

The Steam Reforming of Naphtha-The Technology that Saved British Gas

Dr Fred Starr PhD, FIMMM, FIE, MIMechE, CEng

Part 1: Historical Background and Implications for the Coming Hydrogen Economy

Abstract

In the 1950s the Gas Industry in Britain was becoming uncompetitive because of its reliance on the old coal retort processes. The focus of Part 1 of this story about steam reforming are the economic factors that were leading to the gradual demise of British Gas in the 1950s. Notably the reliance on coal, and that electricity was becoming a cheaper form of energy than gas. The industry had begun to make gas from oil, but these early “cyclic” processes had serious limitations. It was the introduction of the ICI steam-naphtha reforming process which was really revolutionary and helped to promote further advances. The main shortcoming of the ICI process was the low methane content of the product gas, so it was soon supplemented by the Gas Industry’s own high calorific value designs. By 1967 half the gas in the Britain was coming from oil based processes. Nonetheless, the steam reforming era, and the technical and economic history, by which it came about, is forgotten.

A further reason for writing this paper is the current interest in the hydrogen economy, which in some quarters is envisaged as replacing natural gas in the domestic heating sector. Here “blue hydrogen” coming from steam reforming and “green hydrogen” via the electrolysis of water, using renewable power. As this paper will argue, the lessons of the 1950s show that unless hydrogen is significantly cheaper than electricity, which seems unlikely, it will only be a minor part of our way of life.

Key Words

Perilous State of Gas Industry 1950-60, Reliance on Coal, Critical Importance of Electricity to Gas Price Ratio, ICI development of Naphtha Steam Reforming, Hitchin Reforming Plants - Worlds Most Advanced Site, Prospects for the Hydrogen Economy and the Domestic Heating Sector

1. Introduction

The steam reforming revolution is a neglected episode in the history of the UK Gas Industry, keeping it alive until North Sea Gas was brought ashore. Although this revolution took place just 50 years ago, the people who took the decision to move to making gas from oil, using an extremely novel process, are no longer with us. Modern accounts, as posted on the internet, do not mention steam reforming. Even the National Gas Archives only says of this crucial period...

“During the 1960’s technical advances were made within the industry, and the first imported liquefied natural gas appeared”¹

The author knows of only two documents which were deliberately intended to cover this period. One by Alan Davis, charts the history of steam reforming within the South Western Gas Board, and also gives a summary of the national situation ². The other is by Andrew Jenkins who discusses “Government Intervention in the British Gas Industry 1948-1970”³. In terms of engineering history, although valuable, both accounts have shortcomings.

The paper by Davis, although giving some technical background, assumes that the reader does know what a steam reforming plant looks like and how it was operated. The Jenkins paper focuses on the difficulties that the Gas Industry was experiencing by the 1950s, and how much help the Government was giving, in for example, relaxing financial targets, and allowing a switch from coal to oil. Jenkins appears to think that the Government was supportive, but that was not the way that it was perceived by everyone in the Gas Industry. But Jenkins does emphasise that the key decisions were not made centrally by the Gas Council, which was ostensibly responsible for planning. The Area Boards decided upon their own course. It is one reason why such a diverse range of plants and technologies were utilised when it became vital to move to using oil as a feedstock.

In this context there is also an excellent piece by Gibson of the Gas Council, given in 1965, at a joint meeting of the Institute of Petroleum and the Deutsch Gesellschaft für Mineralölwissenschaft und Kohlechemie e.V, when steam reforming was just beginning to make a serious impact ⁴. Gibson’s paper is an overview of the Gas Industry, summarising why there had been a move to oil based processes. He, however, expressed concern that in the very near future light distillate or “naphtha” as it was called, might become scarce, as the petrochemical industry began to realise what a useful feedstock was it. The arrival of North Sea gas changed everything in that respect, of course.

The author was one of the players in the revolution, and although never involved in any major decisions, saw what was happening in a very practical way. After leaving University in 1966 with a degree in metallurgy, and having spent five years in the steel industry, he was looking for a job in engineering. He was taken on as shift engineer by the Eastern Gas Board on a newly built steam reforming plant complex, at Hitchin, Herts, just north of the point where the railway lines to the North and to Cambridge diverge. A lack of experience of refinery plant operations did not seem to be an obstacle in the recruitment of him or his fellow graduates who were starting work.



Figure 1: The Eastern Gas Board Hitchin Site. The complex nearest the gas holder comprises the CRG and steam reformers of the sidewall fired variety. Further up, on the other side of the diesel generator building, are four standard ICI steam reformers. The very small tower shaped unit between the ICI and reformers and the trees is the Otto plant. The three white spheres contain liquid butane or propane.

Hitchin could be described as the most advanced gas making complex in the world. At the time the author started work, it was a site that had only just brought into full use four ICI steam reforming plants or “streams”, using naphtha as a feedstock. It also had an “Otto” peak load steam reformer, using butane. Furthermore, at the time, the Otto was being used to test the Stretford nickel-uranium steam reforming catalyst, which did not suffer from one of the major shortcomings of the ICI 46/1 catalyst. The site was also in the throes of commissioning two streams which utilised the CRG (Catalytic Rich Gas) process. These plants were the first to be of a major size, the CRG being a process that had been developed by British Gas itself. The details of these and other key processes will be described later. Figure 1 shows an aerial view, when from the absence of steam from the Benfield plant and unoccupied railway sidings (which brought in naphtha) it appears that all units had been shut down.

