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Abstract

This Final Activity Report contains an expanded version of the executive summaries for the three Periodic Activity Reports for each of the reporting periods of DYNAMIS project.

In section 1 Project execution an overview of general project objectives, the contractors involved and work performed is given together with the main achievements of the project. Some text has been copied from the public deliverable D5.3.2 Recommendations for the HYPOGEN initiative. That report presents a publishable summary of the more comprehensive restricted deliverable D5.3.1 with same title.

In section 2 Dissemination and use a list of public deliverables and scientific papers/presentations given under DYNAMIS is presented. The reports, papers and presentations are available at the DYNAMIS website. Again, the deliverable D5.3.1 and D5.3.2 contain recommendations for how the knowledge generated within DYNAMIS project could be used for first demonstrations and commercial deployment of HYPOGEN plants.

www.DYNAMIS-hypogen.com

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Revision history (if required)

Date	Revision	Author(s)	Comments

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1 PROJECT EXECUTION

The project

The DYNAMIS project was a three year integrated project within the sixth framework programme of the European Union. The contractual start date was 1 March 2006 and the project hence terminated at the end of February 2009. The total budget was 7,4 million Euro and the contribution from the European Commission amounts to 4,0 million Euro.

<u>Overall objectives</u>
The overall objective is preparing for large-scale hydrogen production from decarbonised fossil fuels including CO_2 geological storage. This implies that the project will prepare the ground for large-scale European facilities producing hydrogen and electricity from fossil fuels with CO_2 capture and permanent storage or, eventually, to be used for enhanced oil or gas recovery.

DYNAMIS responds to the growing interest in this field by addressing ways of decarbonising fossil fuels within a sustainable framework.

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 electric power generation.
2. Hydrogen separation including cleaning, conditioning and export facilities for piped, tanked or liquefied hydrogen.
3. New power cycles requiring a 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.

DYNAMIS undertakes by 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 using advanced flow cycle(s) with hydrogen-fuelled gas turbines in the 250-300 MW class.
- Hydrogen production corresponding to 25-50 MW with the flexibility to adjust the output of the plant from 0 to 100% hydrogen.
- 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 reckoned from a (current) level of €50-60 per tonne of CO_2 captured.

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 was organised in five technical Sub-projects while two work packages for project management and co-ordination and lead project workshops were organised in the additional Sub-project SP1, see Figure 1.

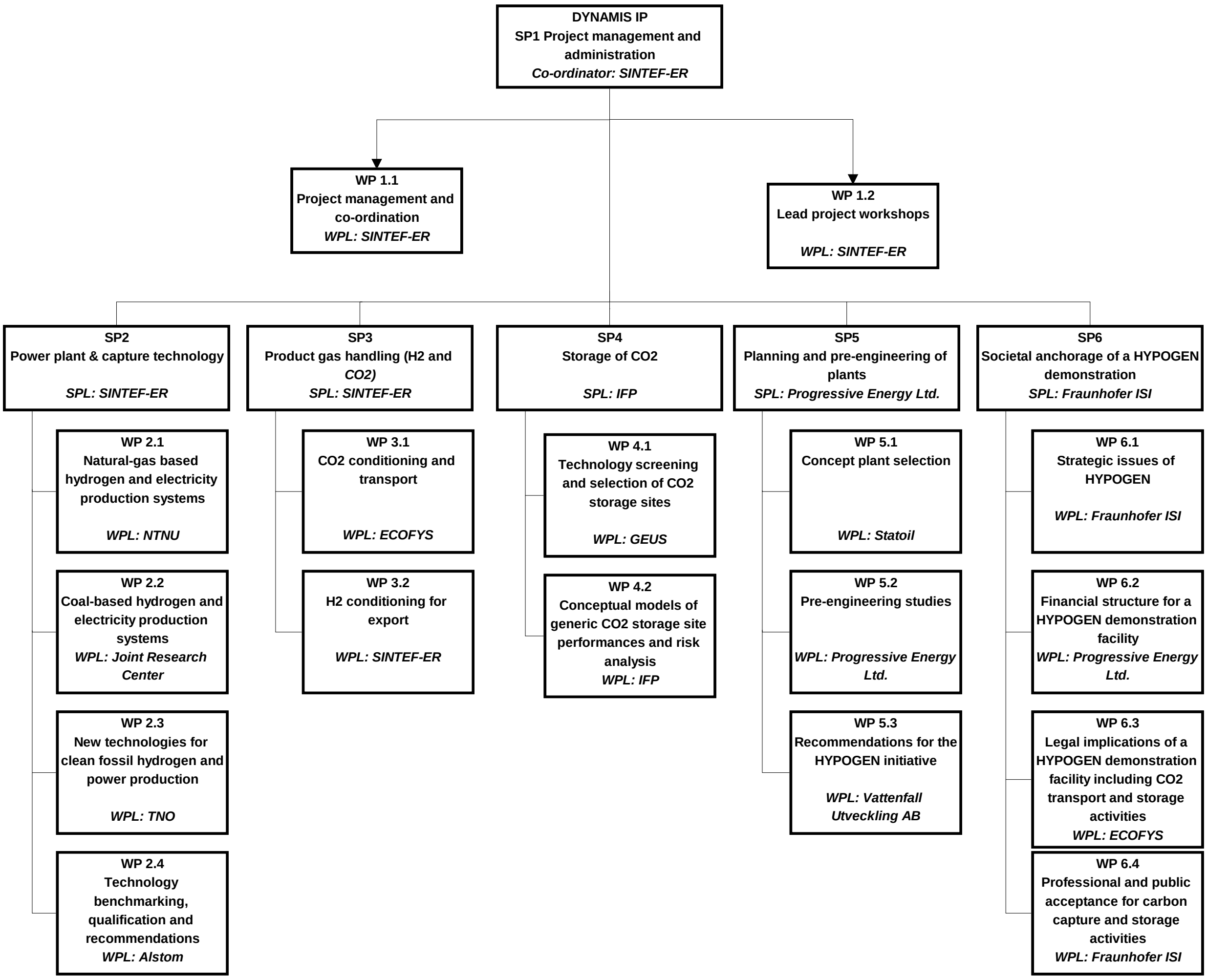


Figure 1: Work Breakdown structure.

The contractors

The DYNAMIS consortium has been established by leading European enterprises and RTD providers comprising 29 legal entities spread within nine EU Member States and two Associated countries (Norway and Switzerland). The consortium exhibits a full value chain of stakeholders and can be thought of as four inter-related islands of proficiency organised for joint actions towards demonstration of large-scale co-production of hydrogen and power:

a) 14 RTD providers (research institutes and universities - plus Vattenfall Laboratory and STATOILHYDRO Research Centre)
b) 7 technology providers (leading manufacturers of energy and power equipment and engineering companies including 1 SME having an important role to play as the leader of SP5 and WP5.2)
c) 7 energy providers (in power generation and fossil fuel supply)
d) 1 financing institution

DYNAMIS employs a strong team of professionals that gathers the critical mass that is capable of achieving the stated targets. The strong involvement by the industries is conceived as a commitment for rapid usage of the project results. Based on the Contractors' business areas, resources and determination, the Contractors will be highly capable of providing the skills, knowledge and resources for pursuing the project objectives.

The RTD providers constitute an eminent group that jointly represents a leading position in energy systems, technologies and knowledge pertaining to H_2 production and CO_2 capture. All and every RTD provider can list topical familiarity of significant relevance to DYNAMIS. The RTD providers also represent a high degree of complementarity in the sense that they all offer skills and capabilities that are needed to broach technologies for integrated power and hydrogen production including carbon capture.

The technology providers are among the largest and most significant industries in Europe - of all sectors - having a leading international position in energy and processing technologies, and also in other technological areas. The manufacturers cover a wide range of knowledge and skills, and are supplying state-of-the-art technologies pertaining to energy and power worldwide. In general terms the technology providers are defined as competitors. Their participation is highly relevant to DYNAMIS – especially for providing key components for H_2 production from fossil fuels, H_2 processing, pre-combustion processing and capture equipment.

The energy providers are basically suppliers of fossil fuels (both gas and coal) and power companies, representing the end-users of fossil fuels. They are strongly involved in the operation of thermal power plants. As they are facing a need for reducing their greenhouse gas emissions, they have committed themselves to be in the forefront of new power generation and capture technologies and are desirous of making use of the DYNAMIS results as appropriate. The suppliers of fossil fuels include several oil & gas companies (STATOIL, BP) and one coal supplier (SNSK) whereas the power companies are directly involved in the supply of both coal and gas. The energy providers have significant operations in 5 European countries.

In Table 1 the 29 Contractors who acceded to the Contract with the European Commission are listed. In addition to these Contractors three participants have signed the Consortium Agreement; Norsk Hydro ASA, Vattenfall AB and Shell Hydrogen b.v.. They have decided to support the DYNAMIS project financially and hence they were defined as Third parties in Annex I to the Contract.

Table 1: Participants list.

Role	No	Name	Short name	Country
CO	1	SINTEF Energiforskning AS	SINTEF-ER	NO
CR	2	STATOILHYDRO ASA	STATOIL	NO
CR	3	BP	BP	UK
CR	4	Store Norske Spitsbergen Grubekompani	SNSK	NO
CR	5	Vattenfall Research and Development AB	VRD	SE
CR	6	E.ON UK plc	EON	UK
CR	7	Endesa Generacíon, S.A.	ENDESA	ES
CR	9	Enel Produzione S.p.a.	ENEL	IT
CR	10	Alstom Power Centrales SA	APC-FR	FR
CR	11	Alstom (Schweiz) AG	AP-CH	CH
CR	12	Alstom Power Environment ECS France	APE-FR	FR
CR	13	Siemens Aktiengesellschaft	SIEMENS	DE
CR	14	Air Liquide SA	AIR-L	FR
CR	15	Etudes et Production Schlumberger	SLB	FR
CR	16	Progressive Energy Limited	PEL	UK
CR	17	Société Générale London Branch	SG	UK
CR	18	Stiftelsen SINTEF	SINTEF-GR	NO
CR	19	SINTEF Petroleumsforskning AS	SINTEF PR	NO
CR	20	Joint Research Center	JRC	NL
CR	21	Fraunhofer ISI	FH-ISI	DE
CR	22	Institut Français du Pétrole	IFP	FR
CR	23	British Geological Survey	BGS	UK
CR	24	Ecofys Netherlands b.v	ECOFYS	NL
CR	25	Geological Survey of Denmark and Greenland	GEUS	DK
CR	26	Netherlands Organisation for Applied Scientific Research	TNO	NL
CR	27	IEA Environmental Projects Ltd.	IEA EPL	UK
CR	28	Bundesanstalt fur Geowissenschaften und Rohstoffe	BGR	DE
CR	29	Technical University of Sofia	TUS	BG
CR	30	Norwegian University of Science and Technology	NTNU	NO

*CO = Coordinator, CR = Contractor

1.1 Main project approach and major achievements

The overall objective of the DYNAMIS project has been to prepare the ground for large-scale European facilities producing electricity and hydrogen from fossil fuels with CO_2 capture and permanent storage. DYNAMIS has been organised as an integrated project (IP) under the 6th Framework Programme of the European Union. The following specifications for the plant were put forward:

- Electrical power output in the 400 MW class
- Hydrogen production corresponding to up to 50 MW higher heating value, and the hydrogen produced fulfilling the specifications of an European hydrogen infrastructure
- 90 per cent CO_2 capture rate

DYNAMIS has put considerable efforts on technology selections and optimisations, to obtain practically and commercially feasible plant concepts, that manufacturers would be prepared to offer, having the best possible performance, but still with good/acceptable operability, reliability and maintainability. For hard-coal and lignite fired plants, IGCC (Integrated Gasification Combined Cycle) with pre-combustion CO_2 capture was the obvious choice of technology. For natural gas fired plants, evaluation of a number of possible concepts - including several IRCC:s (Integrated Reforming Combined Cycle) with pre-combustion CO_2 capture - resulted in the choice of state-of-the-art NGCC with post-combustion CO_2 capture in parallel to a state-of-the-art natural gas fired steam reforming plant, which in turn produces hydrogen. Technical and economic aspects of handling of produced hydrogen and CO_2 were also evaluated.

