CENTRE FOR RESEARCH INTO ENERGY DEMAND SOLUTIONS

'Let's get to work': the zero-carbon energy transition

Nick Eyre

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Aims of this talk

To persuade you that:

- Getting to zero carbon energy systems requires a major thermodynamic change: moving from using 'heat' to using 'work', and that.
- This will allow big increases in the energy efficiency energy.

To share some questions about the implications for policy and regulation.

Energy Efficiency
https://doi.org/10.1007/s12053-021-09982-9

ORIGINAL ARTICLE

From using heat to using work: reconceptualising the zero carbon energy transition

Nick Eyre

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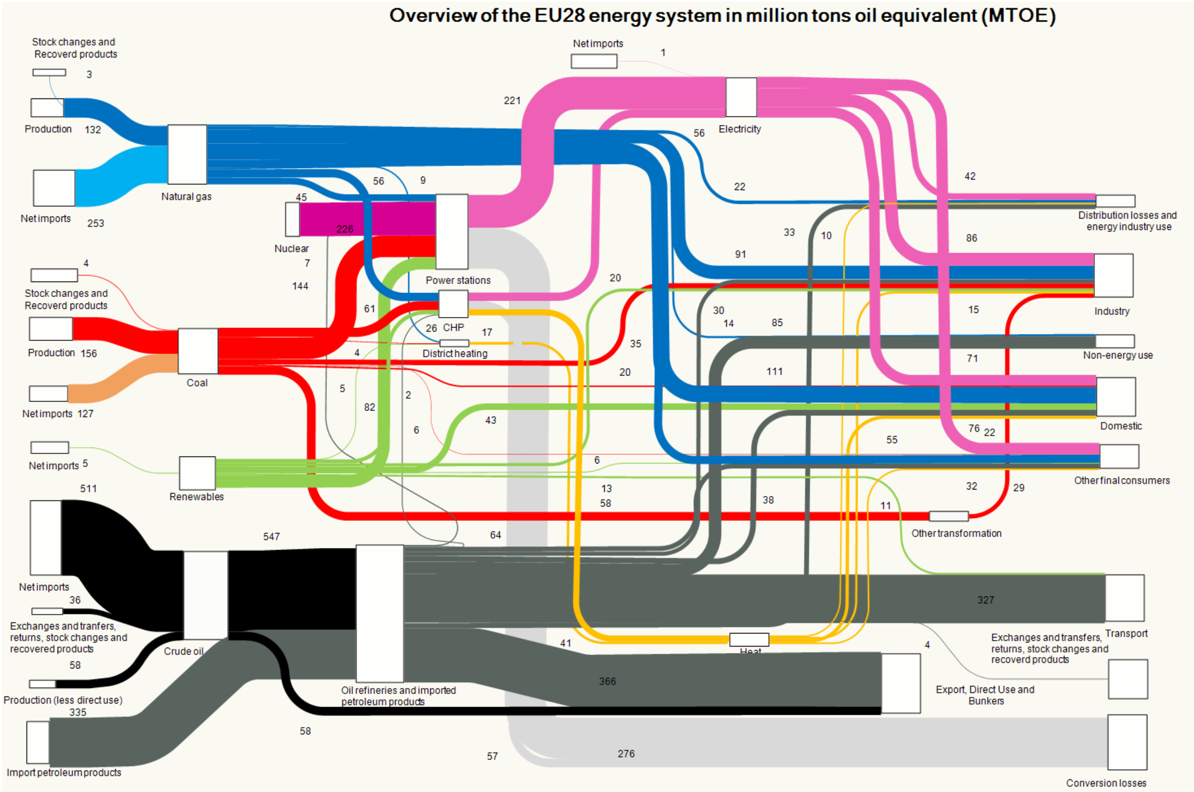
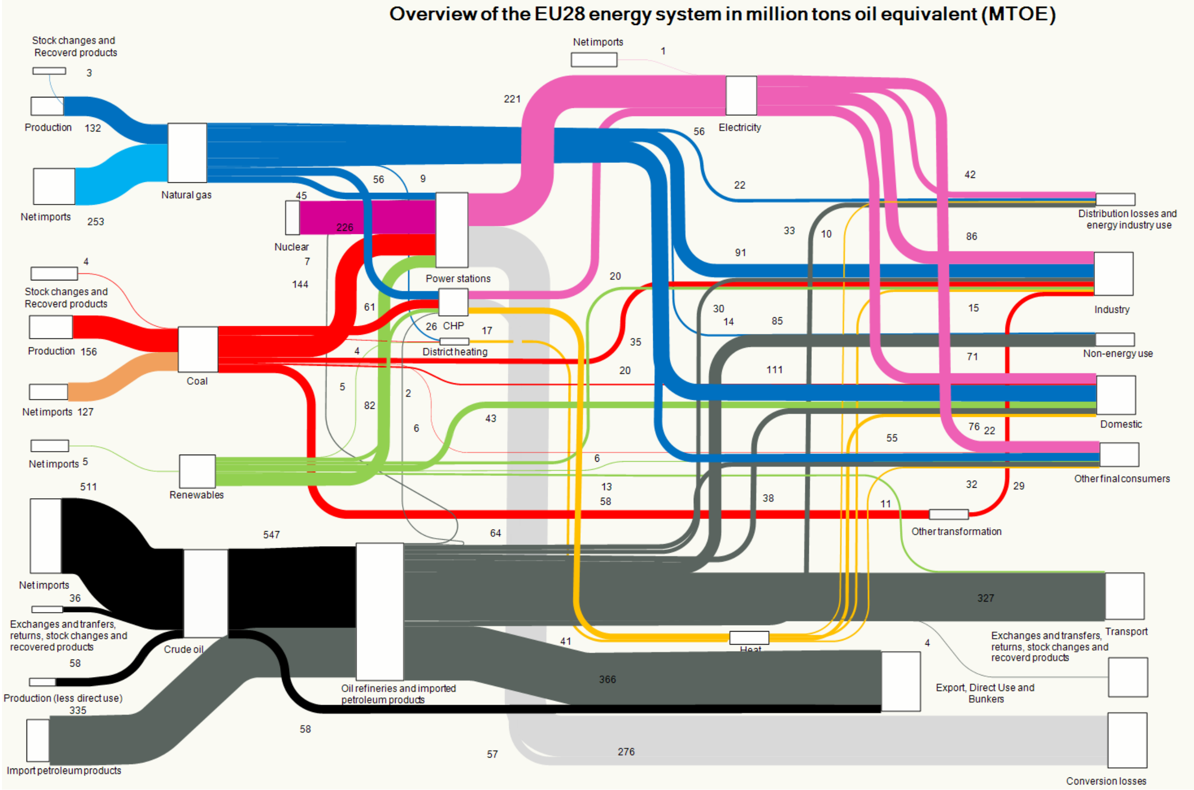
A representation of the 'energy system': A Sankey Diagram