The author was only at Hitchin for just about a year when he was invited to join one of the main British Gas R&D Groups, at London Research Station in Fulham, where he stayed for the next 27 years. In so doing he picked up many anecdotes about how the industry had developed, and some of these are incorporated into the text, unreferenced. At Fulham he was responsible for failure investigation of steam reforming plants, mainly in the southern half of the UK. Accordingly, this paper is written from a personal standpoint, but has the merit that unlike most

company-derived accounts it does not gloss over the reality. For example, a few months before my arrival at Hitchin, when the first CRG plant was being brought into use, the steam reformer had blown up because of overheating of the tubes. And earlier that year, the car industry in the Birmingham area was shut down as a result of a succession of failures, one of them catastrophic, in the various reforming plants belonging to the West Midlands Gas Board. Where possible the statements made in the paper are referenced, but in a number of cases, it would be difficult if not impossible for reader to acquire these since the organisations who produced them have gone out of business. Both ICI and British Gas no longer exist, and everyone who is still alive and worked on these plants, if they are still alive, will be in their mid seventies or even older.

A further reason for writing the paper is to emphasise the critical important to the Gas Industry of the original ICI steam reforming process. Although it had some major shortcomings, the most obvious of which was it being a high temperature process, the gas produced having a relatively low calorific value, needing to be “enriched” with expensive methane, butane and propane. But in the initial stages of the steam reforming revolution, it was the only “continuous catalytic process” available which could use an oil based feedstock. In the discussion to a presentation by G. Milner of the Power Gas Corporation, K. Nunneh from North Thames Gas asserted that although there had been other steam reforming catalysts, ICI had made a real breakthrough. When using naphtha as a feedstock, the amount of steam needed was much lower than its competitors, and the ICI 46/1 catalyst allowed continuous operation without depositing carbon ⁵. Nunneh might also have added that the catalyst could withstand operation at about 100°C less and at higher pressures than needed for the manufacture of hydrogen, which was the original reason for the developments at ICI. Lower steam rates, temperatures and higher pressure increased the levels of methane, making the process attractive to the British Gas Industry.

Nevertheless, within a very short time, to the basic ICI reformer plant other processes were added, which produced gases of a high calorific value, these replacing the methane, butane and propane. Most of these were developed by the Gas Industry itself, and in the author’s opinion have tended to receive undue prominence. But it is doubtful if the CRG, the gas recycle hydrogenator and rival ICI 500 processes would have had a chance to prove themselves, if it had not been possible to “piggy back” them onto the original ICI concept.

The absolutely amazing rate of switchover to steam reforming, and continual improvements in technology, like the addition of the CRG and GRH to the standard ICI process, meant that designers, contractors and operators were continually having to catch up. Those at the sharp end of the reforming plant revolution were keen to share their experiences, some of which involved catalyst failures, overheating of equipment, defective instrumentation and materials problems. The presentations on these subjects were often made at “secondary level meetings” such as subsidiary divisions of the Institute of Gas Engineers ^{6,7,8,9}.

Because these plants were of the oil refinery type, and so different to those of the past, it was decided to set up an organisation which would be responsible for giving advice and support to the Area Boards on the engineering issues of steam reforming. This began as a group

temporarily based at the London Research Station at Fulham, under John Van der Post (brother of Laurens Van der Post), but after about a year the group moved to Newcastle, in a new purpose built establishment known as the “Engineering Research Station”. Most of their work would have stemmed from the metallurgical failures which bedevilled early reforming plants.

However, almost as soon as “ERS”, as it was called, was set up in Newcastle, it was decided that all work on reformers should be dropped. North Sea Gas had been discovered, the priority for British Gas being the development of the high pressure transmission system and the refurbishment of the local pipeline network. Although ERS kept a toe hold in the reformer field, the bulk of the failure investigations was done by a few individual metallurgists, who apart from myself, at London Research Station, were employed at one of the Area Board research organisations. In some cases, as with North West Gas, failures were investigated by external organisations such as the British Engine Insurance Company.

2. The Gas Industry After Nationalisation

Following the election of the 1945 Labour Government, the Gas, Electricity and Coal Industries were all nationalised. In the case of the Gas Industry, Britain was divided into twelve “Area Boards”. One aim was to close down as many local gas works as possible, replacing them with more centralised plants. Each Area Board had considerable powers and autonomy. This subsequently influenced the take up of oil as a gas making feedstock and the development of the steam reforming sector. Some centralisation had started much earlier. Before WWII the gas supply in London came from The Gas Light and Coke Company, and the South Metropolitan Gas Company. After nationalisation, the former became North Thames Gas, which stretched from Marlow-on-Thames through to Southend. The South Metropolitan Gas Company became the South Eastern Gas Board, covering most of South London and Kent.

The post war gas industry in Britain was not in good shape, although the relaxation from wartime controls and economic resurgence disguised its weakness. All of its gas was produced from coal, but the British coal industry had long passed its peak. Some supplies to the North Thames Gas Board were imported from India. The gasification processes were based on the mechanically loading versions of the old horizontal coal retorts, and the rather more modern, less manpower intensive vertical retorts. Both types, being made of refractory bricks, were impossible to run at pressure, and this restricted the supply of gas to a few kilometres from each plant. A prewar PEP report stated that “an annual output of 1 million therms per annum was large enough for economic operation” (of a big gas works)¹⁰. This would be equivalent to a gas output of about half a million cu.ft a day. One steam reformer could produce twice as much an hour. Legislation that hamstrung the industry in considering new approaches, was the requirement to develop and maintain a supply of coke.

Since the processes were based on the pyrolysis of coal, only a fraction of the energy content appeared as gas. From a ton of coal, one might get 14000 cu ft of gas or less than a quarter of the energy input of the coal^{11, 13}. Of the remainder, just over half of the energy appeared as saleable coke, and in addition there was a mass of byproducts needing disposal. These included tar, motor spirit, ammonium sulphate and phenols. At one time they were saleable

commodities, but with the development of oil refining in Britain, and large scale manufacture of ammonia, the market was disappearing. Sir Dennis Rooke***, who came to be one of the greatest chairmen of British Gas, was adamantly opposed to any process that resulted in byproducts.

