Transforming the Foundation Industries…

… to have absolutely zero emissions by 2050

Transforming Foundation Industries Network+ Conference, Sheffield.
Tuesday 5th December 2023, 10.30-11.10

Professor Julian Allwood FREng

Use Less Group, University of Cambridge

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Access and references

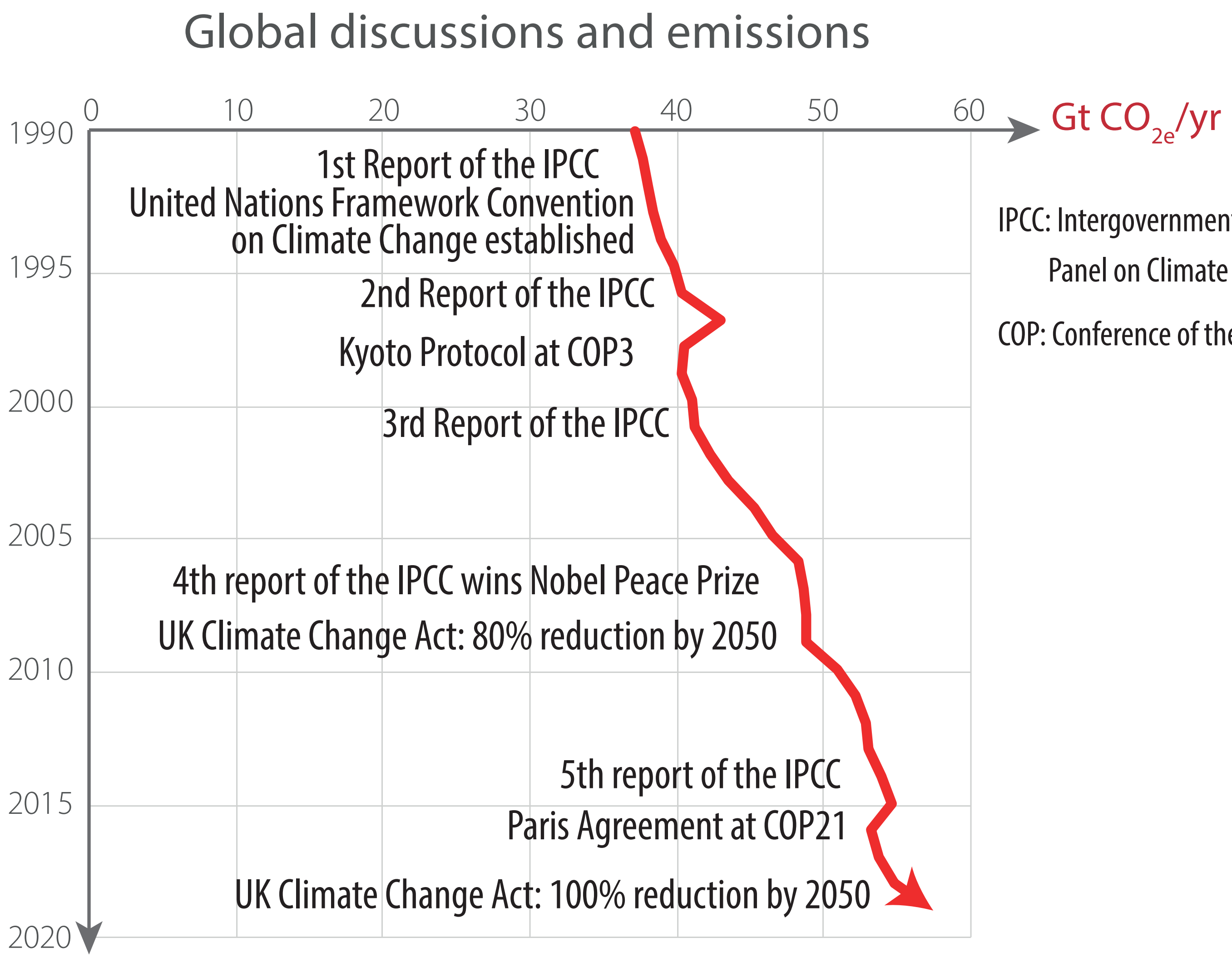
- A pdf of the slides used in this talk can be downloaded from:

www.uselessgroup.org/about-us/blog

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

Climate policy summary

Rising emissions and pledges



IPCC: Intergovernmental Panel on Climate Change

COP: Conference of the parties

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:

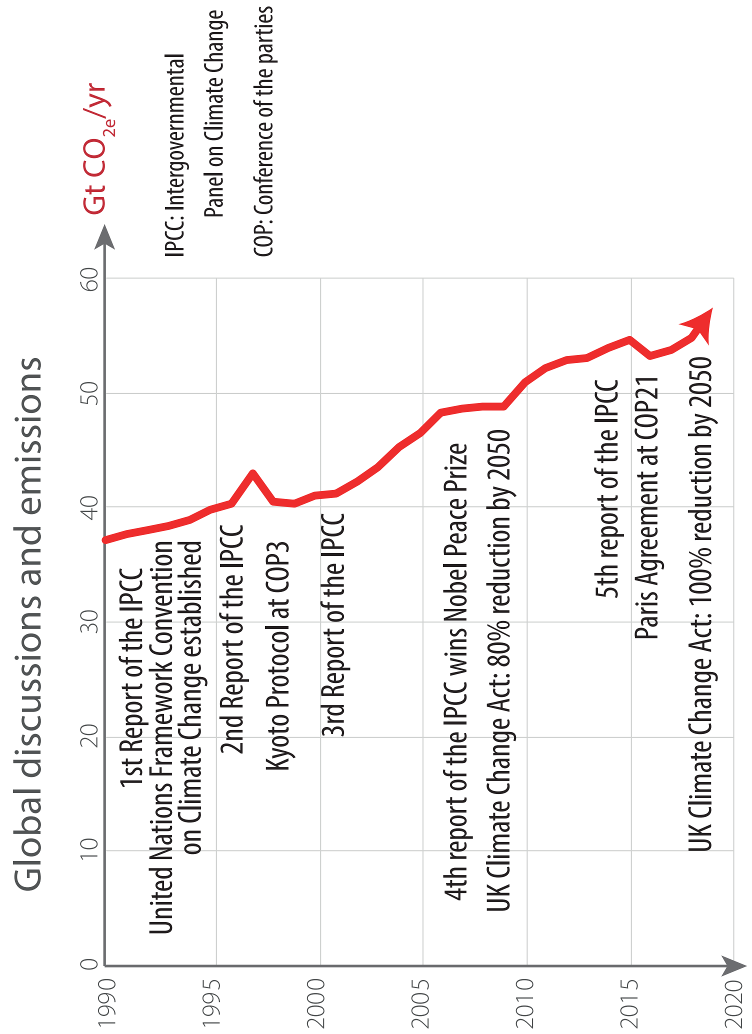
- **China**

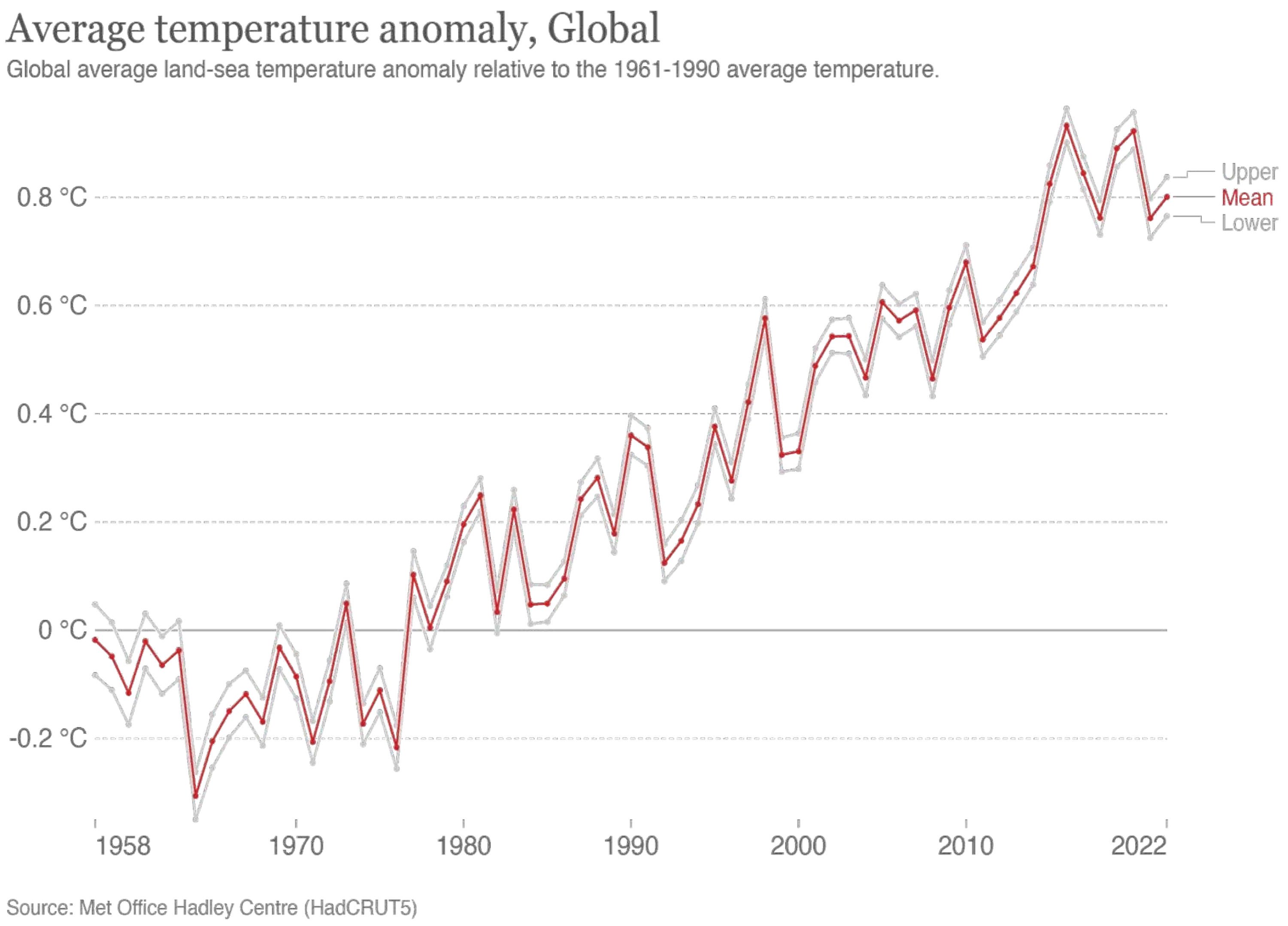
Policy document for zero emissions by 2070:

- **India**

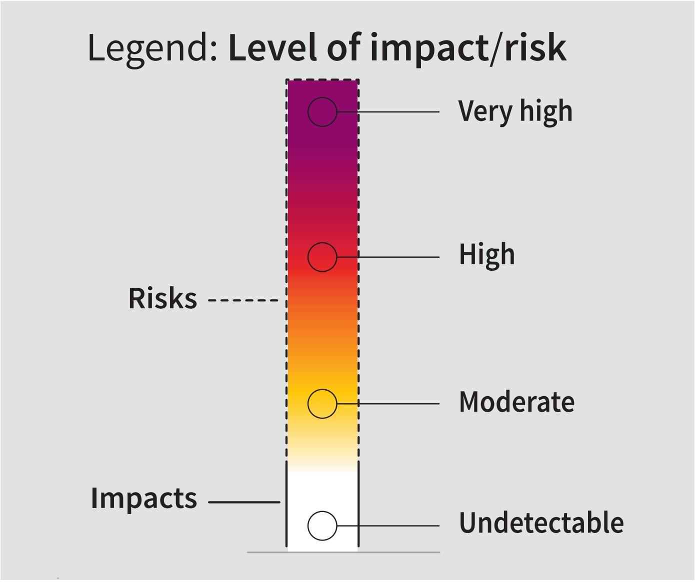
Data from https://eciu.net/netzerotracker

Rising temperature and risk

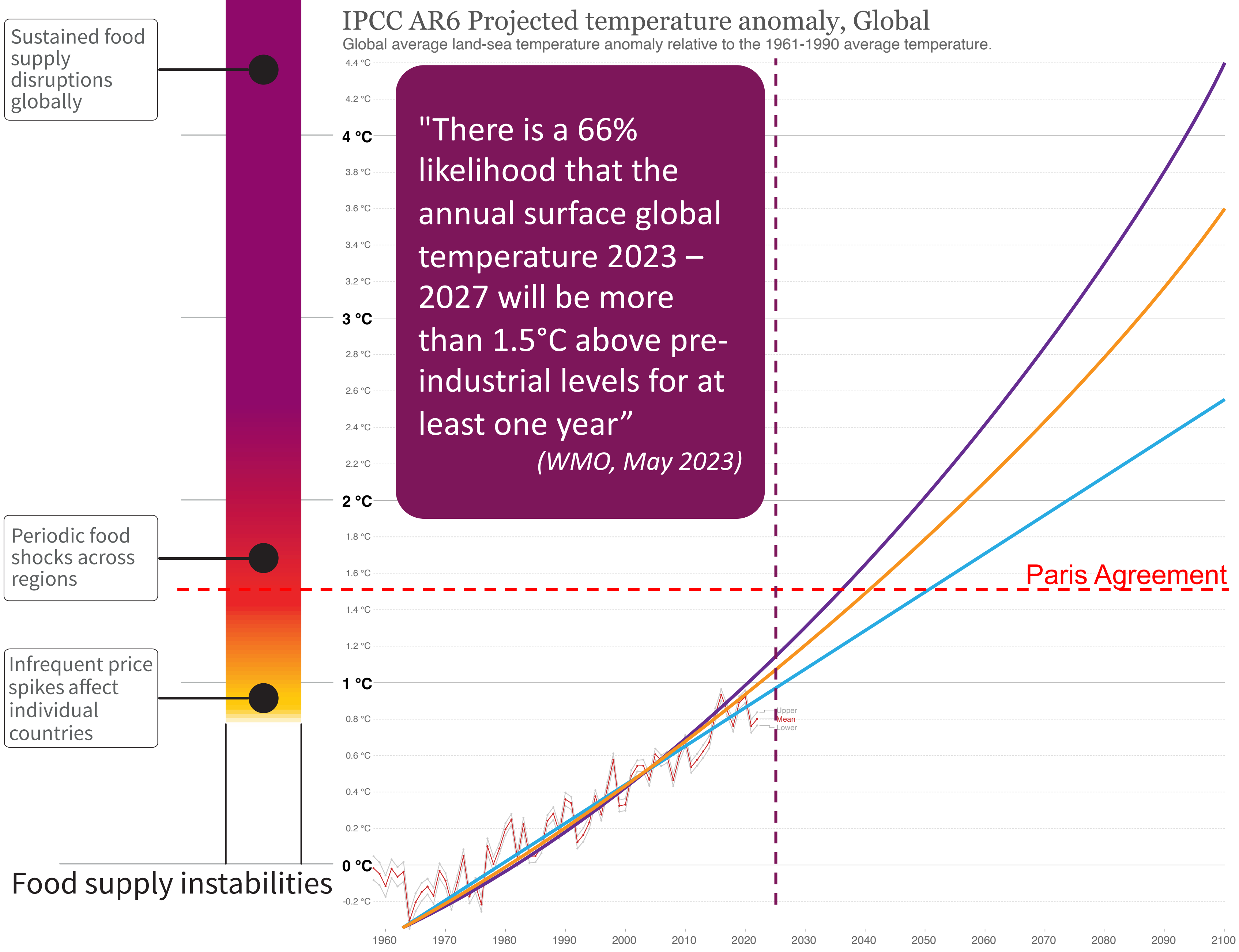




Rising temperature and risk

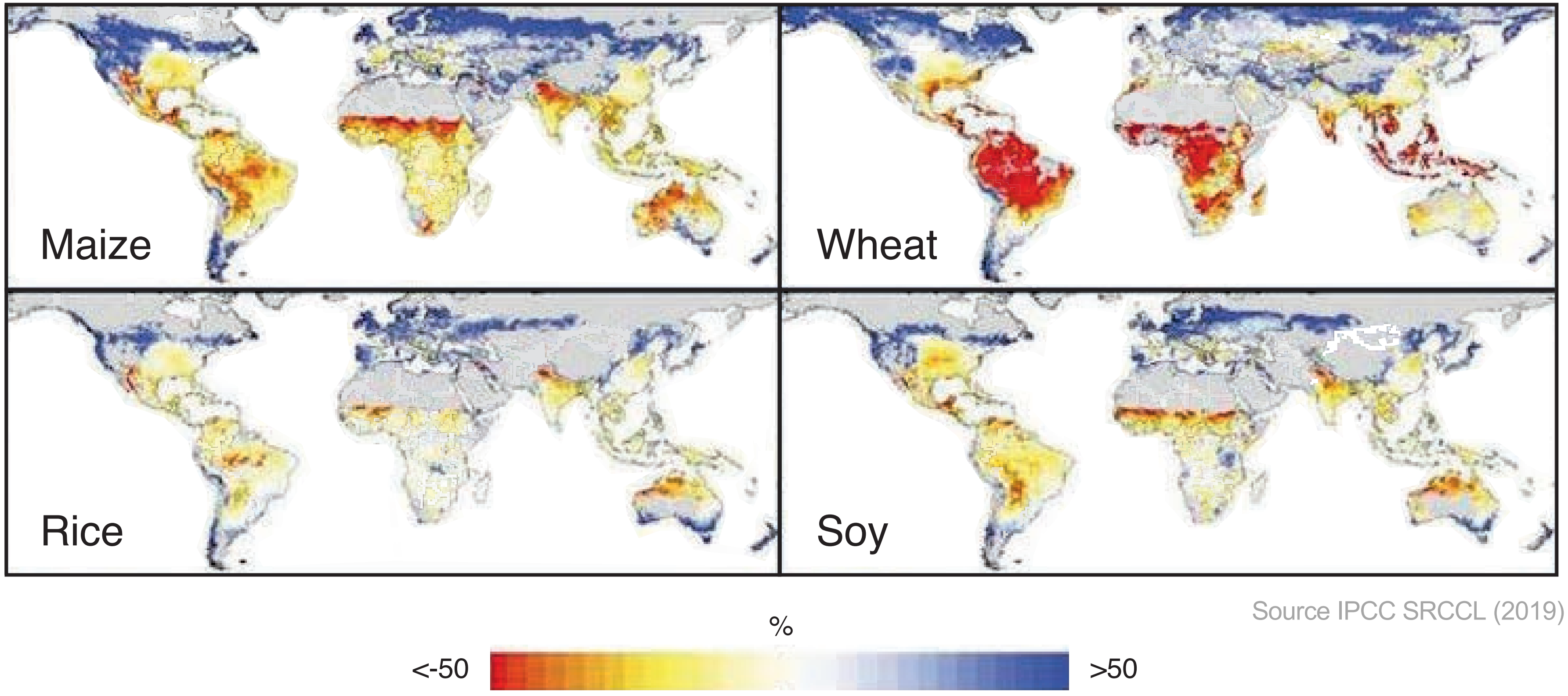


Source IPCC SRCCL (2019)



