Natural gas network development in the UK (1960-2010)

Coping with transitional uncertainties and uncertain transitions

Final case study report as part of Work Package 2 of the UKERC project: 'CCS – Releasing the Potential?'

December 2011

UKERC/RS/CCS/2012/008

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Summary of key findings

Carbon Capture and Storage (CCS) exists today as sets of discrete components and types of expertise. Integrating these into working CCS systems applied to power plants is a challenge in itself, and there is uncertainty as to what technical and organisational form this will take (Markusson, et al., forthcoming).

This case study is about the transition of the system for gas provision in the UK from town gas to natural gas, as an analogue for the challenges of integrating large, infrastructural technical systems. The case study unfolds chronologically in order to provide a co-evolutionary and comprehensive understanding of the uncertainties that the system development and network integration in the UK natural gas industry faced. Two periods are identified: the first from the 1960s to the mid-1980s, which was a period of nationalisation and centralisation; and the second from the mid-1980s to the present, which has been characterised by privatisation and market liberalisation. For both periods, the practice of system integration has been approached in its dual character: the horizontal (geographical) and the vertical (governance) integration. The case study argues that while in the first period the Gas Council was the main actor in the management of the uncertainties of network integration, a multiplicity of actors emerged in the second period increasing the complexity of the system. In the latter period, regulatory bodies, private companies and government departments have all contributed in the process of network integration.

Initially, the case study focuses on the introduction of natural gas in the UK in liquefied form (Liquefied Natural Gas, LNG). It is argued that the development of the LNG transmission network facilitated the integration of the natural gas network. Subsequently, the focus is moved to the uncertainties that were introduced with the decision of the rather radical transformation from manufactured gas to natural gas. It is

argued that the conversion project involved tensions and ambivalences and necessitated the management of technical and non-technical components of the socio-technical system. The next section considers the implications of that conversion of the system design, focusing both on the horizontal and the vertical aspects of system integration and their uncertainties. The fourth and final section argues that regime changes since the mid-1980s, and mostly since the mid-1990s, influenced the network design and triggered new uncertainties in relation to its stability and security. The transnational character of the natural gas network and the interconnector became more important within the context of market liberalisation and a new regulatory and governance framework that influenced the very conceptualisation of system security and energy sufficiency.

Several lessons for the network integration of the CCS system can be drawn from the historical reconstruction of the natural gas network:

1. It might be better to understand CCS within a context of fragmented regionally integrated systems where the hubs for the collection of CO_2 from the various plants will be the critical infrastructure.

2. The first UK CCS demonstration plant could be designed and planned to provide the ‘back bone’ hub of a regional integrated CCS system.

3. More attention needs to be paid to the vertical integration of the CCS system, and not only the horizontal integration, and the technological and organizational uncertainties that this can involve.

4. The interconnection to a European CCS network – even if only partial – can be considered as a critical infrastructure for increasing the flexibility and capability of the system and for contributing to the resilience of the system to critical events.

5. A focus on the management of the multiple types of expertise necessary for the establishment of CCS networks could be important to facilitate the implementation of CCS projects.

1. Introduction

The present case study is focused on the transition of the UK natural gas network from 1960 to 2010. The aim is to understand the history of the system integration of the natural gas network as an uncertainty. It is also to analyse the uncertainties as they appeared or as they have been perceived by contemporary practitioners (mostly engineers, policy makers and politicians) during the period of transition. The study of the history of system integration of the UK natural gas network has been chosen as a historical analogue to CCS integration for several reasons:

- they are both network technologies that involve transmission of gases
- both systems are influenced by developments in geological exploration particularly of the North Sea
- the natural gas network includes storage and liquefied natural gas facilities that increase the complexity of the system integration with possibly helpful lessons for the CCS case
- natural gas system integration involved an extensive conversion program from manufactured to natural gas and the study of the conversion and the integration of the existing gas networks with the new transmission lines has been considered as potentially informative in relation to the integration of the CCS system and of the CCS technologies to the existing power stations.

The analysis starts from the premise that system integration is a continuous process; thus by adopting a transitional perspective we can understand it better through the study of the structural changes and the historical contingencies. In this context the system integration is approached through the lenses of the 'multi-level perspective' of technological transitions (Geels, 2002; 2005) that stresses the co-evolution and co-constructive character of network technologies with changes in the political, policy and regulatory regimes.

Furthermore the system integration process is approached as a socio-technical activity that is conducted in two dimensions: the 'horizontal' and the 'vertical' integration. The concepts have been introduced by the historian of technology Lars Thue and are influenced by Hughes's analysis of large technological systems (Thue, 2012 (forthcoming): 366; Hughes, 1983). The first denotes the spatial development, expansion and growth of the system and is related to relevant uncertainties and vulnerabilities that this can introduce in network technologies. The second type of integration denotes something specific and more than the hierarchically structural formation of the industrial sector that economic and business historians tend to describe as 'vertical integration' (Thue, 2012 (forthcoming)). In the large technological system approach (Hughes, 1983) the 'vertical integration' is related to (a) the way technologies, small or sub-systems overlap and interconnected in a larger system, and (b) the way control technologies are introduced to effect the coupling and when necessary the decoupling of the different systems and the several components (Thue, 2012 (forthcoming): 360-404) Through the introduction of control technologies infrastructures acquire their physical and symbolic character while in the same time their resilience and uninterrupted performance are secured (Thue, 2012 (forthcoming): 360-404; Hughes, 1983:5-6).

In the case of natural gas the vertical integration is referred to the pattern of hierarchical governance that was followed by the Gas Council as well as the introduction of new information and control technologies. The latter technologies improved the control and security of the system, but also increased its complexity and may have added to its vulnerability. During the period of coverage there were important changes in the socio-technical regime that influenced the network integration in the natural gas industry. Two main periods of historical importance in the development and integration of the network can be identified: the first is from late 1950s to the mid-1980s and the second is from mid-1980s to the present. Political and regulatory regime changes influenced the network integration. The first period was the period of centralisation and the Gas Council was the crucial actor in the integration of the system while the subsequent period that characterized by the privatisation and liberalisation of the industry the actors involved in the system development multiplied with private companies to have the leading roles in relevant infrastructure investments. System integration was effected mostly through regulatory innovations.

Evidence for the case study is based on the extensive existing historical literature as well as on some new evidence gathered by the author from technical journals of the period, most prominently the *Journal of the Institute of Gas Engineers* and the *Gas Engineering and Management.*

2. Contextual Background

In the period before the Second World War the UK gas industry was dominated by manufactured gas produced by private and municipal companies. Fragmentation and deregulation prevailed. After the War and particularly with the Gas Act 1948 the industry moved toward nationalisation and amalgamation, a policy that supported and executed by the Labour Party. With the new Act a new governance system was introduced with the establishment of the Gas Council and the 12 Area Boards. The Area Boards were independent statutory bodies which had the responsibility of the regional gas industry. The new political and regulatory regime resulted in changes in the production of gas. While in 1949 there were 1050 gas works, in 1959 due to the governance, legislative and policy changes the number of gas production works had become 536. In 1962 the production units had been reduced further to 341 with the 74 of them to produce the 73% of the gas. The centralisation and concentration of power was boosted further with the Gas Act 1972. The Gas Council was renamed to British Gas Corporation and the Area Boards to Regional Councils while the British Gas Corporation acquired the governance and administrative control from the Regions and a National Gas Consumers' Council was established to secure the consumers' interests. (Simmonds, 2001:1; Williams, 1981:118–119; 236–241).