The “town” gas that was produced contained about 50% hydrogen, 30% methane, giving it a comparatively low calorific value. The remaining 20% consisted of carbon monoxide, carbon dioxide and a small amount of ethane. The carbon monoxide was highly poisonous. At the time it was sardonically observed that a quick way to commit suicide was to “put one’s head in the gas oven”.

None of these processes could be scaled up, and were manpower intensive. The plant needed to remove byproducts added greatly to the plant size, trebling the area needed. The cost of coal was continuing to increase, and the result was that unlike electricity, where the demand was increasing year-on-year, gas output was becoming static as shown in Figure 2 ¹⁴.

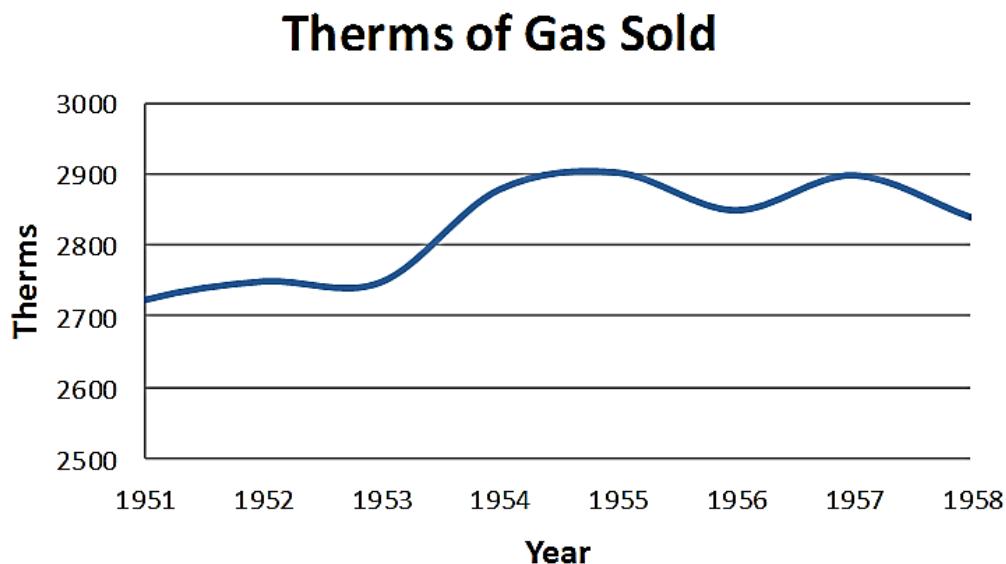


Figure 2: Stagnation of gas output in the 1950s

The increasingly desperate situation is highlighted in a book by Falkus about North Thames Gas. Chapter 3 is entitled “The Struggle for Survival”, the struggle being against what were seen to be the predatory instincts of the National Coal Board ¹⁵. The latter were probably charging a fair rate for the type of “coking coals” required by the Gas Industry, a specialised variety coming from pits in Durham (that were nearing exhaustion.... author comment) ¹⁶. However, the view from the Gas Industry was that, whenever it proved possible to use a different type of coal, the price would be raised.

****Sir Dennis Rooke was largely responsible for initiating and setting up the first long distance transport of LNG by tanker. This from Algeria to Britain, and later did the negotiations with the oil companies over North Sea Gas. The long term fixed price contract, enabled British Gas to underwrite the conversion from Town to Natural Gas. As BG Chairman, Rooke, in the 1970s, supported R&D work into making substitute natural gas from coal and oil, in the belief that this would be needed when North Sea Gas ran out.*

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

TABLE 1: Change in Average Price of Fuels (Domestic and Industrial) 1950-1960 ¹⁷

In 1950, the cost of a thousand tons of coking coal was £3112 (n.b. the daily throughput at Beckton, claimed to be the largest gas works in the world, was 4500 tons). By comparison, the cost of power plant coal was £2557, not too great a disparity. In 1959 power station coal had risen to just £3754, but the price charged for coking coal had gone up to £6200 ¹⁸. Since the price of coal made up 40% of costs, gas was becoming uncompetitive compared to oil, and, more importantly, to electricity. See Table 1.

