Project no.:
019672

Project acronym:
DYNAMIS

Project title:
Towards Hydrogen and Electricity Production with Carbon Dioxide Capture and Storage

Instrument : Integrated project
Thematic priority : 6.1.3.2.4
Capture and sequestration of CO_2, associated with cleaner fossil fuels

Start date of project: 2006-03-01
Duration: 3 years

D 1.2.1
Project Policy Document, Revision 1

Final

Due date of deliverable: 2006-06-30 *(version #1)*
Actual submission date: 2006-06-30

Latest update: 2007-02-28 *(version #5)*

Organisation name of lead contractor for this deliverable:
SINTEF Energiforskning AS

Project co-founded by the European Commission within the Sixth Framework Programme (2002-2006)		
Dissemination Level		
PU	Public	x
PP	Restricted to other programme participants (including the Commission Services)	
RE	Restricted to a group specified by the consortium (including the Commission Services)	
CO	Confidential , only for members of the consortium (including the Commission Services)	

Deliverable number:	D 1.2.1
Deliverable name:	Project Policy Document, Revision 1
Work package:	WP 1.2 Lead Project Workshops
Lead contractor:	SINTEF Energiforskning AS

Status of deliverable

Action	**By**	**Date**
Submitted (Author(s))	Jens Hetland, Clemens Cremer	2006-06-30
Verified (WP-leader)	Jens Hetland, SINTEF-ER	2007-02-28
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Abstract

This Project policy document (PPD) outlines the main policy issues and presumptions that are going to be implemented in the subprojects, work packages and tasks as appropriate. The PPD Revision 1 is a working document that will be updated in steps in order to outline the basis for project decisions and prerequisites.

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1 INTRODUCTION

The purpose of this Project Policy Document (PPD) is to address specific policy issues relating to the technical and non-technical dimensions to be addressed under the DYNAMIS project in due consideration of the subsequent HYPOGEN demonstrator. All policy issues addressed herein relate to the stated objective of the DYNAMIS project and its underlying subprojects and work packages, as well as the interpretation of the actual call for proposal and relevant information issued by the European Commission.

This PPD postures the firm framework for the work to be conducted in terms of technology options, plant locations, storage sites, and a sub-set of non-technical issues. Guidance has been sought to ensure that the endeavours be harmonised with governmental policies, industrial sector strategies and ongoing R&D. The aim of this work is to harmonise the content of the project with all stakeholders, and to establish a common policy to adhere to for the execution of the project.

1.1 Interim working document

This PPD will maintain the status as a working document during the first 18 months, in order to include appropriate expert opinions through three dedicated workshops (as appropriate) pertaining to the policy issues of DYNAMIS.

1.2 Commitments

DYNAMIS forms a part of the HYPOGEN initiative under the European Commission's Quick-Start Programme for the Initiative for Growth. The pronounced ambition of the Commission is to provide Europe with a realistic and economically viable route to a hydrogen economy, which includes as an interim step through the construction of a large-scale demonstration facility for the co-production of hydrogen and electricity from decarbonised fossil fuels – with safe and permanent storage of the CO_2.

<u>**The DYNAMIS consortium**</u> has jointly undertaken to investigate the viability of plausible routes for large-scale cost-effective hydrogen and electricity production via decarbonisation of fossil fuels with CO_2 capture and integrated CO_2 management. Within February 2009 DYNAMIS shall address five main dimensions that are deemed quite essential for pursuing the HYPOGEN initiative. These dimensions are:

1. **the supply chain** via decarbonisation of fossil fuels,
2. **product gas conditioning** (specifying hydrogen deliveries ex plant),
3. **handling and storage** of the captured CO_2 in geological formations,
4. **conceptual plant design** (of a HYPOGEN demonstration plant), and
5. **societal anchorage** (such as economic, legal and public issues).

Hereunder, options will be ranked and steps will be made to reduce risk elements associated with the subsequent development of a full-scale HYPOGEN pilot plant by industry post 2008. Inherently, investigations will relate technical, economic and societal pre-requisites of each dimension to early decisions in order for a HYPOGEN plant to go on stream by 2012. Furthermore, as DYNAMIS involves only intellectual work without any planned demonstration, its results will be delivered mainly as written reports and otherwise via communication in seminars and meetings.

1.3 Stated Objective(s)

During the project period supply routes will be addressed and the state of technology development appraised in consideration of risk and societal impacts. Important aspects are

- the assessment of key technologies versus yield, cost and emission index;
- the availability and flexibility of primary energy sources.

This entails criteria for technology selection, including plausible locations for plants and CO_2 storage sites in Europe. DYNAMIS will further identify and rank candidate technologies, and differentiate between technologies that can be engineered and those that have to undergo research and development.

Five topical areas are identified as having a special bearing on the overall objective:

1. Decarbonisation of fossil fuels facilitating co-production of hydrogen and electricity.
2. Hydrogen separation including cleaning, conditioning and export facilities for piped, tanked or liquefied hydrogen.
3. New power cycles requiring an advanced large-scale topping cycle based on gas turbines that operate on hydrogen or hydrogen-enriched fuels (still to be developed for their intended purpose).
4. Reliable storage of CO_2, via capture, pre-treatment, transport, and injection of CO_2 into geological structures or - optionally - for enhanced oil/gas recovery (EOR/EGR).
5. Societal anchorage, including legal, regulatory, funding and economic aspects, and public issues.

1.4 Technological objectives

- **Identification of optimal configuration** including assessment and ranking of prospective technologies on technical, environmental and commercial terms, and the selection among the best alternatives for further improvements and optimisation. In this pursue – beyond the non-technical factors, the state of development, lead-time, cost, maturity and risk are deemed decisive.
- **Quantification and minimisation of risk**. One important aim is to optimise the overall plant efficiency, and to quantify and minimise risks and uncertainties and their consequences. This endeavour requires complementary skills, efforts and capabilities, and focused R&D.
- **Recommendation of gap-closing measures**. To the extent that proven technologies are not available special measures will be needed - either by obviating the needs or by diverting to additional research on specific processing steps.
- **Addressing pre-normative issues**. Valuable insight will be provided relating to the fact that (particularly) the storage of CO_2 may have a legal and regulatory bearing on the selection of storage site and necessary infrastructure.

Further investigation and conceptual development of large-scale cost-effective hydrogen production routes with integrated CO_2 management techniques will be included, building on the efforts of prior EU-FP6 projects of reaching the technological and economic targets of CO_2 capture and storage. However, as underground storage, including the transport system for CO_2, entails a high capital investment, large quantities of CO_2 would be required to justify CCS. Therefore the HYPOGEN demonstration plant must be sized accordingly, and this in turn applies to hydrogen-fuelled gas turbines that have to be developed for this duty.

1.5 Stated targets

DYNAMIS undertakes at the turn of 2008 to substantiate that the following targets can be deemed achievable for practical operation by 2012 pursuant to the objectives of the current call:

- Power generation in the 400 MW class[1] using advanced flow cycle(s) with hydrogen-fuelled gas turbines in the 250-300 MW class.
- Hydrogen production corresponding to 25-50 MW[2] with the flexibility to adjust the output of the plant from 0 to 100% hydrogen[3].
- Produced hydrogen will be in accordance with the specifications of a European hydrogen infrastructure (beyond 2010).
- 90% CO_2 capture rate envisaged
- 50% capture cost reduction envisaged[4] reckoned from a (current) level of €50-60 per tonne of CO_2 captured[5].

Hence, DYNAMIS undertakes to:

- **Qualify and generalise methodologies** to assess, research and perform required development work and rank technologies capable of co-producing hydrogen and electric power, including capture and safe storage of the CO_2. These pursues will be characterised by potentiality, constraints and governing mechanisms.
- **Validate candidate technologies**: In order to coin the conceptual technology appropriate, validation in more directions is required to ensure viability in regards of versatility, environmental impact, and primary energy demand.
- **Address challenges** associated with scale-up when using multiprocessing schemes (in contrast to traditional unit operations), – and also pertaining to the integration with existing plants and systems.
- **Reduce risk** following a risk assessment study of candidate HYPOGEN technologies (judged necessary until recommendations be given for pursuing a subsequent HYPOGEN project by 2008.)

DYNAMIS will furthermore set out the conclusions, recommendations and technology selection for the subsequent demonstration or production unit (HYPOGEN) covering technical and non-technical issues (SP1).

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[1] Typically comprising a 270-300 MW gas turbine and 100-130 MW bottom Rankine cycle. From coal a 3-400 MW power generation would be suitable. For comparison the Buggenum IGCC is rated at 250 MW, and the Puertollano IGCC at 335 MW)

[2] This corresponds to some 5-10 000 ton H_2 p.a. (on the HHV basis) – i.e. about 0.1-0.2% of the current European hydrogen production (6 Mton p.a.)

[3] Should the recommended plant require a higher degree of integration, interference with the power generation could (probably) not be avoided.

[4] Provided there is a market for plants of this kind that is ready to pay the additional cost, and the R&D/industrialisation can be written off, and the learning curve be established at a realistic level.

[5] As stated in the Work Programme, and also in other FP6 projects e.g. ENCAP / SES6-CT-2004-502666

2 EQUIPMENT AND INPUTS TO THE PLANT

2.1 Decarbonisation of fossil fuels – state of the art[6]

When comparing pre-combustion and post-combustion capture one finds a fundamental difference: As the isolation of the CO_2 much depends on the partial pressure, pre-combustion capture is prone to offer more compact and less energy-intensive processing equipment for the CO_2 removal from the synthesis gas than those that are required in post combustion techniques.

2.2 Main process steps in decarbonisation (pre-combustion capture):

The main route for decarbonised hydrogen includes:

- Oxygen production in an air separation unit (ASU) – although not necessary
- Coal gasification, reforming of natural gas or partial oxidation that forms a synthesis gas
- Gas clean-up (and desulphurisation) of the synthesis gas
- Water-gas shift reaction – turning CO to CO_2 in the presence of superheated steam
- CO_2 capture
- Hydrogen purification – dependent on use[7]

Main technical and non-technical issues will be addressed that are deemed essential for the deployment of one or more HYPOGEN-type plants in a European context. Such plant(s) will be based on technology for co-production of hydrogen and electric power via decarbonisation of fossil fuels with safe geological storage of the CO_2 in permanent sinks. The latter will be either aquifers or active or depleted oil and gas fields. This implies that a rather comprehensive interface must be defined for the plant versus its surrounding environment.

