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Hydrogen Storage and Flexible Carbon Capture and Storage

Den Gammer for ERP

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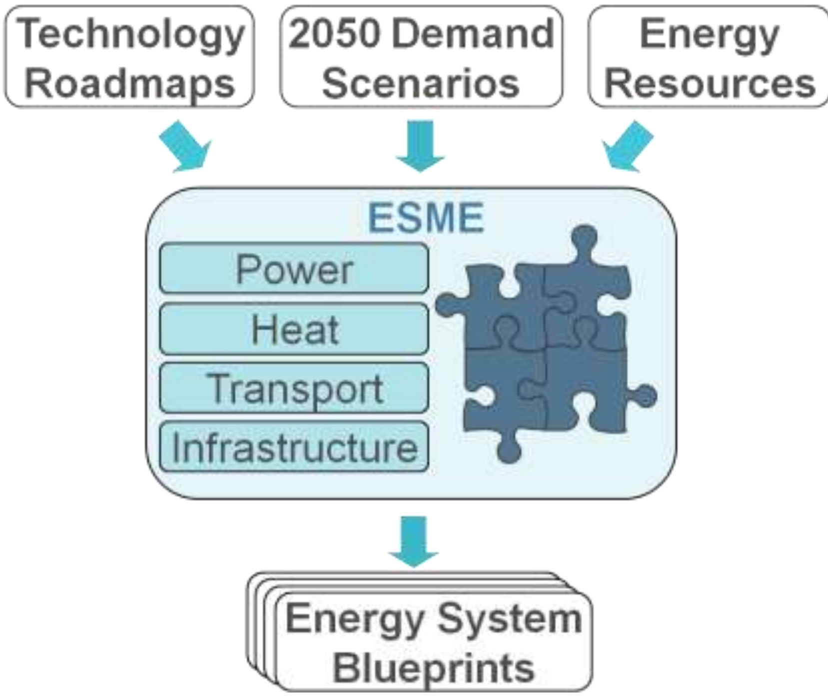
Energy Systems Modelling Environment

- Least cost optimisation, policy neutral
- Deployment & utilisation of >250 technologies
- Pathway and supply chain constraints to 2050
- Spatial and temporal resolution sufficient for system engineering
- Probabilistic treatment of key uncertainties



ESME
Energy System Modelling Environment

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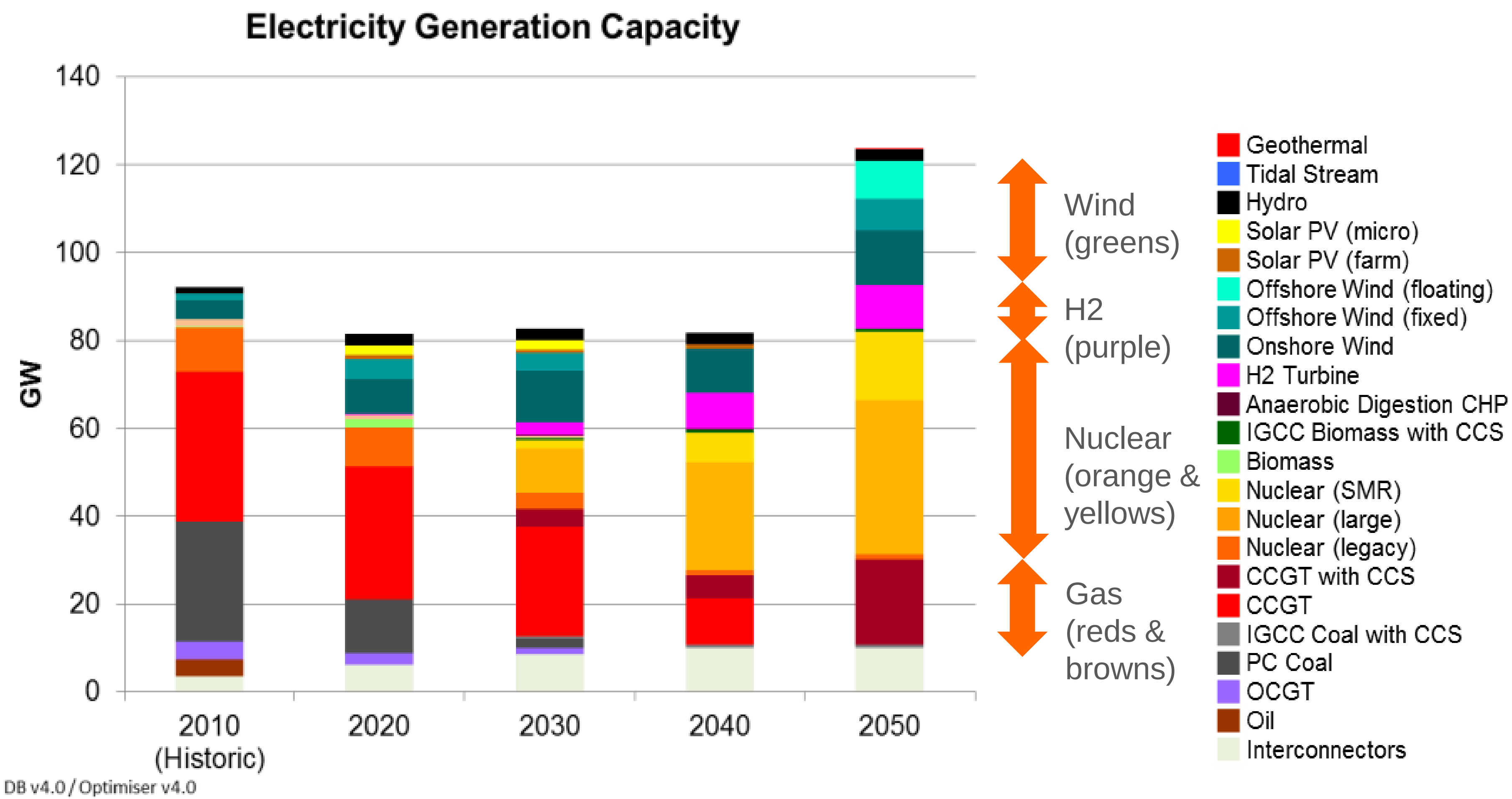
ESME – a place for H2 in power capacity post 2030



