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Comparisons of methods for representing Hydrogen in MARKAL and TIMES models  
Paul Dodds and Will McDowall



## Introduction

- H<sub>2</sub> energy system
  - Production
  - Delivery
  - Vehicles
- Implementation in UK MARKAL and TIAM-UCL
- Initial findings

## Philosophy for technology data

How many technologies?

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Single authoritative source?

OR

Multi-source comparison?

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Full investment and O&M data?

OR

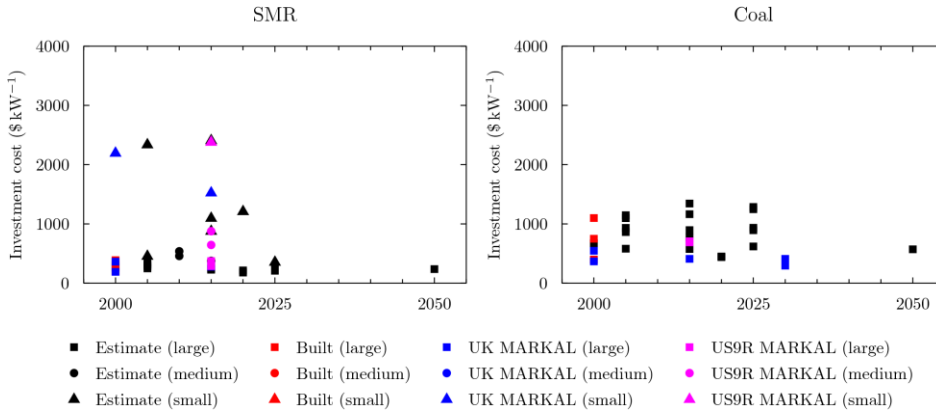
Representative VAROM?

## Hydrogen production

Old UK MARKAL model	New UK MARKAL model
Liquid H <sub>2</sub> import	Liquid H <sub>2</sub> import
SMR (size, CCS)	SMR (size, CCS)
Coal (IGCC, membrane, CCS)	Coal (flexible IGCC, CCS)
Biomass (fuel type)	Biomass (fuel type)
Electrolysis (size)	Electrolysis (size)
	High-temperature nuclear?



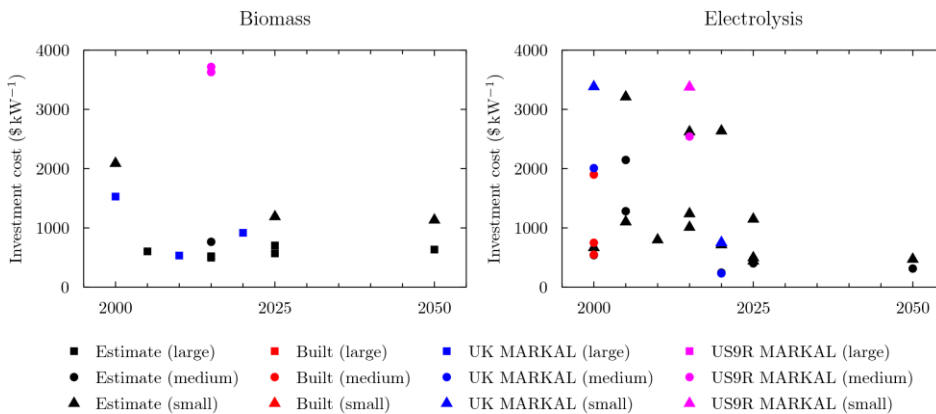
## SMR and coal gasification: investment costs



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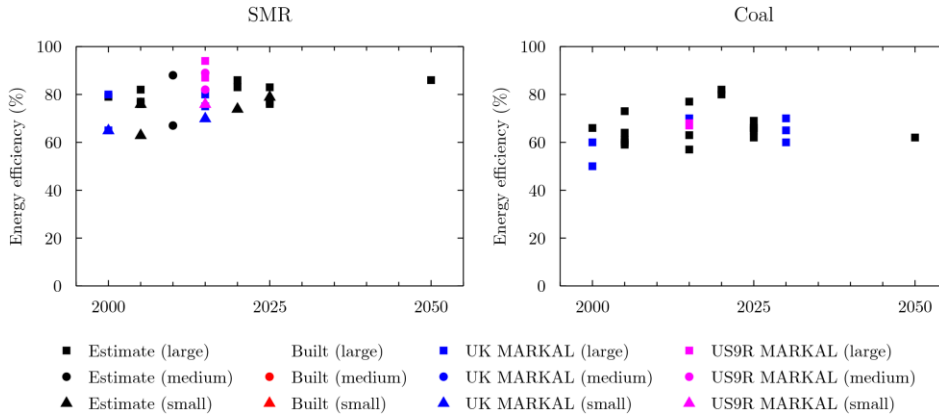