2.3 Focal areas and structure of project

The project is structured in 6 sub projects (SPs) and subordinate work packages (WPs) in the following way:

- SP5 is responsible for developing case studies derived from work performed by SP2, SP3, SP4 and SP6 pertaining to the HYPOGEN demonstration plant. Hereunder:
  - The reference plant(s) will be provided (WP5.1) that will be subjected to pre-engineering actions (WP5.2). The current possibility for financial support for initiatives performed under the EU-FP6 projects ENCAP and CASTOR will be reviewed (WP5.1). Site selection for the case studies will be guided by the proximity to potential CO_2 and hydrogen markets identified under SP3 and SP4.
  - Environmental Impact Studies required to evaluate key site selection criteria for these designs will be performed (WP5.2) – including an assessment of the case studies in the context of Planning Policies together with provision of Specialist Reports on appropriate areas, such as socio-economic assessment of the key beneficial and adverse impacts of the case study, particularly with respect to employment, economy and industry, which shall include:
    - Assessment of visual impacts.

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[6] CO_2 removal by absorption in industrial processes is deemed proven technology. Reference is given to the Saline Aquifer CO_2 Storage project at the Sleipner field in the North Sea, Norway (SACS)

[7] Typically by means of pressure swing absorption (PSA). The purity would be higher than 99.9% H_2 for fuel cells, whereas no specific purity level would be required for a gas turbine.

        - Assessment of the impacts on terrestrial and marine ecology.
        - Assessment of the impact on air quality, which may require dispersion modelling studies.
        - Assessment of the impacts on noise and vibration.
        - Assessment of the impacts of connecting the case to the electricity grid transmission system.
        - Assessment of the impacts of connecting the case study to the gas transmission system.
        - Providing the design base for selection of the Major Plant Equipment Suppliers.
        - Refining the projected Capital and Operation & Maintenance costs of said case studies.
        - Providing a baseline for Detailed Design Engineering work to be subsequently undertaken by the Engineering Alliance Consortium during the EU-FP7 programme.

- Furthermore, an implementation strategy will be established (WP5.3), which involves the following topics:
    1. **Feedstock supply:**
    - **Solid Fuel Technology Options:** A mix of solid fossil fuels to be utilised in the reference solid fuel plant concept. The basis of feedstock supply to the Power Station to be assessed.
    - **Gas fired Technology Options:** Work to be performed on the options available to prospective Project purchasers for natural gas supply contracts to the Power Station.
    - **Pilot plant:** Reviewing the merit and possible drawbacks in constructing a medium sized plant as a step towards the reference plant design.
    - **Large scale demonstration facility:** Reviewing the merits of building a large-scale plant close to the reference design but incorporating features that would permit it to demonstrate innovative gas treatment systems, etc.
    - **Offtake Arrangements:** The commercial issues associated with the combined supply of Carbon Dioxide, Hydrogen and Electricity to be assessed and supported by simplified case studies. Issues for Carbon Dioxide supply to be developed in conjunction with work performed under SP3 and SP4.

The reference project flow schemes must incorporate the production and storage of hydrogen for utilisation in markets other than electricity (such as combined cycle), preferably in conjunction with initiatives relevant to case studies under the EU/FP6 project Road2Hycom, HyWays and also the EU-based Hydrogen and Fuel Cells Technology Platform (HFP)[8].

Results from SP6 will feed in to structure the availability of European Investment Bank Finance (EIB) to optimise the attractiveness of equity investment. The final activity of the feasibility study is to produce a Prospectus-like presentation that could be used as a platform for potential equity investors. This will determine whether the project can next proceed to full-scale

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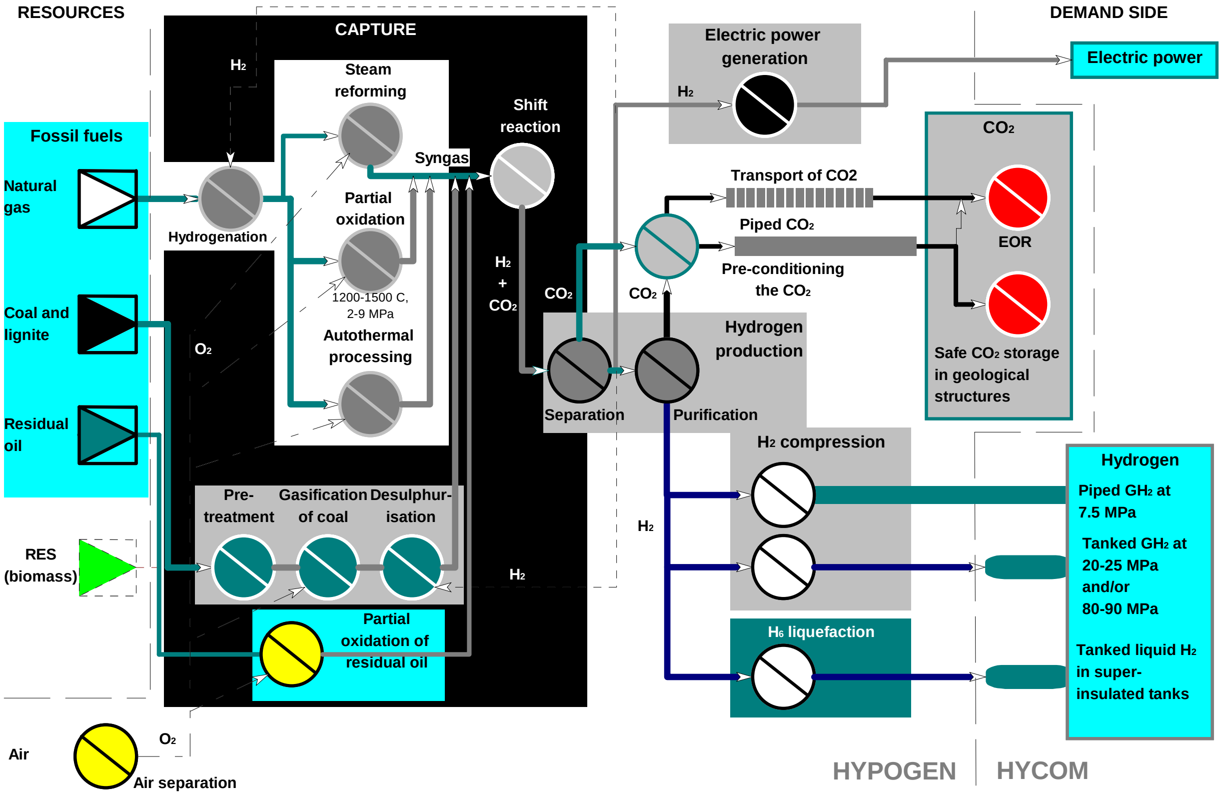
[8] A specialist meeting was organised by DYNAMIS and the EC/JRC in Brussels on 18 January 2007 entitled "Synergies between HYPOGEN and the hydrogen economy". The objective of said meeting was to identify synergies and possible links between the HFP and the Zero Emission Power Generation Technology Platform (ZEP TP). The minutes of said meeting has been uploaded to the DYNAMIS' eRoom.

commercial deployment, or whether there is a need for demonstration at pilot scale to underwrite technology or market risk.



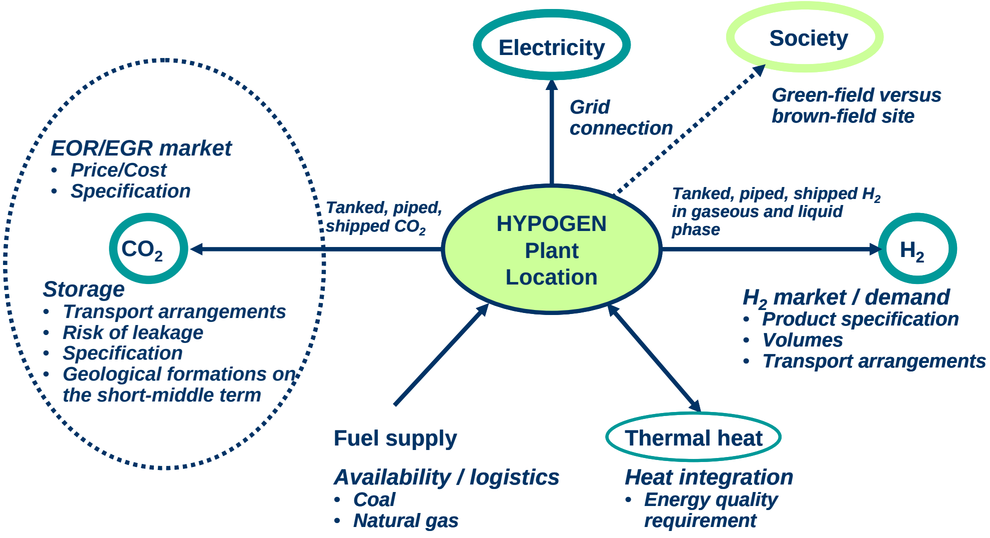
SINTEF Energy Research / Jens Hetland, 2004

Figure 1: The HYPOGEN Demonstrator. Conceptual layout.

2.4 Location issues in regards of HYPOGEN

A (possible) grey zone has been identified between the HYPOGEN demonstrator and the HYCOM programme (see Figure 1 lower right part) that calls for a concerted action to define in more detail the interface between the export systems of the HYPOGEN plant and the distribution systems and the market demands commonly referred to as infrastructure (HYCOM). The practical implication of this is, however, that DYNAMIS is more focused on the plant dimension and thereby the definition of the HYPOGEN plant, whereas other projects will be focused on the infrastructure dimension – assumingly under the HYCOM initiative of the European Commission.

As depicted in Figure 2 specific considerations are required to define the fuel supply (1), the grid connection for the generated electricity (2), and the produced hydrogen (3) that must comply with specifications dictated by a market that remains to be developed, but which is expected to emerge from these supplies via a rather weak distribution system. This also involves an interface definition for the captured CO_2 (4), as the pre-treatment of the CO_2 will much depend on the distance and the transport means to the storage site. Furthermore, the interface definition must also take into consideration opportunities for heat integration (5) with external industries or societal needs for cooling and heating. And finally, a subset of societal issues is to be addressed (6).



SINTEF Energy Research / Jens Hetland, 2006

Figure 2: The HYPOGEN plant and its immediate surroundings.

Ad 1): The fuel will be natural gas, oil or coal, however with options for renewable energy sources on the longer term like biomass, as depicted on Figure 1.
Ad 3): According to the Quick-start Programme of the European Union hydrogen is basically needed for the fuel cells, particularly in the transport sector. This means that the purity of the hydrogen yield must comply with the market demand for hydrogen by 2012.

