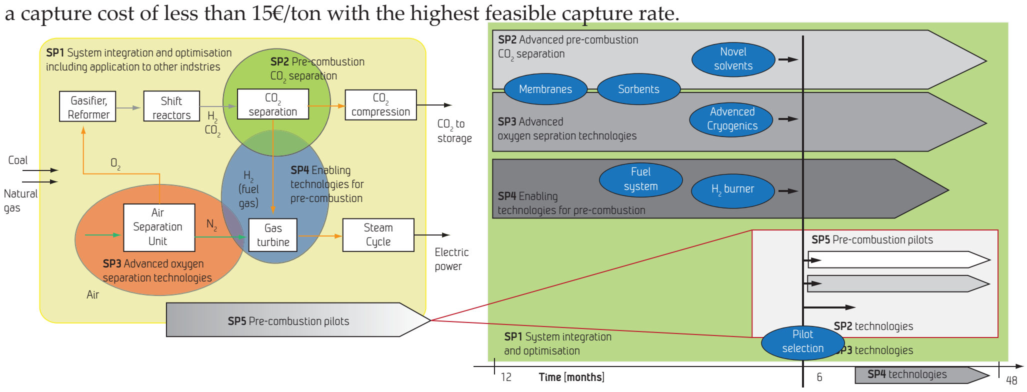

## Publishable summary

# Project Overview

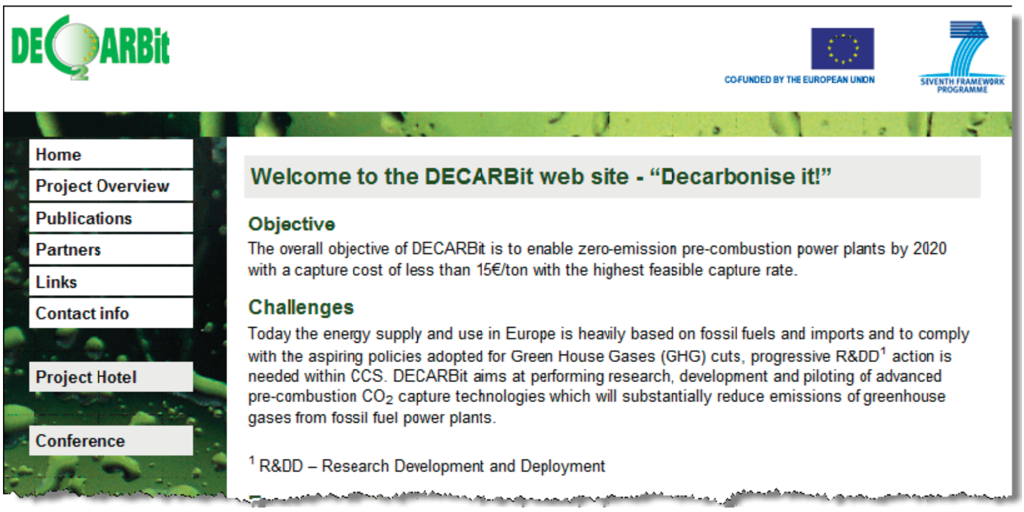
DECARBit responds to the urgent need for further research and development in advanced pre-combustion capture techniques to substantially reduce emissions of greenhouse gases from fossil fuel power plants. The project will accelerate the technology development and contribute to the deployment of large-scale carbon capture and storage (CCS) plants, in line with the adopted European policies for emission reductions. The project focus is to pursue the search for improved and new pre-combustion technologies that can meet the cost target of 15€/ton $CO_2$ captured as stated in the Work Programme. DECARBit is designed as a Collaborative Large-scale Integrating Project. The RTD activities are structured in 5 sub-projects directly responding to the objectives of the Work Programme:

SP1 System integration and optimisation
SP2 Advanced pre-combustion $CO_2$ separation
SP3 Advanced oxygen separation technologies
SP4 Enabling technologies for pre-combustion
SP5 Pre-combustion pilots

The overall objective of DECARBit is to enable zero-emission pre-combustion power plants by 2020 with a capture cost of less than 15€/ton with the highest feasible capture rate.




