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Hydrogen? The viable storage option

Mark Crowther

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Assertions

- The world is not short of renewable energy
  - 6,200 km^2 of Sahara desert would produce all UK final energy needs
- The world does require an energy vector
  - Reliable and modestly priced to move this energy from its point of production/capture and transfer it to the consumer when it is required
- Historically, storage has enabled transparent markets
  - The separation of production from use improves the efficiency of both
- Ideally the vector should not be poisonous, or of short life
- Ideally no greenhouse gas emissions at point of use

Sahara

- **Red square shows land area required for UK final energy needs at 300 kWh/m²/y**

Options for energy vectors include

- **Electricity - a good vector but no storage**
- **Hot water/steam - expensive and complex to store.**
- **Methane with a biologically derived carbon atom (always risks food competition; the market moves in complex ways)**
- **Ammonia etc - technologically complex**
- **Hydrogen**

Hydrogen

- Flammable, colourless, biologically inert gas burns to water
- Very light gas, density ~0.08kg/m^3 (about 1/8 methane, ~0.67kg/m^3)
- Low calorific value of about 12,750kJ/m^3 (about 1/3 methane, ~39,000kJ/m^3)
- Good safety record with ~60million tonnes per year produced, transported and used in industry.
- A long record as Towns Gas (50-65% hydrogen) both in the UK and still in the Far East
- Can be conveyed through repurposed existing MP and LP gas networks with change of appliance

Hydrogen

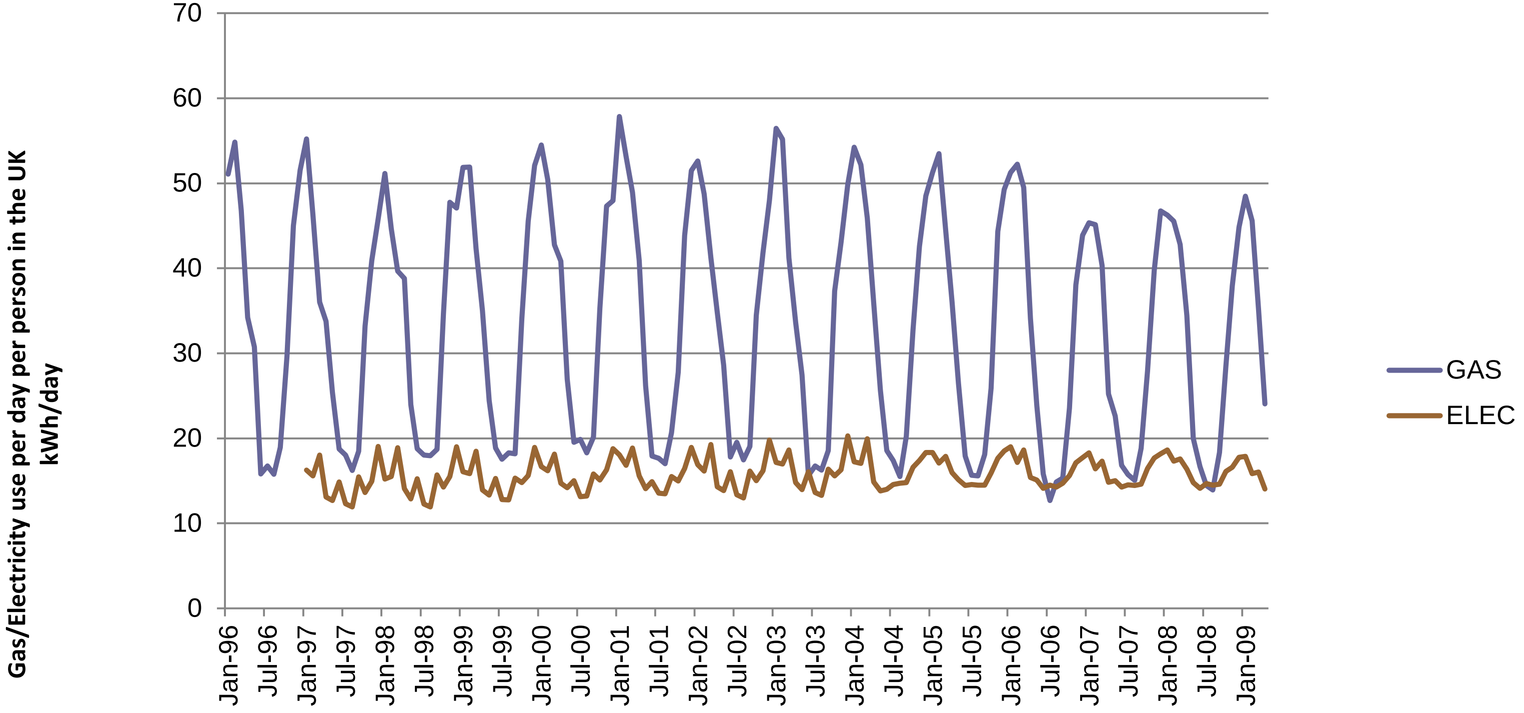
- **The need for storage is encapsulated in the following numbers**