The overall configuration of plants that employ gasification technologies for the decarbonisation of coal and lignite (via a synthesis gas) will be determined, and reforming technologies for natural gas to be used for a combined production of hydrogen and electric power generation (SP2). This includes advanced process integration studies, benchmarking and optimisation to show how configuration, design and techniques for hydrogen purifications and efficiency improvements could be incorporated. The feasibility of these schemes is to be evaluated and demonstrated. This includes the most appropriate concepts for base-load and a flexible plant in terms of electricity and hydrogen yield ratio. Innovative gas processing and heat recovery techniques will be exploited in WP2.1 for natural gas and WP2.2 for coal.

In WP2.3 technological and economic information will be provided on new technologies for decarbonisation of fossil fuels. This information, along with the results from WP2.1 and WP2.2, will be further used to benchmark technology options for cogeneration of hydrogen and electricity with CO_2 capture, using a multi-criteria assessment methodology in WP2.4. A short list of the most promising concepts for combined production of hydrogen and power with CO_2 capture will be submitted as recommendations for the establishment of case studies in SP5, in which natural gas and coal are used as feedstock. Further techno-economic issues that are addressed in WP2.4 (and WP2.1 and WP2.2) will be made available to support SP5.

3 YIELDS

As already stated there will be a compound yield made up by electricity, hydrogen and carbon dioxide, with further options for the utilisation of low grade heat.

3.1 Electric power: 400 MWe

The metrics and specifications of the plant are going to be decided in SP5.

As decarbonisation represents the main technology in advanced power cycles with high efficiency, hydrogen-enriched fuel is likely to be fed into a gas turbine that constitutes the topping cycle. As the HYPOGEN plant will be a technology demonstrator, the gas turbine engine will be chosen among the engines in the upper range of the state of the art in commercial heavy duty gas turbines (i.e. 250-300 MWe). The exhaust system of gas turbine will be diverted through a heat recovery steam generator that delivers steam to a steam-turbine bottoming cycle so that the two drives jointly generates 400 MWe. The combined power cycle will be further defined and specified in SP2.

3.2 Hydrogen: 25-50 MW based on HHV

3.2.1 Positioning of hydrogen as an energy vector

The European Commission has initiated a set of actions to keep pace with the US and Japan, and to cope with the main ideas behind the "Hydrogen and Fuel Cell Technology Platform"[9] which was established in 2004.

Accordingly, DYNAMIS shall plan for delivery of both gaseous and liquid hydrogen (as appropriate) to the refuelling stations, and if not otherwise justified by firm market forecasts the share should be roughly 50/50 gas and liquid. Hence, provisions shall be made for supplying hydrogen as shown in Figure 1 via:

1. pipelines at typically 7-7.5 MPa;
2. cylinders at 20-25 MPa (or higher) to be transported on trucks;
3. in liquid phase in cryogen tanks.

The amount of 50 MW hydrogen (HHV) corresponds to some 1000 busses (i.e. city busses and/or regional busses). Typical of these busses are that they are prone to form a fleet of vehicles operating within a rather limited area. This implies that hydrogen could be offered and supplied as an alternative fuel in some regions until a pan-European hydrogen infrastructure is deployed (as would be required for other transport vehicles and personal cars except for some fleet-operated light duty vehicles). Hence, in terms of hydrogen and future fuel cell vehicles, city busses and regional busses are prone to constitute the primary target for initial take-offs in Europe[10]. The amount of hydrogen supply from a HYPOGEN demonstrator (50 MW), however, does not exceed the volume of fuel that is required to operate the busses of one larger city.

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[9] *http://forum.europa.eu.int/Public/ irc/rtd/eurhydrofuelcellplat/library*

[10] The assumption is that a regional bus makes some 200 000 km per year. The specific fuel consumption depends on the driving cycle, and current busses are prone to consume (typically) 0.4 litre of diesel per km. Hence, the fuel demand amounts to P=ρ*consumption per km*HHV*distance p.a.= 812 MWh p.a. (ρ=0.85 kg/litre, and HHV=43MJ/kg for diesel). As 50 MW hydrogen corresponds to 435000 MWh per year, the number of hydrogen-driven busses would amount to 535 with a similar efficiency. If some efficiency improvements and perhaps

3.2.2 Hydrogen export systems and take-offs

The definition and specification of the hydrogen export system will be established in SP3. As a guideline, the hydrogen yield and its purity shall comply with the market expectations for fuel cells by 2012, in due consideration of the main market that is expected to be the transport sector.

SP3 will provide:

- Insight in the need for:
    - Appropriate capture and storage sites in Europe
    - Available transport concepts for CO_2 (best available technology)
    - Required CO_2 infrastructure (versus plant and storage site)
- Requirements:
    - H_2 treatment to meet the stated purity level and export quality of H_2
    - Interface requirements towards a future European hydrogen infrastructure
    - CO_2 gas quality for piping and/or shipment
    - Transport and injection technology for storage of CO_2
- Gap analyses (based on the above results). From these analyses the necessary short-term developments needed for transport will be identified.

Furthermore, the existing European infrastructure for CO_2 transport will be evaluated (WP3.1) in terms of capacity, location, legal constraints, ownership and planned development. Based on the findings, the transport alternatives considered feasible by 2012 will be evaluated in terms of capacity, costs, flexibility and legal issues.

3.2.3 Alternative take-offs

No provisions shall be made to offer hydrogen in qualities lower than that required by the PEM-based fuel cells (transport option).

Hydrogen supply for industrial use in such as refineries and other industries is not within the scope of DYNAMIS. For comparison reasons, however, the difference in unit cost versus purity level should be assessed, thus relating to a purity ranging from 95% to 99.99%. Important, however, is the limitation of some impurities, which are dealt with in Annex 1 Hydrogen Specification and Impurities.

3.2.4 Hydrogen distribution

The alternatives for hydrogen conditioning processes based on the expectation of an early development of a European hydrogen infrastructure, capacity considerations, technology maturity and time horizon will be evaluated (WP3.1). As liquefaction of hydrogen is associated with a large exergy input that depends, however, on technology and size, Figure 4 will be used as a basis for justifying and comparing technologies selected for a HYPOGEN demonstrator. The bars of the figure represent the state of current hydrogen liquefaction concepts versus

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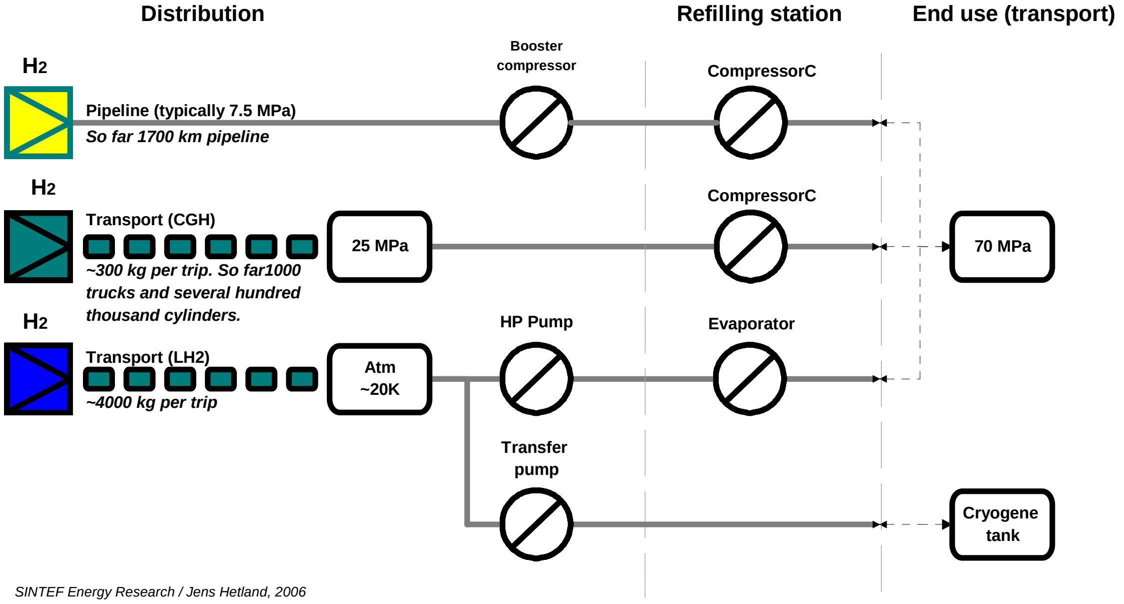
somewhat reduced range are assumed, the amount of hydrogen would be sufficient to feed a captive fleet totalling some <u>1000 fuel-cell driven busses</u>. For comparison; Berlin has about 1700 busses (according to HyWays).
For comparison: London city busses typically make 3 miles per gallon (average), which is equivalent to 4.8 km/4.56 litre or 1.06 km/litre, or 0.95 litre diesel per km (i.e. twice the amount that was used in the calculation).

exergy demand, and the interpretation is that a) a large amount of exergy – say from 17 to 38% of the energy content of the hydrogen yield - is input to the liquefaction process, and b) the specific exergy demand is prone to decrease as the plant size increases[11].



SINTEF Energy Research / Jens Hetland, 2006

Figure 3: Conceptual hydrogen distribution concepts for DYNAMIS and HYPOGEN. The end user market will be strongly focused on hydrogen for fuel cell vehicles and ICE engines with on-board storage either as compressed gaseous hydrogen (CHG) in pressurised tanks or in liquid phase in cryogen tanks.

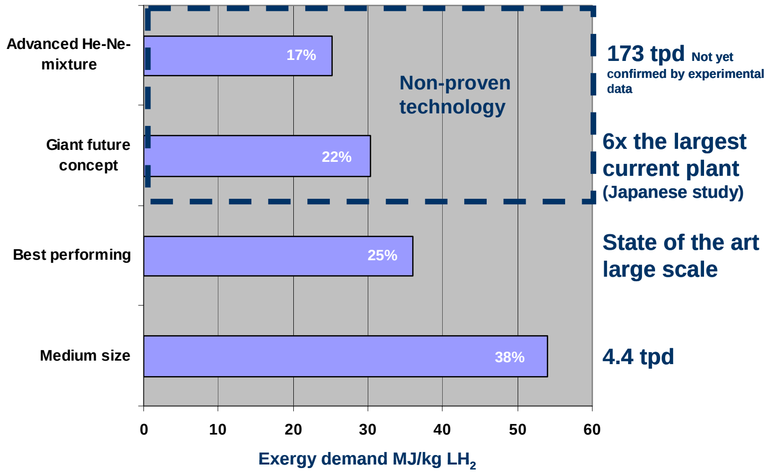


Figure 4: Actual and possible exergy demand for liquefaction of hydrogen.