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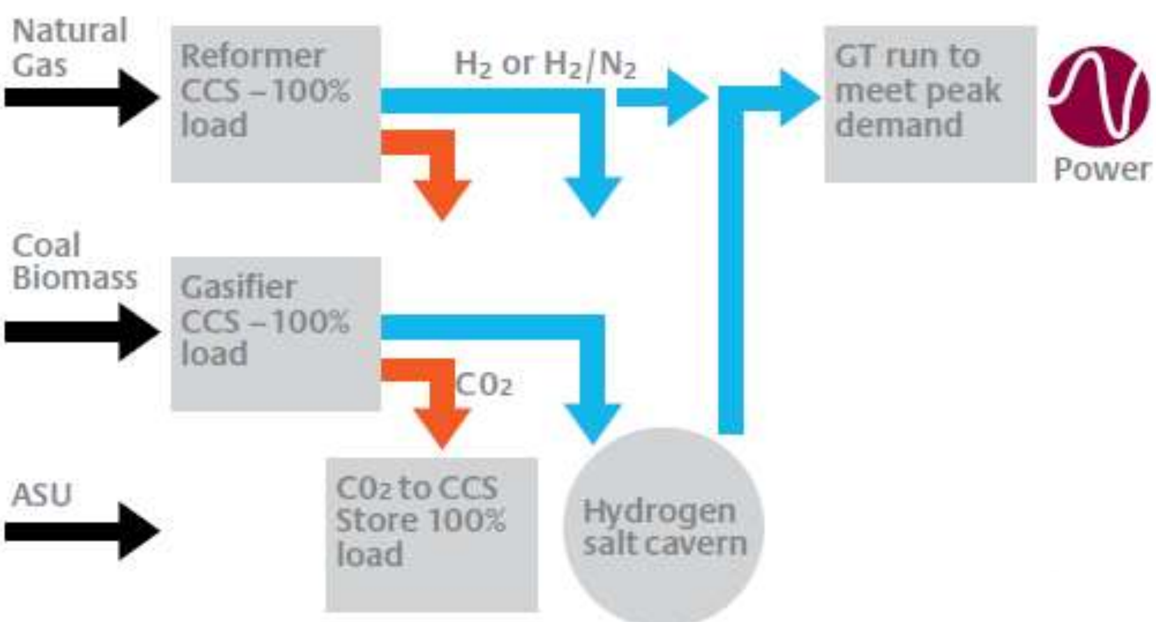
Using H2 storage to maximise use of CCS investment