Average annual gas consumption UK property	kWh	18,750
Average daily gas demand	kW	2.14
Typical peak daily winter demand	kW	10.00
Typical daily summer demand	kW	0.33

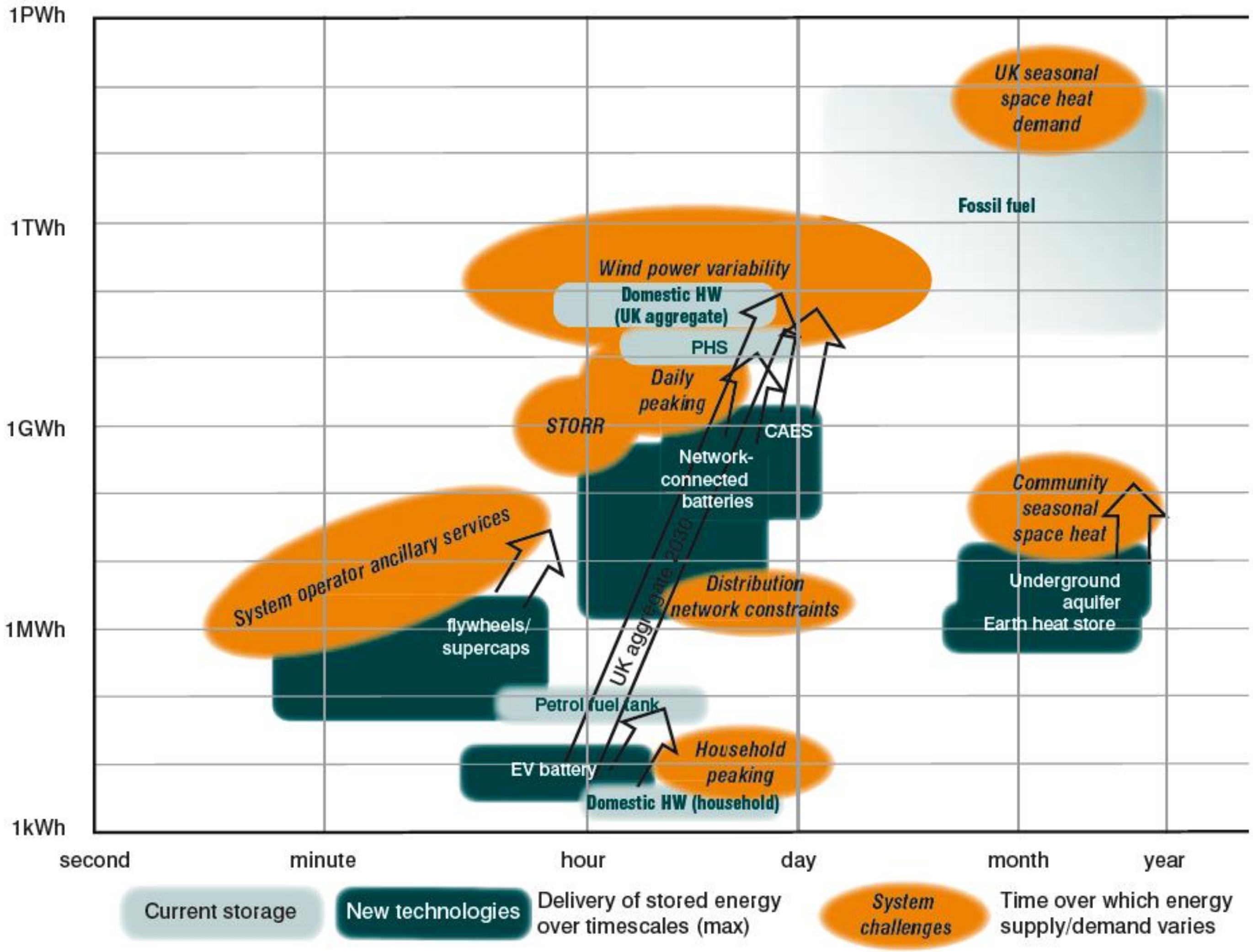
- **Even at a national scale there is large swing between summer and winter energy (gas) demand**