3.2.5 Hydrogen quality issue

The amount of hydrogen intended for the export system shall comply with the target of the project, as stated in Annex I Description of Work: The hydrogen yield shall correspond to 50

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[11] 50 MW hydrogen yield corresponds to 30.4 tpd (HHV).

MW (HHV) due for delivery to an emerging European hydrogen infrastructure, and be delivered as CGH via pipes and/or in cylinders, as well as in liquid phase in cryogen tanks. The purity of the export hydrogen shall be in accordance with the specification of European fuel cell vehicles (PEM), as anticipated by year 2012.

3.2.6 Hydrogen specification policy

In a future perspective the transport sector is foreseen to become a dominating consumer conditioned on an awaited break-through of the PEM fuel cell. Hence, the development of industrial standards for hydrogen appears like a moving target following the state of technology development of the fuel cell. The problem is that these standards (may) strongly influence the economics of the hydrogen production and purification processes.

ISO TS14687-2 requires 99.99%, (the SAE standard is harmonised with the ISO). The impurity levels of the ISO are not consistent with the requirements for the PEM fuel cells determined by testing (Air Liquide):

- Sulphur is deemed to represent a problem only if the content is 60 times higher than that of the ISO.
- 10 ppm CO is sufficient to poison the fuel cell, whereas the fuel cell remained unaffected at 5 ppm CO.
- H_2S is considered the most serious impurity owing to its impact and limited recoverability of the fuel cell.

An ISO working group has been set to establish a specification of hydrogen for future fuel cells. The impact of adapting too strict specifications is quite severe, as this may lead to erroneous exclusion of technologies that otherwise may be deemed sound and viable. Meanwhile, DYNAMIS has undertaken to define and justify a hydrogen specification that is notably less restrictive than the ISO. This means that the specification of impurities in DYNAMIS will be kept at the least stringent level in regards of life and decay of the PEM fuel cell.

Furthermore, as - according to DYNAMIS - HYPOGEN will have one outlet with liquid hydrogen, prerequisites must be made to meet a purity level of 99.9999% determined by the compression process operation of the liquefaction unit.

3.3 CO_2: 90% capture rate

CO_2 pre-treatment, transport and safe storage of CO_2

It is known that the capital cost of underground storage – including the transport system for CO_2 – is quite substantial. One immediate conclusion is that large quantities of CO_2 would be required to justify the investment. It is further assumed that because of the required infrastructure for CO_2 a facility for co-production of hydrogen and electric power should be sized accordingly. To some extent a network for collecting CO_2 from smaller distributed sources could be included. This option is, however, outside the scope of the DYNAMIS project. The value chain of the CO_2 capture and storage is made up as follows:

- The **cost penalty for CO_2 capture**, due to (1) higher investment cost, (2) lower product yield, (3) higher operational cost (e.g. steam required to regenerate a solvent or for absorbent replacement), (4) compression of the CO_2 to a high pressure (typically 7-10 MPa for pipeline distribution), and (5) pre-treatment (e.g. removing water from the CO_2 flow).

- **Transportation** of CO_2 to the storage site either piped or shipped. On a longer term piping may become part of a larger infrastructure when CO_2 volumes exceed a certain threshold.
- **Storage**, determined by the capacity required and the operation of necessary surface facilities.

The optional CO_2 chains are conceptually drafted in Figure 5 with indicative exergy demand for the conditioning listed to the right. Additional exergy is required for the transport and injection (not quoted on the chart).

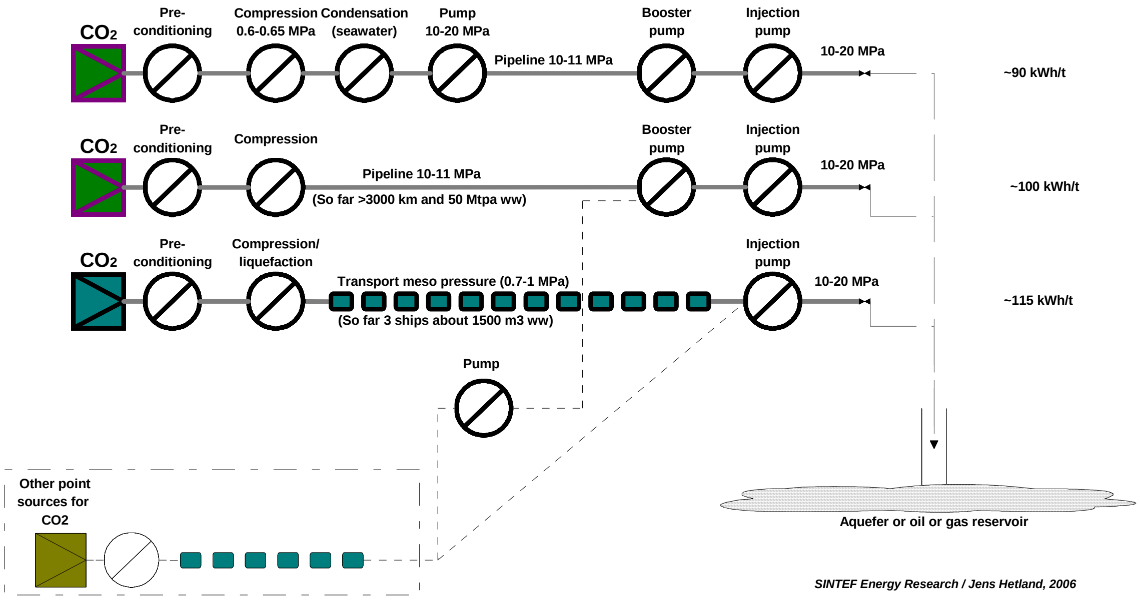

Figure 5: CO_2 preconditioning and transport chains associated with CCS. The exergy demand indicated at the right hand side refers to the pre-conditioning, and does not include the cost of transporting and injection.

The methodology and specification for pre-treatment and transport conditions of the CO_2 will be further determined (SP3) with input from the storage requirements (SP4). Further options will be looked at for use in EOR/EGR (part of SP4).

Storage in geological formations under inhabited land areas is much more likely to cause major controversies than storage under the seabed. This is because on land, health and safety concerns for people in case of leakage are added to the list of potential problems. Depending on local geological circumstances, underground storage of CO_2 could also lead to disturbance of groundwater resources or it could induce local seismic activity (small earthquakes).

The basis for recommending plausible storage sites for CO_2 – and alternative industrial use of CO_2 – will be established (SP4), eventually for enhanced recovery of oil and gas. In order to pursue the targeted realisation of a large-scale demonstration of CO_2 capture and storage in geological formations in Europe for the HYPOGEN demonstrator by 2012 the storage sites must meet the following criteria:

- Be ready when needed (especially if enhance oil recovery is to be investigated).

- Sink capacity that corresponds to at least 30 years of plant operation (Annex II)
    - 60 million tonnes CO_2 with natural gas reckoned at 2 Mt/y
    - 100 million tonnes CO_2 with coal
- Residence time beyond a thousand years.
- Health and local environment safety deemed unproblematic.
- Be accessible on any term such as regulatory, geographical, economic, public acceptance and also the distance from CO_2 source to storage site.

More detailed site selection criteria will be established (WP4.1), mainly from a geological and technical point of view, developed in GESTCO and in collaboration with GeoCapacity, however, with a more comprehensive set of site selection criteria, including also parameters beyond the strictly technical ones.

A series of generic storage data sets will be developed (WP4.2), covering typical situations (aquifer: sand or carbonate, small or large, high quality or stratified, onshore or offshore; oil field: sand or carbonate, etc....). These generic storage fields should be considered movable to any geographical location in Europe. Deliverables hereunder are performance and design assessment reports of the generic CO_2 storage sites.

3.4 Heat integration

As just about 50% of the chemical energy of the fuel is transferred to the primary yield of the HYPOGEN project, a large portion of energy will be available as low-quality heat for heat integration – if appropriate. This energy could be used in adjacent process industry, or the waste heat might be considered for district heating or absorption cooling to serve the society nearby the plant with heating and cooling services (SP2 and SP5).

4 NON-TECHNICAL ISSUES

Obviously, a new technological solution that involves hydrogen production and CCS must be accepted by the public as a safe and useful environmental policy measure before it can be introduced on a larger scale. This includes safety aspects in the handling of hydrogen on-site as well as the export systems, and credible technical measures to ensure safe and permanent storage of the CO_2. Open communication about the risks and benefits related to these options is deemed important.

4.1 Product markets

The HYPOGEN Programme should demonstrate the economic feasibility of a power conversion plant producing hydrogen and electricity from decarbonised fossil fuels. By consequence, a HYPOGEN demonstration plant will produce electricity and hydrogen as primary products. Depending on the storage solution, CO_2 could be a product sold to EOR operations. Further heat delivered to industry or domestic customers can constitute a product of a HYPOGEN plant. The product markets for electricity and hydrogen will be investigated in SP6. The main challenge here is located in the task to model the integration of a future HYPOGEN facility into the electricity market and into the hydrogen market. In view of the objective of the HYPOGEN Programme to prepare the ground for a European hydrogen economy, the analyses with respect to hydrogen markets will be carried out based on the assumptions for evolving markets for hydrogen in the transport sector. Further, the technology development and the technology integration for HYPOGEN will only be a success if the technologies can be marketed on a larger scale worldwide. Therefore important future global technology markets will have to be identified and characterised.

4.2 Policy environment

The introduction of a technological system with two distinctive new dimensions – CO_2 capture and storage and hydrogen production for transport markets – will be influenced by the political environment. This can be on all levels of policy making starting from a local level, where public bodies might try to create favourable conditions for a HYPOGEN plant by acquiring ground for it or might foster the construction of local hydrogen filling stations. On a regional level a favourable policy environment might be created by development plans for hydrogen markets to remediate air pollution. On a country level policies might foster the development of CCS and hydrogen markets by implementing a favourable legal environment.

The policy environment should not be viewed at the present situation of laws and regulations but as the framework being created by plans and visions established by politicians and public decision makers by the time when a HYPOGEN plant comes to the realisation phase.