Power station configurations using H_2 storage



UK salt beds are not widespread
but are situated in good locations

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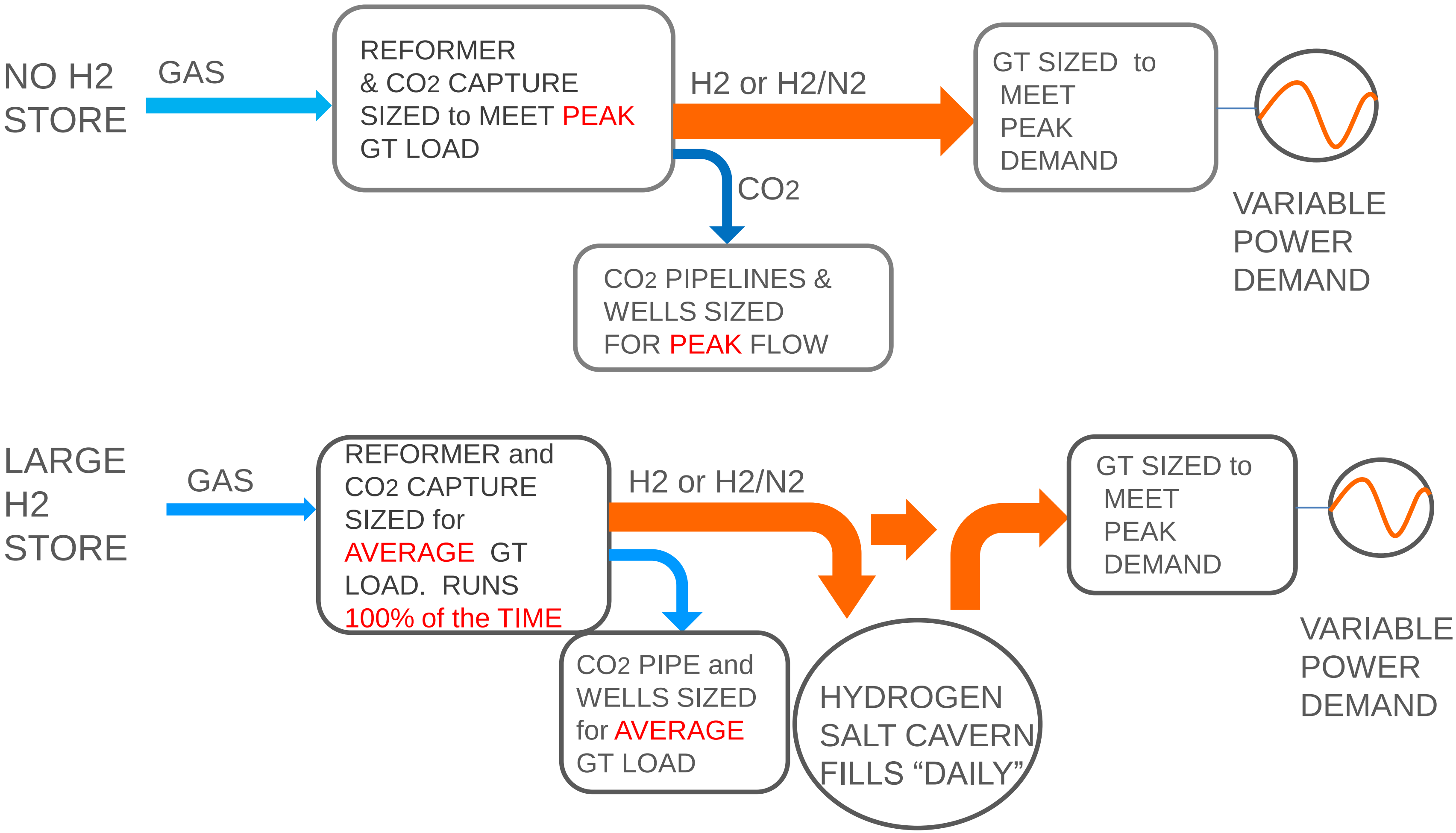
Configuration Benefit



The average load could be a small fraction of the peak load. GT capex << rest of plant