All these technical issues were then further illustrated by four commercial case studies of potential HYPOGEN plants with CCS, sponsored by industrial Contractors and representing a spread of fuel types, storage types / locations and hydrogen utilisation possibilities:

- East England, UK, sponsored by E.ON UK; Bituminous coal based plant with offshore CO_2 storage
- North East UK, sponsored by Progressive Energy Ltd; Bituminous coal based plant with offshore CO_2 storage including EOR (Enhanced Oil Recovery)
- Mongstad, Norway, sponsored by StatoilHydro: Natural gas based plant with offshore CO_2 storage.
- Hamburg region, Germany, sponsored by Vattenfall; Bituminous coal based plant with onshore or offshore CO_2 storage.

The case studies also provided considerable knowledge on transport of CO_2 and on injection and storage of significant volumes of CO_2, based on best practice for the specific locations with their various types of storage sites.

Non-technical aspects that are critical for realising HYPOGEN plants were also assessed; mainly comprising market perspectives and social, legal and regulatory issues.

This report summarises major findings and – based on these – outlines conclusions on how first demonstrations and commercial deployment of HYPOGEN plants with CCS could become a reality. In addition to needs for R&D and validations, several issues will to a large extent be relevant for all types of large power plants with CCS. This includes that decisions to commission FEED (Front End Engineering Design) studies and on following investments will require appropriate fiscal mechanisms to be in place to encourage CCS from power plants; including sufficient financial support and market incentives, as well as the necessary legal frameworks.

1.2 Overview of what has been achieved

1.2.1 Plant technology

1.2.1.1 Hard-coal and lignite fired plants

Pre-combustion systems convert synthesis gas (from gasification of coal or lignite or from reforming of natural gas) in a shift reaction to produce streams of CO_2 and hydrogen, which can be separated. The hydrogen can then be used as a fuel in a gas turbine combined cycle generating electricity, and/or be supplied to external users. For hard coal and lignite-fired plants, IGCC (Integrated Gasification Combined Cycle) with pre-combustion CO_2 capture would therefore be the choice of technology. The technology choices for the main process steps in the co-production of electricity and hydrogen from hard coal and lignite and their evaluation can be summarised as follows (process units in italics are indicated in the subsequent flow scheme in Figure 3.1):

- **Oxygen production** in an *air separation* unit (ASU). Cryogenic air separation is the only commercially viable technology for this large scale within the time frames anticipated for HYPOGEN plants.
- **Synthesis gas production** via coal or lignite gasification. Oxygen-blown *gasifiers* are the most appropriate for HYPOGEN plants.
    - The entrained flow type appears to be the optimal option for bituminous coal, offering a high hydrogen production efficiency and produces minimal amounts of methane and other gaseous compounds including nitrogen and argon. To achieve high efficiencies, gasifiers with dry fuel feeding and gas cooling using waste heat boiler (Shell) or water quench (Siemens) were recommended in the generic concept evaluations, and also anticipated in the case studies. Of these, the Shell gasifier is the best proven for hard coal.
    - The gasification of lignite is less straightforward due to its high gasification reactivity but on the other hand high trapped water content, high ash content and low heating value. Lignite is also believed to present problems in water-based slurries as it floats. Of the evaluated options, the moving bed gasifier (BGL, British Gas Lurgi) appears to have significant advantages in terms of its ability to gasify feedstocks with high inherent water contents, and still achieving high efficiencies. Tars need to be separated and recycled, and high methane contents limit CO_2 capture rates to around 80%. Fluidised bed gasifiers (HTW High Temperature Winkler) also achieve high efficiencies, but require pre-drying of lignite and low carbon conversion (~95%) together with high methane contents in the syngas limit CO_2 capture rates to less than 85%. Entrained flow gasifier with dry fuel feeding and gas cooling using water quench (Siemens) offers higher CO_2 capture rates but still offering reasonably high efficiencies. The lignite gasifiers will need to be further verified / demonstrated for the actual full scale.
- **Conversion of CO** (carbon monoxide) and water vapour to CO_2 and hydrogen by water-gas-shift-reaction. The *shift reaction* is accomplished using a "sour shift" or of CO from the raw gas (cobalt-molybdenum sulphur tolerant catalyst) using two catalytic beds.
- **Acid Gas Removal** (AGR), i.e. desulphurisation *(Sulphur removal)* of the synthesis gas and CO_2 separation *(CO_2 absorption* from synthesis gas and *CO_2 desorption* from the solvent). A thorough evaluation of available AGR systems revealed that a physical solvent is most appropriate, thus the choice was between a DMEPEG process (such as

Selexol[1]) and Rectisol (methanol). Both have been used in gasification to hydrogen plants. It appears that Rectisol is more complex and more energy intensive, but gives a higher purity CO_2 product stream than Selexol. However, the purity requirements of DYNAMIS can be met by Selexol.

- **Compression of separated CO_2** to required pressure for transport to the storage site.
- **Hydrogen purification**; with the requirement of a purity level of at least 99.95 mol% it was considered that *PSA* (Pressure Swing Adsorption) would be the most suitable for a HYPOGEN plant
- **Power generation** in a *Gas Turbine* Combined Cycle (GTCC). The initial generic concepts developed were based on E-class gas turbines, since such GTs modified for syngas are moderately well-proven. The DYNAMIS consortium then concluded that the use of F-class gas turbines does not entail excessive risk to the overall reliability, availability and maintainability of the HYPOGEN plant. GE and MHI are both actively promoting the use of their F-class gas turbines with a high-hydrogen fuel (albeit through diffusion combustion). Both vendors have operating experience on high-hydrogen fuels, which provides some confidence that they are able to deliver such technology, although the total number of fleet hours (on high-hydrogen fuels) is low. Furthermore, it was concluded that the performance penalty associated with using E-class gas turbine technology would be a barrier to successful deployment of pre-combustion capture.

These processing steps are shown in the outline flow scheme in Figure 3.1:

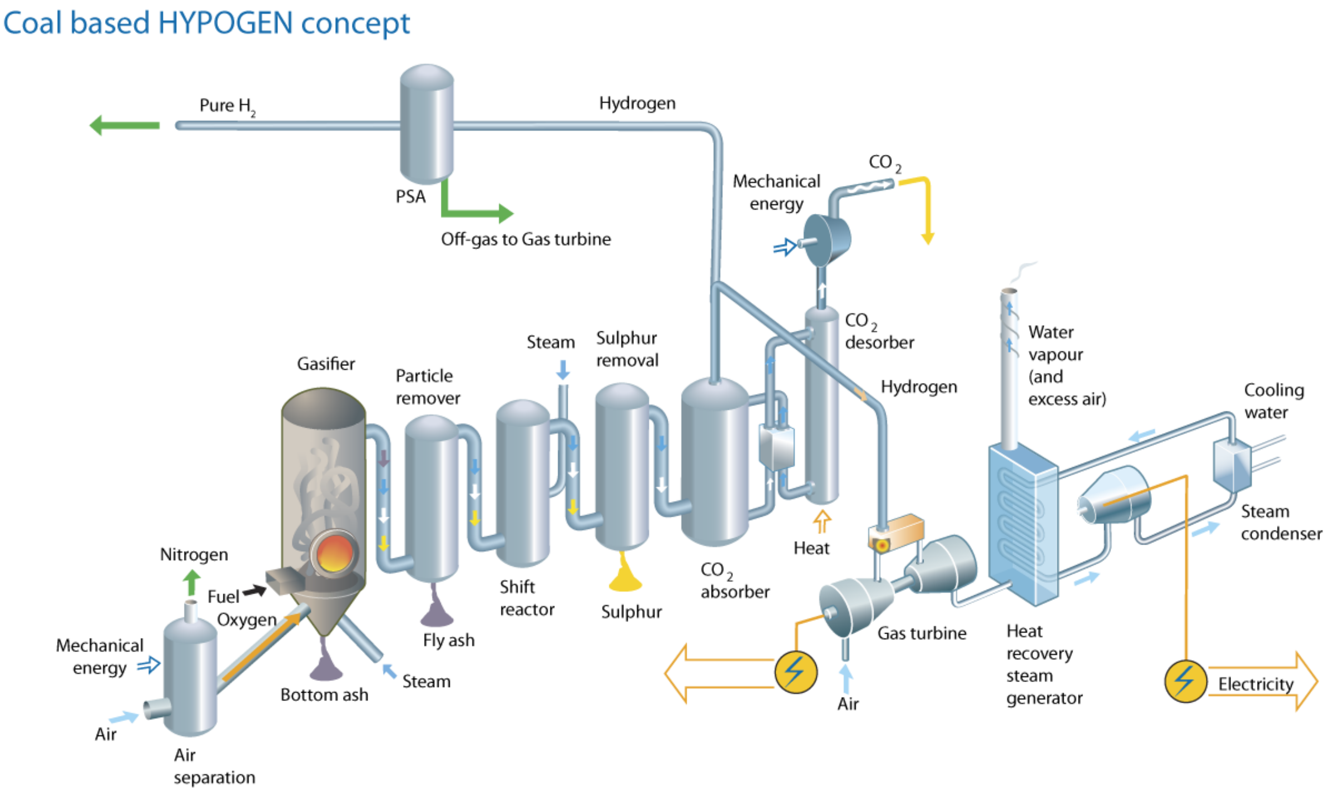


Figure 3.1: IGCC with pre-combustion CO_2 capture for co-production of electricity and hydrogen from coal and lignite.

[1] The DMEPEG process Selexol® is a mixture of dimethyl ethers of polyethylene glycol and has the formulation of CH3(CH2CH2O)nCH3 where n is between 3 and 9.

The DYNAMIS cases are designed for one F-class gas turbine combined cycle – thus producing around 400 MW electricity net. Future plants (after the 1st demonstration(s)) could be designed for two ore more parallel F-class GTs, which will enable larger gas production trains and beneficial economy of scale.

The hydrogen production for external supply offers the possibility to meet certain requirements for power load variations, by varying the ratio between hydrogen and electricity production, and at the same time maintain operation of the gasification and gas production at full load. Intermediate storage of hydrogen could then be used to also match hydrogen demands. The technical limitations for such flexibility will be determined mainly by the lowest load at which the GT still operates at acceptable performance (i.e. still provides sufficiently high exhaust gas temperatures).