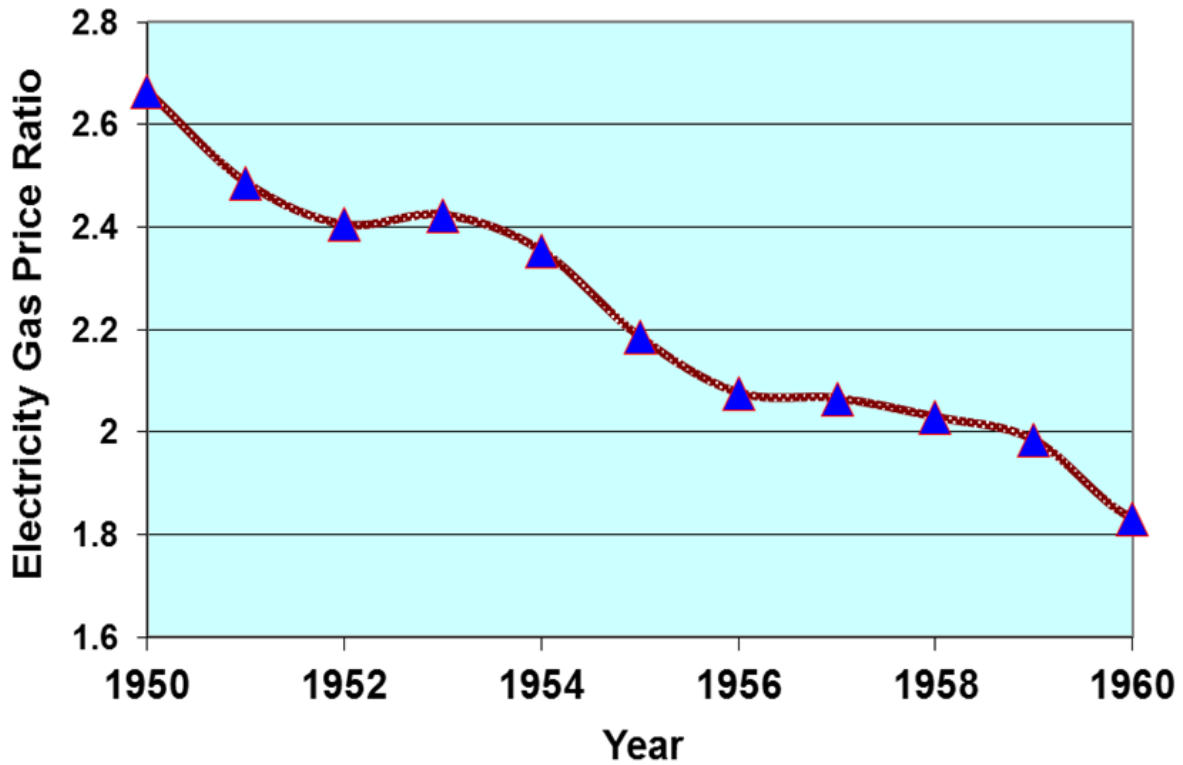


Figure 3: Electricity/Gas Price Ratio based on data from Handbook of Electricity Supply Statistics (1967 edition) ¹⁸

The fragmented nature of the Industry, with just a weak central body in the shape of the Gas Council, and 12 Area Boards, sometimes worked against it in its deliberations with the Government. Hence Andrew Jenkins states...

By the end of the 1950s with gas sales showing some tendency to decline and the industry slipping into deficit the Treasury was asking increasingly tough questions about investment plans.

He points out that although the Gas Industry had scaled down its planned expenditures in 1958/59 and 1959/60 to £62 and £56 million, the Treasury was demanding significant reductions on those figures, amounting to £17 million in total. Fortunately, some civil servants in the Ministry of Power were attuned to new developments that were using oil rather than coal, so there was some support for gas¹⁹. My guess, is however, is that the Government was far more preoccupied with coal and electricity, than what was generally perceived to be an industry that had had its time.

3. Options for a Rejuvenated Industry

If the Gas Industry was to survive, continuing with retort type technology was not an option. It was essential that any new process should be able to use feedstocks other than coking coal. If there were byproducts, they should be of high value, able to compete with those being produced by the petrochemicals sector. In addition, new processes should operate at high pressure, facilitating the transmission of gas around each Area Board, enabling a few large “gas works” to cover the whole region. The possibilities were:

- If gas was to be made from coal, it should be based on large scale high pressure processes, ideally using power station coals
- To import liquefied natural gas, sending it by high pressure pipe line throughout Britain for the manufacture of town gas or for enrichment purposes
- To use the less expensive oil refinery products, including oil, in new forms of gas making

High pressure coal gasification was a reasonable prospect. Since 1936, a German company, Lurgi GmbH, had been marketing a “moving bed” gasifier, contained within a tall pressure vessel where a mixture of superheated steam and oxygen was blown through a rotating hearth at the base of the gasifier. As they percolated their way up through the gasifier bed they reacted with the coal. The main drawback was that the Lurgi was as restricted in its range of coals as were the older processes. Temperatures had to be kept below 1200°C to prevent the ash in the coal from melting and clogging up the bed. For similar reasons, a non-coking coal was needed. The low gasification temperature implied that the coal should have a high reactivity. Hence, the preferred coal was of the lignite type.

But Britain is a country of high rank coals, apart from area in the Fife region of Scotland. Here four Lurgi gasifiers were built next to an open cast coal mine at Westfield, where the coal was non-caking, had an ash melting point of 1400°C, and contained some carbonaceous shale bands^{20, 21}. The Westfield scheme was also noteworthy in requiring the construction of a pipeline network running at 250 lb/in², connecting the Lurgi plant, near Loch Leven with Dundee, Edinburgh and Glasgow. Another Lurgi was built at Coleshill in the West Midlands, but this was closed when the steam reforming processes were established. But the Lurgi had the old gas industry problem. Although operating at high pressure, its gas contained the byproducts and contaminated effluents of a conventional retort type gasifier.

There was some home grown work on advanced coal processes on the hydrogenation of coal, dating back to the 1940s, at the gasworks at Poole, in Dorset. It was an ideal site for this activity since Poole had been responsible for producing hydrogen for the wartime balloon barrage ²². ²³. It had the equipment for producing hydrogen at high pressure. By the middle fifties, the work eventually switched to the Midland Research Station, in Solihull, under Dr Dent, whose efforts were recognised by his elevation to the Royal Society. However, only about 40%, by weight, of bituminous coal will react with hydrogen to form methane and ethane. The char which remains has got to be gasified using steam and oxygen, not only to make the process economic, but to provide the hydrogen for the hydrogenating reaction. Eventually the work at Solihull switched to the lighter varieties of oil, which are easier to hydrogenate, although this process also needs a supply of hydrogen. This would come from an ICI type reformer.

The issues connected with gasifying coal at high pressure, either using the Lurgi, or by hydrogenation, meant that R&D on coal was shelved, although work restarted in the 1970s. These matters are outside of the scope of this paper. Perhaps the most far reaching decision at the time was to import Liquefied Natural Gas (LNG) by tanker from Algeria. It required the conversion of a standard oil tanker to carry liquefied gas at -162°C, the building of a gas storage terminal at Canvey Island, and the construction of a high pressure gas pipeline from Canvey to Leeds. There was a short spur off to Hitchin, where the methane could be converted to town gas by steam reforming or used for enrichment. The cost of LNG was higher than oil based feedstocks, and this restricted its use. A chapter in the book by Sir Kenneth Hutchinson covers this initiative, which was so far advanced in its time that, even in 1969, these three tankers represented almost all of the shipping devoted to the transport of LNG ²⁴. It is worth noting that Gibson was the Gas Council's man in Algeria, and who also supervised some of the first landings of LNG at Canvey.