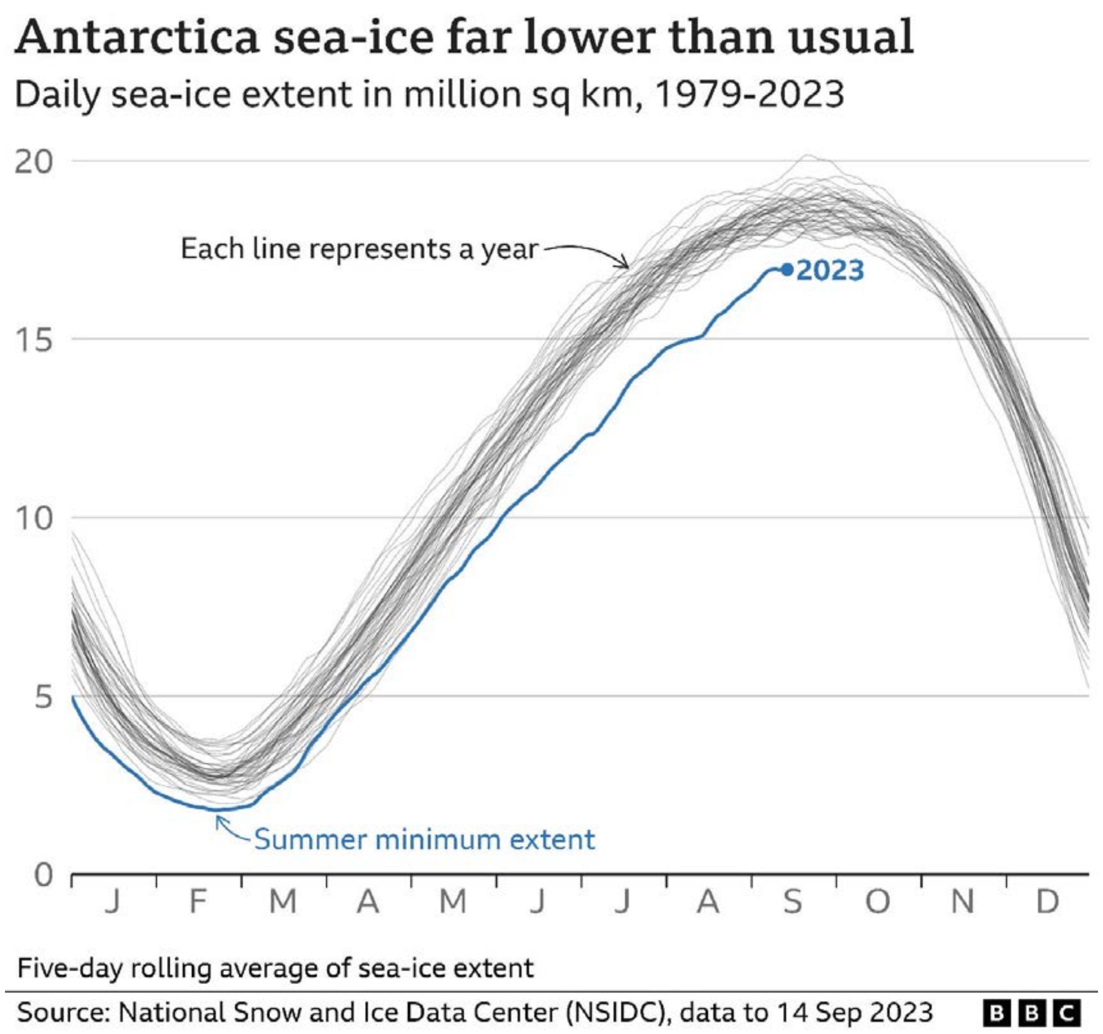
Rising temperature and risk

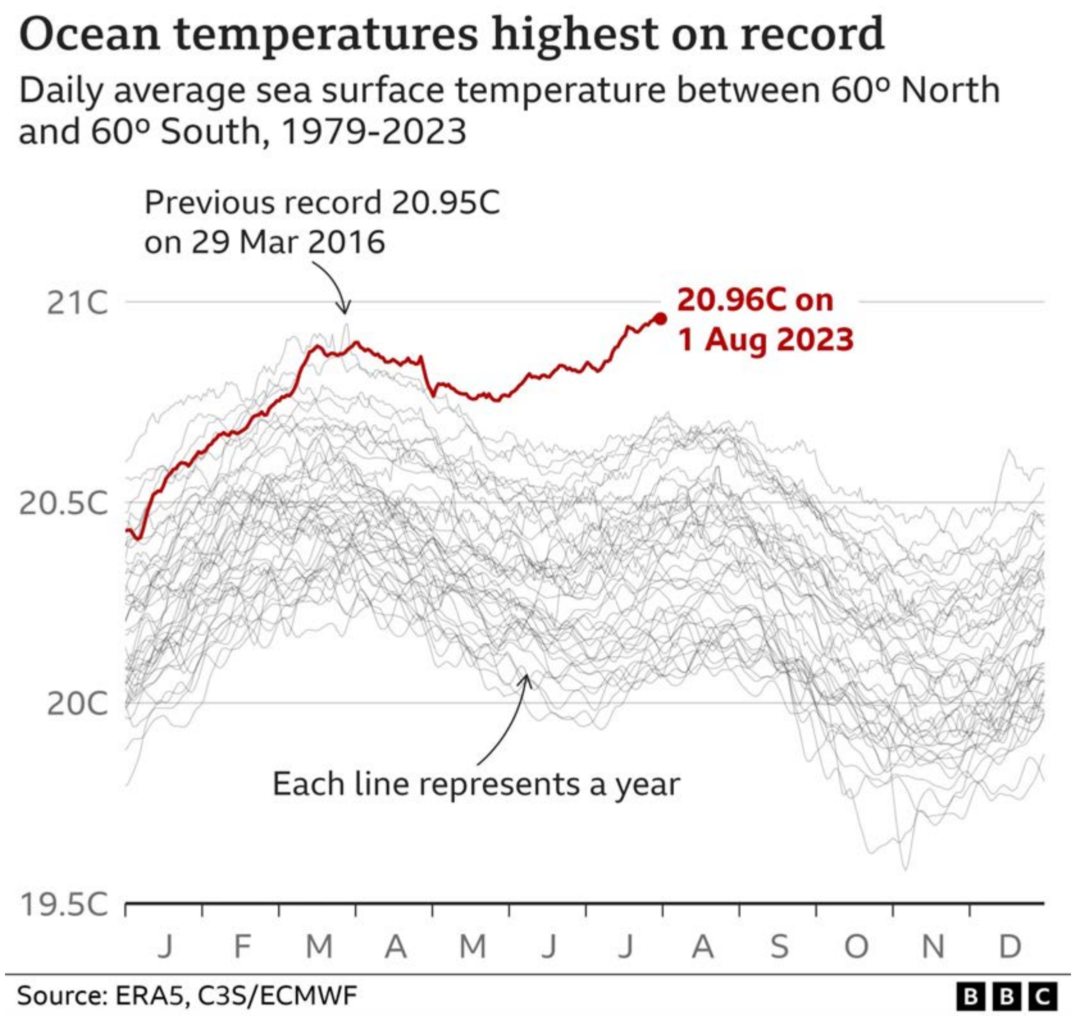
Crop yield changes 1990-2090 averaged over Global Gridded Crop Models



Source IPCC SRCCL (2019)

Rising temperature and risk: tipping points



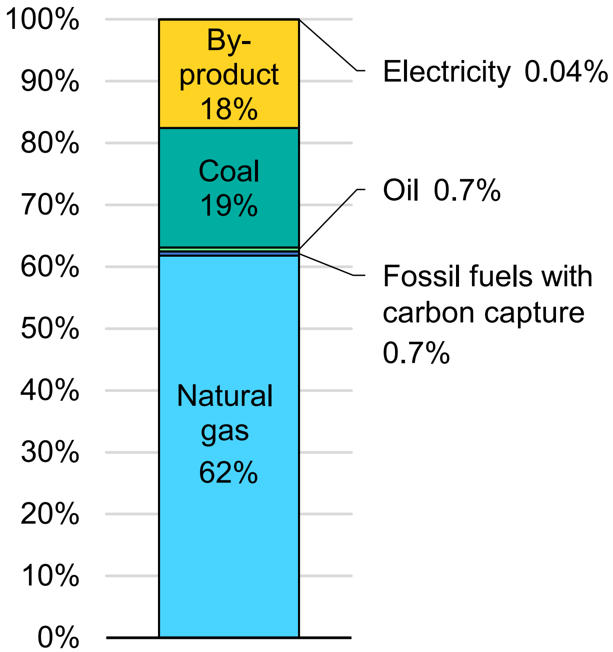


Why isn’t it working?

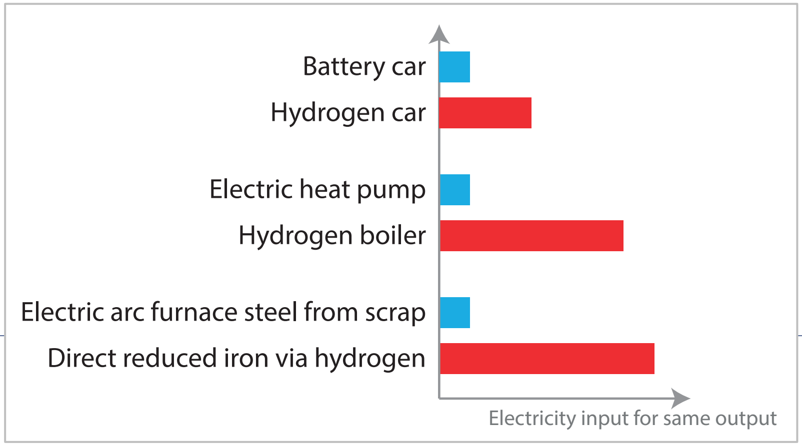
Unpacking burden-shifting via aggregation & deployment rates

“Don’t worry! We’ll solve it and you won’t notice…”

Hydrogen production 2021



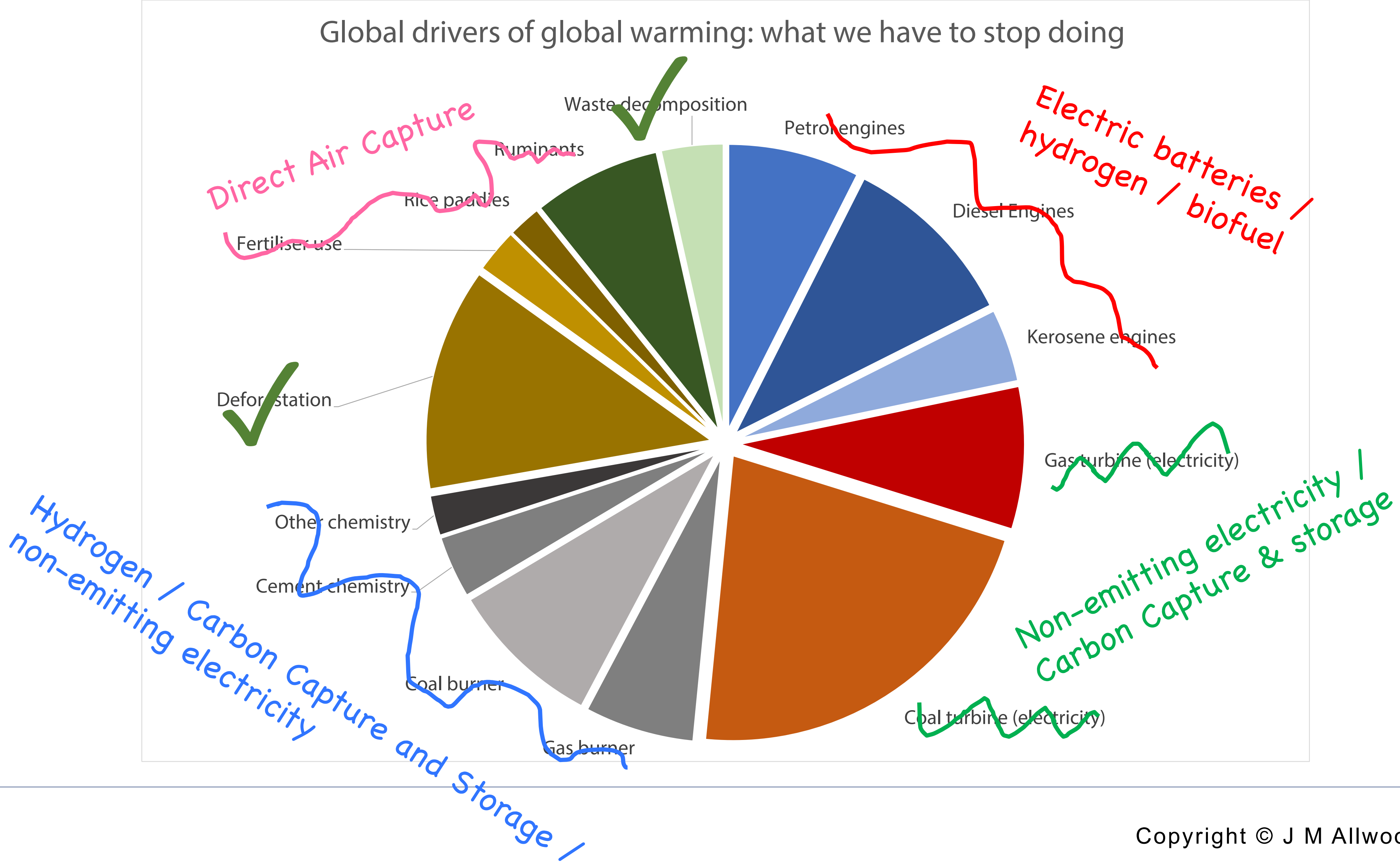
Source: International Energy Agency (2022)



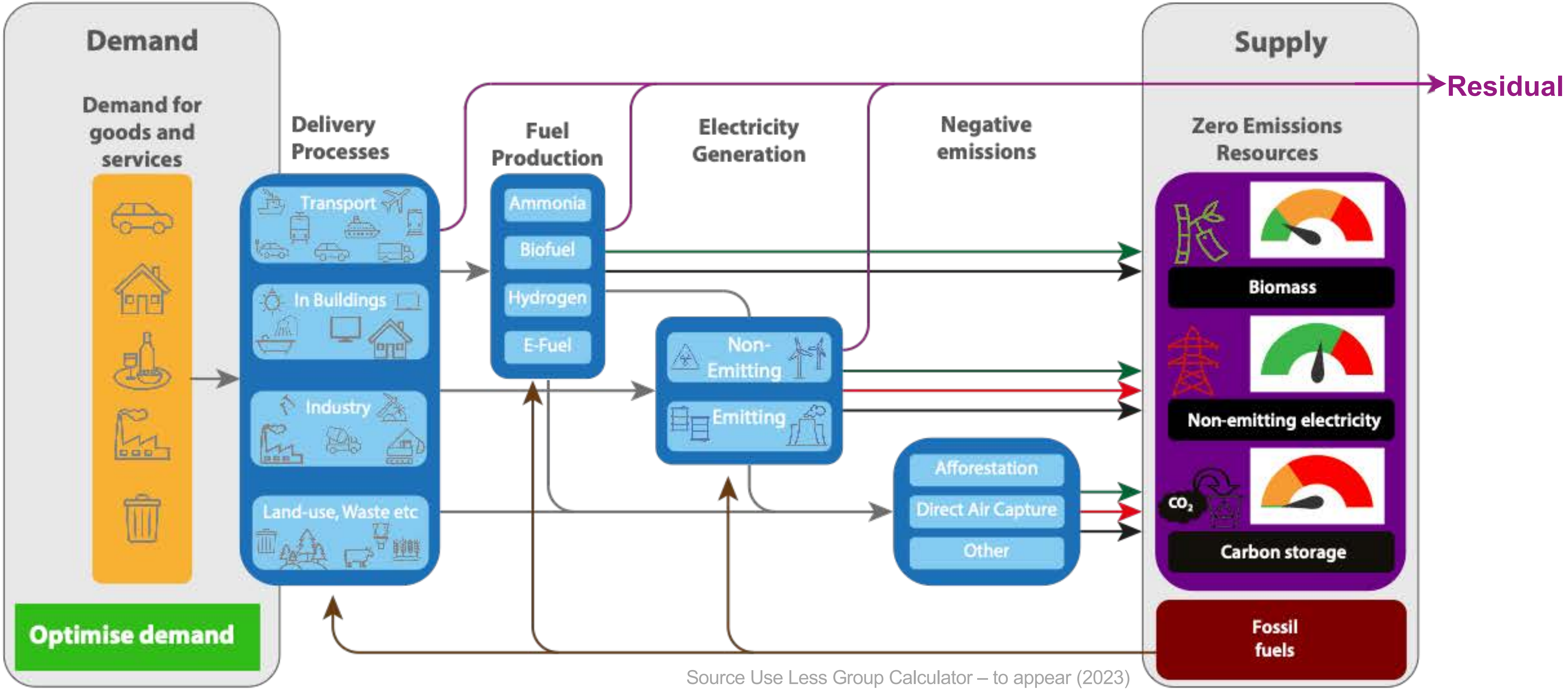
- Hydrogen
- Trade
- Carbon offsets
- “Negative emissions technologies”
- Bio-fuels
- Synthetic fuels
- …

Burden-shifting is endemic to climate policy at present

Incumbent thinking on how to reach zero emissions



Aggregating demand for three "zero-emissions resources"



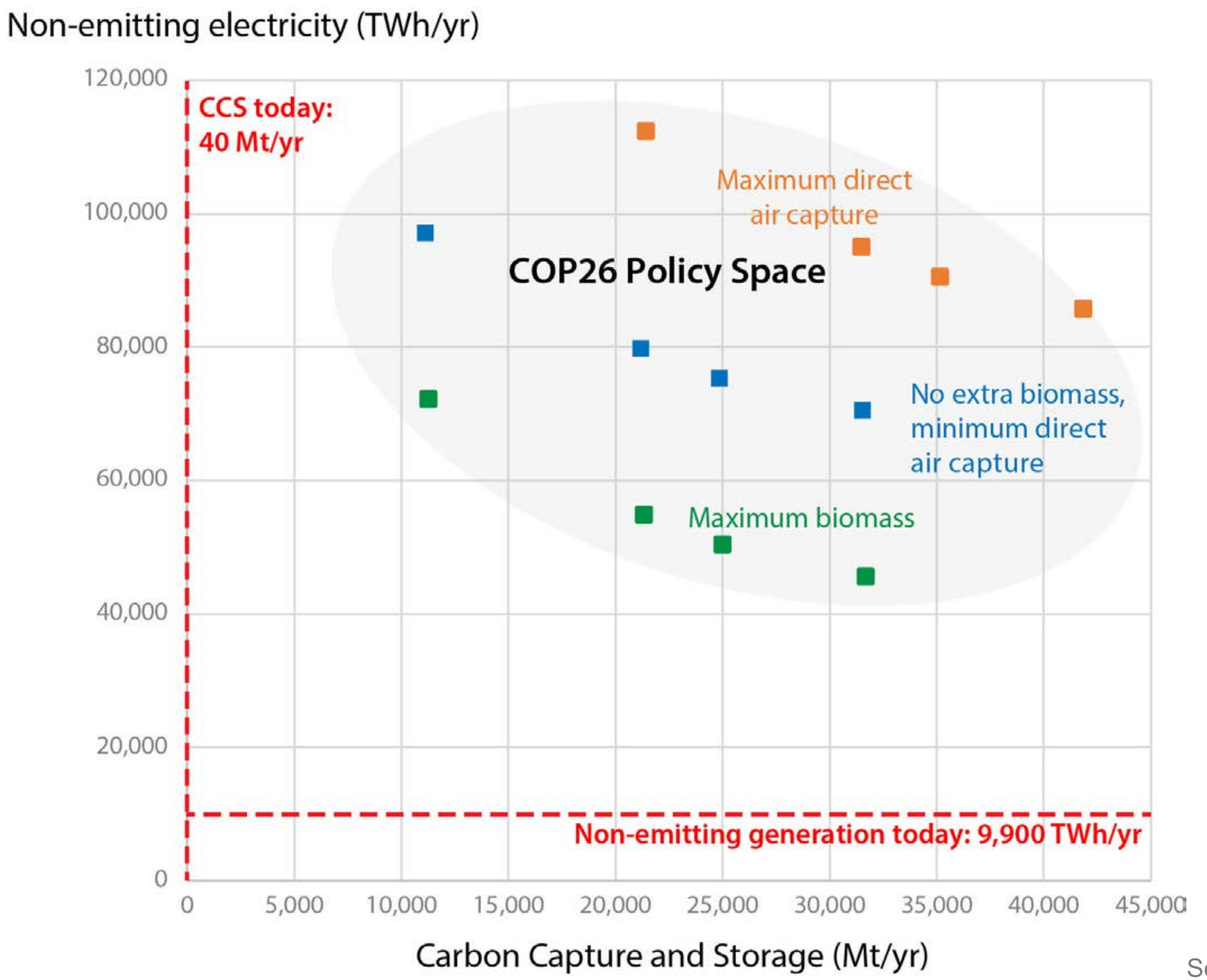
Source Use Less Group Calculator – to appear (2023)