1.2.1.2 Natural gas fired plants

For plant using natural gas, evaluation of a number of possible concepts in DYNAMIS - including several IRCC:s (Integrated Reforming Combined Cycle) with pre-combustion CO_2 capture - resulted in the choice of state-of-the-art NGCC (Natural Gas Combined Cycle) with post-combustion[2] CO_2 capture in parallel to a state-of-the-art natural gas fired steam reforming plant which in turn produces hydrogen. The steam reformer furnace exhaust gas is also fed to the CO_2 capture unit. In addition, heat from the steam reforming section is used to raise IP steam to HP steam for the combined cycle. All this is mature state-of-the-art technology, except for the post-combustion CO_2 capture unit. The post-combustion CO_2 capture unit consumes significant energy mainly as LP steam extraction from the HRSG/steam turbine. Another internal energy consumer is of course the CO_2 compression

This concept is illustrated in the outline flow scheme in Figure 3.2:

[2] CO_2 is separated from the exhaust gas after combustion

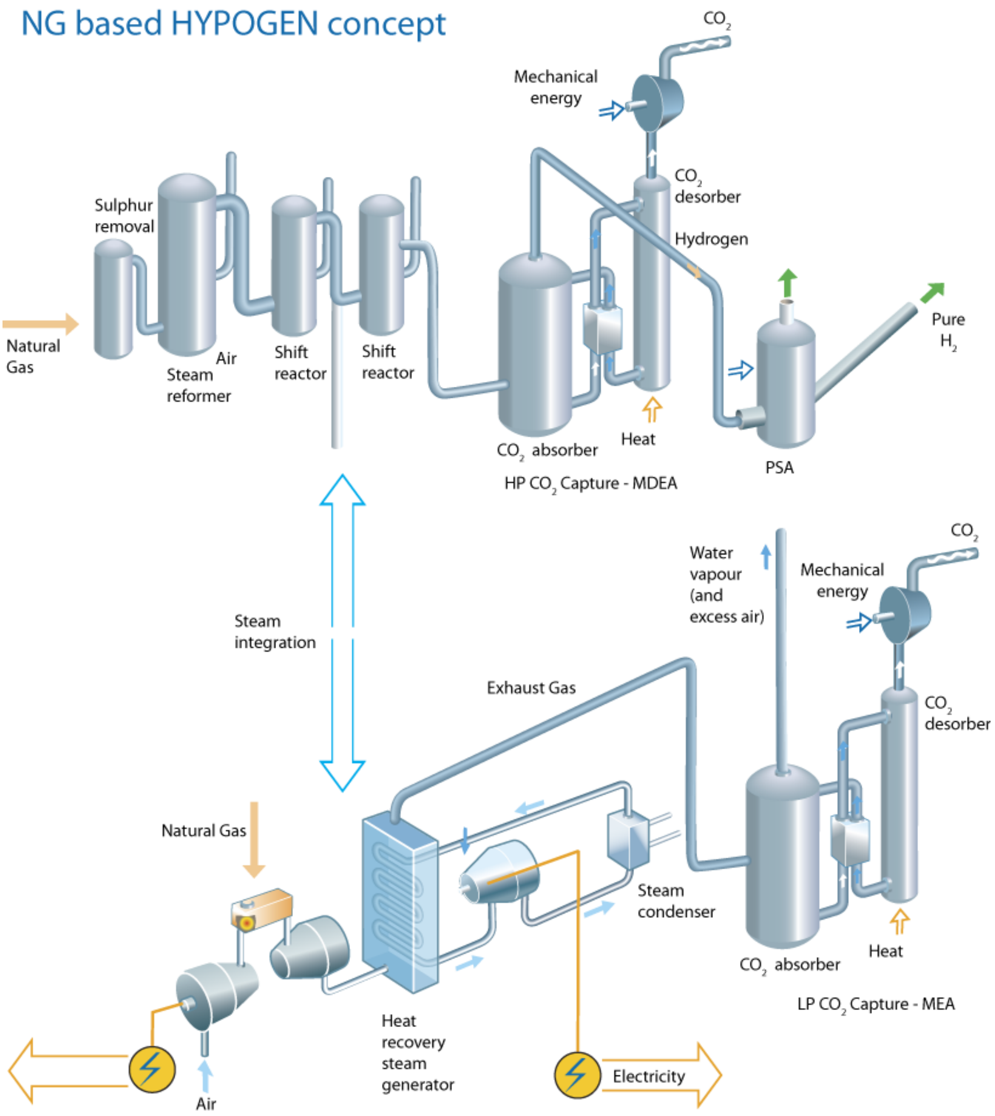


Figure 3.2: Parallel power and hydrogen generation with steam reforming and post-combustion CO_2 capture

The choice of GT, at least for a condensing plant, is made only from a power production point of view, and a state-of-the-art GT (today F-class, later H-class) would be the choice in most cases. For a Combined Heat and Power (CHP) plant this may not always be the optimal choice; the Mongstad case study is based on a CHP plant using two E-class GT:s and one steam bottoming cycle, thus producing 190 MW_e net and 350 MW heat. The demand for process heat is high and the process is in this case optimised for this purpose rather than electric efficiency.

1.2.2 Definition of CO_2 and H_2 purity

It is essential to establish quality specifications that, for the produced CO_2 stream reflect transport and storage requirements from a technical, geologic and HSE (Health Safety and Environment) point of view, and for the produced hydrogen stream fulfil the technical requirements for its distribution and use. Such quality requirements must be developed based on solid technical and scientific information and unnecessarily severe or challenging requirements will result in high additional costs for extensive cleaning.

1.2.2.1 Carbon Dioxide purity

Recommendations for the composition of the CO_2 stream have been provided from the perspectives of transport of the CO_2 in order to ensure safety and durability of the transport system, thereby also ensuring efficient use of the transport capacity. In consideration of the CO_2 stream this implies that existing regulation pertaining to safety and toxicity has been duly considered in order to limit the concentration at a maximum level of any chemical component that is likely to occur in the CO_2 stream – especially in the event of a pipeline rupture. Furthermore, owing to the risk of hydrate formation and corrosion the mechanical integrity of the transport system is very much dependant on the absence of free water. Other impurities should be omitted mainly for technical reasons (e.g. increased compression work and reduced transport capacity). The table below presents the recommended upper concentration limitations pertaining to pipeline transport of impurities that are prone to occur in the CO_2 stream captured from a HYPOGEN plant.

Table 3.1: Quality recommendations for the captured CO_2 stream at pipeline conditions for a HYPOGEN plant

Component	*Upper concentration limit*	*Rationale / comments*
H_2O	500 ppm	Technical: To avoid corrosion and hydrate formation. Concentration to be lower than solubility limit of H_2O in the CO_2. No significant cross effect of H_2O and H_2S. Cross effect of H_2O and CH_4 is significant but within the limits for water solubility. Note: This recommended upper concentration level is significantly higher than in some other CCS projects that specify 50 ppm (*).
H_2S	200 ppm	Health & Safety (***)
CO	2000 ppm	Health & Safety (***)
O_2 (**)	Aquifer < 4 vol%, EOR 100 – 1000 ppm	Technical: Concentration limit on non-condensable gases(**) Range only for EOR, lack of practical experience from impacts of O_2 underground. Oxygen is not likely to occur in pre-combustion capture processes.
CH_4 (**)	Aquifer < 4 vol%, EOR < 2 vol%	Technical. The effect of CH_4 on the solubility of water in CO_2 is significant, but not harmful for transportation of CO_2 at CH_4 concentrations lower than 5% and a maximum water level of 500 ppm
N_2 (**)	< 4 vol % (all non condensable gasses)	Technical Concentration limit on non-condensable gases(**)
Ar (**)	< 4 vol % (all non condensable gasses)	Technical Concentration limit on non-condensable gases(**)
H_2 (**)	< 4 vol % (all non condensable gasses)	Technical. Concentration limit on non-condensable gases(**) Further reduction of H_2 is recommended owing to its energy content and market value
SO_x	100 ppm	Health & safety (***)
NO_x	100 ppm	Health & safety (***)
CO_2	>95.5%	Balanced with other compounds in CO_2

Note (*): Under expected transport conditions for a HYPOGEN plant (pressure, temperature and other possible contaminants) this water level is deemed sufficiently low and the risk of free water and hydrate formation is low.

Note (**): The concentration limit of all non-condensable gases together, like O_2, CH_4, N_2, Ar and H_2, should not exceed 4 vol%, owing to exergy demand for compression. In particular O_2, N_2, Ar, H_2 and CO are immiscible with oil and they may thus increase the minimum miscibility pressure (MMP). (de Visser et al. (2008), [2]) A combined total of these components larger than 5% would impact EOR operations negatively.

Note (***) Health and safety issues for pipeline transport of CO_2 relate to short term leakages in case of rupture (or similar blow out). The maximum concentrations are derived from STEL (Short Term Exposure Limits) for toxic components in relation to STEL for CO_2

The geologic storage itself is not believed to impose any additional or more severe quality requirements, but this still remains to be scientifically verified. EOR storage options may impose more stringent requirements, as indicated in the table, due to interactions with the oil.

1.2.2.2 Hydrogen purity

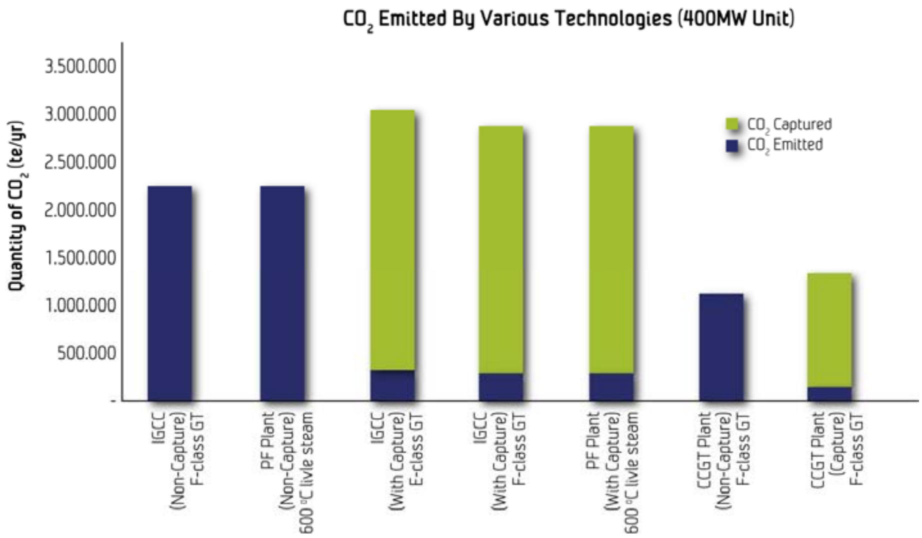
Pre-normative efforts have been made in DYNAMIS in establishing a plausible purity level for the hydrogen yield while addressing end user requirements – notably the PEM fuel cell. These efforts included extensive experimental work carried out (mainly) at Air Liquide (France), which suggest that special care must be taken to the amount of inert components and to carbon monoxide (CO). With due comparison of relevant sources, DYNAMIS suggests the purity levels for hydrogen as listed in the table below as a new norm to apply for future hydrogen PEM-based transport market. These levels will not only comply with performance and life expectancy of the fuel cells, but will also suppress the investment cost and operational expenses, and thereby make hydrogen a more competitive fuel.

Table 3.2: Proposed hydrogen quality recommendations for a HYPOGEN plant, addressing PEM fuel cells in the market.