The other possibility was to switch the Gas Industry over to oil as far as possible. Oil had been used to supplement coal in gas making for some time, principally in carburetted water gas plants, which were used for peak periods. Here water gas was produced by blowing steam through white hot coke, which produced a mixture of hydrogen and carbon monoxide. This was enriched by spraying oil into the "carburettor", the oil cracking to form methane and ethane, thereby raising the calorific value.

The carburetted water gas process was "cyclic", the coke bed losing heat from the endothermic reaction of steam and carbon. Hence, in the reheating phase, the bed temperature was restored by passing air through the bed which began to burn in the normal way. Much ingenuity was used in the design of these processes to maximise gas production. Steam purging between the switch over to air was needed to minimise the risk of explosion.

During the late fifties, new development came into use, such as the Segas, Onia-Gegi and MS (Micro Simplex) processes, in which oil, in conjunction with steam, was led into a hot catalyst bed, in which a combination of cracking, reforming, and water gas reactions occurred. These processes, too, were of the cyclic type, with the catalyst having to be brought up to temperature and ridding itself of carbonaceous deposits by burning oil. Here again steam purging was required. Hence plant output was limited and the gas was at atmospheric pressure. These

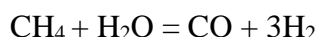
processes, and others are covered in the BP book on gas making, the first edition being published in 1959²⁵. The book is indicative that oil, as gas making feedstock, was becoming a significant in Britain and the rest of Europe.

The Segas process, developed by the South Eastern Gas Board, is an example of how autonomous were the Area Boards. The first plant was installed at a completely new works at the Isle of Grain, close by the Esso refinery. The time for a complete gasification/reheating cycle was 210 seconds. Eventually refinery gas was used in two of the reactors, this increasing the overall rate of production²⁶. The utilisation of refinery gases in such processes was a big step towards the true steam reforming revolution, giving some of the staff the first taste of operating something akin to a modern chemical plant.

4. Catalytic Steam Reforming

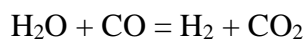
Catalytic steam reforming had come into use in America, using natural gas as a feedstock, as early as 1939²⁷. The process was originally developed to produce hydrogen for the manufacture of ammonia in the Haber-Bosch process. The basis of steam reforming is quite simple, whereby sulphur free natural gas and superheated steam are reacted over a heated catalyst to produce hydrogen and carbon monoxide.

Assuming the main reactant to be methane, the reaction is as follows:



In practice, for thermodynamic and kinetic reasons, not all the methane is converted. Excess steam is needed to drive the reaction to the right, but even so some methane remains. Also, a small amount of carbon dioxide forms, but both the amount CH₄ and CO₂ can be minimised by doing the reforming at the highest possible temperature, around 900°C, and at a relatively low pressure.

To increase the level of hydrogen in the feed to the Haber Bosch process, the product gas from the reformer was cooled down to about 350°C and sent into a pressure vessel containing a “shift catalyst”. Here the steam is reacted with the carbon monoxide as follows:



The subsequent processing steps were quite simple. Excess steam condensed as the process gasses were cooled, and the carbon dioxide was removed using an alkaline based wash. The final delivery pressure was a few atmospheres, which was very helpful in reducing the compression costs associated with putting a hydrogen feed into the Haber Bosch reactor.

ICI was the main manufacturer of ammonia in the UK, but was being left behind, having built its first plant at Billingham in 1923²⁸. Here a huge water gas plant was used to generate hydrogen by blowing a mixture of air and steam through a bed of coke. In effect ICI were operating a gas works of the “producer type” with all the complexity, costs and dirt that might be expected. By the 1950s ICI were becoming uncompetitive in the fertiliser market. Natural gas was yet to be discovered in the North Sea, and long distance transport of LNG was also in

the future. However, refinery capacity in Britain was increasing and a variety of oil products were coming on the market.

One of these was naphtha, a relatively light and inflammable product, somewhat similar to petrol, resulting from the production of fuel oil. The problem with naphtha, is that the molecules of its constituents are much larger than that of methane, consisting of short hydrocarbon chains. Simple heating tends to “crack” the chains, into “radicals”, as they are called. These recombine to form complex carbon rich compounds, which in the mass form deposits of “carbon”. Depending on the actual process conditions, the bulk of the naphtha will form gaseous molecules, including CH₄, H₂ and C₂H₄, etc, but the tendency of naphtha to crack and form carbon, degraded most catalysts.

DP. Haines, Chief Engineer at Power Gas indicated how ICI had come to develop naphtha steam reforming²⁹. Back in 1940 ICI had built a small unit at Heysham, Lancs, using refinery gas from the nearby Shell complex. The hydrogen from the reformer was used in the manufacture of aviation gasoline. But after the war, ICI utilised the hydrogen to make ammonia, still using refinery gas.

TABLE 2: Effect of Temperature and Pressure on Exit Gas Compositions from ICI Reforming Processes and a Typical Town Gas for Comparison^{31, 32}

Dry Gas Composition Vol %	Hydrogen for Ammonia Synthesis 815°C/ 175psi	Reforming for Town Gas 775°C/400psi	Town Gas as Supplied
CO	14.0	9.1	13.8
CO₂	13.6	17.1	3.7
H₂	70.8	64.4	48.0
CH₄	1.6%	9.4	22.2
Unsaturated Hydrocarbons	----	----	2.8
N₂	----	----	9.3
O₂	----	----	0.2
Calorific Value	285 Btu/cu.ft	327 Btu/cu. ft	480 Btu/cu. ft

In 1954, after some pilot plant work with new catalysts, ICI converted the original reformer to run on naphtha, and in 1959 a second purpose built unit was built. These were apparently

running at a very modest pressure. Haines states that work at ICI Billingham, resulted in a reformer with an outlet pressure of 180 psi, this being better for Haber Bosch ammonia synthesis, keeping pressurisation costs down. The grade of naphtha being used was LDF 115, a paraffinic distillate, with a final boiling point of 115°C. It is worth noting that Power Gas, as a petrochemical contracting company, was based in Stockton, just a few miles from the Billingham petrochemical complex. And Ludwig Mond, the founder of Power Gas, had been instrumental in developing ammonia synthesis on Teesside.