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	

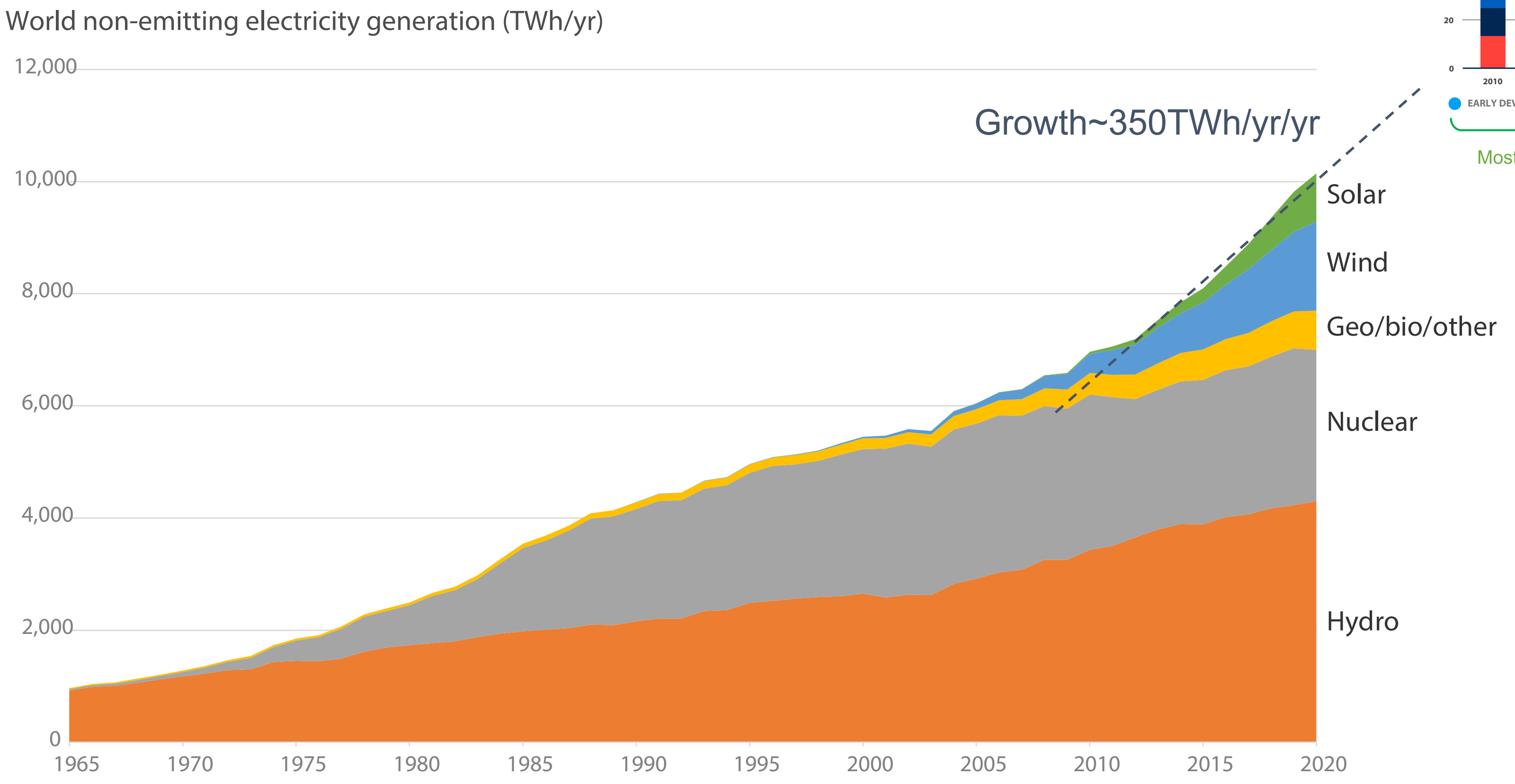
Data from multiple sources: https://ukfires.org/blog-cop26/

Aggregation of plans discussed at COP26



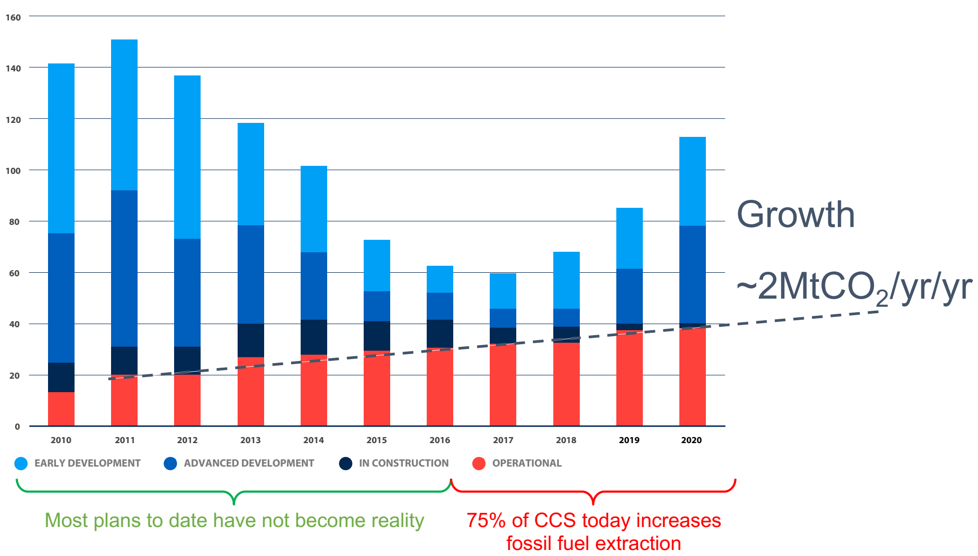
Source: https://ukfires.org/blog-cop26/

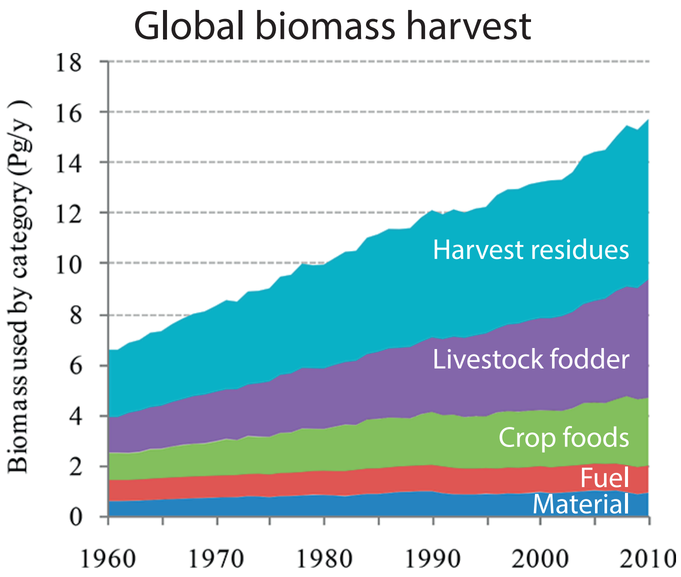
Deployment rates



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

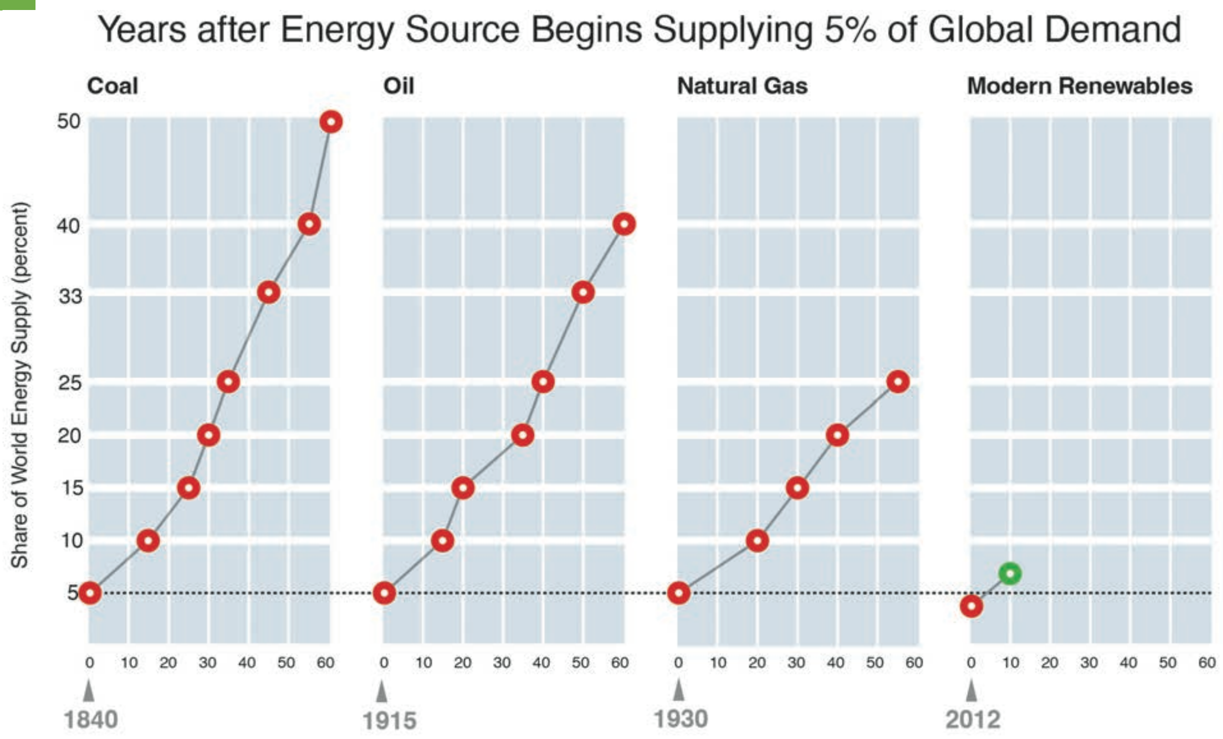
Source Global CCS Institute (2021)



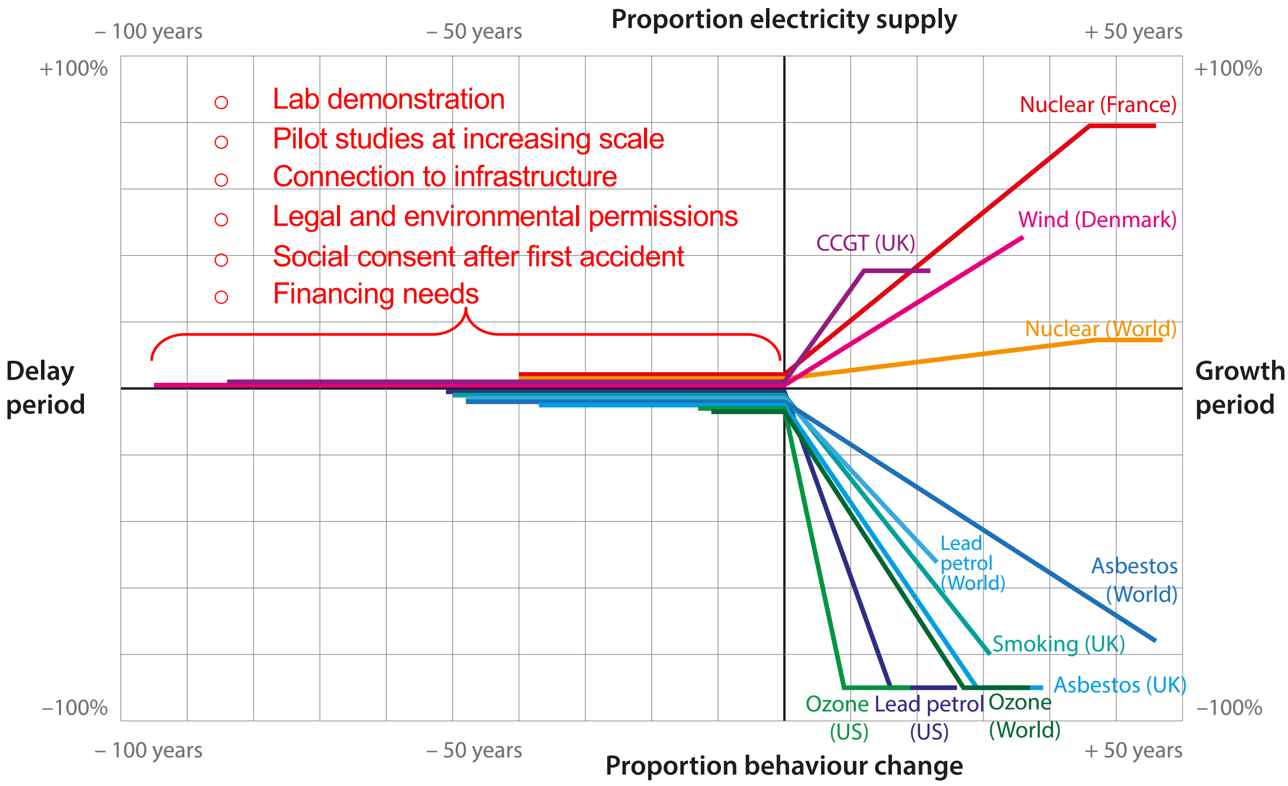


Source Zhou et al. (2018)

Deployment rates



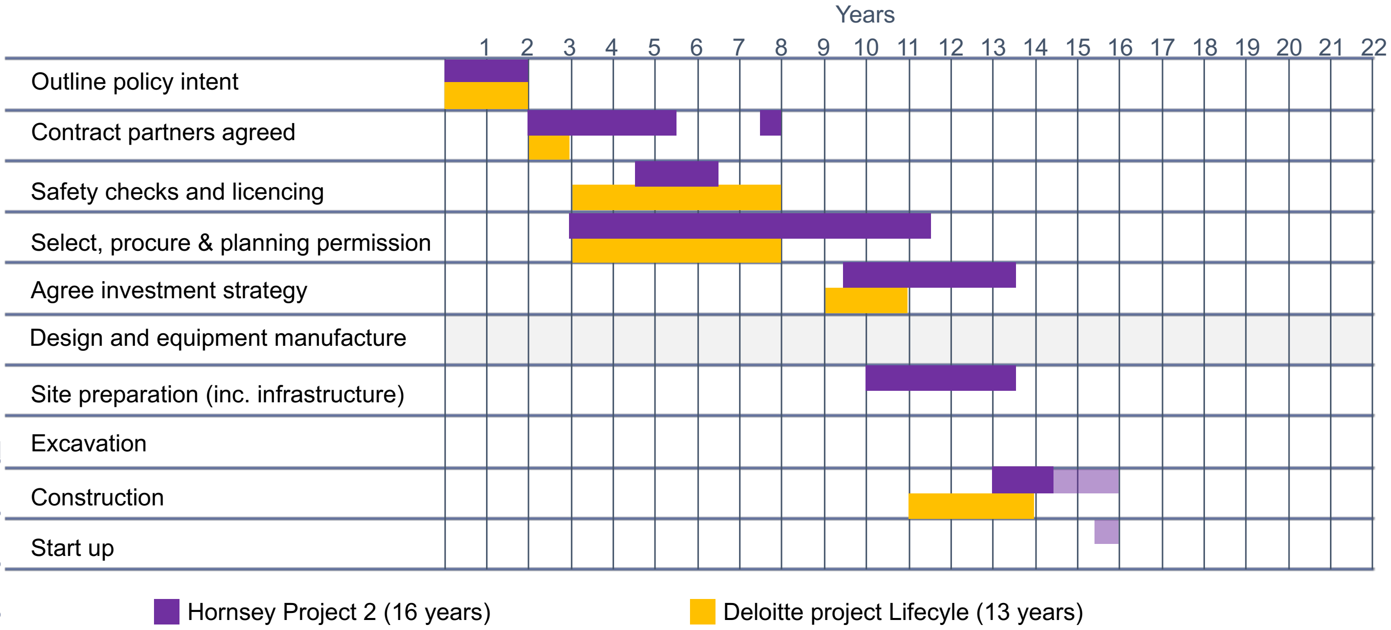
Sources: Smil (2014), update BP World energy statistics (2022)



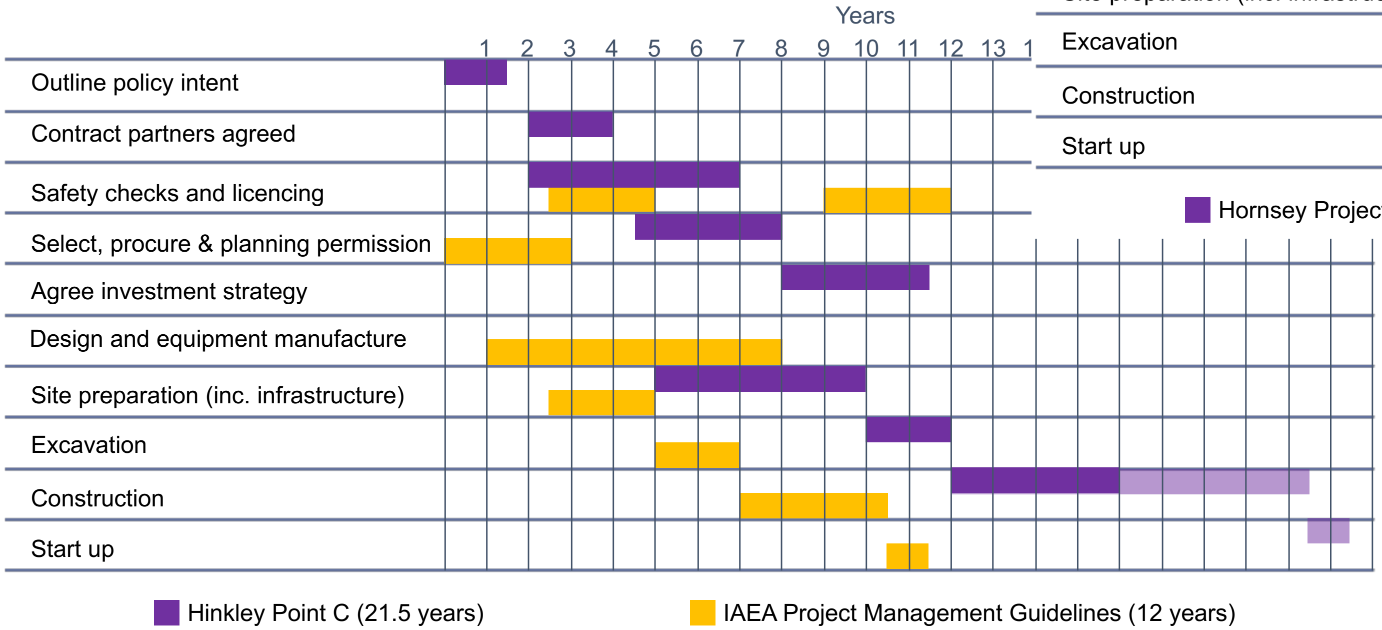
Source: Nelson & Allwood (2021)