Three problems with this representation:

1. It ignores what we use energy for.
2. It treats all types of energy as being of equal value.
3. It's too complicated to help with describing the zero carbon transition

A representation that includes what we use energy for



Energy services

Thermodynamics shows not all energy is equal

Classical thermodynamics ...is the only physical theory of universal content that ...will never be overthrown.

Albert Einstein

The relevant thermodynamics in one slide

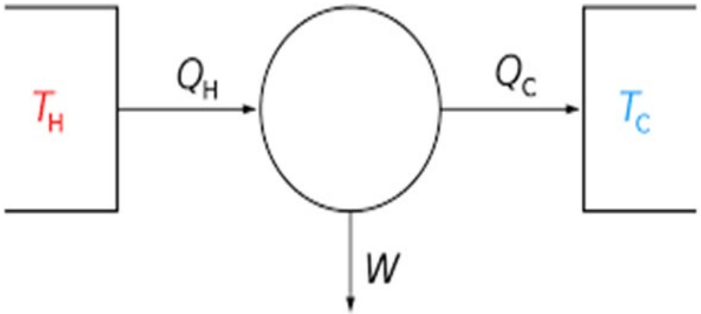
Thermodynamics deals with the relationships between heat and other forms of energy.

First Law of thermodynamics:

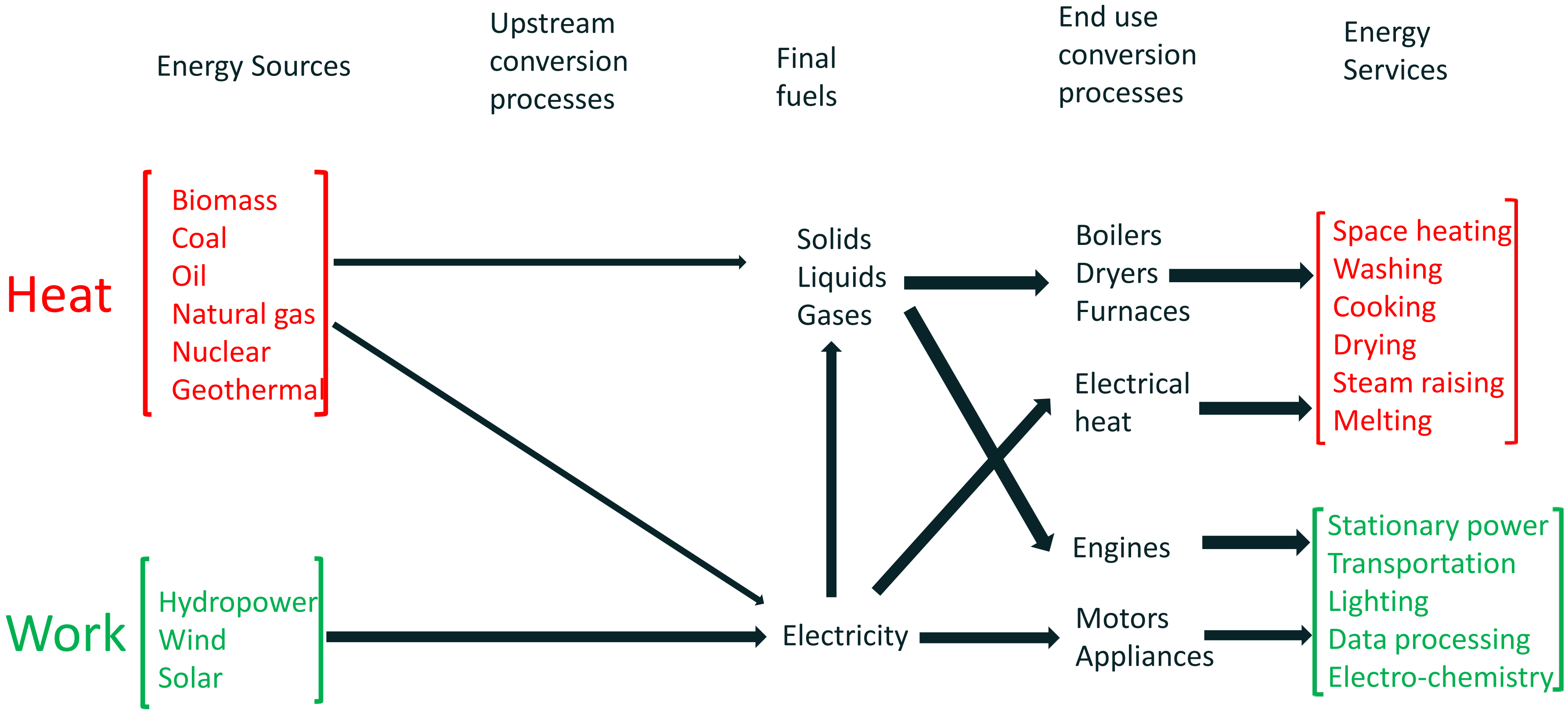
- Heat and work are both forms of energy and can be converted into each other,
- Energy is conserved.

