The Hydrogen Economy

A Blast from the Past
OR
Rave from the Grave?

Dr Fred Starr FIMMM, MIMechE, C.Eng
“The only use for gas is as an easy and convenient way of committing suicide.”

A 1950s view from our rivals..... the CEGB

Gas only competes......

...........if its much cheaper
Lessons from the 50s, 60s and 70s

The Current Situation

Overlooked Technical Aspects in the Changeover to Hydrogen
Town Gas from Coal and Oil is different to Natural Gas

**Town Gas:**
- **55% H₂**, **19% CH₄**, **12% CO**, **4% CO₂**, **5% N₂**
- plus higher hydrocarbons

**North Sea Gas:**
- **92.5% CH₄**, **3.5% C₂H₆**, **2.6% N₂**
- plus higher hydrocarbons and CO₂

 Hydrogen is easy to produce from fossil fuels

Carbon Monoxide is highly poisonous
Horizontal Retorts

Heroic but Obsolete
Fulham Gasworks 1968
Continuous Vertical Retort
Launceston
Obsolescent
Obsolescent

In the 1950s the Gas Industry was slowly dying

Continuous Vertical Retort
Launceston
Sales of byproducts
Benzol, Creosote, Road Tar, Ammonium Sulphate were dead
## Relative Change in Price of Fuels to Domestic and Industrial Consumers

<table>
<thead>
<tr>
<th>FUEL</th>
<th>1950</th>
<th>1955</th>
<th>1960</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gas</td>
<td>100</td>
<td>135</td>
<td>173</td>
</tr>
<tr>
<td>Electricity</td>
<td>100</td>
<td>112</td>
<td>123</td>
</tr>
<tr>
<td>Oil</td>
<td>100</td>
<td>131</td>
<td>141</td>
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Decline in Gas Competitiveness
1950-60

Ratio of Electricity to Gas Prices
The Fifties: Decade of Stagnation??

Therms of Gas Sold Annually

Around 9000 MW
The Fifties: Decade of Stagnation??

Electricity Doubled its Output Over this Period

Around 9000 MW
Switching Away from Coking Coal

1. Use oil to boost output and gas quality of producer gas plants

2. Develop semi-continuous catalytic processes using heavy oil or refinery products

3. Use refinery or imported natural gas in continuous catalytic steam reforming processes

4. Build and assess the high pressure Lurgi Coal Gasifier
Switching Away from Coking Coal

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4. Build and assess the high pressure Lurgi Coal Gasifier
ICI Steam Reformers: Billingham 1962
Designed to make hydrogen for ammonia synthesis
Used cheap naphtha rather than natural gas
Benfield CO2 Removal Units

Steam Reformers

The endothermic reforming reaction makes for a very efficient process.

CO2 removal by the Benfield Process is ideal for CCS.

But........ Purifying hydrogen to 99.99% for PEM Fuel Cells has an impact on costs and efficiency.

ICL Gas Making
Granton, Edinburgh
Just Turn a Knob to control

- Fuel input to reformer burners
- Steam – to - naphtha ratio
- Inlet temperature to shift converter
- Plant pressure
Energy Price Advantage of Gas over Electricity


Electricity to Gas Price Ratio

- 1950: 2.6
- 1954: 2.4
- 1958: 2.2
- 1962: 2.0
- 1966: 1.8

The graph shows a decline in the electricity to gas price ratio from 1950 to 1966, indicating a growing advantage of gas over electricity in terms of price.
Energy Price Advantage of Gas over Electricity

Electricity to Gas Price Ratio

Year


Obsolescent Retort Gasmaking

Steam Naphtha Reforming

Oil Based Processes
East Anglia
High Pressure Pipeline System
for distribution of town gas
1966

Supplied by reformers
at
Hitchin
Chelmsford
and
Watford
Impact of the New Oil Based Processes
1962-66

Annual Increase in Gas Sales
1960s Central Heating
When Gas was Expensive

Radiator to give air temperature of 18°C

Gas Fire to give added and immediate warmth
The absence of hydrogen in Natural Gas results in badly burning flames.
The Conversion of Homes and Businesses to North Sea Gas 1967-74
Sir Dennis Rooke
Chairman of British Gas
The Conversion to Natural Gas in 12 Million Homes: “The Greatest Peacetime Operation Ever”

Cost: £500 Million

Around £1100 per household at today’s prices

But the consumer did not pay

British Gas had a monopoly

Bought at 5d/therm, then sold it at 20 d/therm

In Modern Money

Buy at 1.99p/kWh ……Sell at 7.96 p/kWh
North Sea Gas (Conversion Programme)

HC Deb 05 November 1968 vol 772 cc665-6

4. **Sir B. Rhys Williams** asked the Minister of Power if he will make a statement on his consultations with the Gas Council on the problems involved in the conversion of consumers to North Sea gas.

