Hydrogen as part of a future whole energy system

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Overview

- The Energy Systems Catapult and whole-systems thinking
- Energy Systems Modelling Environment (ESME)
- The role of hydrogen in the low carbon energy transition

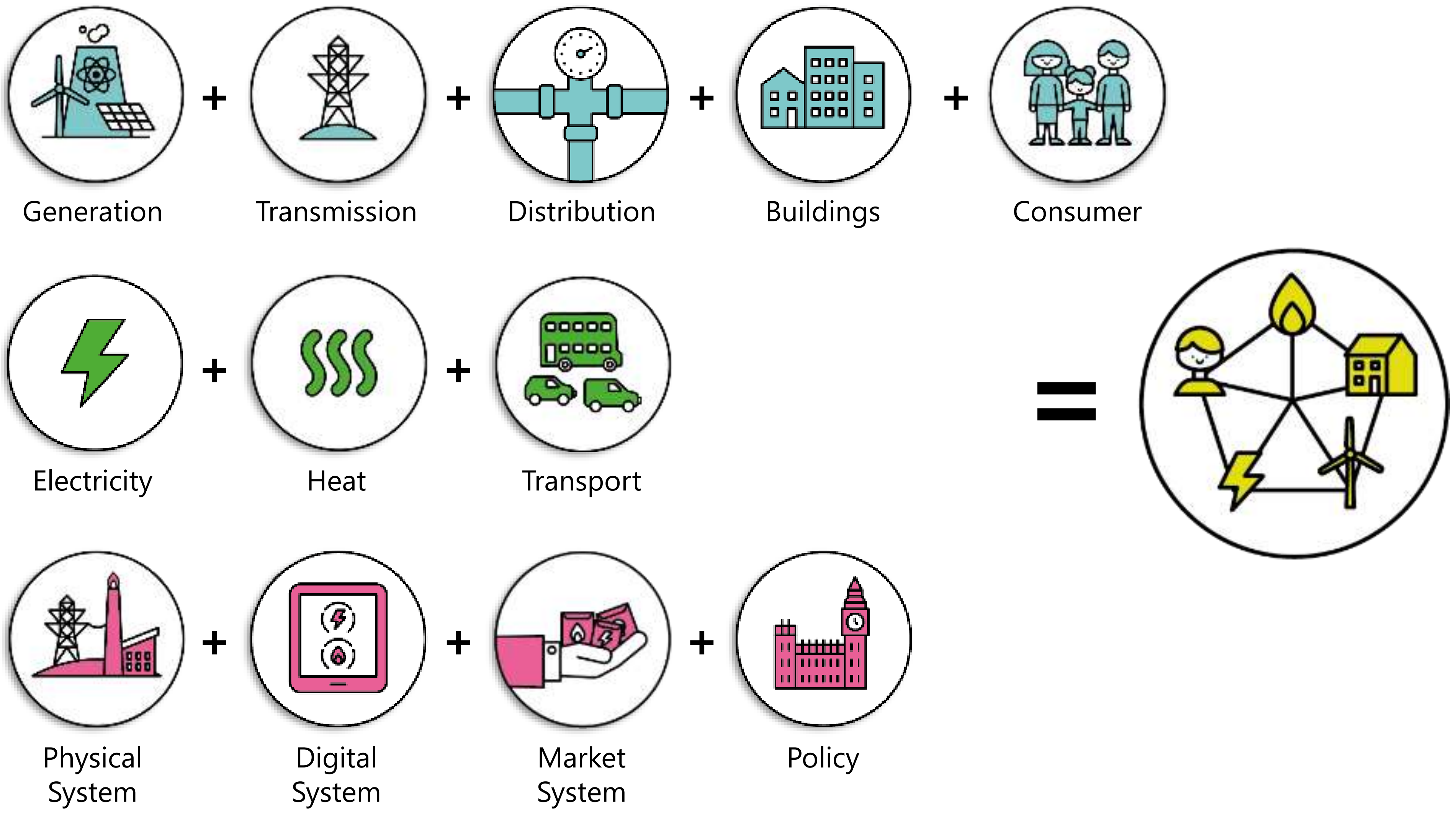
What is whole systems thinking?

CATAPULT
Energy Systems

Joining up the system from sources of energy to the consumer

Breaking down silos between energy vectors

Joining up physical requirements of the system, with policy, market and digital arrangements

