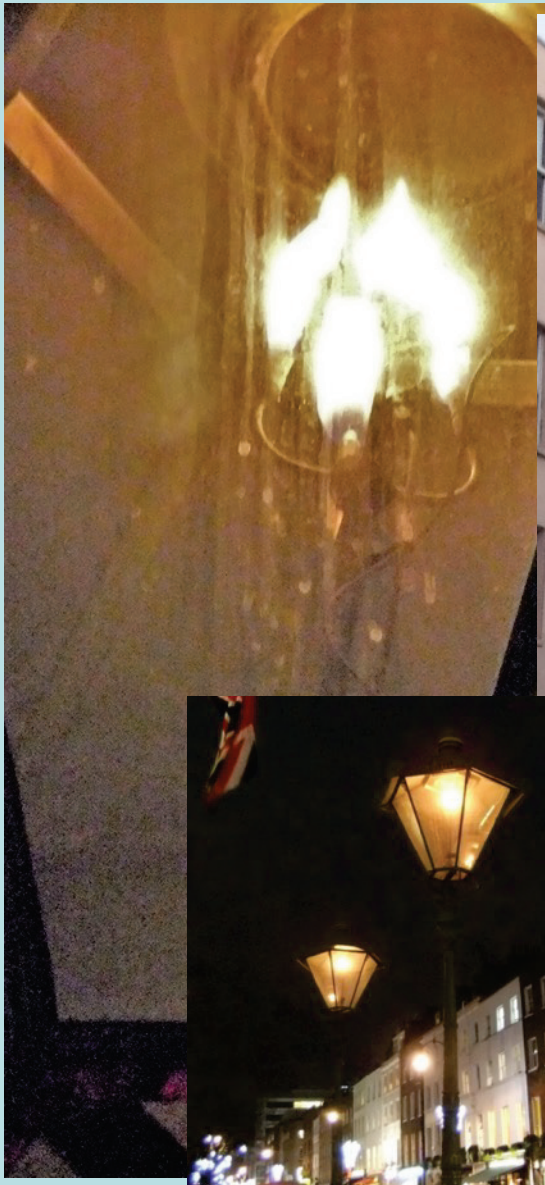
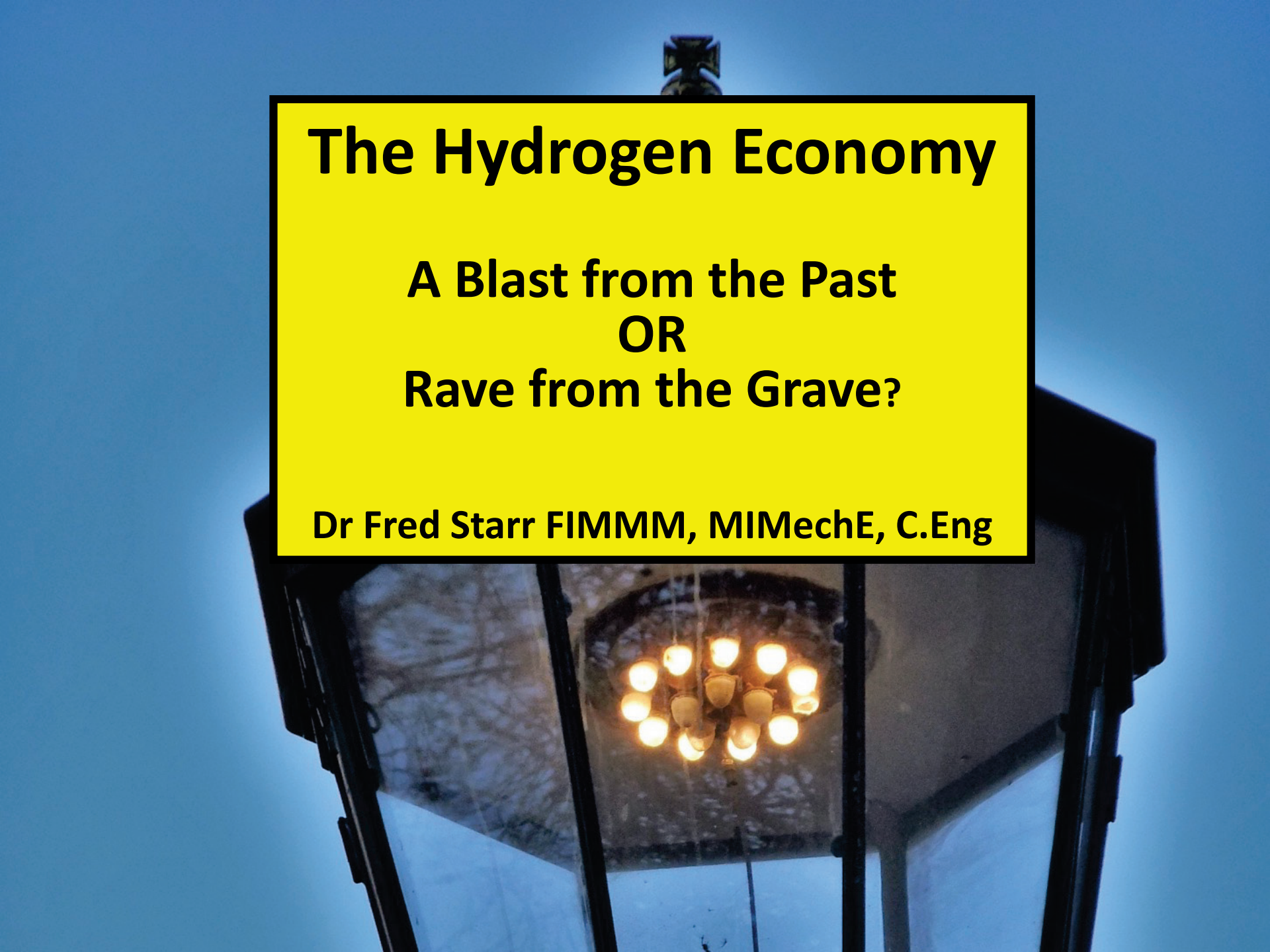
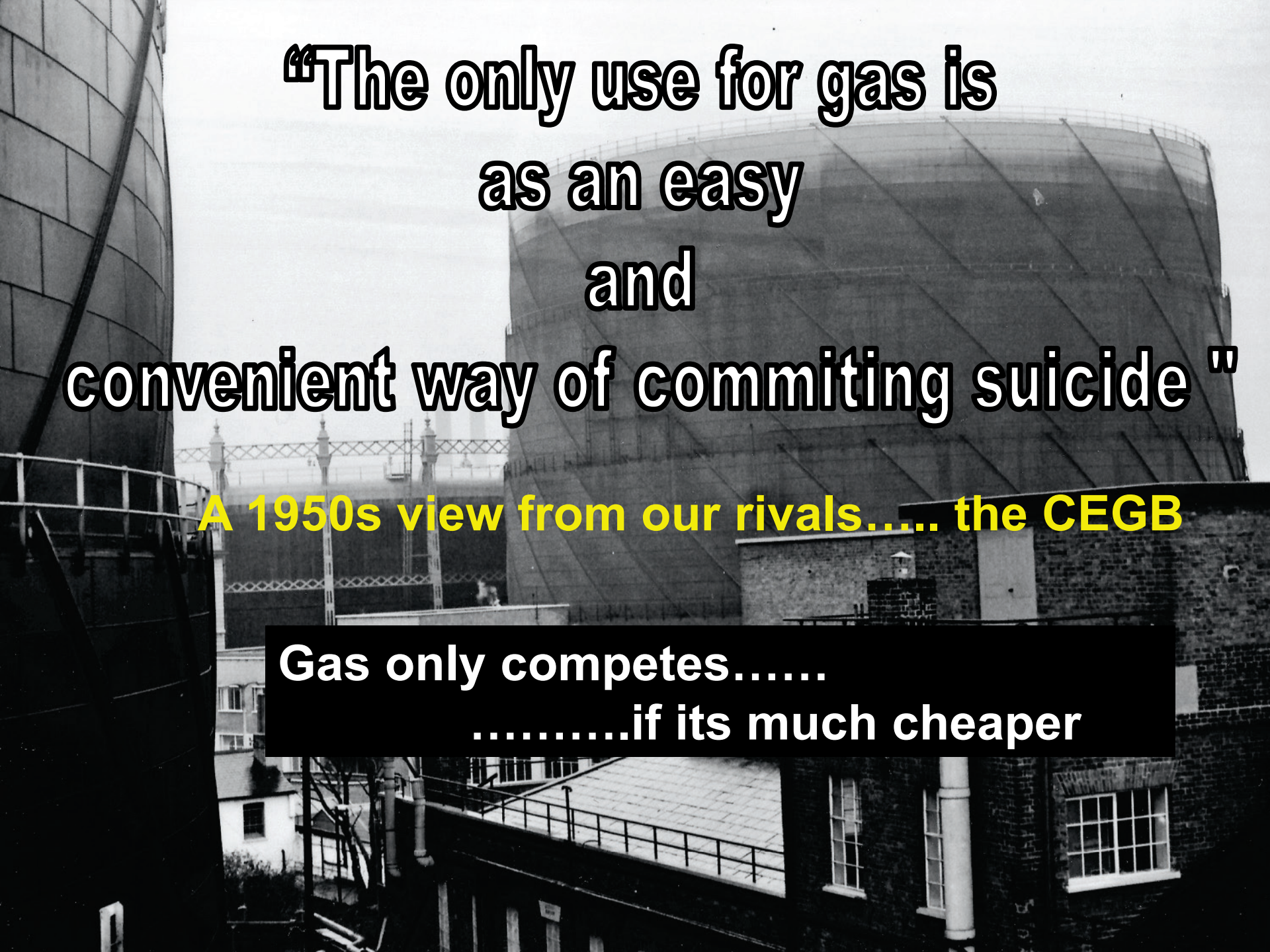




The Hydrogen Economy

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 commiting 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% H_2, 19%CH_4, **12% CO,** 4% CO_2, 5% N_2

plus higher hydrocarbons

North Sea Gas:

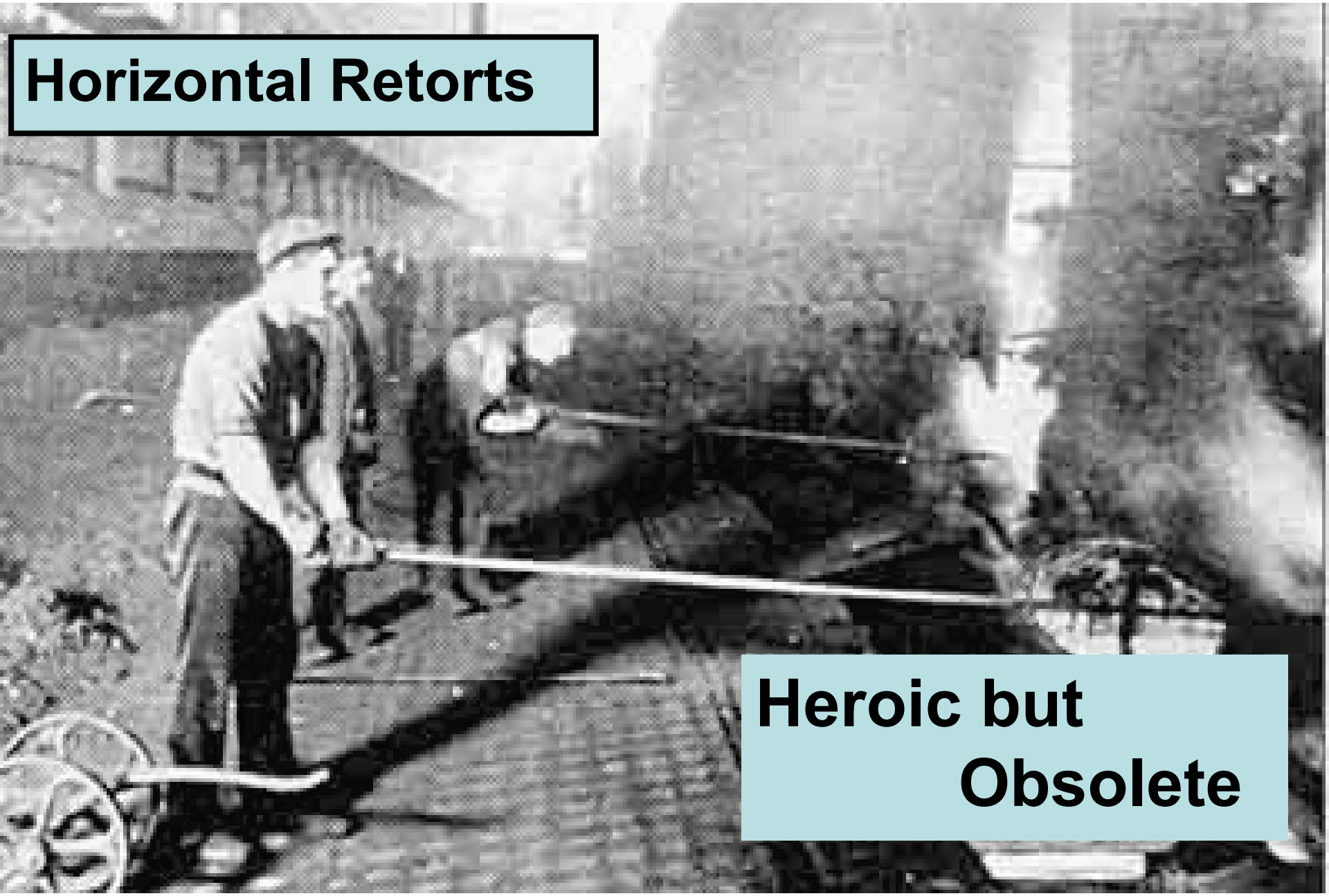
92.5% CH_4, 3.5% C_2H_6, 2.6% N_2

plus higher hydrocarbons and CO_2

Hydrogen is easy to produce from fossil fuels

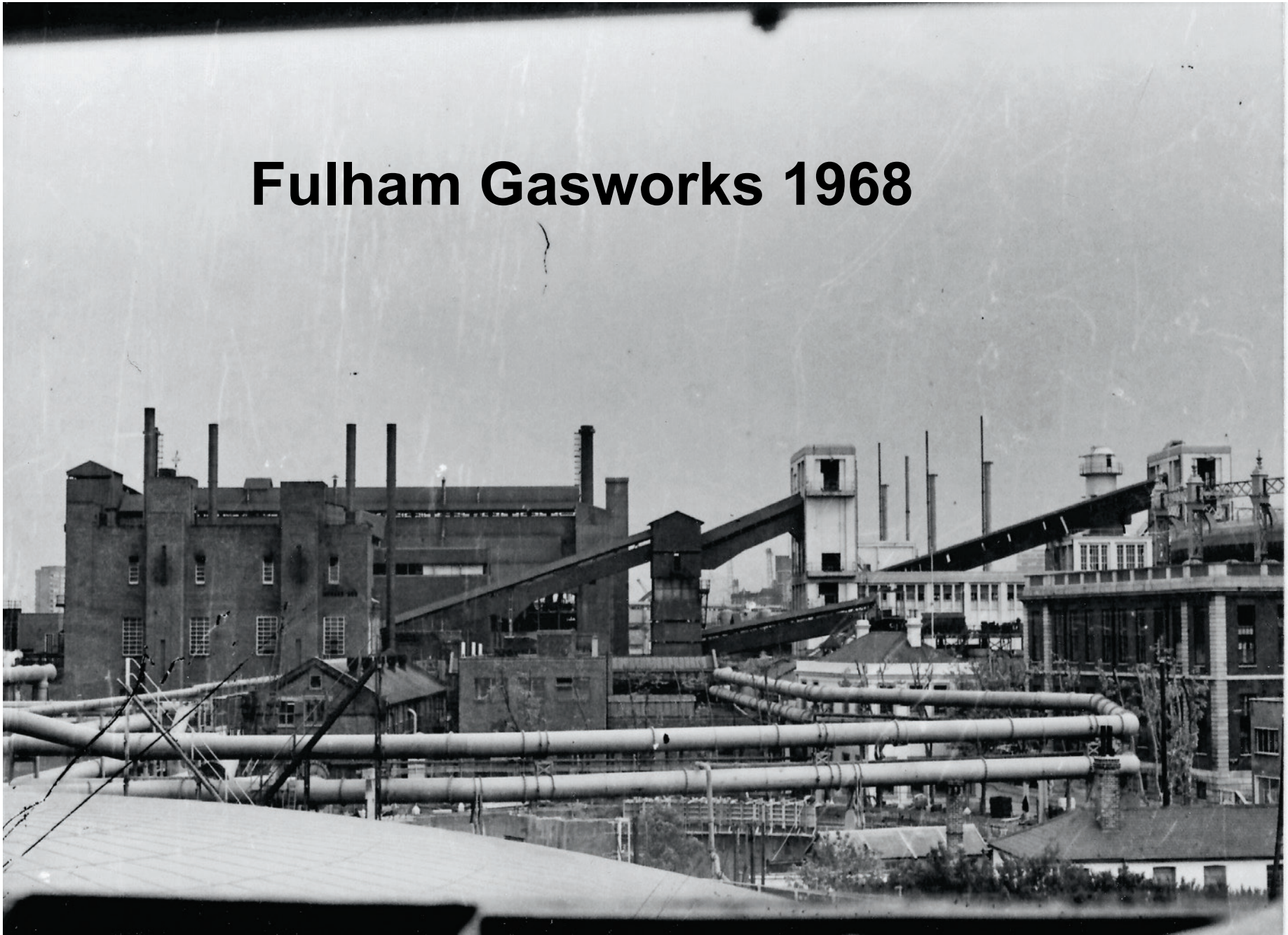
Carbon Monoxide is highly poisonous

Horizontal Retorts



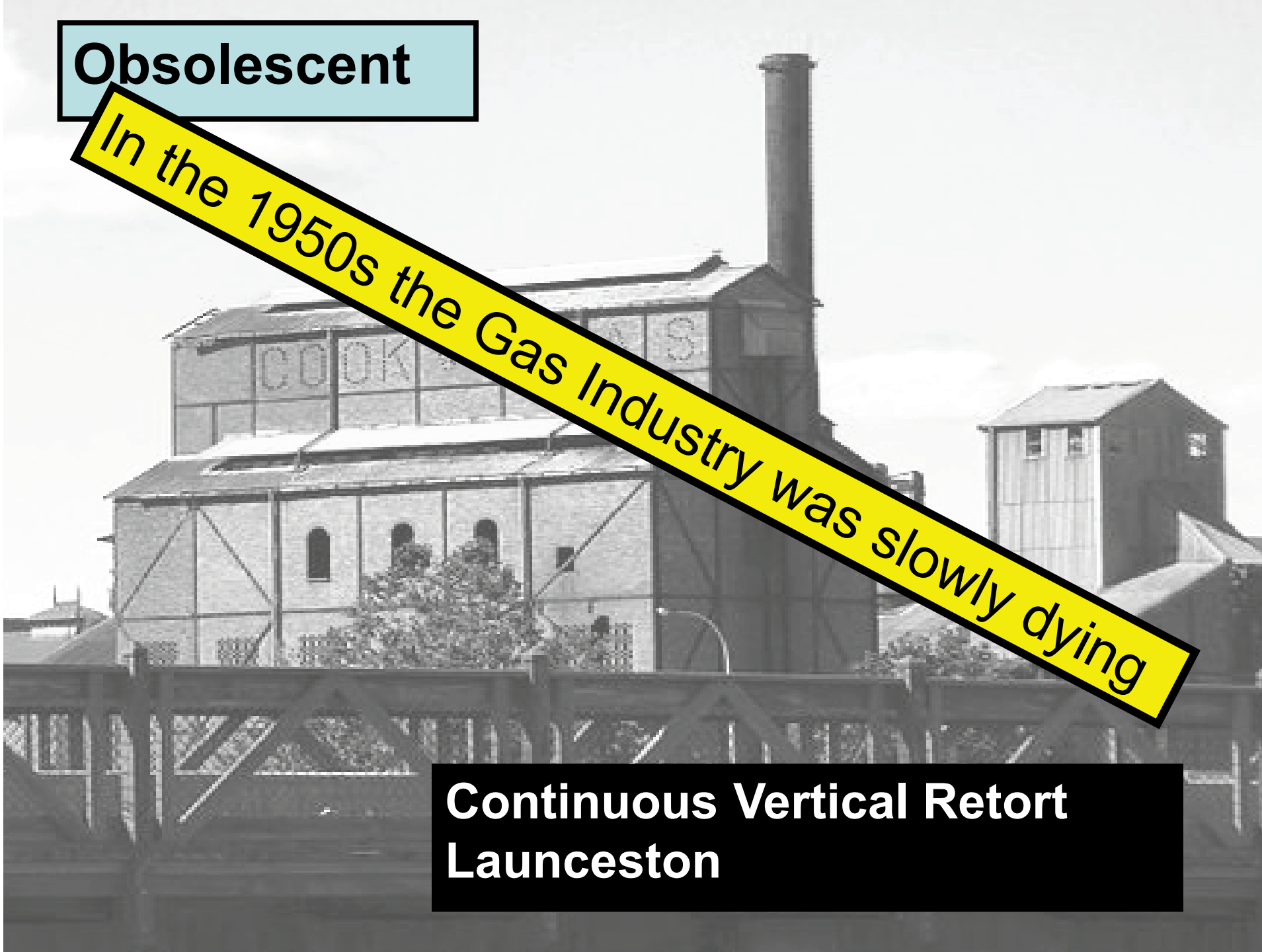
Heroic but Obsolete

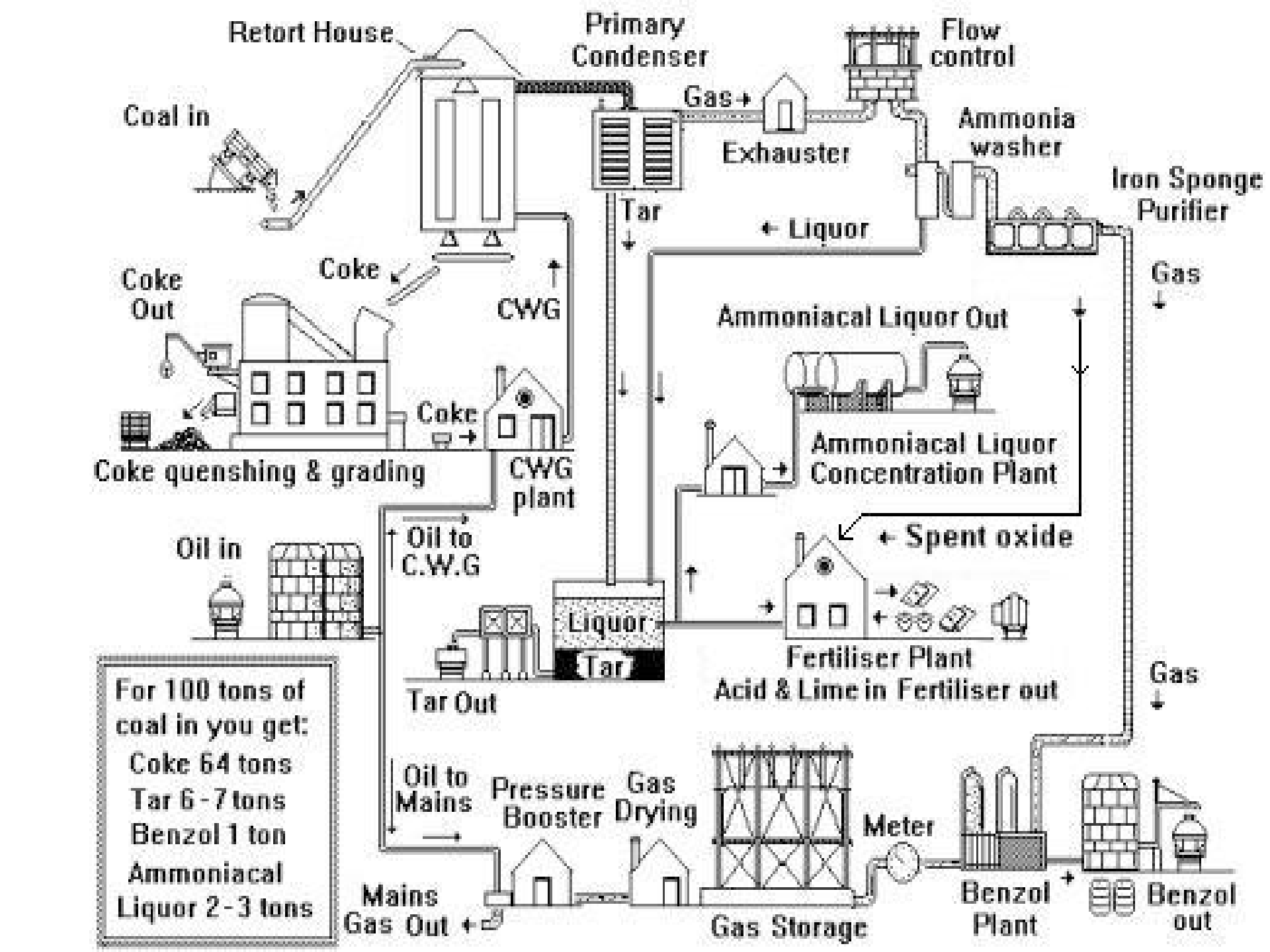
Fulham Gasworks 1968



Obsolescent

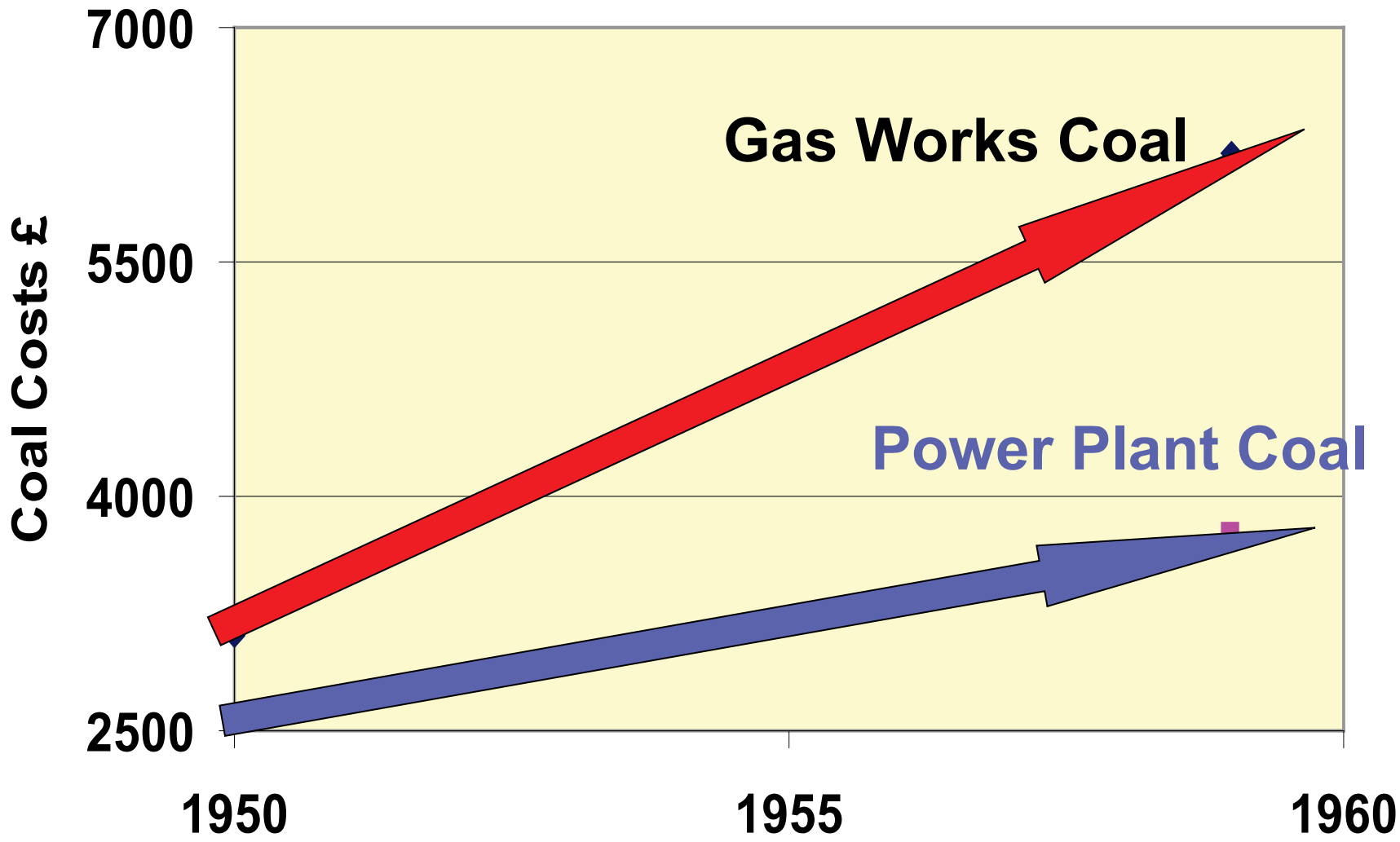
Continuous Vertical Retort
Launceston


Obsolescent
In the 1950s the Gas Industry was slowly dying
Continuous Vertical Retort
Launceston


Retort House
Primary Condenser
Flow control
Coal in
Gas
Exhauster
Ammonia washer
Iron Sponge Purifier
Tar
Liquor
Coke
Coke Out
CWG
Gas
Ammoniacal Liquor Out
Coke
Ammoniacal Liquor Concentration Plant
Coke quenshing & grading
CWG plant
Oil in
Oil to C.W.G
Spent oxide
Liquor
Tar
Fertiliser Plant
Acid & Lime in Fertiliser out
Tar Out
Gas
For 100 tons of coal in you get:
Coke 64 tons
Tar 6 - 7 tons
Benzol 1 ton
Ammoniacal Liquor 2 - 3 tons
Oil to Mains
Pressure Booster
Gas Drying
Meter
Mains Gas Out
Gas Storage
Benzol Plant
Benzol out

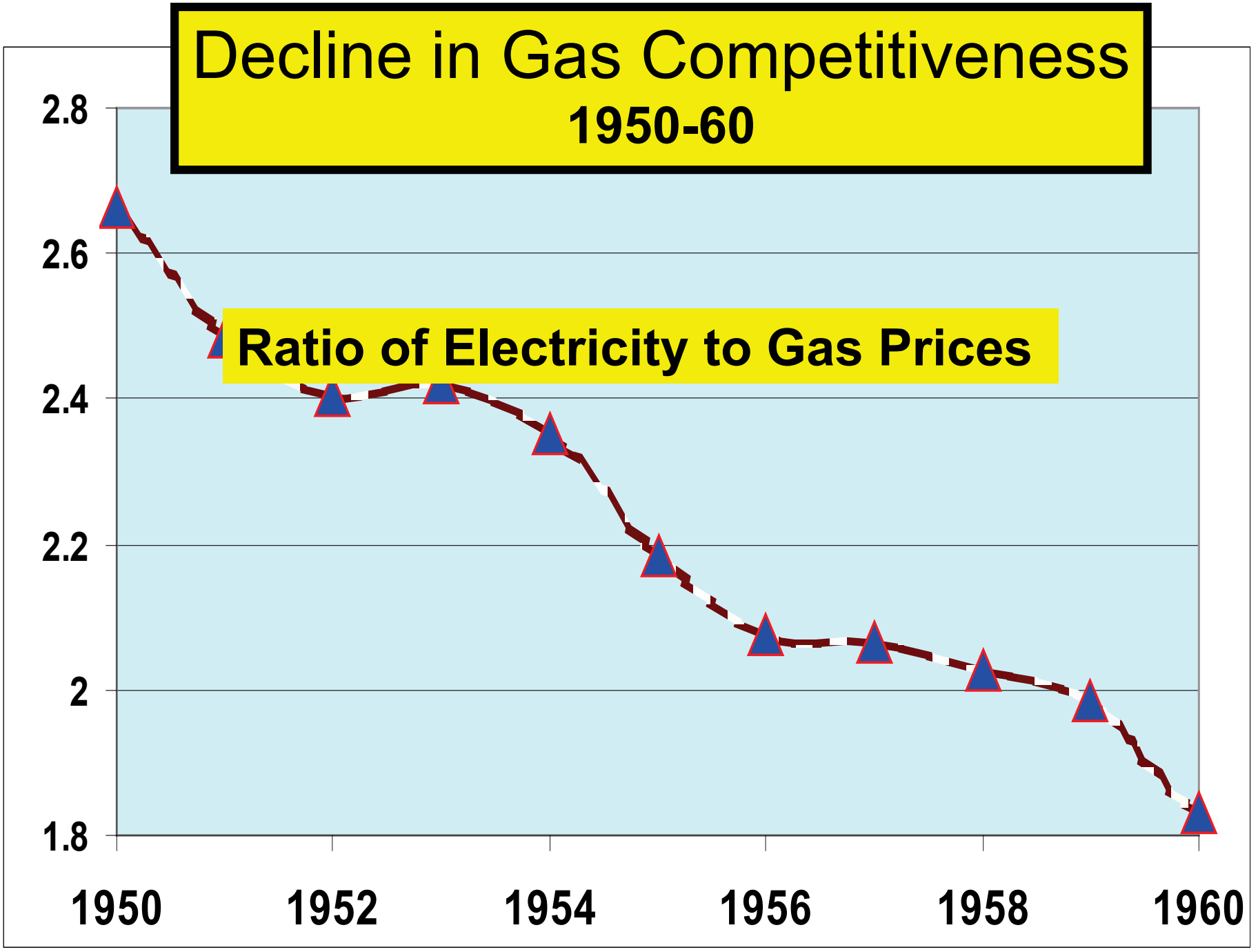
Sales of byproducts Benzol, Creosoate, Road Tar, Ammonium Sulphate were dead