**The Parliamentary Secretary to the Ministry of Power (Mr. Reginald Freeson)** The main conversion programme began this year and about 250,000 consumers have been dealt with. The Gas Council have informed my right hon. Friend that a small number of consumers have suffered real inconvenience, but the boards are trying hard to overcome it in difficulties so that the operation is carried out smoothly and efficiently.

**Sir B. Rhys Williams** Is my hon. Friend aware that there is widespread public feeling that insufficient has been done to inform consumers, particularly domestic consumers, of their rights? What steps does he propose to take to remedy this?

**Mr. Freeson** That is not my experience. I have been around a number of Gas Boards, and I am aware of the tremendous efforts which are being made to ensure excellent public relations and information services in this matter. If the hon. Member has a particular case in mind, no doubt he will get in touch with us.

**Mr. David Watkins** Is my hon. Friend aware that considerably more than 30 million appliances will have to be converted? Is he satisfied that the Gas Council is geared to this immense task without causing too much inconvenience to consumers?

**Mr. Freeson** In a massive operation of this kind, there is bound to be some inconvenience, considering the large number of consumers involved, but we are satisfied that the Gas Council and the boards are well organised for this purpose. There are proposals to strengthen the central organisation in connection with the absorption of natural gas.

**Mr. Emery** The Minister said that a small number of consumers had been inconvenienced. What number does he mean by "a small number?"

**Mr. Freeson** I am not in a position to quote the specific figure.
Will it be a nine-day wonder?

Why does everybody have to have their gas appliances converted?

No. Already enough gas has been discovered to supply the industry's present sales for more than 120 years. What is more, the exploration has only just started, and experts are sure of finding much greater reserves under the waters of the North Sea.
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Not a penny. The Board bears the complete cost of conversion, which they estimate will work out at around £30 per householder. Moreover, from C-day your gas will be cheaper.

Yes; but the Board will try to minimise the inconvenience and to convert all appliances as quickly as possible.
She wanted to know what will it cost her

Nothing in 1970

What will be the cost of conversion to hydrogen?

NOT a penny. The Board bears the complete cost of conversion, which they estimate will work out at around £30 per householder. Moreover, from C-day your gas will be cheaper.

YES; but the Board will try to minimise the inconvenience and to convert all appliances as quickly as possible.
Moving to the Hydrogen Economy

How the Gas Industry has Changed

• Replaced coal as the driver of the British Economy
• Loss of expertise and engineering judgement
• Gas holders have gone
• Vast high strength steel transmission pipeline network
• Burners designed for natural gas
• NOx from burners (16 % of emissions) is a coming issue
• Polyethylene distribution system
Hydrogen’s Biggest Question

Can we use the existing infrastructure?

Neglected or Overstated Issues

- Loss of Storage Capacity
- Long Distance Transmission
- Hydrogen Embrittlement
- CCGT Plant Loss of Efficiency
- Hydrogen must be made smelly
- Domestic and Industrial Burners
- The Challenge of Electricity
Gas Supplies 50% of British Electricity

- Gas: 136 TWh
- Wind etc: 69 TWh
- Nuclear: 65 TWh
- Thermal Renewables: -32 TWh
- Coal: 17 TWh

(TWh)
Natural Gas Usage
TWh

Domestic - 309
Power Stations – 273

Averaging 97 Giga Watts
2.8 times electricity
Natural Gas Usage
TWh

Domestic - 309
Power Stations – 273

Into Electricity - 123

Averaging 97 Giga Watts
2.8 times electricity
Gas Holders are Being Scrapped

Total Reliance on Pipeline Storage ??????
Alrewas Compressor Station and the Pipeline Network
Thyssenkruppe Modules for Electrolytic Hydrogen

Capital cost: Similar to CCGT?

Excludes compressor...I expect!
Compressor Stations for Natural Gas and Hydrogen

Natural Gas - 80 km Separation

Hydrogen: More Stations for the Same Energy Flows – c.30 km Separation

Hydrogen

Has to flow faster – bigger pressure drops
Lighter, less dense gas – More difficult to compress in compressor stations

Redesign of Compressors and Power Units Needed
Compressor Stations for Natural Gas and Hydrogen

Natural Gas - 80 km Separation

Hydrogen: More Stations for the Same Energy Flows – c.30 km Separation

- Hydrogen has to flow faster, leading to larger pressure drops.
- It is lighter, less dense gas, making it more difficult to compress in compressor stations.

Redesign of Compressors and Power Units Needed

Alternative: Position most electrolysis “factories” next to CCGT power plants
Existing Pipelines and Hydrogen Embrittlement

Hydrogen induced cracking
(close up)
Professor Ernest Shannon

Professor Ernest Shannon, who died on September 2 aged 73, was an engineer who developed a revolutionary breed of pipeline “pig” – sensors that detect cracks and scrapes in gas networks before such problems lead to catastrophic ruptures.