UK inter-seasonal variation in energy demand

- **14 years energy demand**



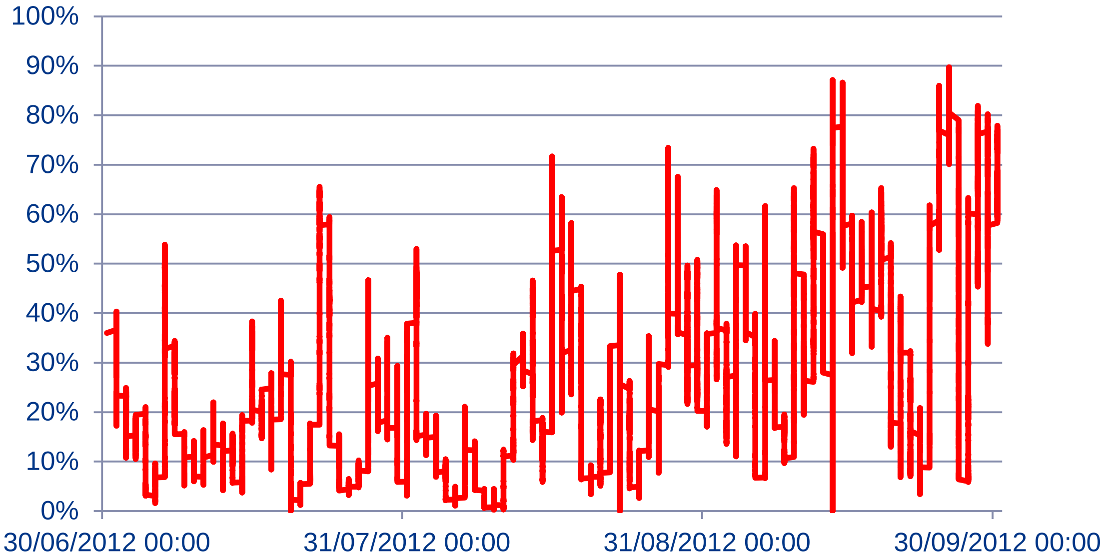
UK requirements for energy storage



Ref: http://www.energyresearchpartnership.org.uk/tiki-download_file.php?fileId=291|Energy%20Storage%20Full%20Report.pdf

UK requirements for energy storage

- Typical UK average wind intermittency



Relative space for 90 days of energy

Annual demand per property	kWh	18,750
Mean load	kW	2.14
Turbine yield		29%
Size of turbine	kW	7.38
Days storage		90
Required store	kWh	4,623
Options		
Mass of Hydrogen	kg	119
Hot water		
Upper temp	°C	75
Lower temp	°C	60
Delta T	°K	15
Mass of hot water storage	Tonnes	265