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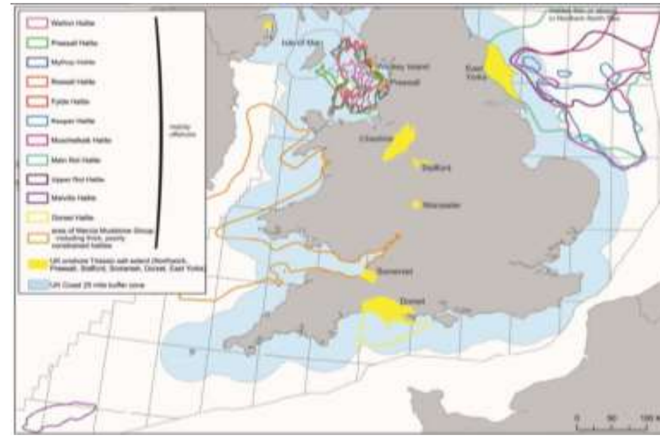
UK Salt fields

- Used for natural gas and hydrocarbons
- Over 30 large caverns in use
- Offshore operation is twice the cost of onshore
- Screening led us to focus in 3 areas



Region	Typical Depth, m	Bed Thickness, m	Cavern size, 000m3	Pressure bara
Teesside	300	35	70	45
Cheshire	800	200	300	105
E Yorkshire	1800	175	300	270

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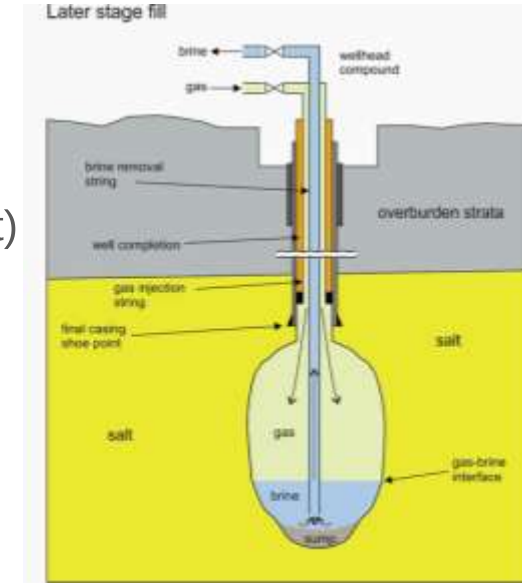
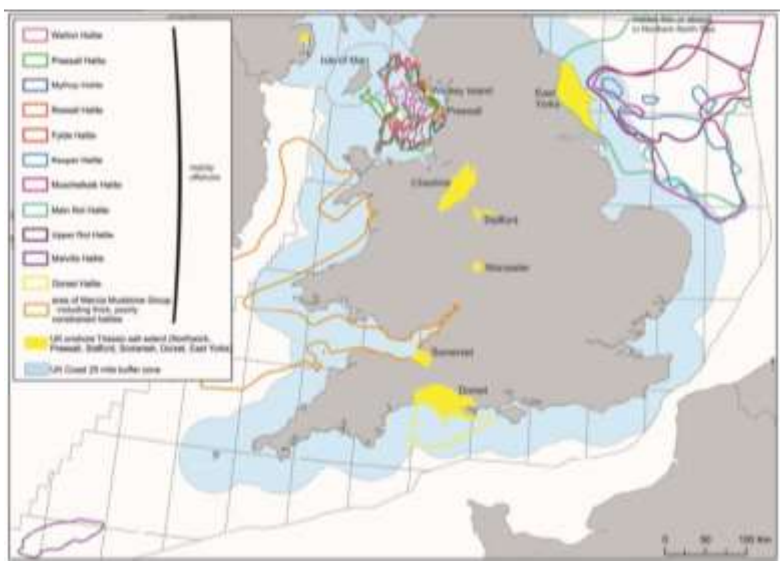
H2 Storage - Metrics

- Salt caverns are already used for H2 in UK and US
- One cavern family - 30GWhe daily
  (c.f Pumped hydro at Dinorwig 10GWhe, 75% efficient)
- Coal/bio to power – no penalty for going via H2
- Gas to power – penalty for going via H2





- Geographical limitation of stores
- “Fast churn” stores in operation on natural gas duty
- Rapid empty modes used for CAES
  (compressed air energy storage – Germany)
- Stores can be run on a “constant pressure” basis by flooding with brine – not covered in the ETI analysis

