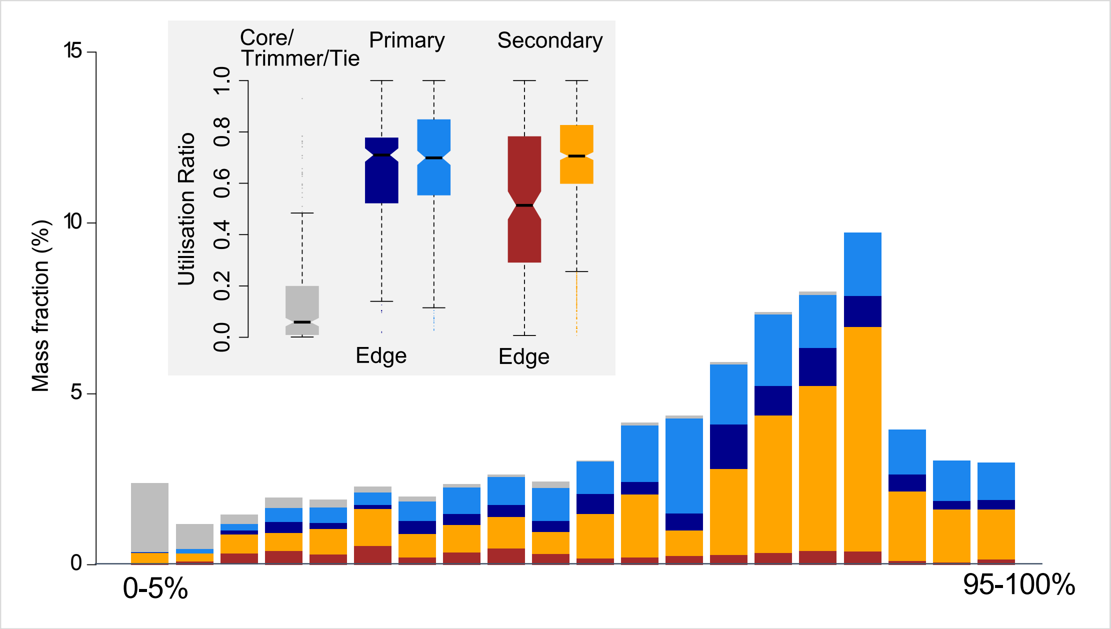


www.ukfires.org

Specification scrap: construction

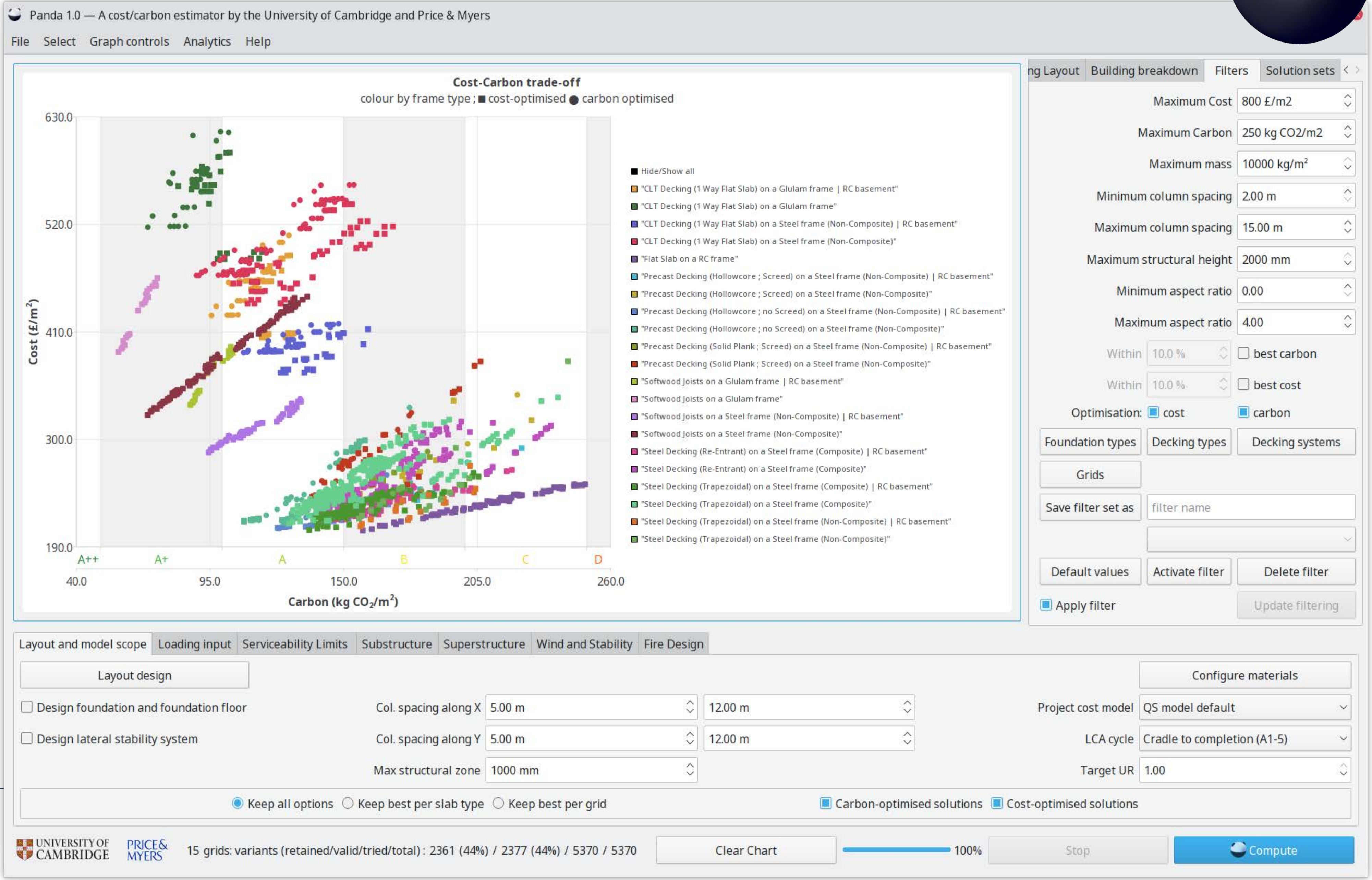


Source Moynihan & Allwood (2014)