One key element in the success of the ICI process was a technique to remove all traces of sulphur compounds from the naphtha (which on delivery contained about 100 ppm total sulphur), as these would poison the steam reforming catalyst³⁰. The other vital step, by ICI, was to add potassium salts to the catalyst, increasing its reactivity and reducing its tendency to deposit carbon from the naphtha. For the Gas Industry the improved reactivity was crucial as it allowed the catalyst to operate at lower temperatures, increasing the amount of methane in the product gas. Table 2 shows that reducing the reformer outlet temperature to 775°C, and increasing the pressure to 400 psi, from the levels best suited to hydrogen manufacture, increased the methane content from 1.6 to 9.4%. These figures are probably theoretical, in which the chemical reactions come to equilibrium, but they do give a good indication of trends.

TABLE 3

Cost of Gas by Various Processes in 1964³³

Process	Main Feedstock	Cost at 65% Load Factor (d/therm)	Cost at 45% Load Factor (d/therm)
Continuous Vertical Retort	Coking Coal	13.89	18.04
Carburetted Water Gas	Coke	12.23	13.45
Continuous Reforming Process	Liquefied Petroleum Gas	9.51	10.33
Catalytic Rich Gas Process	Naphtha	6.69	7.57
Continuous Reforming Process	Methane from Canvey	9.04	9.52

The cost of naphtha was low at about £6.40 a ton, weight for weight similar to good quality coking coal. But the calorific value of naphtha was almost twice that of coal, and in terms of converting chemical energy into gas, steam reforming was over 90% efficient, the water gas process just 75%. After passing through the shift reactor, the carbon monoxide in the mixture intended for towns gas would drop to about 2-3%, and the hydrogen content would rise to about 70%. Although still toxic, gas from a reformer was safer than that from the old gas making processes. It was said that there was now about as much chance of a gas leak blowing you up,

as poisoning you through from carbon monoxide. But both old and new processes required enrichment to bring the calorific value to the standard town gas figure of 500 Btu /cu. ft (18.6 MJ/cu.m).

The economics of steam reforming can be judged from Table 3, when North Thames Gas had reforming plants at Romford and Canvey, using methane as a feedstock, piped from the LNG storage site at Canvey. Even using LNG, which is expensive compared to naphtha, reforming easily beat carburetted water gas and continuous vertical retorts, especially at low load factors. It seems likely, using naphtha in the straight forward ICI process, the cost would have been about 8d/therm or about 3.3p/therm in today's money (excluding inflation). A few years earlier it was affirmed that for gas to compete, the production cost would have to be under 10d/therm. Also note the extremely low costs associated with the Catalytic Rich Gas Process, a technology developed by British Gas. This was eventually used in conjunction with steam reforming, replacing the need for expensive enrichment.

5. Town Gas History and the Hydrogen Economy Future

5.1 What Seems to Being Offered

It may be bizarre to include a section in this historical account about the hydrogen economy, which even on present projections is some way off. Nevertheless, as **George Santayana**, the writer and philosopher has stated “Those who cannot remember the past, are condemned to repeat it”. Such an axiom, aimed at politicians and the military, applies to energy planners, too. Accordingly, Part 1 ends with a realistic and, hopefully, objective tailpiece about the “prospects” for hydrogen, drawing on what happened to the Gas Industry in the 1950s.

Much is being heard about the hydrogen economy, and the issues, technical and economic, in switching from natural gas^{34,35,36}. Nevertheless, we have been here before, when Britain switched from Town Gas to North Sea Gas. As this paper is being written, in 2021, one proposal is that a quick and easy, politically acceptable way to the hydrogen economy is to add up 20% H₂ to natural gas. This should be compatible with the types of burners that are currently used in central heating boilers. A 20% mixture would avoid the billions needed to convert boilers to pure 100% hydrogen.

In the late 1960s, the cost of conversion was born completely by British Gas, a state-run industry, which was in total control of gas supplies. The company also regulated costs and prices, being able to take a decade long view of business profitability. In consequence, British Gas was in the fortunate position of being able to underwrite the expense of the switchover, shielding the householder from the cost of a new gas boiler. A situation which does not prevail today. Quite the opposite, where one after another, tiny companies initially set up to play the “gas market” have folded, when gas prices soared.

Hence the attraction of adding 20% hydrogen to natural gas, which minimises the economic and political cost, of changing burners and gas boilers. While it makes the gas system look green, a 20% addition, is, in fact, rather pathetic, as the hydrogen only accounts for 7% of the calorific value. But for our leaders it disguises the high cost of hydrogen as an energy source.

In this respect in its “Hydrogen Strategy” document, the UK Government envisages only 1TWh of hydrogen penetrating the heating sector by 2030, but then postulating a rapid growth to 45TWh in the next five years. It seems a large amount, but the usage of domestic natural gas in 2019, was just under 310 TWh, which would make the hydrogen contribution less than 15%. There does not seem to be any prediction for domestic use of hydrogen beyond 2035.