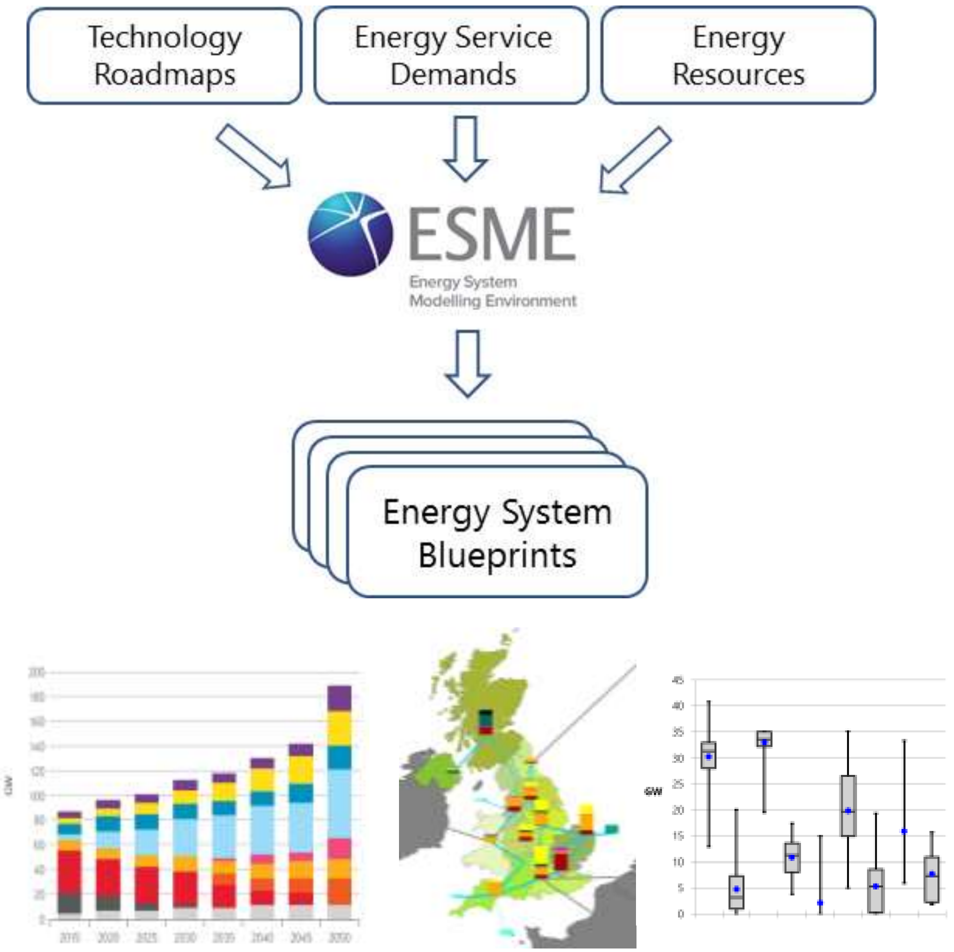


Energy System Modelling Environment (ESME)

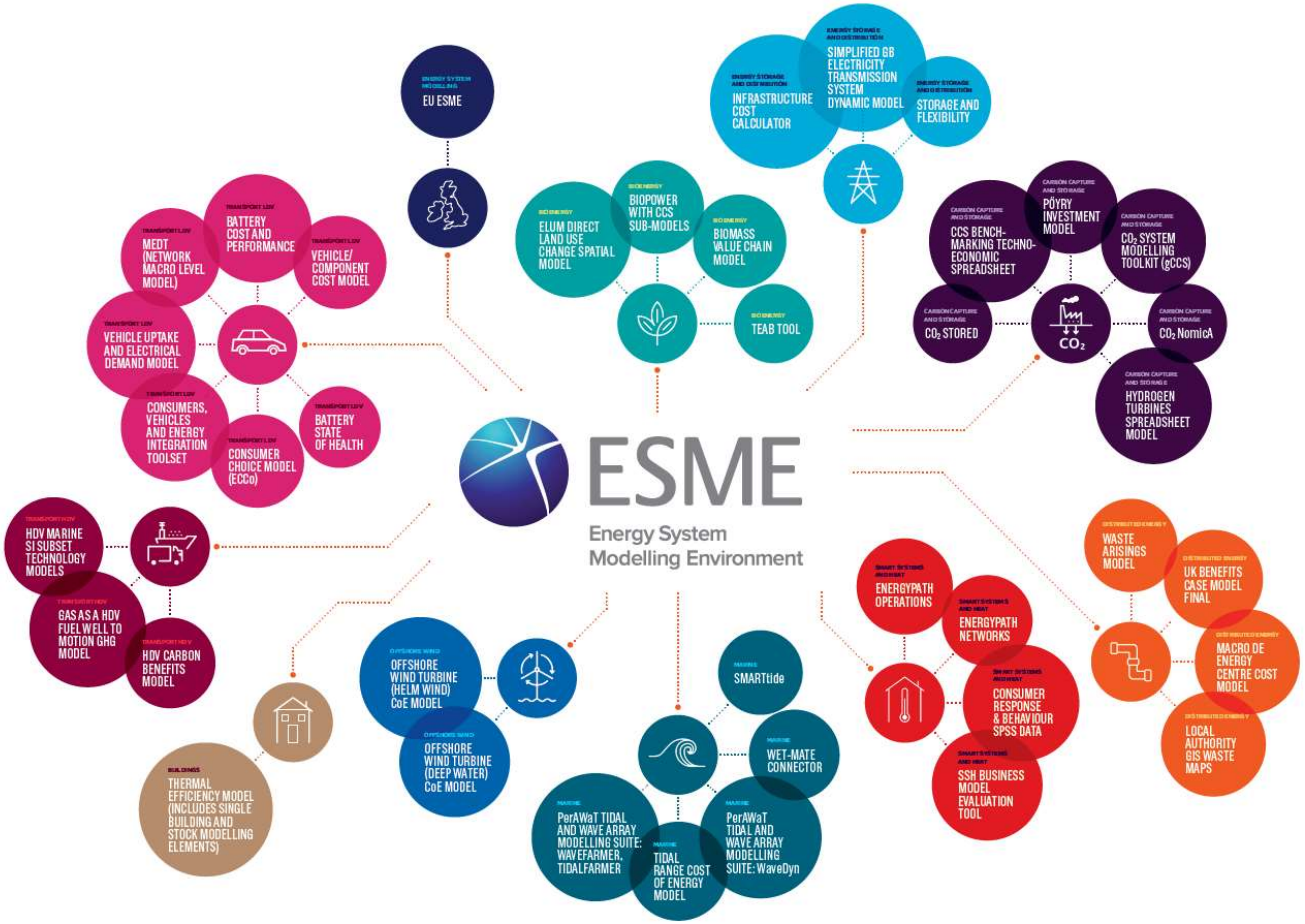
- Whole energy system approach to 2050
- Deployment and utilisation of ~ 400 technologies
- Least cost optimisation
- Probabilistic treatment of uncertainties
- Spatial and temporal resolution sufficient for system engineering

Typical questions:

- What might be ‘no regret’ tech choices?
- What is the total system cost of meeting defined targets?
- How “valuable” are individual techs at the system level?
- What is the impact of delaying deployment of key techs?



