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Selected location for pilot plant SEWGS

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1 Executive Summary

The feasibility of Sorption-Enhanced Water Gas Shift (SEWGS) as a CO_2 capture technology has been demonstrated in two process development units at the Energy Research Centre of the Netherlands (ECN). In a next development step, the technology should be scaled up and demonstrated in an industrial environment. One question that arises is what the best location for such pilot unit would be. That question is answered in this report.

A host site at a blast furnace at Tata Steel in IJmuiden was selected as the best location for a SEWGS pilot unit. The selection was based on an assessment of the Technology Readiness Levels of SEWGS for various applications, and further taking into account site-specific criteria such as commitment of the management, availability of utilities, available plot area, permits and regulation issues, and so on.

The carbon-rich top gas from blast furnaces is sometimes used as a fuel gas in gas turbines. The SEWGS process can remove CO and CO_2 from gas streams at temperatures between 350 and 500 °C by reversible adsorption of CO_2 on a solid material combined with conversion of CO to CO_2 by the water-gas shift reaction. Simulation studies and techno-economic studies have indicated that SEWGS could be an efficient and viable CO_2 capture technology for blast furnace top gas.

In the pilot unit the process could be demonstrated as a CO_2 capture technology for blast furnace top gas. The operational data gathered would validate the techno-economic assessments. The gas would need to be compressed and carbon monoxide would need to be partially converted to carbon dioxide in a water-gas shift reactor to bring the feed gas to suitable inlet conditions for the SEWGS unit. The results from the pilot unit operation could also be utilised for other applications. As such, the SEWGS pilot unit would be a stepping stone towards full scale demonstration at blast furnaces and at NGCC and IGCC power plants.

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Table of Content

2 Applicable/Reference documents and Abbreviations

2.1 Applicable Documents

(Applicable Documents, including their version, are documents that are the "legal" basis to the work performed)

	Title	Doc nr	Version
~~AD-01a~~	~~Beschikking (Subsidieverlening CATO-2 programma verplichtingnummer 1-6843~~	~~ET/ED/9078040~~	~~2009.07.09~~
~~AD-01b~~	~~Wijzigingsaanvraag op subsidieverlening CATO-2 programma verplichtingennr. 1-6843~~	~~CCS/10066253~~	~~2010.05.11~~
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AD-01f	Besluit wijziging project CATO2b	FES1003AQ1FU	2010.09.21
AD-02a	Consortium Agreement	CATO-2-CA	2009.09.07
AD-02b	CATO-2 Consortium Agreement	CATO-2-CA	2010.09.09
~~AD-03a~~	~~Program Plan 2009~~	~~CATO2-WP0.A-D.03~~	~~2009.09.17~~
~~AD-03b~~	~~Program Plan 2010~~	~~CATO2-WP0.A-D.03~~	~~2010.09.30~~
AD-03c	Program Plan 2011	CATO2-WP0.A-D.03	2010.12.07

2.2 Reference Documents

(Reference Documents are referred to in the document)

1. Manzolini G Integration of SEWGS for carbon capture in NGCC. Part A: Thermodynamic analysis. *Int J Greenhouse Gas Cntrl* 5 (2) 200 – 213, 2010.
2. Manzolini G, Macchi E, Binotti M, Gazzani M. Integration of SEWGS for carbon capture in NGCC. Part B: Reference case comparison. *Int J Greenhouse Gas Cntrl* 5 (2) 214 – 225, 2010.
3. Gazzani M, Arcara G, Romano MC, Macchi E, Manzolini G. Application of SEWGS process for CO_2 capture and power generation from blast furnace gas. 10^{th} Conf on Carbon Capture & Sequestration, Pittsburgh, May 2-5, 2011.
4. Gazzani M, Macchi E, Manzolini G. CAESAR: SEWGS integration into an IGCC plant. *Energy Procedia* 4, 1096 – 1103, 2011.