There is another scenario, compatible with 45TWh of hydrogen, which is not good news for the Gas Industry. Where, because of the cost of hydrogen, consumers begin insulating their houses, and switching to electricity for home heating. Either directly, or via heat pumps. Not using domestic gas, if they can possibly can. It is a scenario analogous to the challenges of the 1950’s , where when the electricity/gas price ratio fell to less than 2/1, consumers began switching away from gas.

5.2 Hydrogen Costs to the Domestic Consumer

Table 4 shows a selection of projected gas and electricity prices published by BEIS (Department for Energy and Industrial Strategy), for domestic and industrial users. Up to 2040 electricity prices show a 10% drop, then stagnating. This seems reasonable given the gradual improvement in CCGT plants and the reduction in the cost of wind and solar energy. Over this period domestic costs rise by almost 10%. The increase, one would suppose, largely reflects the market price, with world wide reserves on the decline, and world wide markets growing

TABLE 4

Future BEIS Projected Gas and Electricity Costs (p/kWh at 2020 prices)

Year	Domestic Gas	Industrial Gas	Domestic Electricity	Industrial Electricity
2021	5.35	3.33	22.5	14.7
2028	5.66	3.83	22.4	14.3
2035	5.81	4.33	20.9	13.2
2042	5.83	4.12	20.5	13.3
2050	5.83	4.12	20.5	13.3

On this basis it looks like gas is still the better bet for the householder in the distant future. In 2021 the electricity/gas price ratio is 4.20. In 2035, it has dropped to 3.6, which is still on the side of gas. It is still good in the 2040s.

But just how reliable are these predictions? With the world coming out of the Covid disaster, all is confusion. Wholesale gas prices have shot up from about 40p to well over 200p/therm. That is from 1.3 to 7.0p kWh. Wholesale electricity has gone from about 6 to about 18p/kWh.

If these costs work though, in the very near term domestic gas increases to about 11p/kWh and domestic electricity to 34.5p/kWh. The electricity/gas price ratio falls to 3.13.

Turning back to the prospects for hydrogen, it is officially, although unwillingly admitted, that hydrogen will be more expensive than natural gas. In 2040 when hydrogen could be making a real contribution to the energy economy, the BEIS estimated costs vary widely according to the method of production.

The cheapest routes use variants of steam reforming using natural gas as a feedstock, where the price of the natural gas is critical. BEIS, in their estimates, would be using prices similar to those quoted in Table 4, and would be those for supplies to an industry. These would be about 20% higher than today. Reductions in capital costs, especially for the more advanced type of reformers are assumed to offset any increase in the market price of natural gas. Carbon capture and storage are an essential feature of all type of steam reforming, and are costed into the BEIS figures..

Depending on the sophistication of the reforming plant BEIS estimates range from 46 to £66/MWh for as-generated hydrogen, the higher price corresponding to a “bog standard” reformer of the type used by British Gas in the 1960s. It would result in **domestic hydrogen** costs of about 9p to 11p/kWh. By a coincidence these are not too different to what gas consumers might see if today’s natural gas prices stabilise at 200p/therm. The big difference is that domestic electricity prices, in the 2040s will be around 20.5p/kWh. The electricity/gas price ratio would then be in the dangerous 2/1 range.

The most critical factor, not considered by BEIS, is that it is more than likely that natural gas prices will not be anywhere near the levels of today. Producers, having seen how desperate is the world for such a clean fuel will be exploiting the situation. The well head price will be much higher than 40p/therm. Accordingly hydrogen will be rather more expensive than that predicted by BEIS. Furthermore, given that in 2040 much of our electricity will be coming from renewables, any price increases from this sector will be modest. We might therefore see the electricity/gas prices ratio falling below 1.5/1. If we stuck with steam reforming this would be a catastrophe for the Gas Industry.

Would it be better if hydrogen were made by electrolysis? The BEIS predictions suggests not, even with the improvements we could expect in 2040 to power generation and electrolysis assembles. The BEIS figures show that if the price for electricity is that paid by industrial users, as-generated electrolytic hydrogen will cost £127/MWh. This would work through to a price for the domestic user of around 17p/kWh. The lowest price is where the electrolysis plant runs on “curtailed (wind or solar) electricity”. That is when there is a high level of surplus power on the grid, the electricity is essentially being given away. However, because the electrolysis plant would be being operated at part load, capital and fixed costs have a bigger impact. Hydrogen falls in price to £43/MWh, so domestic hydrogen would be about 9p/kWh.

5.3 Hydrogen and Waste of Resources

Although the hydrogen might look green, it only qualifies as such, in that, at the point of use, there are no emissions of carbon dioxide. Until fairly recently, going “green” meant that (a) all energy should come from renewables, wind, solar, hydro, wave and tidal and (b) energy from these sources should not be wasted, unnecessarily. Accordingly, the more objective and clear thinking protagonists for a renewable economy would point out that production and use of hydrogen results in serious energy losses.

It is a serious drawback, especially when the hydrogen is made by the steam reforming. Here, since natural gas is being used as the source of the energy, this is no more sustainable than our present day use of natural gas to heat homes. Worse, in fact. According to the BEIS report, up to 30% of natural gas is wasted in steam reforming. In consequence, switching to the hydrogen economy gets us through British and World reserves 40% faster.

Given that wind is “free and inexhaustible” how does wind power compare? The loss of energy in the electrolysis of water is again around 30%. The issue here is that 40% more wind farms, undersea connectors, and electrolysis plants would be needed compared to using the electricity for direct heating. The situation is even worse if the electricity was used to power heat pumps.

There are further losses when hydrogen is used in central heating. The combustion of hydrogen produces a large amount of water vapour which must be condensed. This enables as much as is possible of the heat that is generated passes into the central heating boiler. Government regulations call for a boiler efficiency of 92%. In practice this figure will be lower as it requires a low return temperature of the water from the radiators back to the boiler. In practice at least 10% of the heat will be lost.