Welcome to the DECARBit web site - "Decarbonise it!" **http://www.decarbit.com/**




### SP1 System integration and optimisation

In Year 2, SP1 partners worked on all work packages, although with different priorities along the months. Work in WP 1.1 – Operational Requirements – covered heat and mass balance calculations for new cycle propositions, based on new technologies investigated in Decarbit. Report D1.1.2 – Heat and Mass Balances for Selected Cycles - was delivered, containing the analysis of four cycles: IGCC plant with $CO_2$ sorbent for pre-combustion $CO_2$ separation, IGCC plant with novel solvent systems for pre-combustion $CO_2$ separation, IGCC plant with cryogenic $CO_2$ separation and IGCC plant with high temperature membrane based air separation and selexol for AGR. With respect to the Puertollano dynamic simulator, a report was delivered on the tuned simulator for the study of the DECARBIT IGCC cases, as mentioned above.

In Work package 1.2 – Techno-Economic Analysis – cost analysis of the IGCC base cycle was carried out. For the base cycle without capture, costs of the following items were considered: coal handling, gasifier, gas turbine, steam turbine, heat recovery steam generator, low temperature heat recovery, cooling, air separation unit, ash handling, acid gas removal, gas cleaning balance of plant, water gas shifting reactor and Claus burner. For the base cycle with capture, all the above were considered plus the selexol-based capture process and the compression of $CO_2$. The economic assessment was made in terms of cost of electricity against specific investment, fuel price, percentage change in operations and maintenance costs and capacity factor.

In Work Package 1.3 – Coordination and Application to Other Industries - the main topic was the communication between SP1 and the SPs dedicated to $CO_2$ separation and oxygen production. Communication between SP1 and the other SPs has improved in comparison to the first year. SP1 members participated in SP2 and SP3 meetings along the year. A final report on boundary conditions for the other SPs was delivered and also a final report on the status of communication between SP1 and the other sub-projects.

In Work Package 1.4, the European Benchmarking Task Force achieved considerable progress, although the work of this group has proved to be more challenging than thought at the beginning of the project. The reason of some obstacles was the simple fact that three projects are involved, carrying the concerns and interests of a large number of partners. The Common Framework Definition Document - CFDD was concluded in May, with the delivery of a version dated 06 May 2009. It is possible that before the end of the CESAR and CAESAR projects, another version is issued, containing additional material on the economics of the studied cycles and a couple of updated parameters. A first version of the report D1.4.2 – Test cases and preliminary benchmarking results from the three projects was completed, containing the technical analysis and comparison of results of three base cases: Advanced Super-Critical, Integrated Gasification Combined Cycle and Natural Gas Combined Cycle. Four face to face meetings of the Task Force were held in London (March), in Amsterdam (May), in London (June) and again in London (December). Two teleconferences were held in February and three others in September, October and November of 2009.

SP1 held three face to face meetings in London (January), Oslo (February) and London (June) Teleconferences were held in February, April, September and October. The integration and optimization work carried out in SP1 is expected to make possible a consistent view of the technical and economic applicability of novel separation technologies, not possible in the investigation of each one independently.

## SP2 Advanced pre-combustion $CO_2$ separation

SP2 aims for a set of advanced ($CO_2/H_2$) separation technologies. Three routes are explored, which are: (WP2.1) selective membranes, (WP2.2) sorbents and (WP2.3) novel solvent systems. The ultimate aim is to develop $CO_2$ capture systems that can operate at high temperature and pressure avoiding a large temperature / pressure swing in the treatment of syngas.

### WP 2.1 - Selective membranes

Within this WP different routes for the development of selective gas membranes are being explored. First, ceramic hollow fibre support have been synthesized, and are made available to the different partners. These supports have been used for the deposition of a selective layer. With respect to the membrane development the focus is on carbon membranes (self supporting hollow fibre and ceramic supported), polymeric membranes with inorganic nanomaterials and dual phase membranes. For the selective layer different types of nanoparticles (e.g. hydrotalcites and zeolites) with high selectivity $CO_2$ have been selected. Hybrid hollow fibre membranes consisting of an alumina support with polymeric layer containing nanoparticles have been prepared successfully.

### WP 2.2 - $CO_2$ Sorbents

The scope of $CO_2$ sorbents focuses on solid adsorbents: carbon based, silica-based, zeolites, polymer-based or MOF-based (Metal Organic Frameworks). To find promising materials, characterization by determining adsorption isotherms for several of the (new) materials is in progress.

Furthermore, these materials, in particular zeolites and MOF-based adsorbents are used in a dual-reflux PSA process. This approach allows for a high purity separation step, and the dual phase aspect assures a heavy and a light product, making it most suitable for IGCC.