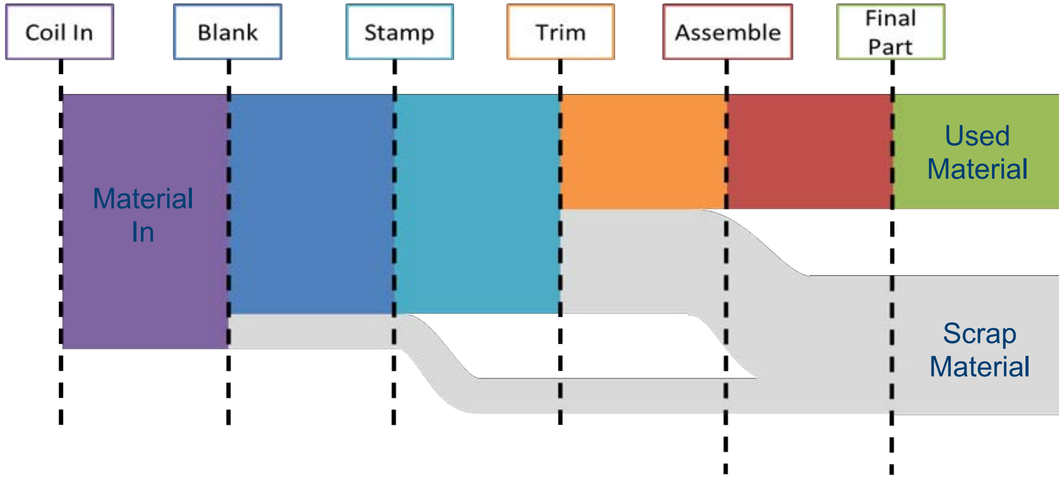


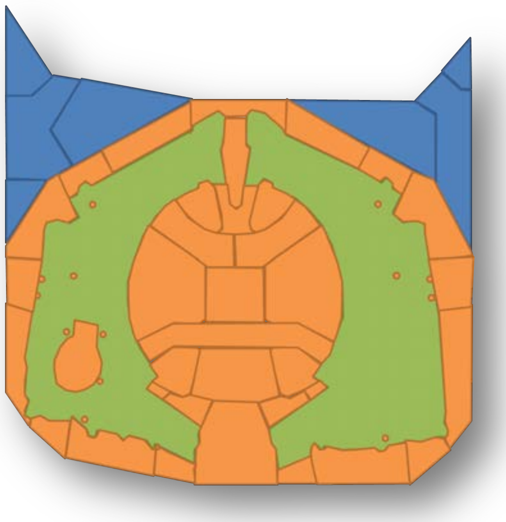
Source Dunant et al. (2018b)

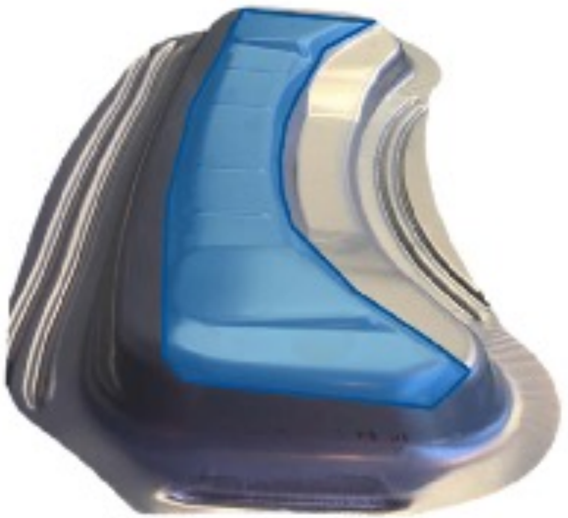
Structural Panda Ltd.