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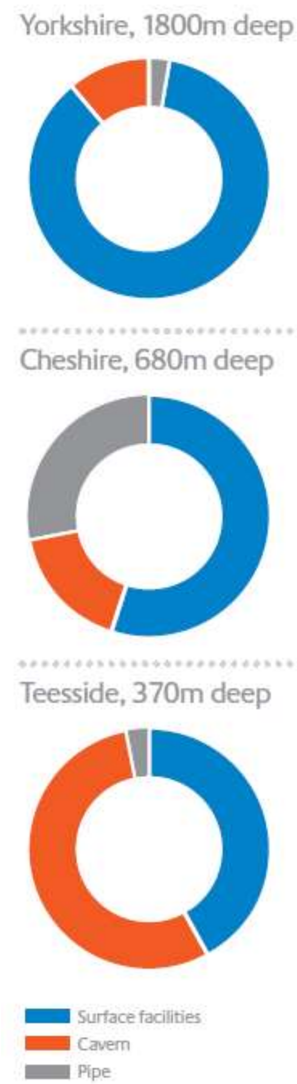
Cost structure varies with store depth

- Although the component costs change with depth, overall costs are similar
- Deep stores have a round trip energy hit (takes 2% points off LHV efficiency of 34% for Yorkshire)
- Shallow stores are unlikely to provide strategic quantities of storage, although constant pressure operation may improve the case



Distribution of costs for stores of different depth, all stores designed in a constant volume - variable pressure mode.

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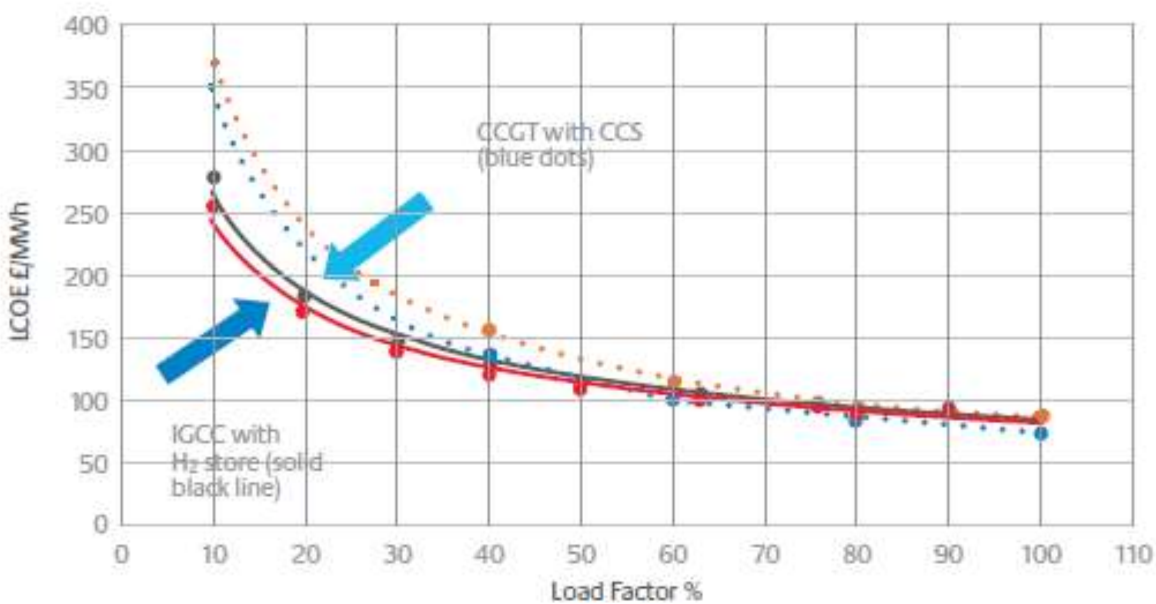
H2 store is cost effective at low load factors

Levelised cost changes with load factor



Hydrogen storage turbines could offer

significant energy system level cost benefits over other storage approaches

- CCGT with CCS is compared to an IGCC with a H2 Store
- “Oxymembrane” means H2 derived from methane by technology in development (separation assisted by membrane per the “Cachet” project)
- Fuel Price assumptions shown in brackets