## Biomass and electrolysis: investment costs

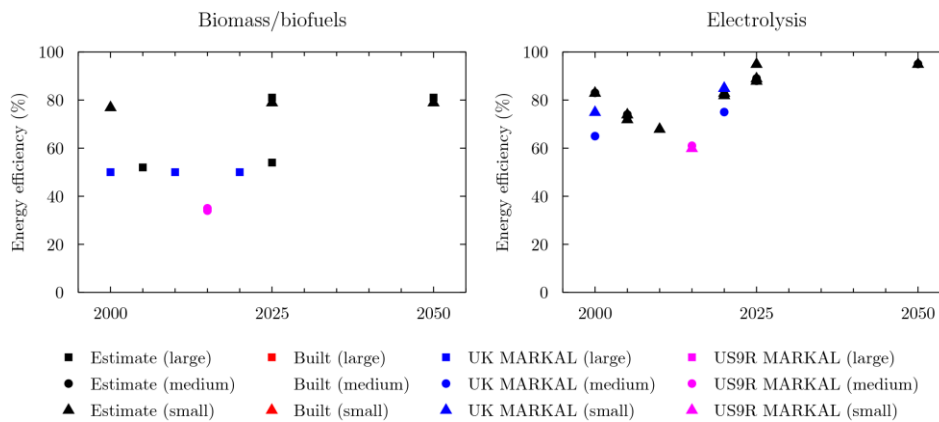


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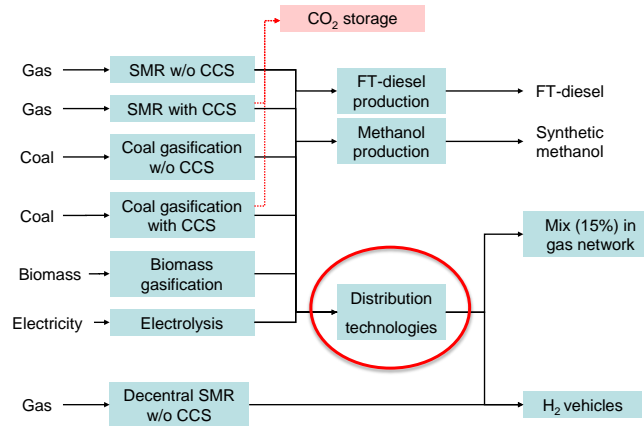
## SMR and coal gasification: conversion efficiency



## Biomass and electrolysis: conversion efficiency



## Hydrogen production in TIAM

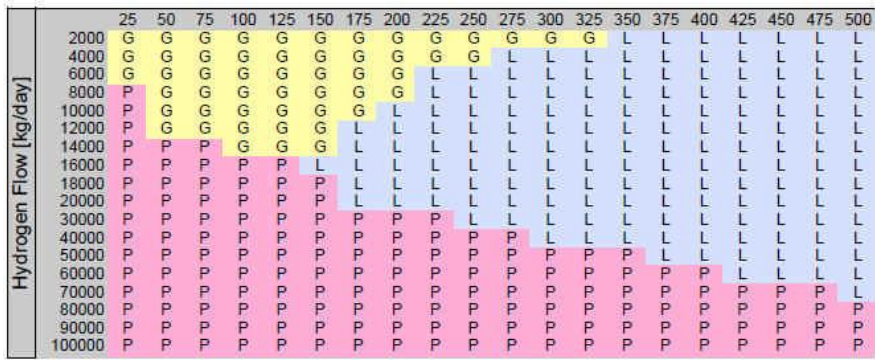


## Hydrogen delivery pathways

1. National liquid hydrogen delivery
2. International liquid hydrogen delivery
3. National high-volume gaseous hydrogen delivery
4. National low-volume gaseous hydrogen delivery
5. On-site hydrogen production
6. National gaseous hydrogen delivery to buildings as a replacement for methane
7. Domestic micro-scale hydrogen production