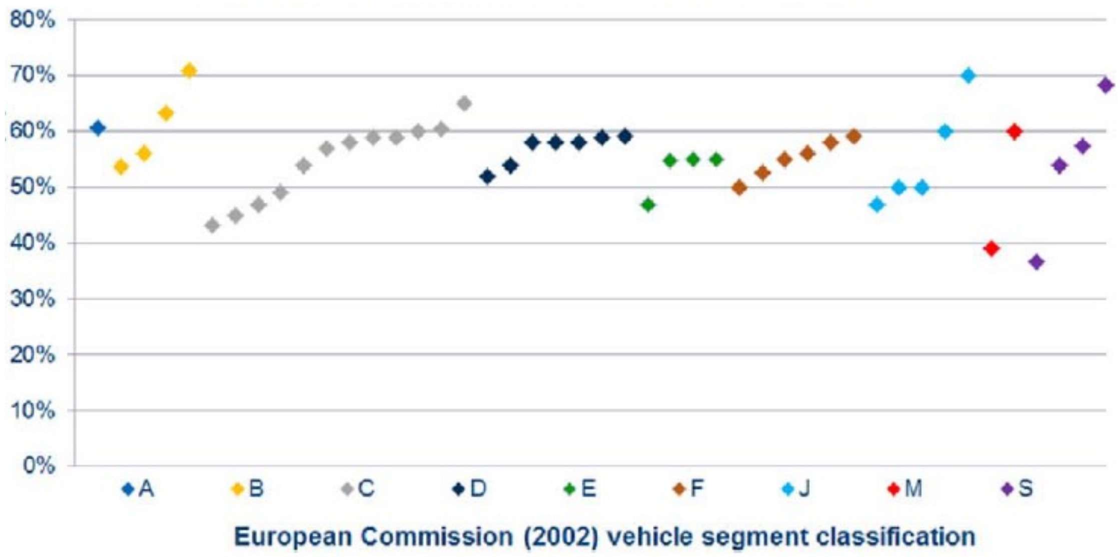


Scrap in car-production



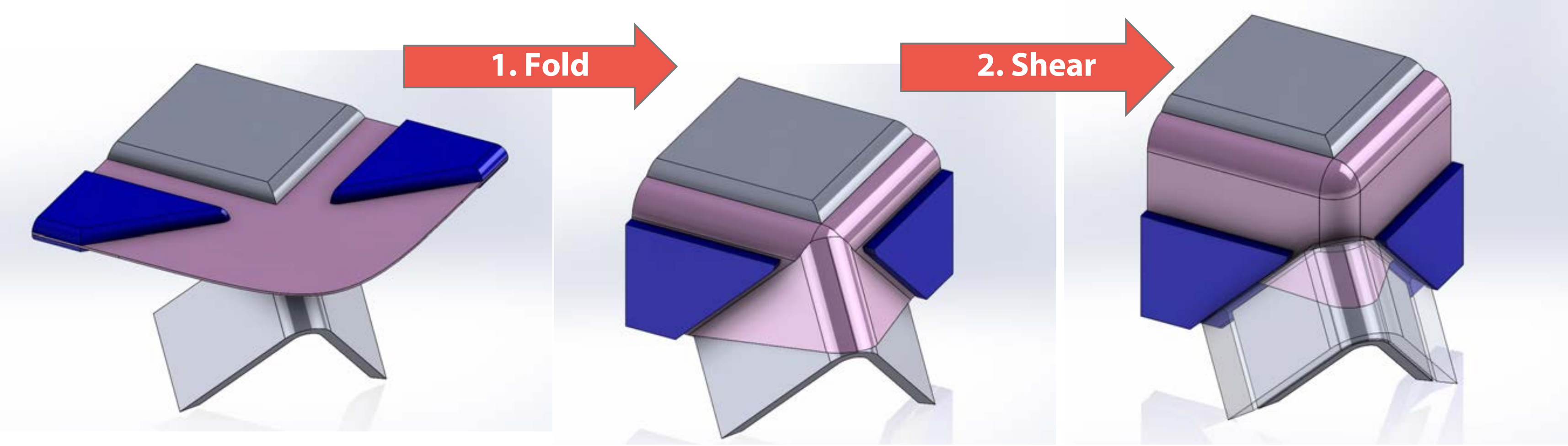






Source: Horton and Allwood (2017)

Folding-Shearing

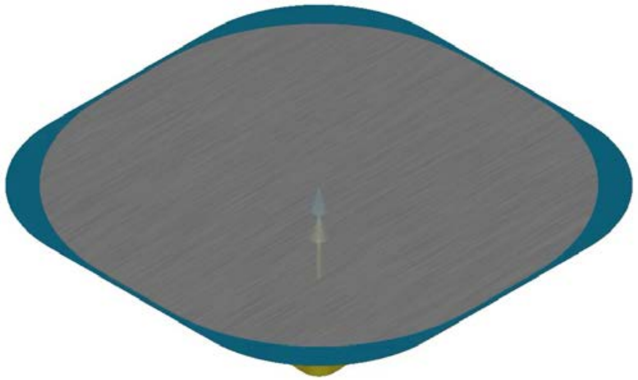


Source: Allwood et al. (2019), Cleaver et al. (2022)