4.3 Financing

A HYPOGEN demonstration facility is not an entirely new technology but it is still technically challenging because it is one of the first attempts to integrate technologies for hydrogen production, for electricity generation and for CO_2 capture in one facility and at a cost and efficiency level that has so far not been demonstrated. Such new technological concepts incorporate an increased amount of risks compared to conventional concepts. Hence, in order to achieve the realisation of a demonstration plant financing mechanisms that are suitable to carry these risks have to be identified. The case of a HYPOGEN demonstration plant is even more challenging from a financing perspective as not only new technological risks are inherent to the programme but also the risks and uncertainties of new markets: the emissions trade market, the market for hydrogen and, depending on the storage option, the market for CO_2 for EOR or EGR operations, and also the future policy for geological storage of the CO_2 as a mitigation option post Kyoto.

The chances and the pre-conditions for acquisition of equity capital and debt capital have to be explored. Further it has to be investigated the share of public support that will be required to allow a sufficient return on equity within the project.

The HYPOGEN programme as envisaged in the Quick-Start-Programme of the European Initiative for Growth shall be implemented as a public private partnership. The investigations on financing options will evaluate public private partnership arrangements taking into account funding options from European level, including sources from regional funds and cohesion funds, funding sources from Member States and or regional funding options. Also a possible role of the European Investment Bank (EIB) will be evaluated. With respect to the risk sharing, the possible consortium structures for a HYPOGEN project will be assessed. A thoroughly created consortium may reduce risks for individual partners and in turn improve financing options.

In the DYNAMIS project financing issues will be investigated in SP6. The findings will also lead to recommendations for the technology development because the perceived risk attributed to a technology by the financing sector may influence technology choices.

4.4 Emissions trade

A HYPOGEN demonstration plant will incorporate a substantial effort to reduce emissions from electricity generation and will also pave the ground for the production of hydrogen with low-emission technologies. Given its size, a HYPOGEN demonstration plant would be subject to the European Emissions Trade System (ETS). Hence, the ETS-market can have significant impact on the economics of the plant. Even more, there is a direct need of a stream of income that compensates the technical efforts and the lower energy yield relating to the CO_2 capture and storage activities. However, the level of the future market price for CO_2 quotas versus the cost of emissions reductions is highly speculative. The main sources of uncertainty about future market prices are:

- the post-Kyoto targets for emissions reductions for the Annex I countries have not yet been negotiated;
- there are large emitters among the non-Annex I countries, China as the second overall largest emitter is the most prominent example. It is not known whether non-Annex I countries will adopt emissions targets in the period starting 2013 or at which later date this will happen. Nor is it known what level these targets will have;
- the future sectoral distribution of emissions reduction requirements in the European Union is not known;
- the potential market for CDM-projects and the contribution of Certified Emissions Reductions generated by the CDM to the ETS is still uncertain;
- the cost functions for emissions reductions in the energy sector and other industries are not certain.

Beyond the overall market situation that generates the price for European Emissions Allowances (EUAs), the Member State-specific allocation methods for EUAs will play an important role for the economics of a HYPOGEN demonstration plant. A HYPOGEN demonstration plant would obviously be a new plant entering the electricity market and the emissions trade market. However, the rules that apply for new entrants to the market vary significantly across Europe. Hence the applicable allocation rules at a location can have a significant impact on the economics of a HYPOGEN demonstration plant.

The emissions trade market will be assessed in SP6 with the aim to contribute to the analyses of the economic perspectives of the plant. By comparing selected national allocation plans, the investigations on the emissions trade contribute to the identification of promising locations.

4.5 Legal environment

To maximize the benefits of the HYPOGEN facilities, and to minimize its risks, it will be necessary to thoroughly address the technical and legal risks inherent in decarbonisation of fossil fuels and geological storage of the captured carbon dioxide. It will also be necessary to comprehensively evaluate existing relevant EU and international law frameworks, assess any barriers to implementation arising from these legal frameworks, and consider the gaps in these frameworks. Similarly, the consequences of the Kyoto legislation for the accountability of CO_2 storage are unknown still. A main problem seen in this area is the safety considerations and monitoring requirements for CO_2 leakage

4.6 Public perception

The concept of using CO_2 capture and storage as a means to mitigate climate change is a relatively new idea to the wider public. Although the number of publications in the mass media is increasing even the most recent research work on public perception leads to the conclusion that the overall knowledge about CO_2 capture and storage is low in most European countries. Further, it cannot be assumed that the perception of this option in general public is not yet settled. During the first phase, the existing understanding on public perception of CO_2 capture and storage in the professional community will be explored. Based on this experience a preliminary general information strategy on CO_2 capture and storage will be elaborated.

5 ENVIRONMENT

5.1 Emissions Reduction

With the implementation of the European Emissions Trade System, the European Union has strengthened its leading position in the realisation of effective policies for the reduction of greenhouse gas emissions. The HYPOGEN Programme is a crucial part of the technology oriented policies that should enable the European economy to realise the politically set agenda for mitigating climate change. With the co-production of electricity and hydrogen from fossil fuels in a process with carbon management, the HYPOGEN plant should demonstrate the feasibility of drastic emissions reductions both in the electricity sector and in the transport sector.

In order to meet the objectives of a major emissions reduction, the investigations on the HYPOGEN demonstration plant will achieve a high CO_2 capture rate of 90%. The high capture rate is important as the emissions reduction that can be attributed to the plant is lower than the capture rate due to the higher primary energy demand compared to a reference plant. In fact the emissions reduction – when comparing to a plant using the same type of fuel in the reference case – can be expressed as:

$$\text{Emission reduction} = \eta_{e+H2,ref} / \eta_{e+H2,HYPOGEN} * \text{Capture rate}$$

where $\eta_{e+H2,ref}$ and $\eta_{HYPOGEN}$ refer to the efficiency of the reference plant and the HYPOGEN plant, respectively, reckoned at the energy content of the primary yield (i.e. electricity and hydrogen ex plant). For most reference plants, however, no hydrogen yield is involved. In the stricter sense the control volume of this equation - as applied to the HYPOGEN plant - should include the CO_2 chain (i.e. pre-conditioning, transport and injection).

5.2 Air pollution

Any technology developed today has at least to be able to comply with the existing environmental regulations. With respect to emissions of air pollutants, the limits set in the Directive 2001/80/EC of 23 October 2001 on the limitations of emissions of certain pollutants into the air from large combustion plants (“Large Combustion Plant Directive”) have to be met. However, there may be national regulations in Member States of the European Union or in other European Countries that require new power plants to meet even more strict limitations of air pollutants. Further, the HYPOGEN Programme envisages a technology applicable in future times and it may be possible that European air pollution protection standards will be tightened some time in the future. By consequence of this, a HYPOGEN plant will have to meet present European emissions regulations and on top should pave the ground to achieve even higher standards. With this ambition the applicability of the technology all over Europe and beyond will be possible.

5.3 Resource demand

A HYPOGEN plant will be more resource demanding than a comparable reference plant without carbon management as there is an inevitable energy requirement for the capture, compression and transport of CO_2. Developing a technology for emissions reduction that on the other hand increases resource use leads to considerations about the sustainability of the approach. In fact, the concept of CO_2 capture and storage principally imposes this problem to weigh up the principal criteria of careful use of resources and of reducing the impact of energy conversion to the climate. The research works within DYNAMIS do not have the objective to identify principal solutions to this problem. However the careful use of resources will be one criterion in the decision making process when examining solutions. This means that optimising the plant efficiency will not only be considered from an economic point of view, but also from the perspective to minimise the use of fossil fuels.

Besides the additional energy requirement for CO_2 capture, handling and transport, a HYPOGEN plant and the associated transport system for CO_2 will also need a higher amount of materials for appliances, machines and installations. These could be the CO_2 capture plant, the compressor station for CO_2, cooling and condensing units or a pipeline to the reservoir where the CO2 is being stored. The use of materials for these additional installations also requires an increased use of resources compared to a reference plant. Weighing up between the targets of effective emissions reductions, economic feasibility of the concept and minimised resource use will also be part of the research work in DYNAMIS.

5.4 Environmental impact of CO_2 transport

Most likely a HYPOGEN demonstration plant will not be located directly at the site where the CO_2 can be put into a suitable storage reservoir. For evaluating transport of CO_2 the cases of on-land transport by pipeline, of sub-sea transport by pipeline and of marine transport by ship have to be looked at.

Although there are already CO_2 pipelines in the US, the experience made suggests that these can not fully compare with the HYPOGEN plant as said pipelines have been built in sparsely populated areas in Texas and other South-Western States. A HYPOGEN plant would probably be constructed in a comparatively densely populated area in order to be close to the markets for electricity and hydrogen for transport purposes. Safety with respect to human health will be the first order importance in the investigations of the environmental impact of CO_2 transport. Beyond human health, transport of CO_2 in fully functional pipelines will mainly have an environmental impact during the construction phase of the pipelines. There, the construction works will have an impact on the plant and animal life along the pipeline route. During operation the impact of pipelines is low compared to other modes of transport as long as there is no failure in the pipeline. In such events, escaping CO_2 could have an adverse effect on plant and animal life in the vicinity of the leak where CO_2 dissipates and is accumulated in the soil gas on the cost of air. In case of major leaks a principal risk to human health exists from CO_2. The content of impurities in the CO_2 also plays an important role for the adverseness effects occurring in case of pipeline failure. The risks and environmental impacts of CO_2 transport will thus be analysed in SP3.

5.5 Environmental impact of CO_2 storage

The environmental impact of CO_2 storage is still uncertain. This holds true even if taking storage in the open waters of the ocean out of the considerations for storage solutions as it is done in DYNAMIS. First of all, it is believed that the environmental impact of CO_2 storage in geological formations is rather low. This hypothesis is based on the assumption that CO_2 can be stored safely in geologic formations for a very long time - and even permanently.

A more significant environmental impact would be caused in case of seepages of CO_2 from storage reservoirs. First of all the seepage would allow the CO_2 to migrate upwards into higher located geologic structures. There the CO_2 could change the chemistry of the formation waters, which could make the water unusable for other purposes especially as drinking water supply. When migrating closer to the surface, CO_2 could change the soil chemistry and the chemistry of water bodies and thus having an adverse effect on marine, lacustrine or terrestrial flora and fauna. Ultimately, the seeping of CO_2 could impose a hazard to human health. Within DYNAMIS, the storage safety will be investigated in SP4.

6 LOCATION ISSUES

6.1 Plant

The construction of a new large technical installation such as a HYPOGEN demonstration plant requires first of all a specific site at a specific location. These site specific conditions on the one hand can have an impact on the economics of the plant but on the other hand they may also express restrictions that make a realisation entirely impossible irrespective of the finances of the plant.