### WP 2.3 - Novel Solvent Systems

This WP focusing on a system suited to combine an absorption and desorption step at elevated pressures where the solvent (or liquid loop) is kept at constant pressure. For this membranes and solvents are being developed, and the integration of the solvent with a membrane in single process is studied. A solvent screening has been performed, as the most promising candidates amines, ionic liquids and physical solvents have identified. In parallel, suitable membranes that are stable in the presence of (one) of the solvents at elevated temperatures are being synthesized.

By the end of 2009 SP2 had submitted three Pilot test applications, one from each Work Package.

## SP3 Advanced oxygen separation technologies

This This DECARBit SP3 sub project proposes to pursue the development of advanced oxygen separation technologies that could allow significant reduction in energy consumption for oxygen production from air.
The main objective of WP3.1 – Oxygen Transport Membranes – is to develop and characterize OTMs for high temperature air separation with high oxygen flux and sufficient chemical/thermal/ mechanical stability under defined conditions. Oxygen production by use of OTMs is for many applications a promising alternative to cryogenic distillation. In the 2nd year of the DECARBit project there has been significant progress on the fabrication procedures for asymmetric membranes. The novel, layered architecture of developed tubular membranes is illustrated in Figure 1, which also indicates defined operation conditions.

Additionally glass ceramic seal materials have been developed and tailored to match the membrane and support material with respect to thermo-chemical properties. The seals show good adhesion to the membrane and support material and are gas tight. The first module has been assembled from a single tubular membrane and flux measurements will be conducted. Optimization of gas tightness, testing of seal in defined working conditions, as well as long term stability measurements are planned for the coming year of the project. The possibilities for scaling up developed procedures for membrane fabrication have been evaluated. Based on this evaluation it was decided to apply for development of an OTM pilot, however, at a modest level to start with.

The objective of DECARBit WP3.2 is to develop a technology for air separation units (ASU) using solid sorbent materials implemented in a configuration in which a rotating support is used for cyclically subjecting the solids to adsorption/desorption gas streams .

The search for new materials in Y1 led to a number of interesting innovative sorbents that showed potential for $O_2$ production that exceed by 2 to 6 fold those of the current LSCF perovskites identified in an earlier EC project (ENCAP). However, despite efforts in Year 2, these new materials still need to be further investigated in order to become of practical use in a process. Difficulties are encountered in reliably synthesizing on class of materials, while for the other class the problem is that the operating temperature window exceeds the target range of 500-600°C. The LSCF perovskite has thus been selected for pursuing the process developmental work.

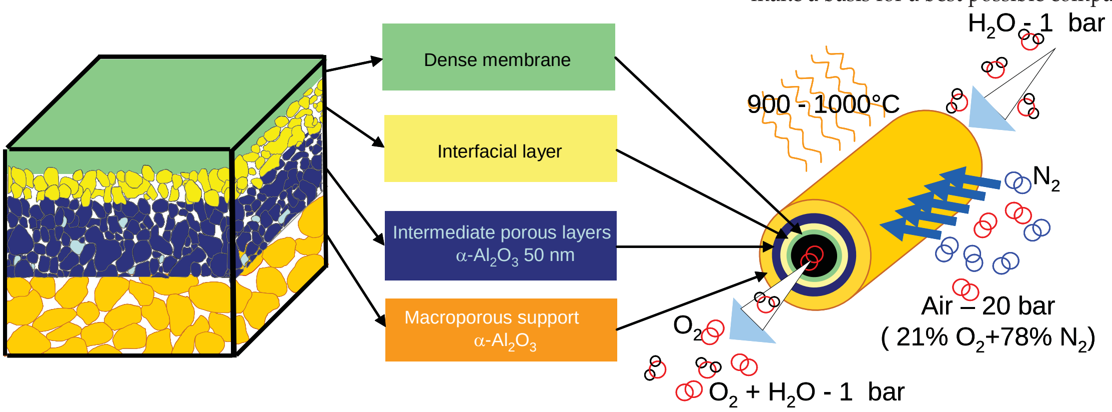
Fundamental fixed bed reactor experiments for beds of LSCF perovskites shaped as beads or pellets or washcoated on monoliths have been performed under realistic flow conditions in various absorption/desorption cycles. These data serve to gain insight into the controlling phenomena, to validate models and simulation tools, and to generate various thermochemical properties of the materials such as multi-constituent absorption isotherms.