Folding-shearing compared to deep-drawing

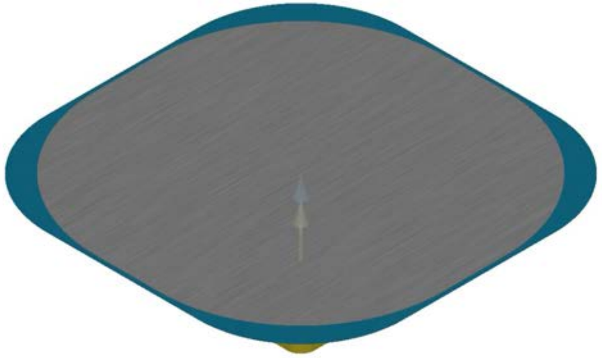
Drawing with blankholder

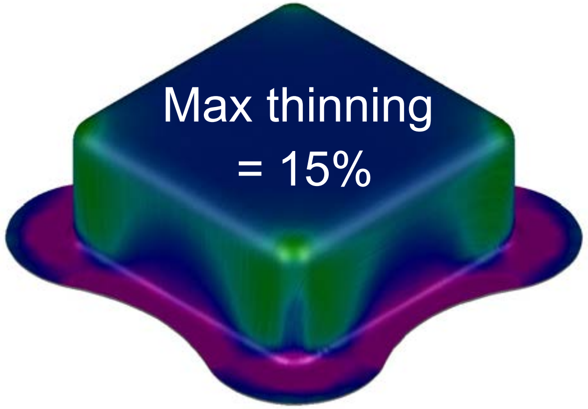
BHF = 15 kN