UK requirements for energy storage

- Hydrogen is particularly suitable for inter-seasonal down to daily load swings

Month	20 year average degree days	Degree hours	Demand	Production	Balance
Oct-10	174	4176	7%	11%	3%
Nov-10	258	6192	11%	11%	3%
Dec-10	360	8640	15%	11%	-2%
Jan-11	345	8280	14%	9%	-7%
Feb-11	300	7200	13%	9%	-11%
Mar-11	291	6984	12%	9%	-14%
Apr-11	219	5256	9%	6%	-17%
May-11	158	3792	7%	6%	-17%
Jun-11	87	2088	4%	6%	-14%
Jul-11	52	1248	2%	7%	-9%
Aug-11	54	1296	2%	7%	-4%
Sep-11	91	2184	4%	7%	0%
Total	2389	57336			

- This indicates monthly mismatch between central heating demand and monthly wind production
- Sized to meet annual demand

Effect of annual production on cost

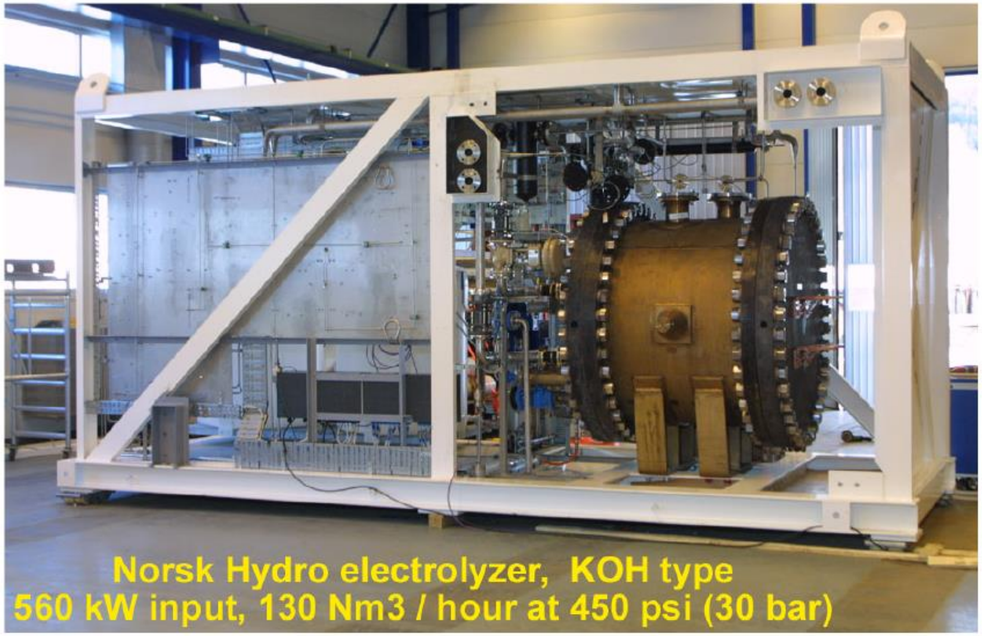
- **The higher the capital cost (e.g. nuclear power) the greater the effect**
- **Value of storage in this instance 0.17p/kWh**

Biomass plant	£ 2,600	£/kW
Cost of biomass	£ 0.020	£/kW
Electric efficiency	45%	
Cost of fuel to electric	£ 0.044	£/kW
Depreciation	20	years
O&M	4%	
Investor return	8%	
Annual cost	£ 442	£/kW
Cost of electricity		
7500hours/y Note 1	£ 0.10	£/kWh
2000hours/y Note 2	£ 0.27	£/kWh

Note 1: Approximate base-load design
Note 2: Upper end of hours to provide electric space heating + DHW