Second law of thermodynamics

- There are limits on conversion efficiencies,
- Work can be converted into heat more efficiently than heat can be converted into work.



A simplified Sankey Diagram: Heat and Work in the Energy System



Heat and Work in a Stereotypical Pre-Industrial Energy System

Energy Sources | Upstream conversion processes | Final fuels | End use conversion processes | Energy Services

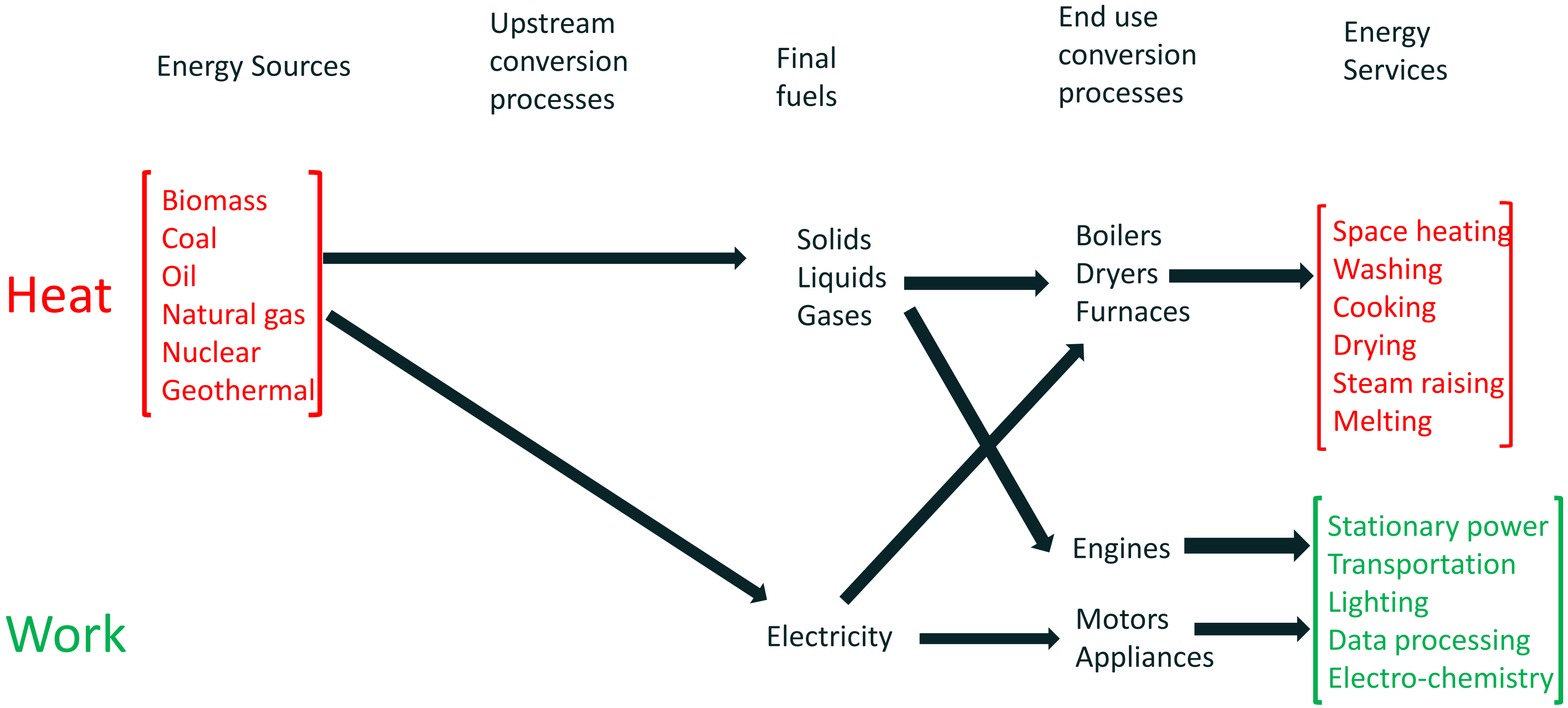
Heat

[Biomass
some fossil fuels] → Open fires
Ovens
Candles/
lamps → [Space heating
Washing
Cooking
Drying
Melting
Lighting]