The reorganization of the gas industry through nationalisation along the lines of centralisation and concentration was not only a political decision promoted particularly by the Labour Party but a response to a declining industry. The quest for rationalisation had been an ongoing concern since the inter-war period. In the post-war period, rationalisation was achieved through the centralisation brought about by the Labour Party's nationalisation programme in relation to coal, electricity, transport and the gas industry. (Williams, 1981:89–119) The response to the continuous decline of the industry triggered research activities for the improvement of the manufacturing processes. In the period of nationalisation the manufacture of gas was based on the carbonisation of coal. The stakeholders in the industry were looking to improve the manufacturing methods so to make the fuel more competitive in relation to electricity and oil. It was acknowledged that the continuation of the use of coking-coal as it was used in the traditional carbonisation methods would increase the cost of production as this type of coal became scarcer and more expensive. (Williams, 1981:121–122).

Researchers sought new methods of producing gas compatible with the nationally established specification of a calorific value of at least 500Btu per f^3, a Wobber number of about 730 and a flame speed factor of about 40. (Williams, 1981:128) The research and development for the new methods was focused on three specific areas:

(a) the development of processes of complete gasification of low grade coal, with the aim of reducing the cost of raw materials and of the production of coke;

(b) the use of petroleum instead of coal;

(c) since the late-1950s the import of LNG had been deemed an appropriate method for enriching manufactured gas. Until the early 1960s the gas industry was dominated by coal gasification (90%). The alternatives – the Lurgi process of gas manufacture and oil-based gas – had made their way in Britain's energy mix but had failed to make a real contribution or to achieve any real share in the gas industry due mainly to their high cost. (Williams, 1981:121-122, 124-125, 128). LNG first made an appearance in 1965 but soon developments in the exploration of the North Sea changed its initial use and meaning (James, 1970). (see § 3.1).

With the prospect of introducing natural gas, and especially with the exploration of the UK Continental Shelf and the discoveries of several extended gas fields (Hutchison, 1965, Sanders and Humphrey, 1965), the Gas Council and then the British Gas Corporation acquired the exclusive and monopoly rights to the sale of gas. A monopsony regime was established in the UK gas industry that defined the development of the network (Davis, 1984: 95-119). The monopolist power of the Gas Council was established through the provisions of the Continental Self Act of 1964 and the 1965 Gas Act. The Gas Council and the Area Boards exercised extensive power and rights in the management of the flows, distribution and sale of natural gas. Strong barriers were placed to reduce the rights of the producers in the supply of gas. The 1965 Act gave the Gas Council the power (not exclusive) to produce and buy gas in the UK and beyond and to supply the gas in the Area Boards. With the new Act the Gas Council could act on behalf of the Area Boards in negotiations with the producers while at the same time being under an obligation to establish a high pressure transmission system that would transfer natural gas to the twelve Area Boards. (Davis, 1984:103) The privileged position of the British Gas Corporation terminated in 1982 with the Oil and Gas Enterprise Act. Further change came with the continuous waves of privatisation and liberalisation of the industry. (Williams, 1981:236-239; Davis, 1984:95-104) During this period the Gas

Council did not only establish a monopoly regime in the sales of natural gas through legislative interventions, but also established interests in the production side by holding in the 1970s shares in three out of five major fields of the period. (see table below):

Gas Council shares in gas fields in the Southern Basin of the North Sea

Field Name	**Estimated Reserves (Billion m³)**	**Gas Council Share (%)**
Indefatigable	127	19.3
Leman	197	14.8
Viking	82	0.6
Hewett	100	no direct partnership but 'interlocked' (*)
W.Sole	62	–
Reserve Totals	568	9.5

(*) The GC was 'interlocked' with the owners of the Hewett gas field as the same group of companies was involved in the Leman field

(Source: Davis, 1984:104 (Table 5.2))

3. Case Analysis

The case study is analysed chronologically in order to provide a co-evolutionary and comprehensive understanding of the uncertainties that the system development and integration involved in its various stages. The first section is focused on the introduction of natural gas in the UK in its liquefied form. It is argued that the development of the

LNG transmission network facilitated the integration of the natural gas network in providing the infrastructure for the fast and smooth implementation of natural gas. The second section is focused on the uncertainties that were introduced with the decision of a rather radical transformation and change from manufactured gas to natural gas. It is argued that the conversion project involved tensions and ambivalences and necessitated the management of technical and non-technical components of the socio-technical system. The third section examines the relevant implications of the conversion in the system design and system integration, focusing both on the horizontal and the vertical integration and the relevant uncertainties. The fourth and final section explores the developments since the mid-1980s when a transformation in the political and policy regime emerged through the privatization and liberalisation of the UK energy market. Regime changes influenced network design strategies and triggered new uncertainties in relation to its stability and security. The transnational character of the natural gas network and the interconnector were came about within the context of market liberalisation and a new regulatory and governance framework that influenced conceptualisations of system security and energy sufficiency.

3.1 The LNG Project: Building the 'Back Bone' of the Network

Before the discovery of North Sea natural gas several schemes and plans where considered and devised based on transport and import of LNG. The most important proposals were the import of LNG from Venezuela and from Nigeria as well as the construction of a pipeline from Holland. In all those cases LNG was introduced as a viable technical solution within the previous technological framework that was built around the manufacture and distribution of town gas (Rooke, 1967: 591). In general and despite the initial integration of the LNG into the manufactured gas system, it has been acknowledged that the liquefaction of natural gas added major flexibility as its volume was reduced by 600 times. This was a comparative advantage to coal gas which could not be liquefied as its main constituent -hydrogen- could only be liquefied when cooled to -240C and still only for small scale storage and only for particular industrial uses. (Tiratsoo, 1972: 210-211; Clar et al., 1967).

In Britain the first load of LNG arrived from Algeria in October 1964. The deal dated from 1961 when the Gas Council signed an agreement to import LNG from Camel Plant in Arzew, Algeria to Canvey Island, Thames Estuary. (see Map 1 in Appendix) (Clar et al., 1967: 654; Cormack et al., 1968). The re-vaporised Algerian LNG was transferred to major centres of consumption in England. A transmission network was built for the LNG providing the 'backbone system' for subsequent developments and the establishment of the natural gas transmission system. (see map 2 in Appendix) (Walters,1971). The new technological regime also heralded changes in the way the supply was organised, and a move away from local production and distribution systems towards a more integrated system. The Area Boards expanded into regions, and the ultimate aim was for the establishment of a national grid. W J Walters from Gas Council argued that: 'The extension of these developments towards a fully integrated national system was always regarded as an ultimate development.' (Walters,1971:549). What really determined the pace of these developments was the use of large volumes of LNG for the enrichment of town gas as well as the discovery of natural gas in the North Sea. (Walters, 1971:549).

Gas Council engineers believed LNG would be a crucial factor in the development of a national grid, because issues related to the LNG transmission pipeline, and storage locations, were similar to those that would need to be considered when developing a national grid infrastructure.

Initially, there was a period of experimentation and acclimatization among managers and the engineers in relation to LNG. An experimental enterprise was set up by the Gas Council and Constock International Methane Ltd, involving the transportation of LNG from Mexico to Canvey Island. It lasted from 1959 to 1960 and by 1961 it had been decided that the transport of LNG – this time from Algeria – should be conducted in a more large scale and commercial basis. The plans for the Algerian liquefied natural gas involved the transport of 700,000 tonnes/a of LNG, and the scheme started in 1964. A base-load supply of a total of 2.8 mill.m^3/d (100 mill. Ft^3/d) was connected to eight Area Boards. The pipeline was constructed to run from Canvey Island to Leeds and it was designed and operated at 68.9 bar (1,000 lbf/in2) (Walters, 1971:549). The natural gas was liquefied in a purpose-built plant in Arzew, Algeria and then from there as LNG was transferred to the Canvey Island by two special tankers, Methane Princess and Methane Progress owned by the Gas Council (Copp et al., 1966: 728). The main pipeline, with a diameter of 18 inches, was constructed, stretching from Canvey Terminal to near Leeds. There were also branch pipelines at a diameter of 6 inches, linking the central pipelines with the different Areas of Gas Boards. The line was considered a major technological step for the integration of the gas industry (Walters, 1971:549).