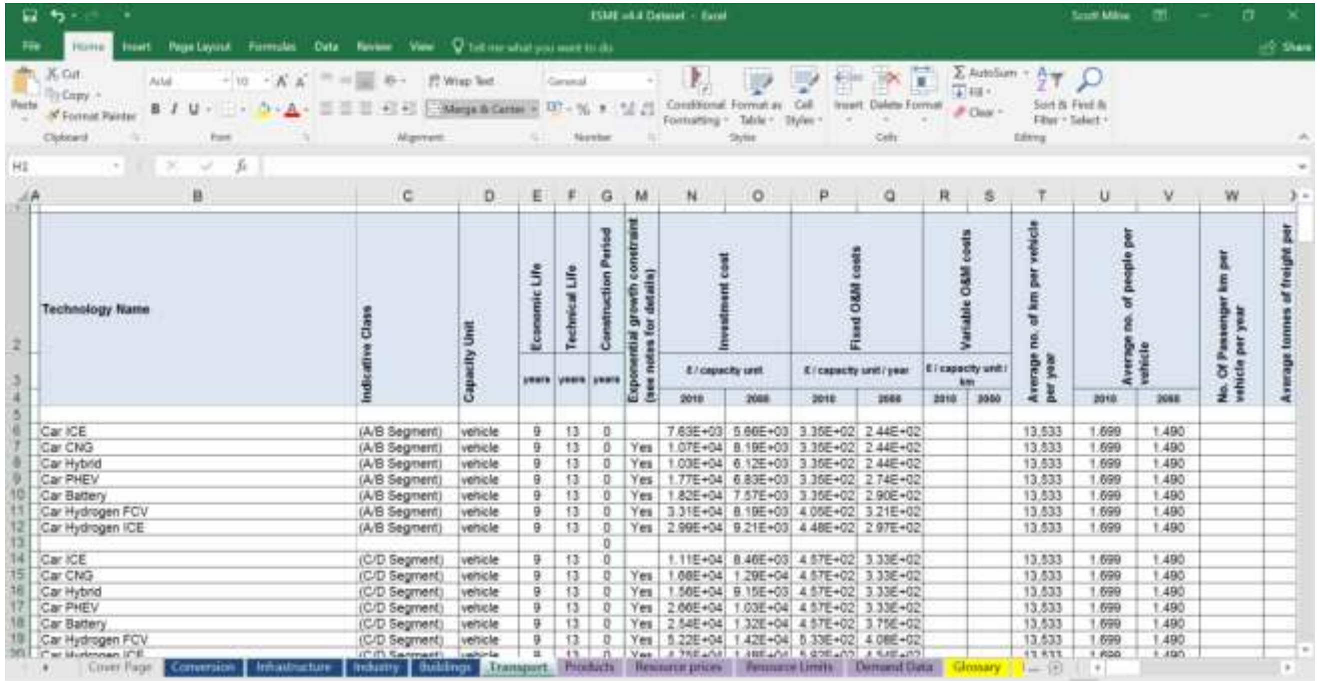
More details of the capabilities and structure of the ESME model can be found at eti.co.uk/programmes/strategy/esme. This includes a file containing the standard input data assumptions used within the model.