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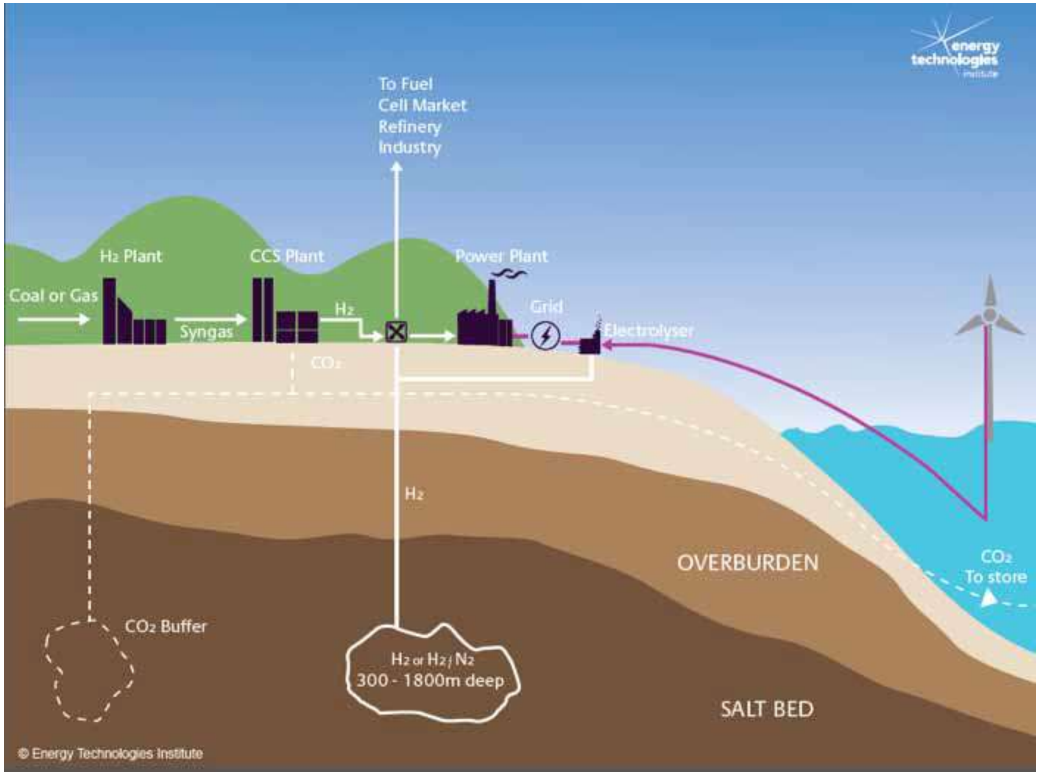
Summary

- H2 storage in caverns could supply grid level quantities of load following and peaking power
- For schemes operating below 40% load factor (turbine) the store adds value by reducing overall system investment. ETI modelling suggests this could happen after 2030
- For schemes above 50% load factor conventional CCS (CCGT plus post combustion capture) are better
- Storage configurations are extendable for both H2 supply and demand options



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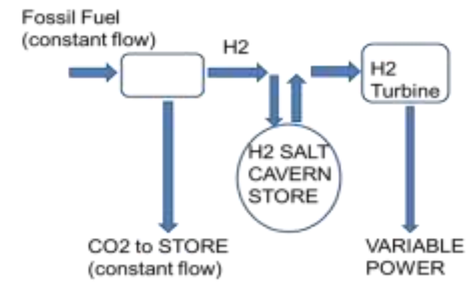
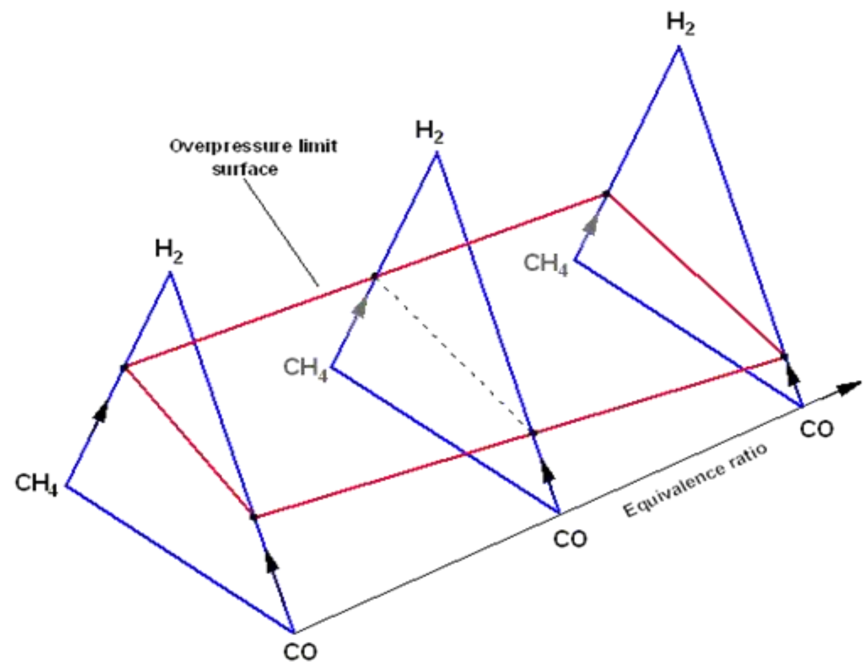
Safe combustion of Hydrogen rich mixtures