Cost of 1000 Tonnes Coal 1950-59

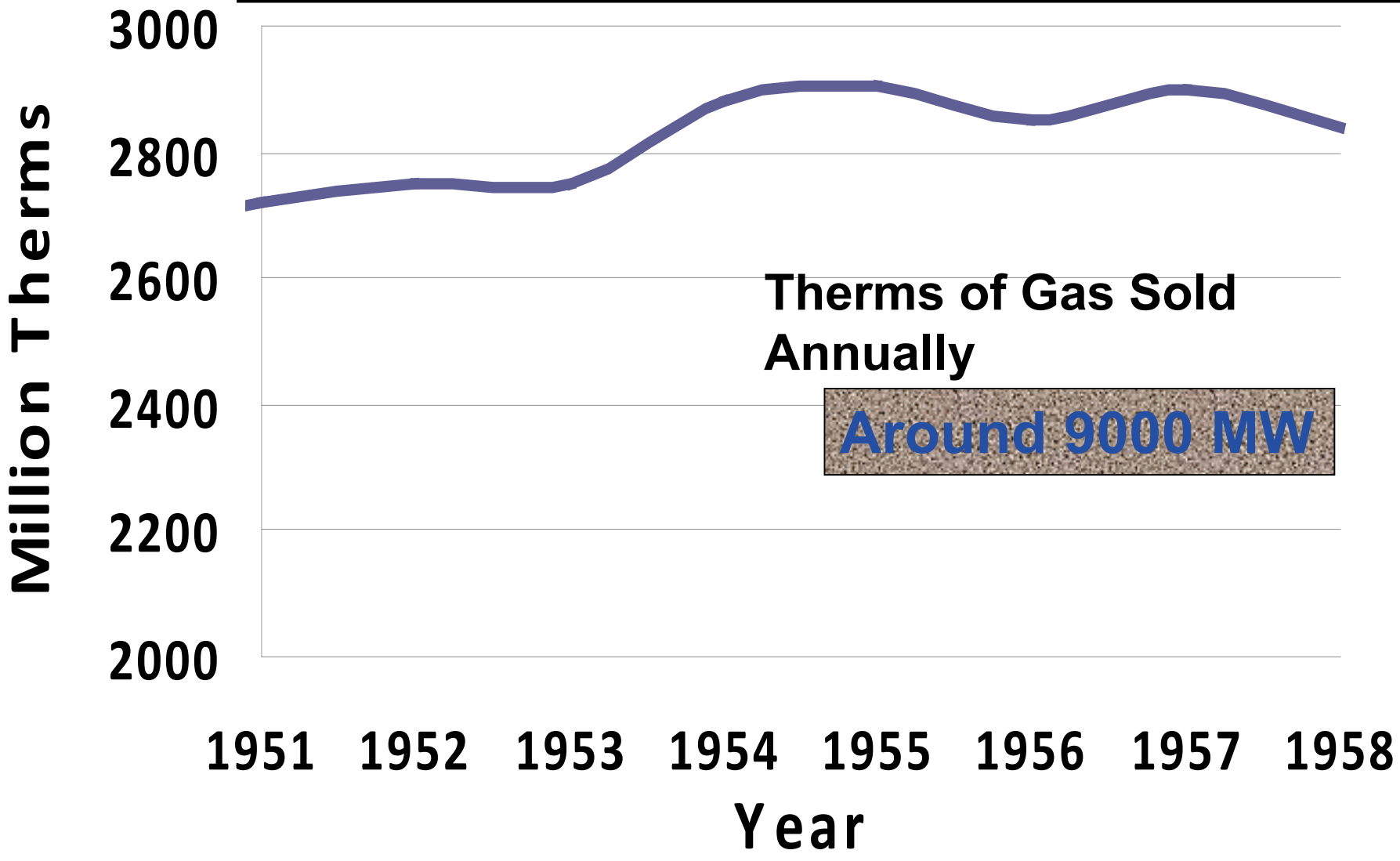


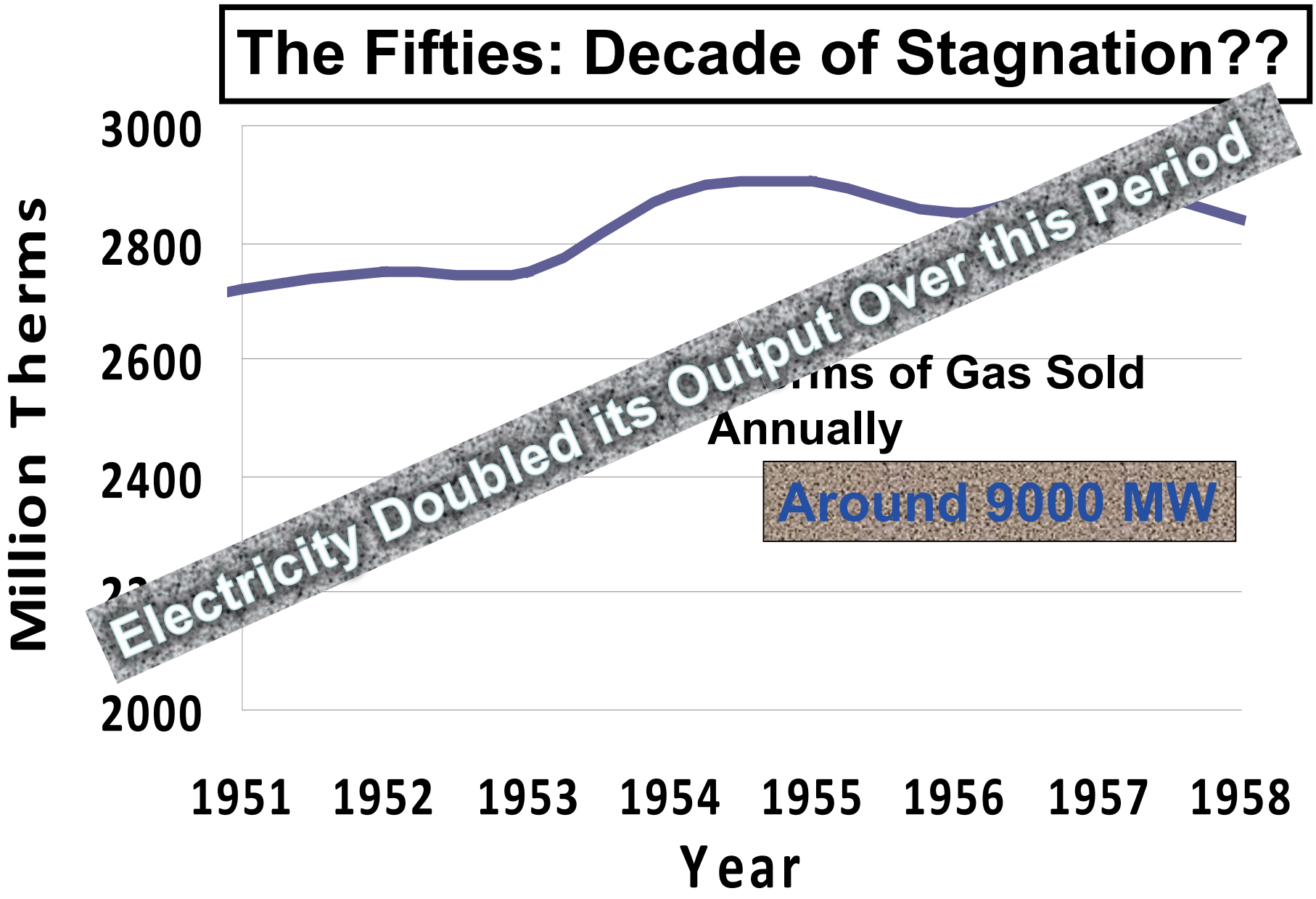
Relative Change in Price of Fuels to Domestic and Industrial Consumers

FUEL	1950	1955	1960
Gas	100	135	173
Electricity	100	112	123
Oil	100	131	141


Decline in Gas Competitiveness
1950-60
Ratio of Electricity to Gas Prices
2.8
2.6
2.4
2.2
2
1.8
1950
1952
1954
1956
1958
1960

The Fifties: Decade of Stagnation??




The Fifties: Decade of Stagnation??
Million Therms
3000
2800
2600
2400
2000
1951
1952
1953
1954
1955
1956
1957
1958
Year
Electricity Doubled its Output Over this Period
ms of Gas Sold
Annually
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

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

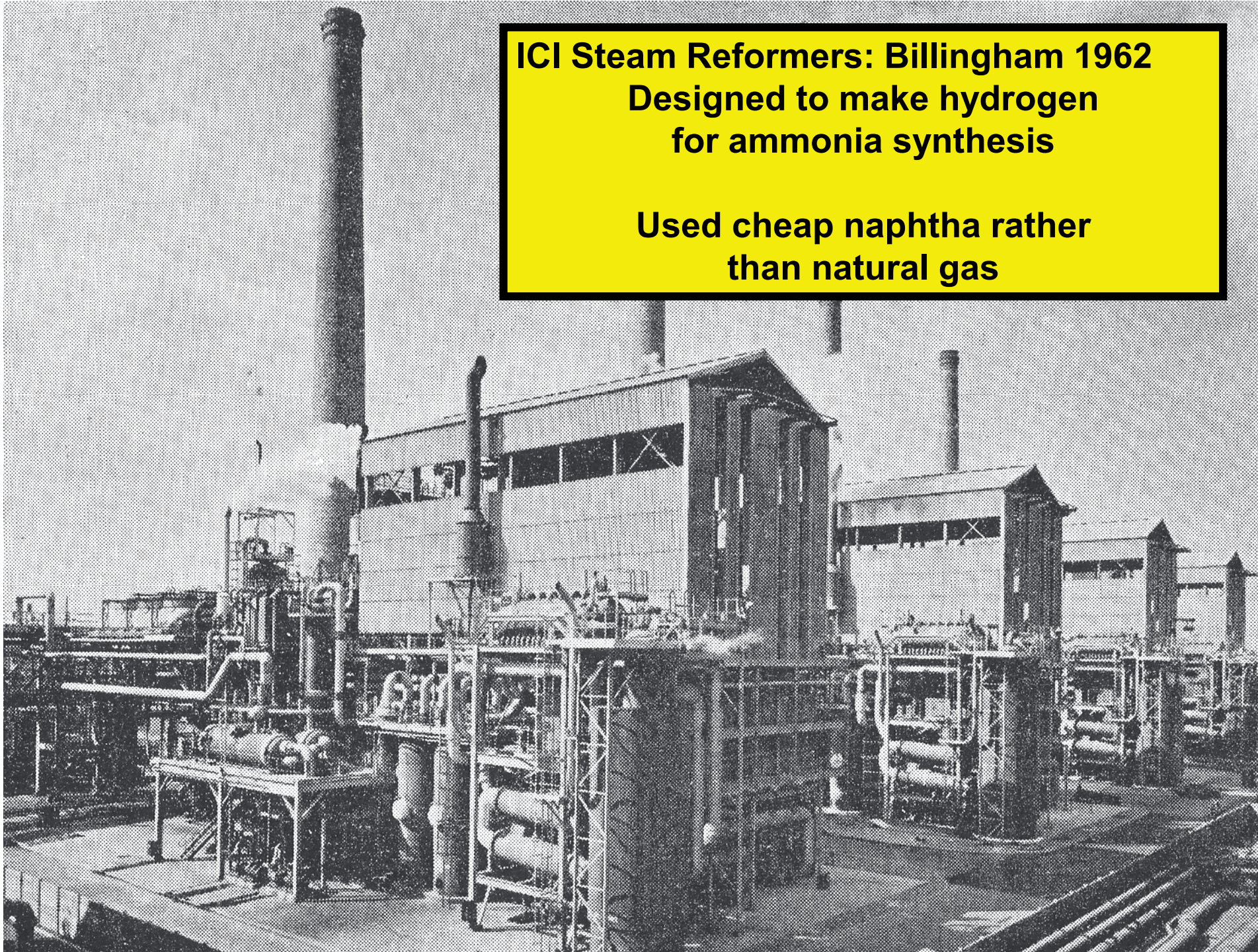
2. Develop **semi-continuous catalytic processes** using heavy oil or refinery products

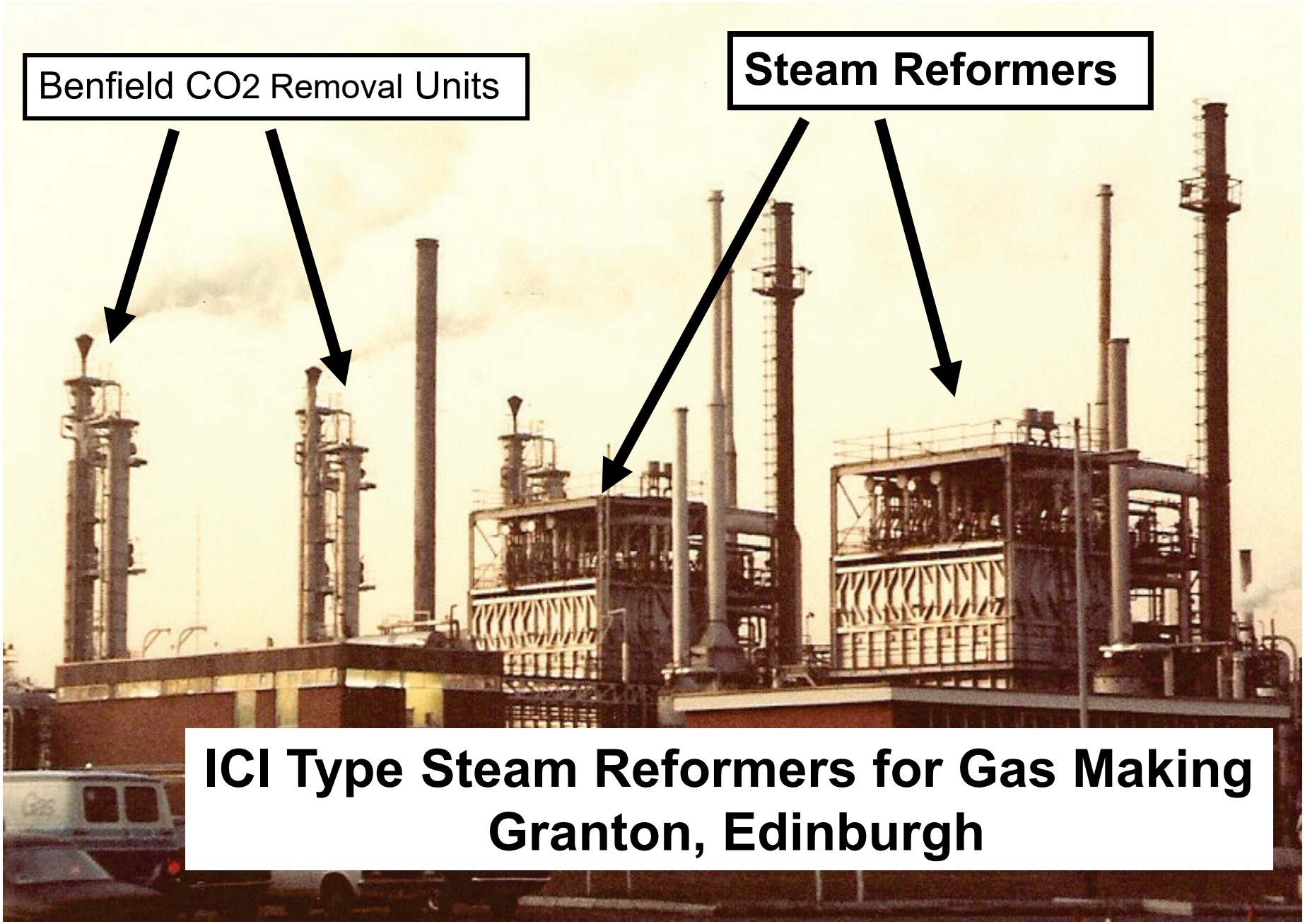
3. Use refinery or imported natural gas in **continuous catalytic steam reforming processes**

4. Build and assess the high pressure **Lurgi Coal Gasifier**

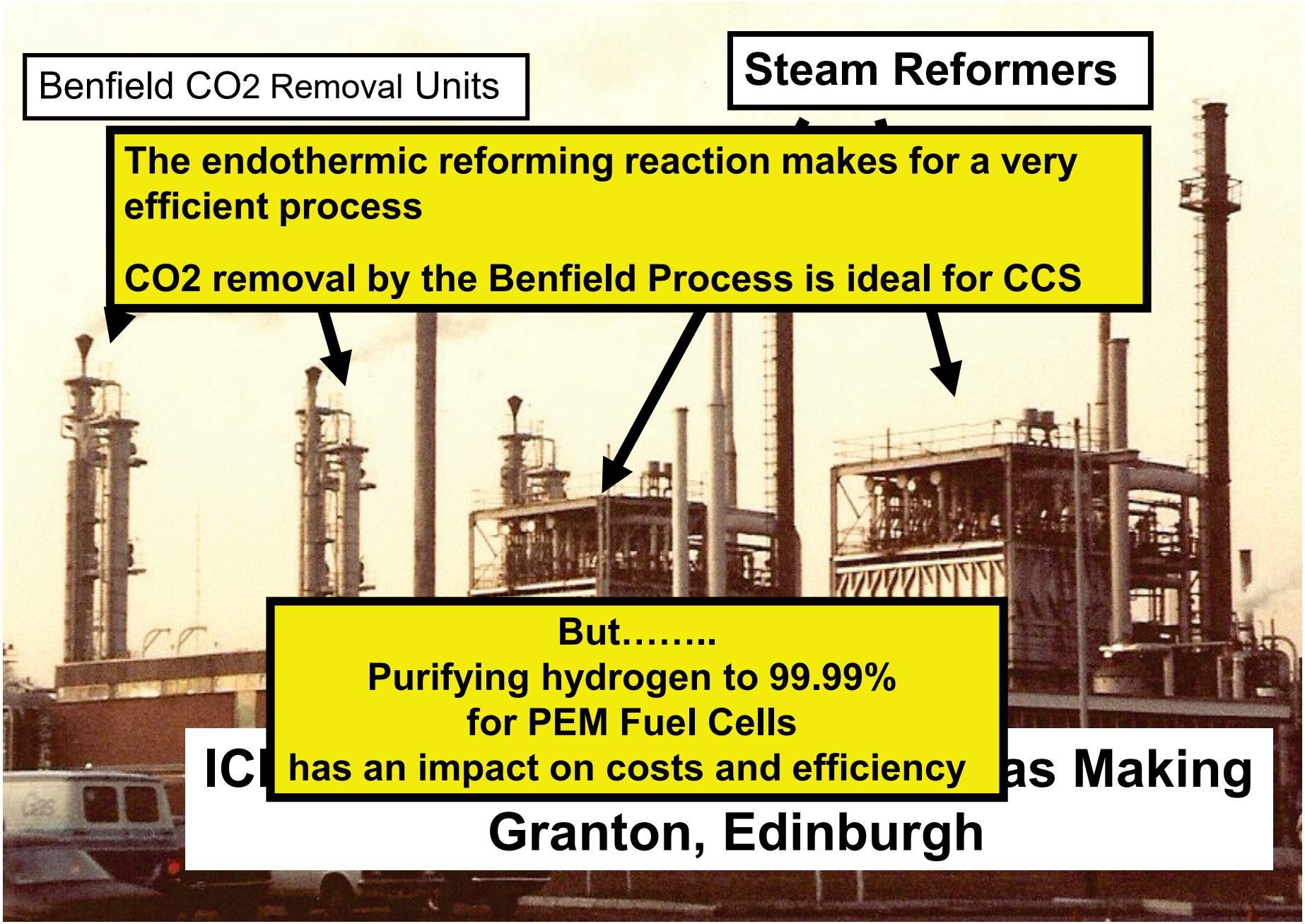
Target Price

Ten Old Pence per Therm


ICI Steam Reformers: Billingham 1962
Designed to make hydrogen
for ammonia synthesis
Used cheap naphtha rather
than natural gas