In early 1961 the Gas Council decided that the plans for the import of natural gas from North Africa would necessitate the introduction of organisational innovations in the management of the planning, designing and construction of the relevant infrastructure. A 'working party'- the Methane Pipeline Working Party- was instituted that comprised of representatives of all the interested Area Gas Boards, two representatives from the Gas Council and an independent chairman (Copp et al., 1966:730). The new technological network was established using a flexible organisational scheme with the 'working party' and a series of *ad hoc* committees to take over relevant sub-projects. Within this institutional framework major decisions about the appropriate route for the pipeline, the settling of the specifications and the precautionary measures required for the smooth operation and function of the network were taken (Copp et al., 1966: 730-731). In drawing up the specifications the Methane Working Party followed the technical instructions and regulations for the construction of high pressure pipelines that had been set by the Institution of Gas Engineers since 1965. It also set the procedures and protocols for the supervision, inspection and maintenance both of the pipeline and the control system and with an emphasis on the concentration and centralisation of those procedures (as the newly instituted position of Central Controller had the responsibility for coordinating actions and activities of all the involved Area Boards) (Copp et al., 1966:730-732; 739).

With the discovery of the natural gas fields in the North Sea and the integration of natural gas in the energy system of Britain, LNG changed in terms of usage and thus of meaning (see §3.3). It was not used as a base load feedstock for the production of town gas but in relation to the development of natural gas production and distribution. In the integrated natural gas system, LNG started to be used as a back up supply of natural gas in periods of peak demands or to provide natural gas supplies in areas that the gas pipeline had not reached (Walters, 1971:597). By 1971 a network of large diameter high pressure feeder mains and extensions had been constructed in quick pace providing transmission infrastructure from the terminals to the Area Boards and to large industrial undertakings (Walters, 1971: 549). The quick pace of development and the new and untested technologies introduced several engineering uncertainties and ambivalences while the plans were implemented. Walters, a deputy director in the Production and Supply Division of the Gas Council, pointed out that 'Since this is the most recent natural-gas system of any magnitude in the world, it has been possible to introduce the latest forms of technology. These innovations coupled with the introduction of a new type of industry to this country, have resulted in a number of problems that have required and will continue to require, considerable effort to resolve' (Walters, 1971:549).

3.2 Coping with Conversion

3.2.1 Conversion and Ambivalence

The discovery of the natural gas in British North Sea sector raised an issue about its use. By the end of the summer of 1967 two pipelines from the gas fields to the mainland were planned and scheduled to be completed. The first was the 24-inch diameter No.1 feeder main to transport natural gas from the West Sole field to the Killingholme works of the East Midlands Gas Board via the terminal at Easington. The 36-inch No. 2 feeder main was planned to transport natural gas from the fields Hewett, Leman Bank and Indefatigable. The position of the fields and the relevant plans were to build major terminals to receive the North Sea gas in the coast of Norfolk (Rooke, 1967:593).

With the discovery of North Sea gas the pressing question was how to use the natural gas more effectively and in what way it should be integrated in the energy system of Britain. There were obvious advantages but also some defects that were related to the momentum of existing technologies and were integrated to the distribution and supply of the town gas. The chemical constitution of the natural gas produced in North Sea was different from the manufactured gas. The natural gas from the North Sea had higher calorific value and at the pressures it was available, its use was more advantageous than the town gas. By 'enriching' a manufactured gas of calorific value of around 500 btu/cf with natural gas of calorific value 1,000 btu/cf to a 'send-out' calorific value of 750 btu/cf would have the same effect in terms of energy delivery as increasing by 50% the capacity of the existing transmission system. In this context it was clear from the starting point that the use of natural gas would effectively double the capacity of the system (Tiratsoo, 1972: 211; Williams, 1981:181-182).

At the same time Britain faced an obvious obstacle and defect in the quick change from town gas to natural gas. This was related to the domestic burners that were used in Britain in comparison with what were in use in other countries. In the latter, natural gas was burned in specially designed premixed aerated burners. In Britain a non-aerated gas burner was used and it was selected because it provided silent, compact, and stable diffusion of flames. The extensive use of natural gas would involve the large scale change of the burners (Tiratsoo, 1972: 211-212; Williams, 1981: 181). Furthermore, it was acknowledged that the issue of the design and manufacture of the burner was of major importance in the development and growth of the natural gas industry. Stability and security were qualifications on which the new burners had to acquire credibility. Research initiatives were considered necessary both from the manufacturing sector and the Gas Council (Gas Journal, 1966:53-54).

The existing infrastructures, the issue with the conversion of the appropriate burning technologies at the end user stage and the lack of a British trustworthy burner triggered an initial ambivalence in relation to the pathway that the gas industry should follow, despite the Gas Council's determination to push the new technology. An intermediate position had been considered and this made provision for the transformation of the North Sea gas to a gas with high calorific value and quality, but with fast burning properties similar to town gas. Engineers who supported such a technical solution gave four main reasons for doing so:

a. To enable areas to be converted in advance of the arrival of natural gas;
b. As a stand-by to natural gas supplies in the early stages;
c. As a means of disposing of feedstocks already contracted for, and which could not be diverted to other uses, or of dealing with an excess of natural gas condensates;
d. To provide seasonal - or peak-load - gas should it prove more economic in some cases than meeting the load by varying the demand on North Sea wells, or taking gas from LNG storage or underground storage (Rooke, 1967:595).

The issue at stake was the maximum use of existing infrastructure and of the plants that had been already erected (Rooke, 1967:595). Experiments on the production of the substitute natural gas had shown that it was compatible with the old types of burners but still some level of modification to appliances was unavoidable (Tiratsoo, 1972:212). However conversion taken in two or more stages would necessarily cost more overall than a single operation; and experience in the United States had shown that even if a gas of intermediate calorific value were to have been chosen as an interim measure the changeover to the highest available calorific value would have happened at a later stage (Tiratsoo, 1972:211-212).

The decision about the conversion process was made in 1966. The single operation and the complete conversion was prioritized as more advantageous and cost effective than the two stage option that existed and was considered by engineers and managers. The initial decision taken was for conversion to more forward, in case the reserves could provide natural gas in such quantities that the flow would be 1,000 m cu ft/d. The reserves proved to be adequate for the appropriate and necessary flow, so this was the plan that was followed. (Tiratsoo, 1972:212) (Walters, 1968:109) The initial cost of the conversion was estimated to be in the area of £400 to £500 million. Those who supported it argued that the benefits and the savings from the conversion were far greater than the initial cost. The efficiency of natural gas was 100% compared to 90% for reformer (substitute natural gas) 90%. The difference in the percentage would result in savings for the expanding industry in the area of £1,000 million. The project was unique in its character and it lasted ten years as 40 million appliances from 14 million users had to be converted and modified or even changed so as to be compatible with the new fuel. Despite the existing alternatives the Gas Council showed determination to make the full scale conversion (Elliott, 1980:6-7).