Pressure	70 barg	
H_2 purity	99.95% (mol)	
Impurities (maximums) :		**Comments**
CO	<0.5 ppmv	Limit because of long term voltage losses
CO_2	<1 ppmv	It is recommended to reduce CO_2 content as much as possible before PSA unit. Further relaxation of this limit to 100 ppmv should be considered by the Fuel Cells community, based on experimental experience with long term operation.
Sulphur Compounds	<0.01 ppmv	Further relaxation of this limit to 0.1 ppmv should be considered by the Fuel Cells community
Total Hydrocarbons - C_2+ - CH_4	 < 2 ppmv < 100 ppmv	
O_2	< 5 ppmv	
Ammonia	< 0.1 ppmv	Further relaxation of this limit to 5 ppmv should be considered by the Fuel Cells community
Inert gas (N_2, Ar, He)	Sum < 500 ppmv	Further relaxation of this limit to 0.2-1% should be considered by the Fuel Cells community. This could increase hydrogen recovery up to 6 percentage points for the coal based cases studied in DYNAMIS.
H_20	< 5 ppmv	

1.2.3 Efficiency optimisations

DYNAMIS has put considerable efforts into technology selections and optimisation, in order to obtain practically and commercially feasible plant concepts, that manufacturers would be prepared to offer, with as high energy efficiencies and low CO_2 emissions as possible, but still with good/acceptable operability, reliability and maintainability. Best achievable CO_2 emissions and efficiencies for these concepts compared with relevant alternatives are illustrated in Figure 3.3.



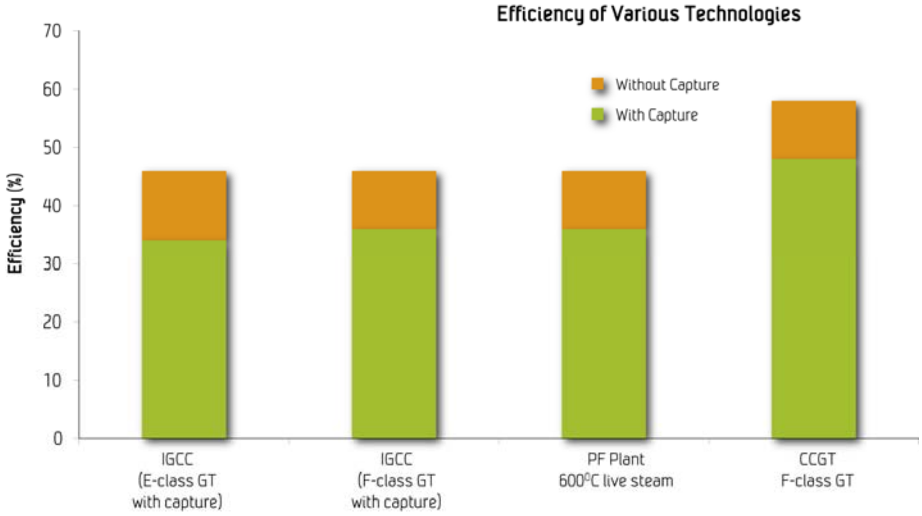


Figure 3.3: Best achievable CO_2 emissions and electric efficiencies for plant concepts developed in DYNAMIS (when producing only electric power) compared to state-of-the-art power plants without CO_2 capture (IGCC without capture optimised for efficiency) and PF plant concepts with CO_2 capture[3].

1.2.3.1 Coal and lignite fired plant

An IGGC with pre-combustion capture is a rather complicated process, involving several sequential stages. Like most other CO_2 capture technologies, its on-site energy consumption is significant; compared to an IGCC without CO_2 capture, mainly as steam for the conversion of carbon monoxide and water vapour to hydrogen and CO_2, and electric power for the CO_2 compression. Much design focus is therefore related to efficiency improvements, including heat and steam integration, and possibly also other measures like GT air extraction to ASU to reduce/avoid separate air compression. The levels of integration are carefully balanced against increasing complexity, so that good/acceptable operability, reliability and maintainability are maintained.

[3] CO_2 capture and compression require additional energy, resulting in increased fuel consumption. Therefore, quantities of captured CO_2 will be higher than the achieved reductions in CO_2 emissions.

Operating experience of several existing IGCCs indicates that some air integration between the GT and the ASU can be beneficial if the GT has a suitable off-take, but experience suggests this should be limited to around 30%. Heat (steam) integration can also create considerable improvements in overall efficiency but this should be limited to the main heat flows as these potential gains in efficiency will not be worthwhile once the additional capital cost and plant complexity are taken into account.

The initial generic concepts developed were based on E-class gas turbines. Their resulting net efficiencies (in electricity-only mode) were 32 - 33% for hard coal[4] and 35 - 38% for lignite[5] (calculated based on fuel LHV, Lower Heating Value).

As mentioned above, the DYNAMIS consortium concluded that the use of F-class gas turbines does not entail excessive risk to the overall reliability, availability and maintainability of the HYPOGEN plant, and that the performance penalty associated with using E-class gas turbine technology would be a barrier to successful deployment of pre-combustion capture.

The three case studies for hard coal fired power plants with CCS consequently were based on F-class gas turbines. They achieved 33 –36 % net electric efficiencies in condensing mode (with no hydrogen production), depending mainly on the detailed choices of types of gasifiers and gas turbines.

1.2.3.2 Natural gas fired plant

As mentioned above, a state-of-the-art NGCC with post-combustion CO_2 capture in parallel to a state-of-the-art natural gas fired steam reforming plant which in turn produces hydrogen was chosen as optimal design among the generic concepts studied in DYNAMIS. Such a concept, using a state-of-the-art F-class GT, producing 366 MWel (net) and 50 MW (HHV) hydrogen, can achieve almost 50% total efficiency (calculated based on fuel LHV). Additional energy consumption compared to state-of-the-art NGCC and steam reforming plants without CO_2 capture, are steam for desorption of captured CO_2 by re-boiling the amine absorbent, and electric power for the CO_2 compression. This concept showed the highest efficiency, at the same time as it required less integration than the IRCC concepts with pre-combustion CO_2 capture.

The DYNAMIS natural gas-based case study is based on a CHP plant. Much design focus was put on the optimisation of the post-combustion CO_2 capture and its integration into the plant.

1.2.4 Heat integration (internal) and DH / industrial heat load

For both coal / lignite and gas-fired plants, a large district and/or process heat demand can offer an additional income from low temperature heat sources. Delivery of district heat introduces certain plant design implications and offers numerous additional heat integration opportunities. District heating has additional benefits in that it utilises low grade heat; such heat is in excess in the IGCC plants studied here and, in most cases, cannot be economically used within the plant.

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[4]**Hard coal:** 8% moisture. Efficiency based on LHV (Lower Heating Value)~1%-points higher than efficiency based on HHV (Higher Heating Value)
[5]**Lignite:** 55.5 % moisture. Efficiency based on LHV ~6%-points higher than efficiency based on HHV. Pre-drying of lignite used to increase efficiencies. ***Efficiencies based on HHV are lower than efficiencies for hard coal on the same basis.***

Such opportunities have been used for the Hamburg coal based case study D (district heat supply to the city of Hamburg) and the natural gas based Mongstad case study C (steam generation and preheating of crude oil for the refinery)

The Hamburg case produces various amounts of district heat, maximum 400 MW, yearly average 270 MW. This lowers the net electric efficiency to a yearly average of 33%, with 56% total efficiency (electricity + heat).

The Mongstad case study C is based on a CHP plant using two E-class GT:s and one steam bottoming cycle, thus producing 190 MW_e net and 350 MW heat. The demand for process heat is high and the process is in this case optimised for this purpose rather than electric efficiency. The process achieves only 25% net electric efficiency (with no hydrogen production) but 70% total efficiency (including both electricity and heat).

1.2.5 Capturing Carbon dioxide

General process description

The carbon dioxide produced from the fossil fuels (coal or gas in this case) can be captured using a physical absorption process which makes use of specially designed absorption chemicals. In simple terms, the mixture of gases containing the CO_2 is passed up an absorption column down which the chemical absorber is passed. The column is filled with packers to maximise the surface area. The CO_2 (and H_2S) is absorbed into the physical solvent at a rate which is dependent upon the partial pressure of that gas. If the state of the physical solvent is then changed, such as by reducing the pressure or increasing the temperature, then the absorbed gases can be released again and the solvent recycled.

For pre-combustion capture, as in the coal-fired Case Studies, solvents such as Rectisol or Selexol are used. Because the CO_2 is produced at high pressure and concentration, the process is relatively easy and reducing the pressure in stages recovers the CO_2 (for conditioning, re-pressurisation and storage) and the H_2S (for recovery of the sulphur in a Claus unit).

In the case of post-combustion capture, such as in the natural gas-fired Case Study C, the CO_2 is much more dilute and at low (atmospheric) pressure. Because of the low pressure the ducts and vessels are very large. Amines are generally used as the physical solvent and have to be chilled / heated to release the CO_2 which requires a considerable energy load.

The specification for the Case Studies is to capture 90% of the CO_2 produced. This represents a realistic level of capture while avoiding very costly equipment and energy penalties to achieve a higher percentage.

1.2.6 Storage possibilities for CO_2

Onshore experience in Europe of CO_2 storage is limited, with the Ketzin project in Germany and small scale EOR/EGR by MOL in Hungary as the only examples. There is a very good record of offshore experience from the Sleipner project, and lately also from the Snøhvit CO_2 storage project, both offshore Norway. The DYNAMIS case studies are all quite different to these and other ongoing projects, pointing at additional R&D and validation challenges to be met in the future.

In DYNAMIS, there has been a screening of both sites suitable for CO_2 capture power plants, and candidate storage sites. The methodologies for doing this have been developed in separate work packages. There is a need to further develop integrated methods involving the different disciplines for screening of full value chain projects that fulfil certain basic requirements.

Almost all deep saline formations confined by appropriate permeability barriers could be used for CO_2 storage. Storage capacity capable of widespread application in Europe was the primary goal of the former European project GESTCO (2001-2003). This project confirmed the presence of significant CO_2 storage capacity in structural traps in porous and permeable reservoir rocks in onshore and near-shore sedimentary basins across the EU and the follow-up project GEOCAPACITY (2006-2009) has focussed on countries in eastern, central and southern Europe not previously covered in detail.

Onshore storage projects can suffer from limited existing data available and/or accessible to the screening of storage sites in a certain region. In these cases, project developments need to balance the possibility of discovering previously unknown storage sites close to otherwise advantageous power plants sites, against known investment costs for pipeline transportation to regions where the knowledge about storage sites is relatively well advanced. This trade-off is quite well illustrated in all of the DYNAMIS case studies.

- The Hamburg case study D: The knowledge about regional storage opportunities is low, with better known areas at relatively long transportation distance. The DYNAMIS project has shown that regional storage sites do exist, with the drawback of lack of data. In the trade-off between transportation distance and regional opportunities, there are indications that investments in regional opportunities are well worth considering.
- The East England and North East UK case studies A and B: The regional geological setting is such that a distant search for candidate storage sites is necessary. The case studies have shown that publicly open data in the UK is sufficient to assess promising offshore storage sites. The trade off between regional and distant opportunities clearly points at continued aquifer investigations offshore in Southern North Sea, while enhanced oil recovery (EOR) can support long distance pipelines to the Central North Sea and beyond.
- The Mongstad case study C: The distance to storage sites from the power plant site has been a central part of the project. The solution with a regional aquifer that had no previous assessment for CO_2 storage was chosen as a preferable solution.

Significant effort has been devoted into CO_2 injection strategies modelling. The targeted 3 million tonnes (Mton) annual injection rate is a significant step-up from the existing experiences on CO_2 injection at the Sleipner, Snøhvit and In Salah (Algeria) projects which all handle about 1 Mton per year. Increased injection rates require increased attention to reservoir pressure management. Results from the DYNAMIS case study reservoir simulations have shown that injection strategy modelling can mitigate the problem of large pressure build-up in the reservoir. However, there is a need for further work in this area, taking into account synergetic effects from simultaneous injection into neighbouring storage sites, and the regional impact as a consequence of how to set relevant boundary conditions to the reservoir models. Further work will also be required to develop the appropriate CO_2 monitoring techniques.