6.1.1 Infrastructure and site availability

The availability of a physical site imposes a restriction because most of new large power plants are built at brownfield locations as permitting at greenfield sites in Europe can hardly be obtained anymore. At brownfield sites however, space usually is limited due to the existence of old existing plants or due to the vicinity of neighbouring industries. The availability of sufficiently large ground for a plant imposes a stop/go criterion for a decision about a HYPOGEN plant.

Further the availability of a delivery and handling infrastructure for the fuels and for the electric grid connection influence the suitability of a site. If not yet in place, the construction of this infrastructure will add costs to a HYPOGEN project. In an adverse case, it could even prove impossible to build the necessary infrastructure to connect a site to the existing transport pathways.

6.1.2 Permitting issues

The permitting of a technical installation is a case specific decision that closely relates to local conditions and regulations, and can not be described in generalised terms. Nevertheless, brownfield sites of existing power plants usually have the strategic advantage that the operation of a power conversion plant as such is permitted there. This in fact makes the specific permitting of a plant with its defined technology configuration much more easy, or often enables this technology specific permitting.

Permitting procedures are prone to vary from country to country – irrespective of whether only in connection with the employed technology or also with the general suitability of a site. For a location decision of a HYPOGEN project, the main question would be the average duration of a permitting process of the nature that would apply and also the average risk of failing to obtain the permit. If no historical information can be made available on the risk of such failure, the general nature of the procedure could probably give an indication, as the clearer the requirements are formulated, the better the chances usually are to predict the outcome of a permitting process.

6.1.3 Site conditions

The specific site conditions have some impact on the design of several parts of a plant such as plant layout and the storage site for solid fuels (if any). Most important, however, are the average ambient climatic conditions that set the framework for the operation – especially the availability of low-temperature cooling water that decides the condenser temperature, and thereby the end-point of the expansion line of the steam turbine. So, although the design calculations will be performed based on one specifically set case (defined in SP2), the location choice will be examined under the criteria, where the ambient temperatures will be low and where possibly water for water cooling would be available that usually allows a more efficient operation of a plant.

6.1.4 Accessibility of fuel

The access to the fuel – coal or gas – has first of all to be realisable in principle. In order for a site to be promising the access to the fuel has to be simple and should not involve too high costs. This holds true both for the investment to realise transport and handling systems and for the operation costs. This means for gaseous fuels, that a pipeline on sufficient pressure level to supply a HYPOGEN plant should be located nearby the area of possible plant location. For coal it means that the site should be located either at a mine (lignite) or it should be located at a navigable waterway (or seaport) where transport costs for coals are low compared to railway transport.

6.2 Storage sites

The UN-based Intergovernmental Panel on Climate Change (IPCC) has estimated that on a world basis there is available storage for about 2000 Gt CO_2, which most likely would meet the global storage needs up to about year 2100. The geological storage capacity just under the Norwegian continental shelf has been estimated to around 500 Gt, which would be sufficient for receiving the assumed collectible CO_2 from the Western-European countries for more than 400 years.

Geological storage of CO_2

Two key areas are identified for CO_2 storage: (1) in geological formations, (2) by use of CO_2 – especially for enhanced recovery of oil and gas (EOR/EGR). The stability of geological storage facilities for CO_2 is subjected to a growing concern. Modelling[12] suggests that safe rendering of CO_2 in the stricter sense may require a retention time at the order of several thousand years in order for CCS to become a climate mitigation option! Owing to social, political and/or technical barriers, other storage options are not deemed feasible on a short-to-medium time scale.

6.2.1 Legislation with respect to CO_2 storage

6.3 Electricity markets

The main product of a HYPOGEN demonstration plant will be electricity. So, by consequence the electricity market will play a crucial role for the economic performance of the plant. Although the wholesale market for electricity is fully liberalised all across the European Union, there are still significant regional differences amongst Member States or groups of Member States. The differentiations stem from the insufficient transport capacity of the grid, that does not allow to fully balance the regional differences relating to the demand and supply. One indicator for the insufficient grid transport capacity is the auctions for transfer capacity that are held at borders of balancing regions (usually equivalent to national borders). Examples for those auctions are the auctions held at the French-German border[13]. Due to these regional differences

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[12] LINDEBERG, E., "The Quality of a CO_2 Repository: What is the sufficient retention time of CO_2 stored underground", Proceeding of the 6th International Greenhouse Gas Control Technologies, Kyoto, Volume I, J. Gale and Y. Kaya (Eds.) Elsevier Science Ltd. 2003. pp 255-260.

[13] Compare e.g. RWE, "Transfer capacity auction", 2006. Internet document downloaded from http://www.rwetransportnetzstrom.com/generator.aspx/grid-usage/transfer-capacity-auction/language=en/id=195360/page.html, 13.8.2006

the location of a HYPOGEN demonstration plant is foreseen to affect the economic performance of the plant.

Main criteria to characterise the regional electricity markets are as follows:

- The (general) price level for electricity with projections for future price regimes and market price development. The general price level gives already a good indication about the contribution to profit that can be generated from electricity wholesales.
- Spread between peak- and baseload. With the planned design to have a flexibility between electricity production and hydrogen production, a HYPOGEN demonstration plant could make use of this flexibility by giving priority to producing hydrogen during low price hours and switch the production to electricity during peak price hours.
- Balancing the power market. A HYPOGEN demonstration plant could not only be designed to make use of the foreseeable intra-day price variations but also to offer capacity to balance the power market. With the option to divert hydrogen from the export stream for additional electricity production on a short notice of a few minutes and for a limited amount of time of a few hours, a HYPOGEN demonstration plant could be configured as a swing producer to offer balancing power that yields higher prices than conventional power. This option would, however, require additional storage capacity for hydrogen.
- Overall investment and re-investment perspectives of regional electricity markets. Any market with high growth projection should usually provide a better environment for a HYPOGEN demonstration than a mature market with a marginal need for replacement. In the former case, prices will more likely tend to reflect the long-term marginal costs. In the latter case prices are prone to stay at a level of short-term marginal costs.

The electricity market perspectives will be investigated with help of electricity market models in SP6.

6.4 Hydrogen market

The regional evolution of hydrogen markets for transport purposes is still entirely uncertain. It is even not sure whether hydrogen will become a transport fuel used in a significant amount at all. Nevertheless, hydrogen plays an important role in the political strategies of reducing emissions of greenhouse gases as well as emissions of local air pollutants from the transport sector. So, by consequence and in line with the objectives of the HYPOGEN programme, the research work within the DYNAMIS project will not comprise the analysis of the probability of a hydrogen market to realise at all or when this will happen. The success of a HYPOGEN demonstration plant will not only depend on the technical and economic feasibility but also on the embedding of both energy products – electricity to be fed to the grid and hydrogen primarily as a vehicle fuel – in adequate markets.

Whereas there is much more knowledge on electricity markets, the research on the location of hydrogen markets will have to rely on more indirect indicators. In order to identify promising areas for the evolution of hydrogen markets, the research work in DYNAMIS will follow the approaches and findings developed in other European projects such as the HYWAYS project. Principal indicators for a high probability of a hydrogen market for transport purposes to evolve are:

- Population density. It can be assumed that hydrogen fuelled vehicles will first be marketed in densely populated areas, where a larger market size can be reached with comparatively lower efforts needed for fuel infrastructures (see Figure 6).
- Vehicle density. Not only the population density plays a role but also the density of vehicles as on the one hand regions with a high density offer larger markets and on the

other hand these regions tend to be subject to air pollution problems that could be tackled also by hydrogen fuelled vehicles that are operated with fuel cells.

- Regional value added or regional level of income. At least in the early years of market development, fuel cell vehicles will certainly be more costly than conventional vehicles with internal combustion engines. This means that the economic ability to buy such a vehicle will play an important role in the early development of hydrogen markets for the transport sector. (See Figure 7)

Beyond these indicators, scientists involved in the HYWAYS project have pointed out the conviction that the regional political effort of developing a hydrogen market will become a crucial and influencing factor in the very first phase of market penetration of hydrogen as a vehicle fuel. Such political movement is evolving for example in regions where road traffic is prone to induce air pollution problems