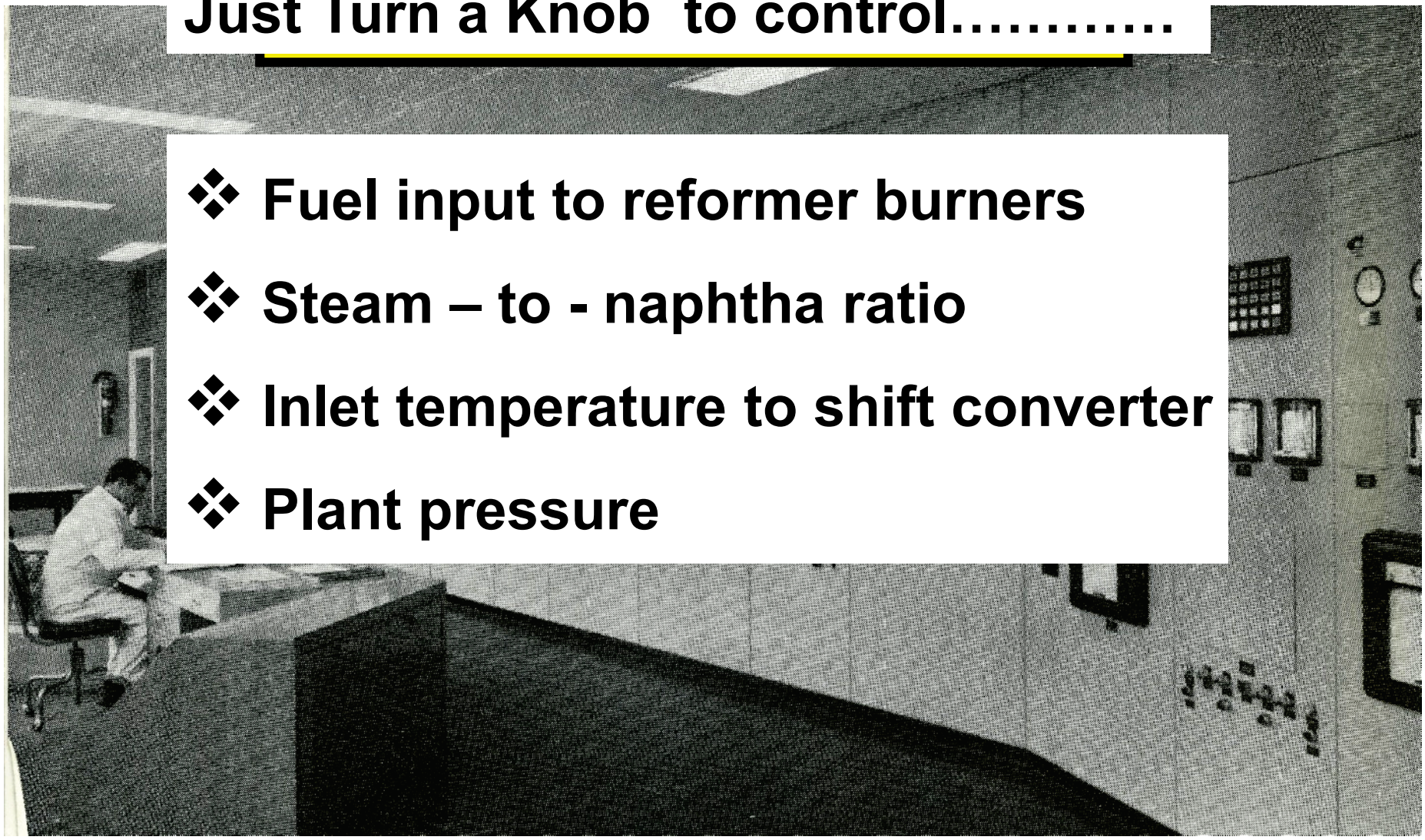


ICI Type Steam Reformers for Gas Making
Granton, Edinburgh

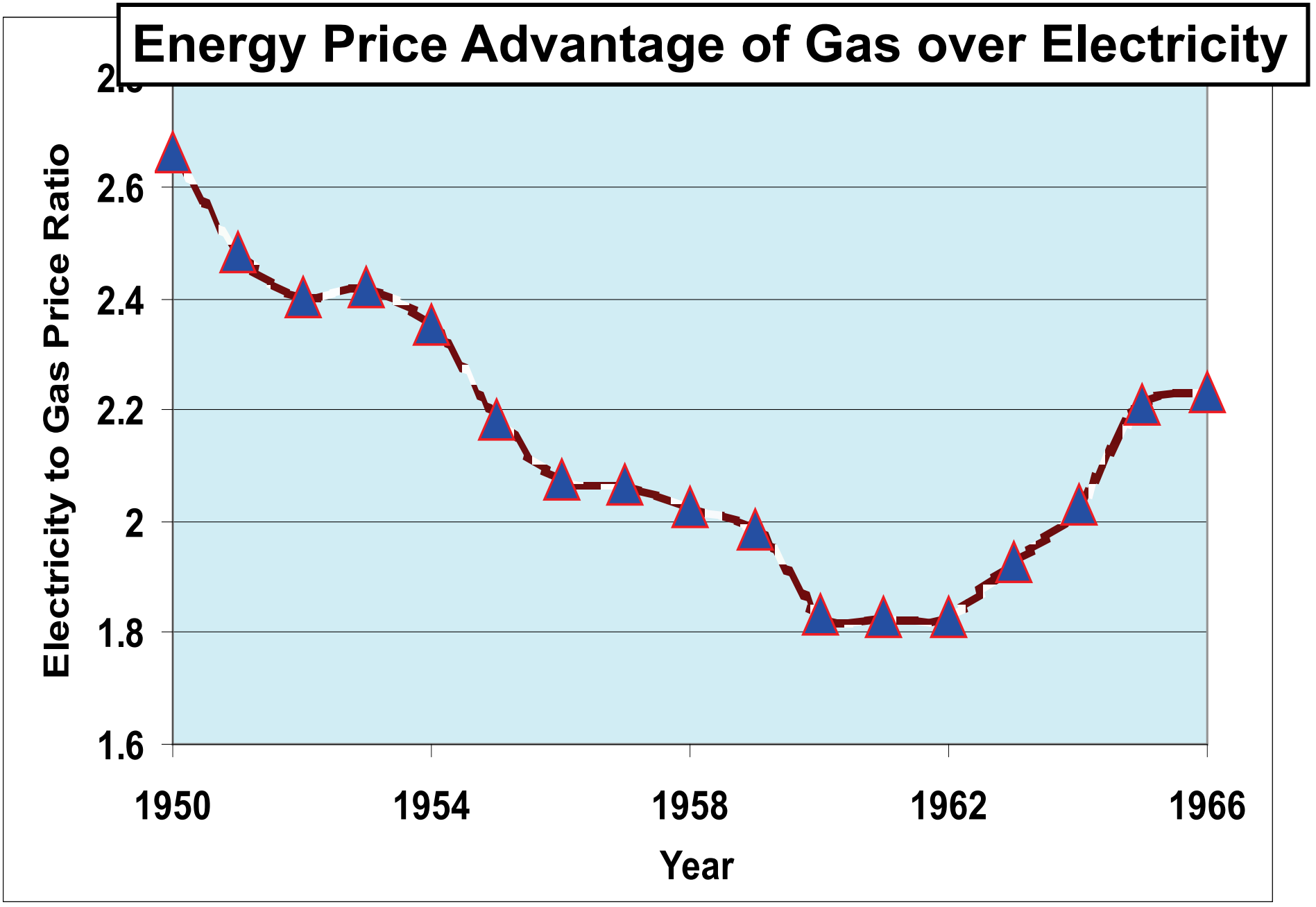

Benfield CO2 Removal Units
Steam Reformers
The endothermic reforming reaction makes for a very efficient process
CO2 removal by the Benfield Process is ideal for CCS
But……..
Purifying hydrogen to 99.99%
for PEM Fuel Cells
has an impact on costs and efficiency
IC as Making
Granton, Edinburgh

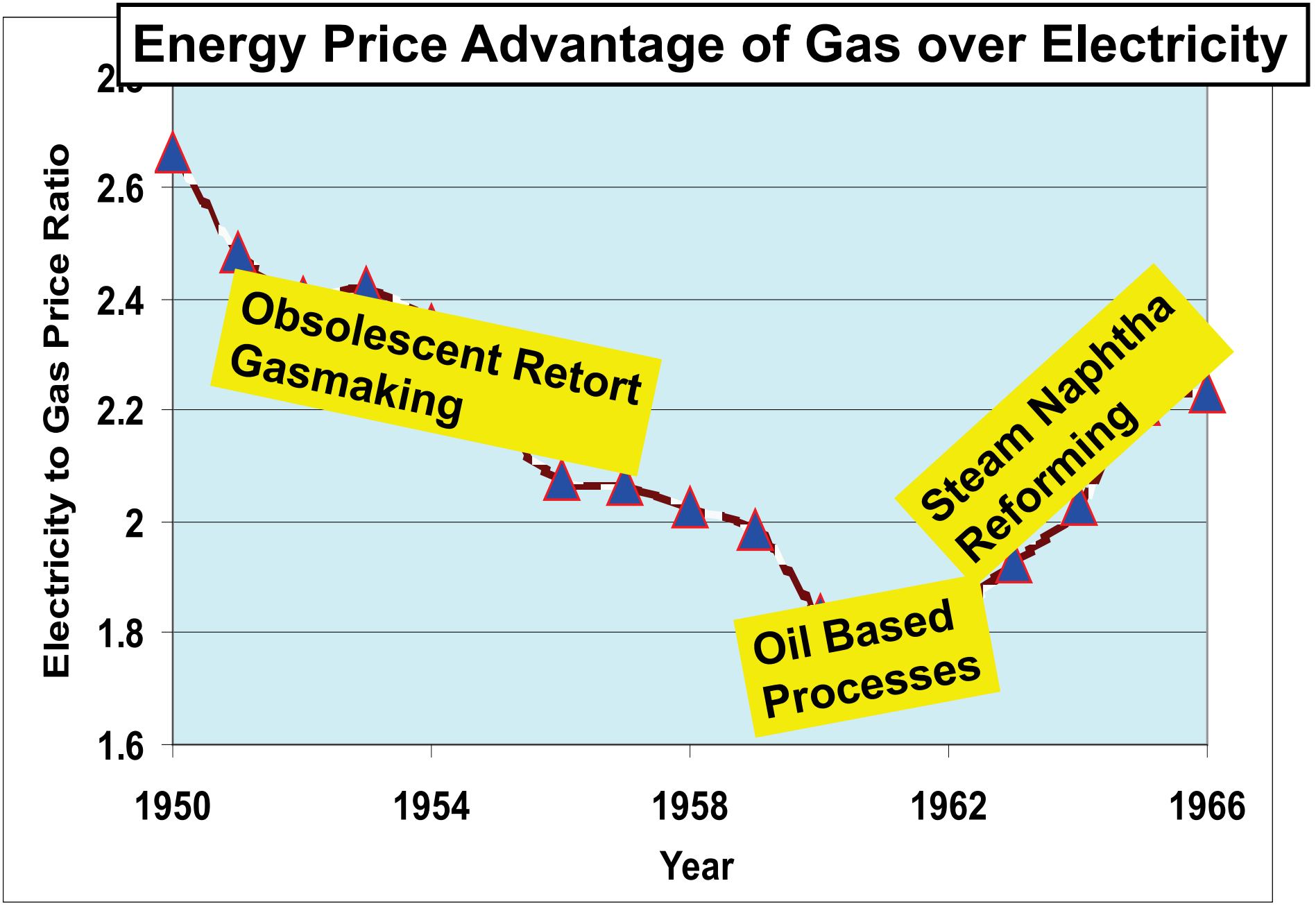
East Greenwich Control Room

Just Turn a Knob to control……



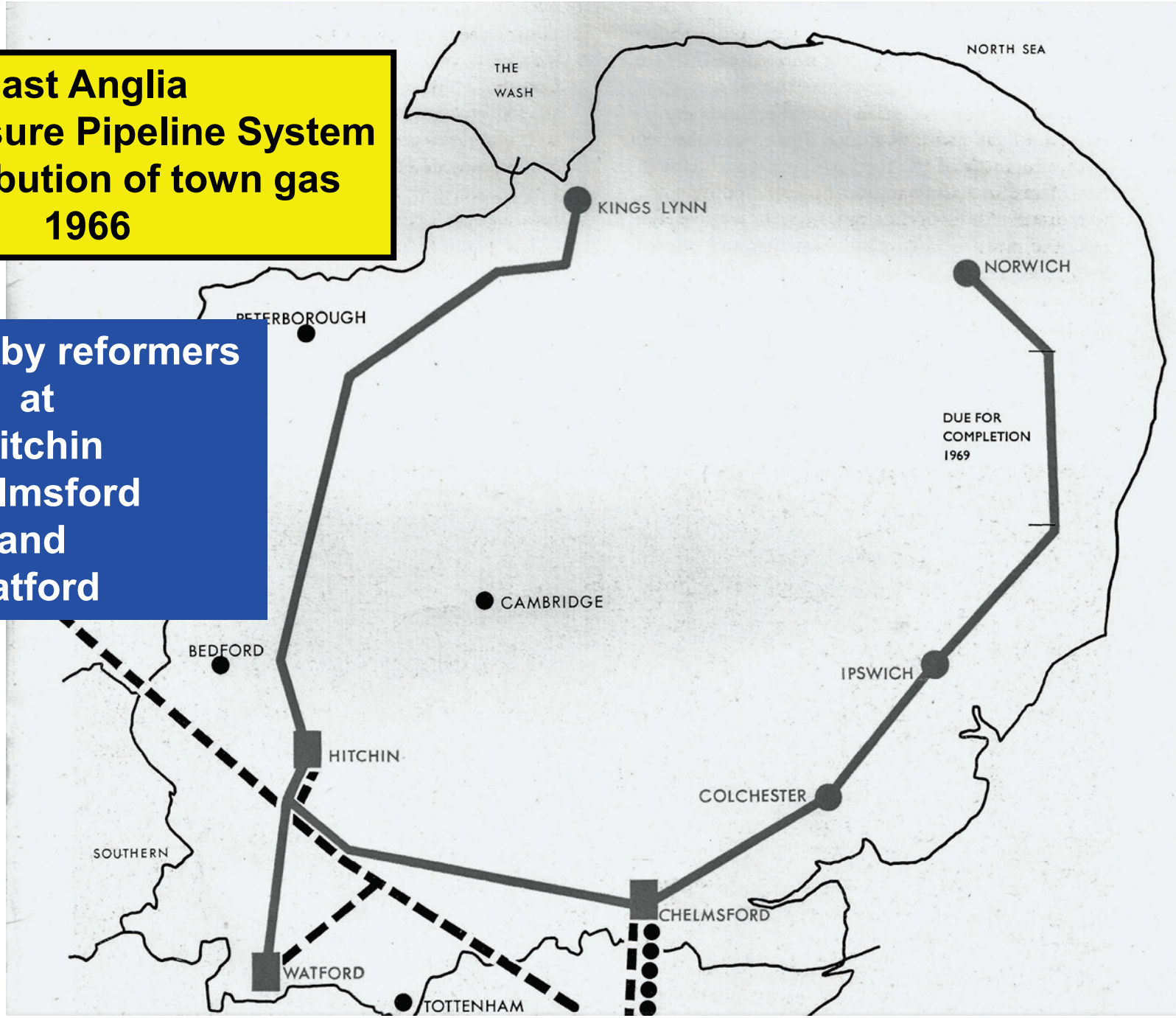
- Fuel input to reformer burners
- Steam – to - naphtha ratio
- Inlet temperature to shift converter
- Plant pressure