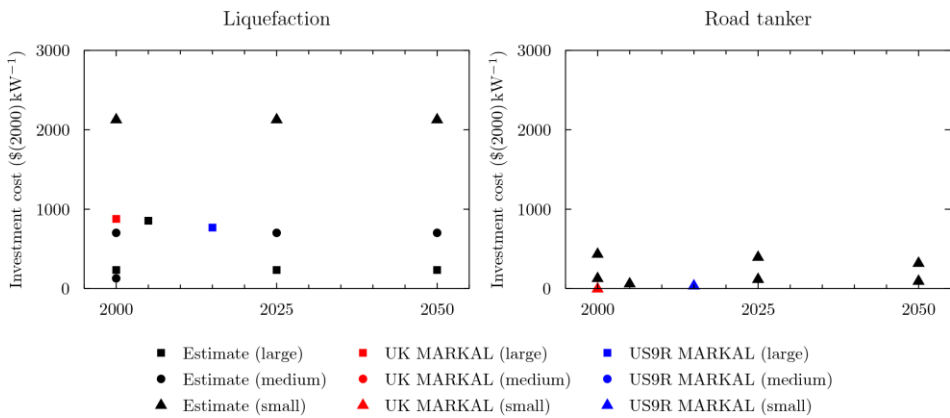
### Delivery: previous modelling approach



Yang and Ogden (2008)

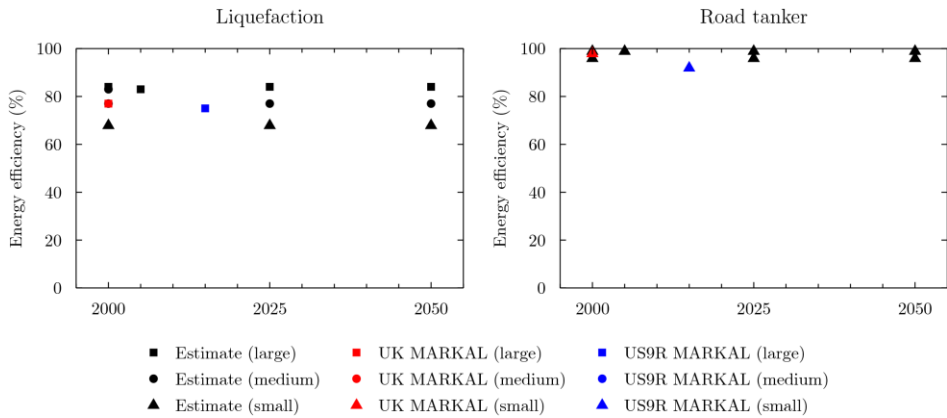


### Delivery: liquid hydrogen investment costs





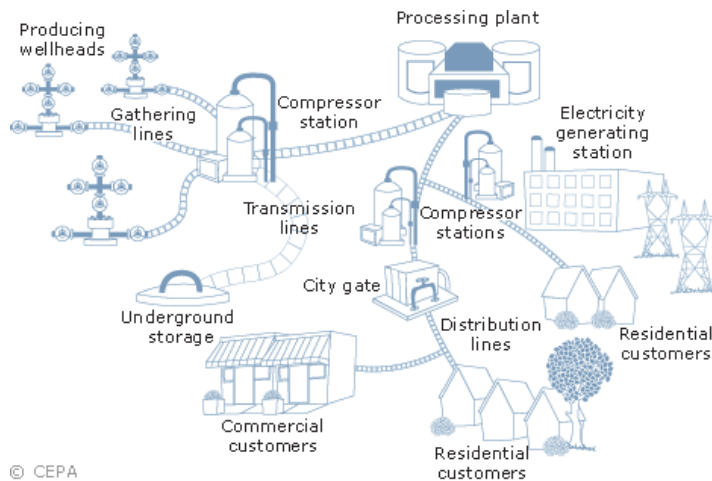
## Delivery: liquid hydrogen delivery efficiency



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## Delivery: gaseous hydrogen pipelines



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## Delivery: gaseous hydrogen pipelines

- Transmission pipeline capital costs depend on:
  - Diameter
  - Length
  - Terrain
- All pipelines have a trade-off between capital costs and operating costs and efficiencies
- It is necessary to design and then cost a pipeline system...