2.3 Abbreviations

(this refers to abbreviations used in this document)

BF	Blast furnace
CCS	Carbon capture and storage
IGCC	Integrated gasifier with combined cycle
NGCC	Natural gas combined cycle
SEWGS	Sorption enhanced water gas shift
WGS	Water-gas shift

3 Introduction

3.1 Need for a Pilot Unit

The demonstration of the SEWGS technology in a pilot unit is a key step towards successful commercialisation. Currently, the SEWGS process has been demonstrated on a 25 kWth scale in the laboratory, with six reactors that can operated with various pressure swing process cycles. Feed gases are always technical gases. Given a sorbent and an optimised process cycle, the performance of the SEWGS process is predominantly determined by the length of the reactors. Since the length of the reactors in the process development unit is close to the length of the reactors in an industrial unit, the performance in the lab is expected to closely match the performance in the field. The next step of designing a pilot plant would thus involve scaling-up the technology, as well as investigating the effects of impurities in industrial syngas on the SEWGS performance. It is aimed at making this step in the years 2012 to 2015.

Further SEWGS development work should focus on long term operation of a significant part of a SEWGS installation at a scale that all critical technical issues in the further development of the SEWGS technology are addressed and tested at appropriate scale. These critical issues can only be resolved by construction of a pilot plant at sufficient scale. The pilot plant will also increase the reliability of the technical and economic data of the SEWGS technology sufficiently in order to progress to full scale demonstration.

An important decision to be made is the selection of the location of a host site. As a first step in the pilot plant planning process, the technology readiness should be accurately be determined. All issues that can be solved in the laboratory shall be solved before building a pilot unit, since it will be much more expensive and time consuming to solve these issues once a pilot unit has been built. As a second step, the selection of the best application for SEWGS, such as NGCC, IGCC, or Blast Furnace application, should be made. The best application will benefit most from the characteristics of SEWGS in comparison to competing technologies and have a large market potential. The choice of the best application will be an important criterion for the selection of a host site.

3.2 Technology Readiness Level

The Technology Readiness Level (TRL) is an indicator used by many of major companies and by government agencies such as the NASA to assess the maturity of a technology before it is applied in a system. The primary purpose of using Technology Readiness Levels is to help management in decision making with regards to the development of technology. As such it is a tool for risk management and to make decisions concerning transition of technology. The nine TRLs are shown in Figure 1. A key element in the development of technologies is to make sure that all issues that *can* be solved at a certain TRL, *will* be solved at that level before moving to the next level. If a technology is classified erroneously in a too high TRL, then the development project risks being jeopardized by delays or cost over-runs.

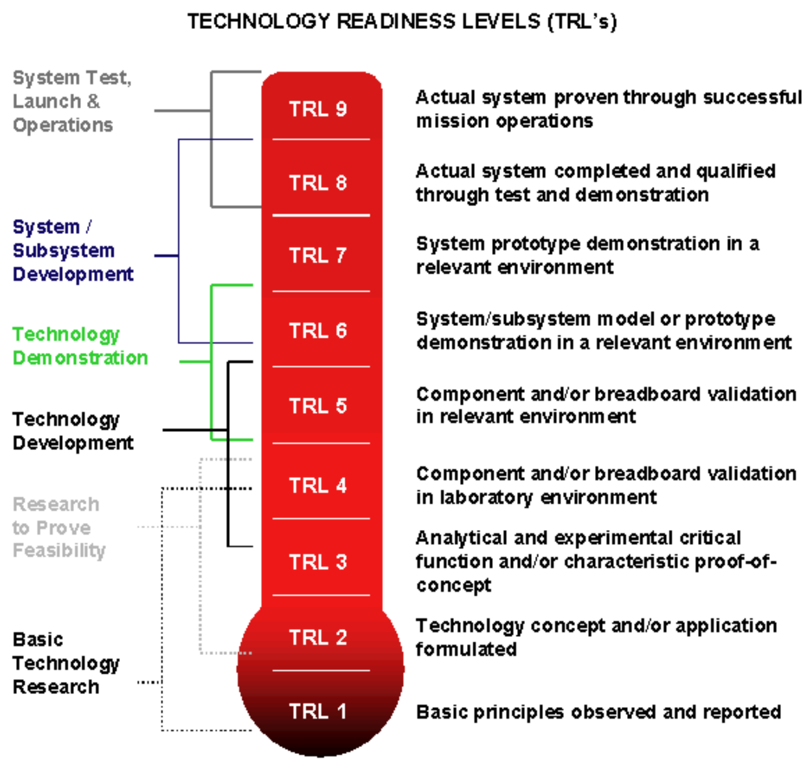

Figure 1 The nine Technology Readiness Levels

The maturity of the SEWGS technology was assessed by this method. Based on the demonstration of the full cyclic process for thousands of cycles in the multi-column test rig at ECN, the Technology Readiness Level of SEWGS was assessed at TRL 5, adopting the definitions used by NASA:

> *Component and/or breadboard validation in relevant environment. At this level, the fidelity of the component and/or breadboard being tested has to increase significantly. The basic technological elements must be integrated with reasonably realistic supporting elements so that the total applications (component-level, sub-system level, or system-level) can be tested in a 'simulated' or somewhat realistic environment.*

This level holds for SEWGS decarbonising low-sulphur feed gas (sweet SEWGS), which is the case for NGCC and Blast Furnace, and IGCC provided that sulphur components are removed upstream.

A more attractive mode of operation in IGCC application is SEWGS removing both carbon oxides and sulphur components simultaneously (sour SEWGS). Coal-derived syngas contains substantial amounts of sulphur which need to be removed by SEWGS selectively. Based on the demonstration of a cyclic process for hundreds of cycles in the single-column test rig, the Technology Readiness Level of the SEWGS technology for simultaneous removal of carbon oxides and sulphur components in an IGCC application was assessed at TRL 4:

> *Component and/or breadboard validation in laboratory environment. Basic technological components are integrated to establish that the pieces will work together. This is "low fidelity" compared to the eventual system. Examples include integration of 'ad hoc' hardware in a laboratory.*

At the time of writing, the demonstration of the sour SEWGS was only in a single vessel for a limited number of cycles under a limited amount of sulphur. The SEWGS development for this application should first be brought to TRL 5 before it can be considered as candidate for a pilot plant.

This means that a pilot unit would necessarily focus on low-sulphur applications, which are NGCC, Blast Furnace, and IGCC with prior desulphurisation. When all issues at the TRL 5 have been solved, the next step of development would be the scaling up to a pilot plant and subsequent demonstration in a realistic environment, in TRL 6:

> *A major step in the level of fidelity of the technology demonstration follows the completion of TRL 5. At TRL 6, a representative model or prototype system or system - which would go well beyond ad hoc, 'patch-cord' or discrete component level breadboarding - would be tested in a relevant environment.*

For the SEWGS development this would translate to designing, constructing and operating of a pilot unit with a full configuration of all components in a true industrial environment.

3.3 Most favourable application

As discussed in the previous paragraph, the application of a pilot unit would be NGCC, Blast Furnace, or sweet IGCC. The best application will benefit most from the characteristics of SEWGS in comparison to competing technologies, such as chemical or physical absorption. Also, the best application will have a large market potential.

Sometimes, blast furnace top gas is used as a fuel gas in a gas turbine. Prior to combustion the top gas is compressed by a compressor coupled to the expander. SEWGS may be used to remove the carbon monoxide and carbon dioxide from the top gas before it is combusted in the gas turbine.

Simulations by Politecnico di Milano show that SEWGS may outperform absorption technologies both in NGCC, IGCC and Blast Furnace applications [1 – 4]. The relative benefits of SEWGS seem to be higher for the Blast Furnace than for the NGCC and sweet IGCC applications, which suggests that Blast Furncace would be favoured. The potential market for NGCC is definitely larger than for Blast Furnace, which suggests that NGCC is favoured.

From a practical point of view, the selection of an application also influences the total project costs of the pilot unit. For instance, the NGCC application would require an additional nitrogen stream to be mixed with a slip stream from a hydrogen production facility, which would lead to additional operational expenses. On the other hand, the Blast Furnace application would require an additional gas compressor and water-gas shift reactor to precondition the gas stream, which would lead to additional capital and operational expenses.

With respect to gas quality, the most important difference is that the gases in the Blast Furnace and sweet IGCC applications contain small amount of sulphur and other impurities, which may generate additional knowledge over the NGCC application.