Energy Price Advantage of Gas over Electricity
Electricity to Gas Price Ratio
2.6
2.4
2.2
2
1.8
1.6
1950
1954
1958
1962
1966
Year

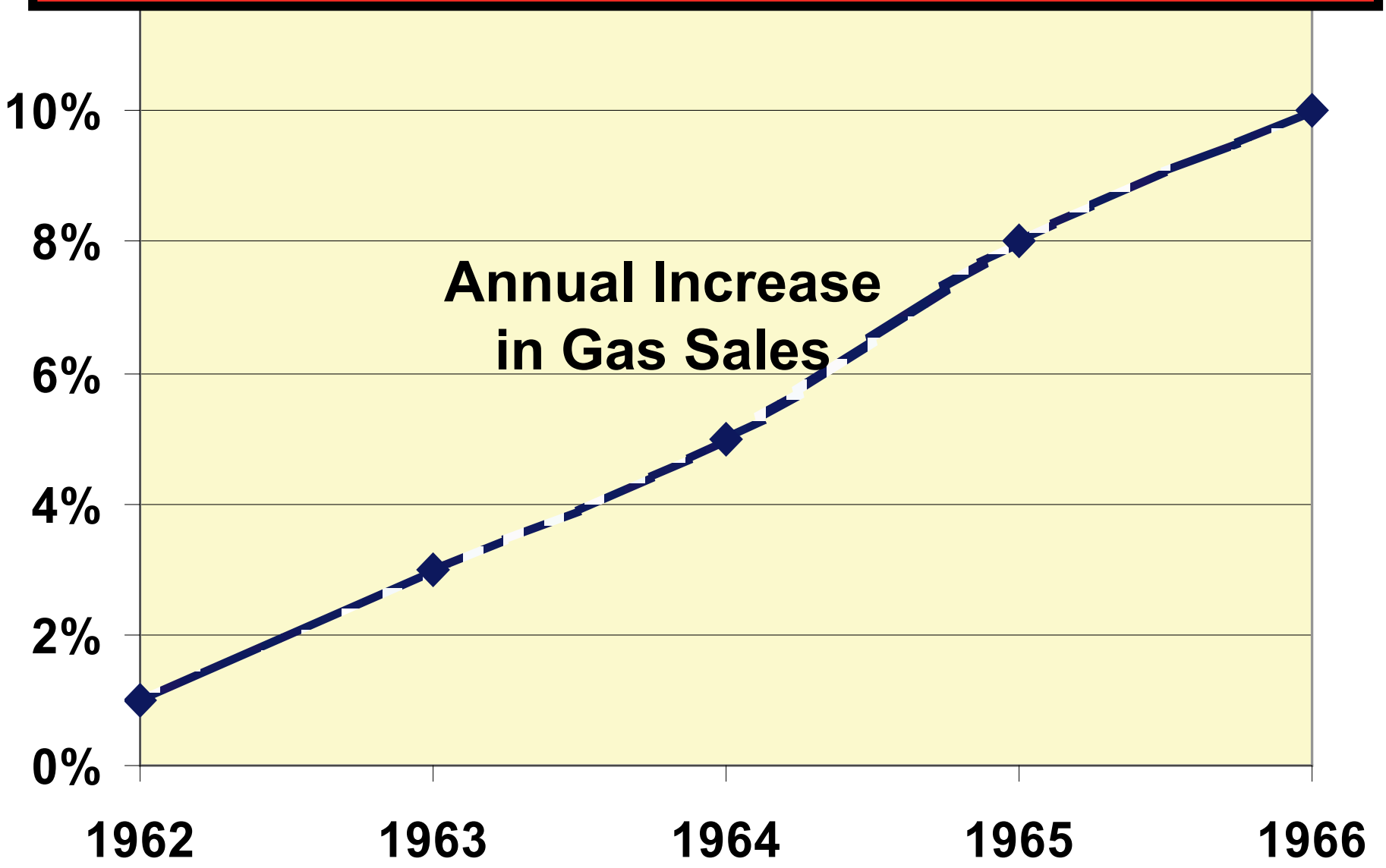

Energy Price Advantage of Gas over Electricity
Electricity to Gas Price Ratio
2.6
2.4
2.2
2
1.8
1.6
1950
1954
1958
1962
1966
Year
Obsolescent Retort Gasmaking
Oil Based Processes
Steam Naphtha Reforming

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

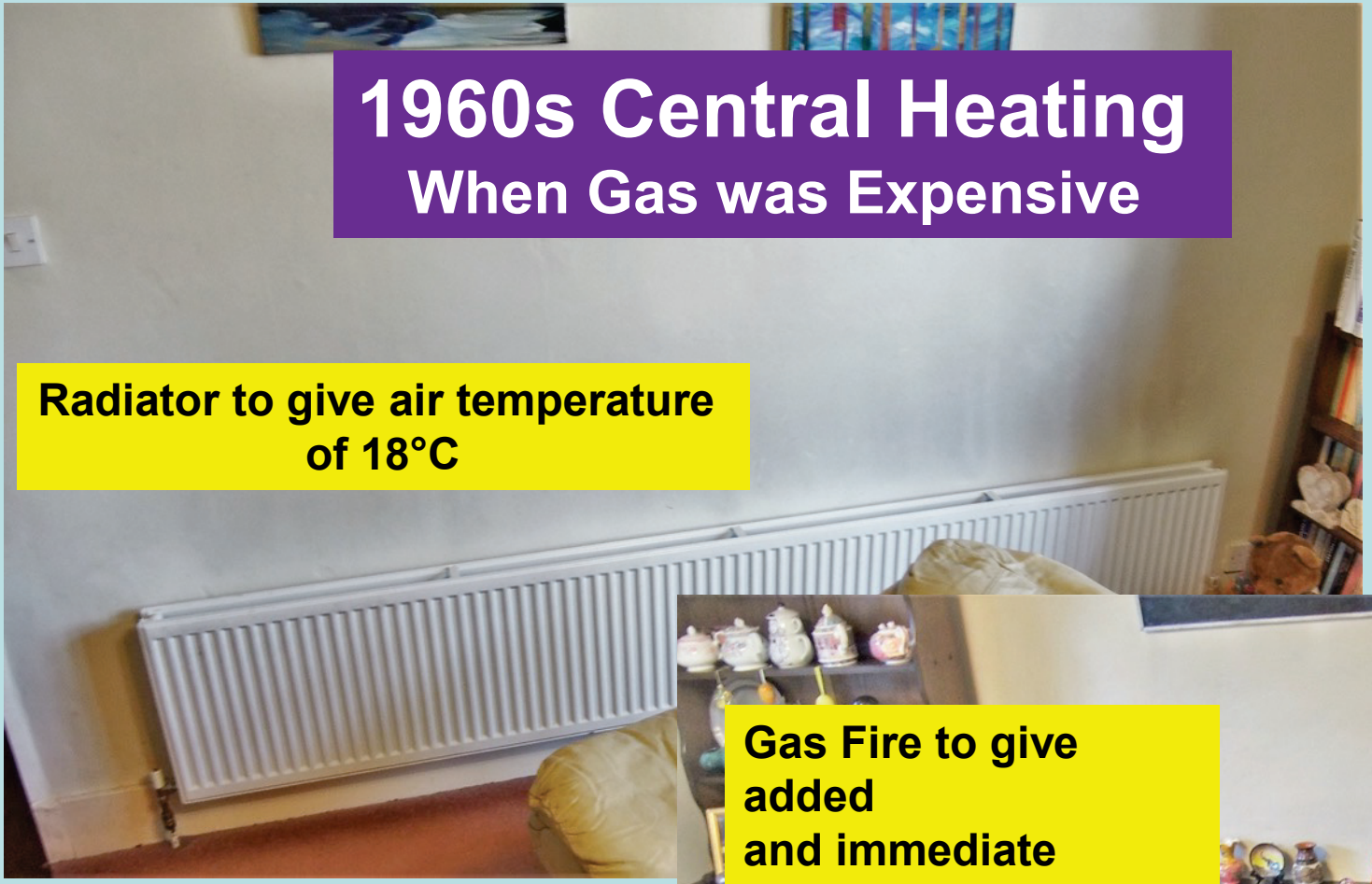
Supplied by reformers at Hitchin Chelmsford and Watford



Impact of the New Oil Based Processes 1962-66



1960s Central Heating
When Gas was Expensive

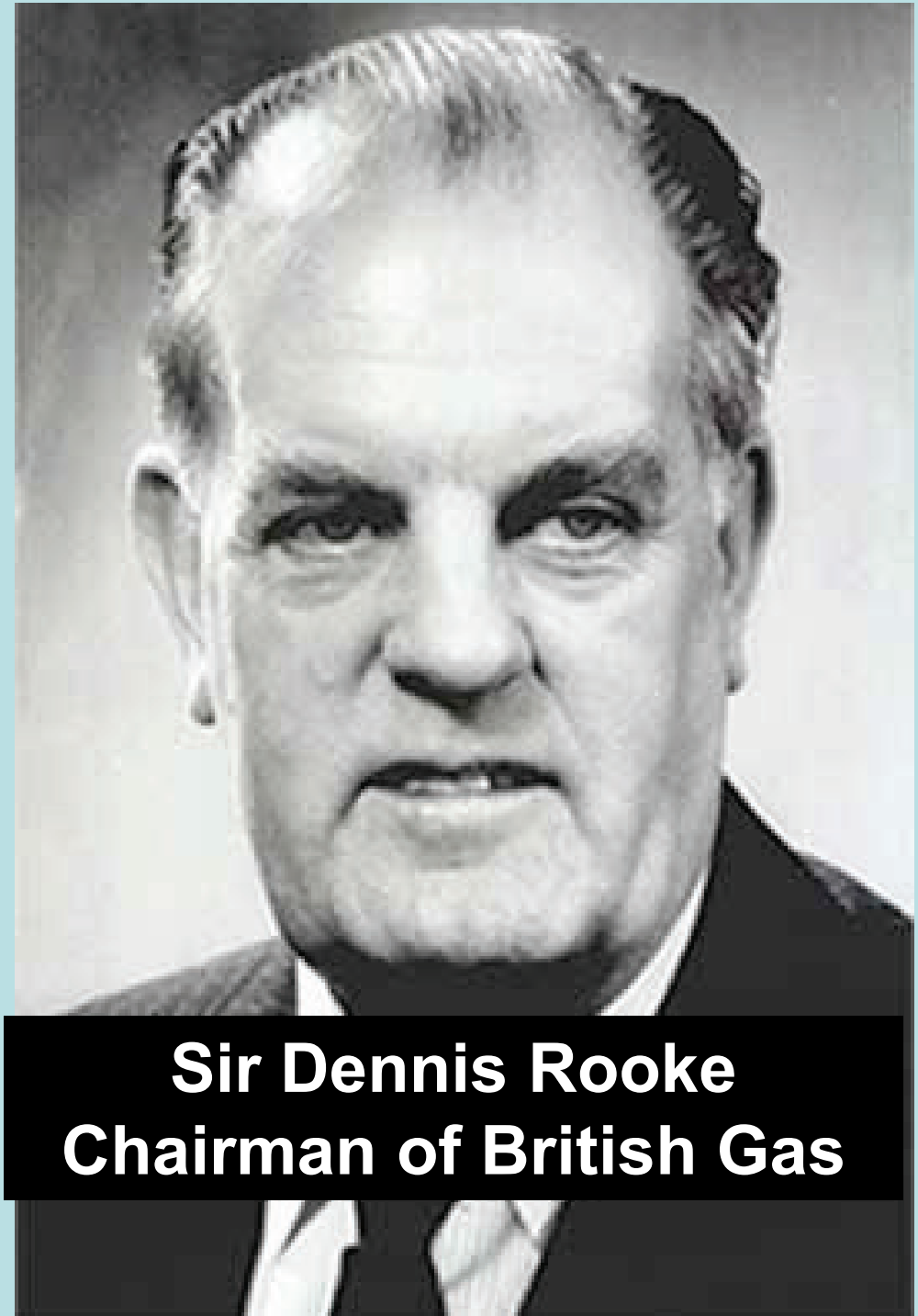


Radiator to give air temperature of 18°C

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

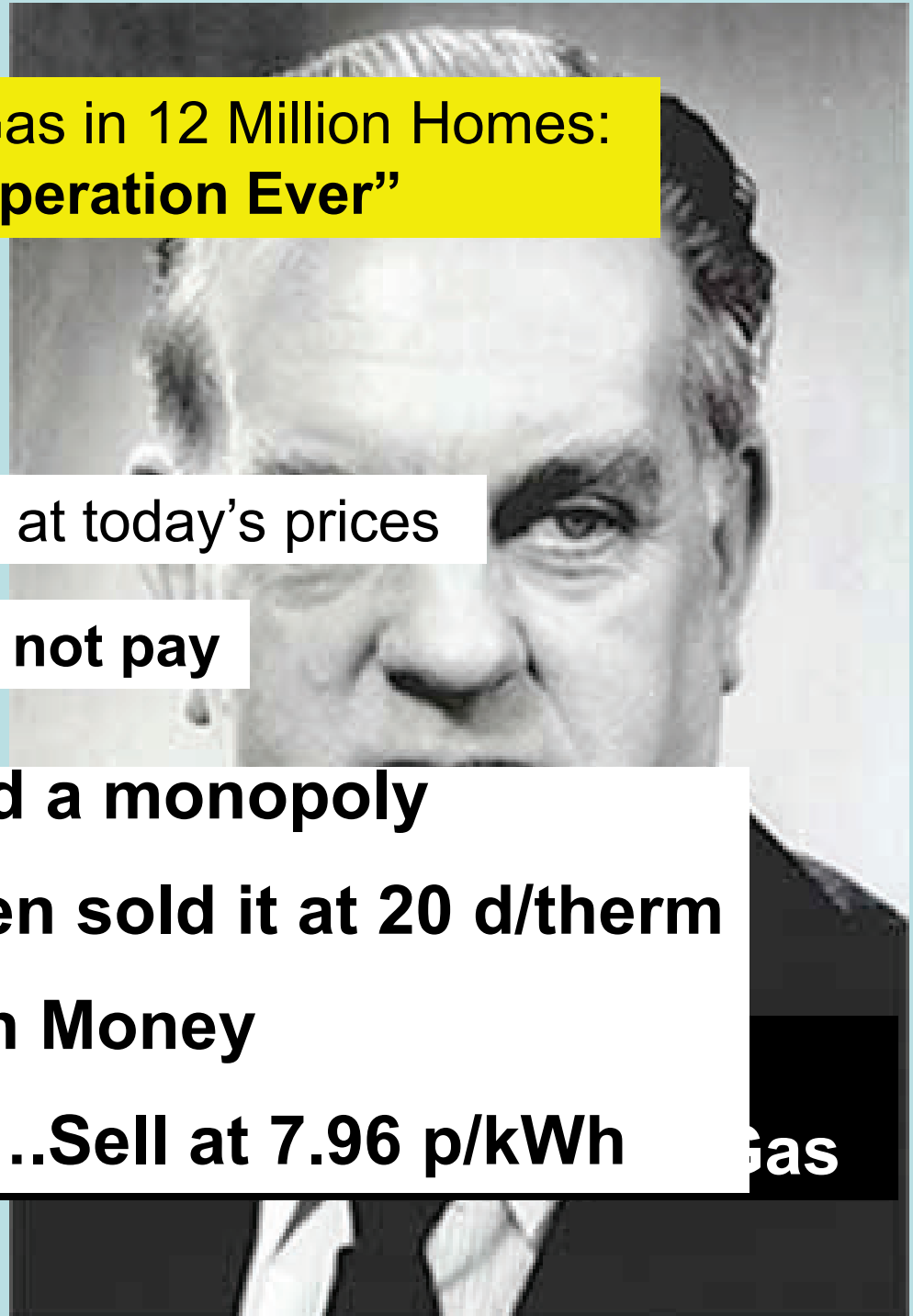
But the consumer did not pay

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 cc665-6 665

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 initial difficulties so that the operation is carried out smoothly and efficiently. §

Sir B. Rhys Williams Is the Minister 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 rectify that? §

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 organise excellent public relations and information services on this matter. If the hon. Member has a particular case in mind, no doubt he will get in touch with us. §