ETI High Hydrogen Project

- Understanding limits on safe use of hydrogen-rich fuels in power production by GTs and engines
- Laboratory test work completed
- Large scale testing in HSL Buxton underway





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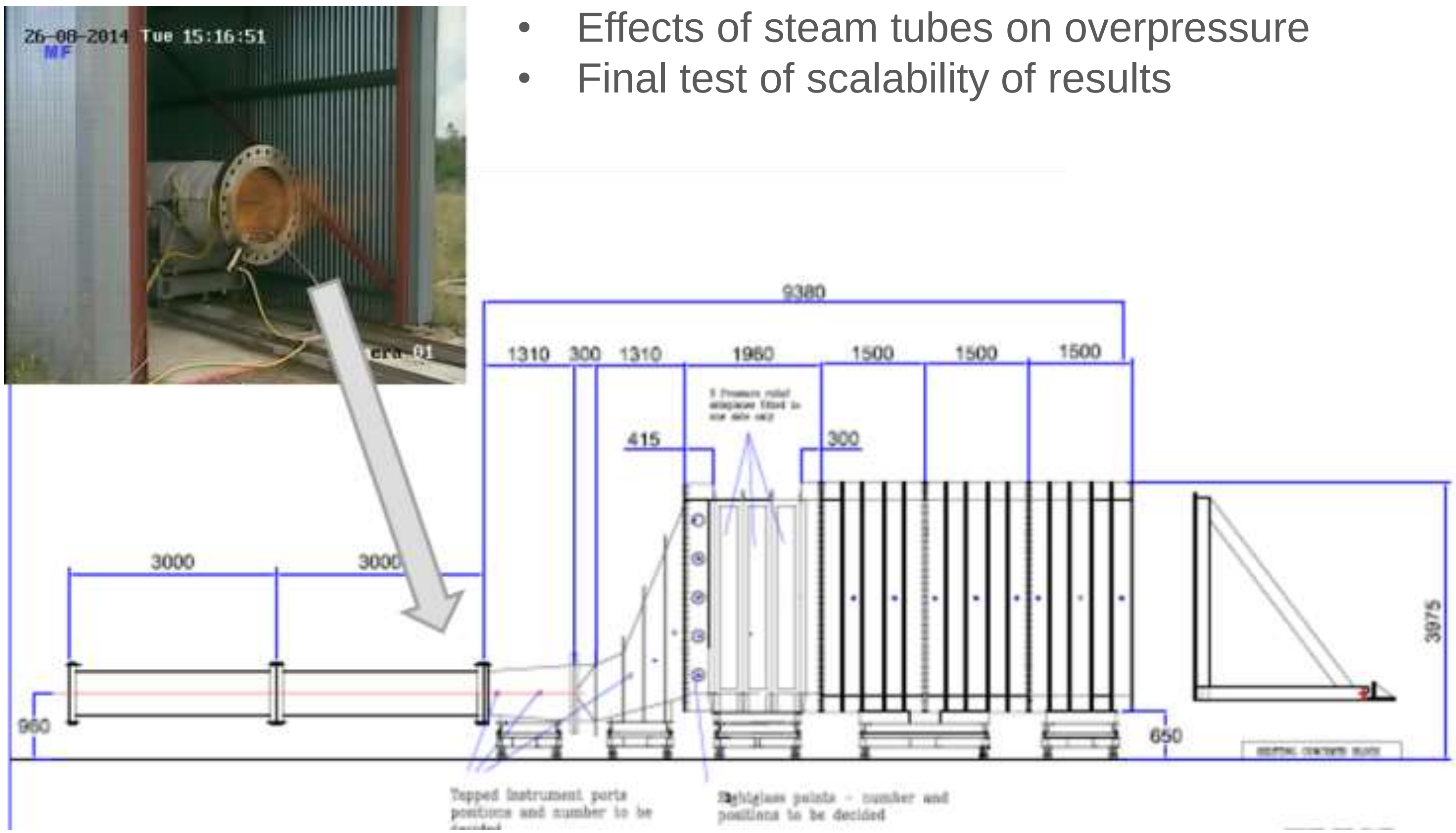
Next Step 1/6th scale 350Mwe Heat Recovery Steam Generator (HRSG)