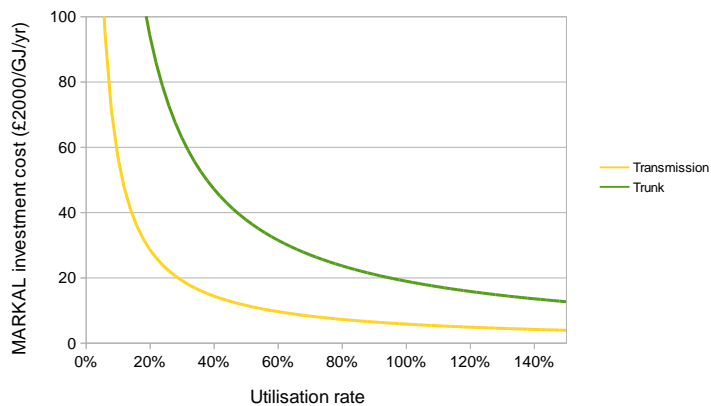


## Delivery: gaseous hydrogen pipelines

	Length (km)	Diameter (cm)	Efficiency	Investment cost (£2000/GJ/yr)		
				Low	Medium	High
<b>Transmission</b>	3467	100	0.98	4	6	7
<b>Trunk</b>	3142	30	0.99	14	19	24
<b>Fuel station</b>	10000	8	1.00	10	12	15
<b>Household</b>	336000	1	1.00	8	11	13