The most important remark here is that the learnings from a pilot unit in one application can also be utilized in the other two applications. For the Blast Furnace application, the gas would need to be compressed to about 20 bar in the pilot unit. It is concluded that NGCC, sweet IGCC, and Blast Furnace are suited as applications for a pilot unit.

4 Choice of host site

An inventory of potentially suitable locations was made. The inventory included a hydrogen production facility, a blast furnace, a coal gasifier, and an oil residue gasifier. Based on the current technology status (see previous Chapter), the oil residue gasifier was rejected because the TRL was below 5 for this application. The other facilities could supply a sulphur-free or low-sulphur syngas stream.

The pilot plant would operate on a small slip stream of syngas. Selection of the location was based on several criteria, including:

- Commitment of the host site management
- Sufficient plot area
- Availability of utilities and steam
- Permitting and regulation issues

The site at a blast furnace at Tata Steel in the Netherlands met all requirements, and was selected as potential host site for a pilot unit.

5 Proposal for a pilot unit

5.1 Objectives

A major objective of building a SEWGS pilot unit would be to demonstrate the value and the maturity of the SEWGS technology in an industrial environment. Issues to be addressed in this development level include: long term stability of the sorbent, reliability of the high-temperature switching valves, vessel design, and verification of cycle performance such as carbon capture ratios, product purities, and steam consumption.

The main objective of the pilot installation at Tata Steel in The Netherlands using real fuel gas (blast furnace gas) proving that the SEWGS technology is a viable pre-combustion CO_2 capture technology to decarbonise blast furnace gases more efficiently and more economically than competitive technologies. The pilot unit will prove the scaling up of SEWGS and is essential to reduce the risk of scaling up to a commercial unit. A blast furnace can be seen as an iron producing coal gasifier and thus the pilot unit may also demonstrate the viability of the SEWGS technology for capturing CO_2 from NGCC and IGCC power plants.

5.2 Approach

To meet the objectives from the previous section, a shift section and a SEWGS pilot unit of a single adsorption vessel will be designed, constructed, and operated on blast furnace gas, completely converting the compressed CO/N_2 mixture via the water gas shift reaction into a high pressure fuel grade H_2/N_2 mixture (Figure 2). The simultaneously produced CO_2 is completely absorbed by the SEWGS sorbent at elevated temperature (400°C). In a full scale application the hydrogen will be fed to the gas turbine to generate power while the CO_2 is transported and could be sequestered.

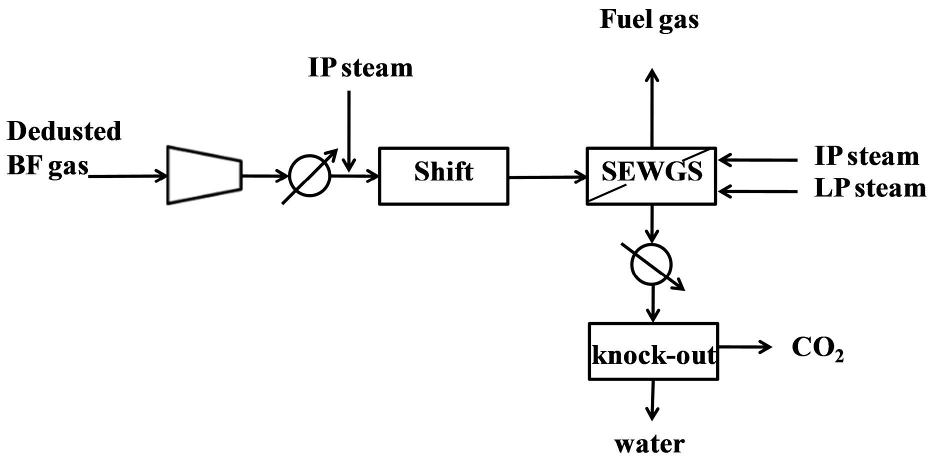

Figure 2 Scheme for the proposed SEWGS pilot unit

The pilot unit should be a platform to address critical issues in the further development of the SEWGS technology and to put into practice the associated mitigation options that have been determined in previous projects. Furthermore, the long term test runs should proof various key performance indicators:

- Is the sorbent material chemically and mechanically stable with respect to removal of CO_2 and CO under real life conditions for a prolonged period.
- What is the long term performance of the high temperature/ pressure valves in SEWGS process under realistic conditions and what does this mean for plant availability and maintenance?
- Are the observed mass and heat transfer processes and fluid dynamics on large scale in agreement with model predictions ?