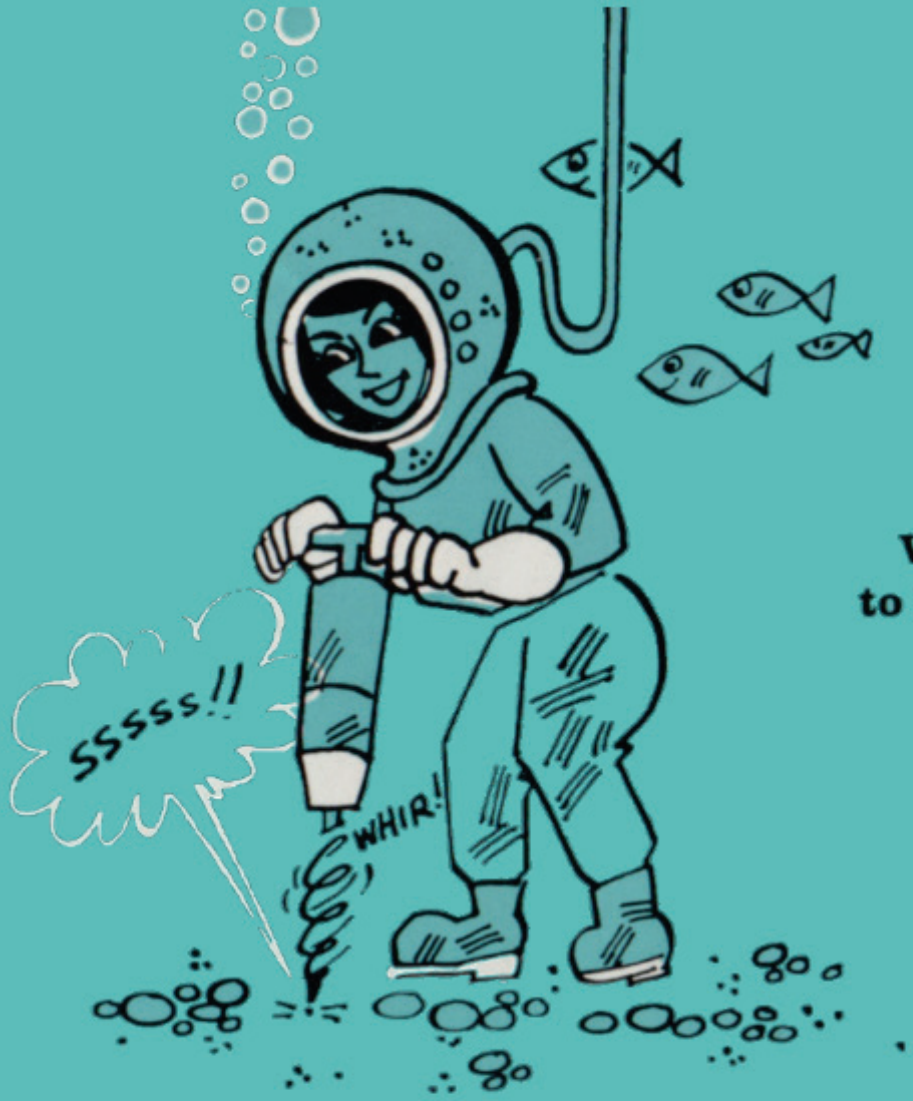
Mr. David Watkins Is my hon. Friend aware that considerably more than 30 million appliances will have to be converted? Is he satisfied that the Gas Council is geared to this immense task without causing too much inconvenience to consumers? § 666

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. §

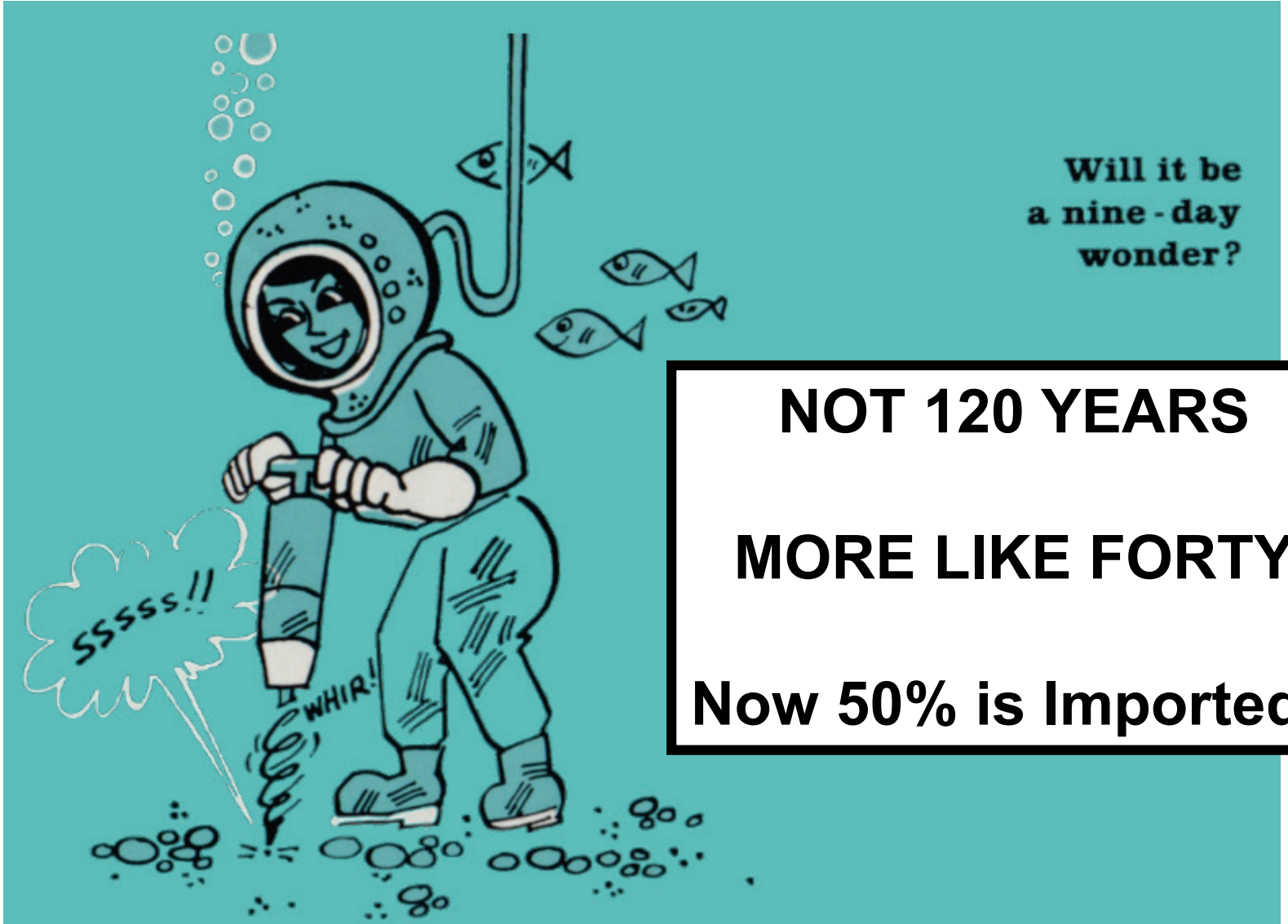
Moans in the House of Commons about the Conversion Programme



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.



NOT 120 YEARS

MORE LIKE FORTY

Now 50% is Imported

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.

Will it cost me anything?

Will it be inconvenient?

How long will it take?

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.

Will it cost me anything?

She wanted to know what will it cost her

Nothing in 1970

What will be the cost of conversion to hydrogen?

How long will it take?

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

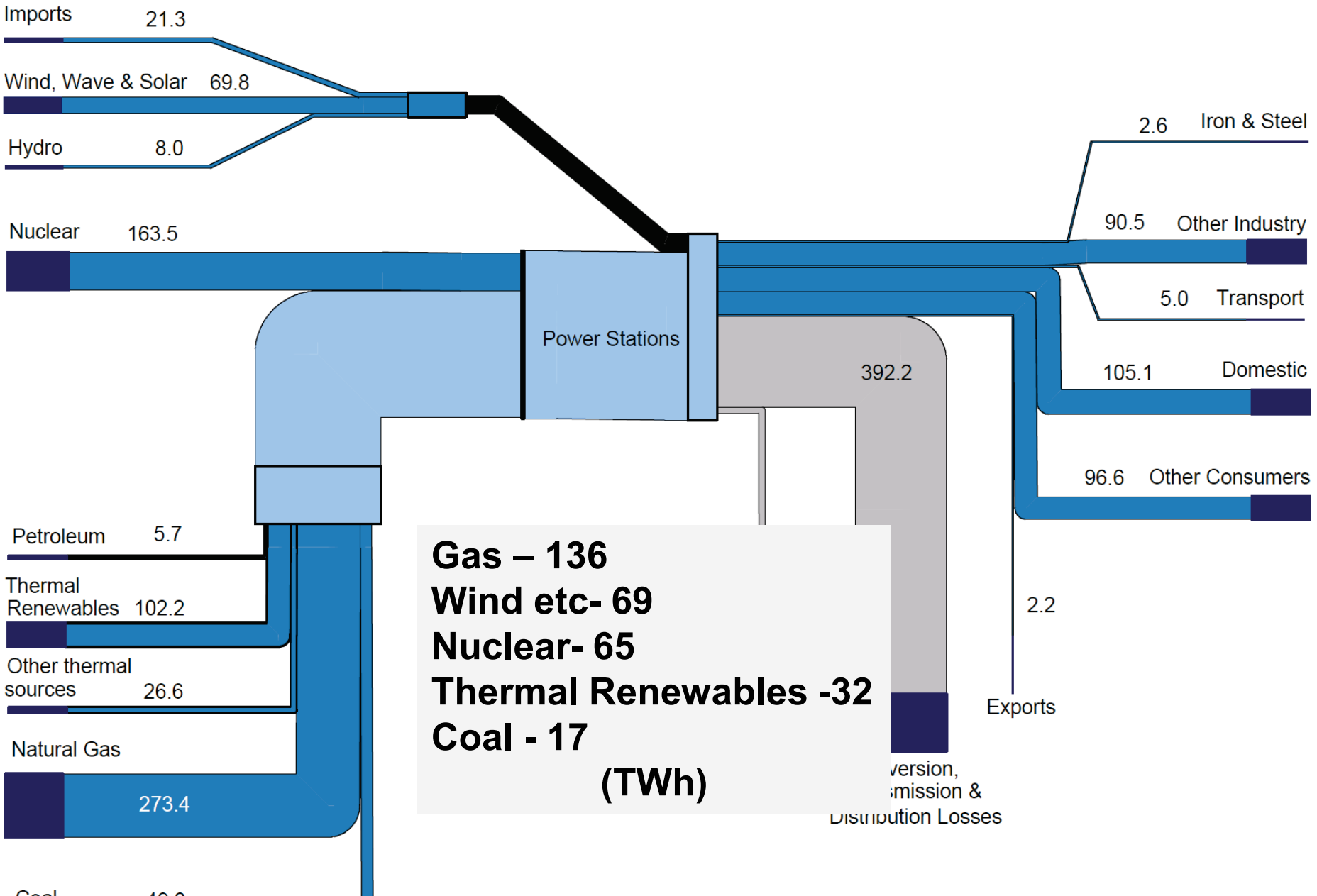
Hydrogen's Biggest Question

Can we use the existing infrastructure?