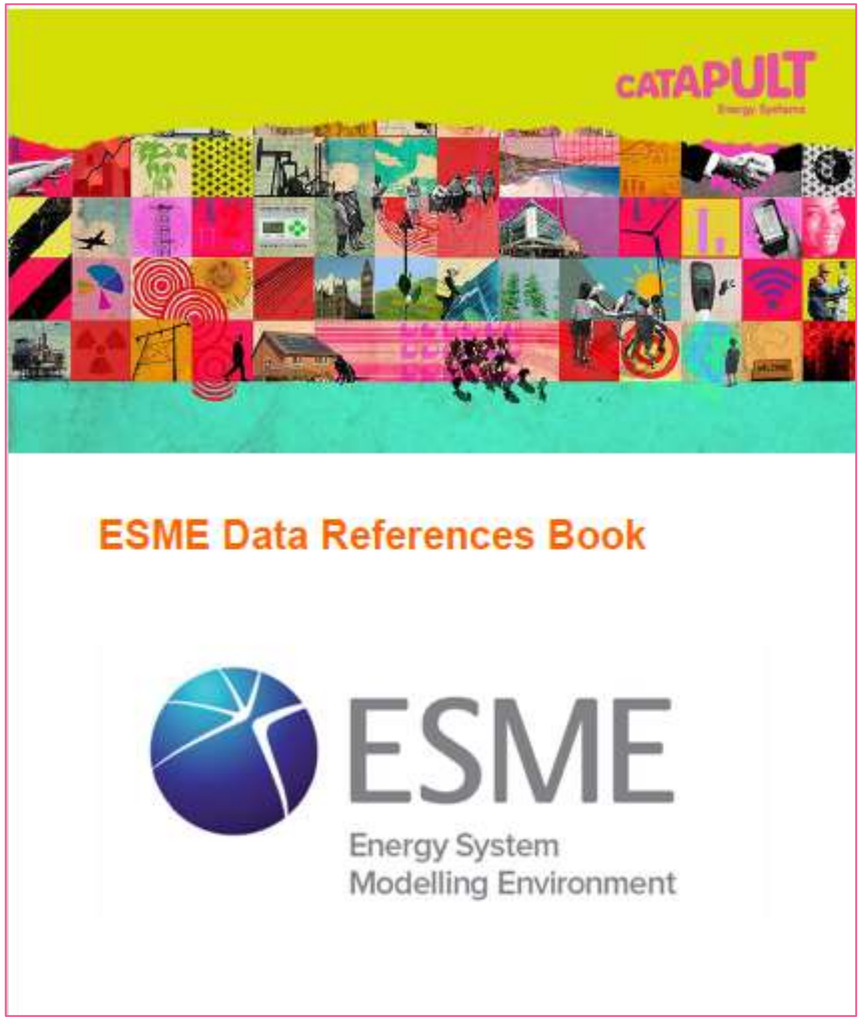
ESME
Energy System Modelling Environment
EU ESME
INFRASTRUCTURE COST CALCULATOR
SIMPLIFIED GB ELECTRICITY TRANSMISSION SYSTEM DYNAMIC MODEL
STORAGE AND FLEXIBILITY
ELUM DIRECT LAND USE CHANGE SPATIAL MODEL
BIOPOWER WITH CCS SUB-MODELS
BIOMASS VALUE CHAIN MODEL
TEAB TOOL
CCS BENCH-MARKING TECHNO-ECONOMIC SPREADSHEET
PÖYRY INVESTMENT MODEL
CO_2 SYSTEM MODELLING TOOLKIT (gCCS)
CO_2 STORED
CO_2
CO_2 NomicA
HYDROGEN TURBINES SPREADSHEET MODEL
MEDT (NETWORK MACRO LEVEL MODEL)
BATTERY COST AND PERFORMANCE
VEHICLE/ COMPONENT COST MODEL
VEHICLE UPTAKE AND ELECTRICAL DEMAND MODEL
CONSUMERS, VEHICLES AND ENERGY INTEGRATION TOOLSET
CONSUMER CHOICE MODEL (ECCo)
BATTERY STATE OF HEALTH
HDV MARINE SI SUBSET TECHNOLOGY MODELS
GAS AS A HDV FUEL WELL TO MOTION GHG MODEL
HDV CARBON BENEFITS MODEL
THERMAL EFFICIENCY MODEL (INCLUDES SINGLE BUILDING AND STOCK MODELLING ELEMENTS)
OFFSHORE WIND TURBINE (HELM WIND) CoE MODEL
OFFSHORE WIND TURBINE (DEEP WATER) CoE MODEL
SMARTtide
WET-MATE CONNECTOR
PerAWaT TIDAL AND WAVE ARRAY MODELLING SUITE: WAVEFARMER, TIDALFARMER
TIDAL RANGE COST OF ENERGY MODEL
PerAWaT TIDAL AND WAVE ARRAY MODELLING SUITE: WaveDyn
ENERGYPATH OPERATIONS
ENERGYPATH NETWORKS
CONSUMER RESPONSE & BEHAVIOUR SPSS DATA
SSH BUSINESS MODEL EVALUATION TOOL
WASTE ARISINGS MODEL
UK BENEFITS CASE MODEL FINAL
MACRO DE ENERGY CENTRE COST MODEL
LOCAL AUTHORITY GIS WASTE MAPS

ESME Dataset and Reference book available online

https://www.eti.co.uk/programmes/strategy/esme



Technology Name	Indicative Class	Capacity Unit	Economic Life (years)	Technical Life (years)	Construction Period (years)	Exponential growth constraint (see notes for details)	Investment cost £ / capacity unit 2010	Investment cost £ / capacity unit 2050	Fixed O&M costs £ / capacity unit / year 2010	Fixed O&M costs £ / capacity unit / year 2050	Variable O&M costs £ / capacity unit / km 2010	Variable O&M costs £ / capacity unit / km 2050	Average no. of km per vehicle per year	Average no. of people per vehicle 2010	Average no. of people per vehicle 2050	No. Of Passenger km per vehicle per year	Average tonnes of freight per
Car ICE	(A/B Segment)	vehicle	9	13	0		7.63E+03	5.66E+03	3.36E+02	2.44E+02			13,533	1.699	1.490		
Car CNG	(A/B Segment)	vehicle	9	13	0	Yes	1.07E+04	8.19E+03	3.36E+02	2.44E+02			13,533	1.699	1.490		
Car Hybrid	(A/B Segment)	vehicle	9	13	0	Yes	1.03E+04	6.12E+03	3.36E+02	2.44E+02			13,533	1.699	1.490		
Car PHEV	(A/B Segment)	vehicle	9	13	0	Yes	1.77E+04	6.83E+03	3.36E+02	2.74E+02			13,533	1.699	1.490		
Car Battery	(A/B Segment)	vehicle	9	13	0	Yes	1.82E+04	7.57E+03	3.36E+02	2.90E+02			13,533	1.699	1.490		
Car Hydrogen FCV	(A/B Segment)	vehicle	9	13	0	Yes	3.31E+04	8.19E+03	4.06E+02	3.21E+02			13,533	1.699	1.490		
Car Hydrogen ICE	(A/B Segment)	vehicle	9	13	0	Yes	2.99E+04	9.21E+03	4.48E+02	2.97E+02			13,533	1.699	1.490		
					0												
Car ICE	(C/D Segment)	vehicle	9	13	0		1.11E+04	8.46E+03	4.57E+02	3.33E+02			13,533	1.699	1.490		
Car CNG	(C/D Segment)	vehicle	9	13	0	Yes	1.68E+04	1.29E+04	4.57E+02	3.33E+02			13,533	1.699	1.490		
Car Hybrid	(C/D Segment)	vehicle	9	13	0	Yes	1.56E+04	9.15E+03	4.57E+02	3.33E+02			13,533	1.699	1.490		
Car PHEV	(C/D Segment)	vehicle	9	13	0	Yes	2.66E+04	1.03E+04	4.57E+02	3.33E+02			13,533	1.699	1.490		
Car Battery	(C/D Segment)	vehicle	9	13	0	Yes	2.54E+04	1.32E+04	4.57E+02	3.75E+02			13,533	1.699	1.490		
Car Hydrogen FCV	(C/D Segment)	vehicle	9	13	0	Yes	5.22E+04	1.42E+04	5.33E+02	4.08E+02			13,533	1.699	1.490		