- Effects of steam tubes on overpressure
- Final test of scalability of results



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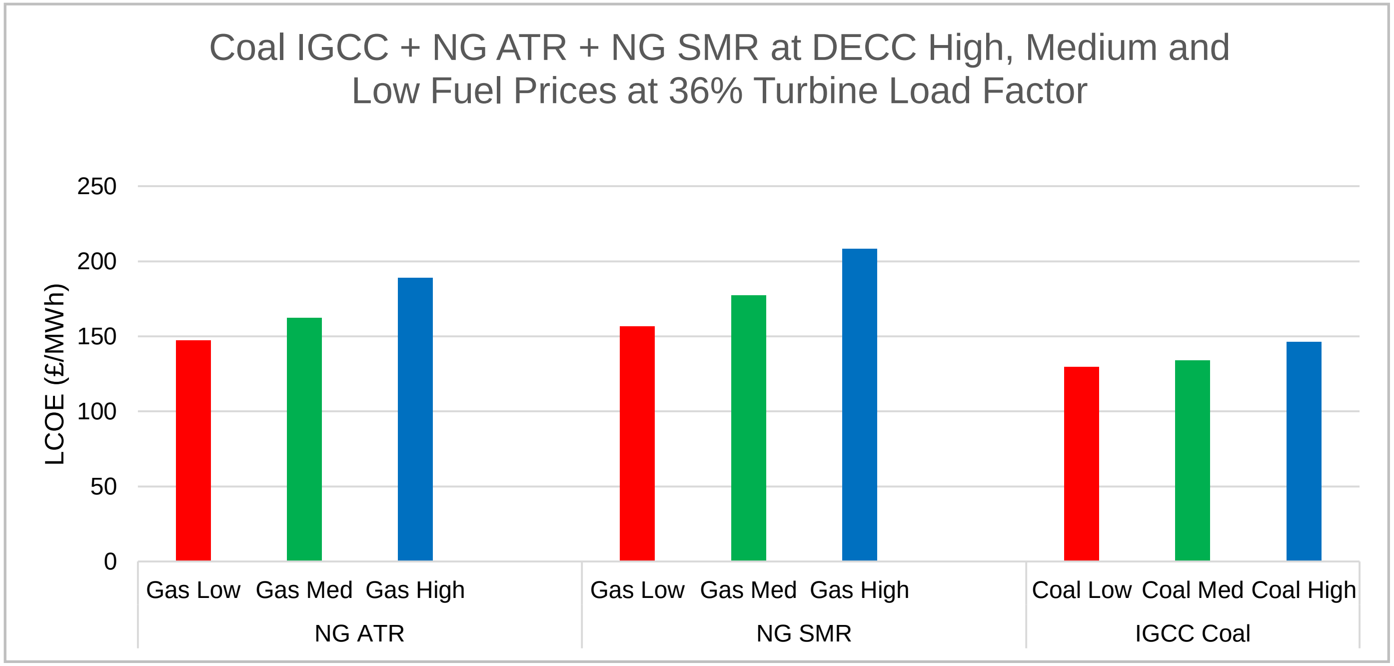
Pre–Combustion Power complex cost structures



- Technology selection for H2 production was not as important as primary fuel choice or price
- Coal price less volatile, less impactful. Opens door to co-firing waste and biomass
- Biomass is most valued feedstock at system level (ESME) for emission reduction
- At 36% Turbine load factor, there is a marked reduction in relative size of H2 plant costs
- CCS pipeline and storage costs are not included above
- Often need to store N2 for large H2 Turbines

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