Project examples

Offshore Wind Power Timeline

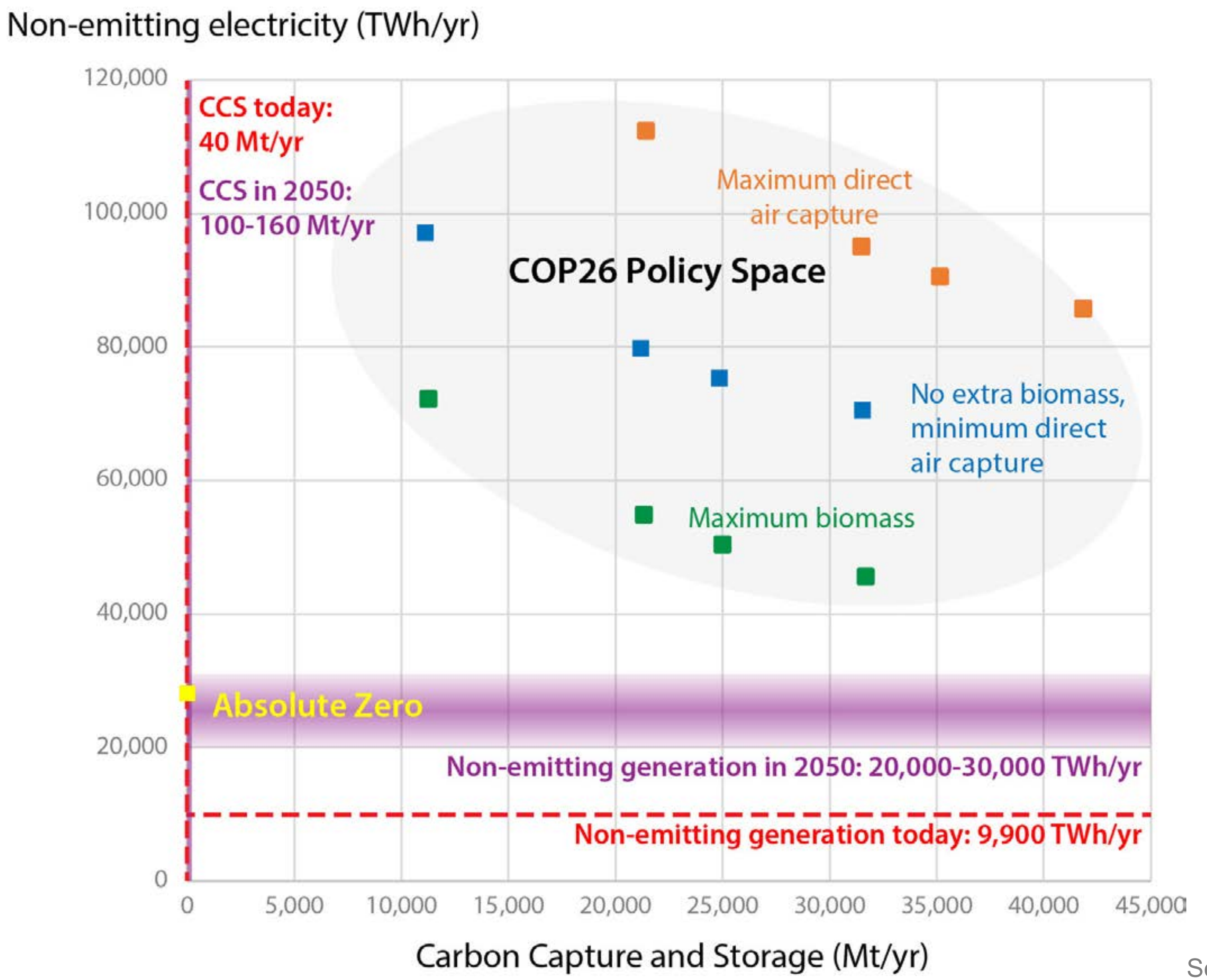


Nuclear Power Timeline



Source: Use Less Group analysis

Preliminary result: policy will be constrained by resources

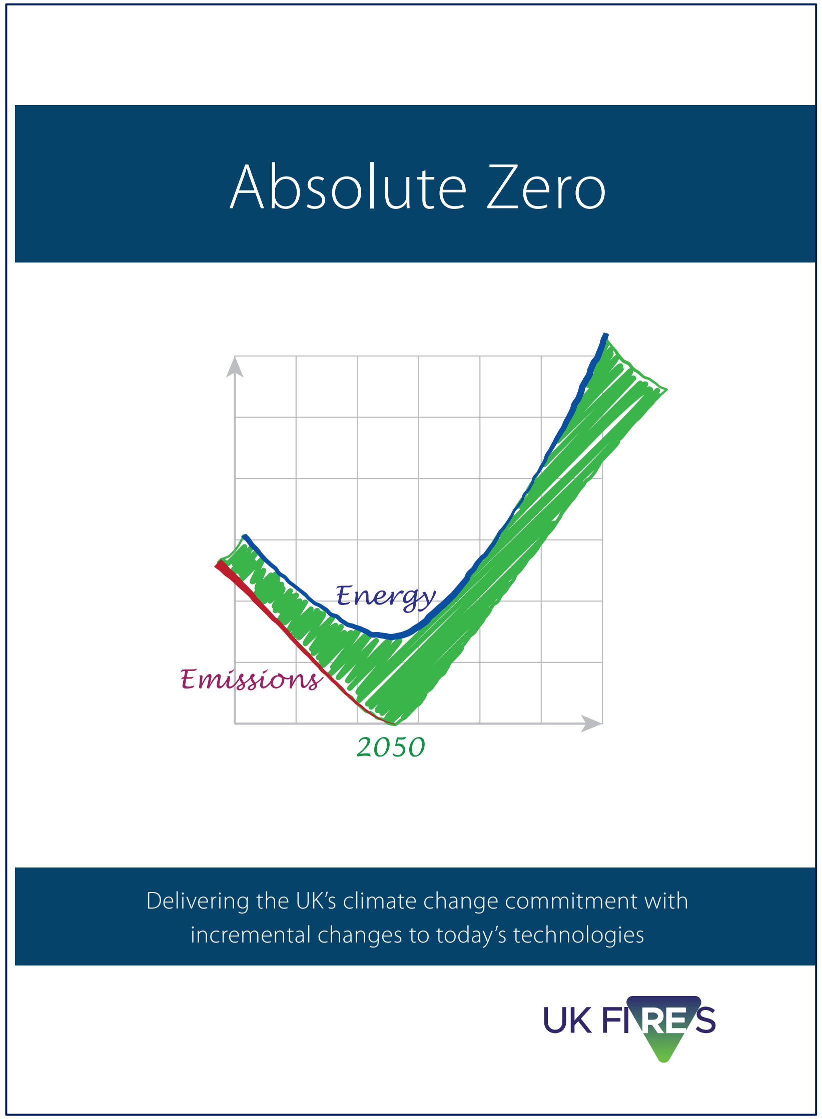


Source: https://ukfires.org/blog-cop26/

Resource-constrained climate policy

The big picture in the UK:

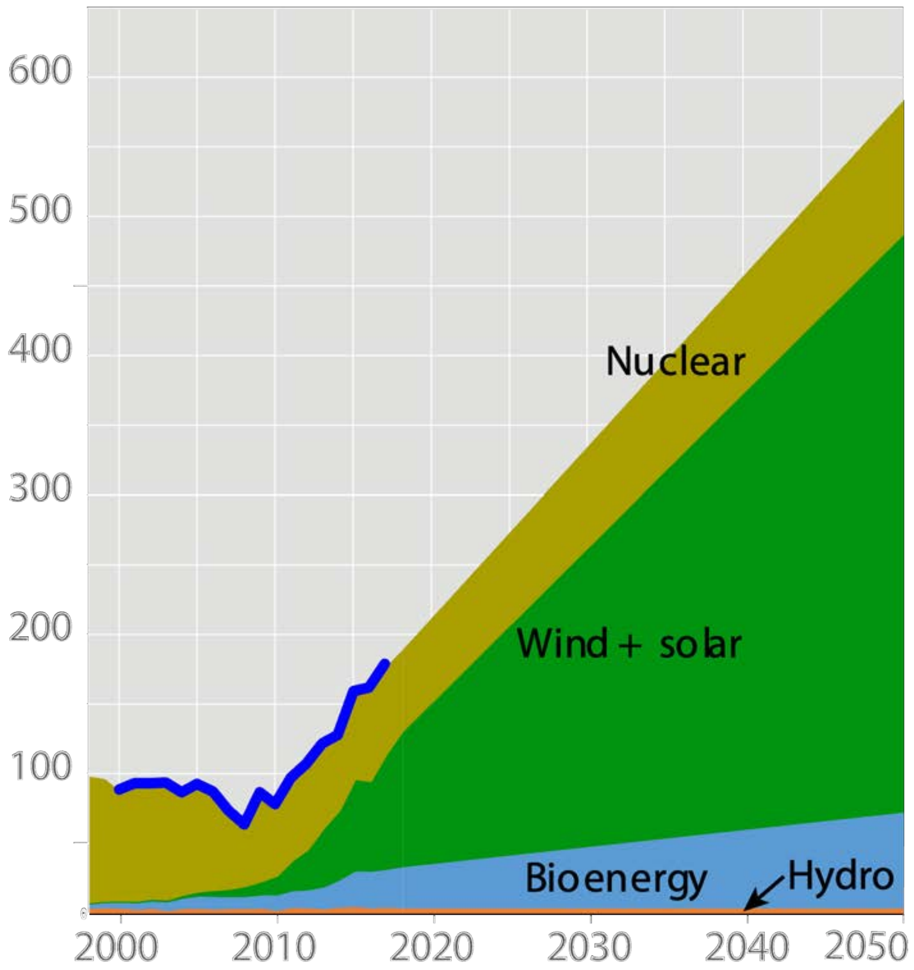
- By 2050 we will have ~ 2.5x as much emissions-free electricity as today
- We will have no significant carbon storage, surplus biomass, hydrogen or negative emissions technologies
- We have to electrify everything possible, close anything else, and use ~60% as much electricity as we'd otherwise like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



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

Is Absolute Zero pessimistic?

UK Emissions-free generation
(as predicted in Absolute Zero, 2019)



Historical and extrapolated low carbon electricity production

Is Absolute Zero pessimistic?

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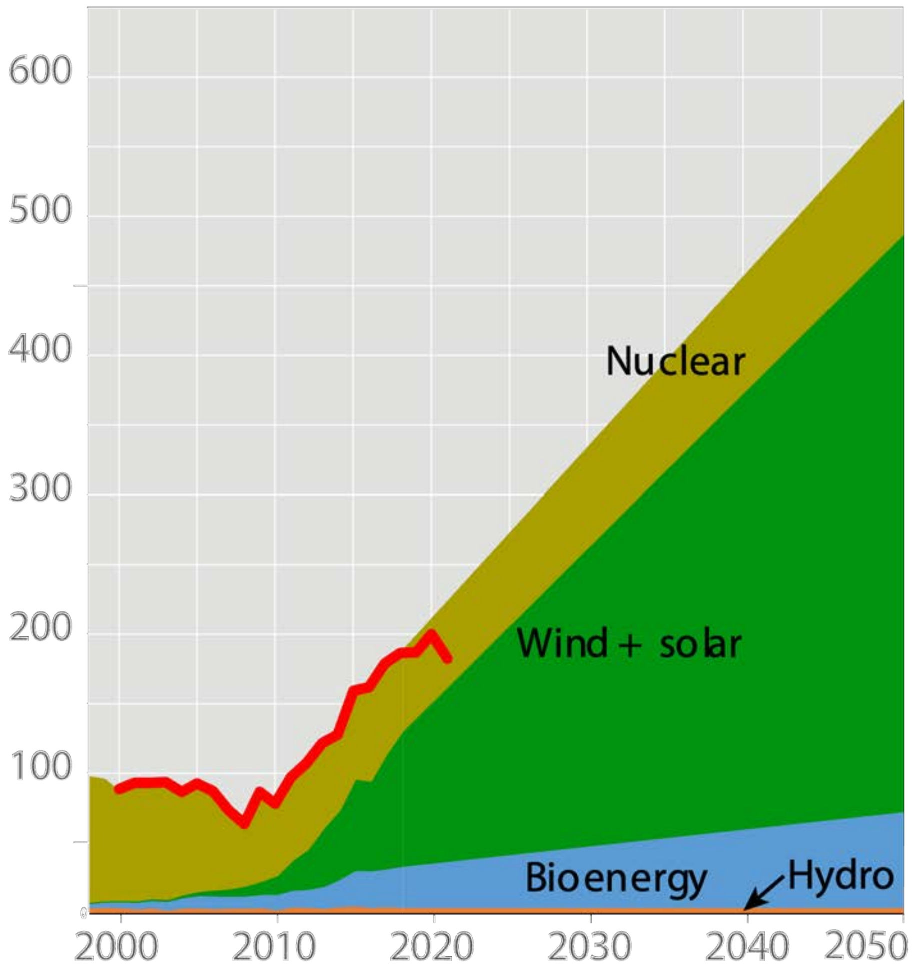
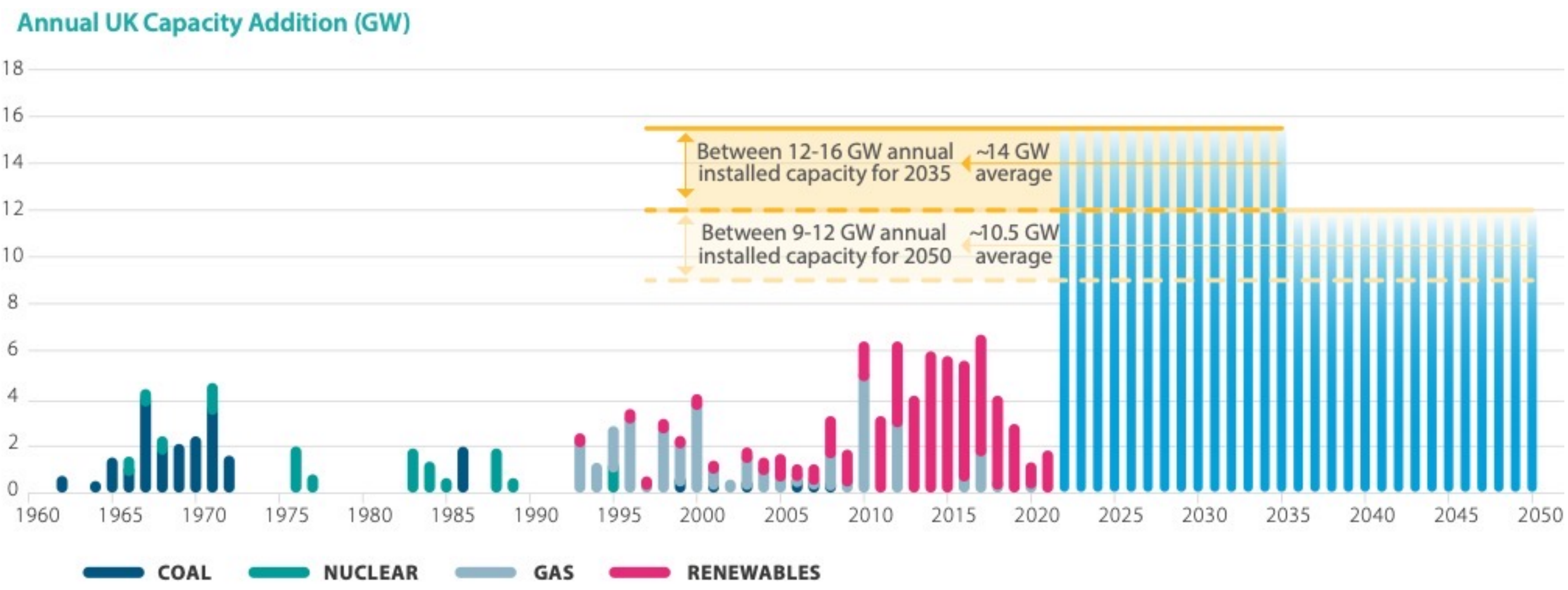


Historical and extrapolated low carbon electricity production

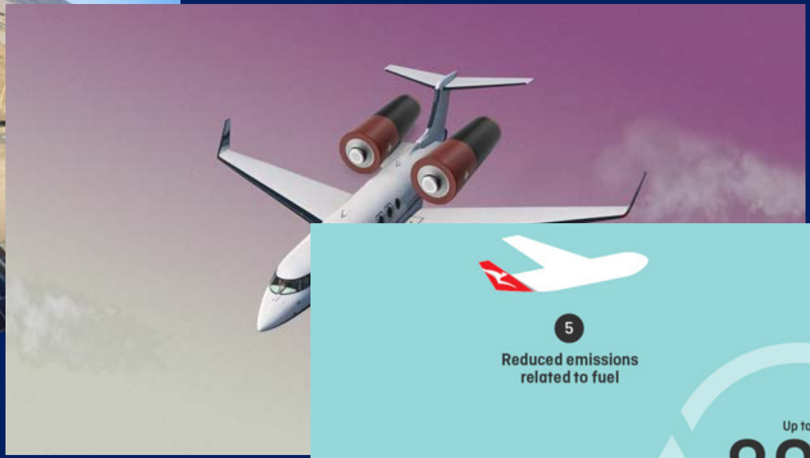
Engineering net zero (Atkins)

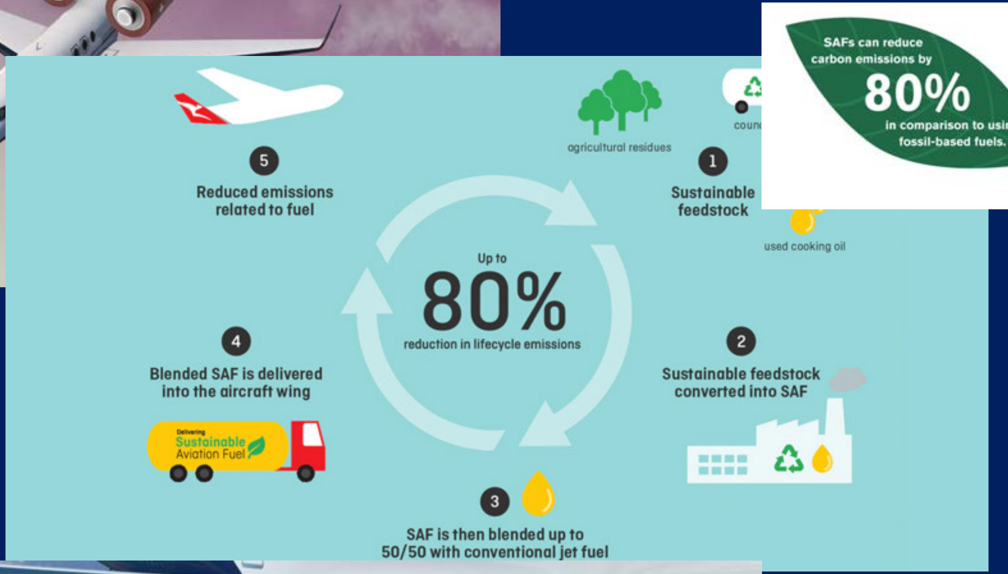


https://www.atkinsrealis.com/~/media/Files/S/SNC-Lavalin/documents/beyond-engineering/towards-energy-security-report.pdf

