Programme Area: Carbon Capture and Storage

Project: Hydrogen Turbines

Title: Executive Summary

Abstract:

The ETI's energy system modelling shows that flexible power generation systems comprising hydrogen generation with CCS, intermediate storage (particularly using salt caverns) and flexible turbines are attractive options for the UK. In the model described here, hydrogen is supplied from coal and biomass fired gasifiers and steam methane reformers, with CO2 captured for storage. This permits the use at high load of capital intensive and relatively inflexible conversion and CCS equipment, filling hydrogen storage when power is not needed, and releasing hydrogen at short notice through turbines when power is at a premium.

Context:

This £300k project, led by global engineering and construction company Amec Foster Wheeler, in collaboration with the BGS, assessed the economics of a range of flexible power generation systems which involve the production of hydrogen (with CCS) from coal, biomass or natural gas, its intermediate storage (e.g. in salt caverns deep underground) and production of power in flexible turbines. The work included mapping of potentially suitable hydrogen storage salt cavern sites in and around the UK and provided the ETI with a flexible economic modelling tool to assess the range of possible options. The ETI's energy system modelling work suggests that systems such as these could provide a valuable contribution to the future energy mix, filling the gap between base load nuclear plant and low carbon power generation.

ETI Executive Summary

Programme: Carbon Capture and Storage

Project Name: Hydrogen Storage and Flexible Turbine Systems

Deliverable: CC2009/D2

Introduction

ESME modelling shows that flexible power generation systems comprising hydrogen generation with CCS, intermediate hydrogen storage (particularly using salt caverns) and flexible turbines are attractive components in the UK energy system. In the model, hydrogen is supplied from coal and biomass fired gasifiers and steam methane reformers, with CO_2 captured for storage. This permits the use at high load of capital intensive and relatively inflexible conversion and CCS equipment, filling hydrogen storage when power is not needed, and releasing hydrogen at short notice through turbines when power is at a premium. .

In August 2012 the Technical Committee approved the launch of a Request for Proposal (RfP) for a Flexible Research Programme (FRP) project with the purpose and focus as follows:

- To improve our understanding of the economics of flexible power generation systems comprising hydrogen production (with CCS), intermediate hydrogen storage (e.g. in salt caverns) and flexible turbines;
- To focus on the potential, economics and technical requirements for salt cavern storage and flexible turbines, as these require refinement in the ESME model in order to confirm or adjust ESME findings.

After an open RfP process, the ETI selected Foster Wheeler Energy Limited (FWEL) to undertake the project, with support from British Geological Survey (BGS) to address issues relating to salt cavern storage. The project started on 21st January 2013, and final, accepted deliverables were received on 3rd September 2013. The final deliverables, including a flexible, Excel-based tool to assess the economics of a wide range of such systems, are comprehensive, and meet or exceed expectations set out at the start of the project.

System Concept

The project investigated the technical and economic aspects of flexible power generation systems comprising 3 primary blocks (Figure 1):

(i) Hydrogen-rich fuel production from the gasification of coal or a biomass/coal mixture, or reforming of natural gas, in each case including carbon capture and storage;

(ii) Interim storage of hydrogen or hydrogen mixtures in underground salt caverns;

(iii) Combustion of hydrogen and flexible generation of electricity using either combined cycle gas turbines (CCGTs) or fast-response aero-derivative turbines (the current project concentrated on CCGTs).

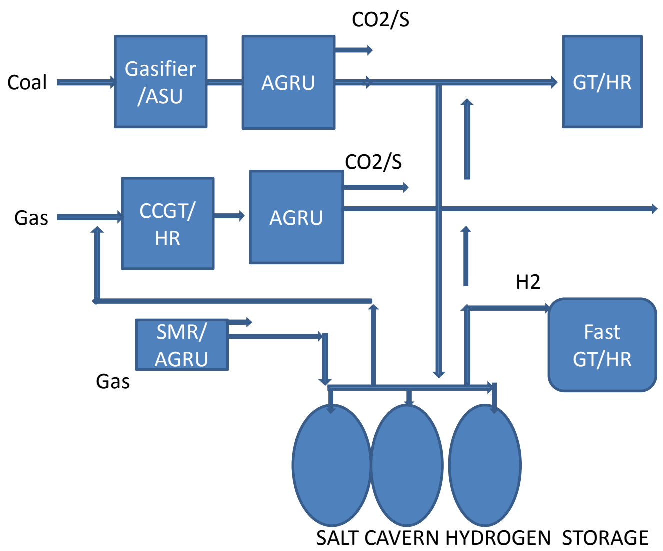


Figure 1 System Concept

In essence the system allows the high capital, inflexible hydrogen production and carbon capture block to operate at steady, 100% load, with the salt caverns storage smoothing out the appetite of the flexible turbine system.

Key Findings

1. WP1 Report – Techno-economic analysis of hydrogen production and power generation options

Four options were analysed (engineering costs and performance): gasification of coal, gasification of a coal/biomass mixture, steam methane reforming (SMR) and autothermal reforming of natural gas (ATR). In each case a high pressure solvent-based method of CO_2 capture was included. These produced hydrogen-rich mixtures, which were burnt in a CCGT designed for hydrogen. Key findings were:

- There was little difference amongst the four options;
- The hydrogen turbine usually requires a diluent. For an IGCC, nitrogen is used, which is a byproduct of the air separation unit which feeds the gasifier. This would need to be stored with (or alongside) the hydrogen, increasing storage costs. As an alternative steam taken from the steam turbine can be used: there is no clear cut cost differential between the two approaches.