3.2.2 Governance, Experience and Expertise

The decision about the conversion resulted in further uncertainties relevant to the implementation of the project. The Gas Council established an *ad hoc* working committee to consider the uncertainties, risk and vulnerabilities of large scale conversion. The group was responsible for studying the complexities of the project and the technical and social (organisational and administrative) challenges, for devising different scenarios and making relevant proposals. The issue at stake that the Gas Council had to resolve was a due balance between centralisation and flexibility at the Area Board level (Elliott, 1980:13). At that moment the twelve Area Boards were autonomous and the Gas Council was the mediating institution between the Ministry of Power and the local Gas Boards (Elliott, 1980:14). The Gas Council embraced the idea for a separate department and so the Conversion Executive was established as the preferred organisational solution. Its role was:

a. to review of the plans of conversion;
b. to supervise the conversion process and to establish the appliances' requirements and appropriate specifications; and
c. to act as a mediator between the Area Boards and the Gas Council, and make recommendations to the Gas Council on matters deemed worthy of further concern and collaboration at a national level (Elliott, 1980:14, 18–20).

Due to the complexity of the project the Gas Council decided that pilot schemes were necessary for testing procedures and acquiring practical experience. Canvey Island was chosen to be the first pilot conversion scheme in Britain both because it had already associated with the supply of natural gas in its liquefied form and for demographic reasons (there were mostly domestic and no industrial users). Also it could be isolated from the existing network of the North Thames Gas Board (Tiratsoo, 1972:212, Rhodes, 1967). The conversion was conducted during the summer months of 1967 (June to August) and it was a 'crash programme' that functioned both for the accumulation of practical experience of the engineering technicalities the project involved, and the promotion of the conversion in the local community (Elliott, 1980:27–29). By April 1971 27% of the total estimated number of appliances had already converted while by 1972 the appliances of 6 million consumers had been converted and the whole programme was ended in 1977 (Tiratsoo, 1972:212).

Despite the experimental project in Canvey Island and the gradual conversion of the whole country the problems still were unavoidable. The first problem that the system encountered was the compatibility of the newly established transmission network with the existing distribution networks in the local Boards. A particular problem was the high pressure natural gas that circulated in the new transmission pipelines but which was in some cases inappropriate for the old, low pressure transmission system that already existed, resulting in incidents of leakage and local failures. In addition, the corrosion that was characteristic of the old pipeline systems in the Area Boards triggered the circulation of gas-borne dust that interrupted and damaged governors, relay valves and pilot jets. The problems were solved through a process of technology transfer from abroad: the United States and the Netherlands, with the Dutch solution found to be the most optimal. The Area Boards were responsible for the relevant solutions with the Gas Council holding responsibility for supervising the processes (Tiratsoo, 1972: 214-215).

There had been another, frequent problem during the conversion; the failure or delay of ignition had resulted in the accumulation of explosive gas mixture, increasing the risk of accidents. Despite the technical problems contemporary statistical analysis of the period has shown that the change from manufactured to natural gas did not increase accidents and fatalities. While in 1963 registered fatalities were 53, six years later the number was 46. The contemporary report by F Morton that followed an explosion at Ronan Point showed and argued that natural gas was a safe fuel. At the same time, natural gas was represented as a safe fuel because it reduced the risk of poisoning. While under the town gas regime the poisoning deaths were 1,193 in 1963, in 1969 the number was 250, five times lower. This reduction led to increased confidence in the safety of natural gas (Tiratsoo, 1972:215; Morton, 1970).

Another uncertainty was whether the appropriate and necessary expertise, particularly in relation to engineering and technology, could be developed. As has been mentioned, the conversion moved forward with the Gas Council having central control and the Area Boards taking responsibility for the practical dimensions of the project and, in all but the North Eastern and Southern Areas, was conducted through the involvement of independent contracting companies. Either way, an extensive training programme was necessary. Conversion on such a scale would need to involve a large number of technical experts that were not available in the existing gas industry. The technical staff employed by the Area Boards were insufficient in numbers and lacked the experience of conversions of such scale. New recruits and existing staff, either in the relevant engineering or the administrative and sales departments, had to undergo an intensive programme of instruction. The immediate priority was developing the new technical expertise of the so called 'converters'. Training programmes were organized in 13 schools either by Boards or contractors and lasted four to six weeks. Several actors contributed to the formation of the syllabus of the courses, which was agreed and regulated centrally by the Gas Council in negotiation with the Training Boards of the Gas and Construction Industry and in consultation with the General and Municipal Workers' Union (Elliot, 1980:71). The training was continuous and the newly established technical group of 'converters' was organized in professions of various grades (Elliot, 1980:71). The programmes were also tailored to develop the necessary administrative and business expertise which, along with the development of the necessary and engineering expertise, were the hidden, albeit important phases of the conversion project.

3.3 Uncertainties and Network Integration(s)

The existing network for LNG from Bacton to West Yorkshire and the continuous exploration for, and discovery of, natural gas in the North Sea defined the development of the network in the UK from the late 1960s until the late 1980s. The Gas Council and the natural gas producers were the major actors in building the infrastructures for bringing the natural gas on shore. Two major discoveries marked the initiation of the natural gas industry in the UK. In October 1965, British Petroleum discovered the West Sole field off the Yorkshire coast. In April 1966 Shell/Esso discovered the Leman Bank field which was subsequently found to have considerably more potential than was originally envisaged following exploration by the Gas Council/Amoco Group, Arpet and Mobil. The discovery of the first field necessitated the establishment of a reception terminal in Easington while the exploration and subsequent developments in the Leman Bank field resulted, by 1972, in the construction of four terminals at Bacton. Three were owned by the natural gas producers while the fourth was owned by the Gas Council (Cormack et al., 1968: 634; Walters, 1971:551; Tiratsoo, 1972:216-219).

In early 1971 it was envisaged that Bacton, as a critical terminal for the natural gas network at the time, would host most of the volume of natural gas. Four pipelines were designed and constructed to transmit the fuel from the terminal station to the Midlands and the London area. It was predicted that the demand from the North of England and Scotland would increase, so by 1971 a new pipeline connected to the North was planned and designed. This infrastructure would link the terminal with the northern parts of the country and with Scotland. It was designed to be established along the East Coast and to meet the 'back-bone' pipeline in Middlesbrough. The pipeline was planned as a second route to the North and as a way to meet demand that already existed or was predicted in the North of England and Scotland. At the same time it made the network more robust in case of accidents and secured the transmission of natural gas to the North (Walters, 1971:551).

By the early 1970s engineers and managers knew well that the discoveries of new gas fields would influence not only the energy market but also the design of the transmission system. Walters from the Gas Council pointed out: 'Extensions of the exploration activities offshore in locations other than those already being developed could result in the establishment of new sources of supply. In this event the pattern of transmission could change and ultimately require a restructuring of the transmission system. A substantial find north of Scotland, for example, would require the provision of an entirely new feeder system, whereas a similar find off the north-west of England would require only fairly short feeder mains to fit in with the established system. The direction of flow in some planned compressor stations might, however, have to be reversed' (Walters, 1971:551). The discovery of gas fields in the Northern North Sea like the Frigg field and in the Irish Sea necessitated the establishment of reception terminals and the relevant infrastructure in St Fergus and Barrow (Simmonds, 2001:1).

As previously mentioned in the early phase the LNG line provided critical infrastructure for the integration of the natural gas transmission system as it facilitated conversion and technological change in the gas industry. The Gas Council deemed some adjustments appropriate so that the existing network could be expanded and linked with the terminals in the East coast as well as to the distribution networks in the Board Areas. The Council's engineers prioritised the introduction of large diameter pipelines as the necessary technical solution (Walters, 1971: 551,559).