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


SUNSEEKER

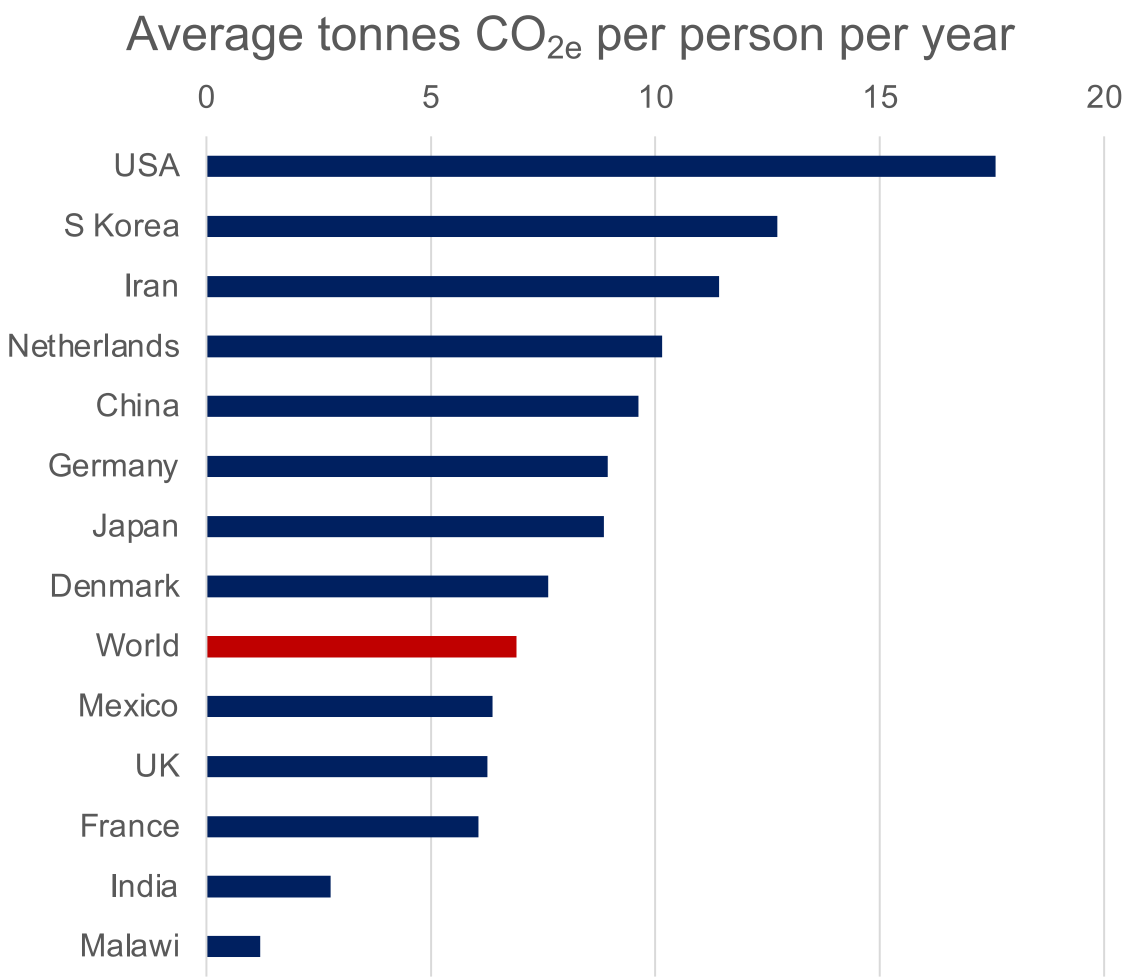


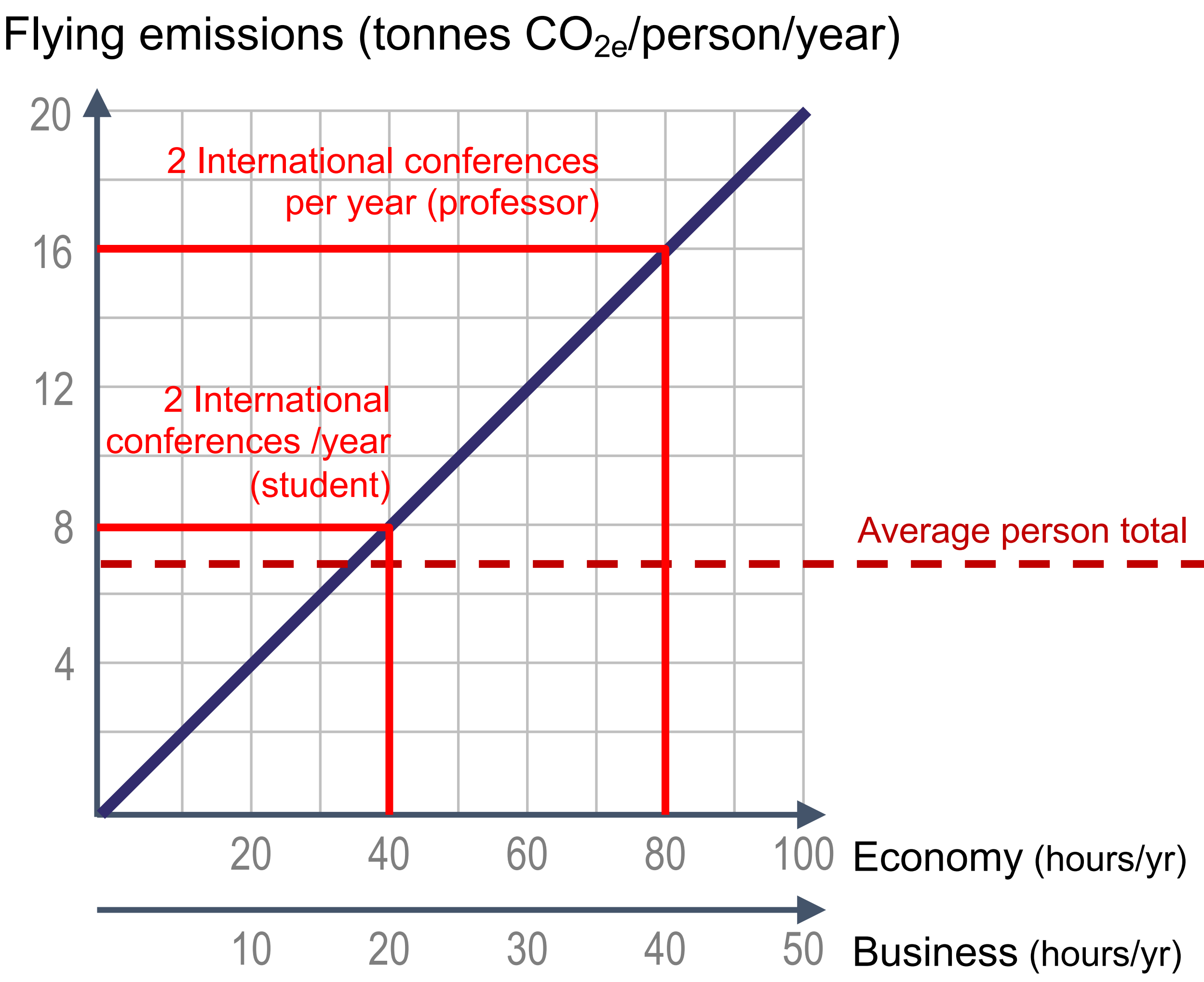

5
Reduced emissions related to fuel
agricultural residues
1
Sustainable feedstock
used cooking oil
Up to
80%
reduction in lifecycle emissions
4
Blended SAF is delivered into the aircraft wing
Delivering Sustainable Aviation Fuel
2
Sustainable feedstock converted into SAF
3
SAF is then blended up to 50/50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


H2 powered


339 BERLIN-TEGEL 2
933 FRANKFURT 2
8260 BUDAPEST 2
5525 PARIS-CDG 2
1508 ISTANBUL 2
3248 HURGHADA 2
939 IZMIR 1
2378 2

Academic responsibility



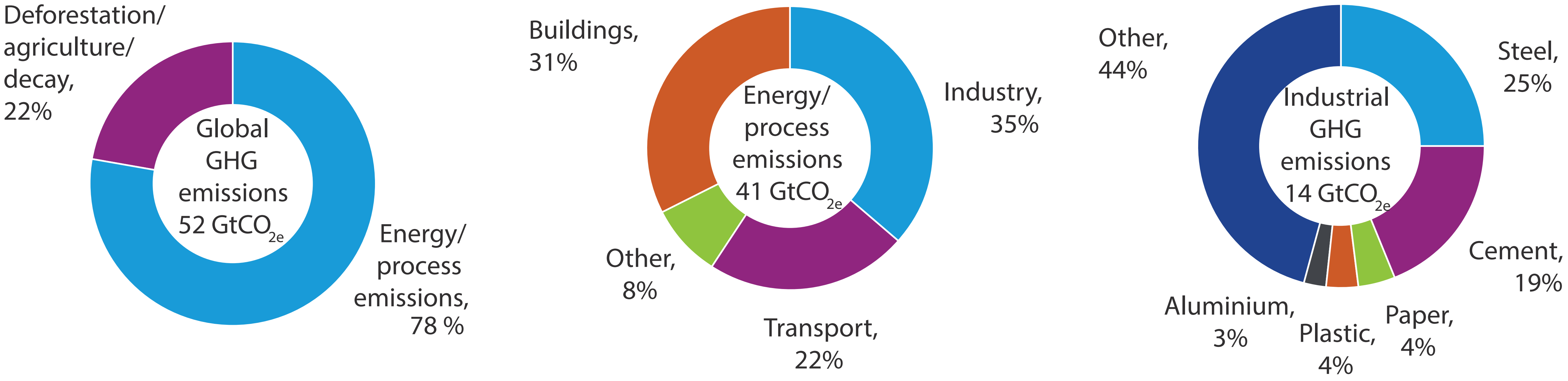


Emissions factors taken from UK Govt (2022)

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

Zero-emissions production of steel

Materials and global emissions



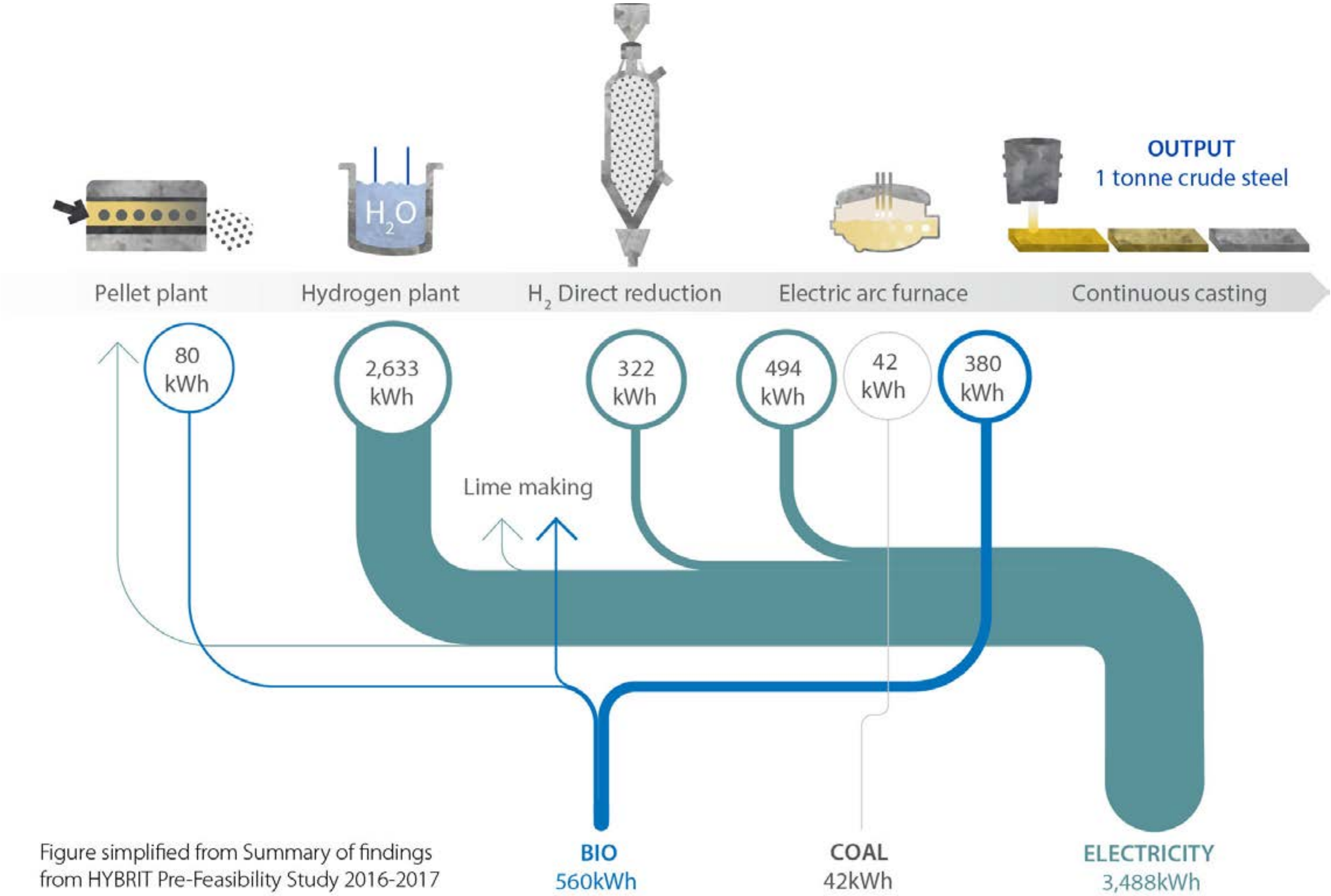
Source Allwood & Cullen (2012)

Options for making zero emissions steel from ore

- Carbon capture and storage
  - One pilot plant in Abu Dhabi (ADNOC Al Reyadah phase 1) opened in 2016 and is making ~400kt steel/year while capturing ~800kt CO_2/year
  - The captured gas is used to enhance the extraction of natural gas – more methane is extracted than CO_2 injected.
  - There is no independent verification of any of the reports from this site
  - No other steel+CCS plants are planned at present
  - Every article written about CCS is authored by a group who want it to happen
  - At best CCS captures 90% of the emissions.

Options for making zero emissions steel from ore

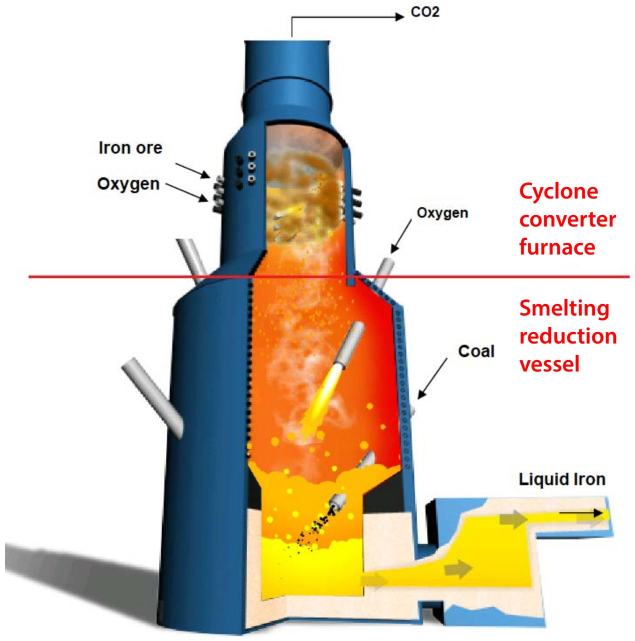
- Hydrogen
  - SSAB in Sweden has begun early trials of the HYBRIT process and may begin industrial operation after 2040
  - "Fossil Free Electricity is the Key": the process requires 3,500 kWh/tonne steel compared to ~500 kWh/tonne for making steel from scrap with an electric arc furnace: **seven times** more

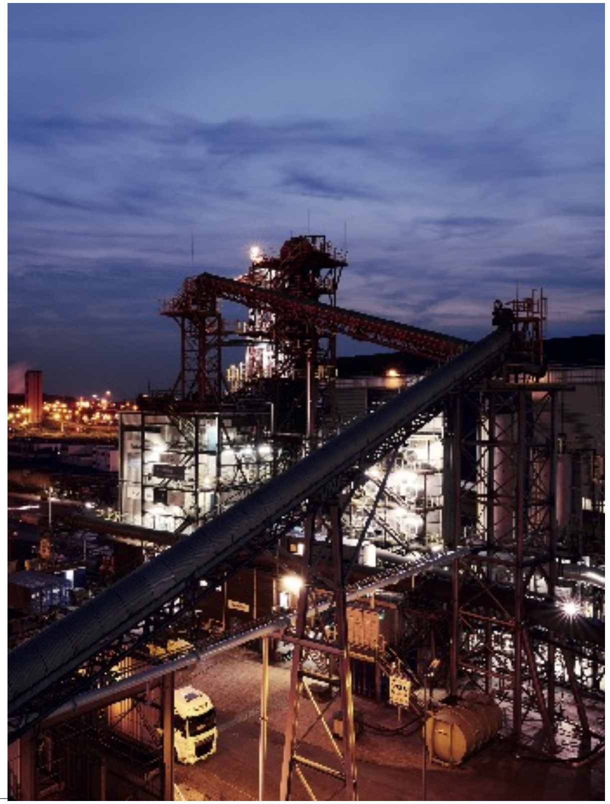


Source HYBRIT (2017)

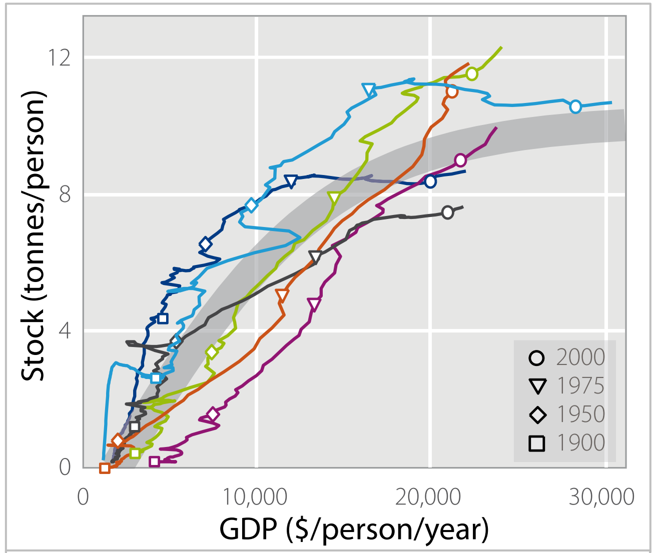
Options for making zero emissions steel from ore

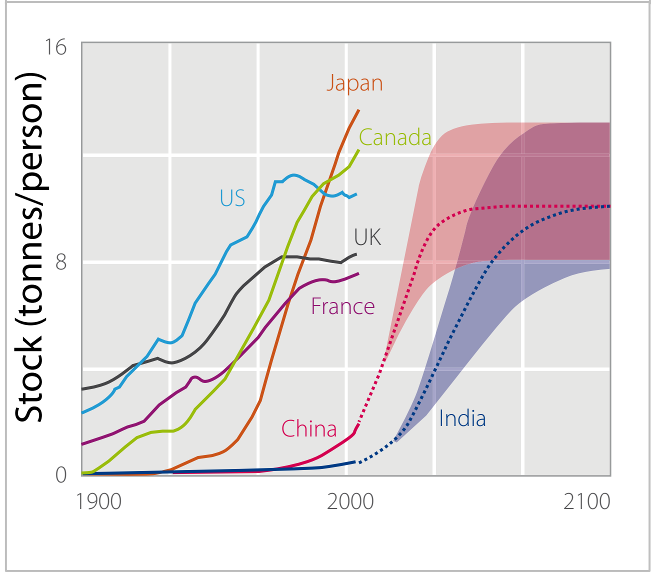
- Others
  - ULCOS in Europe explored a range of options to make steel with *less* CO_2 – i.e. not zero
  - HISARNA at Tata Steel Ijmuiden has been in development since 1986, has a theoretical capacity of 65,000 tonnes of steel per year, but has only been tried for a few weeks. It reduces emissions by ~20% and could potentially by connected to a CCS operation
  - Tata is considering an industrial scale plant in India - by 2030 at best

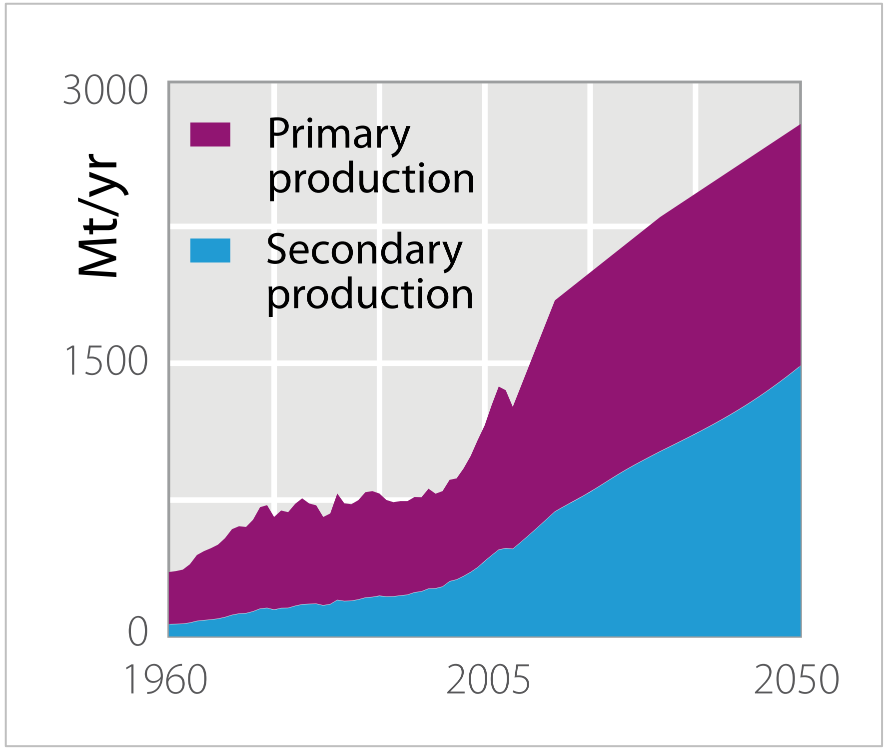




Recycling will grow with scrap-supply







Source Allwood & Cullen (2012)