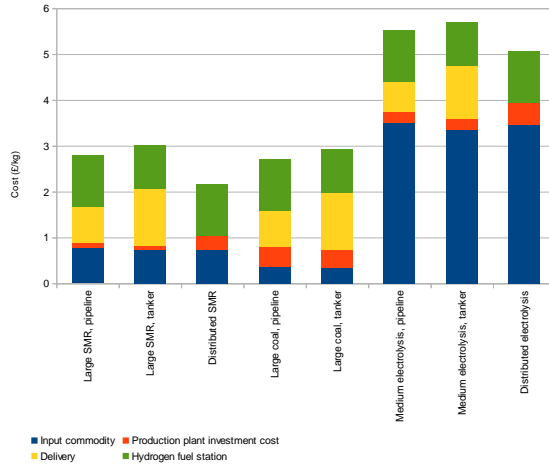
## Delivery: gaseous hydrogen pipelines

Pipeline investment costs for a range of utilisation rates

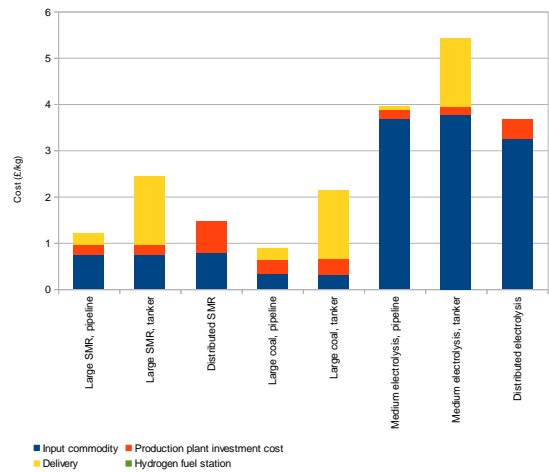




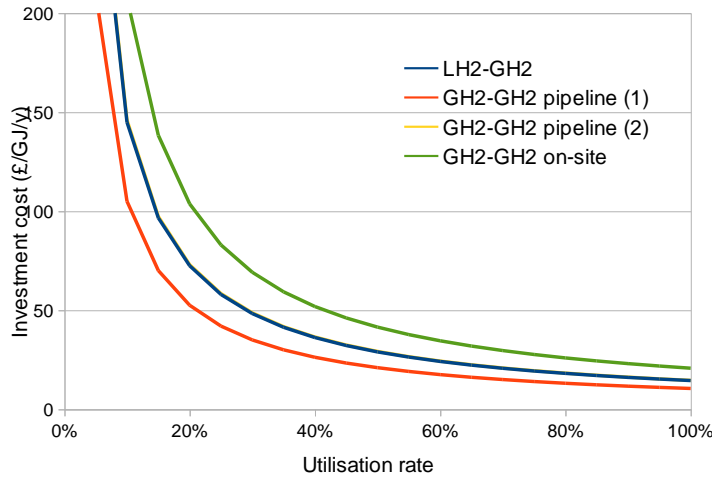
### Delivery: mature economy



### Delivery: mature economy



## Delivery: hydrogen fuel stations



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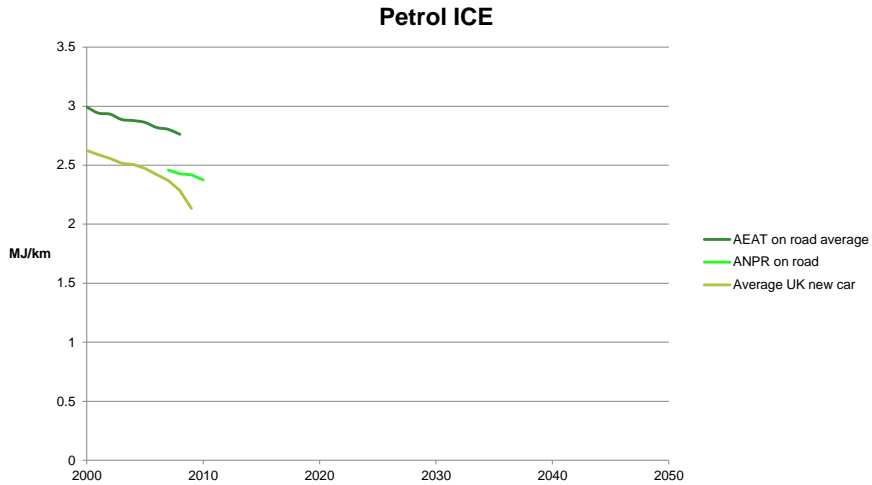
## Vehicle types

	Basic	Hybrid	Plug-in hybrid
Petrol	X	X	X
Diesel	X	X	X
Hydrogen FC	X	X	X
Hydrogen ICE		X	
Battery	X		
CNG	X		
LPG	X		
E85	X		

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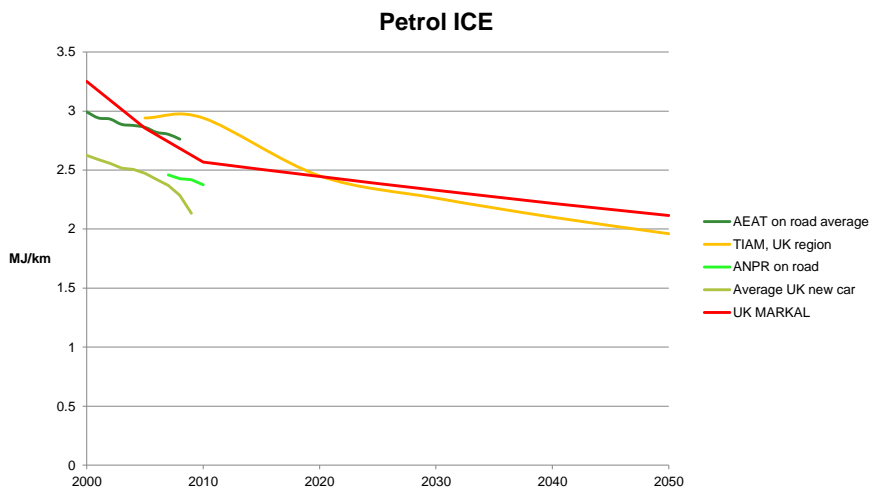
### Vehicle efficiency: petrol ICE



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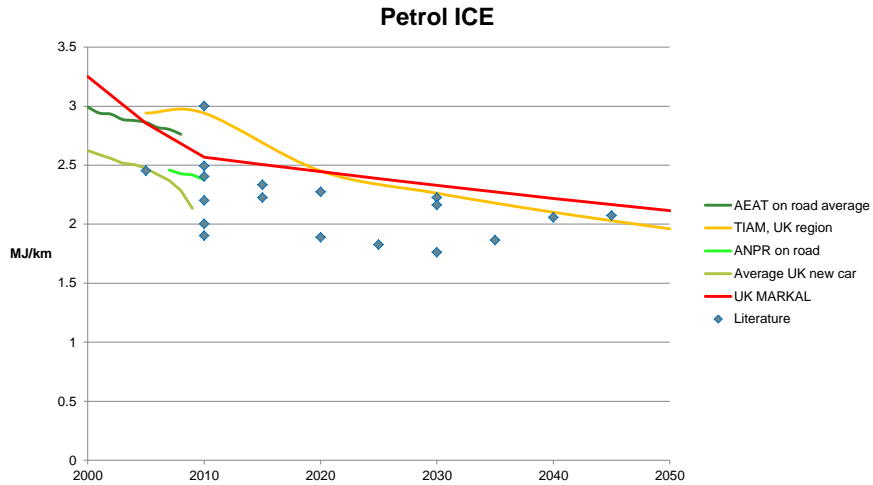
### Vehicle efficiency: petrol ICE