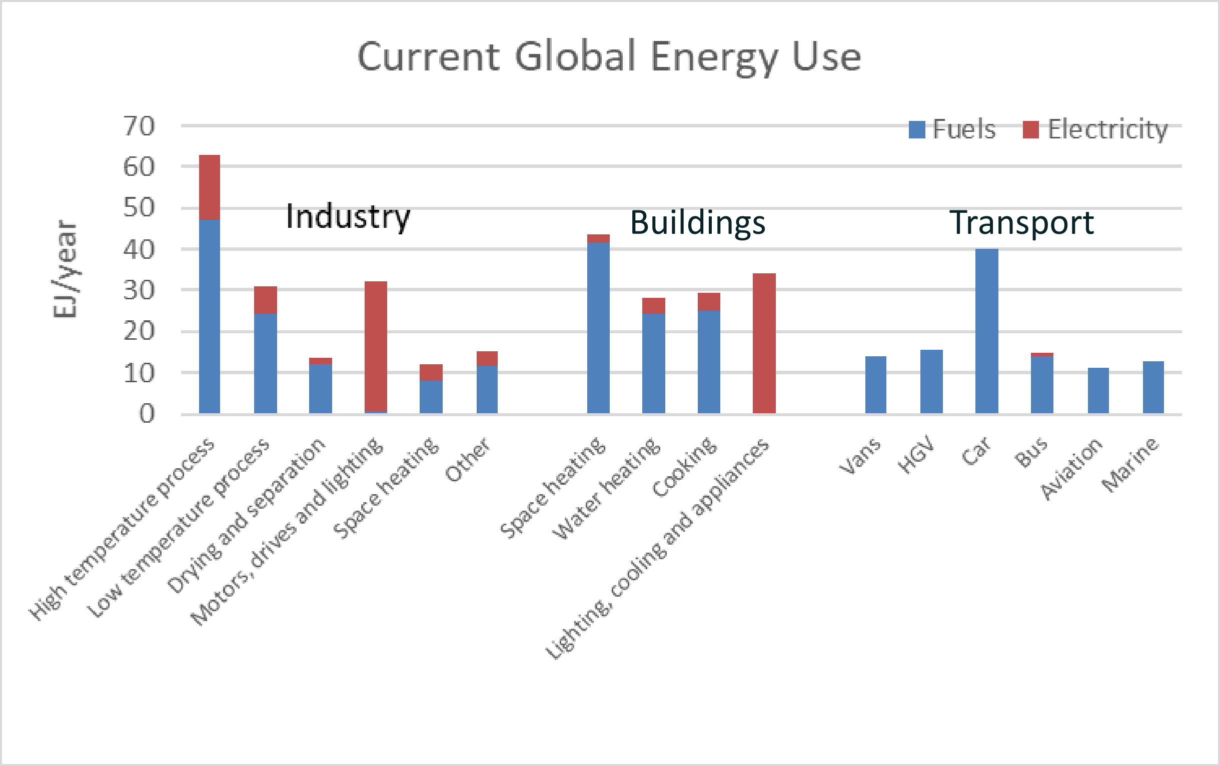
Work

[Human labour
Animals
Hydropower
Wind] → Vehicles
Small processes → [Stationary power
Transportation]

Heat and Work in a Stereotypical Industrial Energy System



Current Global Energy Use



Heat is provided largely by direct combustion of fossil fuels.

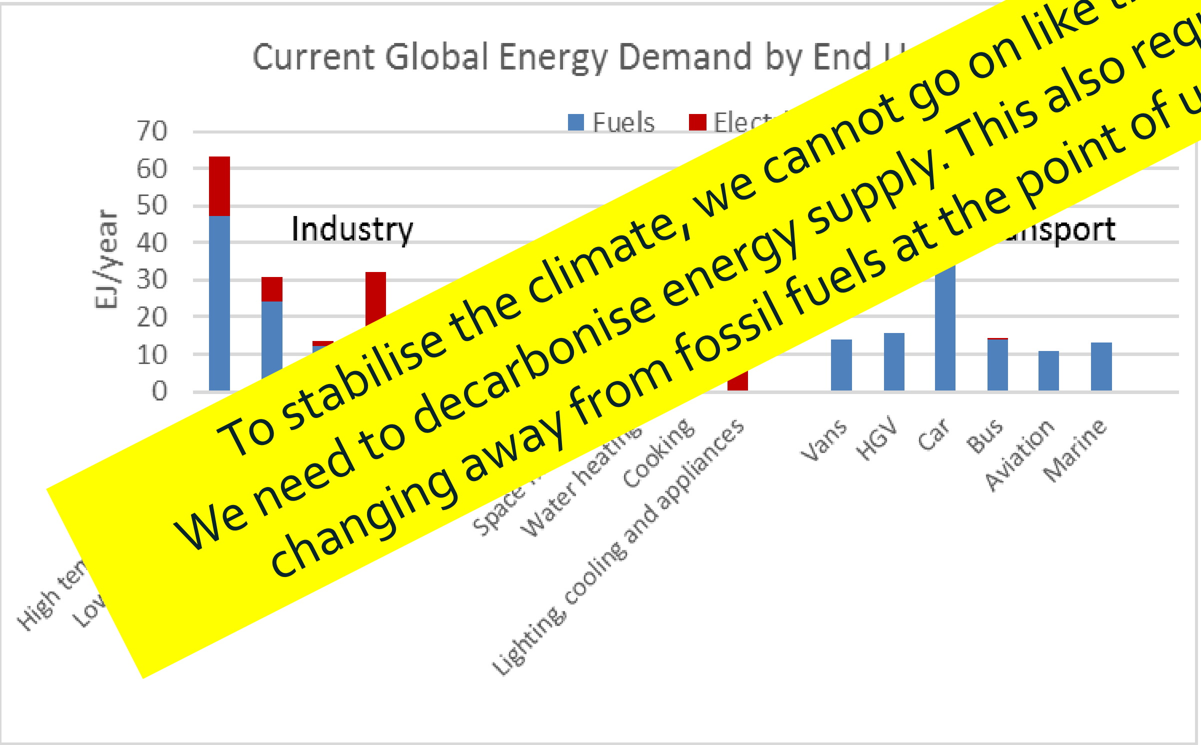
Work is largely provided by:

- Electricity in buildings and industry
- Liquid fuels in transport

Electricity is largely from fossil fuels

Electricity only provides 26% of final energy.

Current Global Energy Use



To stabilise the climate, we cannot go on like this!
We need to decarbonise energy supply. This also requires changing away from fossil fuels at the point of use.

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Work is largely provided by:

- Electricity in buildings and industry
- Liquid fuels in transport

Electricity is largely from fossil fuels.

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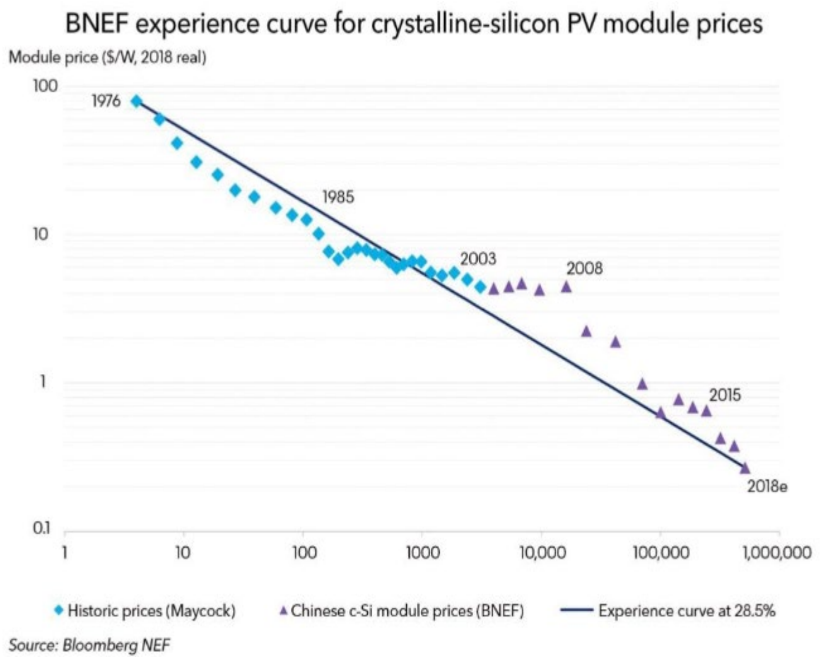
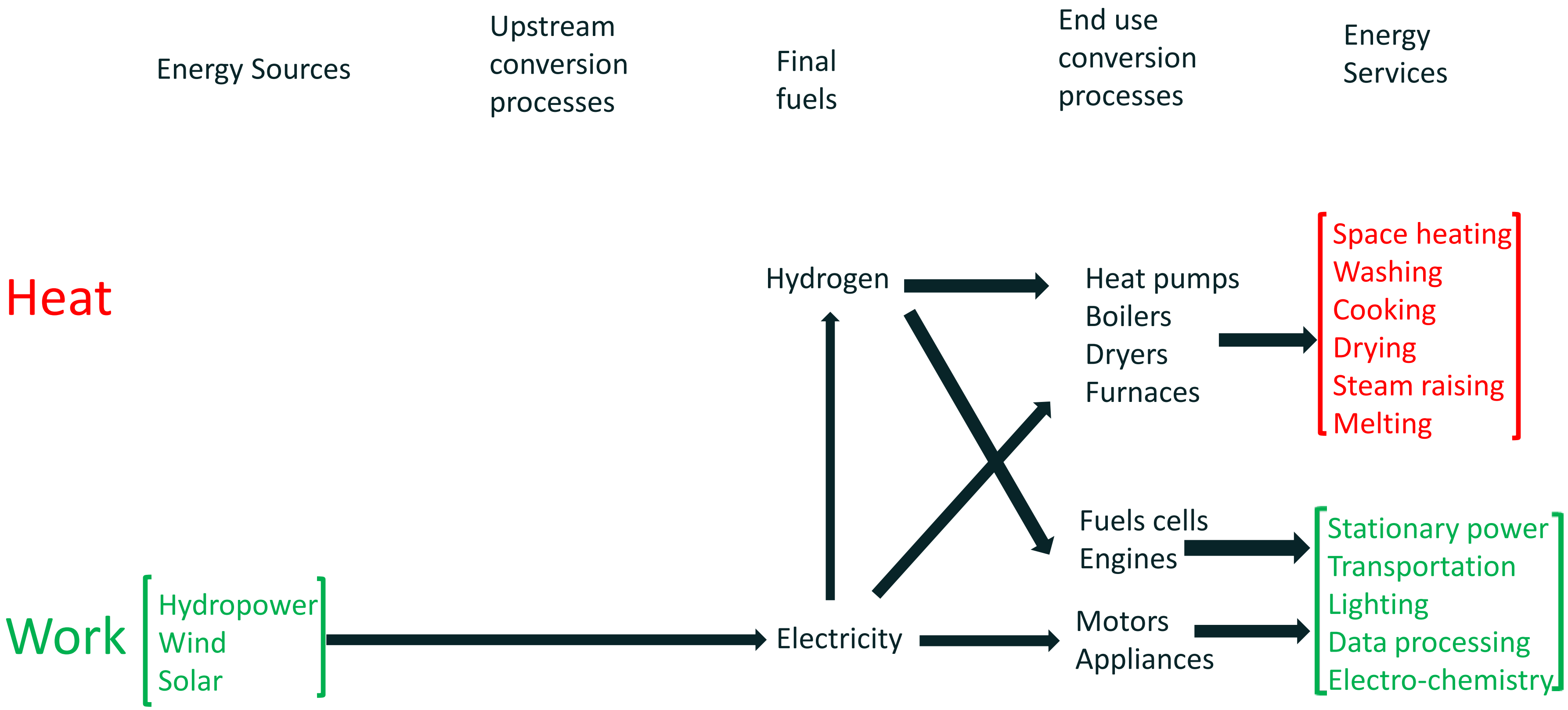
The Energy Transition as a Systemic Change in Four Steps