The role of hydrogen in ESC’s scenarios for a low carbon energy transition

- **Clockwork & Patchwork:** two distinct pathways for the whole UK energy system
- Bound by Climate Change Act targets: 80% GHG reduction by 2050
- Building on many years of modelling, analysis and scenario development using ESME (original scenarios launched in 2015)

www.eti.co.uk/options-choices-actions-2018/

Model (*and scenario*) updates since 2015

Socio-economic assumptions (latest govt projections)

Carbon Capture & Storage (earliest deployment pushed back)

Nuclear (added small modular reactors)

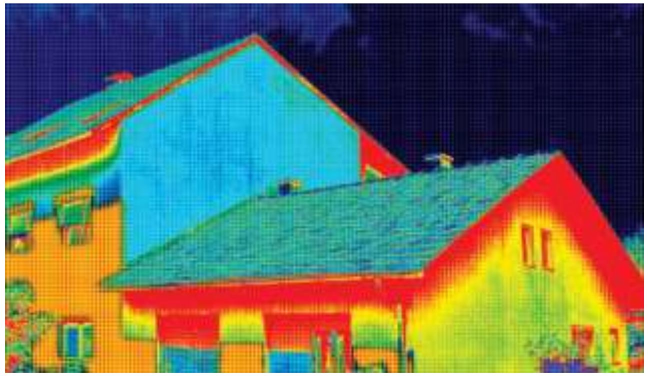
Solar PV (historic capacity & costs updated)

Wind (historic capacity & costs updated)

Low carbon vehicles (historic capacity & EV costs updated, *2040 ICE ban in scenarios*)

Hydrogen for heat (*added to Clockwork*)

Hydrogen for Heat



Increasing interest in using hydrogen for heat in buildings, using existing gas distribution network.

Requires joined up (i.e. whole system) approach to hydrogen production, storage, transmission, distribution.

Now able to model this in ESME (alongside hydrogen in industry and transport). ESME's regional (and temporal) resolution is key to understanding infrastructure needs.

Given the necessary coordination, hydrogen for heat is available in Clockwork, but not Patchwork

CLOCKWORK

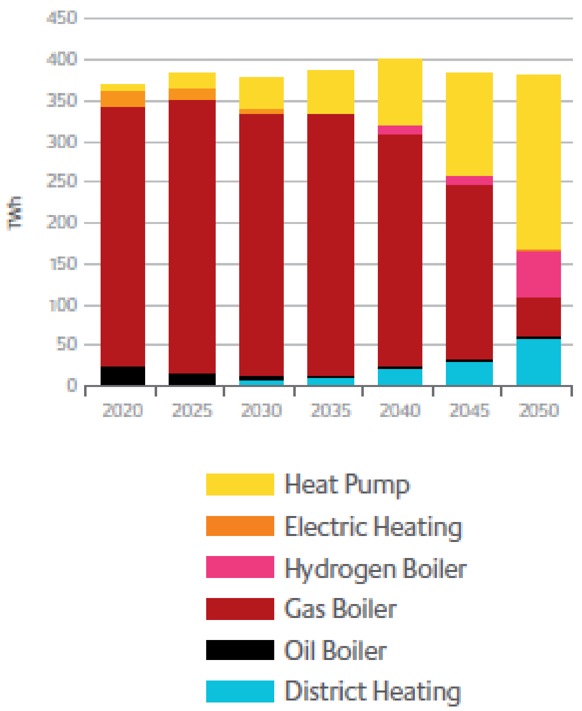
→ In Clockwork, coordination by central government means long-term investment in strategic energy infrastructure.

PATCHWORK

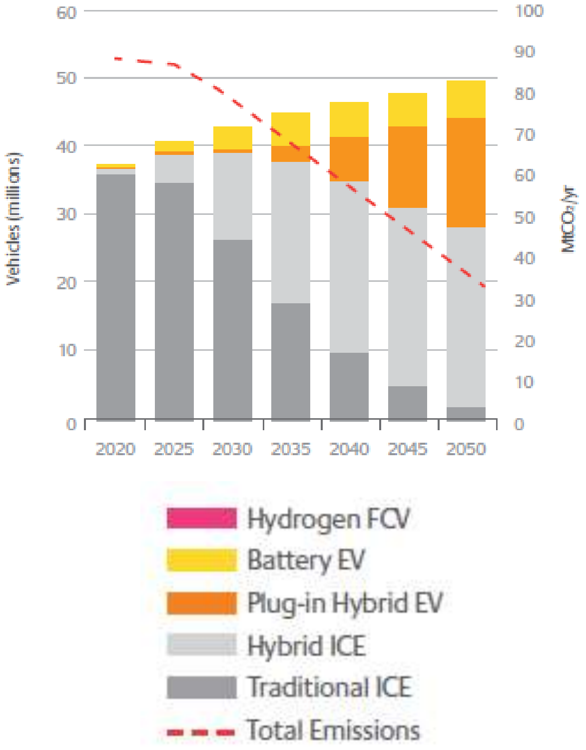
→ With central government providing less strategic coordination, a patchwork of distinct energy strategies develops at a regional/sectoral level.

