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
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

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

Global discussions and emissions

- 1st Report of the IPCC
- United Nations Framework Convention on Climate Change established
- Kyoto Protocol at COP3
- 2nd Report of the IPCC
- 3rd Report of the IPCC
- 4th report of the IPCC wins Nobel Peace Prize
- UK Climate Change Act: 80% reduction by 2050
- 5th report of the IPCC
- Paris Agreement at COP21
- 5th report of the IPCC
- UK Climate Change Act: 100% reduction by 2050

Average temperature anomaly, Global
Global average land-sea temperature anomaly relative to the 1961-1990 average temperature.
Rising temperature and risk

"There is a 66% likelihood that the annual surface global temperature 2023 – 2027 will be more than 1.5°C above pre-industrial levels for at least one year”

(WMO, May 2023)

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

Antarctica sea-ice far lower than usual
Daily sea-ice extent in million sq km, 1979-2023

Ocean temperatures highest on record
Daily average sea surface temperature between 60° North and 60° South, 1979-2023

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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
- 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

Global drivers of global warming: what we have to stop doing

- Petrol engines
- Diesel engines
- Kerosene engines
- Gas turbine (electricity)
- Coal turbine (electricity)
- Gas burner
- Coal burner
- Cement chemistry
- Other chemistry
- Deforestation
- Fertiliser use
- Rice paddies
- Ruminants
- Waste decomposition

✓ Electric batteries / hydrogen / biofuel
✓ Non-emitting electricity / Carbon Capture & storage
✓ Direct Air Capture

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Aggregating demand for three “zero-emissions resources”
# Aggregation analysis

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

Data from multiple sources: [https://ukfires.org/blog-cop26/](https://ukfires.org/blog-cop26/)
Aggregation of plans discussed at COP26

Non-emitting electricity (TWh/yr)

CCS today: 40 Mt/yr

Maximum direct air capture

No extra biomass, minimum direct air capture

Maximum biomass

Non-emitting generation today: 9,900 TWh/yr

COP26 Policy Space

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

Years after Energy Source Begins Supplying 5% of Global Demand

Coal  Oil  Natural Gas  Modern Renewables

Share of World Energy Supply (percent)

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

Proportion electricity supply

Delay period

Growth period

-100%  -50 years  +50 years  +100%

Lab demonstration
Pilot studies at increasing scale
Connection to infrastructure
Legal and environmental permissions
Social consent after first accident
Financing needs

Proportion behaviour change

-100%  -50 years  +50 years  +100%

Lead petrol
Asbestos
Ozone
Wind
CCGT
Nuclear

Sources: Nelson & Allwood (2021)
Project examples

Nuclear Power Timeline

<table>
<thead>
<tr>
<th>Year</th>
<th>Outline policy intent</th>
<th>Contract partners agreed</th>
<th>Safety checks and licencing</th>
<th>Select, procure &amp; planning permission</th>
<th>Agree investment strategy</th>
<th>Design and equipment manufacture</th>
<th>Site preparation (inc. infrastructure)</th>
<th>Excavation</th>
<th>Construction</th>
<th>Start up</th>
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Offshore Wind Power Timeline

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<th>Year</th>
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</table>

Hinkley Point C (21.5 years)  
IAEA Project Management Guidelines (12 years)

Hornsey Project 2 (16 years)  
Deloitte project Lifecycle (13 years)

Source: Use Less Group analysis

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Preliminary result: policy will be constrained by resources
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:
  o fossil boilers,
  o fossil cars,
  o fossil planes,
  o ruminants.

https://ukfires.org/absolute-zero/
Is Absolute Zero pessimistic?
Is Absolute Zero pessimistic?
Engineering net zero (Atkins)

Annual UK Capacity Addition (GW)

Between 12-16 GW annual installed capacity for 2035
~14 GW average

Between 9-12 GW annual installed capacity for 2050
~10.5 GW average

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

… and we’re going to test the new e-carbon storage tech right under your school.