For transport and storage purposes, it is required to keep the CO_2 in a dense phase and preferably at a lowest practical temperature. As previously described, recommendations for the composition of the CO_2 stream have been provided by DYNAMIS from the perspectives of transport of the CO_2 in order to ensure safety and durability of the transport system, thereby also ensuring efficient use of the transport capacity. Continued R&D is needed to cover the corresponding recommendations on CO_2 storage.

1.2.7 EIS (Environmental Impact Study) issues

In order to get a permit for CCS facilities and to gain acceptance for the technology, the operator must be able to show that the environmental benefits of CCS outweigh any negative impacts that may arise.

The chosen topics for DYNAMIS concentrated on those aspects of an Environmental Impact Assessment (EIA) that were peculiar to, and particularly relevant for, the CCS aspects of a project. These included, inter alia:

- visual, traffic and noise impacts of capturing plant
- environmental impact of capture solvents and emissions
- impact of sub-sea infrastructure and potential leaks of CO_2 on marine ecology
- onshore pipeline impacts

From the wide-ranging work, the general conclusion is that there are relatively few areas where the impact of the CCS chain technology gives rise to significant issues for the environment. The case studies indicate that there are no substantial environmental issues related to emissions to air during the operation of the power plant and that, in general, IGCC plants combined with pre-combustion CO_2 capture can result in substantial reductions of gaseous emissions (including CO_2) when compared to existing plants. There were also no significant changes to cooling water requirements that would cause any environmental impact due to CCS technology. Generally, there is no indication that the challenges associated with the construction of environmentally acceptable North Sea carbon dioxide pipelines are any different from those set by hydrocarbon pipelines in similar areas and the impact of the construction of a CO_2 pipeline on land is similar to that from a gas pipeline of similar size.

There are a few remaining issues where it is considered that further work would be useful in establishing confidence in safe environmental boundaries for CCS technology:

- For post-combustion capture of CO_2, more information will be required on the environmental properties of amines and their degradation products. Specific attention should be given to emission to air and properties of waste.

- Power plants are generally located in the vicinity of major cities, which means that the population density of the area is often relatively high. Transporting the CO_2 from the power plant and capture facilities to the storage site may then involve covering a distance of complex urban areas and other conflicting interests such as for example nature reserves and industrial activities. Risk mitigation and management will be one of the main challenges of CO_2 transport. To put it into perspective, it should be noted that natural gas is transported today through pipelines in many major cities.

- There will be a need to estimate potential leakage characteristics and environmental effects as part of the risk assessment process. At present, there is a lack of information about potential CO_2 emission rates and likely durations for a range of reservoir circumstances, in the unlikely event of leakage through a well or fracture. Most of the information on environmental impacts is given for certain species rather than whole ecosystems.

- For offshore storage, future environmental impact assessment would benefit from further research on marine ecosystems in the North Sea. Such research on possible impacts of CO_2 on the marine environment is ongoing.

1.2.8 Hydrogen prospects in the transport and industrial sectors

Significant transport-related hydrogen demand in Europe is not unlikely to develop in the initial part of the timeframe anticipated for the first HYPOGEN plants; at least 25 years starting around year 2015. Captive fleets – predominantly in larger cities – would then be the most probable types of early mover hydrogen demands in the transport sector, and the hydrogen capacity – 50MW (HHV) – of a HYPOGEN plant could in such a case be used to stimulate and supply a fleet of city buses.

Existing or forecast industrial hydrogen demands are also important to secure hydrogen sales from at least the first HYPOGEN plant(s). Such demands were identified for all the case study locations.

1.3 Significance of achievements

1.3.1 Context of 400MW and 3 million tonnes (Mt) CO_2 per year reduction in emissions

The recently published "EU Demonstration Programme for CO_2 Capture and Storage (CCS). ZEP's Proposal" [6], outlines a possible implementation of CCS within Europe. This study concludes that, if an EU Demonstration Programme takes place, depending on the aggressiveness of the roll-out, 80-120 large-scale CCS projects could be operational in Europe already by 2030 – representing a reduction in CO_2 emissions of ~400 million tonnes per year (EU's current CO_2 emissions are around 3.8 billion tonnes per year), with the potential to reduce annual global CO_2 emissions by 9-16 billion tonnes by 2050. This would mean potential for a significant number of HYPOGEN plants – each 400 MW block contributing with 3 million tonnes CO_2 emission reductions per year – as well as power plants with other capture technologies in the future.

1.3.2 Economics of complete plants with CCS

Outline financial models of each of the case studies were created covering the whole CCS chain from power plant to end storage. These models have been used to assess the commercial viability of the projects as described above and, in particular, the level of ETS carbon price which it would be necessary to achieve in order to support the projects under certain scenarios. Two main energy scenarios were used, derived from the EC PRIMES[7] work, the Low one based on a fairly flat oil price starting around \$55/bbl and the High one with oil escalating from \$75/bbl. Other energy prices were in line with the main assumptions and district and process heat prices were derived from the average prevailing gas price.

Inflation and escalation of fuel prices were set to 2%, except for the short-term capital cost escalation (to escalate 2008 prices to project financial close) which was set slightly higher at 2.5%. Debt, where applicable, was taken to be available at a rate of 8% and the term of the projects and the debt were taken as 20 years. It was decided to set a minimum hurdle rate for the IRR of the complete case study projects at 13% nominal to reflect a reasonably commercial level at which a project could be supported.

Because of the diversity of the projects, including in particular the infrastructure and storage costs, and because of the use of two different background scenarios, a range of results has been derived. The Hamburg and Mongstad case studies also benefit from additional incomes from district heat to the city of Hamburg and from steam generation and preheating of crude oil for the refinery, respectively. It is believed that this derived range is reasonably representative of the uncertainty in the requirements for projects of this kind which have been designed by commercial sponsors to be cost-effective and as efficient as possible.

Assumptions have necessarily been made in order to derive reasonable figures and the most important of these are that:

- the plant will run baseload, given a reasonable availability profile
- the income streams and cost levels (in particular the carbon price) are achieved at the level described through fixed price contractual arrangements rather than having a high market uncertainty

[6] EU Demonstration Programme for CO2 Capture and Storage (CCS). ZEP's Proposal", November 2008
[7] EC Second Strategic Energy Review, An EU Energy Security And Solidarity Action Plan {COM(2008) 744}

Possible support for CCS has been factored into the models in what appears at the present time to be the most likely form. This has been taken as a free additional carbon allowance for each tonne of CO_2 stored in the period of European Union Emission Trading System (EU-ETS) Phase III (2015 – 2020). It has also been assumed the plant are each operational in time to realise this support.

Given this set of assumptions, the range of ETS carbon price needed to make the case studies financially viable is as follows, in each case excluding the case B against the High scenario, where it is supported by high oil revenues:

- Without any support: 42 – 80 €/t
- With 6 yrs support: 28 – 53 €/t

At these levels it would appear that debt finance with a Debt Service Cover Ratio of around 1.5 might just be achievable, but the percentage level of debt may have to be reduced to achieve a satisfactory margin.

It should be stressed that these results are intended to be indicative for the purposes of these evaluations and cannot be taken as firm limits on the required carbon price, nor as considered price requirements by the industrial sponsors of the individual case studies. Also in comparing levels with values produced from different sources it is vital to ensure that such comparisons are made on an equivalent basis and with compatible assumptions.

1.4 Consortium management

Figure 2 shows the management organisation of DYNAMIS. The General Assembly (GA) met four times, approximately 30 days after a reporting period has expired. The Executive Board (EB) met seven times, normally the day before the annual GA meeting and 20 – 30 days after the intermediate 6 month's period. A Project Management Team (PMT) consisting of the four Sub-project leaders, Co-ordinator and Project Management was established. This team met physically bi-annually in conjunction with the EB- (and (annually GA-) meetings. And approximately every month a teleconference was arranged to report progress and discuss possible challenges and remedial actions proposed.

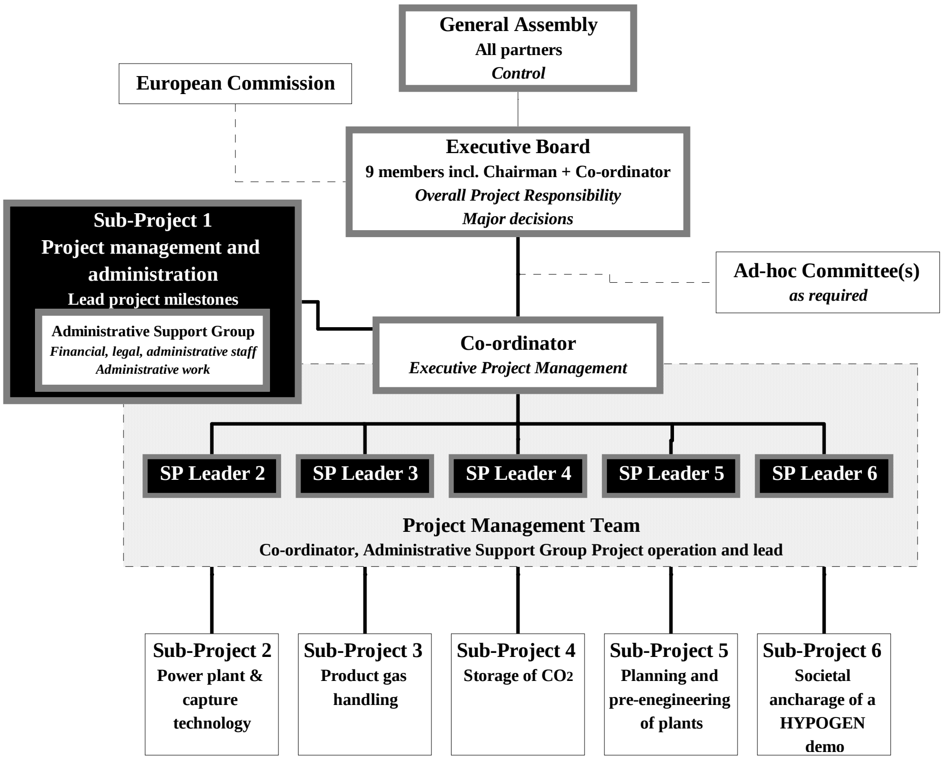

Figure 2: Description of the bodies in the project organisation and the decision-making.

A project hotel, eRoom, was established and presented to the consortium at the kick-off meeting in Oslo 7-8 March 2006. The eRoom kept track of all relevant information as contract documents, meetings, plans and progress reporting, deliverables and publications, status reports and periodic reporting to the Commission.

More detailed information on the management of the consortium can be found in these three deliverables:

D1.1.1 Project Master Plan (dated 2006-10-12)
D1.1.3 DYNAMIS Financial Infrastructure (dated 2007-04-13)
D1.1.4 Project Metrics (dated 2007-04-12)

1.4.1 Contractual issues

The Contract was signed by Co-ordinator SINTEF Energiforskning AS on behalf of the Consortium on 20 March 2006 and by the European Commission on 10 April. The start date agreed by the Contractors was 1 March 2006. The last Form A – accession to the Contract – was signed on 10 July.

After the kick-off event in Oslo 7 – 8 March 2006 the two partners Norsk Hydro ASA and Vattenfall AB were included in Annex I as Third parties, after discussion with the Commission's scientific and legal officer. Representatives from Shell Hydrogen B.V. contacted personnel from Co-ordinator at various events during the summer and autumn 2006 with the wish to explore the possibilities to be involved in the project. By the end of the first reporting period it had been agreed that Shell could be a partner through the Consortium Agreement. All existing Consortium partners have to accept any new partner. On 24 April 2007 the last remaining Contractor informed Co-ordinator that Shell is accepted as Consortium partner. Hence Shell Hydrogen B.V. was included in Amendment no. 1, Annex I, Appendix A3 Third parties together with the existing two Third parties. As from 1 October 2007 the business unit within Norsk Hydro ASA that was a partner to the Consortium Agreement merged with Statoil, and Statoil changed name to StatoilHydro. Hence Hydro ceased to be a third party from that day.