Drawing with blankholder

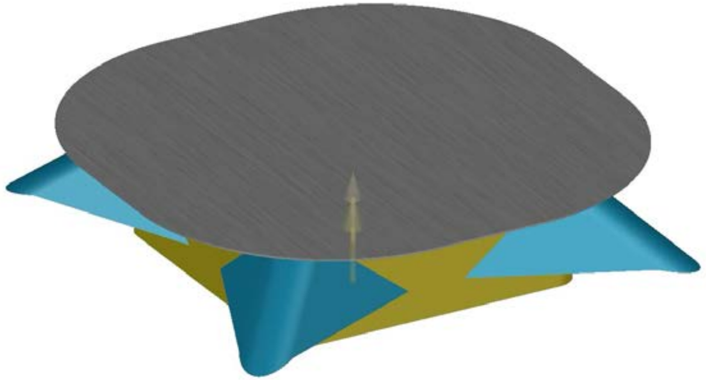
BHF = 50 kN

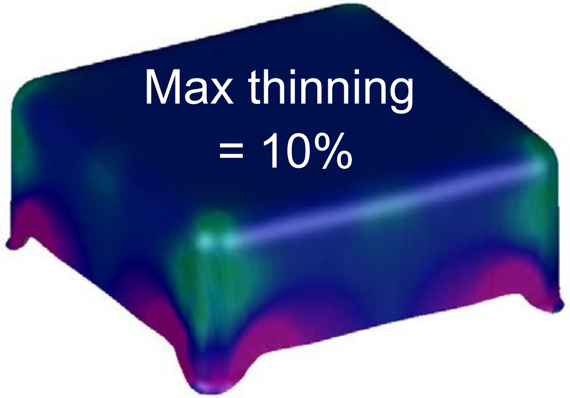




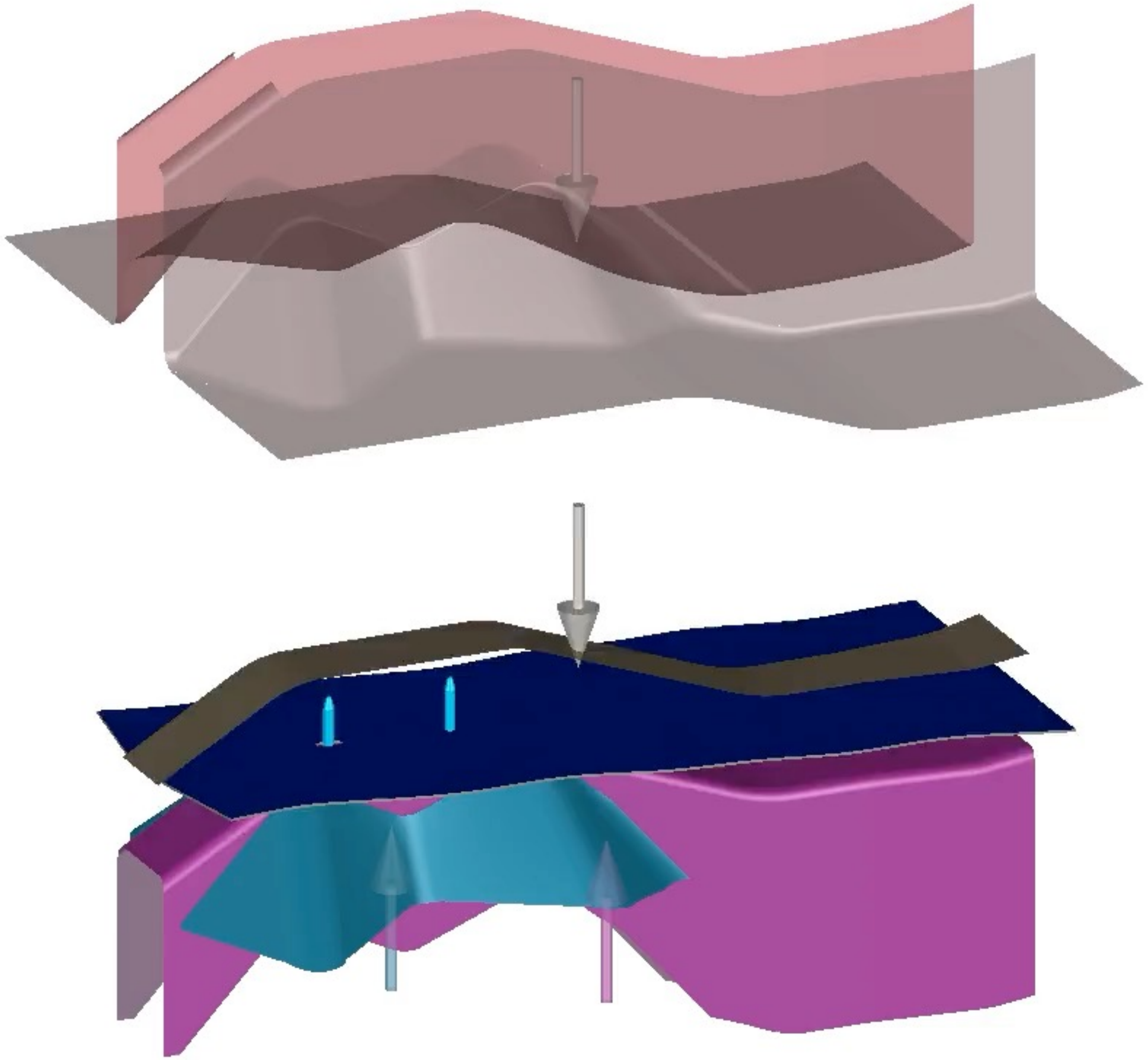
Folding-shearing