No problems! And if you need to cut teachers to pay for it, go ahead.
Academic responsibility

Average tonnes CO$_2$e per person per year

- USA
- S Korea
- Iran
- Netherlands
- China
- Germany
- Japan
- Denmark
- World
- Mexico
- UK
- France
- India
- Malawi

Flying emissions (tonnes CO$_2$e/person/year)

- 2 International conferences per year (professor)
- 2 International conferences /year (student)

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

- **Global GHG emissions**: 52 GtCO$_2$e
  - Energy/process emissions: 41 GtCO$_2$e
  - Buildings: 14 GtCO$_2$e
- **Deforestation/agriculture/decay**: 22% of energy/process emissions
- **Buildings**: 31%
- **Energy/process emissions**: 78%
- **Other**: 8%
- **Transport**: 22%
- **Industry**: 35%
- **Other**: 44%
- **Steel**: 25%
- **Cement**: 19%
- **Aluminium**: 3%
- **Plastic**: 4%
- **Paper**: 4%

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 CO₂/year

• The captured gas is used to enhance the extraction of natural gas – more methane is extracted than CO₂ 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 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

Figure simplified from Summary of findings from HYBRIT Pre-Feasibility Study 2016-2017

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 CO₂ – 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 be 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

<table>
<thead>
<tr>
<th>Technology</th>
<th>Blast furnace</th>
<th>Gas + DRI</th>
<th>Electric Arc Furnace</th>
<th>Blast Furnace + CCS</th>
<th>Hydrogen reduction</th>
</tr>
</thead>
<tbody>
<tr>
<td>Global capacity Mtonnes/yr</td>
<td>1,300</td>
<td>100</td>
<td>700 and will double</td>
<td>0.4</td>
<td>0</td>
</tr>
<tr>
<td>Emissions (tonnes CO$_2$/tonne steel)</td>
<td>2.9</td>
<td>~0.9-2.0</td>
<td>0.3</td>
<td>0.3</td>
<td>2.1</td>
</tr>
<tr>
<td>Electricity (kWh/tonne)</td>
<td>500</td>
<td>500</td>
<td>500</td>
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<td>3500</td>
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<tr>
<td>Zero emissions?</td>
<td>CCS only</td>
<td>CCS only</td>
<td>Yes</td>
<td>90% reduction, one small demonstrator</td>
<td>Yes – but huge electricity demand</td>
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</tbody>
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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.

A bright future for UK steel

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

Steel Arising

Tata Steel: Unions condemn plans for UK’s biggest steelworks

Opportunities for the UK in a transforming global steel industry
UK steel industry: new upstream opportunities

Source Nakajima et al. (2010)
UK steel industry: new upstream opportunities

- 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
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

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

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Cambridge Electric Cement

Recovered Cement Paste → Heat in EAF → Rapid cooling → Portland cement

28-day strength

<table>
<thead>
<tr>
<th>Source: Dunant et al. (under review)</th>
</tr>
</thead>
</table>

Fine ground and well-sulphated
- Commercial OPC
- Commercial LC³

Coarse ground and under-sulphated
- Commercial OPC
- Commercial LC³

100% CEC
- CEC LC³

Commercial grades: 32.5, 42.5, 52.5

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Cambridge Electric Cement
Cambridge Electric Cement

We have made 28 slags...

...which are Portland when Alite+Belite > 66%
Cambridge Electric Cement

Cost (£/tonne cement)

Emissions (tonne CO₂/tonne cement)

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Potential for UK co-recycling of steel and cement
Innovation for living well with less material
Utilisation ratio

0.75 - 1.0
0.5 - 0.75
0.25 - 0.5
0 - 0.25

Source Moynihan & Allwood (2014)

Mass fraction (%)

Source Dunant et al. (2018b)
Scrap in car-production

Source: Horton and Allwood (2017)
Folding-Shearing

1. Fold

2. Shear

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

Max thinning = 15%
Max thinning = 10%
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
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
References used in the talk:


References used in the talk:


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

www.uselessgroup.org/about-us/blog