Steel-making options

Technology	Blast furnace	Gas + DRI	Electric Arc Furnace	Blast Furnace + CCS	Hydrogen reduction
Global capacity Mtonnes/yr	1,300	100	**700 and will double**	0.4	0
Emissions (tonnes CO_{2e}/tonne steel)	2.9	~0.9-2.0	**0.3**	0.3	2.1
Electricity (kWh/tonne)		500	**500**		3500
Zero emissions?	CCS only	CCS only	**Yes**	90% reduction, one small demonstrator	Yes – but huge electricity demand

The UK Steel Industry

2012
www.withbotheyesopen.com


MATERIALS WORLD

January 2016

The future of steel: time to wake up

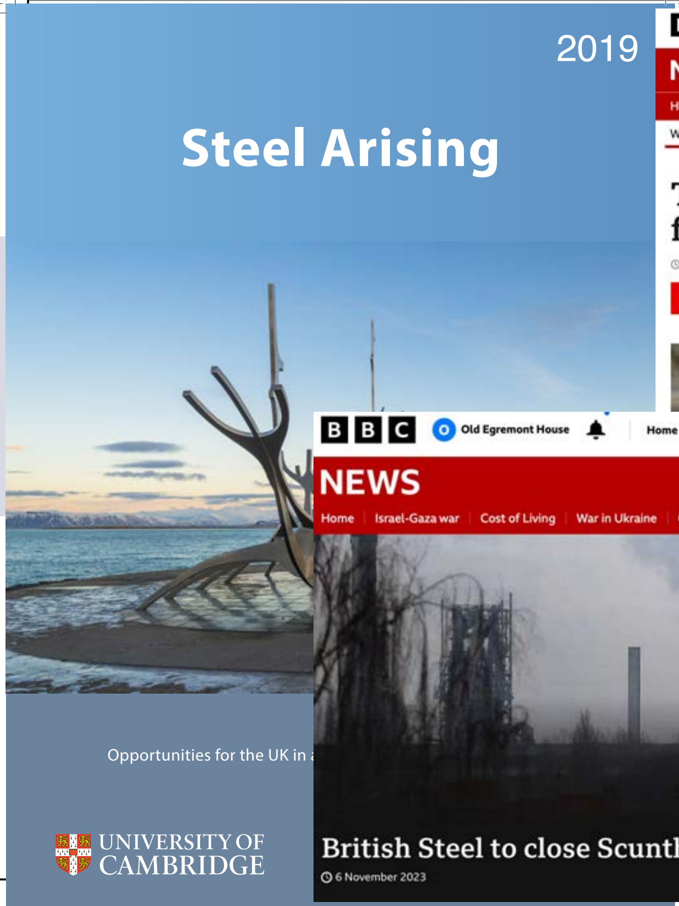
Professor Julian Allwood considers the recent developments in the European steel industry and offers an approach for the future.


April 2016

A bright future for UK steel

A strategy for innovation and leadership through up-cycling and integration

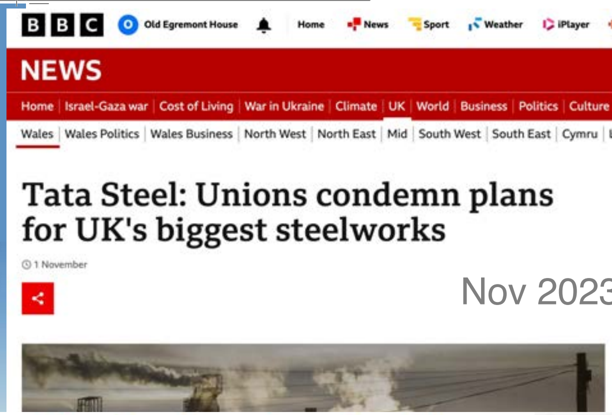
UNIVERSITY OF CAMBRIDGE


2019

Steel Arising

Opportunities for the UK in a

UNIVERSITY OF CAMBRIDGE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Tata Steel: Unions condemn plans for UK's biggest steelworks

1 November

Nov 2023


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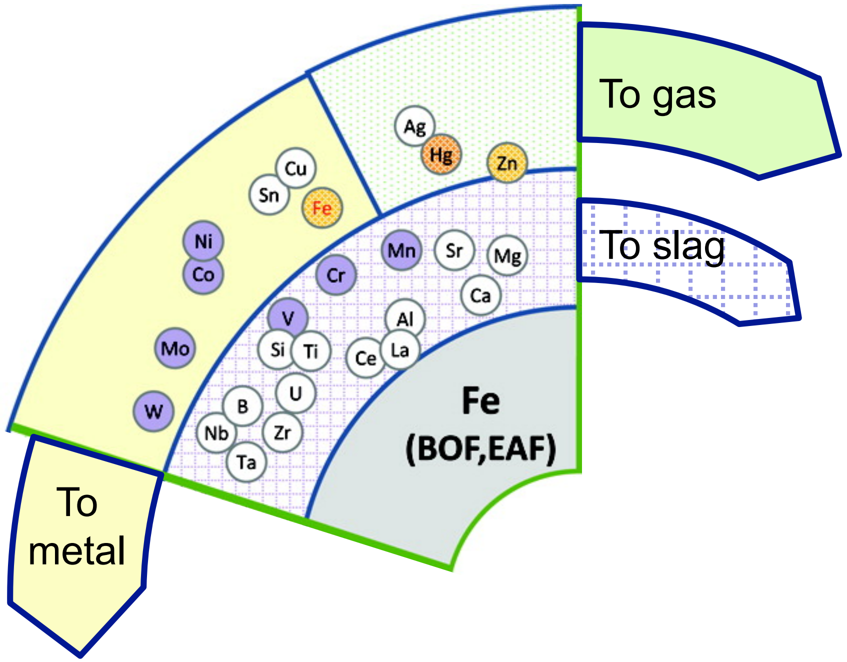
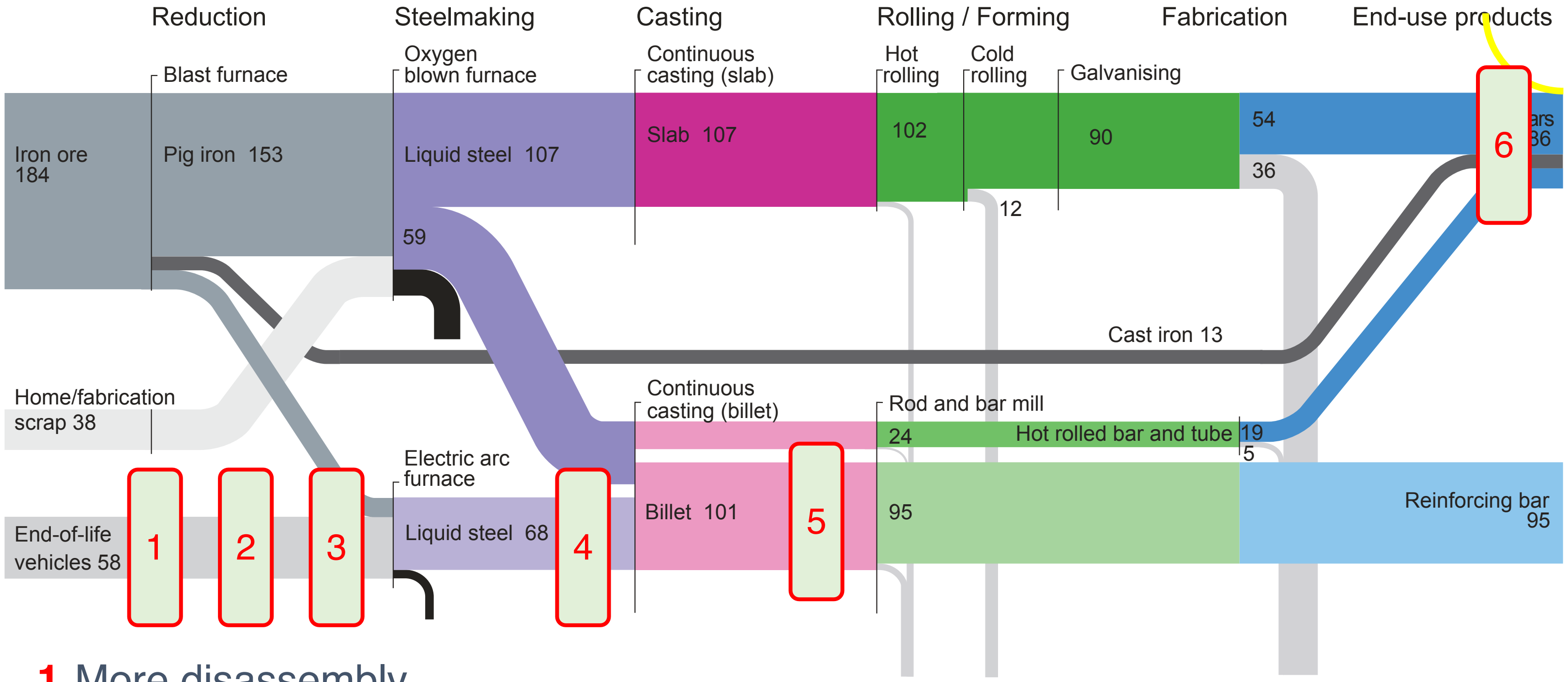
British Steel to close Scunthorpe blast furnaces

6 November 2023

UK steel industry: new upstream opportunities



Source Nakajima et al. (2010)



1 More disassembly

2 Alternative shredding

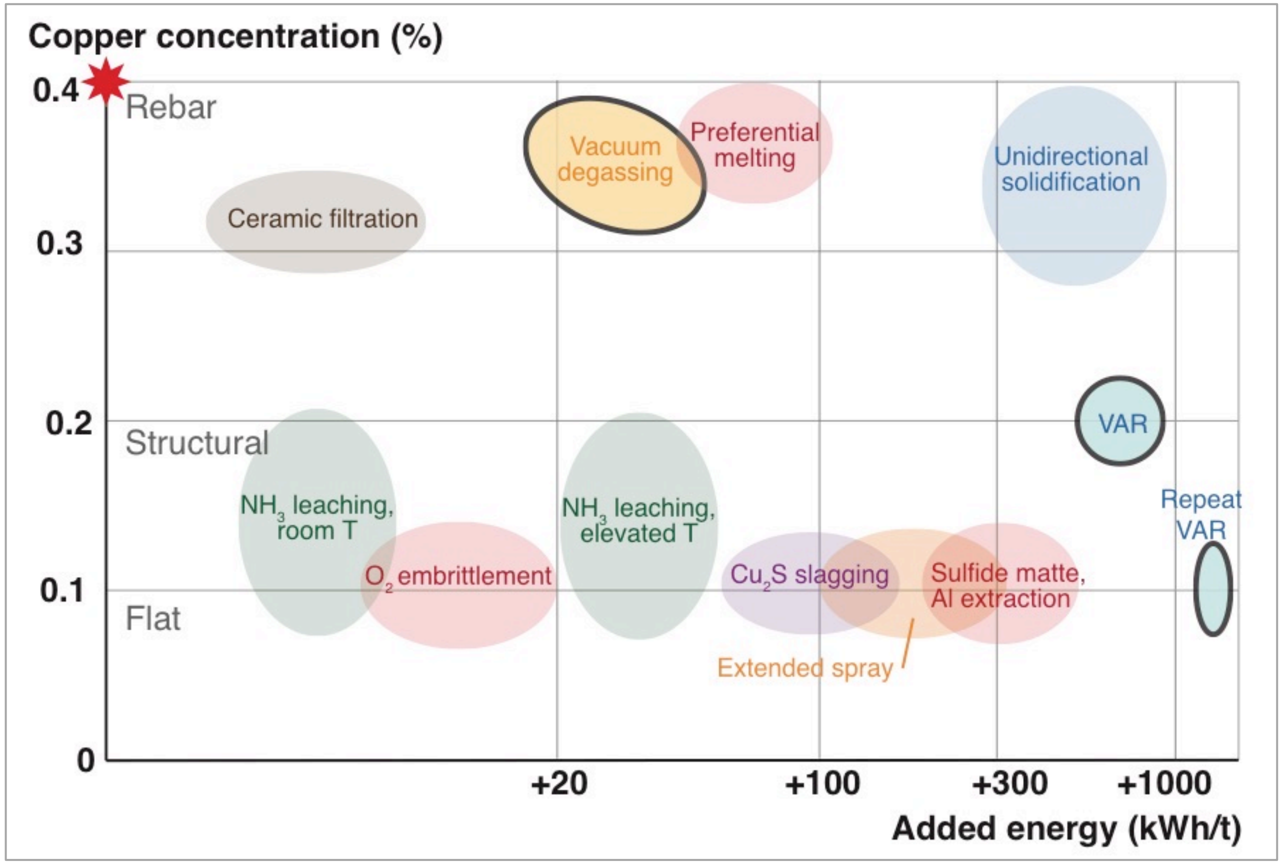
3 Better sorting

4 Melt control

5 Cu tolerant casting

6 Reduce Cu content in new cars

UK steel industry: new upstream opportunities



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

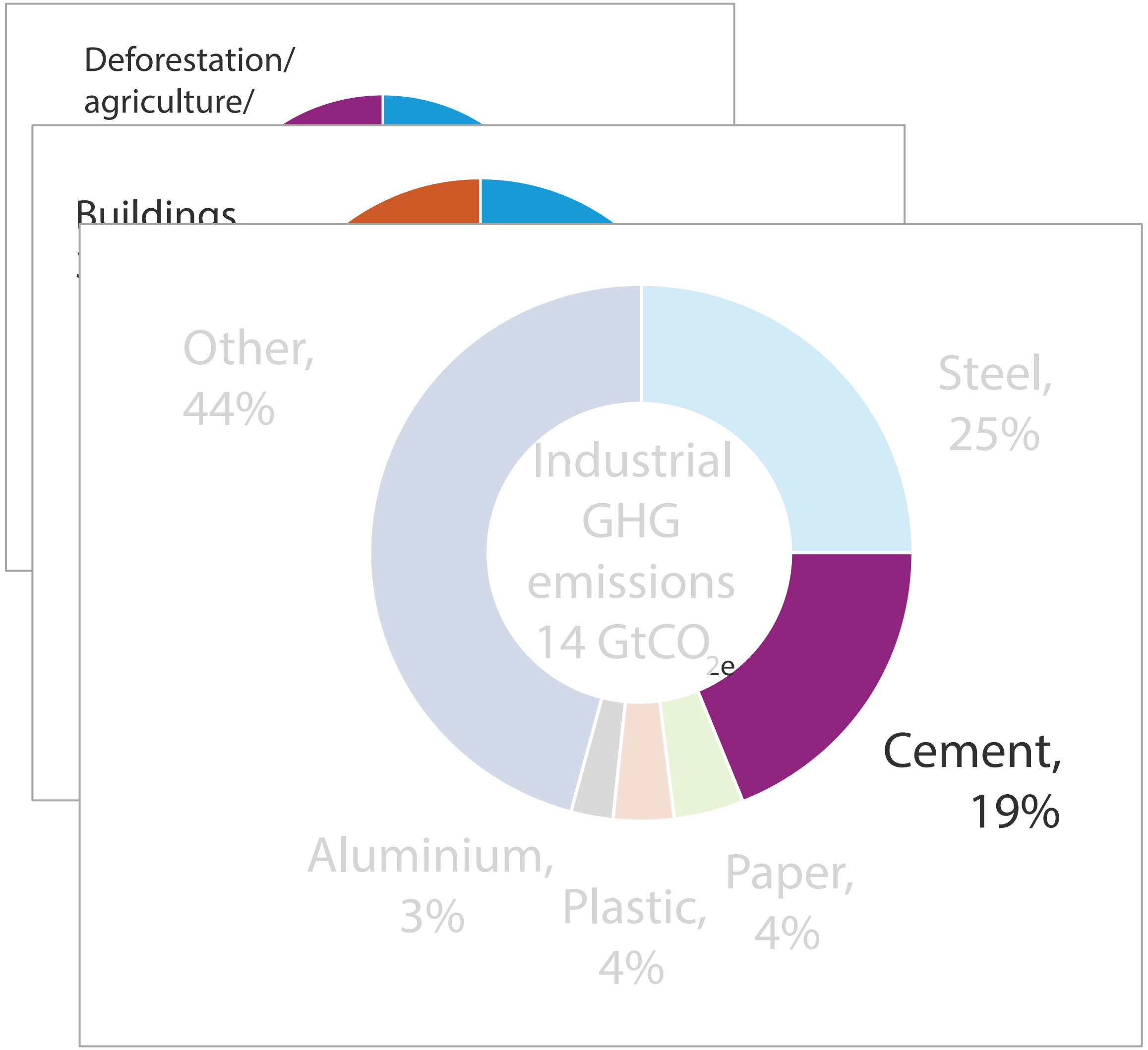
Find out more at **royalsociety.org/events/for-scientists**

THE ROYAL SOCIETY

Image: © zephylwer0 from Pixabay.