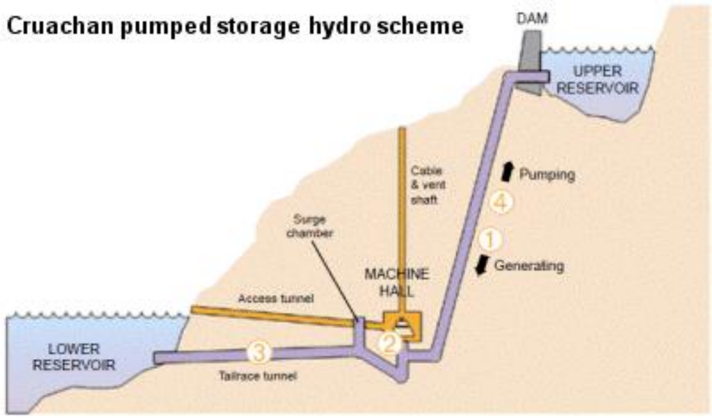
By Electrolysis

- **By electrolysis from renewable sources e.g. this electrolyser operates at an efficiency of around 80% (including ancillary power consumption)**



Hydrogen Storage

1 * Energy storage cavern in Texas =
50 * Cruachan pumped storage schemes



Refs:
http://www.pbworld.com/capabilities_projects/power_energy/underground_storage.aspx

http://www.scotsrenewables.com/blog/wp-content/uploads/2011/02/cruachan.gif

http://www.oban.org.uk/listing/Cruachan-Power-Station

Hydrogen Storage

- **Compressed underground hydrogen storage is entirely proven and new sites are under-construction today e.g. PRAXAIR in Texas**

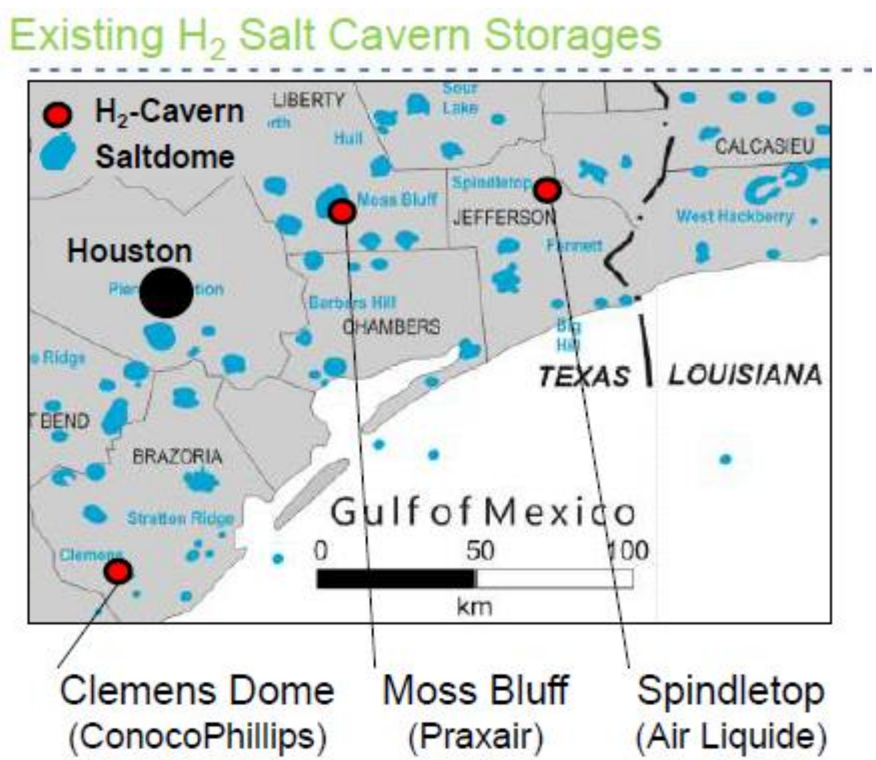
Hydrogen caverns are operated in

- Teesside, UK, by Sabic Petrochemicals (3 x 70,000 m^3)
- Clemens Dome, Lake Jackson, Texas, U.S., by ConocoPhillips (580,000 m^3)
- Moss Bluff salt dome, Liberty County, Texas, U.S., by Praxair (566,000 m^3 maximum permitted capacity)