Results from the pilot testing can be used for the basic design of a full scale SEWGS unit (SEWGS-1500) and for the techno-economic assessments.

6 Conclusions and Further Work

The conclusions are summarized as follows.

- The favoured applications for a SEWGS pilot unit are NGCC and Blast Furnace. Gasifiers are not recommended because the development level of SEWGS for these high-sulphur containing gases is not yet sufficient.
- For the SEWGS pilot plant, a host site at a Tata Steel blast furnace in IJmuiden was selected. This host site meets all requirements for a pilot unit.

Choice of the location is needed to be able to define the user requirements, such as carbon capture ratio, feed gas composition including contaminants, and sizing. Next, a Basis of Design document will be drafted. The scale-up would be somewhere between the laboratory system, roughly 10 kW_e, and a full size commercial unit , roughly 100 MW_e. The size of the pilot unit would preferably chosen such that a reliable scale-up can be made when going from the pilot unit to a full size commercial unit. It has to be born in mind, though, that the size will be limited by financial constraints and host site integration issues.

Based on the Basis of Design document and on the results from the project, a Basic Design Package of a pilot unit will be made in the last project year. This design will include heat and material balances, process flow diagrams, piping and instrumentation diagrams, a Hazop study, a cost estimate and so on. The SEWGS pilot unit is then ready for detail engineering and construction by a subcontractor. Reliability issues will be identified and addressed.

In September 2011, a consortium including ECN and Tata Steel have submitted a project proposal for supporting the construction and operation of a SEWGS pilot unit in IJmuiden.

7 Attachment: TRL definitions

U.S. Department of Defense definitions

Technology Readiness Levels in the Department of Defense (DoD)
(Source: DoD (2006), *Defense Acquisition Guidebook*)

Technology Readiness Level	Description
1. Basic principles observed and reported	Lowest level of technology readiness. Scientific research begins to be translated into applied research and development. Example might include paper studies of a technology's basic properties.
2. Technology concept and/or application formulated	Invention begins. Once basic principles are observed, practical applications can be invented. The application is speculative and there is no proof or detailed analysis to support the assumption. Examples are still limited to paper studies.
3. Analytical and experimental critical function and/or characteristic proof of concept	Active research and development is initiated. This includes analytical studies and laboratory studies to physically validate analytical predictions of separate elements of the technology. Examples include components that are not yet integrated or representative.
4. Component and/or breadboard validation in laboratory environment	Basic technological components are integrated to establish that the pieces will work together. This is "low fidelity" compared to the eventual system. Examples include integration of 'ad hoc' hardware in a laboratory.
5. Component and/or breadboard validation in relevant environment	Fidelity of breadboard technology increases significantly. The basic technological components are integrated with reasonably realistic supporting elements so that the technology can be tested in a simulated environment. Examples include 'high fidelity' laboratory integration of components.
6. System/subsystem model or prototype demonstration in a relevant environment	Representative model or prototype system, which is well beyond the breadboard tested for TRL 5, is tested in a relevant environment. Represents a major step up in a technology's demonstrated readiness. Examples include testing a prototype in a high fidelity laboratory environment or in simulated operational environment.
7. System prototype demonstration in an operational environment	Prototype near or at planned operational system. Represents a major step up from TRL 6, requiring the demonstration of an actual system prototype in an operational environment, such as in an aircraft, vehicle or space. Examples include testing the prototype in a test bed aircraft.
8. Actual system completed and 'flight qualified' through test and demonstration	Technology has been proven to work in its final form and under expected conditions. In almost all cases, this TRL represents the end of true system development. Examples include developmental test and evaluation of the system in its intended weapon system to determine if it meets design specifications.
9. Actual system 'flight	Actual application of the technology in its final form and under

proven' through successful mission operations	mission conditions, such as those encountered in operational test and evaluation. In almost all cases, this is the end of the last "bug fixing" aspects of true system development. Examples include using the system under operational mission conditions.