Several further factors influenced the design and expansion of the transmission network, with the most important related to demand and growth. The load factor, the location of the distribution area, and the rate of the growth of the system contributed to the developed design practices. In the 1970s gas demand was influenced by the oil crisis and its growth was rapid, doubling during the period between 1967 and 1979 (Simmonds, 2001:1). These factors comprised a matrix that changed and varied according to the case and the situation, thus flexibility was stressed as the appropriate design strategy so as to respond effectively to variations and avoid incompatibilty with specific conditions (Walters, 1971: 555). From the early 1970s it was deemed that flexibility could be achieved through the correct 'blend' of the appropriate size of pipeline and a system of compressor installations and storage facilities. This design approach was considered the most cost effective solution. The distance between the compression stations varied in relation to the load and demand as well as the rate growth but in the British case it had been calculated and standardized at around 65 km (Walters, 1971:555, Clarke et al., 1971).

The transmission system of natural gas pushed LNG towards a different use – from enriching manufactured (coal- or oil-based) gas to securing supply during peak hours and critical events- which as a result triggered more investment in storage facilities, planned and strategically placed in critical points of the infrastructure network. The first storage facilities of two 1,000 tonnes storage tanks were built at the Canvey Island. They were used to store first the LNG, arriving first from Mexico and subsequently that from Algeria. The use of LNG to cover peak demand resulted in the establishment at Canvey of more storage space of 84,000 tonnes of LNG (Walters, 1971:557). LNG was considered critical technology for the security of the system. An installation of storage capacity of 20,000 tonnes at Glenmavis, Scotland – on the north end of the network – was considered key to increasing the security of supply by 200 times. The installation included an over-ground cryogenic tank of the necessary tonnage and a liquefaction plant with an evaporation system (Walters, 1971:560-561). Thus the design principle that prevailed among engineers in the Gas Council promoted investment in critical LNG storage infrastructure in strategically selected points of the network (Clarke et al., 1971).

The prospects for a national grid resulted in major uncertainties relevant to the control of the network in relation to failures, accidents and the uninterrupted flows of gas. The management of risks and vulnerabilities as well as of the fuel's flows made the introduction of telemetering, and control of data in the production and the transmission side, necessary for securing the smooth operation of the network and its resilience in critical events (Tiratsoo, 1972). Those needs were accommodated through the introduction of a computerised control system, comprising a telemetering network that could extract and gather relevant information and data from plants and equipment over a large distance while at the same time controlling remote plants, equipment and processes (Domican, 1990:186; Bower et al;, 1971; Jones et al., 1971).

The control and information management of a network that was continuing to expand provided another dimension in the system integration of the natural gas industry, that of vertical integration. In the 'back bone' the management of the information was done via telephone, and only covered a specific and rather minimal number of locations. With the expansion of the system, sophistication increased. A computerised control system was introduced in 1971, based in two centres: one in the Midlands, which operated the remote monitoring and control side, and another in London where the strategy and overall control was conducted. The system served British Gas for sixteen years before it was upgraded (from a 24 MB memory to 700 MB central processor) to a system which also incorporated elements of 'intelligence' (Domican, 1990: 187; Bower et al., 1971; Jones et al., 1971). The new system consisted of 180 installations on a national level that included existing terminals, compression stations and storage sites and it functioned as the interface between the local control systems and the central control of the Gas Council in the Midlands and London (Domican, 1990: 187).

3.4 Regime Change and the Network: From mid-1980s to 2010

3.4.1 Politics, Policy and Governance Changes in the UK gas industry

The period from the mid-1980s to the late 1990s was characterised by regime change under the Conservative administration, which favoured the privatization of the gas industry and self-sufficiency in relation to technological policy in the natural gas industry. The Gas Act of 1986 provided the political and legal setting for the privatisation and subsequent liberalisation of the UK gas industry. The Act changed the socio-technical regime by mandating the privatisation of the state-owned British Gas Corporation which had the monopoly in the transportation, distribution and supply of gas. The Act required British Gas to make accessible its infrastructures (transmission and distribution pipelines) to all industrial large non-domestic customers. It specified that the privatised British Gas had responsibility for maintaining and developing a National Transmission System (NTS) able to cope with that the kinds of critical weather events known to increase maximum demand, which were calculated, using meteorological data from the last 50 years, as being likely to occur once every twenty years (OECD/IEA, 2004: 398; Howdon and Stevens, 2001: 217-218).

With the new Gas Act a new regulatory authority, Ofgas, was established. In 2000 Ofgas, the gas regulator, and Offer, the electricity regulator merged and formed the Office of Gas and Electricity Markets (Ofgem). Ofgem supervised the gas and electricity markets so they would function according to specified rules that would secure fair and healthy competition. Ofgem also provided incentives that have been necessary to guarantee the expansion and efficiency of the system operation (OECD/IEA, 2004: 398).

Further legal and regulatory interventions boosted the liberalisation of the market in the late 1980s and until the mid-1990s. In 1990 BG was restricted from buying more than 90% of the natural gas production of a gas field while in the year 1991/1992 its monopoly over distribution was reduced to all users with demand below 2,500 therms per annum, which liberalised the market for comparatively large consumers (particularly industrial). Those users could choose their gas supplier. A further push towards liberalisation was given first by forcing British Gas to reduce its share to 40% of the market and through the intervention of the Monopolies and Mergers Commission (MMC) in 1993, which recommended that British Gas be forced to separate its gas production and marketing from the transmission and storage business in order to privatise the first (OECD/IEA, 2004: 394-395). The new 1995 Act expanded the authority of the regulatory agency and permitted private companies to get licences for transport, shipping and distribution of natural gas. Since 1998 all UK gas consumers (including household consumers) have been able to choose their gas suppliers with no restrictions (OECD/IEA, 2004: 394-395).

The reforms and changes in the policy and regulatory regimes necessitated and triggered changes to the business organization of the gas industry and particularly to the structure and form of British Gas. In 1997 the company was split into two components: Centrica and the BG plc. Centrica took over the distribution network while retaining ownership of some gas production facilities including Morecambe gas field. BG plc retained Transco – which owned, managed and operated the transmission system and the storage of natural gas – and British Gas's natural gas exploration and production infrastructures. In 2000 Transco was separated from BG plc and became part of the Lattice Group plc. During the same period Transco LNG was established within the Lattice Group in order to take ownership and management of the LNG peak-shaving facilities. Until 2000 Transco had a monopoly over the transmission and storage business, but in that year the storage facilities and business (Rough and Hornsea facilities) became part of BG Group plc. Several changes of the ownership of storage infrastructure have occurred since 2000. (Simmonds, 2001:4-8). In July that year US Dynegy bought BG Storage from BG Group plc. A year later Hornsea storage facilities were bought by the Scottish and Southern Energy while in late 2002 Centrica became the owner of the Rough offshore storage facility. The same year Lattice Group plc and National Grid plc merged and formed National Grid Transco plc which became the owner, operator and developer of the UK gas transportation system that comprised the National Transmission System and the 8 Distribution Systems. The latter emerged through the restructuring of the 12 Local Distribution Zones. The whole system was an infrastructure of 275,000 km of transmission and distribution pipelines (Simmonds, 2001:4-8).

In 1996 the 'Network Code' was introduced to control and regulate gas transmission, distribution and supply. The code was introduced as a legal and operating interface between the multiple actors that emerged under the new regime. Its introduction aimed to 'facilitate a competitive market; provide a "level playing field" for all shippers of natural gas; ensure system safety and security; Meet statutory and regulatory requirements' (Dewar, 1995:5). Transco's role in the development of the code and its operation has been crucial. Transco has responsibility for securing the physical balance of the system, capacity planning, the forecasting of demand and distribution arrangements, and the overall operation of the system. The code is a technological interface that regulates flows, relations and roles of the different contributors in the gas network: producers, shippers, storage companies, transmission operator and owner and the customers (Dewar, 1995:5-6). In this way it contributes to both the horizontal and the vertical integration of the system.