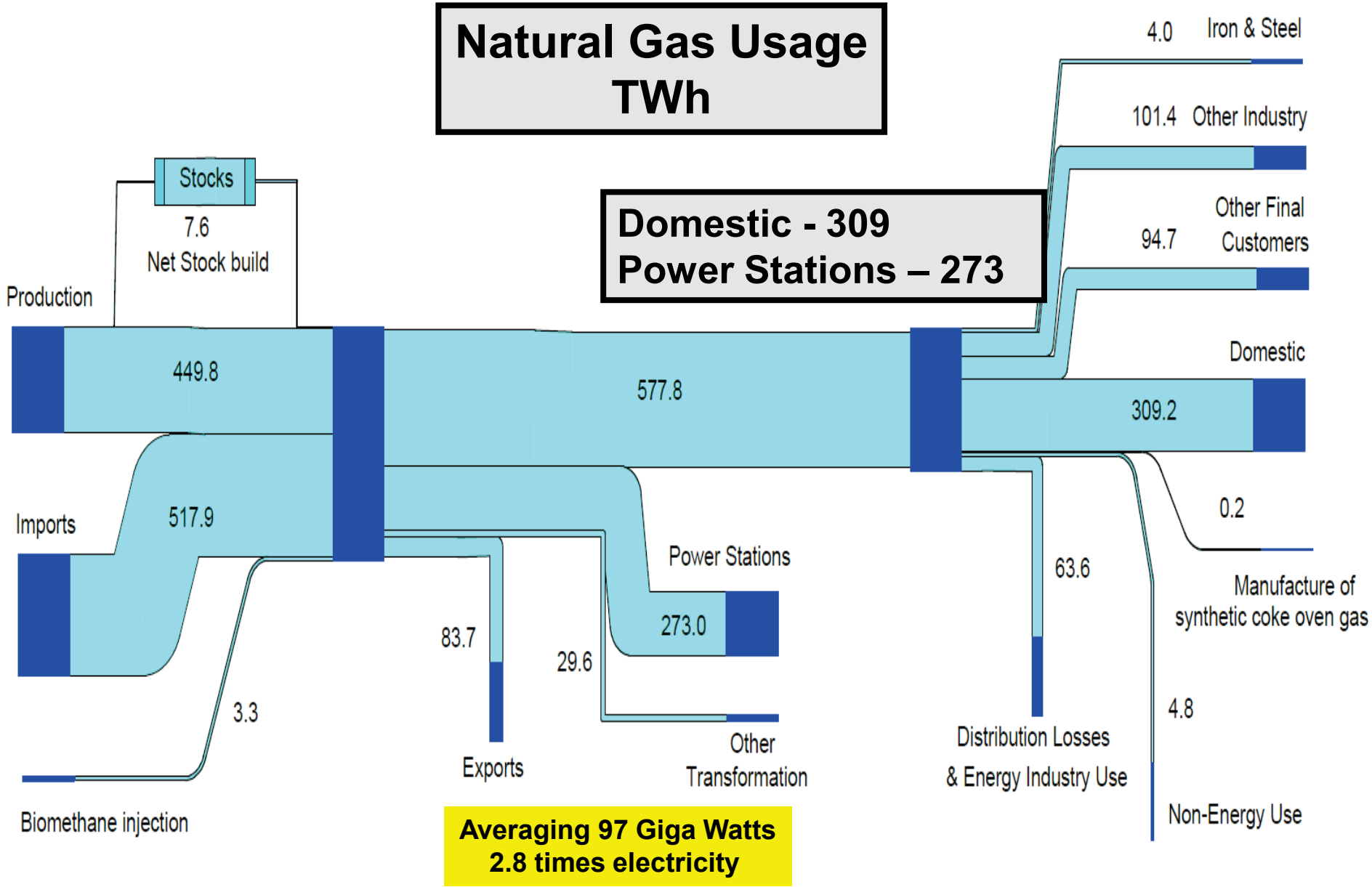
Neglected or Overstated Issues

- **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



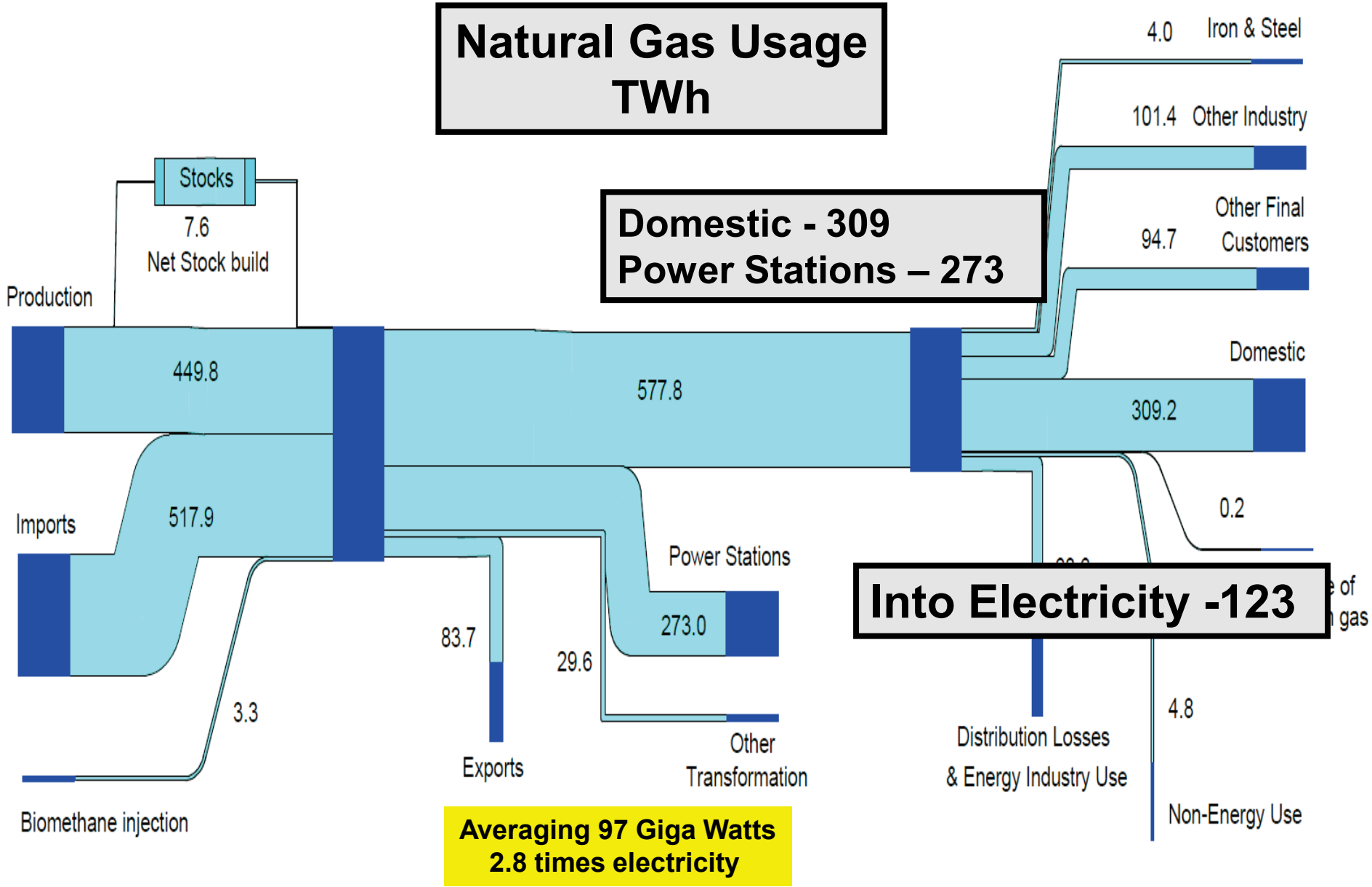
Natural Gas Usage TWh



Domestic - 309
Power Stations – 273

Averaging 97 Giga Watts
2.8 times electricity

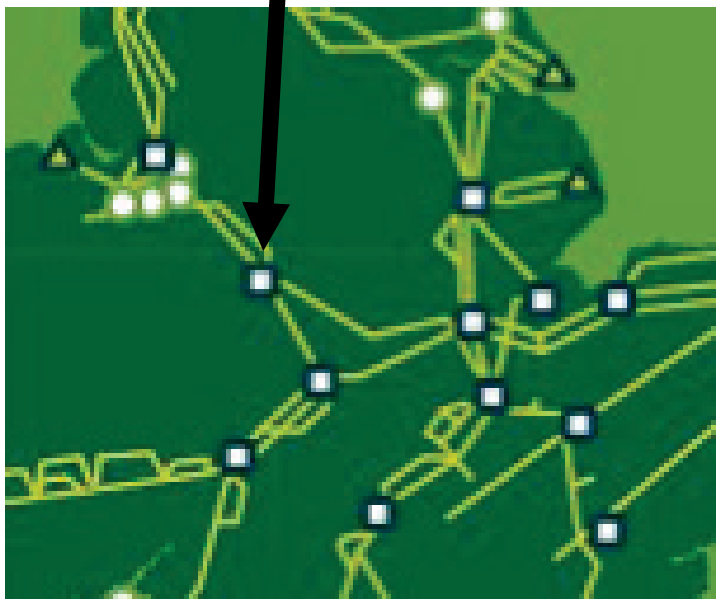
Natural Gas Usage TWh



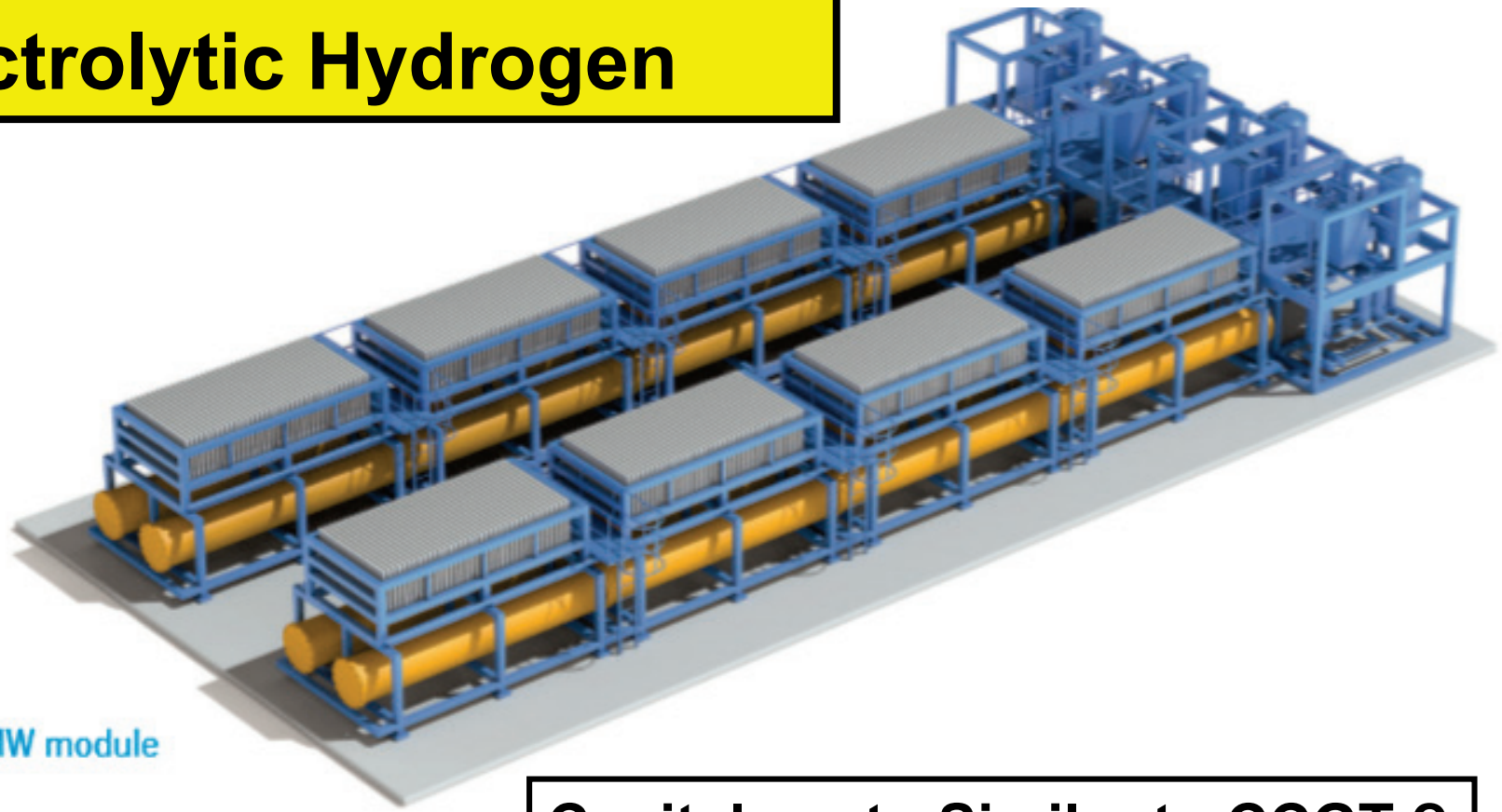
Gas Holders are Being Scrapped

Total Reliance on Pipeline Storage ?????

Alrewas Compressor Station and the Pipeline Network



Thyssenkruppe Modules for Electrolytic Hydrogen



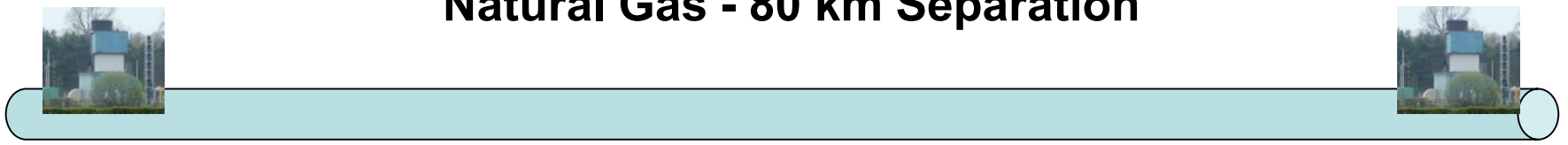
20 MW module

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

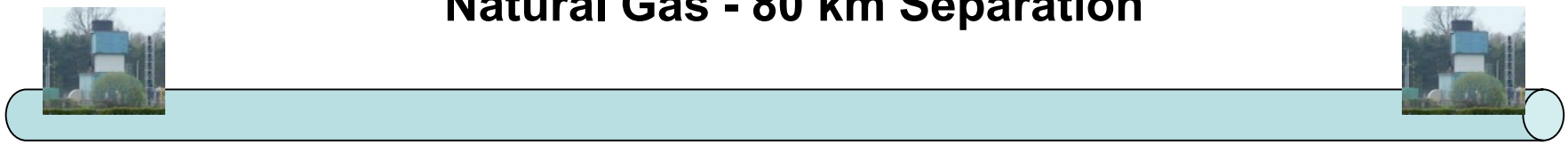
Has to flow faster –bigger pressure drops

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



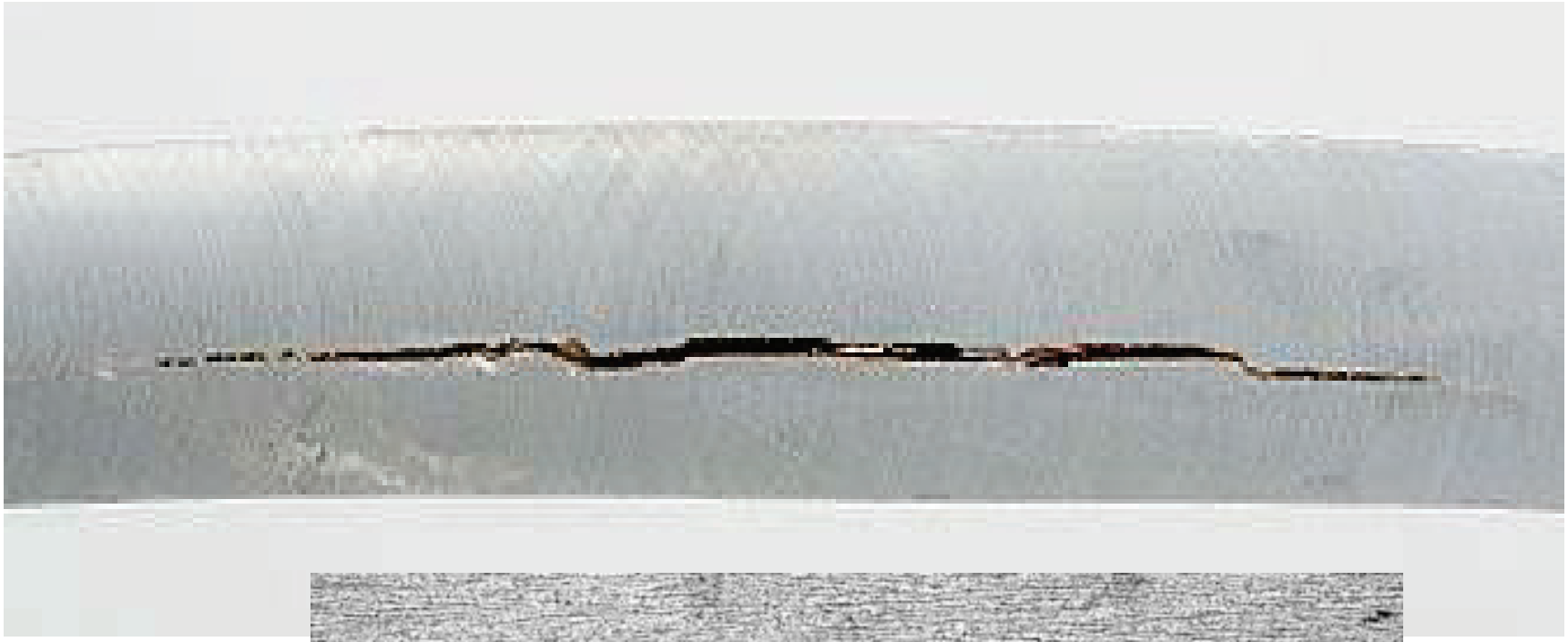
Hydrogen: More Stations for the Same Energy Flows – c.30 km Separation

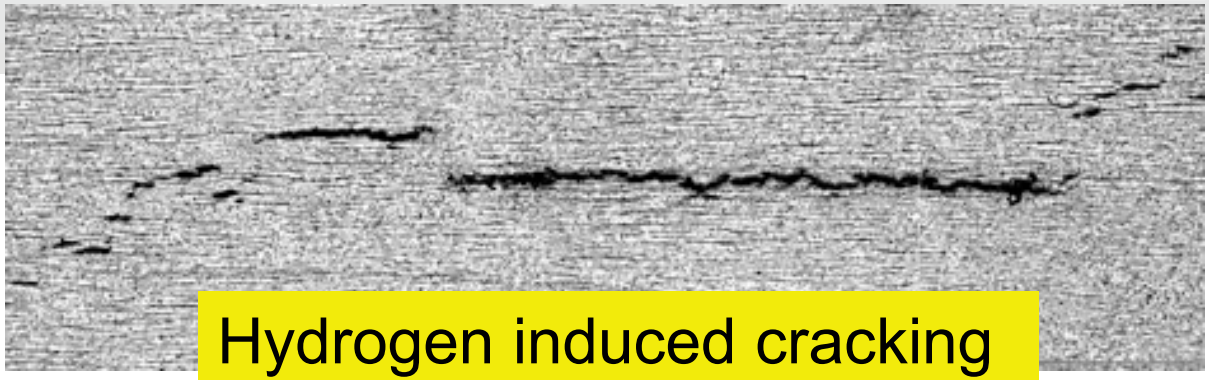
Alternative: Position most electrolysis "factories" next to CCGT power plants

- pressure drops
- More difficult to compress in compressor stations

Redesign of Compressors and Power Units Needed

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.

Technology Obituaries
Obituaries »
Science Obituaries »

In Technology Obituaries

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

Shannon's Opinion on Hydrogen Embrittlement (2)

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

My Own View (1)

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

My Own View (1)

My Own View (2)

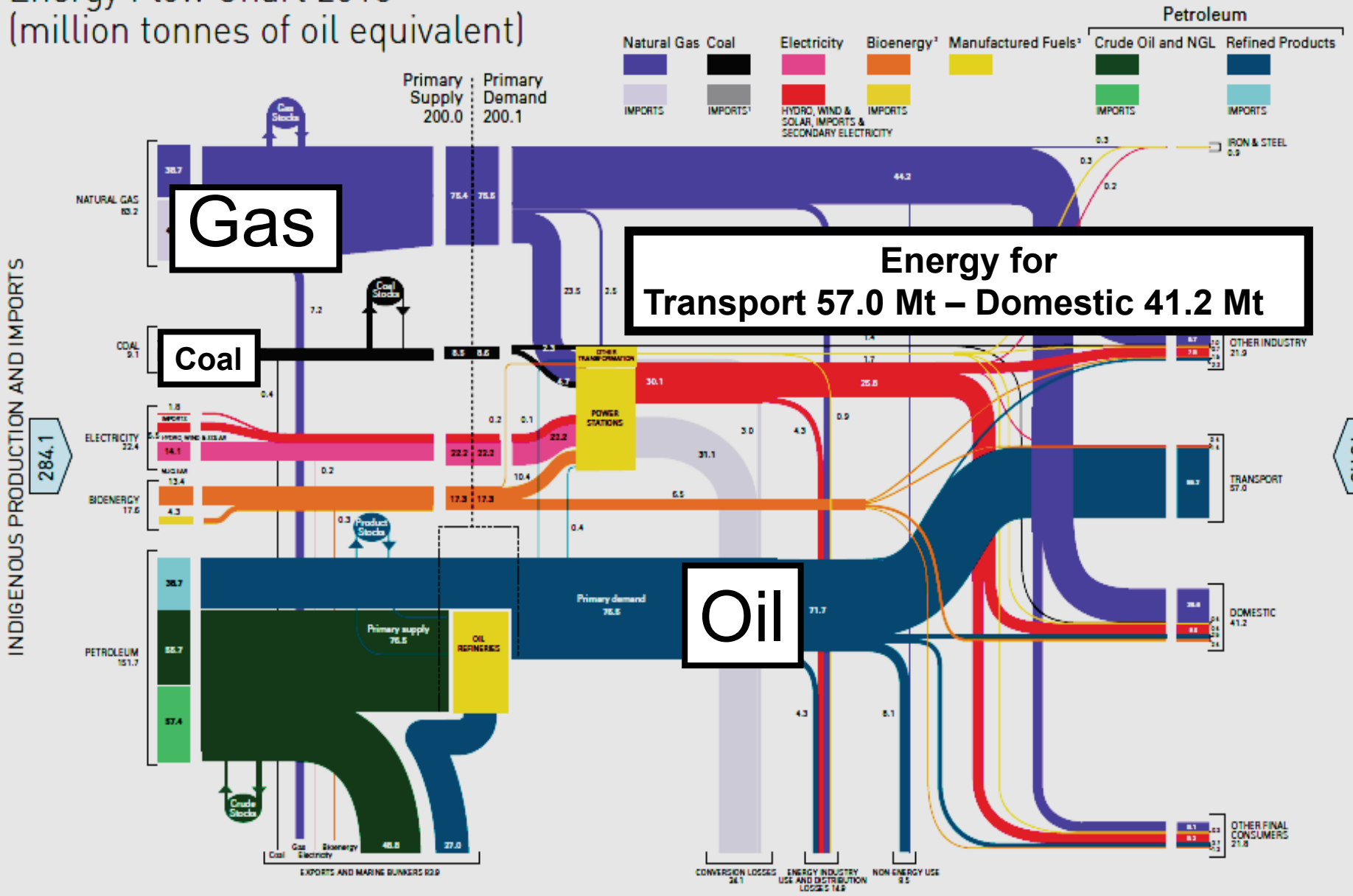
We are doomed to unnecessary expense and concern if we don't do a sensibly targeted R&D programme to assess the effect of hydrogen pressure in pipelines on

- **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

My Own View (2)

Energy Flow Chart 2018
(million tonnes of oil equivalent)