BHF = 15 kN



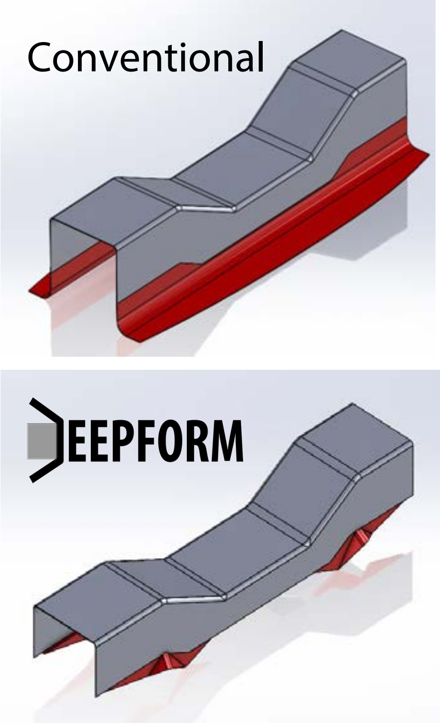


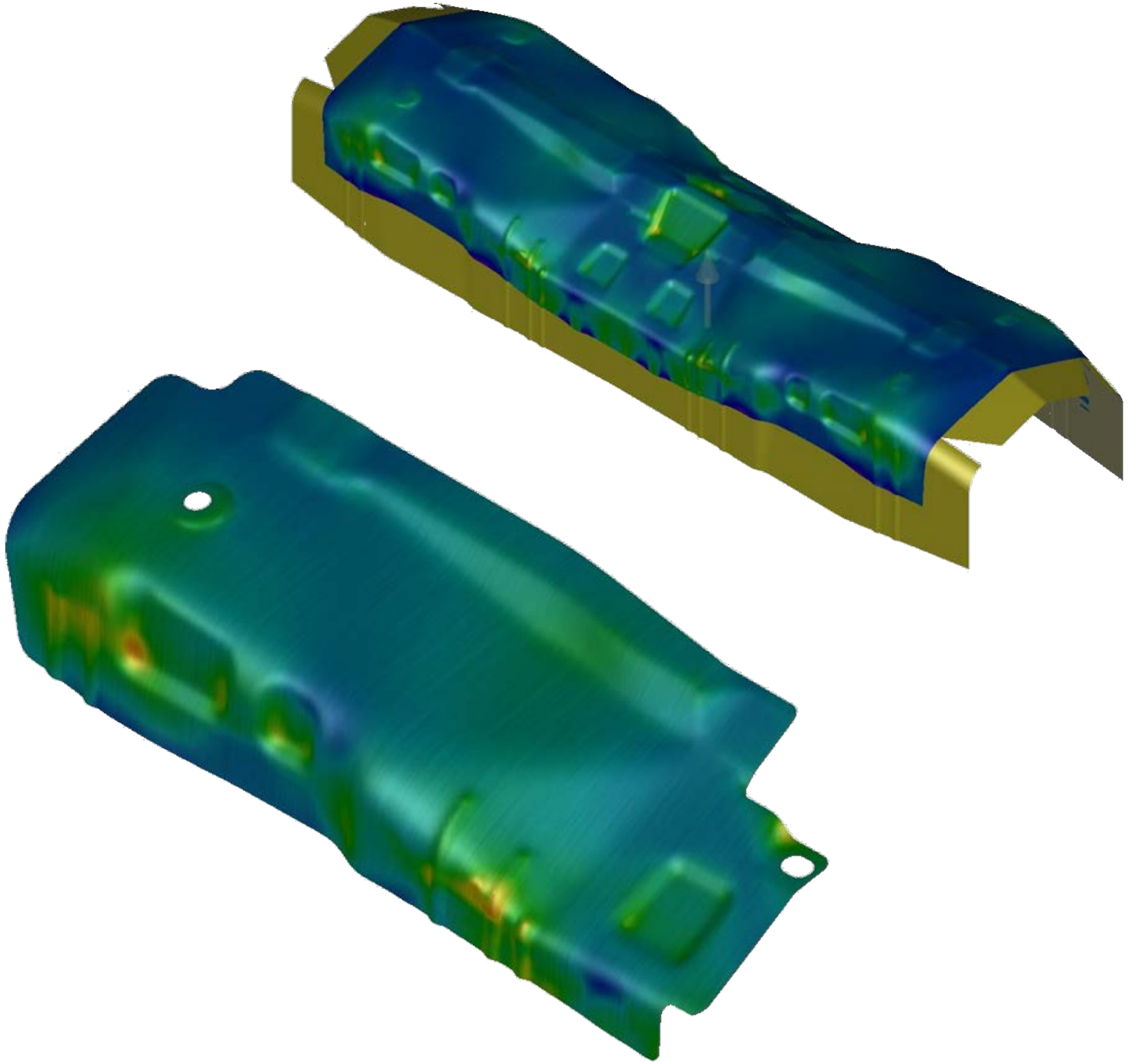
Folding-Shearing



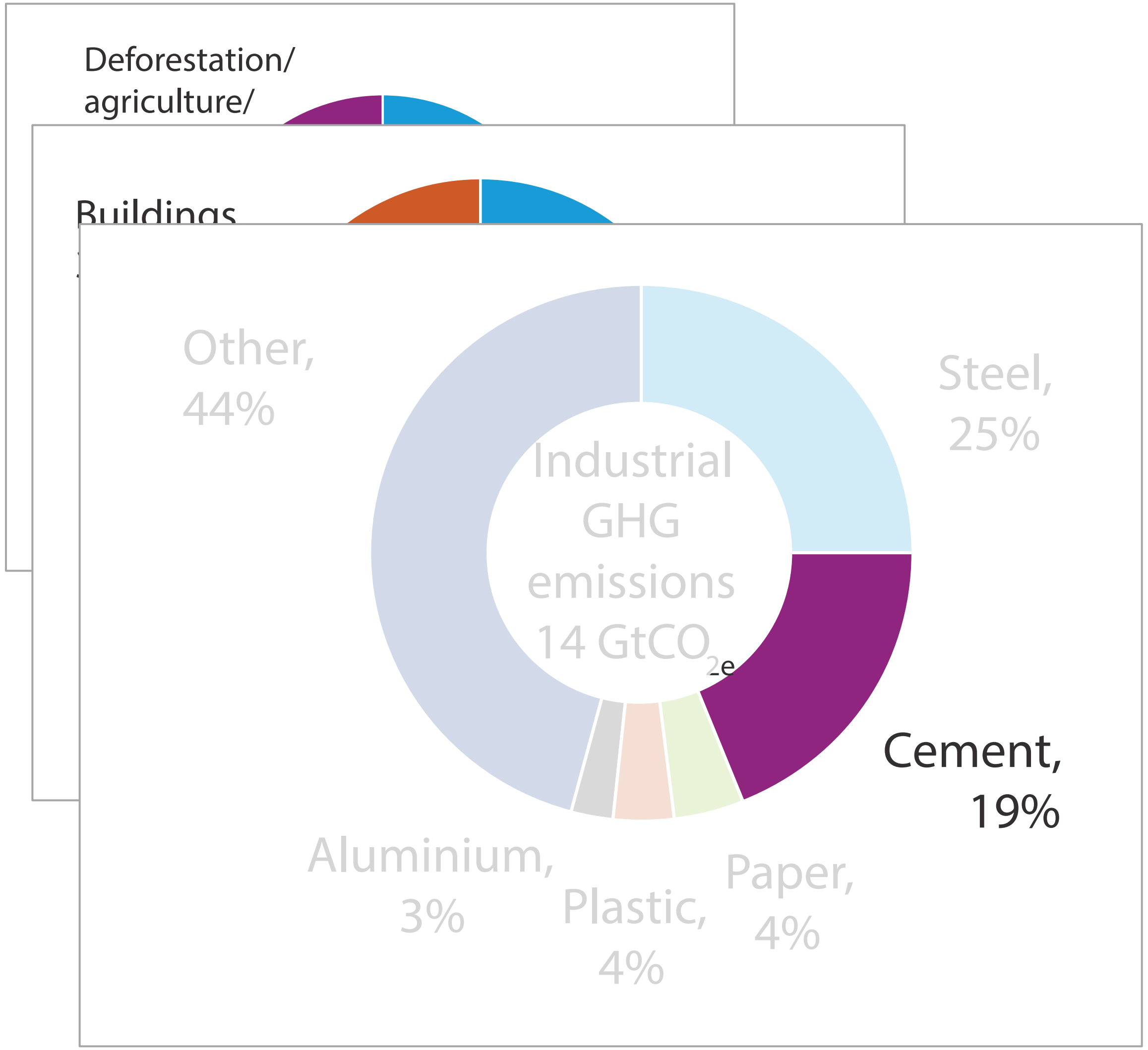
DeepForm Ltd.

