Programme Area: Carbon Capture and Storage

Project: Hydrogen Turbines

Title: Hydrogen Storage and Flexible Turbine Systems- Final Report Introduction

Abstract:

The purpose and focus of the Hydrogen Turbines project is to improve the ETI's 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, and to provide data on the potential economics and technical requirements of such technology to refine overall energy system modelling inputs. The final deliverable (D2) comprises eight separate components. This document is D2 – Summary Report, providing an Overview of the project.

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.

Contract No.:	1.17.13058
Client's Name:	The Energy Technologies Institute
Project Title:	Hydrogen Storage and Flexible Turbine Systems
Project Location:	Generic UK

REVISION	**Rev 01 (Draft)**	**Rev A1 (Final)**			
DATE	12 July 2013	26 July 2013			
ORIG. BY	T. Abbott	T. Abbott			
CHKD BY	G. Skinner	S. Ferguson			
APP. BY	T. Abbott	T.Abbott			

Hydrogen Storage and Flexible Turbine Systems
Final Report Introduction

CONTENTS

DISCLAIMER

The information contained herein is provided by Foster Wheeler Energy Limited (FWEL) to Energy Technologies Institute LLP (ETI), solely to assist ETI in improving its understanding of flexible power generation systems comprising of hydrogen production, storage and turbines, and to enable ETI to refine its Energy System Modelling Environment (ESME) model.

FWEL has not made any independent verification of data and information contained herein that has been supplied by ETI or other third parties. This report is intended for the sole use of ETI and FWEL makes no representation or warranty, express or implied, and assumes no obligation or liability, whatsoever, to any third party with respect to the veracity, adequacy, completeness, accuracy or use of any information contained herein.

The information provided is not, and should not be construed as, a recommendation by FWEL that any recipient provide finance to the project. Each recipient of this document should make its own independent evaluation of the project and of the relevance and accuracy of the information contained herein, and should make such other investigations as it deems necessary to determine whether to extend credit to the project.

1. INTRODUCTION

The Energy Technologies Institute (ETI) is a public private partnership between global industry members - BP, Caterpillar, EDF, E.ON, Rolls-Royce and Shell with the UK government. The ETI brings together projects that accelerate the development of affordable, clean, secure technologies needed to help the UK meet its legally binding 2050 targets. The ETI's mission is to accelerate the development, demonstration and eventual commercial deployment of a focused portfolio of energy technologies, which will increase energy efficiency, reduce greenhouse gas emissions and help achieve energy and climate change goals.

The ETI's modelling, using its Energy System Modelling Environment ("ESME") shows that flexible power generation systems comprising hydrogen generation with Carbon Capture and Storage ("CCS"), intermediate storage (particularly using salt caverns) and flexible turbines are attractive components in a future UK Energy system. In such a system, hydrogen is supplied from coal and biomass fired gasifiers, autothermal reformers and steam methane reformers, with carbon dioxide ("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. Superficially there are no barriers to using salt caverns as stores; as such stores are in use in the USA. However, these are for high value added applications and not for use in power where loss of efficiency is a more serious drawback. The ETI currently lacks sufficient data and knowledge to build a good representation of costs or efficiency (particularly relating to hydrogen storage) in ESME.

The purpose and focus of this project is:

- To improve the ETI's 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; and
- To focus on the potential, economics and technical requirements for salt cavern storage and flexible turbines, to enable refinement of the ETI Energy System Modelling Environment (ESME) model in order to confirm or adjust ESME findings.

2. SCOPE OF STUDY

The Hydrogen Storage and Flexible Turbine Systems Project was split into five work packages.

- WP1 – Hydrogen Power Production;
- WP2 – Hydrogen Storage;
- WP3 – Supporting Studies;
- WP4 – Development of a Flexible Modelling Tool; and
- WP5 - Identification of a Representative System & Comparison of CCGT w. CO2 buffer storage.

The first three work packages (WP1, WP2 & WP3) were focussed on data collection and research in order to derive a basis for techno-economic analysis and modelling in WP4. Using the output from the WP4 modelling, a representative system was selected. In WP5, this representative system was compared against a post-combustion CCGT case.

3. METHODOLOGY

Execution of the Hydrogen Storage and Flexible Turbine Systems Project was split into three separate phases:

1. Data Collection and Research
   Work Packages WP1, WP2 and WP3 are largely independent. These research activities were executed in parallel and separate reports produced for each. In addition, the British Geological Survey produced a report as part of WP2 which has been included in full as an attachment to the WP2 report.

2. Development of a Flexible Modelling Tool
   In WP4, the results of WP1, WP2 & WP3 were developed into a flexible model, capable of calculating the key design parameters, performance data, estimated capital costs, estimated operating costs and levelised cost of electricity for multiple scenarios. The modelling tool allows users to analyse the relative techno-economic merits of different scale, hydrogen production technology and gas turbine operating regimes. The modelling tool also has the capability to undertake sensitivity analysis for pricing and cost parameters.

3. Identification of a Representative System and Comparison of CCGT with CO_2 Buffer Storage
   In WP5, a representative system for UK application was selected based on the findings of the WP4 modelling, and developed to allow comparison of the performance and economics of that system against those of a CCGT with post-combustion carbon capture using CO_2 buffer storage.