In a nutshell, hydrogen when used for domestic heating, loses 30 to 40% of the energy that is used to produce it. Not green at all, really.

6. Discussion and Conclusions

Within this author’s life time, natural gas has come to replace coal, completely, for home heating and most industrial purposes. Coal’s last stronghold is in the blast furnace, for the initial stage in the production of iron. The move to natural gas has enabled politician to claim that the UK is well ahead in cutting its greenhouse gas emissions. These having coming down by over 40% since 1990 ³⁷.

But a gaseous source of energy, whether it is town gas, natural gas or hydrogen has serious drawbacks. Gases are not as convenient to store as petroleum, or even coal. And the main use of inflammable gases, such as these is for, heating. Without the use of equipment such as the IC engine and the gas turbine, and the skilled manpower to supervise and maintain them, gaseous fuels cannot produce mechanical power. This is a huge drawback compared to electricity which can be used to drive electric motors of any size, without supervision and with minimal maintenance. And electricity can also be used for heating. Both is a crude manner, via resistance heating, or in much more sophisticated way such as the microwave, induction heating and the electric arc.

Certainly, if it was not because of the cost, electricity would be the sole energy vector “piped” into British domestic households or business premises, as we see in some other countries. The lesson that the Gas Industry in Britain was learning all through the 1950s. Rescue for the industry came with the steam reforming of naphtha and then, a bit later, with North Sea Gas.

These were technological answers greatly reduced the cost of gas and pushed all other challenges, electricity, coal and oil into the background. Hydrogen does nothing of the kind for the gas industry, pushing up its prices. Hydrogen may be the ultimate carbon free gaseous form of energy, but it will impact very severely on what the consumer pay. Given this scenario, the domestic householder of the 2030s will turn off the gas and switch over to power.

References

1. The National Gas Archives: History: Nationalisation 2005
2. A. Davis “The Reforming Era” South Western Gas Historical Society Sept 1995
3. A. Jenkins “Government Intervention in the British Gas Industry” Business History 2004 46:1, pp 57-78
4. GH. Gibson “Gases from Petroleum Resources- Part 1- Use by the Gas Industry “The Petroleum Industry in the United Kingdom” ed. People (Inst of Petroleum 1966), pp 74-103
5. G. Milner “Continuous Steam-Hydrocarbon Reforming and Town Gas” Gas Journal, Jan 9th 1964 pp 25-32 (See Discussion)
6. EL Faulkner and CW. Higton “ICI Reforming Plants at Effingham Street”, pp 127-131 Gas Journal 11th May 1966
7. AA. Clark, GFI Roberts, PJ. Savage and E. Spivey “Continuous Catalytic Reforming Plants in North Thames” pp 139-151 The Gas Journal 9th Feb 1966
8. J. Sharp and VJ. Welch “The Killingholme Continuous Catalytic Reforming Plant”, pp 59-62 Gas Journal 19th Oct 1966
9. MK. Barrett “First Major Overhaul of Bromley Hydrocarbon Plant”, pp 185-187 Gas Journal 9th Nov 1966
10. P.E.P Report on The Gas Industry in Great Britain, P.E.P March 1939, p.119
11. P.E.P Report on The Gas Industry in Great Britain, P.E.P March 1939, p.36
13. CE. Prockter, BW. Pendred, Kemps p 451 Engineers Year Book Vol 2 Morgan Bros 1960 p.451

14. Table 56-Part 1 Gas Industry Production, pp 88-89 Electricity Supply Statistics 1967 published by The Electricity Council
15. M. Falkus "Chapter 3: The Struggle for Survival" in *Always Under Pressure- A History of North Thames Gas Since 1949* (Macmillan 1988), pp 47-60
16. M. Falkus, p 47
- 17.M. Falkus Table 3.4, p 48
18. Tables 38 and 58 Handbook of Electricity Supply Statistics 1967 Edition c/o the Electricity Council (1967)
19. Jenkins pp 62-64
20. TS.Ricketts "The Westfield High Pressure Coal-Gasification Plant" *Trans. Inst. Gas Eng.*1959-60 pp 848-925
21. TS.Ricketts "The Operation of the Westfield Lurgi Plant and the High-Pressure Grid System" pp 563-588 *Inst. Gas Eng. Journal* Oct 1963
22. G Percival private communication 2011
23. K. Hutchinson and D. Hebden "Frederick James Dent 1905-1973" *Biographical Memoirs of Fellows of the Royal Society* Vol 20 1974
24. K Hutchinson "Chapter 11-The Methane Venturers", pp 177-195, *High Speed Gas-An Autobiography* pp 177-195, Duckworth 1988
- 25 "BP Gas Making" revised edition 1965 c/o Technical Services Branch, The British Petroleum Company Ltd
26. C. Stott "Gasification at the Isle of Grain" *Trans. Inst. Gas Eng.*1959-60, pp 926-987
27. JC. Maginn "Steam Reforming by the Imperial Chemical Industries Process" c/o Selas Corporation of America c.1965
28. PWB Semmens "Chemical Process Engineering at ICI Billingham" pp 52-60 *Trans Newcomen Soc* Vol 55 (1983-84)
29. DP. Haines "Trends in Gas Production Processes in the Past Decade" pp 281-284 *Gas Journal* 29th May 1963
30. BP Gas Making, pp 116-177
31. From Table 22, BP Gas Making, p118
32. CE. Prockter, BW. Pendred, p397

33. M. Falkus from Table 4.1 in "The Struggle for Survival" in *Always Under Pressure- A History of North Thames Gas Since 1949* (Macmillan 1988) p 71
34. UK Hydrogen Strategy: HM Government 2021
35. Hydrogen in a low carbon economy: Committee on Climate Change Nov 2018
36. Rising to the Challenge of the Hydrogen Economy : DNV July 2021
37. 2019 UK Greenhouse Gas Emissions-Final Figures BEIS 2021