- 75% reduction in trimming **scrap**
- **Environmental benefit**: 30% reduction in embodied emissions per part
- **Cost savings**: 20% reduction in piece cost





Cambridge Electric Cement Ltd.



- Concrete = cement + water + sand + aggregate;
- Cement = clinker + gypsum + supplementary materials
- Portland clinker emissions = emissions from heating + process emissions

Cambridge Electric Cement Ltd.

Category	Technology	Heat	Chemical Emissions	Market fraction potential	Maximum abatement	Cost
Deployed in existing processes	SCMs	●	●	80%	45%	Low
	Grinding	●	●	100%	20%	Low
	Alternative fuels	●		80%	20%	Low
	CDW raw meal		●	5%	10%	Low
CCS - capture demonstrated but not storage	LEILAC		●	100%	60%	Moderate
	CCS lime production		●	100%	55%	Moderate
	Carbon cycling		●	20%	10%	Moderate
Novel ideas at laboratory scale	Calcium silicates		●	Low	60%	??
	Electrolytic production of CH		●	Low	50%	Extremely high
	Solar ovens	●		Low	40%	High

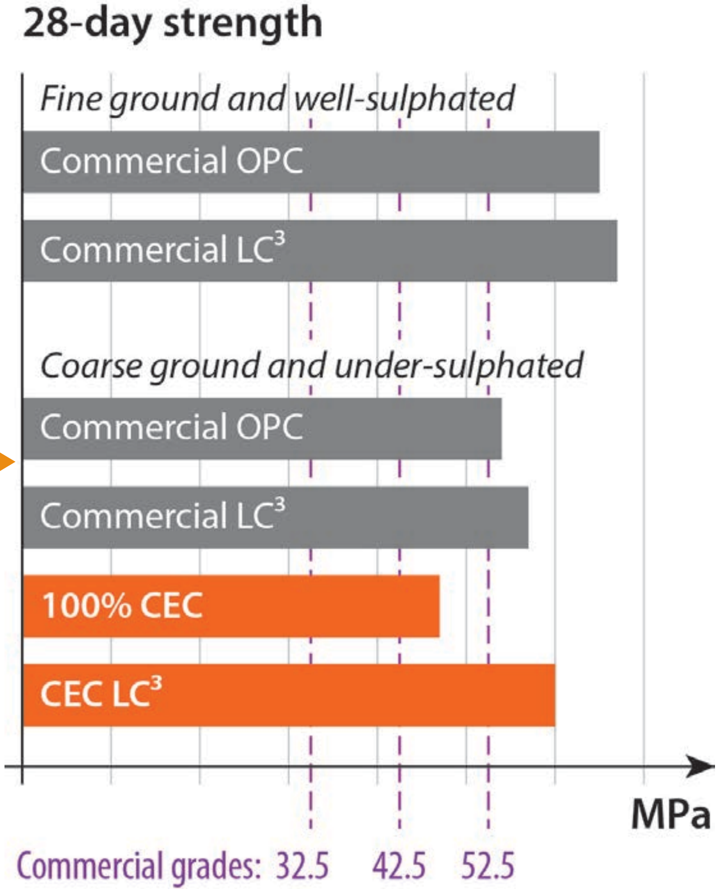
Cambridge Electric Cement Ltd.

Recovered Cement Paste

Heat in EAF

Rapid cooling

Portland cement



Source: Dunant et al. (under review)

Cambridge Electric Cement Ltd.

Conclusion

Conclusion: the role of engineers in climate mitigation

- Deployment at scale and speed is everything
- We desperately need credible engineering analysis to call out burden-shifting
- Re-focus on demand to ease impossible requirements on supply – untapped innovation potential
- New technologies can't solve the problem in time – so we must be part of a societal dialogue.

Access and references

- A pdf of the slides used in this talk can be downloaded from:

www.uselessgroup.org/about-us/blog

- There is a full set of references at the end of the slide-pack

References used in the talk:

Allwood J.M. and Cullen J.M. (2012) Sustainable Materials: with both eyes open, UIT Cambridge, England, pp 384.