1.4.2 Project Progress Monitoring

Work Package status reports/Planning and Progress Reporting (PPR) tool

The DYNAMIS Consortium agreed that the progress status of the project had to be formally reported every third month through the Work Package (WP) leaders to the Sub-Project (SP) leaders. However, all Contractors were also instructed to immediately report to relevant WP leader should something that might impact the progress occur. The Project Management Team (PMT) agreed to use the same format for this internal reporting as for the annual external reporting to be submitted to the European Commission (EC). A template WP status report was developed during the first six months of the project with some adjustments based on experience and feed-back mainly from WP leaders and SP leaders. It was emphasised that the status reports should focus on deviations and any remedial actions required.

A self-made Excel workbook Planning and Progress Reporting tool (PPR-tool) was established a few months after the start of DYNAMIS. All Contractors were instructed to fill in resources deployed (person-months) and costs incurred (Euro) at least every third month. The PPR-tool contains various graphs for different levels of DYNAMIS making it easy to monitor progress compared with budget. Some of these graphs were used in periodic activity and management reports.

Deliverables list
Another way of monitoring the progress was through the updating of the deliverables list in every PMT teleconference which took place quite regularly about every month.

A total of 85 reports have been produced as deliverables in the within DYNAMIS project, see list on next page.

SIXTH FRAMEWORK PROGRAMME

Table 2: Deliverables list – month 1-36.

Del. no.	Deliverable name	Date due		Actual/ Forecast delivery date	Lead contractor	Nature	Dissemination level
D1.1.1	Project Master Plan	3	May-06	2006-10-12	SINTEF-ER	R	RE
D1.1.2b	Midterm report	18	Aug-07	2008-04-27	SINTEF-ER	R	RE
D1.1.2c	Final summary report	39	May-09	2009-07-23	SINTEF-ER	R	PU
D1.1.3	DYNAMIS financial infrastructure	3	May-06	2007-04-13	SINTEF-ER	R	RE
D1.1.4	Project metrics	3	May-06	2007-04-12	SINTEF-ER	R	RE
D1.1.5	Distribution of Community financial contribution	?	?	Apr-10	SINTEF-ER	R	RE
D1.1.6	Abstracts for sll Deliverables produced in DYNAMIS			2009-09-22	SINTEF-ER	R	RE
D1.1.A-1	Periodic Activity Report no. 1 (rev. 1)	12,	Feb-07	2007-07-13	SINTEF-ER	R	RE
D1.1.A-2	Periodic activity report no. 2	26	Apr-08	2008-05-08	SINTEF-ER	R	RE
D1.1.A-2 rev1	Periodic activity report No 2, Rev. 1			2008-11-28	SINTEF-ER	R	RE
D1.1.A-3	Periodic activity report no. 3	38	Apr-09	2009-07-22	SINTEF-ER	R	RE
D1.1.A-F	Final activity report	38	Apr-09	2009-07-23	SINTEF-ER	R	PU
D1.1.D-F	Final Plan for Using and Disseminating the Knowledge			2009-09-22	SINTEF-ER	R	PU
D1.1.M-1	Periodic Management Report no. 1	12	Feb-07	2007-04-25	SINTEF-ER	R	RE
D1.1.M-2	Periodic management report no. 2	26	Apr-08	2008-05-08	SINTEF-ER	R	RE
D1.1.M-3	Periodic management report no. 3	38	Apr-09	2009-07-22	SINTEF-ER	R	RE
D1.1.M-F	Final management report	38	Apr-09	2009-07-23	SINTEF-ER	R	RE
D1.2.1	Project Policy Document Revision 1	4	Jun-06	2007-02-28	SINTEF-ER	R	PU
D1.2.2	Project Policy Document, rev. 2	16	Jun-07	2008-02-12	SINTEF-ER	R	PU
D2.1.1	Options and evaluation of reforming processes	8	Oct-06	2007-01-04	SINTEF-ER	R	RE
D2.1.2	Post-combustion CO2 capture options in a NG fuelled Hypogen	8	Oct-06	2007-02-28	TNO	R	RE
D2.1.3	CO2 capture, compression, drying and purification	10	Dec-06	2007-02-28	SINTEF-ER	R	RE
D2.1.4	Integration of Natural Gas based hydrogen and electricity production systems	15	May-07	2008-02-22	NTNU	R	RE
D2.1.5	Conceptual designs of Natural Gas based hydrogen and electricity production systems	17	Jul-07	2007-08-20	NTNU	R	RE
D2.2.1	Best option gasification technologies for coal and lignite based HYPOGEN plants	5	Jul-06	2006-07-31	JRC	R	RE
D2.2.2	Configuration of Fixed and Flexible H2/Electricity Ratio Dynamis Plant	11	Jan-07	2007-02-27	JRC	R	RE
D2.2.3	Potential Improvements to methods of treating syngas, CO2 capture and hydrogen purification, and evaluation of the efficiency and economic benefits. Part 1, Review of AGR Processes	12	Feb-07	2007-02-28	JRC	R	RE
D2.2.4	Report on near term technological initiatives for improvements to HYPOGEN plants	15	May-07	2007-10-16	JRC	R	RE
D2.2.5	Second report in issues linked to gasifier flexibility	15	May-07	2007-05-31	JRC	R	CO
D2.2.6	Conceptual designs of coal-based HYPOGEN plants	17	Jul-07	2007-07-02	JRC	R	RE
D2.3.1	Preliminary results of technology assessment	14	Apr-07	2007-04-18	TNO	R	RE
D2.3.2	Report on technology assessment of researched technologies	14	Apr-07	2007-08-13	SINTEF-ER	R	RE
D2.4.1	Common framework of evaluation methods and criteria	4	Jun-06	2006-07-05	APC-FR	R	RE
D2.4.1_1	Common framework of evaluation methods and criteria, Rev. 1	14	Apr-07	2007-04-27	APC-FR	R	RE
D2.4.2	Preliminary report on concept evaluation	14	Apr-07	2007-06-22	APC-FR	R	RE
D2.4.3	Final report on concept evaluation	18	Aug-07	2007-12-20	APC-FR	R	RE
D3.1.1/D3.1.2	Assessment of technical experience and engineering practice for CO_2 pipelines	26	Apr-08	2009-05-11	ECOFYS	R	CO
D3.1.3	DYNAMIS CO2 Quality recommendations	13	Mar-07	2007-06-21	ECOFYS	R	PU
D3.2.1 rev 1	H2 conditioning and recommendations for further technology development - rev. 1	16	Jun-07	2007-06-29	SINTEF-ER	R	RE
D3.2.2	DYNAMIS H2 quality recommendations	13	Mar-07	2007-04-20	SINTEF-ER	R	PU
D4.1.1	Shortlist of potential CO2 storage sites	8	Oct-06	2007-04-03	GEUS	R	PU
D4.2.1	Geological definition and model of the conceptual CO_2 storage sites	18	Aug-07	2008-04-14	IFP	R	RE
D4.2.3	Performance assessment of the specific CO_2 storage sites	30	Aug-08	2008-09-15	IFP	R	RE
D5.1.1	Guidelines for Plants and Sites	6	Aug-06	2006-08-31	STATOIL	R	RE
D5.1.2	Preliminary Results from SP2, 3, 4 & 6	18	Aug-07	2007-09-04	STATOIL	R	RE
D5.1.3	Suggesting for a pre-selected set of sites and technologies for further evaluation	18	Aug-07	2007-09-04	STATOIL	R	RE
D5.2.1	Environmental Impact Studies of CCS Plant: Summary Report of Case Studies	30	Aug-08	2008-10-30	PEL	R	RE
D5.2.1-1	Effects of Infrastructure and CO_2 leakage on the Marine Environment			2008-08-29	PEL		CO
D5.2.1-A	Environmental Impact Statement for the Killingholme Case Study			2008-08-29	EON		RE
D5.2.1-B	Environmental Impact Study for PEL Case Study B			2008-08-29	PEL		CO
D5.2.1-C	Environmental Impact Assessment of the Mongstad Case Study			2008-09-01	StatoilHydro		CO
D5.2.1-D	Environmental Impacts - Hamburg Case Study			2008-11-07	VRD		CO
D5.2.1-D1	Special Report: Assessment of Changes in Resource Consumption and Material Flows			2008-11-07	VRD		CO
D5.2.1-D2	Special Report: Risk management of transporting CO_2 in an onshore pipeline in the Hamburg region			2009-01-15	VRD		CO
D5.2.1-D3	Special Report: Impacts on terrestrial ecosystems relating to a potential leakage of CO_2			2008-11-07	VRD		CO
D5.2.2	Summary of Case Study Engineering Designs	30	Aug-08	2008-10-30	PEL	R	RE
D5.2.2-A	Engineering Design Study for Case Study A			2008-09-04	EON		RE
D5.2.2-B	Engineering Design Study for Case Study B			2008-08-31	PEL		RE
D5.2.2-C	Engineering Design Study for Case Study C			2008-09-09	StatoilHydro		CO
D5.2.2-D	Vattenfall Hamburg Case Pre-Engineering Design Study			2008-11-07	VRD		RE
D5.3.1	Recommendations for the HYPOGEN initiative. Detailed Report	35	Jan-09	2009-04-26	VRD	R	RE
D5.3.2	Recommendations for the HYPOGEN initiative. Public Report	36	Feb-09	2009-04-26	VRD	R	PU
D6.1.1	Modelling Framework and Reference Data Report	9	Nov-06	2006-12-06	FH-ISI	R	PU
D6.1.2	General Assessment and Considerations in Competitiveness of HYPOGEN Technology	13	Mar-07	2007-06-30	IEA-EPL	R	RE
D6.1.3	Emissions trade market assessment study for a HYPOGEN plant	12	Feb-07	2007-03-15	FH-ISI	R	PU
D6.1.3 rev. 1	Emissions trade market assessment study for a HYPOGEN plant, rev1	26	Apr-08	2008-10-24	FH-ISI	R	PU
D6.1.4	Electricity market model overview study	18	Aug-07	2007-12-18	FH-ISI	R	RE
D6.1.5	Detailed market modelling of HYPOGEN cases	27	May-08	2009-01-08	FH-ISI	R	RE
D6.2.1	Identification of Base Conditions for Debt Finance	9	Nov-06	2006-11-30	PEL	R	PU
D6.2.2	Financing perspective on technology options studied in SP2	18	Aug-07	2007-08-30	PEL	R	RE
D6.2.3	Potential role of EIB and Public / Private Partnerships	12	Feb-07	2007-03-20	PEL	R	PU
D6.2.4	Hypogen investment risk profile assessment	18	Aug-07	2007-08-31	PEL	R	PU
D6.2.5	Proposed financing for each Case Study	30	Aug-08	2009-02-06	PEL	R	RE
D6.2.6	Detailed specific Case Models and Financial Recommendations	36	Feb-09	2009-01-30	PEL	R	RE
D6.3.1	Policy, legal and regulatory issues for CCS projects	18	Aug-07	2007-10-30	ECOFYS	R	PU
D6.3.1 rev. 1	Policy, legal and regulatory issues for CCS projects			2009-01-08	ECOFYS	R	PU
D6.3.2	Evaluation of key issues on relevant emission trade regulation frameworks in relation with CCS	26	Apr-08	2008-01-20	ECOFYS	R	PU
D6.3.3	Policy, legal and regulatory situation for realising an HYPOGEN plant in the United Kingdom, Norway and Germany	27	May-08	2008-10-30	ECOFYS	R	RE
D6.3.4	Status of Monitoring and reporting guidelines for Carbon Capture and Storage projects at UNFCCC and European Level	27	May-08	2008-10-15	ECOFYS	R	RE
D6.4.1	EU-wide mapping report of existing findings on public perception and acceptance of CCS	9	Nov-06	2007-01-12	FH-ISI	R	PU
D6.4.1 rev. 1	EU-wide mapping report of existing findings on public perception and acceptance of CCS			2008-11-26	FH-ISI	R	PU
D6.4.2	Report on the professionals' acceptance of CCS	18	Aug-07	2007-09-03	FH-ISI	R	PU
D6.4.2 rev. 1	Report on professionals' acceptance of CCS			2008-01-15	FH-ISI	R	PU
D6.4.3	Report on the assessment of CCS acceptance on a regional level	27	May-08	2008-11-03	FH-ISI	R	RE
D6.4.4	Guideline report for outreach strategies for CCS-activities	27	May-08	2008-11-10	FH-ISI	R	RE

1.4.3 Timetable and status

Figure 3 shows the DYNAMIS timetable. The bars show the planned duration of the various Work Packages as stated in Annex I. The dotted bars show that the WP leaders realised that the duration for some of the activities had to be extended. These proposed extensions were included in the new implementation plan for next period.