- **This last facility has the capacity of up to 65,000toe or >50 Cruachan pumped storage stations**

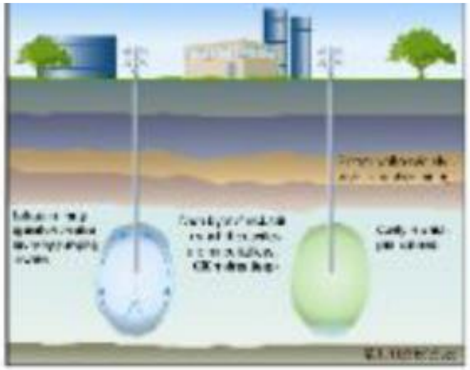
Hydrogen Storage

- **Locations of Texas hydrogen storage**



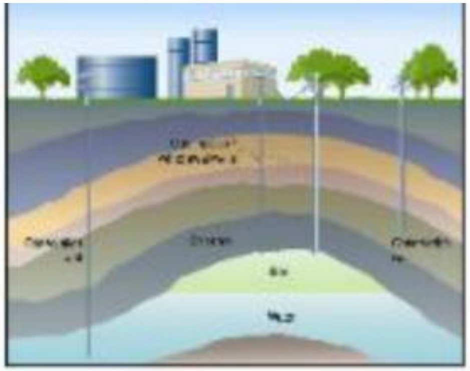
Ref: **EU Underhy project**

Hydrogen Storage



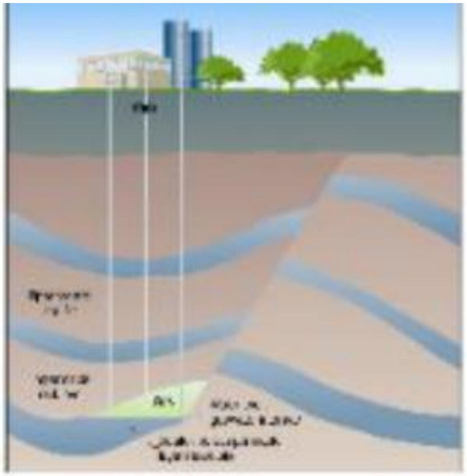
Salt Caverns

- Salt caverns are solution mined cavities within either salt domes or bedded salts that do not match reservoir volume capacity.



Depleted Oil/Gas Reservoirs

- Depleted reservoirs are proven gas reservoirs that are easy to develop and operate due to existing infrastructure.



Aquifers

- Aquifers are similar in geology to depleted reservoirs, but have not been proven to trap gas and must be developed.

Ref: http://prod.sandia.gov/techlib/access-control.cgi/2011/114845.pdf

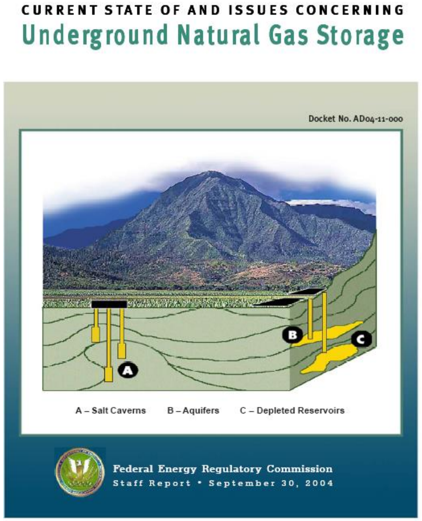
Hydrogen Storage

- **Salt Cavern**
  - **simplest and only commercially proven**
- **Redundant Gas field**
  - **will produce severe contamination of the hydrogen in early years**
- **Aquifer**
  - **may have significant technical problems with hydrogen loss**

- **Unfortunately truly low cost hydrogen storage is currently driven by geological chance and is strongly dependent upon scale**