Zero-emissions production of cement

Cement and emissions



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

Innovation space

		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

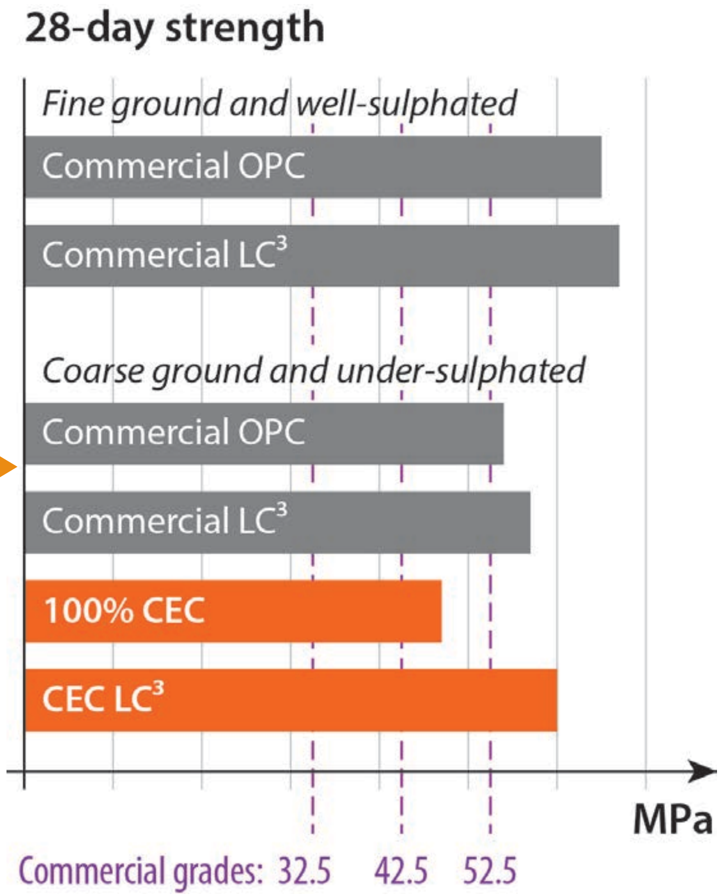
Cambridge Electric Cement

Recovered Cement Paste

Heat in EAF

Rapid cooling

Portland cement



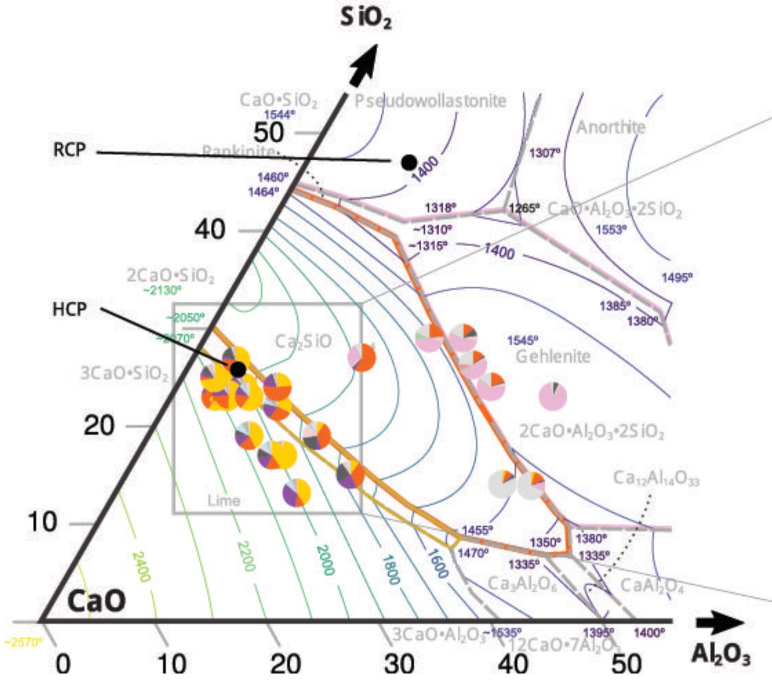
Source: Dunant et al. (under review)

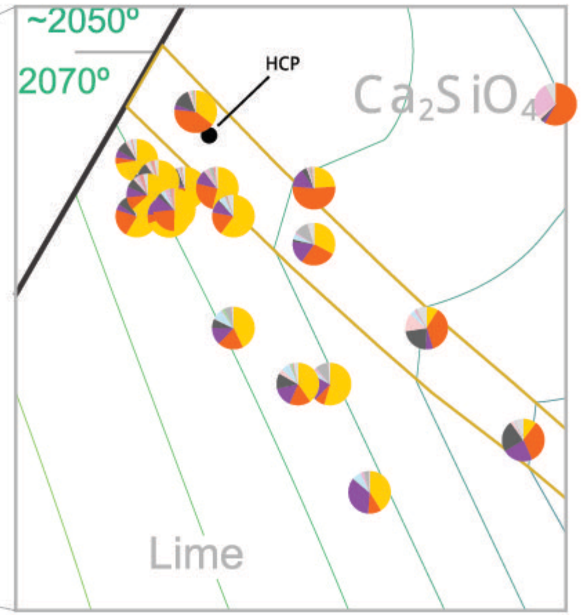
Cambridge Electric Cement

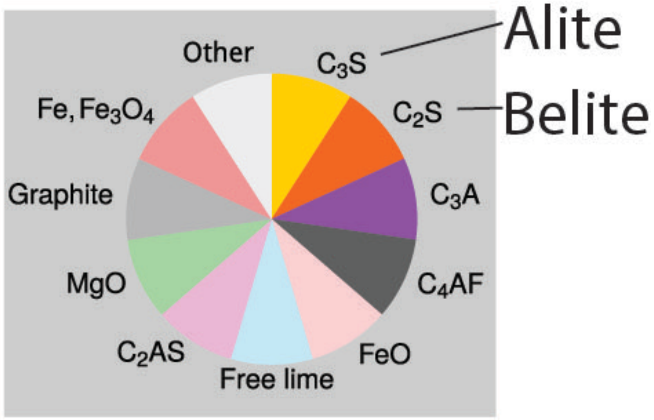
CAMBRIDGE ELECTRIC CEMENT

Cambridge Electric Cement

We have made 28 slags...

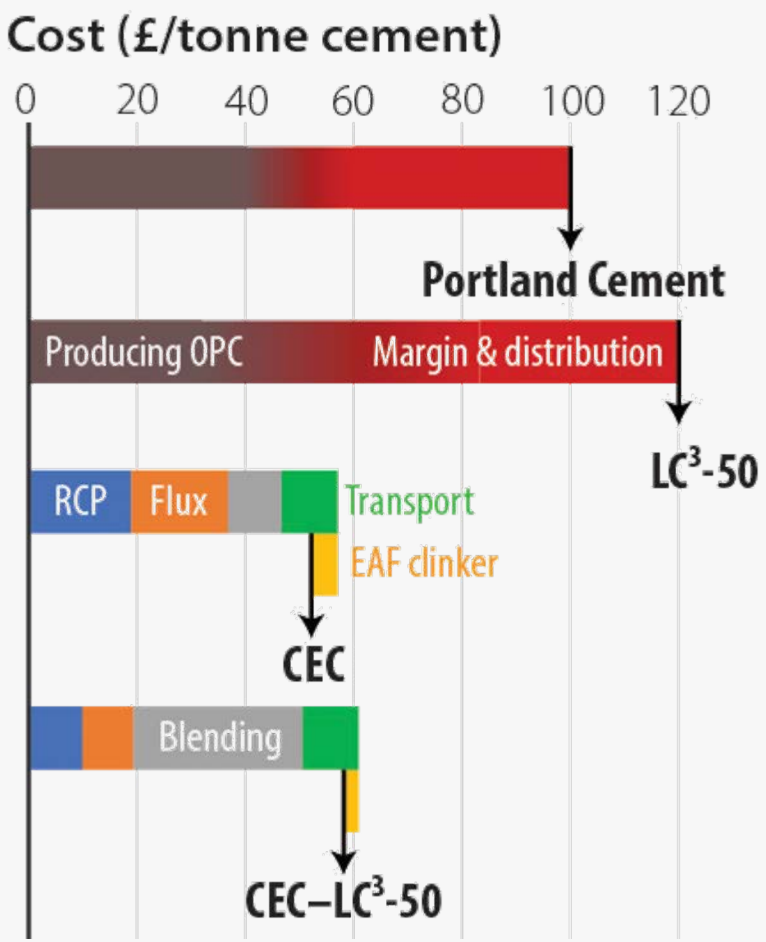


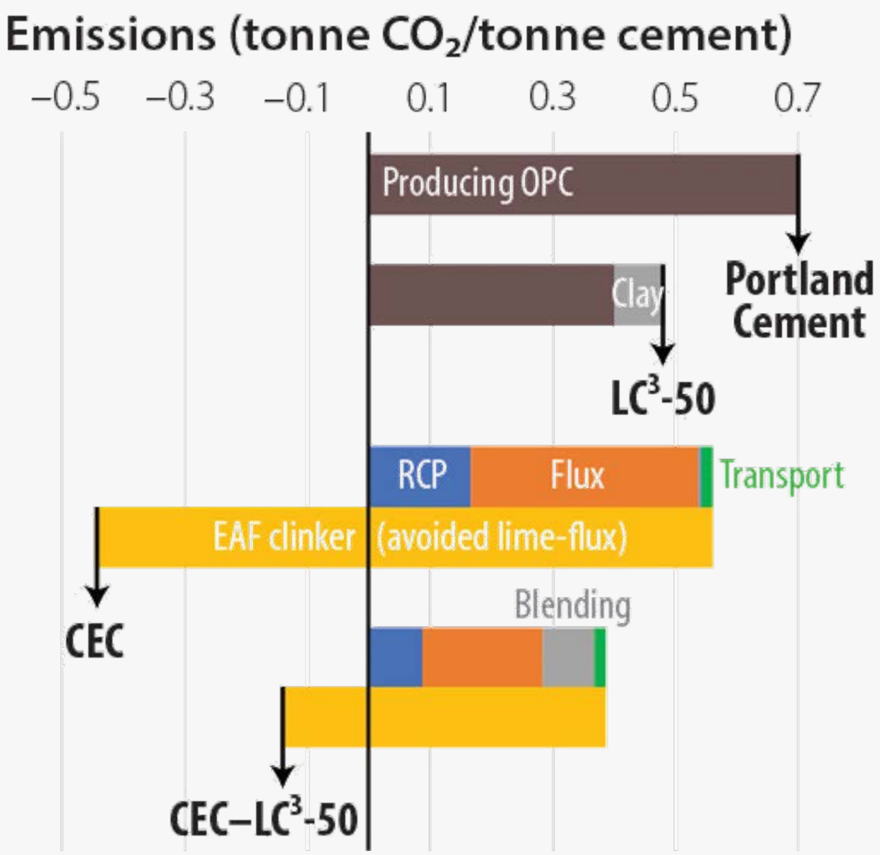




...which are Portland when Alite+Belite > 66%

Cambridge Electric Cement





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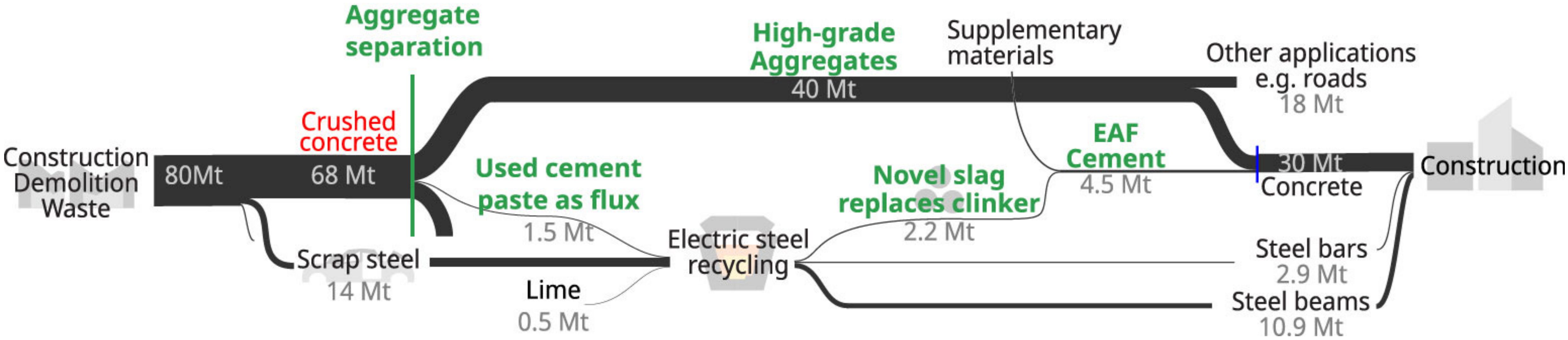
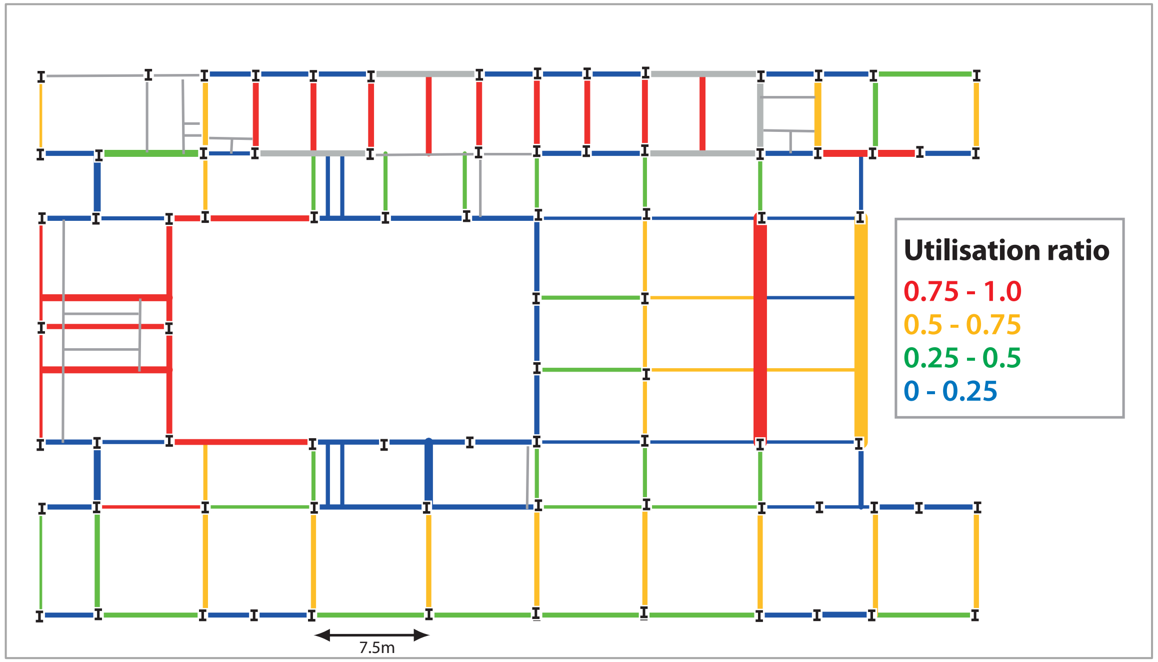
Cambridge Electric Cement

Potential for UK co-recycling of steel and cement

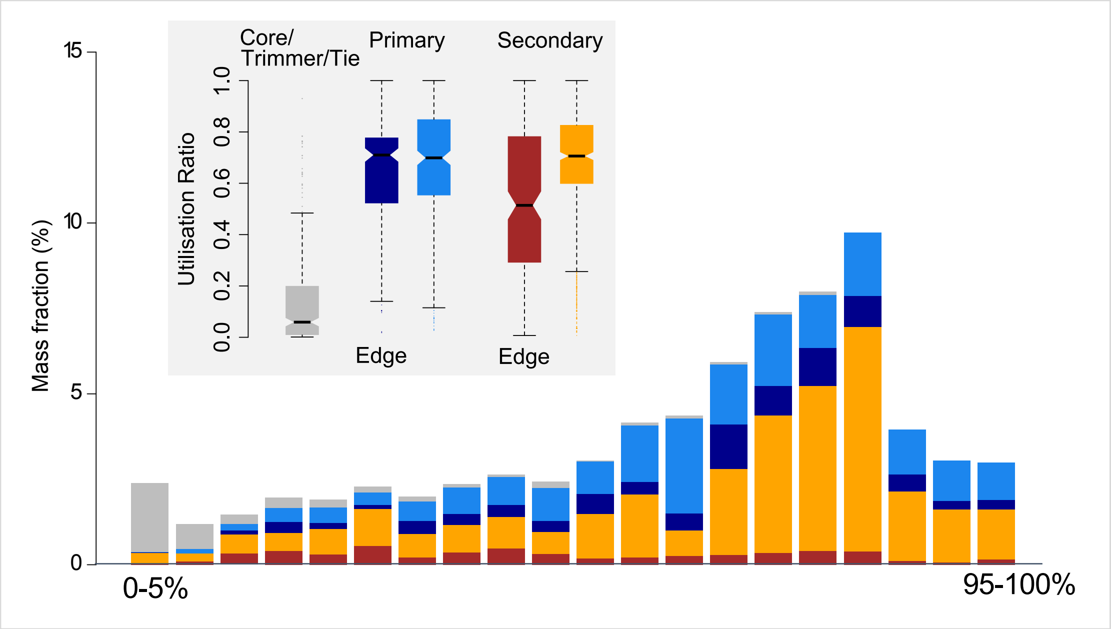


Innovation for living well with less material

Specification scrap: construction

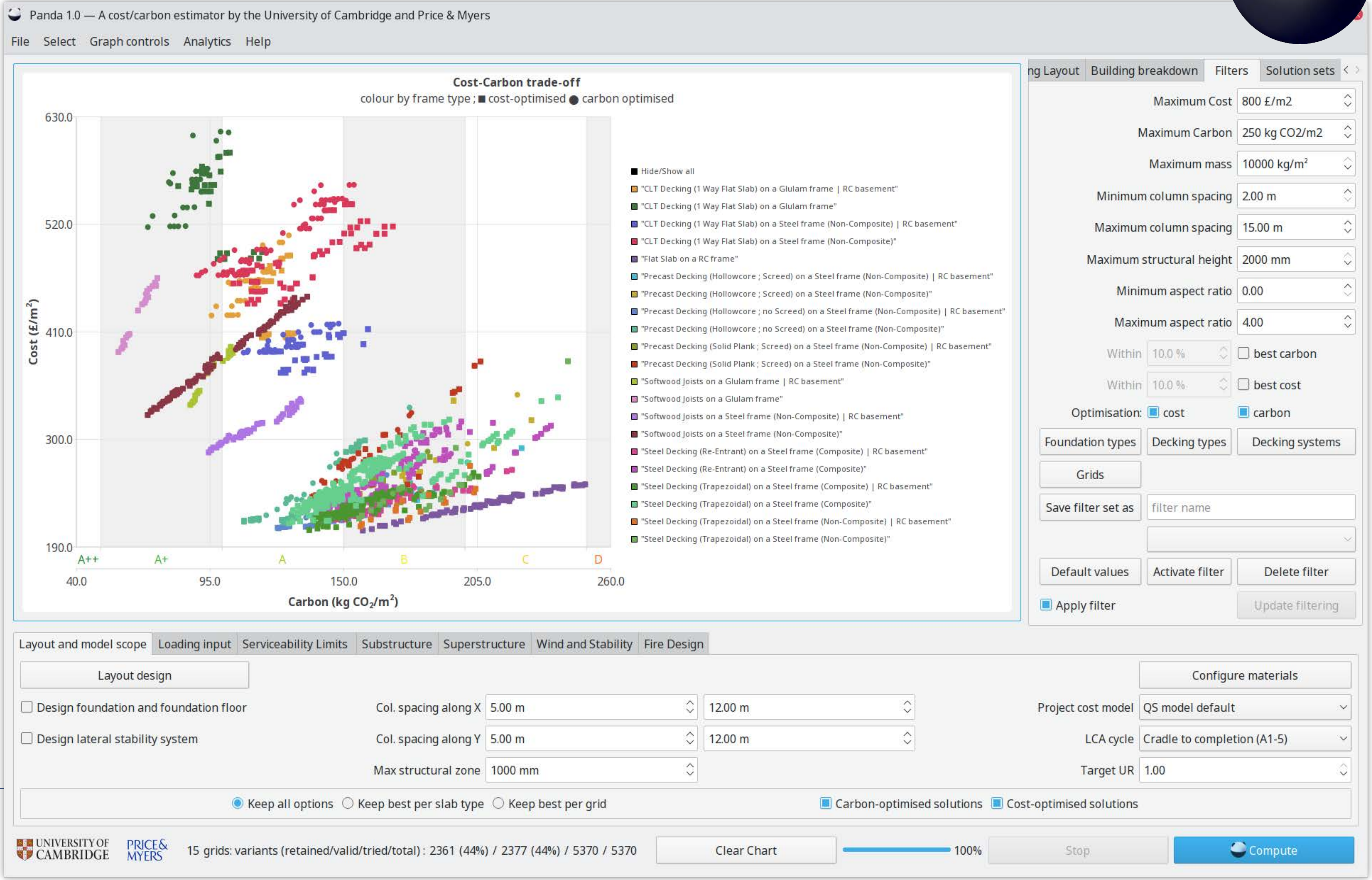


Source Moynihan & Allwood (2014)

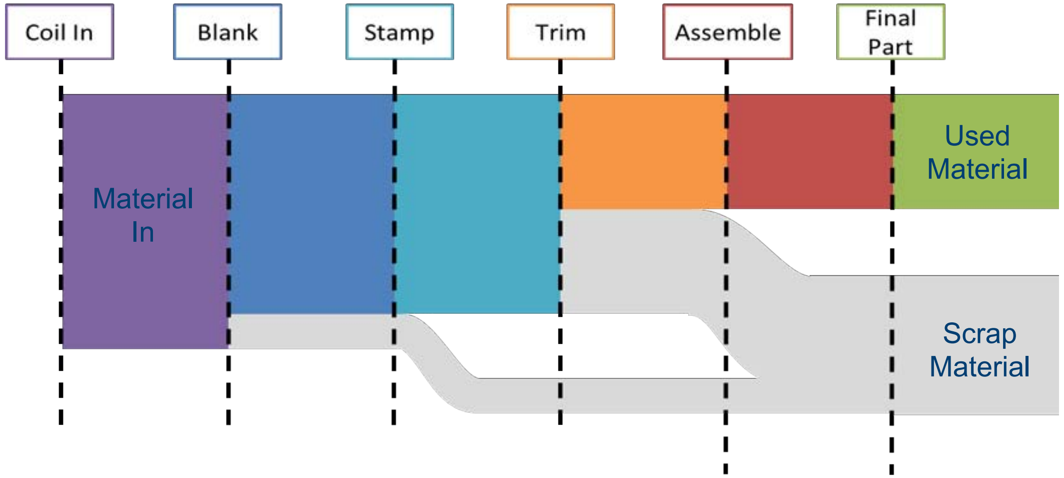


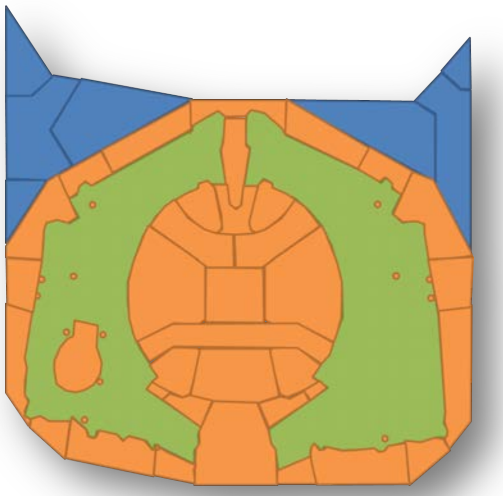
Source Dunant et al. (2018b)

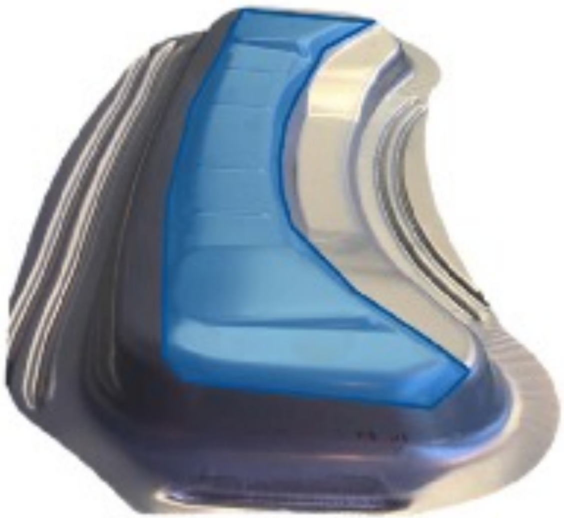
Structural Panda Ltd.