The progress status of the various WPs was estimated by WP leaders in co-operation with the Contractors involved in respective WPs. The status for WPs is shown as blue coloured bars while the overall status on SP level is shown by the violet bars.

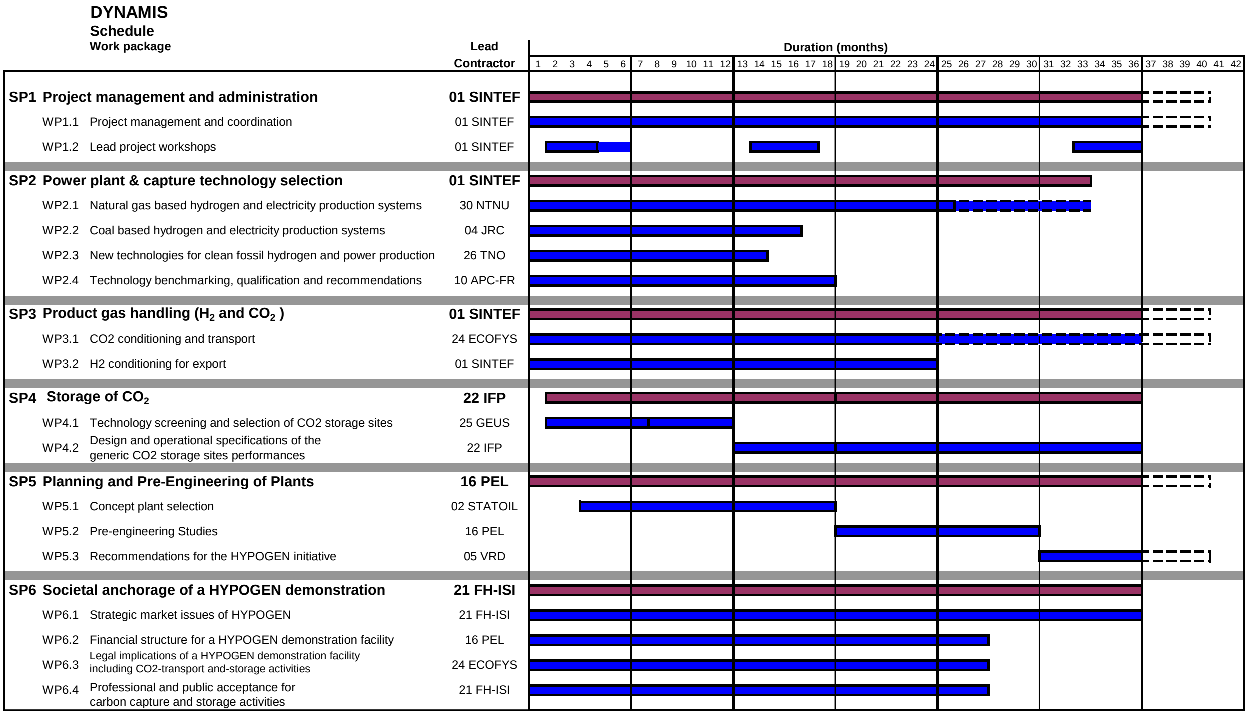

Figure 3: DYNAMIS Progress schedule.

The reasons for delays or forced work were explained in the WP status reports.

1.4.4 Coordination activities

Once again we would like to refer to the deliverable D1.1.1 Project master plan where the most important issues related to co-ordination activities are described. Some of these actions and issues are briefly described below.

DYNAMIS eRoom

The establishment of the DYNAMIS eRoom at the very start of the project proved to be a success to the efficient management of the project. The eRoom keeps track of all relevant information and is used as a live communication tool. It is used constantly during the PMT teleconferences; the eRoom provides the flexibility that all participants can view the same documents spontaneously and simultaneously during the meeting.

Meetings
The various meetings at the management level in DYNAMIS project has been presented in section the WP status report in section 3. At the SP and WP level there are also co-ordination meetings and agendas, list of participants and minutes of meetings from these meetings can also be found in the eRoom.

Deliverables list
The Excel version of the Deliverables list is being updated during every PMT teleconference, thus sharing at the SP leaders' level latest information on progress throughout the project.

Project member list
An Excel-sheet easily available to all project members is kept constantly updated. By the end of DYNAMIS the list contained approximately 150 persons.

Planning and Progress Reporting tool (PPR-tool)
A self-made Excel-based planning and reporting tool was prepared the first months of the project. It was implemented and introduced to the project participants in month 3 (May 06). Tools used in other EU projects were evaluated, to see if one of these could be used in DYNAMIS. In order to reduce the administrative and bureaucratic burden on the technical people involved in the project as much as possible, the decision to prepare the PPR-tool was taken. The PPR-tool can be used for monthly planning and reporting, however, the Contractors were obliged to report only every three month. In practice many Contractors reported their efforts in person-months and total costs in Euro every month.

WP status reports
As already explained a template for WP status report was established. Every three month the completed WP status reports were discussed at the PMT, and every six month at the EB meetings. They are as all other documents online available to all Contractors in the eRoom.

Periodic reporting
How to collect information from all Contractors for the periodic reporting to the Commission in an as efficient way as possible was being considered from the first months of the project. As mentioned before the content of the WP status report was developed over a period of time to combine the needs for more often internal reporting with the requirements of the annual reporting to the Commission.

Even though most of the Contractors have extensive experience as participants in EU projects some Contractors (and some of the individuals employed at those experienced Contractors) participating in DYNAMIS have less experience with EU project reporting. Therefore a one page instruction about financial reporting was distributed in month 6 (Aug 06). The need for proper documentation of costs and time-sheets together with correct calculation of hourly rates were emphasised.

The periodic reporting and planning of the new implementation plan started month 7 (Sep 06) at the PMT teleconferences. And a system for online submission of input to the various periodic reports from all Contractors were established by Co-ordinator and sent to all Contractors about one month before the end of first reporting period.

During the hectic reporting period in month 12 – 14 (Feb – Apr 06) the project management at SINTEF Energiforskning AS has been available for queries from all Contractors . Especially the less experienced Contractors needed quite extensive assistance during this period.

Unfortunately the reporting of the first reporting period was delayed more than one week. The main reason for this delay was the initial disagreement between different Contractors on how the EU rules on reporting of Receipts should be interpreted regarding contribution from the Third parties Norsk Hydro ASA and Vattenfall AB. Also the fact that the Easter period this year coincided with the most hectic period for the collection of input from Contractors led to slower reaction from some Contractors during a period of more than one week.

2 DISSIMINATION AND USE

2.1 Dissemination of knowledge

The plan for dissemination of knowledge generated by and within DYNAMIS was directed towards different target groups and stakeholders, at various classification levels. Knowledge aggregated in deliverables may be protected or open for distribution in accordance with the classification codes given in Description of Work, Annex 1 to the Contract between Co-ordinator and the Commission.

Four classification levels apply to the deliverables according to the stated meaning:

- PU: Public
- PP: Restricted – although it may be made available to other programme participants
- RE: Restricted – although it may be made available to a group specified by the consortium
- CO: Confidential, to be available only for members of the consortium

In no case will these classification levels exclude the Commission services. Programme participants refer to third parties that are formal Contractors of other projects organised under EU/FP6.

2.1.1 Lead Project Workshops, Seminars and Conferences

A separate work package WP1.2 was defined to harmonise the knowledge and content of the project with all the stakeholders and to provide a Project Policy Document (PPD). The PPD is not classified (i.e. public). The PPD defined the firm framework of the work to be conducted in terms of technology, plant locations and storage site selection.

During the 36 months' duration of DYNAMIS several lead project workshops were planned and conducted:

a) Kick-off (Oslo, March 2006)
b) Large CCS Projects Meeting (Brussels, September 2006)
c) Synergy between HYPOGEN and the Hydrogen Economy (Brussels, January 2007)
d) Midterm review (Madrid, September 2007)
e) Joint EU_CCS projects' workshop (Lyon, January 2008)
f) Internal dissemination seminar (Hamburg, April 2008)
g) European Conference on CCS Research, Development and Demonstration (Oslo February 2009)

b) and c) were organised in close collaboration with the Commission and JRC
a), d) and f) were internal workshops/seminars
e) and g) were common workshop/conference for selected EU co-funded CCS related projects (public).

2.1.2 Web-site

A web-site was established when DYNAMIS started, and it will be maintained for some time after the end of the project. The website contains all available public materials. The web-site address is: http://www.dynamis-hypogen.com/

Furthermore, an internal project hotel was established and used for internal working platform for the DYNAMIS project, as it kept track of all relevant information and live documents, thus offering a joint office library among all Contractors and the several contributors.

2.1.3 Project metrics

A leaflet was made and distributed explaining the project in a wider context including main information on DYNAMIS.

2.1.4 Presentations and scientific papers

Numerous presentations pertaining to DYNAMIS have been given in and outside Europe (also in China). The project has also been presented in the press.

Scientific papers have been presented in international conferences and journals, and some have been prepared for journals or presentation in upcoming conferences during 2009-2010. The relevant papers and articles are uploaded to the eRoom, and some will be published at the web-site.