4. DOCUMENT STRUCTURE

The purpose of this introduction document is to describe the purpose and content of the deliverables for each of the work packages WP1 to WP5. This introduction document, combined with the work package deliverables described below, constitute the Final Report for the project.

This introduction document describes the content of each of the project deliverables but does not summarise their findings. A summary of the findings of each of the report deliverables is provided in the executive summary of each report.

5. DATA COLLECTION AND RESEARCH

The data collection and research phase of the project was executed in three work packages:

- WP1 – Hydrogen Power Production;
- WP2 – Hydrogen Storage; and
- WP3 – Supporting Studies.

5.1 Work Package 1 – Hydrogen Power Production

The aim of WP1 was to review the technical options and economics for hydrogen production with CCS and hydrogen fired turbine power generation, against the likely energy system requirements of 2030.

The scope of WP1 consisted of:

- A review of options for hydrogen production;
- Techno-economic definition of the following four options for hydrogen production:
  - gasification of coal;
  - gasification of a coal/biomass mix;
  - autothermal reforming of natural gas; and
  - steam reforming of natural gas (both with N2 and steam diluents);
- Characterisation of basic design requirements for cost effective hydrogen stores;
- A review of requirements / options for hydrogen turbines, being:
  - Power generation gas turbines;
  - Gas expansion turbines;
- A brief study of the economics of hydrogen pipelines;
- A brief discussion of the effects of hydrogen purity.

5.2 Work Package 2 – Hydrogen Storage

The aim of WP2 was to provide a summary of suitable location, costs, risks and schedule associated with creation and use of salt caverns for hydrogen storage.

The scope of WP2 consisted of study work undertaken by Foster Wheeler and specialist geological consultancy support from the British Geological Survey (BGS):

- Identification of potential salt cavern locations within UK and first 25 miles of UK Continental Shelf;
- Salt cavern cost structure;
- HSE challenges of cavern construction and operation;
- Managing loss of containment;
- Licensing and build timeline;
- Alternative cavern use; and
- Landscaping study of alternatives to salt caverns.

5.2.1 BGS Study Scope

The scope of WP2 required specialist geological knowledge which was provided by British Geological Survey (BGS), and included as Attachment 1 to the WP2 Report.

Major rocksalt (halite or salt) bodies located onshore or offshore on the UKCS provide sites for the creation of underground caverns for gas storage purposes and possibly hydrogen. The salt beds need to be of sufficient size (extent and thickness), depth, location and quality to eb considered for gas storage. The BGS Report focuses on the suitable hydrogen storage sites provided by such salt beds from onshore, out to 25 miles off the UK Coastline. Other possible forms of geological storage are also reviewed briefly.

5.3 Work Package 3 – 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.

The scope of WP3 consisted of the following landscaping studies:

- Review of alternative hydrogen production options and their relative costs;
- Review of alternative hydrogen to power conversion options and their relative costs;
- Addition of hydrogen to National Gas Grid;
- Value of hydrogen for other uses;
- Review of availability and efficiency of hydrogen fired gas turbines;
- Consumer view of hydrogen as a natural gas substitute;
- Integrated solutions deploying hydrogen stores.

6. DEVELOPMENT OF A FLEXIBLE MODELLING TOOL

The aim of Work Package 4 was to pull together the findings from WP1, WP2 & WP3 into an MS Excel-based flexible economic modelling tool with associated documentation.

The purpose of the flexible modelling tool is to provide users with a means of calculating the key design parameters, performance data, estimated capital costs, estimated operating costs and levelised cost of electricity for multiple scenarios.

Variable technical parameters include:

- Syngas Plant Technology
- Distance from Syngas Plant to Salt Caverns
- Location of Salt Cavern
- Gas Turbine Operating Regime
- Number of Gas Turbines
- Hydrogen Export

The modelling tool incorporates study cost data from WP1, WP2 & WP3 and applies scaling factors for each element of the facility scope. The tool provides separate costs for the three main blocks (hydrogen production, storage and power generation) and provides outputs which are compatible with the requirements for the ETI's ESME model.

A Modelling Basis and User Guidelines Report has been produced. The purpose of this document is to provide users of the modelling tool with a brief overview of the modelling basis and the variable parameters within it, along with guidelines for how to use the model in order to calculate results.

7. IDENTIFICATION OF A REPRESENTATIVE SYSTEM AND COMPARISON OF CCGT WITH CO2 BUFFER STORAGE

The aim of Work Package 5 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 vs a CCGT with post combustion carbon capture option.

The representative system has been defined through development of:

- Design Basis
- Block Flow Diagram
- Process Description
- Outline Heat & Material Balance
- Outline Utility Summaries
- Outline Project Execution Schedule
- Capital and Operating Cost Estimates
- Unit Lifetimes and Availability

The representative system defined and developed in WP5 has been compared to a baseline of a CCGT with post combustion carbon capture, both with and without CO_2 storage buffering. The CCGT case has been based on the results of earlier study work performed by Foster Wheeler for ETI.