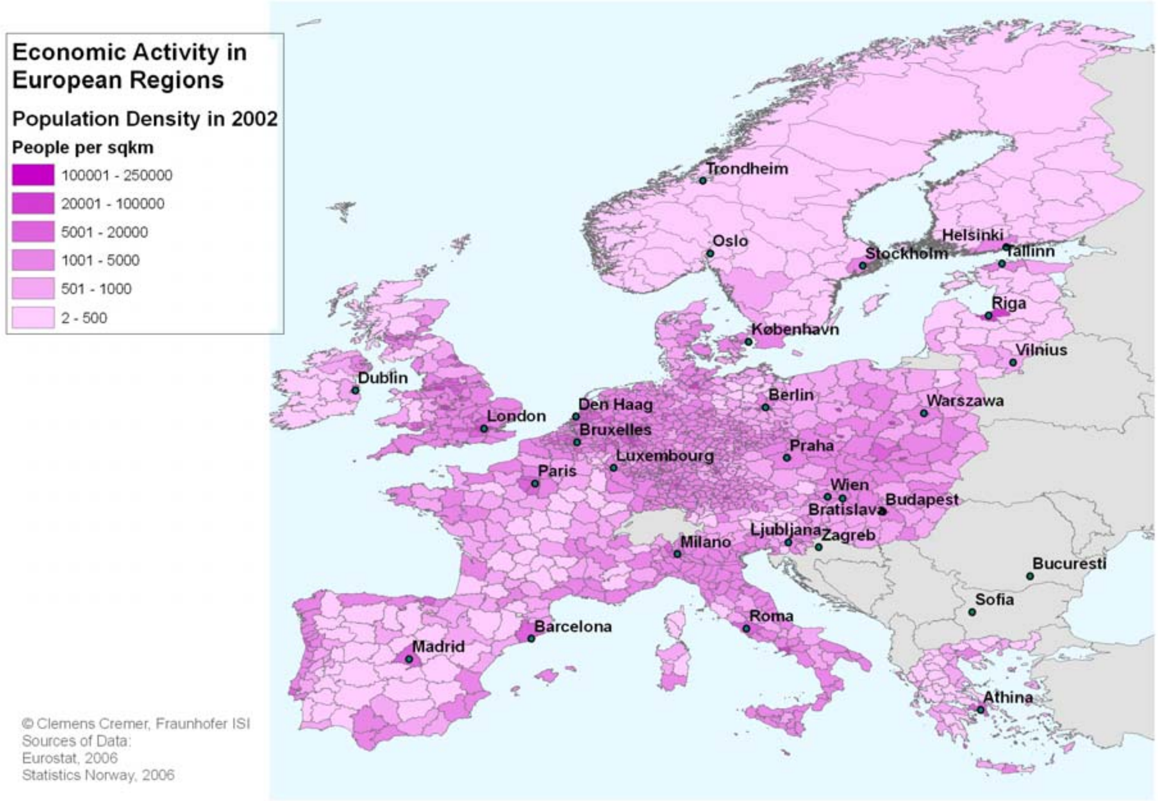
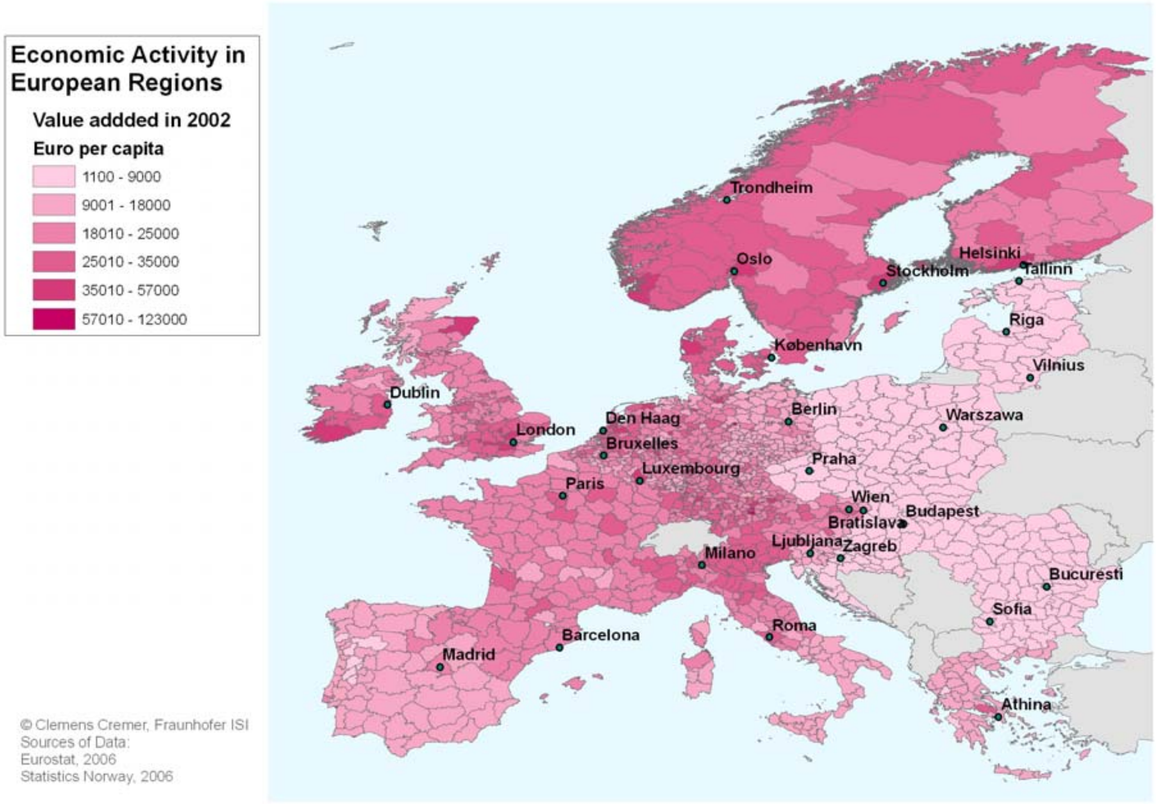


Figure 6: 2002 population density in European regions on the NUTS3 level.



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Sources of Data:
Eurostat, 2006
Statistics Norway, 2006

Figure 7: 2002 regional value added in European regions on the NUTS3 level.

6.5 European Emissions Trade System

The European Emissions Trade System (ETS) creates the world's largest market for greenhouse gas emissions certificates (i.e. the European Emissions Allowances, usually abbreviated as EUAs). The existence of this market opens for economic opportunities for low emission technologies in a twofold way. First of all, in a functioning electricity market, the value of the EUAs necessary for the operation of a plant have to be calculated into the bid price for electricity at the stock exchange or for direct contracts. Consequently, the market price for electricity should reflect the value of EUAs used by the price setting power plants. Overall this mechanism should lead to an increase of the wholesale electricity price. A power plant that does not have to use emissions certificates will benefit from a higher price. The second way how a HYPOGEN plant could profit from the ETS is the allocation of EUAs at no costs that is performed for the bulk of the EUAs today. The rules that are applied to new market entrants, however, vary amongst the Member States of the European Union. Hence, the research efforts of the DYNAMIS project as carried out in SP6 will also be directed at identifying Member States where the allocation to new market entrants promises a favourable supply with EUAs at no cost. Theses EUAs could be sold on the market for EUAs and by this add to the income of a HYPOGEN demonstration plant.

6.6 Markets for CO_2 as a product (EOR)

- to be added in Revision 2 -

6.7 Public, stakeholder and policy impact

- to be added in Revision 2 -

6.7.1 Political programmes and subsidies

- to be added in Revision 2 -

6.7.2 Regional industrial commitment

- to be added in Revision 2 -

6.7.3 NGO and stakeholder groups

- to be added in Revision 2 -

6.7.4 Public perception

- to be added in Revision 2 -

6.8 Overview location criteria

Table 6-1: Overview table of location critria

				Indicators	
Category		***Criterion***	***Description***	***Type***	***Expression***
Equipment and inputs	**Plant**	Infrastructure and site availability	Physical availability of space; availability of infrastructure	- Site dimensions sufficient	Yes/no
				- Electricity grid connection	Yes/no
				- Fuel infrastructure	Yes/no
		Permitting issues	Public inquiry procedure; permiiting time	Availability of already permitted site (brown-field)	Yes/no
				Average time for permitting procedure (green-field/brown-field)	Months
				Risk of failure in permitting procedure (Note 1)	High/low or %
		Site conditions	Climate conditions	Average annual temperature (Extreme temperature low and high)	°C
				Watter cooling available	Yes/no
				Average cooling water temperature	°C
	Fuel	Accessibility to fuel	Infrastructure available for importing fuels (coal, NG)	Distance to Natural Gas grid	km
				Distance to navigable waterway or harbour for coal (or other fuel)	km
				Distance to railway tracks	km
				Distance to lignite mine	km

Note 1: How well are the permitting procedures and how predictable are they?

Products	**Power**	Access to grid	Possibilities and need for integrating 400 MWe power production	Regulations concerning grid access	Favourable/ average/ poor
				Grid transport capacity at site (are there risk for congestions?)	Good/ average/ weak
		Cost of connection	What us the cost to connect plant to grid	Distance to suitable high voltage grid	km
				Availability of existing transformer station	Yes/no
		Electricity markets (spot; peak and base)	Is there a good market for power (base, peak, spot)	Absolute level of power prices	€/MWh
				Spread between peak and base load	€/MWh
				Prices for balancing power	€/MWh
	Hydrogen	possible market for hydrogen	Potential (current) costumers of (excess of hydrogen) present; possible demonstration of hydrogen system planned; possible future transport market; sufficient large market to balance demand and supply	Distance to existing hydrogen users	km
				Projections about future hydrogen market for transport users in the area of the site: time of market evolution	year
				Size of projected hydrogen market	GJ/a
		Available distribution for hydrogen	Pipeline infrastructure available; other infrastructure?	Is there a hydrogen transport infrastructure?	Yes/no
		Costs of connection	What are costs to connect plant to hydrogen use (pipeline e.g.) Cost of establishing a system tank transport (cylinders and cryogen) and receiving system?	Distance to hydrogen pipeline	km
				Cost of connection	€
		Programmes	Possible connection to local, national or community programmes to support hydrogen applications	Financial support schemes available	Yes/no
				Political support expectable	Yes/no
				Industrial drivers nearby (e.g. manufacturer of fuel cells or fuel cell cars	Yes/no
	CO2	Availability of suitable locations	Suitable storage or use of CO2 available	Suitable geological storage available	Yes/no
				Degree of geological exploration	Very good/good/medium/poor
				Kind of storage	Saline aquifer, depleted oil or gas field, EOR, EGR, coal bed#
				Market for EOR/EGR?	
				Sensitivity of storage structure with regards to side components and contaminants in CO2	High/medium/low
				Legislation for CO2 storage existent	Yes/no
				Legislation for CO2 storage favourable	Yes/no

		Distance to storage location	Transportation distance limited?	Distance on land	km
				Distance covered by existing infrastructure	km
				Cost of infrastructure construction	High/medium/low
				Distance at sea	km
				Distance covered by existing off-shore infrastructure	km
				Cost of infrastructure construction	High/medium/low
		Complexity of CO2 transport		Intermediate storage needed	Yes/no
				Change of state of CO$_2$ needed (e.g. liquefaction from dense phase)	Yes/no
		Combining more point sources for CO$_2$	Transport costs are sensitive to volume; combining CO2 volumes from more sources (like CO2 from pure sources) may reduces specific costs considerably. Are such opportunities available?	Volume of additional sources in vicinity	Million tons of CO2/a
		Cost of storage	What are the costs to transport and/or use the CO$_2$; what are possible revenues	Transport costs	€/t of CO2
				Storage costs	€/t of CO2
				Monitoring and verification costs	€/t of CO2 a
		Energy penalty for storage	What is the additional energy input ex plant?	Energy input for pre-treatment, conditioning, loading, transport, injection of the CO$_2$	(Joule/tonne CO$_2$)
		CO2 market	CO$_2$ can be used in industrial processes, greenhouses, EGR and EOR	Availability of CO2 market	Yes/no
				Price projections for CO2	€/t of CO2
		ETS	ETS enables the operator to generate additional income. Different national NAPs may create different opportunities	Site is located in ETS area	Yes/no
				Amount of allocation of EUAs expectable under actual allocation regime	% of emissions without capture (calculated basing on the specific emissions of the fuel used)
				Duration of guaranteed allocation in allocation plan for new plants	Years
				CO$_2$ tax avoidance?	€/t CO$_2$

Financial environment		Taxation policy			
		Other incentives (subsidies, stimulation funds, industrial support, local support, etc)			Specific amount e.g. in €/MW installed or €/kWh of electricity
Non eco-technical issues	**National**	Legislative issues	Permitting issues	Favourable legislative regimes available	Yes/no
		Political willingness	Favourable national energy policies that can foster the realisation of the plant; are there already national policies to support or implement CCS or hydrogen use	Existence of support policies and programmes for CO2 free electricity	Yes/no
	Stakeholders	Industrial willingness	Is there a positive attitude; are there possible cooperation opportunities;	Equipment manufacturers	Yes/no
				Large power plant operators	Yes/no
				Oil and gas industries	Yes/no
		NGO position	Is the position of NGOs supportive, neutral of against?	Opinion on CCS	Positive/neutral/opposing
		Public opinion	What is the attitude of the public (local as well in general)	Attitude towards CCS	Positive/neutral/opposing/unknown
		Other stakeholders' position	In the event of offshore geological storage (and EOR/EGR) what is the position of stakeholders within fisheries?	Opinion on CCS	Positive/neutral/opposing/unknown

7 EVALUATION

In the chapters above, issues are described that make up the set of criteria for decision making. As the DYNAMIS project aims at evaluating a low number of specific cases in SP5, a procedure for this decision making process has to be implemented. More specifically, on a first level these criteria will lead to a technical configuration and suitable locations for some plausible cases on a regional basis. On a second level, a comparison between these cases as investigated in SP5 will be performed in order to further elaborate the firm recommendations for the HYPOGEN Programme.