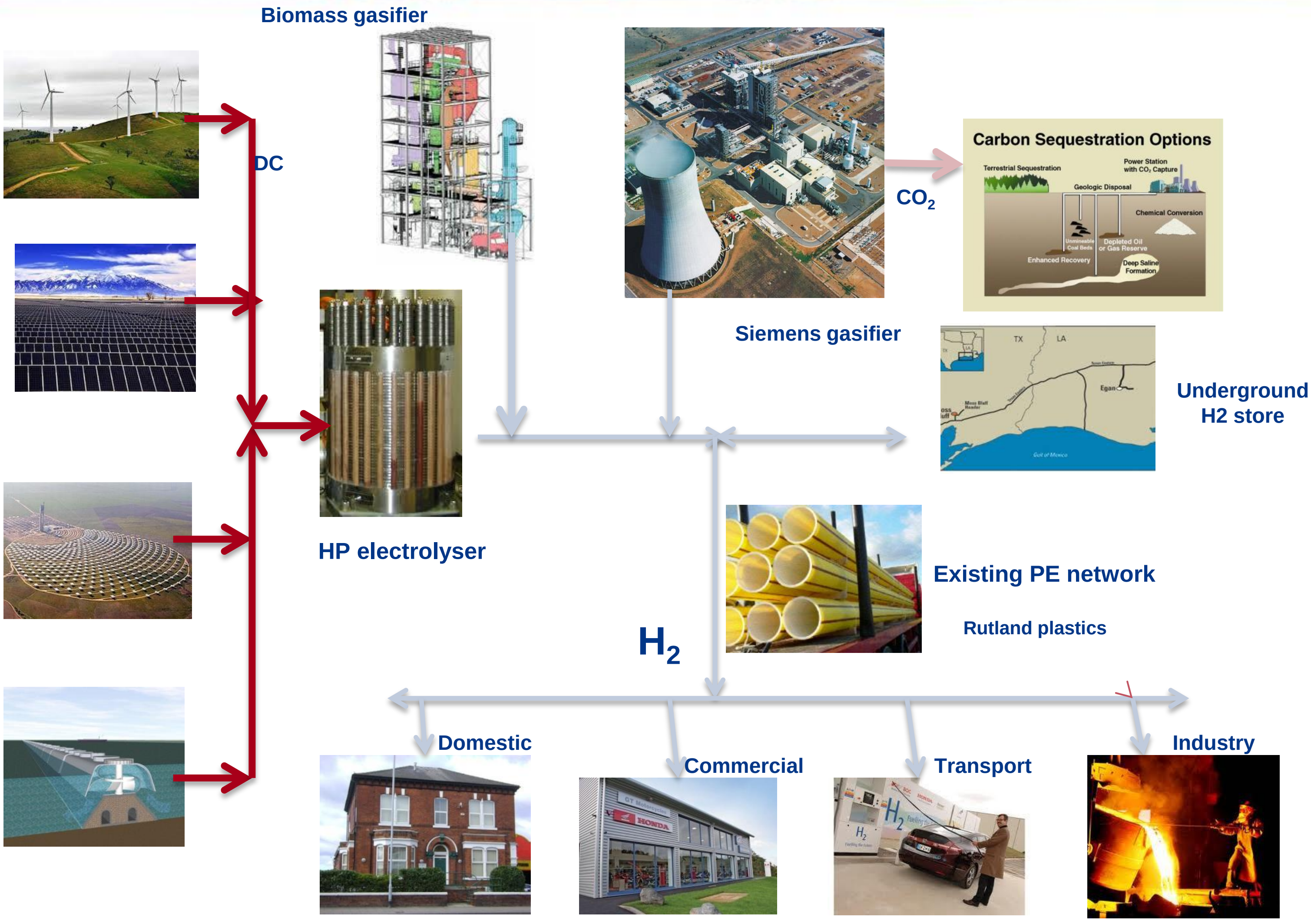
Indicative costs of storage

- This is about 1/4 to 1/10, the 'value' arising from the intermittent use of biomass generation (i.e. 0.17p/kWh)
- The surest route to reducing energy production cost is to increase operating hours of the producer and/or not restrict output