(~160 TWh of hydrogen in 2050)

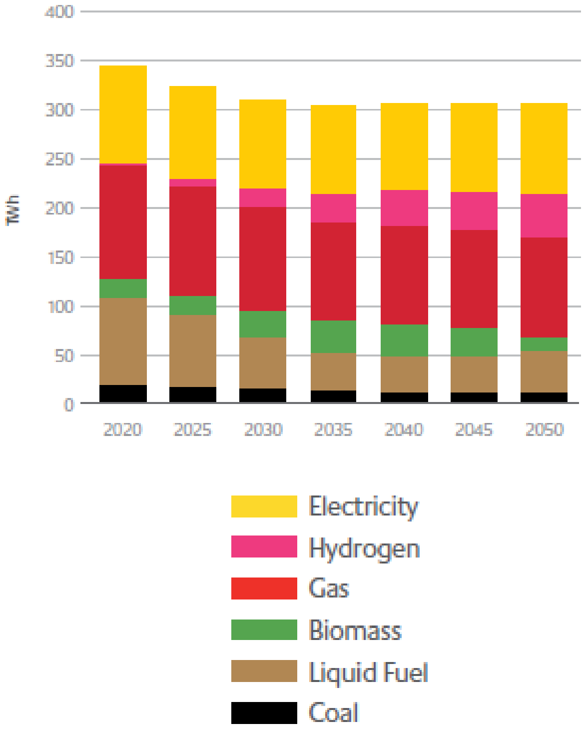
Space Heat Production (TWh)



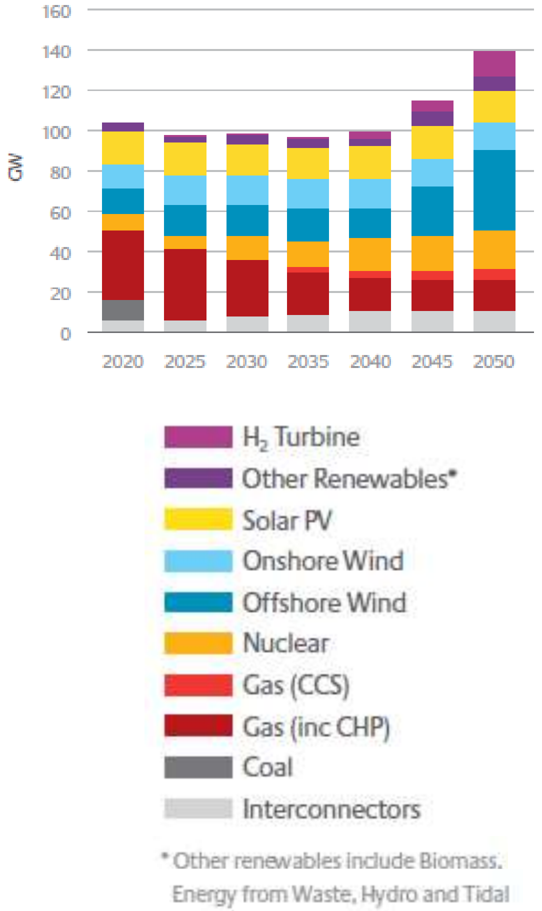
Road Transport Fleet



Industrial Energy Consumption



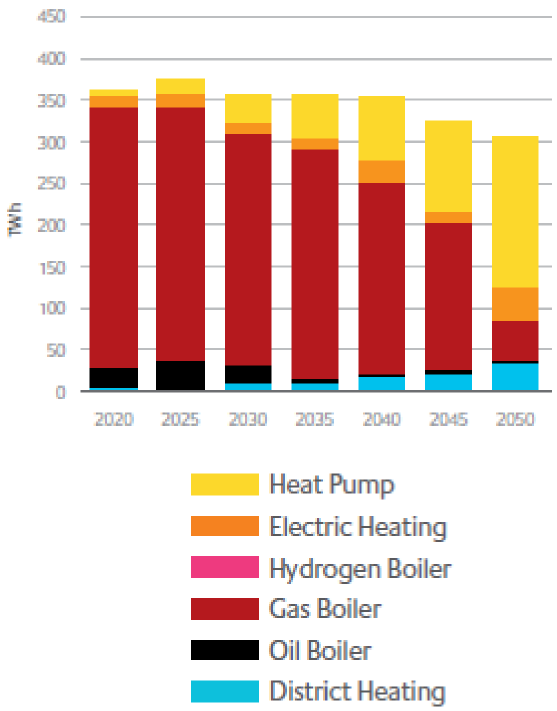
Electricity Generation Capacity



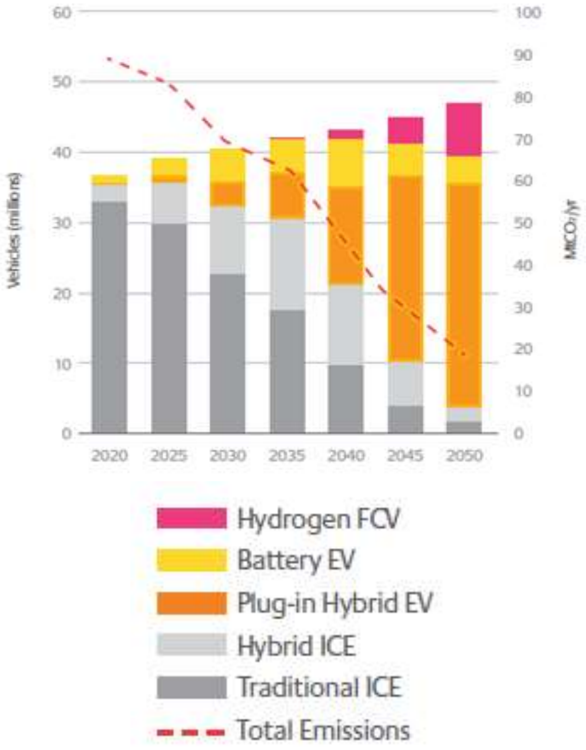
- All of the hydrogen production relies on CCS (including biomass gasification which also delivers negative emissions into the system)