7.1 Evaluation and "optimisation" of individual sites and technology cases

Within the DYNAMIS project the assessment of a future HYPOGEN plant is performed largely on a bottom-up procedure following two stages: In the first stage, the work in the sub-projects SP2, SP3, SP4 and SP6 includes a detailed assessment of some technology concepts that are deemed promising candidate plants. These concepts will be based on several options for technology, transport and storage of the CO_2, as well as the societal implications of a future HYPOGEN plant. From this initial process feed back is foreseen to reveal possible improvements, and the results from individual sub projects will be further evaluated. Especially in SP6, the analyses on markets, financing options, and on public perception will be based on the candidate technologies and storage options at hand, as compiled in SP2, SP3 and SP4. In turn, the outcome of the assessments made in SP6 will intentionally support the decision making that is required in the technology oriented sub-projects SP2, SP3, SP4 and SP5.

The work in the sub-projects SP2, SP3, SP4 and SP6 will generate a large amount of data and information that will further be used to characterise the options for a HYPOGEN plant. These data sets will make the basis of the main work to be performed in SP5. The first step thereof will be the defining of a limited amount of candidate HYPOGEN plant cases (intentionally two to five). In this endeavour it is important to make adequate use of the expertise, knowledge and views of the partners that are involved in this process. Furthermore, the participants of SP5 will investigate and make recommendations for an appropriate decision making procedures that will be required to identify and select the most relevant concept[14]. On this basis the work resulting from the first stage of the work performed by SP5 will be used to generate the cases that will be further investigated in the second phase of the DYNAMIS project.

7.2 Comparison and assessment of all cases

The final works of the DYNAMIS project will comprise the comparison and assessment of the cases analysed in SP5 enabling the project team of DYNAMIS to generate a well founded set of recommendations to the European Commission and to the participating industry partners on how to proceed within the HYPOGEN programme.

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[14] One possible methodology could be the "Analytical Hierarchy Process (AHP)" that provides a stringent procedure to integrate a views and expertise of participants with different background into a decision making process.

8 ECONOMIC PARAMETERS

The analyses on economic feasibility and on profitability usually will make use of two types of assessment:

- net present value of an investment
- internal rate of return.

The general parameters for the calculation of the net present value are the interest rate and the duration ("lifetime") of the period, in which the earnings from the investment will be generated. For the assessment of a HYPOGEN demonstration plant, it is proposed to apply

8% interest rate and
20 years financial lifetime of the plant

The expected internal rate of return of an investment can be calculated based on the investment costs and the forecasted payment series over the lifetime of the project. The measure of the internal rate of return is then used by possible equity providers and debt providers to evaluate the viability of the project against its risk profile. Hence the internal rate of return that has to be achieved by the project is ultimately defined by the providers of capital.

Usually a project such as a HYPOGEN demonstration plant would need to achieve a return on debt capital of 7% to 8%. The return on equity capital needed to be around 15% when it is raised on a project finance basis. If the equity was to be provided from large utilities a return on equity capital of 10% could be sufficient to meet the investment requirements. Depending on the envisaged consortium structure for a HYPOGEN demonstration the calculated internal rates of return should be achieved as described.

9 CONCLUSION

- to be added in Revision 2 -

ANNEX I: HYDROGEN SPECIFICATION AND IMPURITIES

The input hereunder is to be developed by SP3.

- to be added in Revision 2 -

ANNEX II: REQUIRED GEOLOGICAL STORAGE CAPACITY FOR CO_2

Plant size: 400 MW el + 50 MW H2
Assuming efficiencies:
with NG: 0.45-0.5 for power, 0.7 for H2
with coal: 0.4-0.45 for power, 0.7 for H2

HHV/LHV:
NG: 55/50 MJ/kg (using CH4 as the prevalent component)
Hard coal: 26-33 MJ/kg
Bituminous coal: 24-35 MJ/kg

SIMPLE APPROACH:

Reaction schemes:
NG: 1 CH_4 + → 1 CO_2 +
This means that 2.75 kg CO_2 is formed per kg NG

Coal: 1 C + → 1 CO_2 +
This means that 3.67 kg CO_2 is formed per kg carbon

A: NG with 45% efficiency:
(400/0.45 + 50/0.7)*3600*24*360*275/(1000*50) = 1.64 Mtpa CO_2 produced

with 90% capture rate this means 1.48 Mtpa CO_2 to store → **44 Mt over 30 years**.

B: NG with 50% efficiecy:
Likewise: 1.49 Mtpa CO_2 produced and 1.34 Mtpa CO_2 to store → **40 Mt over 30 years**

C: Coal with 40% efficiency and HHV=24 MJ/kg

Fuel	***Efficiency***	***HHV (MJ/kg)***	***CO_2 produced Mtpa***	***CO_2 to store Mtpa***
Coal either hard coal or bit coal	40%	24	5.10	**4.59**
Coal either hard coal or bit coal	40%	35	3.49	**3.14**
Coal either hard coal or bit coal	45%	24	4.57	**4.11**
Coal either hard coal or bit coal	45%	35	3.13	**2.8**

Storage capacity required to meet 30 years of nominal operation (no contingency):

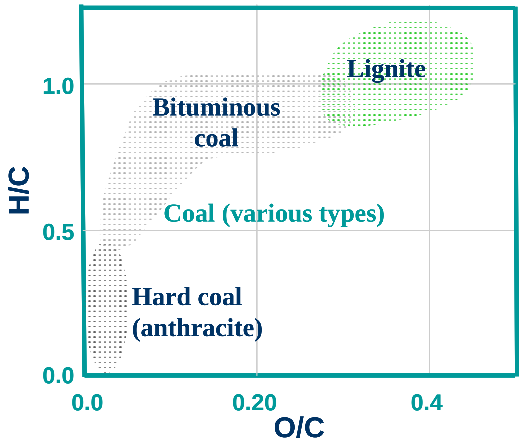
	Produced amount of CO2 produced per year (Mtpa CO_2)	***Required amount of CO2 to store ” 90% capture rate (Mtpa CO_2)***	***Storage capacity required for 30 year feed-in time (Mt CO_2)***
Conservatively:			
Natural gas	1.64	1,48	**44**
Coal	5.10	4,59	**138**

Optimistically			
Natural gas	1.49	1,34	**40**
Coal	3.13	2,8	**84**

This means that the most optimistic calculation with natural gas may end up with 40 Mt storage capacity, whereas coal would require more than the double capacity. The question is which efficiency we may end up with?

A MORE DETAILED APPROACH:

Presumptions for natural gas are maintained from the simple approach. However, the coal composition is assumed from the above van Krevelen chart:



for hard coal (anthrasite)
H/C = 0-0.4 and O/C = 0-0.02

for bituminous coal
H/C = 0.4-1 and O/C = 0.02-0.3

Then the fuel may be reformulated into the following form by eliminating the inert material which does not take part in any of the reactions and thus does not affect the forming of any CO2:

CH_aO_b
with a=0-0.4 and b=0-0.2 for hard coal
and a=0.4-1 and b=0.02-0.2 for bit coal

Indeed, the calorific value does tell something about the combustible matter of the coal, but also about the inert matter content. And likewise as the oxygen content only affects the combustion in the sense that less oxidant is needed to be supplied from outside – and thus does not contribute to the calorific value, one may even reformulate the fuel into diagenetic reactants in the following way:

CH_a

The final reactions will then go this way: $CH_a \rightarrow CO_2 + a/2\ H_2O +$

Thus denoting that there will be some difference between the HHV and the LHV. Following this procedure one may form the following path of the reactive components and their products:

$CH_a + \rightarrow CO_2 + a/2\ H_2O$

i) with a = 0.4 the following amounts will be formed: 3.5484 kg CO2/kg CH_a
ii) with a =1 the amounts would be: 3.3846 kg CO2/kg CH

the individual reactions are:

$C + \rightarrow CO_2$ which releases 33.9 MJ/kg C
$H_2 \rightarrow H_2O$ which releases 142 MJ/kg

Superpositioning gives:

$$\text{HHV} = 12*33.9 + a/2*142 = \begin{cases} 435.2 \text{ MJ/kmole } CH_{0.4} \text{ or } 35.1 \text{ MJ/kg } CH_{0.4} \\ 477.8 \text{ MJ/kmole } CH \text{ or } 36.538 \text{ MJ/kg } CH \end{cases}$$

Hence: with a = 0.4 one gets:

(400/0.4 + 50/0.7)*3.6*24*360/35.1*3.5484 = 3.370 Mtpa CO_2 produced

and then with 90% capture rate on will have

3.032 Mtpa CO_2 to store ➔ **91 Mt over 30 years**

And likewise with a=1 one will get:

3.2184 Mtpa CO_2 produced, and

2.8956 Mtpa CO_2 to store ➔ **87 Mt over 30 years**

For the lower a-numbers, however, the previous calcualtions would remain unchanged. In that case the difference between the 33.9 MJ/kg and the actual calorific value assumed is explained by the amount of inert material (and oxygen if any). This means that we are still talking about the same order of magnitude in terms of storage capacity.

Reommendation:
It is, hence, suggested to make provision for storing all CO2 captured over the entire life of the plant (30 years). This translates to the following requirements:

- 60 million tonnes of CO_2 with natural gas (reckoned at 2 million tonnes per year)
- 100 million tonnes of CO_2 with coal