With the decline and reduction of the natural gas resources that started to be acknowledged since the late 1990s, policy makers understood that the UK energy system should shift emphasis from a design and policy paradigm that focuses on self-sufficiency to one that promotes interconnections and transnational trade. In 2003 the Energy White Paper recognised that due to the decline of gas reserves the UK would be transformed into a net importer, a situation that would increase the uncertainties of the network and possibly its vulnerability to price changes and fluctuations, political instability, external interruptions of supply, and regulatory problems relevant to its relations with other countries or foreign suppliers.

A series of infrastructure works in transnational interconnecting lines and in storage and LNG facilities were planned and designed for the first ten years of the 21st century (see table below). The changing regime caused new uncertainties that resulted in changes in the socio-technical order too (OECD/IEA, 2004: 397-398). The new uncertainties and risks are related to:

(a) dependence on non-UK facilities;

(b) uncertainty in relation to dependence on other countries' markets; and

(c) the timing of the investment in infrastructures, and the nature of these investments in relation to ensuring system security and resilience during major critical events (OECD/IEA, 2004: 417-419).

Existing and Planned UK Gas Import and Storage Infrastructure in 2004

Mode	**Project**	**Capacity bcm/year**	**Available**
Pipeline	Interconnector (Belgium-UK)	8-24	2007/2008
Pipeline	Vester;ed (Norway-UK)	4-10	2004
Pipeline	Langeled (Norway-UK)	15-25	2007/08
Pipeline	Balgzand (Netherlands-UK)	10-17	2006/07
Storage	Rough Field	2.80	2004
Storage	Humbly Grove	0.28	2005/06
Storage	Aldbrough	0.42	2007/08
LNG	Isle of Grain	5-15	2005
LNG	Milford Haven (2 terminals)	10-25	2007
Total		52-119	By c. 2007

Source: Postnote, 2004:4

The increase in UK gas imports can have substantial positive side-effects; it can increase the diversity of sources that an energy system needs. According to recent projections for 2020, the gas supplies will be comprised of 43% LNG, 27% North Sea natural gas from Norway, 17% UK natural gas resources from the UK Continental Self, and 13% from the interconnectors with Continental Europe, which the UK is also linked to via the Russian gas industry (Watson, 2010: 22). This diversity has increased the flexibility and resilience of the UK gas supply system in cases of critical events, severe weather incidents or geopolitical pressures. But due to the international character of the gas market the diversity of the gas supply has not reduced UK gas prices which, because of EU obligations to foreign suppliers, remain high in periods of high demand (Watson, 2010:22).

3.4.2 Interconnectors as a Network Design Change

Since the 1970s the British Gas Corporation had a consistent policy of importing gas from abroad in order to cope with demand and the security issues of the network. First it concluded an agreement with Total Oil Group for the purchase of gas from the Frigg gas field which was located 130 miles north east of the Shetland Isles at the northern corner of Scotland and was shared by Norway and Britain as it is crossed by the Continental Shelf Convention median line. The contract specified the delivery of the gas by 1976; with gradual investments in infrastructures the daily load that would be transferred from the field would be 2000 million ft^3/day, with plans to increase this to 3000 to 4000 million ft^3/day by the mid-1970s. The Total Oil Group constructed a 260 mile pipeline to bring the gas on shore – one of the longest pipelines constructed during this period (Gas Engineering and Management, 1974:29) (Stern, 1986a:11).

In continuation of that policy in 1982 the British Gas Corporation started to consider and negotiate with Statoil the supplies of natural gas from the Sleipner field. The project was considered as a viable substitution for the gas delivered from the Frigg field which was estimated as likely to be exhausted by 1993 at the latest (Stern, 1986b:12). The negotiations lasted twenty months and although BGC and Statoil reached an agreement for gas imports for the period from 1990 to 2010, they were not supported by the British government which had to give its formal approval. The initial response of the Department of Energy was positive but further negotiations were deemed appropriate in order to secure a more extended involvement of British contractors to the infrastructure development, secure improved terms and conditions for the flows of the fuel, and clarify several matters of the relevant treaty (Stern, 1986a:11; 1986b). Finally, and mainly for financial reasons, the government rejected the project, deciding to avoid any significant imports until the British energy system needed them. Thus they forged further the self-sufficiency policy that matched the discourse developed by British Petroleum and other oil companies, and which stressed both the unnecessary character of the project and the UK's capability to secure self-sufficiency in gas until 2000 through the exploitation of existing sources and a large number of 'new discoveries' (Stern, 1986b). While the decision to abandon the project would secure the self-sufficiency of Britain in the short term, policy analysts predicted that the decision would increase the imports of gas in the late 1990s and the early years of the new century (Stern, 1986b).

Since the 1970s there have been proposals for the interconnection of the UK grid with other European grids via undersea pipelines. In the 1970s and 1980s British Gas considered and proposed an interconnection with Norway but the plans were abandoned at a very early stage due to the government's policy of restricting any imports to the minimum possible. In the early 1990s further plans and proposals were devised by natural gas producers: BP, CONOCO, ELF, SHELL, NORSK HYDRO AND STATOIL (Futyan, 2006:5). Either in collaboration or independently, the private companies devised studies aimed at exploring the feasibility of an Interconnector that would cross the Channel and interconnect grids in Continental Europe directly with offshore fields or pipelines (Futyan, 2006:5). In 1992, under the initiative and the at request of the Energy Minister, Tim Eggar, the private companies considering possible interconnection schemes collectively considered the interconnection of the UK grid with European networks. This group was dubbed the 'Study Group' and its coordinated action led to the organisational and technological development of interconnections. This was a period during which the UK government was adopting a policy of European integration – as evidenced by projects such as the natural gas interconnection and the Channel Tunnel development. At the same time the government also considered the potential attached to oversupply in the liberalised UK gas market, and concluded that it would increase price volatility in the new policy and governance regime, forcing both a reduction of, and stagnation in UK Continental Shelf (UKCS) investments. Furthermore, there was a demand in European countries from the manufacturing sectors to devise policies that would reduce the price of gas in Europe and thus make the EU more competitive in relation to USA (Futyan, 2006:7-8). In mid-1997, analysts and policy makers commented: 'The 20 bcm/y capacity interconnector will effectively allow the UK to export the results of its own market liberalisation to the Continent, the form of relatively cheap surplus gas, which is sure to have an impact on the European gas market' (quoted in Futyan, 2006:9).

Concurrent with the new policy strategy, a new design principle of 'interchangeability' emerged in the design of the natural gas network in the UK, a common design practice for gas networks that accepted fuel from a variety of sources and in various qualities (Wood and Mokhatab, 2007; Williams, 2009; McLaughlin, 1996; White Paper, 2005). Part of this approach has been an emphasis on the interconnection of the network to that of the Continental Europe. In December 1994 the Interconnector (UK) Ltd was established as a collaborative scheme of nine companies, including British Gas (McLaughlin, 1996).