(~90 TWh of hydrogen in 2050)

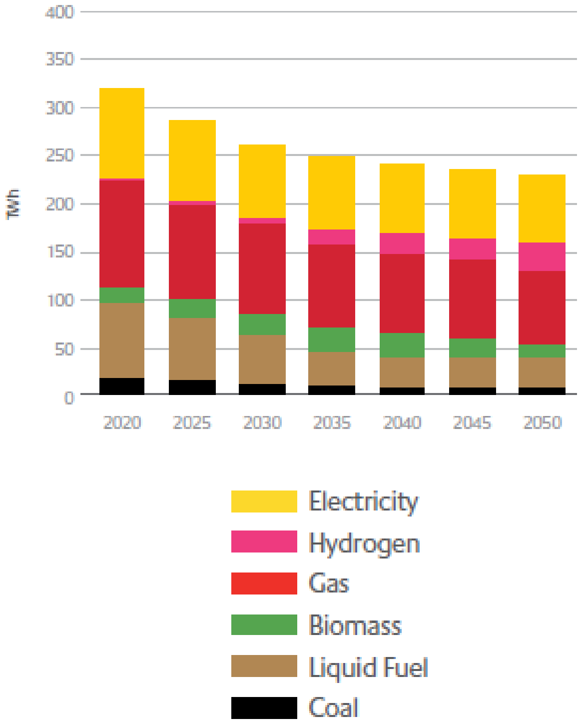
Space Heat Production (TWh)



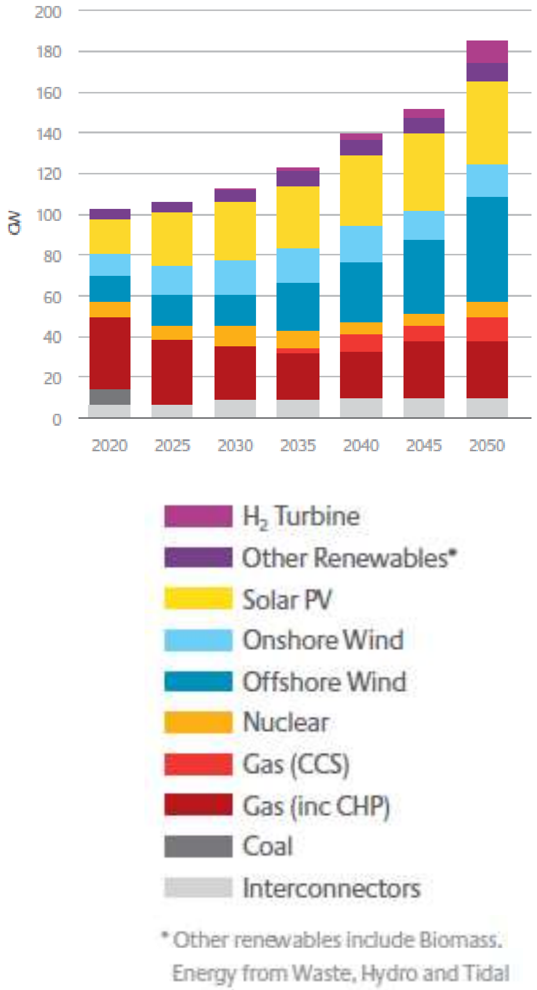
Road Transport Fleet



Industrial Energy Consumption



Electricity Generation Capacity



- All of the hydrogen production relies on CCS (including biomass gasification which also delivers negative emissions into the system)

Alternative view - “High Hydrogen” (~530 TWh of hydrogen by 2050)

CATAPULT Energy Systems

- We explored a High Hydrogen pathway to 2050 where, by 2050:
  - All cars and vans are hydrogen
  - Gas distribution network is fully converted to hydrogen
  - 20% of industrial energy demand is delivered by hydrogen
  - The use of bioenergy with CCS (BECCS) was prohibited
- Hydrogen production in this case was ~ 530 TWh in 2050
- Implies hydrogen production overtakes electricity generation in energy terms within 20 years

- The vast majority of hydrogen in 2050 is produced SMR with CCS, with a small amount from coal gasification with CCS (as no BECCS is available)

What about abatement costs for these three futures?

Pathway	Key features	Hydrogen production required (in 2050)	2050 annual abatement cost
Clockwork	All technology options available (including BECCS from ~ 2025 and hydrogen for heating), assumes long-term investment in strategic energy infrastructure	~ 160 TWh	£36bn (or **1.1%** of scenario 2050 GDP)
Patchwork	All technology options available (including BECCS from ~ 2030) apart from hydrogen for heating, but less strategic co-ordination in energy infrastructure development	~ 90 TWh	£37bn (or **1.0%** of scenario 2050 GDP)
"High Hydrogen"	No BECCS, major rollout of hydrogen infrastructure for heating, near 100% fuel cell vehicles by 2050	~ 530 TWh	£121bn (or **3.5%** of scenario 2050 GDP)

‘Net zero’ emissions target

Implications of 1.5°C Paris Agreement ambition

- Global net zero emissions well before the end of the century
- CCC advice – net zero for UK by 2050?