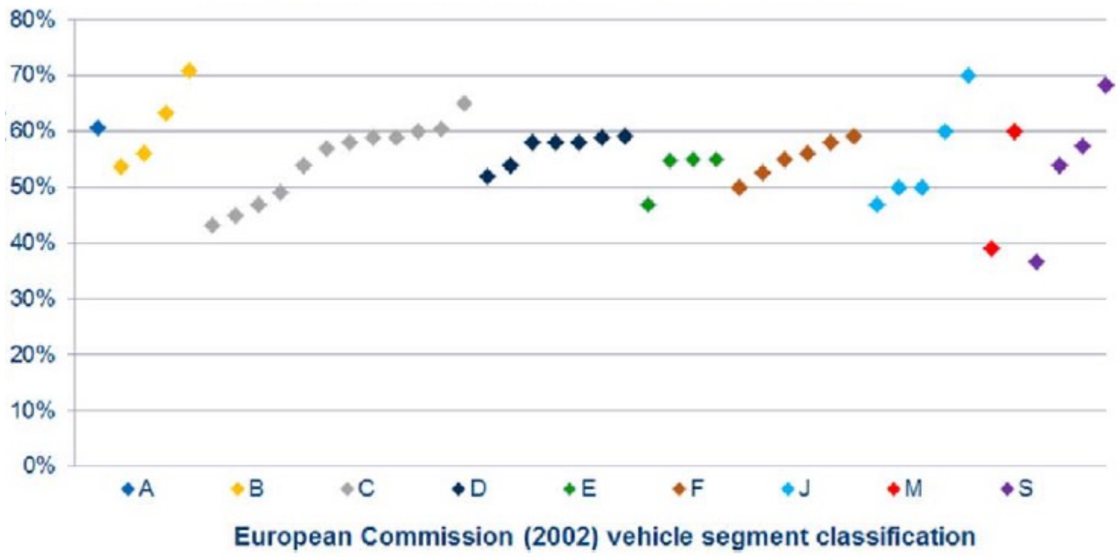


Scrap in car-production



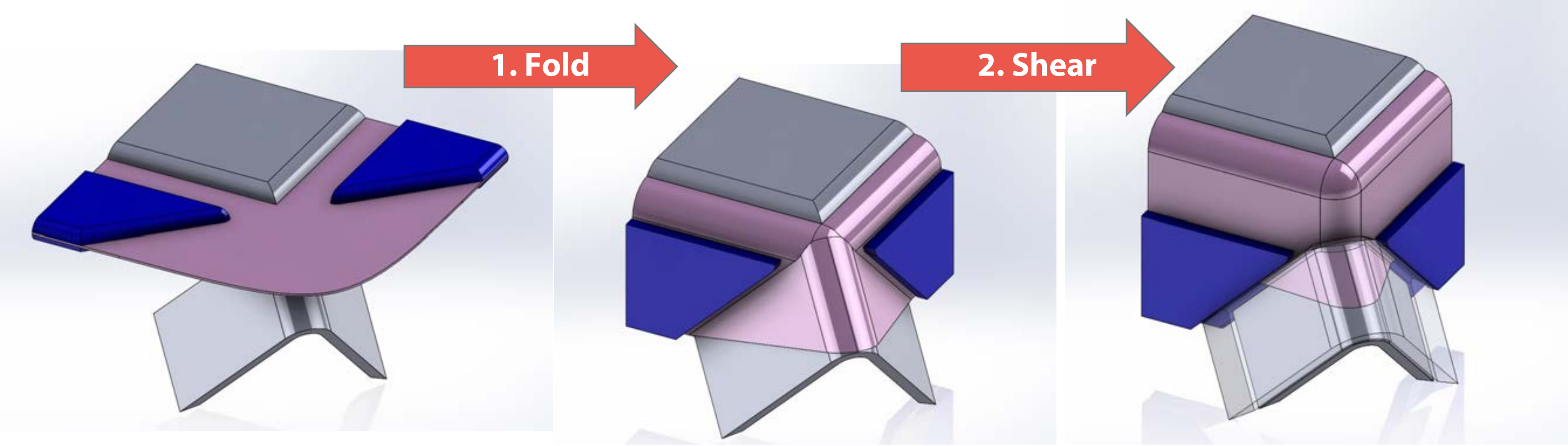






Source: Horton and Allwood (2017)

Folding-Shearing

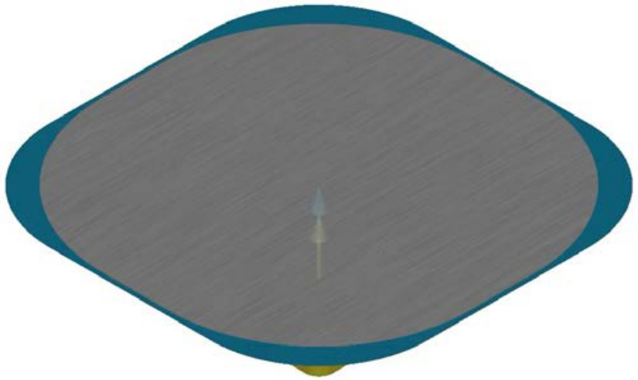


Source: Allwood et al. (2019), Cleaver et al. (2022)

Folding-shearing compared to deep-drawing

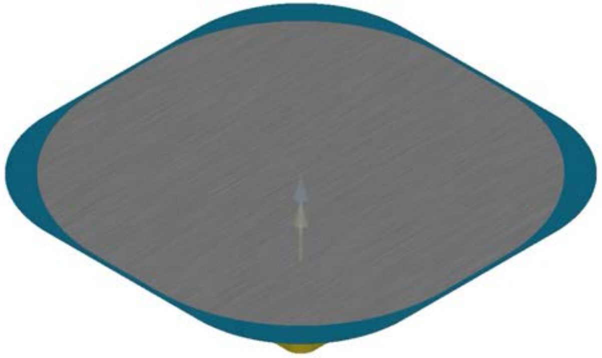
Drawing with blankholder

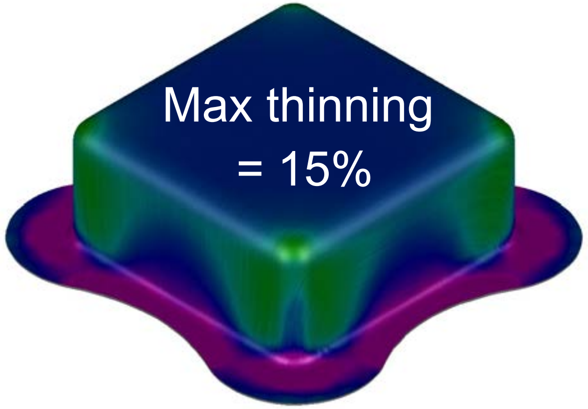
BHF = 15 kN



Drawing with blankholder

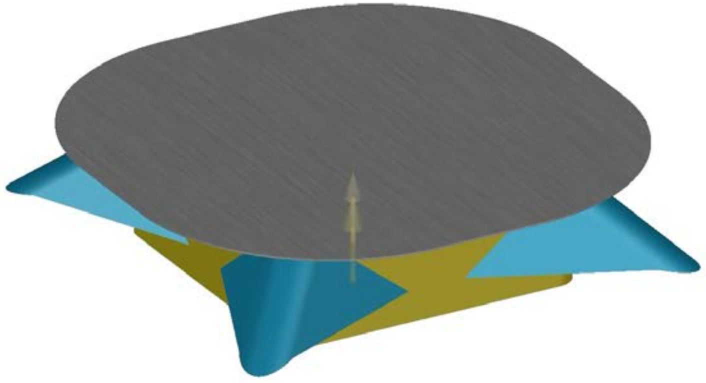
BHF = 50 kN

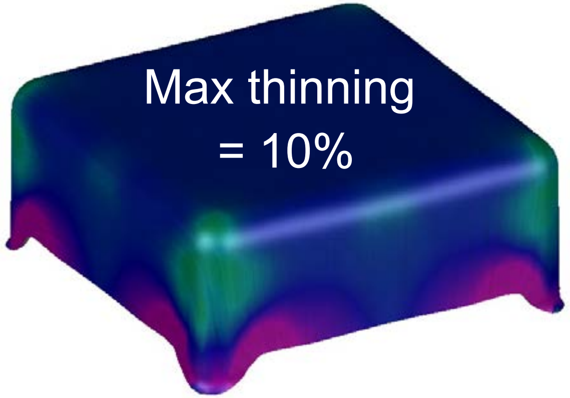




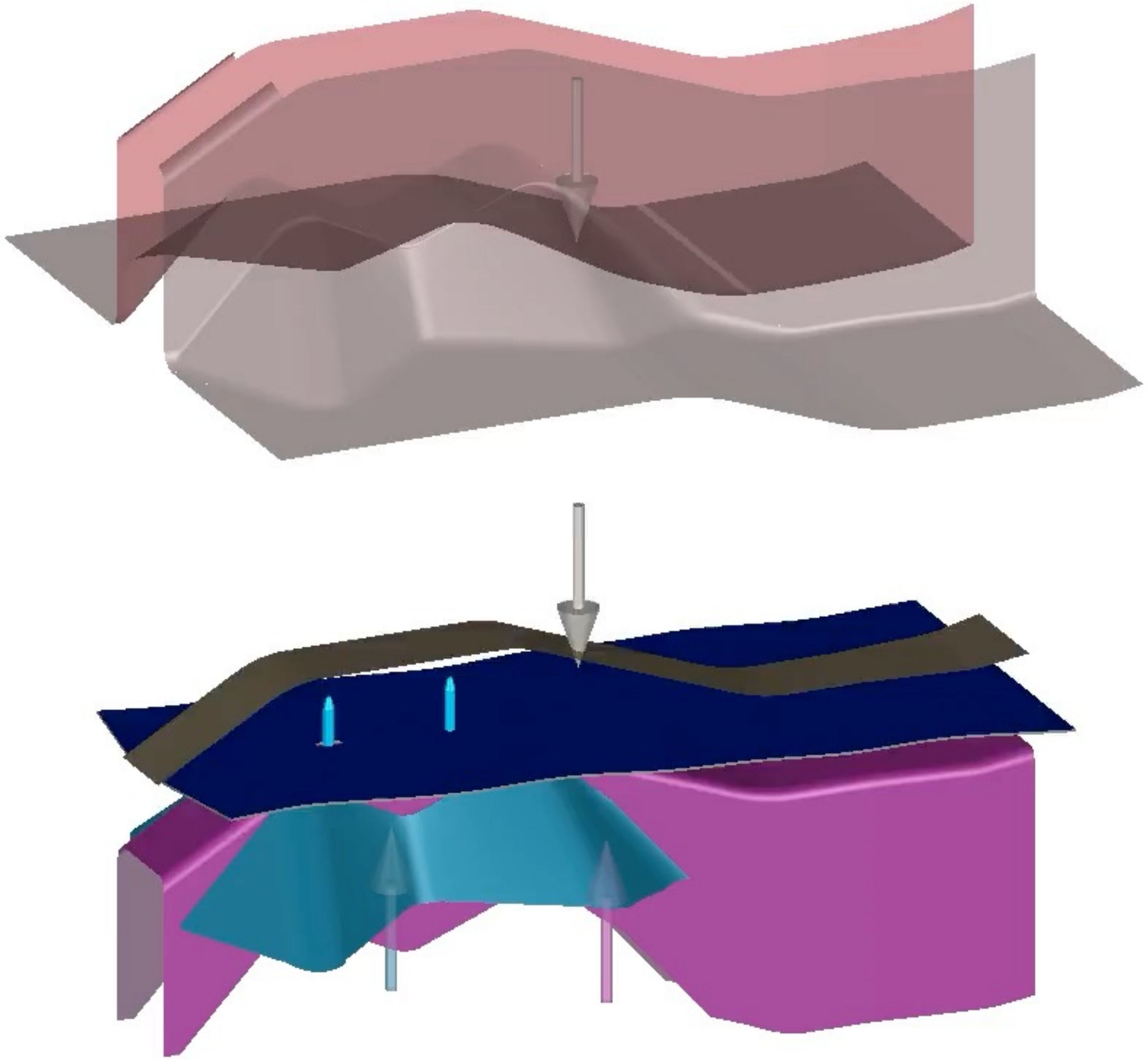
Folding-shearing

BHF = 15 kN





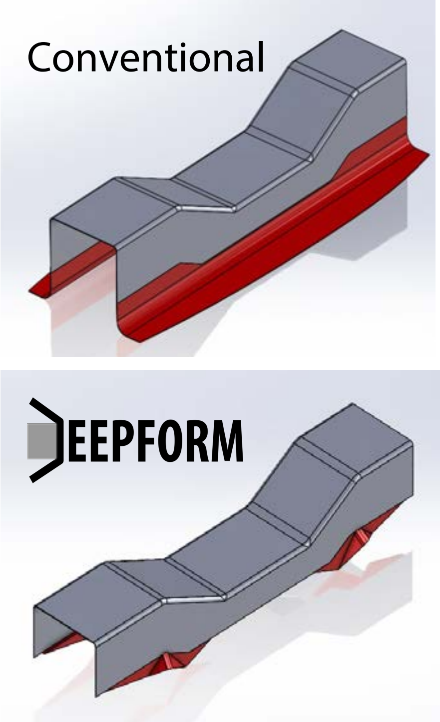
Folding-Shearing

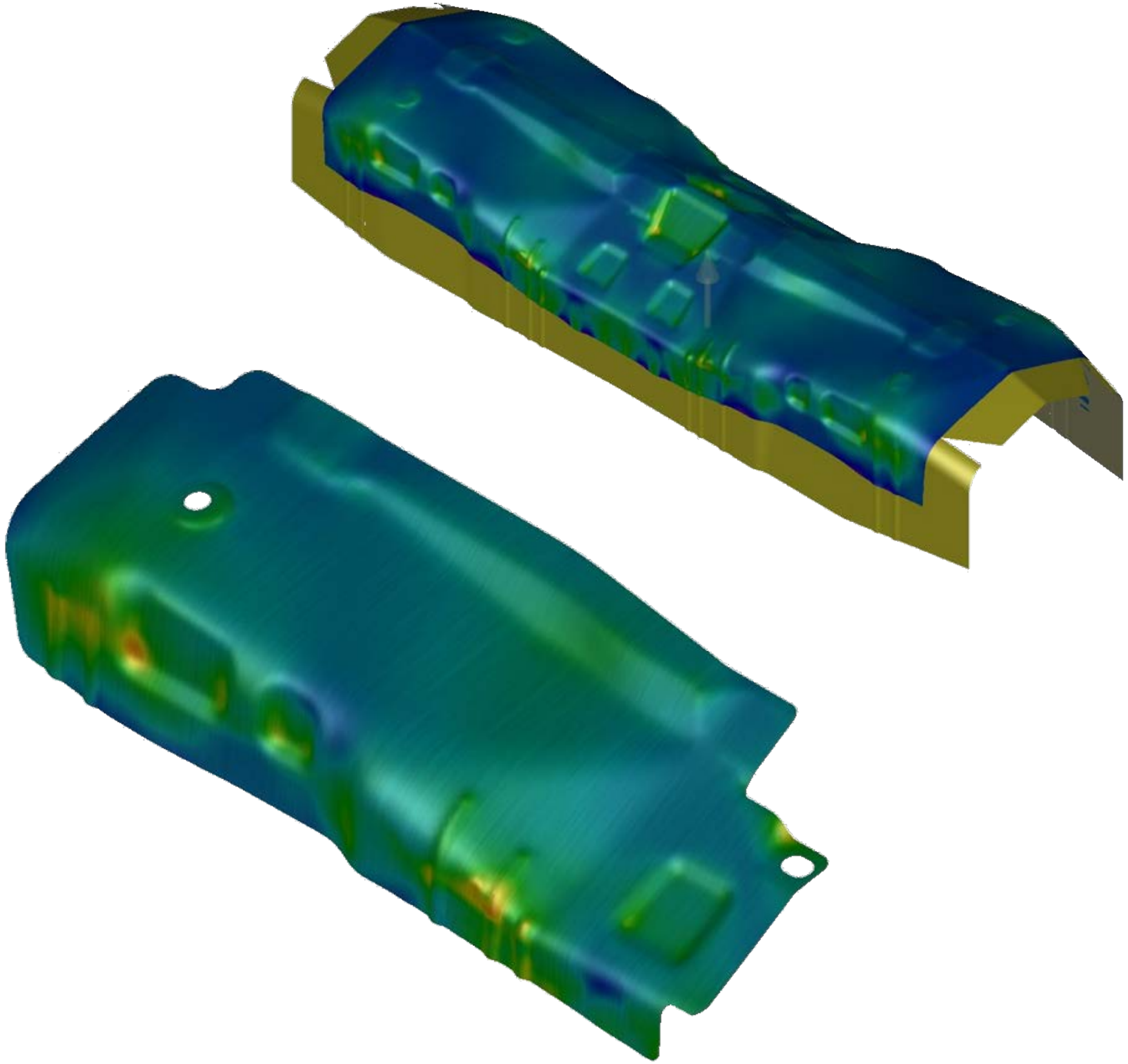


DeepForm Ltd.

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

DeepForm





Conclusion

Conclusion

- Current climate policy will not deliver in time, due to resource constraints
- A whole-systems view is essential, to identify scale and avoid burden-shifting
- Zero-emissions supply of the bulk materials will be much lower than demand in medium future
- The UK’s transformation to electric steel production creates rich upstream opportunities
- There are rich business and research opportunities in making more use of less material

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