2. WP2 Report – Survey of potential hydrogen storage in the UK, including costs.

BGS provided a comprehensive survey of salt beds both onshore and offshore in the UK, which could potentially be used for hydrogen storage. Salt caverns are produced using a solution mining process (pumping down water and pumping out brine). The most promising salt beds were identified and costs to produce and operate the caverns determined, based on available data (caverns are already in use for storage of gas and hydrogen). Three main potential areas were identified: 'shallow' (~300m deep) beds around Teesside; intermediate depth (~1000m) in Cheshire and surrounding areas and deep beds (~2700m) in East Yorkshire. Key findings:

- Shallow caverns are too small and expensive for strategic storage (e.g. monthly, seasonal);
- Deep caverns show a round trip cost/efficiency hit of c. 10% (daily);
- The intermediate depth caverns are probably in the wrong place (inland, rural Cheshire) and/or already in use;
- Offshore storage is too expensive for daily storage;
- Daily storage makes inefficient use of storage volume: it needs 90% "cushion" gas.

3. WP3 Report – Supporting studies

The aim of WP3 was to investigate the broader context of the study by considering alternative hydrogen production and hydrogen-based power generation technologies, the viability of adding hydrogen to the National Gas Grid, alternative forms of hydrogen storage and potential synergies achievable by combining different technologies. The scope of this work package consisted of research from existing literature. Key findings:

- For hydrogen production, electrolysis capital costs are acceptable, so the key is the value put on the power consumed (i.e. would be economic if ‘free’ electricity is available);
- No other way of manufacturing hydrogen was deemed economic;
- For converting hydrogen to power, fuel cells were seen mainly for smaller applications, with solid oxide fuel cells (SOFC) being the most promising type for larger units;
- Broad distribution of hydrogen into the gas transmission and (particularly) distribution grid was not seen as a practical proposition.

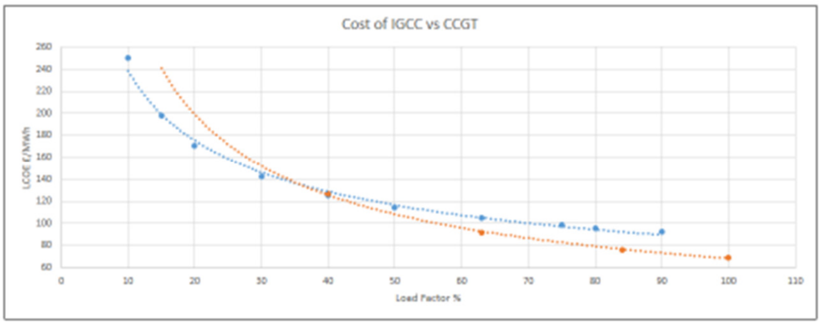
4. WP4 Flexible Modelling Tool

The aim of WP4 was to produce a flexible, scalable Excel model which can be used to calculate the costs of the various hydrogen and power production options in WP1 and the main three storage options from WP2. Hydrogen production, hydrogen storage and power production are in three separate blocks, so that costs can be isolated and other technologies can be added for study. There is an extensive range of options, including:

- Plant scale (costs are scaled according to standard industry practice);
- Plant load regime (e.g. the GTs can operate 100% or various other “on/off” scenarios. The current model does not include part-load operating scenarios);
- Fuel costs are adjustable;
- Three depths of cavern are available, with ‘typical’ cavern size included for each depth;
- Capex adjustments can be made;
- Some of the hydrogen can be exported (with a specified value).

The model has been used to generate some initial insights, and is a valuable tool to probe a wide range of scenarios. An example is shown below.

Comparison of IGCC+CCS and CCGT+CCS LCOE values at different load factors



IGCC DATA
Coal price = £70/te
Co-Storage
Salt Cavern Location –Yorkshire (Cavern depth 1800m, cavern storage 300,000 m3)

CCGT DATA
Gas Price = £265/te

This compares costs for a coal gasification case with hydrogen storage (blue line) against a CCGT with post combustion capture (orange line). It can be seen that, for the specific assumptions made in this example, the cost of electricity for both is the same for a load factor of around 36% (LCOE ~ £125/MWhr). For lower load factors the economics of the coal/storage option become advantageous and vice versa.

5. WP5 Report – Representative System

The aim of WP5 was to pull together the work in WP1, WP2, WP3 & WP4 to identify and develop the configuration for a representative system for UK application and to provide a comparison of the representative system with a CCGT with post combustion carbon capture. A 36% load factor was assumed, based on a weekly cycle generating for 12 hours each weekday and off at weekends. The economics of fitting the CCGT/CCS with a CO_2 salt cavern store (to even out CO_2 export) were also examined. Key findings:

- A cavern based scheme with coal gasification has similar economics to a CCGT/CCS at this load factor. The fuel cases assumed approximate to the “medium” price DECC outlook for coal and “low” price outlook for gas. This supports ESME’s adoption of the technology as an economic option for a system with high renewables;
- Addition of a cavern to a CCGT/CCS plant was cost neutral, and may be operationally desirable;
- Power at this load factor has an LCOE of £125/MWhr, compared to about £80/MWhr for a system at full load.

Future Plans

Dissemination

Building on an initial presentation to the CCS SAG, one to one briefings will be held with interested ETI private and public sector Members to share the results and ETI insights.

Further Projects

Further analysis work may be commissioned later in 2014 to investigate issues around the actual flexibility of the turbines, cost saving options and/or technology gaps. However, it is not expected that a major demonstration project will be prioritised in the short/medium term.

Project Exploitation

The results of the study (and particularly the modelling tool) will be used to generate further insights and feed relevant information into ESME. Initial ESME runs with the revised costs emerging from this study confirm that systems of this type are heavily adopted within the post-2030 energy system. Alongside this, further Plexos modelling will be carried out to look in more detail at the dispatchability of such systems.