Hydrogen production from BECCS

- Route to negative emissions production
- Zero carbon energy vector with versatile application across energy system

Closing remarks

- Hydrogen is a versatile, zero emissions energy vector with potential application across the entire energy system (industry, transport, buildings heat, peak power)
- Unlike electrification, an entire infrastructure would have to be strategically planned and built up for production, transportation, storage and end-use
- Hydrogen is likely to be important, but it should be considered as *part* of the solution, not *the* solution – enforcing a very high hydrogen future could have huge implications for overall abatement costs
- Increased ambition on emissions targets will have implications for the role of hydrogen, both for further displacement of unabated fossil fuels and as part of a 'negative emissions' economy

CATAPULT Energy Systems

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The challenges associated with a major transition to hydrogen, and the implications for innovation

Challenges associated with a major UK transition to hydrogen

Hydrogen production

- How to deliver substantial quantities of affordable, low carbon hydrogen into the energy system
- Electrolysis – can it be made cheaply enough and how far can it be scaled? And does it make sense at the system-level when considering the need for electricity input, etc?
- SMR – will need CCS under highly-constrained carbon futures, and there will be residual emissions that will need managing
- Gasification of biomass – low carbon, but will need a lot of sustainable biomass feedstock
- Gasification of biomass with CCS – per above but could deliver negative emissions which are hugely valuable at the system level in highly carbon-constrained futures
- Are there any emerging breakthrough technologies?

Source: ETI

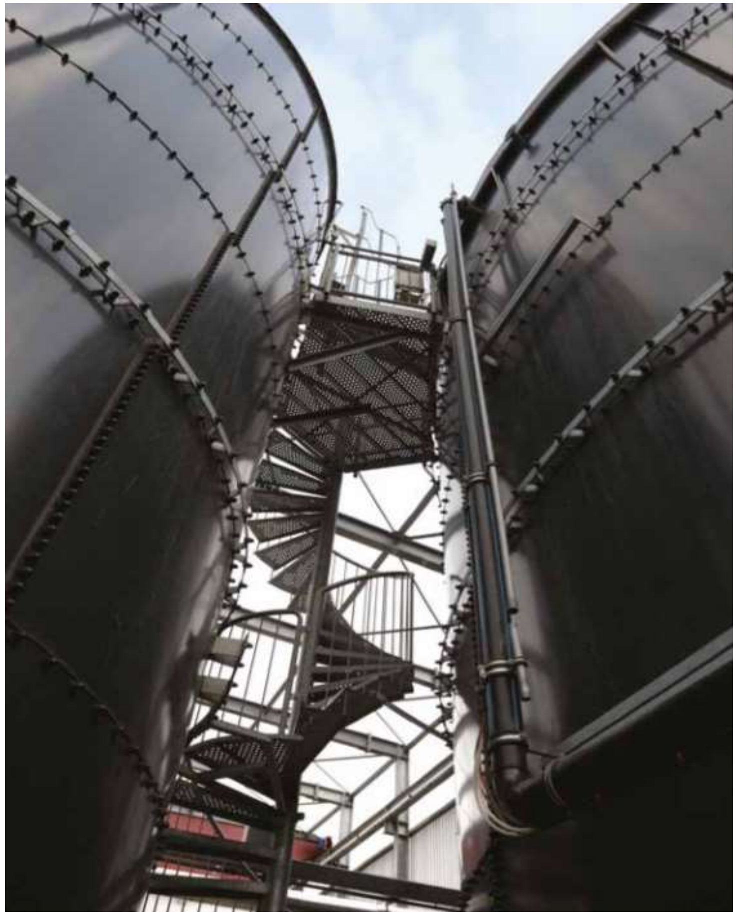
Challenges associated with a major UK transition to hydrogen

Hydrogen transmission / distribution

- Scale of intervention required is huge
- Technical challenges with repurposing parts of gas network
- Greater volumetric flow needed compared with natural gas to deliver the same energy throughput
- Managing safety implications of hydrogen transportation
- Is blending a stepping stone?

Hydrogen storage

- Large inter-seasonal hydrogen storage likely to be needed to support a major hydrogen transition – salt caverns?
- Understanding the balance between large and smaller stores for local supply management
- How to remunerate storage facility providers



Source: ETI

Challenges associated with a major UK transition to hydrogen

Hydrogen for heating

- There is strong competition - other low-carbon heating options are available that are likely (in some places at least) to be more attractive commercially and technically
- Managing a major switch-over from gas to hydrogen - H21 showed how this might be done, but it would need substantial policy intervention (including strategic decision-making) and consumer management
- Managing the safety implications of hydrogen combustion in the home
- The need to take consumers on the whole journey
- How to manage the stranded gas assets that will inevitably be created

Giacomini hydrogen catalytic boiler

Implications for innovation

- There are significant innovation opportunities relating to enabling a major UK hydrogen rollout…
- …these aren't just technical – also need to look at novel business models, consumer interaction, market structures, etc
- It is important to focus innovation thinking at the system level
- Need creative options for the whole hydrogen supply and delivery chain, otherwise good innovations are only likely to attract niche take-up
- Important to consider what whole-system analysis tells us about where priorities lie for hydrogen:
  - Industrial decarbonisation - hard to do without hydrogen
  - Heating - alternative low carbon heating options are available and hydrogen might be more valuable elsewhere in the energy system?
  - Peaking - hydrogen turbines could be good source of low-carbon electricity generation for peaking applications
  - Transport - can hydrogen cars be a significant alternative to battery EVs? What about heavy duty vehicles?