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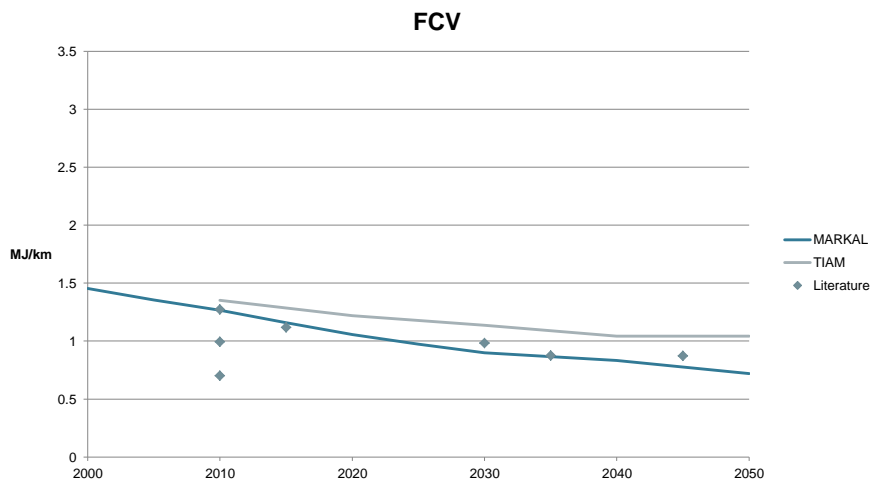
### Vehicle efficiency: petrol ICE



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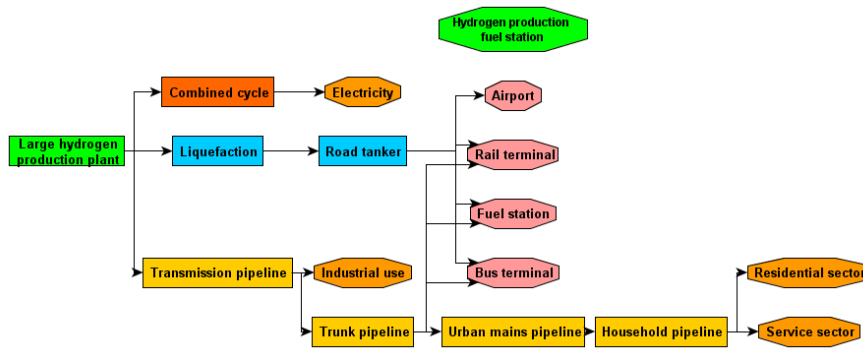


### Vehicle efficiency: petrol ICE



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## Hydrogen in the UK MARKAL RES



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## Early UK MARKAL results

- To meet an 80% emission reduction by 2050, hydrogen is adopted where possible in the transport sector, despite the higher cost of the new infrastructure.
- Hydrogen is produced by coal+CCS and biomass+CCS. There is much uncertainty about the feasibility, costs and lifecycle emissions of biomass+CCS. Neither coal nor biomass are used for electricity generation.
- In some runs, flexible IGCC technologies are important.

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## Early TIAM results

- Thank you Gabriel...

## Next steps

- Update all of the non-hydrogen infrastructure
  - We need an equal playing field for all competing technologies
- Design scenarios of hydrogen systems and implement in the UK MARKAL model (taking into account factors not represented by the model!)
- Under what conditions does hydrogen become a realistic option for the UK?
- How does infrastructure lock-in affect hydrogen use?

## Final thoughts

- We have a much better understanding of some technologies than others – don't rely on one study!
- Energy system infrastructure can be based on implicit assumptions that are not always applicable elsewhere
- Residual infrastructure loss rates are important
- Hybrid and plug-in hybrid hydrogen FCs are the most likely hydrogen vehicles

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## Thank you!!!



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