Actors involved in the process of building the Interconnector

Study Group	**Bidders**	**Initial Shareholders**
British Gas	British Gas	British Gas (40%)
BP	BP	BP (10%)
Elf	Elf	Elf (10%)
Conoco	Conoco	Conoco (10%)
Statoil	Statoil	Distrigas (5%)
Norsk Hydro	Norsk Hydro	Amerada Hess (5%)
Distrigas	Distrigas	Ruhrgas (5%)
	Amerada Hess	National Power (5%)
	Ruhrgas	Gazprom (10%)
	National Power	
	Gazprom	
	Gaz de France	

(Source: Futyan, 2006:11)

The project constructed a link between the UK with Belgium between Bacton and Zeebrugge. While Bacton was chosen as a convenient entry point to the national transmission system (NTS) Zeebrugge was chosen for its strategic position in relation to the European grid and its function as a hub of natural gas flows from different sources: gas supplies through Zeepipe from Norway, LNG imports from Algeria and Abu Dhabi and supplies from the Dutch fields via the Gasnunie network (McLaughlin, 1996:2; Futyan, 2006:7).

The scheme was initially set up both to boost British exports, and provide a critical infrastructure to boost the strategic position of Britain in the European natural gas industry. Declan McLaughlin, network planner at Transco, has stressed that ‘it is clear vision of many in the UK gas industry that a Gas Spot Market should develop at Bacton, becoming the gas equivalent in Europe to the Brent Crude oil market' (McLaughlin, 1996:2). According to the plans gas would leave the UK at the pressure of up to 140 barg (unit of gauge pressure), and arrive at Zeebrugge reception terminal at a pressure of 85 barg with the pressure at the Belgian Distrigaz to vary between 55 and 80 barg. Infrastructure investments were necessary for the construction of compressor units at Bacton as the typical inlet pressure from the NTS was around 45 barg. The necessary facilities would provide the interconnector with the ability to export about 21 billion cubic meters per year (bcm/y) to Europe. The fact that the scheme was developed as a predominantly export infrastructure is evidenced by the fact the pipeline was commissioned with such technical characteristics that imports would not exceed 9 bcm/y (McLaughlin, 1996:2). The interconnector started to operate in October 1998 and by 2006 an upgrade was necessary to increase the import capacity to 25 bcm/y (Futyan, 2006:3).

The development of the interconnector would have an important impact on the development of the NTS. By 1996 Transco developed several scenarios for the changes that the interconnector would affect in the Transco network. Most significant was the need to increase national network capacity by 15% for peak and by over 30% for annual transmission, which resulted in an increase both of the load factor and in the use of the transmission system (McLaughlin, 1996:4). New infrastructures were necessary: compressor stations, changeouts, and rewheels, additional units for parallel operations, pipework modifications, duplication of pipeline, 75 barg uprating, regulators, and after coolers. The issue at stake was how to transfer the appropriate amount of gas from the northern terminals to Bacton to support the function of the interconnector (McLaughlin, 1996:4-5). Furthermore, the integration of the interconnector to the NTS forced Transco to add capacity to key points of the network, and more specifically in 'bottleneck' areas, to secure flexible services without jeopardising the system's security. In this context the shippers maintained the necessary flexibility of the service and the appropriate day balance (McLaughlin, 1996:5).

The increasing need for natural gas made new import pipelines necessary, and since 2004 there have been plans in place for two more. The first is the Langeled project and the second is the Balgzand-Bacton pipeline, connecting the Dutch network with the UK NTS. The Ormen Lange pipeline has connected the Ormen Lange field to Sleipner and Easington. It is the longest undersea pipeline (1,200km), bringing Norwegian natural gas to the UK. The project cost £1.76 billion with several private companies from within the UK energy sector involved (Centrica, Statoil, Norsk Hydro, Royal Dutch Shell and Conoco Phillips). The Balgzand-Bacton project started in 2004 and had been completed two years later, comprising a pipeline of 230km and bringing natural gas from the Netherlands (OECD/IEA, 2004: 397-398).

3.4.3 Storage in the New Socio-technical Regime

LNG and storage of gas continued to be used for periods of peak demand and thus 'peak shaving' storage sites at strategic locations acquired momentum as a design strategy (Llewellyn, 1995:10; Postnote, 2004). The organisational and technological regime in gas storage and LNG started to change with the report of the Monopolies and Mergers Commission in 1993. First of all there was an institutional change in the governance of the LNG storage systems in the UK. Transco founded the Storage Directorate to provide storage services using LNG storage facilities, salt cavities or off-shore depleted or partially depleted gas fields. With the liberalisation of the market Transco was the owner of the transmission and distribution network and the LNG storage systems fell under its jurisdiction through the institutional innovation of the Storage Directorate. Despite the pressure of the Director General of Gas Supply (DGGS) - an institution established to regulate the industry and to promote competition

(Thatcher, 1998) – and the commitment of the government to a liberalised gas storage industry, there was little liberalisation of gas storage by the mid 1990s (Llewellyn, 1995:11). A further push towards further liberalisation of the market was executed by the DGGS after the 1995 Gas Act by proposing separate price caps in transport and storage and a reduction of Transco's charges. The whole issue was referred to the Monopolies and Mergers Commission (MMC) whose 1997 report supported the separation of transport from storage. The separation started in 1997 with the separation of price controls, and continued with investment in infrastructure facilities by private companies competing against British Gas Transco (Howdon and Stevens, 2001: 222-224).

Private companies were the main actors involved in new gas infrastructure development in the early years of the 21st century. Investments were mostly made to enable imported LNG to complement imports via pipelines. Such have been the plans by BP/Sonatrach, BG/Petronas and ExxonMobil/Qatargas. Since 1981 when the LNG terminal in Canvey Island closed there had been no LNG import terminal in the UK. An equally important role has been played by government (for example the Department of Trade and Industry, DTI) and Ofgem in the integration of the new technological infrastructure in the natural gas system of the country. They regulated the function of the companies with the aim of reducing uncertainties and maintaining stability (OECD/IEA 2004: 414). They requested:

(1) an initial offer of capacity to the market in a transparent manner, but with flexibility, if required;
2) rules and procedures promoting secondary trading of capacity rights and '"use-it-or-lose-it" mechanisms' (OECD/IEA, 2004: 414).

They have been, however, sceptical about the case for further intervention to increase the amount of gas storage in the UK – despite evidence that levels of storage are much lower than those in other European countries that use significant amounts of gas. The gas storage capacity of Germany can cover almost the 20% of the annual demand. In France the figure is 25% and in Italy more than 15%, but in the UK it is below 5% of annual demand (Watson, 2010:14).

4. Interactions with Other Uncertainties

The natural gas system is complex and its development and transition involved the participation of a multiplicity of actors that contributed to the making of the network throughout the 50 years of this case study. The process of the system integration was linked to and/or influenced by other uncertainties – particularly those concerned with political, regulatory and economic regimes.

Network integration in all periods of natural gas development was determined by the political regime, the policy decisions and the relevant regulations and regulatory cultures. The focus on the nationalisation of crucial industrial sectors resulted not only in a nationalised gas industry but also in a centrally controlled industry in which the governance of people and technologies were managed by one institution, the Gas Council. The privatisation and liberalisation introduced since the mid-1980s transformed the structure of the industry and changed the terms of network development. The early stage of the industry was marked by a political decision to introduce LNG and the relevant infrastructures in the energy system of the UK. The privatisation and liberalisation of the gas industry was a political decision that determined the design practices since then and the integration of the network in the new regime.

System integration was linked with economic uncertainties too. Before the introduction of natural gas from the North Sea, the gas industry was declining, and experiencing high production costs, and this was an important concern for policy makers and engineers. The introduction of LNG for the enrichment of manufactured gas happened because there was a need for gas production cost reductions and quality improvements. The initial reactions and ambivalent attitudes towards the complete conversion from town gas to natural gas was due to the economic uncertainties that such a large scale project would involve. Such concerns about the economic side of infrastructures in the natural gas industry were prevalent in the period of the study.