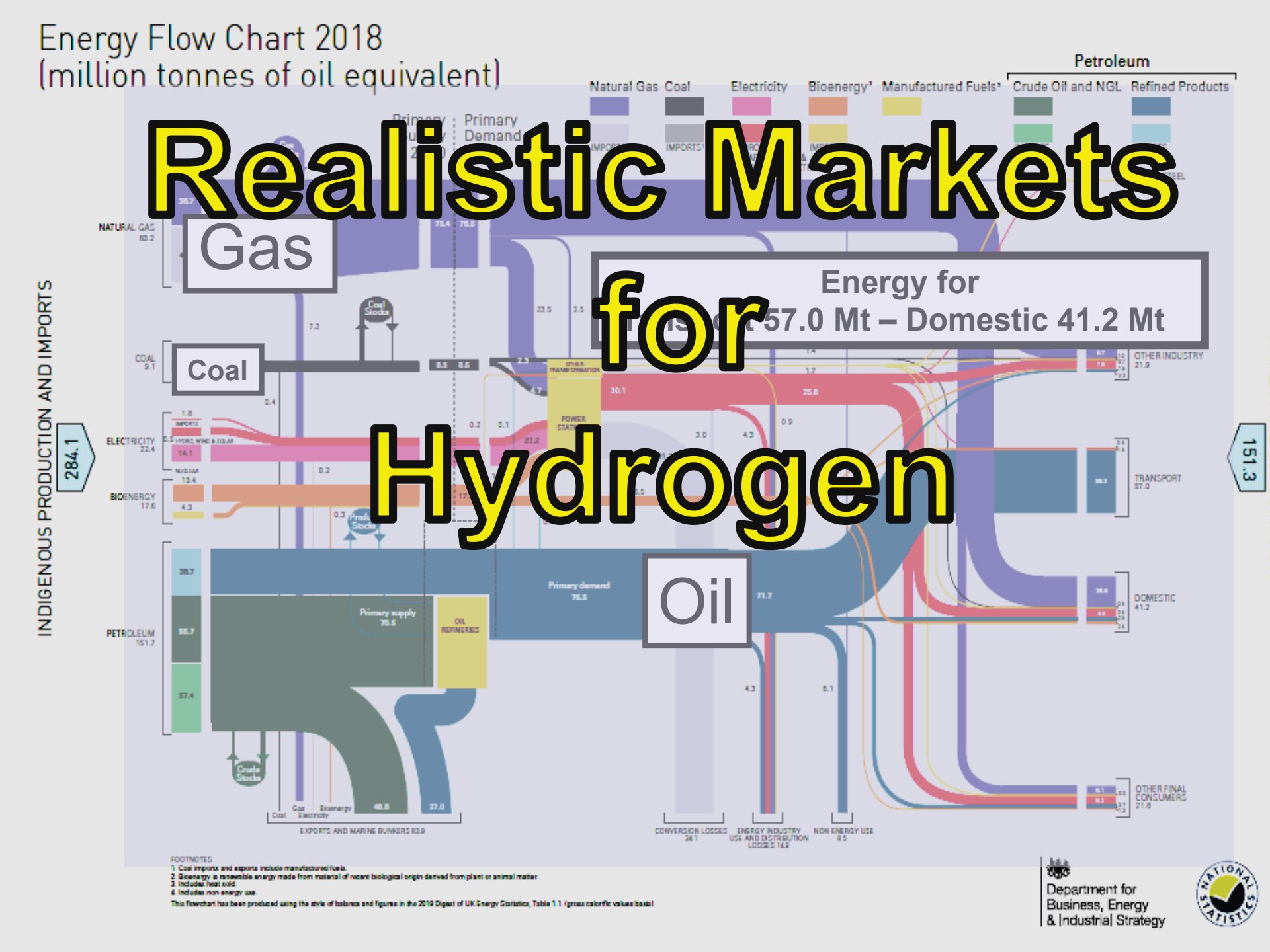


FOOTNOTES:
1. Coal imports and exports include manufactured fuels.
2. Bioenergy is renewable energy made from material of recent biological origin derived from plant or animal matter.
3. Includes heat sold.
4. Includes non energy use.

This flowchart has been produced using the style of balance and figures in the 2019 Digest of UK Energy Statistics, Table 1.1 (gross calorific values basis)

Department for Business, Energy & Industrial Strategy

NATIONAL STATISTICS


Energy Flow Chart 2018
(million tonnes of oil equivalent)
Petroleum
Natural Gas
Coal
Electricity
Bioenergy²
Manufactured Fuels³
Crude Oil and NGL
Refined Products
Primary Demand
INDIGENOUS PRODUCTION AND IMPORTS
284.1
151.3
NATURAL GAS 83.2
COAL 9.1
ELECTRICITY 22.4
BIOENERGY 17.6
PETROLEUM 151.7
Coal Stocks
Prods Stocks
Crude Stocks
POWER STATIONS
OIL REFINERIES
Primary supply 76.5
Primary demand 76.5
OTHER INDUSTRY 21.9
TRANSPORT 57.0
DOMESTIC 41.2
OTHER FINAL CONSUMERS 21.8
EXPORTS AND MARINE BUNKERS 83.9
CONVERSION LOSSES 36.1
ENERGY INDUSTRY USE AND DISTRIBUTION LOSSES 14.9
NON ENERGY USE 8.5
Realistic Markets
Gas
for
Hydrogen
Coal
Oil
Energy for
Transport 57.0 Mt – Domestic 41.2 Mt
FOOTNOTES:
1. Coal imports and exports include manufactured fuels.
2. Bioenergy is renewable energy made from material of recent biological origin derived from plant or animal matter.
3. Includes heat sold.
4. Includes non energy use.
This flowchart has been produced using the style of balance and figures in the 2019 Digest of UK Energy Statistics, Table 1.1 (gross calorific values basis)
Department for Business, Energy & Industrial Strategy
NATIONAL STATISTICS

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

Target Markets for Renewable Hydrogen

Hydrogen from electrolysis has to be more expensive than the electricity from wi

Why should generating plants subsidise a competitor for domestic heating ?

Domestic Heating ... pedream

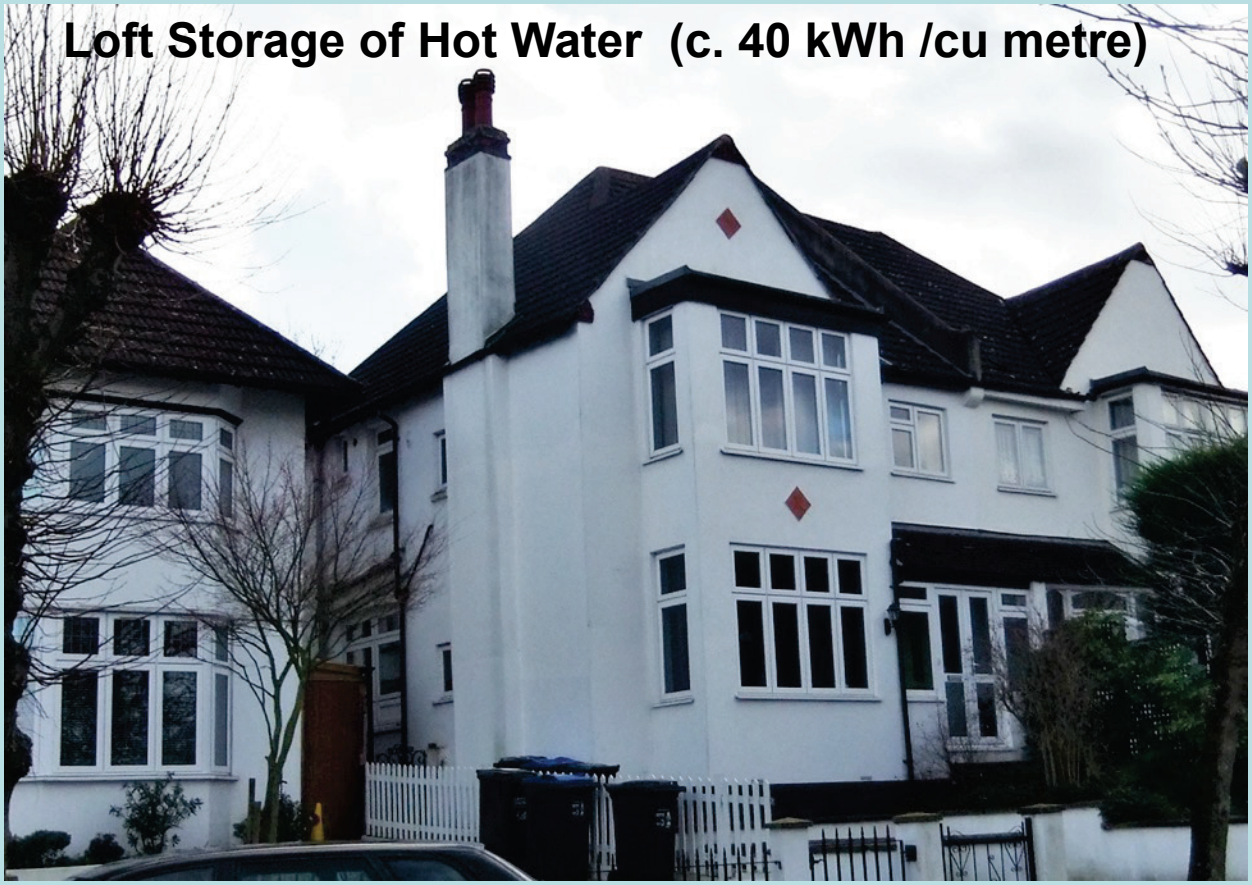
- En... lectric
- ... providing heat
- ... for burner replacements
- Start, then stop market for equipment suppliers
- Needs vote losing political decisions

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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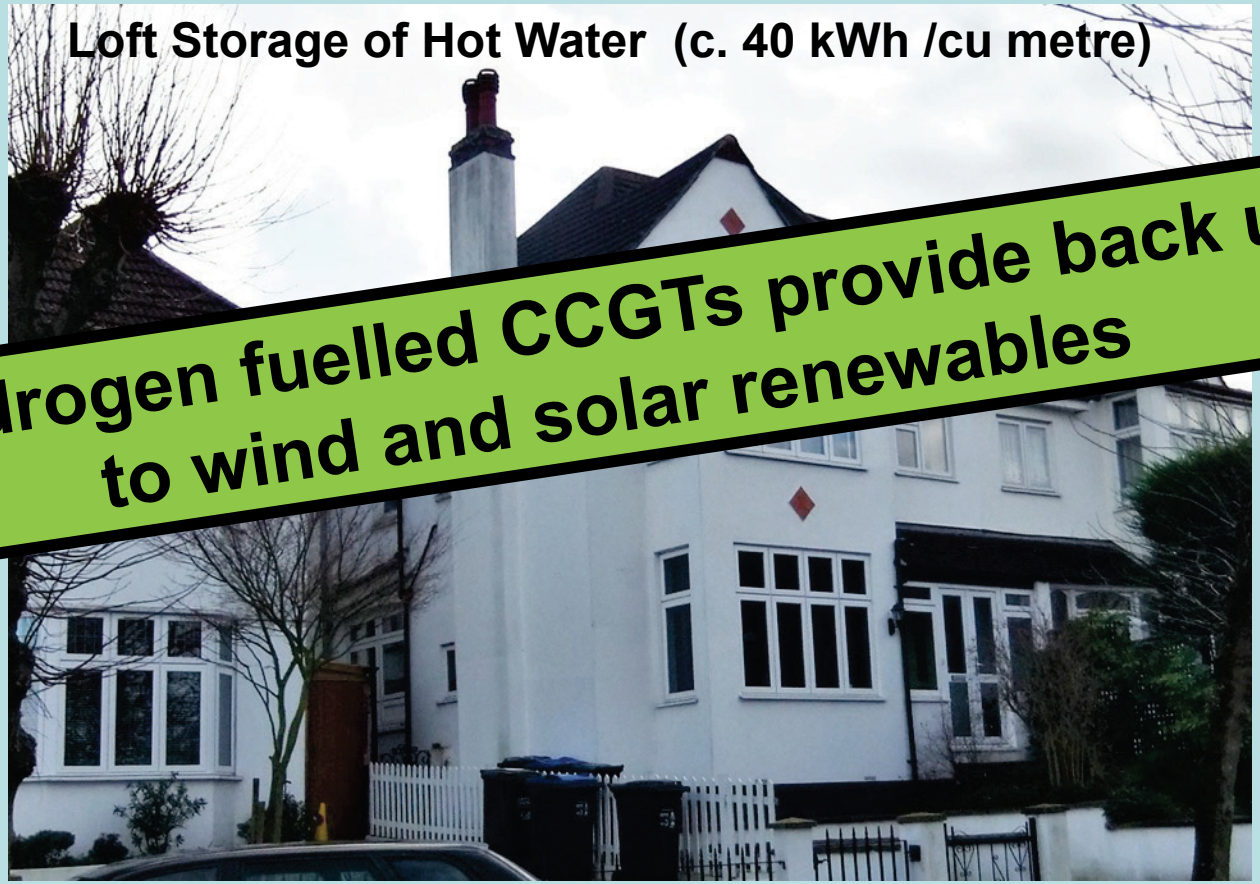


Hydrogen fuelled CCGTs provide back up to wind and solar renewables

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

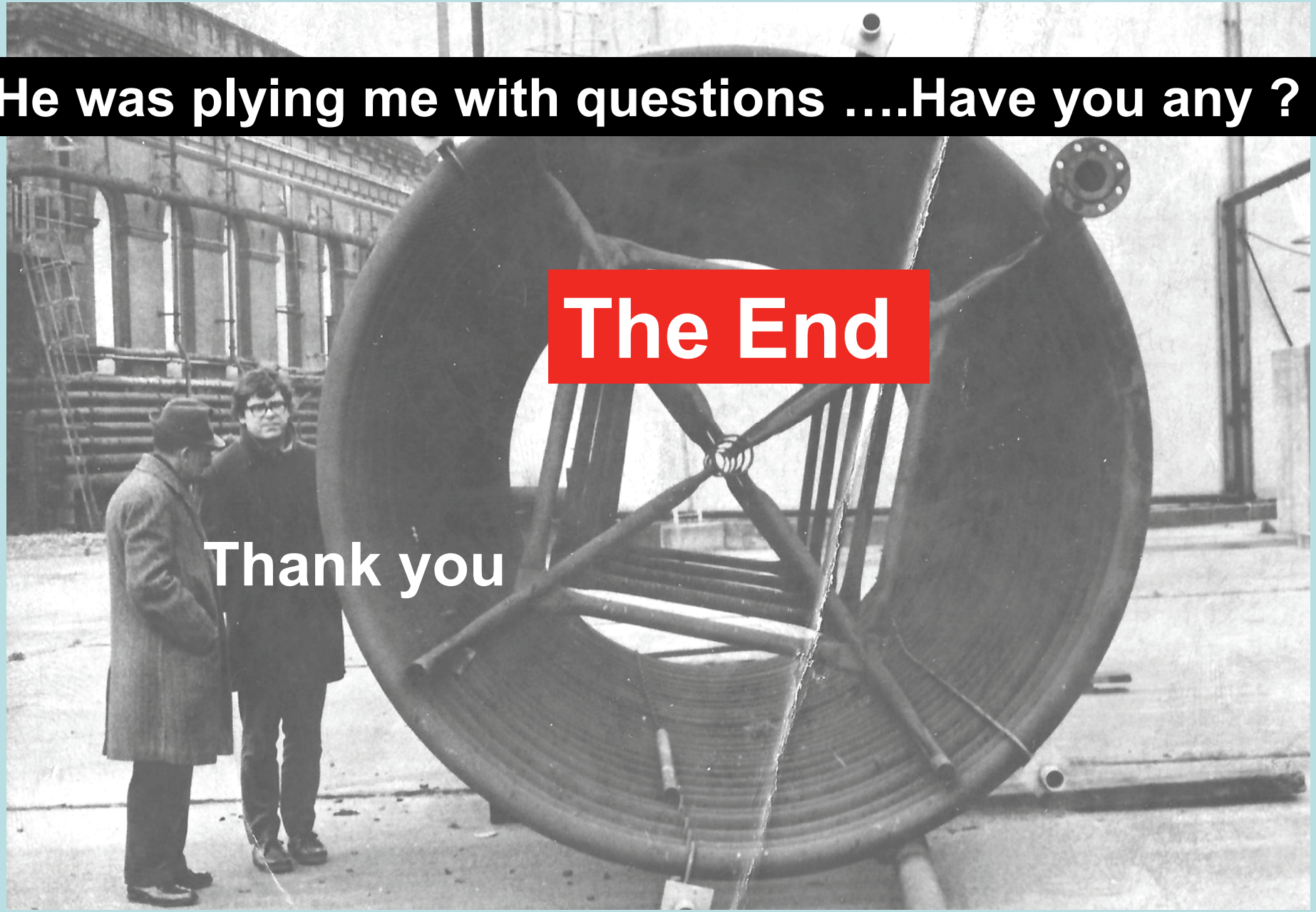
Don’t worry too much about hydrogen embrittlement

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


The End
Thank you


He was plying me with questions ….Have you any ?
The End
Thank you

Lower Heating value hydrogen 119. 96 MJ kg

MJ = 0.28 kWh

: I kg H2 = 33.56 kWh

I ton H2 = 33.56 MWh

= I 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

= 100. 5 MW

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

If pipelines 3ft diameter = Cross section = 9 x3.14/4 = 7.065

Total volume = 25000000 x 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