- **Use low carbon energy sources to replace fossil fuels in electricity generation**. These will be mainly work producing renewables energy sources – wind, solar PV and hydropower.
- Where possible, **convert end uses requiring work to electricity**. Electric vehicles are critical to this.
- Where possible **convert heating to electricity**, e.g. with heat pumps.
- Where electrification is not feasible, substitute fossil fuels with some other zero-carbon final fuel, e.g. hydrogen.



Heat and Work in a Fully Renewable Energy System



Implications of the four stages for energy efficiency

Change	Efficiency impact
Fossil fuelled power generation is largely eliminated	No impact on final energy use Increased primary energy efficiency
Work is largely supplied by electric motors rather than heat engines, e.g. electric vehicles.	Increases end use efficiency
Heat from fossil fuels is replaced by heat from electricity, mainly heat pumps	Increases end use efficiency
Fossil fuels are replaced by manufactured fuels, e.g. hydrogen, e.g. for freight and industry	Increases end use efficiency reduces the efficiency of fuel production

A thought experiment:
how much will this change global demand for energy?

- It's clear that changing from a heat driven energy system to a work driven energy system enables efficiency improvements.
- But by how much?

A thought experiment:
how much will this change global demand for energy?

Assumptions

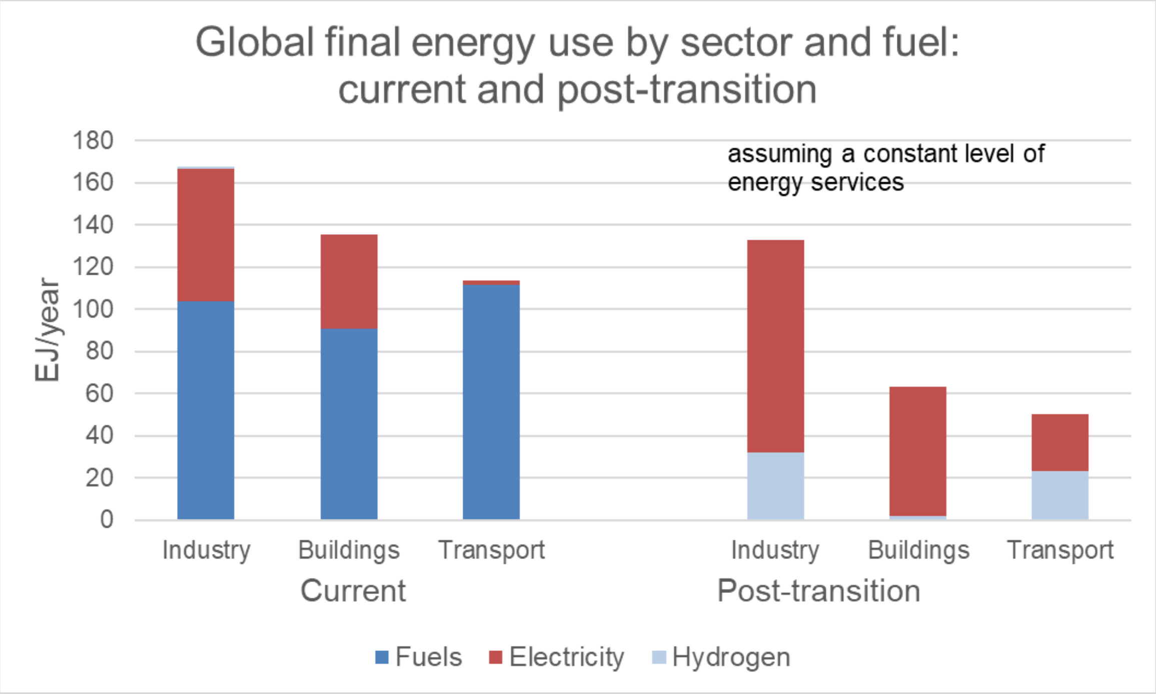
- At some point in the future 100% of energy comes from work producing, zero-carbon energy sources.
- End use is electrified where possible.
- Otherwise energy is supplied by electrolytic hydrogen.
- Demand for energy services is constant.
- The only energy efficiency changes are those enabled by fuel switching.