5. Implications and Limitations of Analysis

5.1 Comparisons

There are differences and similarities in comparing the systems of natural gas and CCS. First we should stress that natural gas is an energy source – and as such, it was introduced alongside technologies for its transmission and use. It was introduced as part of the energy mix in Britain to improve and reform the existing manufactured gas but after large scale discoveries in the North Sea, its conceptualisation and meaning changed. CCS is a set of technologies designed to manage an unwanted environmental side effect of the energy system. It is important to keep this distinction clear because the character of the technology influences the socio-technical arrangement that was constructed. Energy technologies such as those for natural gas contain the complete set of actors: producers, transporters, distributors, and end-users (domestic or industrial). CCS is missing a direct relationship with the end-user. Households do not demand CCS in the way that they appropriated and domesticated natural gas for heating and cooking. In this context there is no need for physical transport of CO2 from individual households. This difference is important because it provides a different angle in the issue of the scale and the character of the network. The natural gas network was conceptualised and established as a large-scale project and the aim was to build a system that would cover the energy demand nationwide. The CCS system has not been conceptualised as a national grid to transmit CO2 emissions from millions of end users.

For any prospective CCS network the end users are coal or gas power plants that are located in specified areas and clusters in the UK, as in the case of the proposed scheme in Yorkshire (CO2Sense Yorkshire, 2010). From the existing plans it is more appropriate to talk of regional CCS transmission lines and the integration of part of the UK CCS with a transnational European system of transmission network that transports CO2 to the Southern North Sea. In the existing scenarios the regional networks comprise a network of pipelines from point sources to transmit CO2 to a hub, and from there through a trunk main to an offshore storage area. The UK CCS system is conceived as only partially integrated. The emissions produced from the Metropolitan London and Central and Eastern England could be connected to the European CCS infrastructures that are conceived as a transnational European network of transmission pipelines from the emission points to the Southern basin of North Sea. All the other carbon capture infrastructures remain independent and are not planned to be integrated in any kind of national grid (Arup, 2010).

In the natural gas network the notion of 'energy security' and the resilience of the system were and have been important design concerns in many aspects: to secure the investments made by either the State or later by private corporations; to make sure the uninterrupted and convenient supply to domestic and industrial users; to avoid pollution hazards the a critical event could have caused. In terms of critical events, the issue of security in CCS networks is more related to environmental risks that transmission and storage (Arup, 2010; Berr, 2007). At the same time control and safety, albeit of a different nature, were of major concerns in both systems.

The network structure of the natural gas in the UK was developed alongside the development of gas fields in the North Sea and the Irish Sea. As long as the exploration proceeded, the network design was adjusted appropriately. Thus engineers and network designers promoted flexibility in the network design. In the case of CCS the network scenarios and design can be and are based on existing credible data about the location and capacity of aquifers and storage sites. This observation does not imply that the problem of storage has been solved but it aims to point out that in the early phase of the natural gas transmission network this kind of uncertainty was higher than in the case of CCS (Arup, 2010; Berr, 2007; Element Energy, 2010).

Another difference between the two technological systems is that the natural gas industry and network emerged in a period of nationalisation and centralised control (politically and organisationally). The natural gas infrastructure was already well developed before the period of privatisation and liberalisation, though considerable additional infrastructure development (especially of LNG facilities, storage sites and interconnectors) has been completed in the liberalised era. On the other hand, it remains an open question whether the development of CCS systems will develop within the current liberalised market context. Electricity market reform may mean a transition to a less liberalised policy and market context. This may have a significant impact on CCS infrastructure development.

5.2 Questions for CCS

The insights and the questions that the study of the history of the UK natural gas network open in relation to the CCS system can be summarised in the following points:

- The history of the natural gas network integration has shown that during the whole period of the study there was both a horizontal and vertical integration of the system with the relevant organizational and regulatory changes. While the reports and scenarios on the CCS networks (Arup, 2010; Berr, 2007; Element Energy, 2010) consider the development of the network spatially by focusing on identifying the storage sites and the routes of the pipelines, little attention has been given to the vertical integration and the technological and organizational uncertainties that this can involve.

- The interconnector of the UK natural gas network with the grids in continental Europe provided flexibility in the natural gas industry of Britain and its energy system because while it was initially built for exports, its use and meaning has gradually changed and it has become a critical infrastructure for the security of the system and the uninterrupted supply of natural gas. The interconnection to the European CCS network - albeit partial - can be considered as a critical infrastructure for increasing the flexibility and capability of the system and for contributing to its resilience during critical events.

- During the conversion from manufactured to natural gas the Gas Council had to confront not only the technological uncertainties but also those related to the management of expertise. The conversion process necessitated the creation of the appropriate technical expertise combining maximum efficiency and minimum risk. Although CCS does not face the similar concerns and barriers, an emphasis on the management of the multiplicity of expertise in complex projects such as establishing CCS networks can help smooth the implementation process. Because of the scale of the conversion, the indications are that, in the case of CCS, it will be a relatively straightforward process to train technical experts, and develop expertise. But clarification is needed as to what kind of expertise can be transferred from the gas and oil industries and the types of capabilities and skills that the emerging industry should invest in. The history of conversions also teaches us that institutions are necessary to provide the necessary training programmes and set strategies implementing the relevant expertise as well as the codes of practice for the CCS technologists.

5.3 Limitations

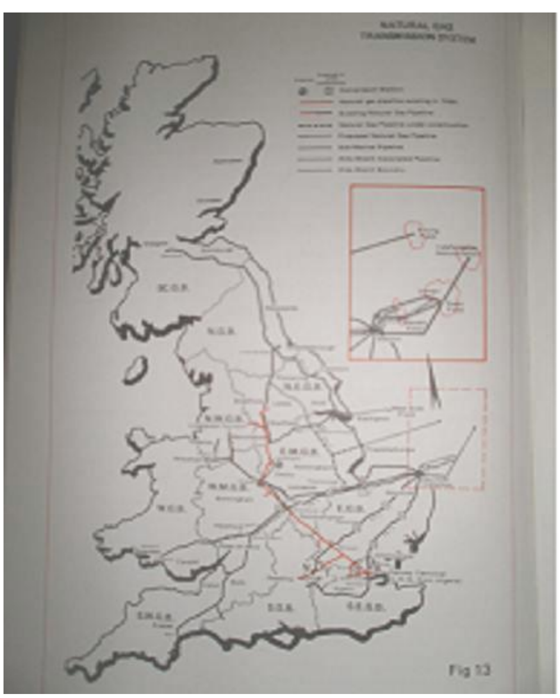
The lack of a large number of end-users provides more flexibility to the CCS network. This characteristic may make it unnecessary to build an extensive national transmission system. It might be better to understand CCS within a context of fragmented regionally integrated systems where the hubs for the selection of CO2 from the various plants will be the critical infrastructure. The CCS network presents more similarities – in relation to the design and structure – with the offshore networks of gas and oil that transmit fuel to the shore rather than with the NTS in the natural gas industry.

In the above context the demonstration plant can be designed and planned as the ‘back bone’ hub of a regional integrated CCS system. This will increase the pace and the technological and organisational uncertainties that the deployment of CCS involves.

Appendix

Map 1: The route of LNG: From Arzew to Leeds via Canvey Island

(Source: Wilson, 1972:23; Courtesy: National Grid plc)



Map 2 The LNG network ('back bone') and the natural gas network

(Source: Wilson, 1972:26; Courtesy: National Grid plc)

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