Allwood, J.M., Cleaver, C.J., Loukaides, E.G., Music, O. and Nagy-Sochacki, A. (2019) Folding-shearing: Shrinking and stretching sheet metal with no thickness change, *CIRP Annals* **68(1)** 285-288

BP (2021) Statistical Review of World Energy 2021, 70th Edition, www.bp.com

Carruth, M.A. and Allwood, J.M. (2012) The development of a hot rolling process for variable cross-section I-beams, *Journal of Materials Processing Technology* **212(8)** 1640-1653

Cleaver, C.J., Arora, R., Loukaides, E.G., Allwood, J.M. (2022) Producing isolated shrink corners by folding-shearing, *CIRP Annals,* **71,** 217-220

Cooper, D.R., Skelton, A.C.H., Moynihan, M.C. and Allwood, J.M. (2014), Component level strategies for exploiting the lifespan of steel in products, *Resources Conservation and Recycling,* **84** 24-32

Cullen, J.M. and Allwood, J.M. (2013). Mapping the global flow of aluminium: from liquid aluminium to end-use goods, *Environmental Science and Technology,* **47**, 3057–3064

Cullen, J.M., Allwood, J.M. and Bambach, M. (2012). Mapping the global flow of steel: from steelmaking to end- use goods, *Environmental Science and Technology* **46(24)**, 13048-13055

Daehn, K.E., Serrenho, A.C. and Allwood, J.M. (2019) Finding the most efficient way to remove residual copper from steel scrap, *Metallurgical Transactions B,* **50B**, 1225-1240.

Dunant, C.F., Drewniok, M.P., Eleftheriadis, S., Cullen, J.M. and Allwood, J.M. (2018b) Regularity and optimisation practice in steel structural frames in real design cases, *Resources Conservation and Recycling,* **134**, 294-302

Dunant, C.F., Drewniok, M.P., Sansom, M., Corbey, S., Allwood, J.M. and Cullen, J.M. (2018a) Options to make steel reuse profitable: An analysis of cost and risk distribution across the UK construction value chain, *Journal of Cleaner Production*, **183**, 102-111

Dunant, C.F., Joseph, S., Prajapati, R. and Allwood, J.M. (2023) Electric recycling of Portland Cement at scale, *Nature*, under review

Global CCS Institute (2021) Global Status of CCS 2021, www.globalccsinstitute.com

Horton, P.M. and Allwood, J.M. (2017) Yield Improvement Opportunities for Manufacturing Automotive Sheet Metal Components, *Journal of Materials Processing Technology,* **249**, 78-88

Hula, A., Maguire, A., Bunker, A., Rojeck, T., & Harrison, S. (2022). The 2022 EPA Automotive Trends Report: Greenhouse Gas Emissions, Fuel Economy, and Technology Since 1975 (No. EPA-420-R-22-029).

References used in the talk:

HYBRIT (2017) Summary of findings from HYBRIT Pre-Feasibility Study 2016-17, https://dh5k8ug1gwbyz.cloudfront.net/uploads/2021/02/Hybrit-broschure-engelska.pdf

IAI (2018) https://international-aluminium.org/statistics/greenhouse-gas-emissions-aluminium-sector/

International Energy Agency. (2022). *Global Hydrogen Review 2022*. OECD Publishing.

IPCC SRCCL (2019) IPCC special report on climate change, desertification, land degradation, sustainable land management, food security, and greenhouse gas fluxes in terrestrial ecosystems, www.ipcc.ch

Keh, Z.H. (2021) Circular Cars, *MEng thesis, University of Cambridge.*

Moynihan, M.C. and Allwood, J.M. (2014), Utilisation of structural steel in buildings, *Proceedings of the Royal Society A,* **470** no. 2168 20140170

Nakajima, K., Takeda, O., Miki, T., Matsubae, K., Nakamura, S., & Nagasaka, T. (2010). Thermodynamic analysis of contamination by alloying elements in aluminum recycling. *Environmental science & technology*, *44*(14), 5594-5600.

Nelson, S.K. and Allwood, J.M. (2021) The technological and social timelines of climate mitigation: lessons from 12 past transitions, *Energy Policy,* **152**, 112155

Smil, V. (2014). The long slow rise of solar and wind. *Scientific American*, *310*(1), 52-57.

UK Govt (2022) UK Government GHG Conversion Factors for Company Reporting, https://www.gov.uk/government/publications/greenhouse-gas-reporting-conversion-factors-2022

Watari, T., Cabrera Serenho A., Gast, L., Cullen, J.M. and Allwood J.M. (2023). Feasible supply of bulk materials within a carbon budget is likely to fall short of expected global demand. *Environmental science & technology*, *under review*.

Zhou, C., Elshkaki, A., & Graedel, T. E. (2018). Global human appropriation of net primary production and associated resource decoupling: 2010–2050. *Environmental science & technology*, *52*(3), 1208-1215.

A pdf of the slides used in this talk can be downloaded from:

www.uselessgroup.org/about-us/blog

Allwood-office@eng.cam.ac.uk