1. Hetland, J.: *'New Schemes for Hydrogen Production via Decarbonisation of Fossil Fuels featuring Carbon Capture and Storage of the CO_2'*. Key-note lecture to be presented at the 16th World Hydrogen Energy Conference, Lyon, France, 13-16 June 2006
2. Røkke, P.E.; Røkke, N.A.; Hetland, J.; Radgen, P.; Cremer, C.; Torp, T.A.: *'DYNAMIS - a step towards the first HYPOGEN plant, producing hydrogen and electricity with near zero emissions'*. Paper to be presented at the 8th International Conference on Greenhouse Gas Control Technologies, Trondheim, Norway, 19-22 June, 2006
3. Cormos, C-C.; Starr, F.; Tzimas, E.; Peteves, S.: *"Gasifier concepts for hydrogen and electricity co-production with CO_2 capture"*, to be presented at the 3rd International Conference on Clean Coal Technologies for our Future, 15 – 17 May 2007, Cagliari, Sardinia, Italy
4. Hetland, J.; Li Z.; Pollard, D.; Xu S.: *"How polygeneration schemes may develop under an advanced clean fossil fuel strategy under a joint Sino-European initiative"*, to be presented at the 3rd IGEC, Vesteraas, Sweden, June 15-18, 2007.
5. Hetland, J.: *"Assessment of pre-combustion decarbonisation schemes for polygeneration from fossil fuels"*, to be presented at AIDIC-PRES'07, Ischia, Italy, June 25-27, 2007.
6. Røkke, P. et.al.: *"CO_2 capture from power plants: Technology maturity and developments towards realization"* presented at the Trondheim CO_2 Conference 2007, 16 – 17 October 2007
7. De Visser, E.: *"DYNAMIS CO_2 quality recommendations"* presented at the Trondheim CO_2 Conference 2007, 16 – 17 October 2007
8. Santos, S.; Kvamsdal, H.: *"Techno-Economic Assessment Based on Multi-Criteria Assessment of HYPOGEN Plant Options in DYNAMIS Project"* presented at the Trondheim CO_2 Conference 2007, 16 – 17 October 2007

9. Røkke, N.A.: *"The Hypogen Candidates - plant sites selected"* presented at the *CO_2*Net 2007 Annual Seminar, Lisbon, 6 – 7 November 2007
10. Radgen, P.: *"The Hypogen Candidates - plant sites selected"* presented at the *CO_2* 2007 Annual Seminar, Lisbon, 6 – 7 November 2007
11. Røkke, N.A.: *"Introduction to DYNAMIS"* presented at Joint EU-CCS workshop (CASTOR-ENCAP-CACHET-DYNAMIS), Lyon, 22 - 24 January 2008
12. Røkke, N.A.: *"Introduction and interaction with ZEP and HFP – towards ZEP"* presented at Joint EU-CCS workshop (CASTOR-ENCAP-CACHET-DYNAMIS), Lyon, 22 - 24 January 2008
13. Hanstock, D.: *"DYNAMIS SP5 - Planning and Pre-Engineering of Plants"* presented at Joint EU-CCS workshop (CASTOR-ENCAP-CACHET-DYNAMIS), Lyon, 22 - 24 January 2008
14. Le Gallo, Y.: *"DYNAMIS SP4 - Storage of CO_2"* presented at Joint EU-CCS workshop (CASTOR-ENCAP-CACHET-DYNAMIS), Lyon, 22 - 24 January 2008
15. Røkke, P.: *"DYNAMIS SP2 - Power plant & capture technologies"* presented at Joint EU-CCS workshop (CASTOR-ENCAP-CACHET-DYNAMIS), Lyon, 22 - 24 January 2008
16. Cremer, C.: *"DYNAMIS SP6 - Societal anchorage of a HYPOGEN demonstration"* presented at Joint EU-CCS workshop (CASTOR-ENCAP-CACHET-DYNAMIS), Lyon, 22 - 24 January 2008
17. De Visser, E.: *"DYNAMIS SP3 - Product gas handling - H_2 and CO_2 quality recommendations"* presented at Joint EU-CCS workshop (CASTOR-ENCAP-CACHET-DYNAMIS), Lyon, 22 - 24 January 2008
18. Bouvart, F.; Prieur, A.: *"Environmental assessment of combined power and hydrogen production pathways with CCS: selection of technologies with natural gas, coal and lignite as fuel for the European HYPOGEN programme"* IFP – OAPEC Joint Seminar, The Gas Industry: Current & Future, IFP, Rueil-Malmaison, France, 17 -19 June 2008
19. Hetland, J.: *Developing and Implementing CCS Capture Technologies.* Presented at the International Conference on Carbon Capture & Storage, Abu Dhabi, 28-29 October 2008 (invited speaker)
20. Visser, E. d.; Hendriks, C.; Barrio, M.;Mølnvik, M. J.; Koeijer, G. d.; Liljemark, S.; Gallo, Y. L.: *"DYNAMIS CO_2 quality recommendations"* International Journal of Greenhouse Gas Control 2 (2008) p478-484
21. Hetland, J.; Røkke, N.A.; Røkke, P.; LeGallo, Y.; Evans, D.J.; Eickhoff, C.: *"Towards large-scale co-production of electricity and hydrogen via decarbonisation of fossil fuels combineD with CCS (geological storage)".* GHGT-9 in Washington D.C., USA, 17-20 November 2008
22. Tzimas, E.; Cormos, C.-C.; Starr, F.; Garcia-Cortes, C.: *"Major issues in the design of carbon capture IGCC-based plants with hydrogen co-production"* GHGT-9 in Washington D.C., USA, 17-20 November 2008
23. Hill, T. A.; Booth, M.-J.; Dorren, C.; Stiff, S. M.; Hull, W.: *"Environmental Impact Study of a Power Plant with Carbon Capture and Storage near the UK Coast"* GHGT-9 in Washington D.C., USA, 17-20 November 2008
24. Frédérique Bouvarta, F.; Prieura, A.: *"Comparison of Life Cycle GHG Emissions and Energy Consumption of Combined Electricity and H_2 Production Pathways with CCS : Selection of Technologies with Natural Gas, Coal, Lignite as Fuel for the European HYPOGEN Programme"* GHGT-9 in Washington D.C., USA, 17-20 November 2008
25. Bergmo, P. E. S.; Lindeberg, E.; Riis, F.; Johansen, W. T.: *"Exploring geological storage sites for CO_2 from Norwegian gas power plants: Johansen formation"* GHGT-9 in Washington D.C., USA, 17-20 November 2008

26. Abu-Zahra, M. R. M.; Jansens, P. J.; Goetheer, E. L. V.: *"New process concepts for post-combustion CO_2 capture process integrated with co-production of hydrogen"* GHGT-9 in Washington D.C., USA, 17-20 November 2008
27. Vandeweijer, V.; Meer, B. v.d.; Kramers, L.; Neele, F.; Maurand, N.; Gallo, Y. L. Bossie-Codréanu, D.; Schäfer, F.; Evans, D.; Kirk, K.; Bernstone, C.; Stiff, S.; Hull, W.: *"CO_2 Storage in Saline Aquifers: In the Southern North Sea and Northern Germany"* GHGT-9 in Washington D.C., USA, 17-20 November 2008
28. Hetland, J.: *Key note lecture over 5 specific CCS topics with acknowledgement to DYNAMIS; Capture, CO_2 Physics, Economy of CCS, Storage, and Action of Ireland*; Carbon Capture & Storage, ESBI Hosted Conference in Dublin, Ireland, 29 January 2009
29. Røkke, N. A.: *"DYNAMIS – Towards Hydrogen and Electricity Production with Carbon Dioxide Capture and Storage"* presented at the European Conference on CCS Research, Development and Demonstration 10-11 February 2009 - Oslo, Norway
30. Eickhoff, C.: *"Recommendations for a HYPOGEN plant in Europe"* presented at the European Conference on CCS Research, Development and Demonstration 10-11 February 2009 - Oslo, Norway
31. Visser, E.: *"Costs for CO_2 pipelines"* presented at the European Conference on CCS Research, Development and Demonstration 10-11 February 2009 - Oslo, Norway
32. Vincke, O.: *"Recommendations for storage sites – methodology and results"* presented at the European Conference on CCS Research, Development and Demonstration 10-11 February 2009 - Oslo, Norway
33. Maurand, N.: *"Storage of CO_2 Offshore Denmark Brine Formation"* presented at the European Conference on CCS Research, Development and Demonstration 10-11 February 2009 - Oslo, Norway
34. Wildenborg, T.: *"Storage of CO_2 North Sea Brine Formation"* presented at the European Conference on CCS Research, Development and Demonstration 10-11 February 2009 - Oslo, Norway
35. Maurand, N.: *"Storage of CO_2 in a North Sea oil field"* presented at the European Conference on CCS Research, Development and Demonstration 10-11 February 2009 - Oslo, Norway
36. Akervoll, I.: *"A study of Johansen Formation located offshore Monstad as a candidate for permanent CO_2 storage"* presented at the European Conference on CCS Research, Development and Demonstration 10-11 February 2009 - Oslo, Norway
37. Hetland, J: *"Aktuelle prosesser for CO_2-fangst fra gass- og kullfyrte kullkraftverk - status og muligheter"* (in Norwegian), presentation to the Norwegian Association of Chartered Engineers (TEKNA), Oslo 18 February 2009
38. Besancon, B.M.; Hasanov, V.; Imbault-Lastapis, R.; Barrio, M.; Mølnvik, M. J.: Hydrogen quality from decarbonized fossil fuels to fuel cells International Journal of Hydrogen Energy 34 (5) 2009 p2350-2360
39. Hetland, J.; Anantharaman, R.: *"Carbon capture and storage (CCS) options for co-production of electricity and synthetic fuels from indigenous coal in an Indian context."* Journal of Energy for Sustainable Development 13 (2009) 56–63
40. Røkke, P. E.: *"DYNAMIS conclusions"* CSLF Technical Group meeting 2 April 2009
41. Hetland, J.: *Key lecturer covering two topics: a) What is carbon capture and storage (CCS) technology and b) Case studies on CCS*. Presented at the Climate Cool Media Workshop: Climate Change and Carbon Capture, Guangzhou, China; on 7 July 2009 and in Chongqing, China, on 8 July 2009. Organised by the British Embassy in Beijing and the regional consulates addressing CCS to Chinese journalists and NGOs
42. Chapoy, A.;Burgass, R.; Tohidi, B.; Austell, J. M.; Eickhoff, C.: "Effect of Common Impurities on the Phase Behaviour of Carbon Dioxide Rich Systems: Minimizing the Risk

of Hydrate Formation and Two-Phase Flow" 2009 SPE Offshore Europe Oil & Gas Conference & Exhibition held in Aberdeen, UK, 8–11 September 2009

43. Tzimas, E.; Cormos, C.-C.; Starr, F.: *"Use of lower grade coals in IGCC plants with carbon capture for the co-production of hydrogen and electricity"* Proposed paper for the International Journal for the Hydrogen Economy

2.2 Publishable results

The following non-classified deliverables have been produced:

D1.1.A-F Final Activity Report (this report)
D1.1.D-F Final Plan for Using and Disseminating the Knowledge
D1.1.2c Final summary report
D1.2.1 PPD rev. 1
D1.2.2 Project Policy Document, rev. 2
D3.1.3 DYNAMIS CO_2 Quality recommendations
D3.2.2 DYNAMIS H_2 quality recommendations
D4.1.1 Short list of potential CO_2 storage sites
D5.3.2 Recommendations for the HYPOGEN initiative (public version)
D6.1.1 Framework and reference data report
D6.1.3 Emission trade market assessment study for a HYPOGEN plant
D6.1.3rev1 Emissions trade market assessment study for a HYPOGEN plant
D6.2.1 Identification of Base Conditions for Debt Finance
D6.2.3 Evaluation of potential role of EIB Finance & Public/private partnership
D6.2.4 Hypogen investment risk profile assessment
D6.3.1 Relevant legal frameworks in relation with CO_2 capture and storage
D6.3.1rev1 Policy, legal and regulatory issues for CCS projects
D6.3.2 Evaluation of key issues on relevant emission trade regulation frameworks in relation with CCS
D6.4.1 EU-wide mapping report of existing findings on public perception and acceptance of CCS
D6.4.1rev1 EU-wide mapping report of existing findings on public perception and acceptance of CCS
D6.4.2 Report on the professionals' acceptance of CCS
D6.4.2rev1 Report on professionals' acceptance of CCS