The thought experiment methodology

Uses existing literature to

- Divide global energy demand into categories of energy use designed to provide different energy services (e.g. space heating, freight transport)
- In each case, determine the share of demand which can be electrified and assume the remainder will be supplied by hydrogen, then
- For each end use / fuel combination estimate
  - final energy conversion efficiencies in the existing system
  - final conversion efficiencies in a post transition system, and
  - by subtraction, the change in demand.
- Aggregate across categories to calculate global totals.

Top line results of the thought experiment



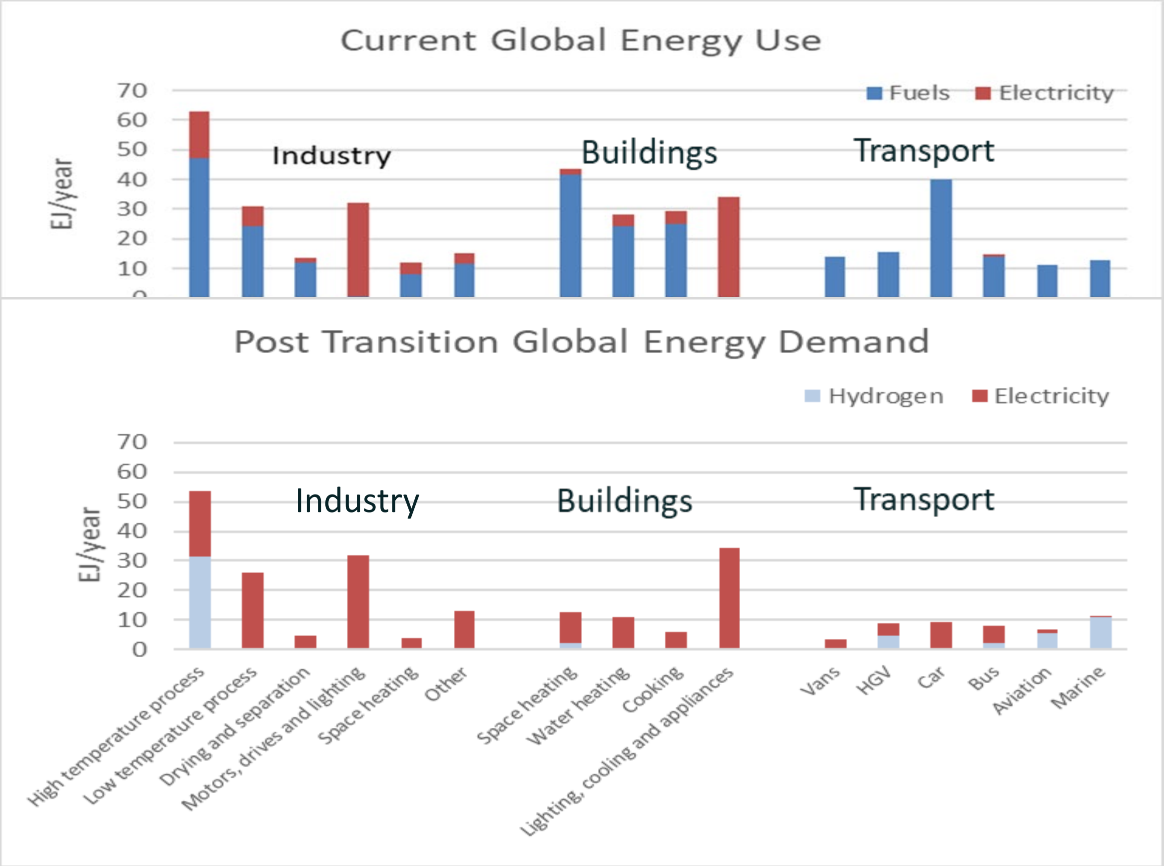
Assumptions

- 100% of post-transition energy comes from hydropower, wind and solar.
- Non-electric final energy is supplied by electrolytic hydrogen.
- Constant energy service demands.
- No efficiency improvement other than in end use conversion.

Results

- Final energy demand reduced 40%.
- > 50% in buildings and transport
- Electricity's share of final demand rises from 26% to 77%.