The British Gas Expert on Fracture in Pipelines

6:41PM BST 20 Sep 2011

His work was prompted in the 1970s by a series of devastating explosions, particularly in America, where fractures more than 10 miles long had ripped along pipes at speeds of up to 2,000 metres per second.
Shannon’s Opinion on Hydrogen Embrittlement (1)

Always been an issue in British Gas

Because pipelines are cathodically protected against corrosion

Atomic hydrogen generated at pipeline surfaces

Atomic hydrogen is a very small atom that diffuses into the steel

The atoms of hydrogen recombine at sub-microscopic defects in the steel creating hydrogen gas

This cannot escape and very high pressures are created within the steel

This leads to cracking
The pressures generated in cracks through cathodic protection are likely to be far higher than hydrogen pipeline pressures.

Didn’t see to see a problem with hydrogen with older X60 type steels.

But the stronger 80 steels may be more susceptible.

Note:

Stresses in pipelines are about 70% of the tensile strength of the steel.

This permits very high gas pressures.
If there is a problem with hydrogen. I suggest …..

Derating pipeline pressures

This will:

Reduce the take up of hydrogen in the steel

Reduce the stress in the pipeline

Reduce risk of mile long fracture incidents
If there is a problem with hydrogen, I suggest derating pipeline pressures. This will:

- Reduce the take up of hydrogen in the steel
- Reduce the stress in the pipeline
- Reduce risk of mile long fracture incidents

Don’t panic! Don’t panic!
My Own View (2)

We are doomed to unnecessary expense and concern if we don’t do a sensibly targeted R&D programme to assess the effect of hydrogen pressure in pipelines on

- Tensile and yield strength etc
- Fatigue properties
- Fracture toughness in the steel and weldments

Finally…… we need to know whether working at reduced pressures and hoop stresses will eliminate risk of fast fracture in hydrogen contaminated pipeline steels
Finally, we need to know whether working at reduced pressures and hoop stresses will eliminate risk of fast fracture in hydrogen contaminated pipeline steels. We are doomed to unnecessary expense and concern if we don't do a sensibly targeted R&D programme to assess the effect of hydrogen pressure in pipelines on...
Energy Flow Chart 2018
(million tonnes of oil equivalent)

Gas
Coal
Oil

Energy for Transport 57.0 Mt – Domestic 41.2 Mt
Realistic Markets for Hydrogen
Target Markets for Renewable Hydrogen

Hydrogen from electrolysis has to be more expensive than the electricity from which it is made.

Domestic Heating by Hydrogen – A Pipedream

Energy cost higher than electric
Less efficient in providing heat
Billions for burner replacements
Start, then stop market for equipment suppliers
Needs vote losing political decisions
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Why should generating plants subsidise a competitor for domestic heating?
Heating the British House of the Future

Halogen or Infrared Radiant Heaters for Instant Warmth

For background heating

Electric Storage Heaters
or

Loft Storage of Hot Water (c. 40 kWh /cu metre)
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Hydrogen fuelled CCGTs provide back up to wind and solar renewables
Main Use for Electrolitic Hydrogen

Fuel for CCGTs providing back up to wind and solar

60% Efficiency  Quick Response  Fuel Cells Eventually
Cars and Trucks – Great Prospects

Huge market

Currently uses “dirty” 19th Century prime movers

Fuel cells halve energy use - even after losses

Fast refuelling ability

Rapid and continuous advance in car models

Reduces oil imports
Conclusions

Electrolytic hydrogen will cost more than electricity

Significant loss of storage capacity

Existing pipeline compressors will need replacement

Don’t worry too much about hydrogen embrittlement

Transport presents better opportunities than the domestic sector

Hydrogen fuelled CCGTs or large scale Fuel Cell units will be needed to provide back up to renewables

Locate Hydrogen Electrolysis Factories close to CCGTs
He was plying me with questions .... Have you any?

Thank you

The End
Lower Heating value hydrogen 119.96 MJ kg

MJ = 0.28 kWh

: 1 kg H2 = 33.56 kWh

1 ton H2 = 33.56 MWh

= 1 MWh = 1 ton/ 33.56 = 0.0298 tonnes

1 GWh = 29.8 tonnes hydrogen

= 9 X 29.8 tonnes water = 268 tonnes water

= 1 GW Hydrogen Plant = 268 tonnes water per hour

= c.4.5 cu metres / min
Hydrogen
290 and 343 BTU /cu ft

Assume Gas holder is 1 million cu ft

On higher heating value = 343 million Btu

\[
\begin{align*}
1 & \quad = \quad 0.000293071 \\
343000000 & \quad \times \quad = \quad 100523.377069 \\
\text{British thermal unit} & \quad \text{Kilowatt hour} & \quad \text{Kilowatt hour}
\end{align*}
\]

= 100.5 MW

Length of pipeline 4760 miles = 25,132,800 ft = 25 million ft

If pipelines 3ft diameter = Cross section = 9 \times 3.14/4 = 7.065

Total volume = 25000000 \times 7 = 175 million cu ft storage capacity

Assume average operating pressure = 60 bar = 10500 million cu ft storage capacity

Assume that 20% can be used for storage = 2100 million cu ft of storage capacity

c. 4 times gas holder storage