	Upper	Lower
Methane Cap Cost $	$ 25,000,000.00	$ 10,000,000.00
Depreciation 20 yrs	$ 1,250,000.00	$ 500,000.00
O&M 4%	$ 1,000,000.00	$ 400,000.00
Return 8%	$ 2,000,000.00	$ 800,000.00
Annual cost	$ 4,250,000.00	$ 1,700,000.00
Annual storage kWh	278,000,000	278,000,000
Annual $/kWh	$ 0.015	$ 0.006
£/kWh	£ 0.010	£ 0.004
Hydrogen BY 4	£ 0.042	£ 0.017

Hydrogen Supply and Use Chain



Hydrogen Transport

Hydrogen Analysis Resource Center: ***European Hydrogen Pipeline Miles by Country***	
Country	**Miles**
Belgium	381
France	188
Germany	242
Italy	5
Netherlands	147
Sweden	11
Switzerland	1
United Kingdom	25
Total	1001

Ref: for all but Germany: http://www.roads2hy.com; European Hydrogen Infrastructure Atlas. J. Perrin. July 2007.
Ref: for Germany: Germany - Taking the Fast Lane to Hydrogen Infrastructure Development. P. Schmidt. August 2008.
Ref: Argonne National Laboratory

Unit Cost of NG & H2 Pipelines Vary with Pipe Diameter & Installation Technology

Diameter (inch)	Capital Cost of Natural Gas Pipeline ($/mi)	Capital Cost of H_2 Pipeline, Cut/Cover ($/mi)	Capital Cost of H_2 Pipeline, Trenchless ($/mi)
3	$200,000	$400,000	$300,000
9	$500,000	$900,000	$700,000
12	$600,000	$1,000,000	$900,000
14	$800,000	$1,400,000	$1,150,000

Argonne National Laboratory
Transportation Technology R&D Center

- **In summary the long distance transportation of hydrogen is well proven and cost competitive**

Hydrogen

- Hurdles to the current widespread development of hydrogen infrastructure with integral storage
- No overt method of valuing stored energy
- Currently natural gas producers do not charge additionally for intermittent demand. Hence the poverty of Natural Gas storage scheme coming forward
- Price of carbon too low and renewables too small a percentage of energy use to create a market for storage
- BUT the UK will require energy storage and hydrogen (next to pumped storage) the only proven technology

Hydrogen: how to proceed

- Large schemes of co-production of hydrogen for power generation and static/transport use avoids any storage issues in the short term
- Produce low carbon hydrogen principally for power generation either from
  - SMR +CCS
  - Waste derived hydrogen
- Distribute swing production locally to establishing a local market for:
  - hydrogen in the static and transport sectors (Cars, buses etc)
  - boilers, fuel cells, gas fires and cookers
- Thus proving hydrogen’s credentials as a low carbon vector

Hydrogen: how to proceed

- **Subsequently start to investigate time shifting of local networks by both their interconnection and inclusion of storage via**
  - **Re-purposed natural gas or other hydrocarbon lines**
  - **New HP hydrogen lines**

- **To**
  - **existing redundant gas fields e.g. Cousland Scotland's first natural gas field**
  - **redundant off shore**
  - **newly washed out salt caverns**

Hydrogen: how to proceed

- **In summary, hydrogen is ideal for local connections:**
  - **Identify an enthusiastic LOCAL community (without gas?)**
  - **Build LOCAL hydrogen production on the back of power generation but with construction of local infrastructure for domestic (1000 houses), commercial and transport use**
  - **Interconnect LOCAL networks to each other and storage to provide a very level of community de-carbonisation, with hydrogen production operational either continuously (if nuclear or fossil plus CCS) or following the vagaries of renewable power.**