More detailed results by end use category

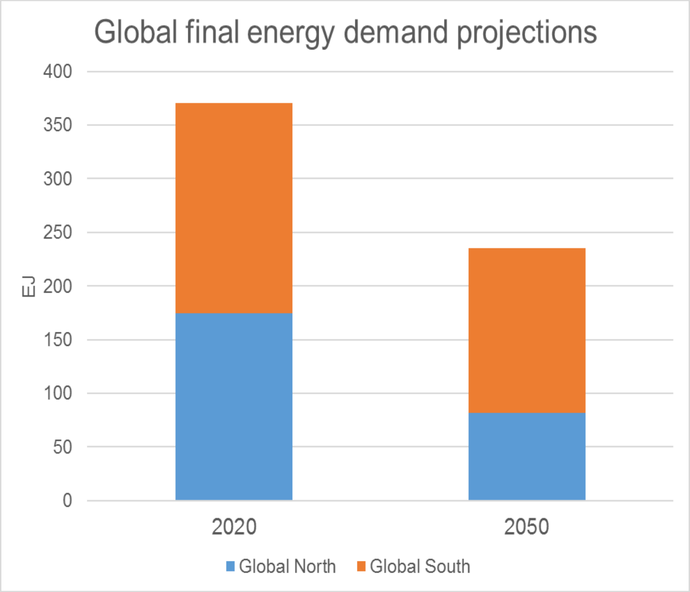


Key insights

- Energy demand falls in all categories except those that are already 100% electrified.
- Demand falls most for road vehicles, cooking, and heating in buildings.
- Much of the change is driven by widespread use of electric vehicles and heat pumps.
- Use of hydrogen is concentrated in ‘hard to electrify’ sectors – industrial processes, aviation, marine and heavy freight.

What might this mean in the real world?

- Conversion efficiency is not the only variable
- Other efficiency changes can be large, notably
  - Improved building fabric
  - Modal switch to more efficient transport
- Some social changes may reduce demand for some energy services, e.g. through
  - Less use of materials in a 'circular economy'
  - Digitally enabled 'sharing economy'
- Rising incomes will continue to drive demand rising demand for services:
  - for basic services in poorer communities, and also
  - for luxury goods/services, e.g. aviation.



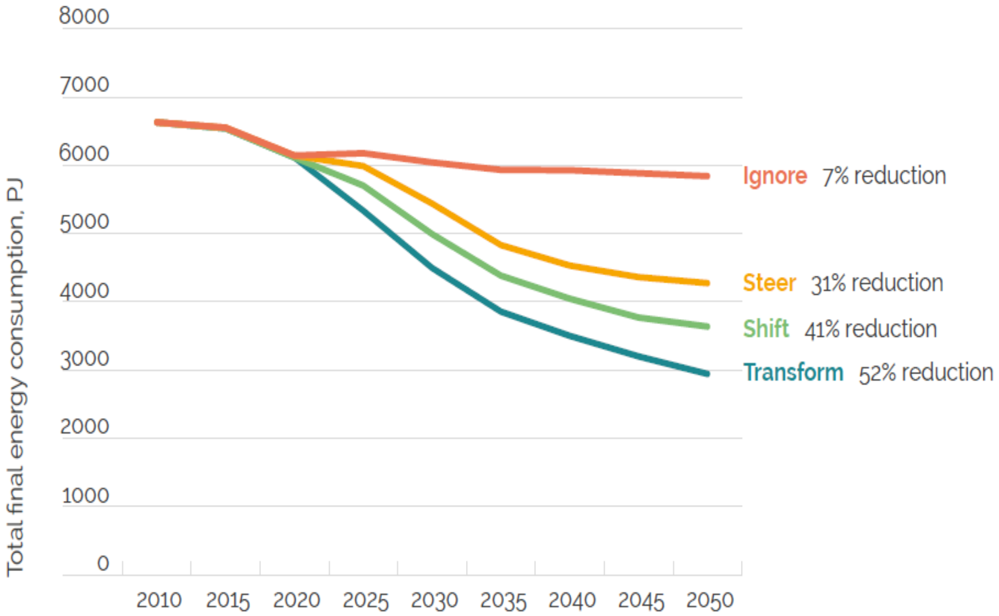
Grubler et al (2018) A low energy demand scenario for meeting the 1.5 C target and sustainable development goals without negative emission technologies. *Nature Energy*, *3*(6), 515-527.

The UK as a case study

Energy use falls 30%-50% in delivering net zero by 2050.

Without social and behavioural change, cost effective energy efficiency increases reduce demand by 30%. This is largely due to efficiency improvements of electrification.

Adding in possible social and behavioural changes increases the potential to above 50%.



Barrett et al (2021) The role of energy demand reduction in achieving net-zero in the UK. CREDS

Conclusions

- In "post carbon" energy systems, the main energy sources will produce work not heat.
- Final energy will be dominated by electricity and (to a lesser extent) hydrogen, with major changes in how society uses energy.
- Key technologies (e.g. electric vehicles, heat pumps) will allow much more efficient use of energy – by about 40%.
- Shifts to renewables and energy efficiency are not independent; there are strong synergies.

Some policy questions

New challenges for policy and regulation in a world where transportation and heating need to be more electrified.

How do we:

1. incentivise efficient options in the use of electricity?
2. avoid increasing peak loads?