The development of numerical tools to simulate the fixed bed experimental system for both particle and monolithic beds has been essentially finalized in year 2. The simulators have been coupled to optimization tools that allow estimating model parameters using the experimental results. The simulators are being further developed to describe the effect of flow cycling in a rotating bed system, specifically for the geometry of the bench scale unit soon to be operational at IFP. Future work will involve further experimentation in fixed bed reactors to better assess thermochemical properties of the materials, specifically in the presence of $H_2O$ and $CO_2$. Test data from our bench scale rotating reactor will be used to assess and improve the final simulator. Testing on this facility is currently delayed due to technical difficulties. Finally, the simulators will be used to size an actual unit which will allow performing an economic evaluation of the process.

The main objective of WP3.3 - Advanced cryogenic technologies - is the development of advanced cryogenic oxygen separation technologies to reduce overall energy consumption. The performed work and main results are so far:

- Concept studies with focus on process integration: Main work has focused on concepts for integration between the Air Separation Unit (ASU) and the $CO_2$ capture/purification unit. In addition, a concept for low-temperature syngas separation has been developed and will be further investigated regarding feasibility and competitiveness compared to conventional technology concepts. Main results show the potential for integration between the ASU and the $CO_2$ capture/purification unit seems to be very low, as the ASU in itself has a high degree of heat integration and the cooling required by the $CO_2$ capture/purification unit differs significantly in terms of temperature level compared with cooling that could be made available from the ASU
- Improved unit operation concepts: A model for air distillation columns of different kind of configurations has been established and presently the focus is on development of an optimisation model for minimisation of entropy production in distillation columns. A pilot concept based on the work performed (heated/cooled distillation stages) in the task has been established.
- Compact heat exchanger basis: Experiments using tubes with small diameters have been performed and the results are being evaluated. A prototype heat exchanger using MPE tubes has been acquired and experimental tests have been performed. Main results are experiments on heat transfer and pressure drop characteristics performed on single tubes and on a compact heat exchanger prototype.

The investigation on heat integration has so far not revealed any promising concepts for integration between the ASU and the $CO_2$ capture/purification unit. Improvement of unit operations will have its main focus on novel distillation column concepts. If one succeeds in improving the overall efficiency, the energy demand for distillation will decrease. Specifically for DECARBit, the cryogenic ASU unit energy consumption will decrease. Development of compact heat exchangers will lead to improved performance and reduced foot-print of the main heat exchanger in the cryogenic ASU. Compact heat exchangers will as well have many potential application areas. In total, the focus of the work is to achieve a cryogenic air separation unit optimized and best possibly integrated to reveal the full potential of this air separation technology. This should make a basis for a best possible comparison to alternative concepts.




Novel architecture of developed layered, tubular, asymmetric OTMs

## SP4 Enabling technologies for pre-combustion

The The objective of SP4 is to enable the development of safe and optimized premixed hydrogen burners and $H_2$ fuel systems for gas turbine conditions.

### WP4.1 – Hydrogen combustion

The first work package, WP4.1 'Hydrogen combustion', consists of a numerical part and experimental part. In the numerical part the focus has been on two different issues related to numerical simulations of hydrogen combustion. The first issue we have worked on is on simulations for showing how hydrogen mix and combust under gas turbine conditions by using very detailed Direct Numerical Simulations (DNS), illustrated in the following figure.

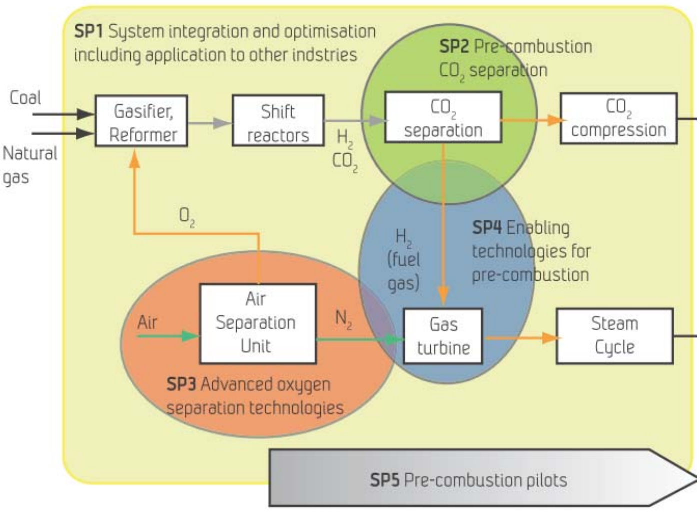
And secondly we have also started verifying how a Linear Eddy Model (LEM) can simulate mixing of hydrogen by the use of significantly less CPU resources than a DNS. The main result of year 2 is that turbulent flame speeds at pressures ranging from atmospheric up to 20 bars have been found.

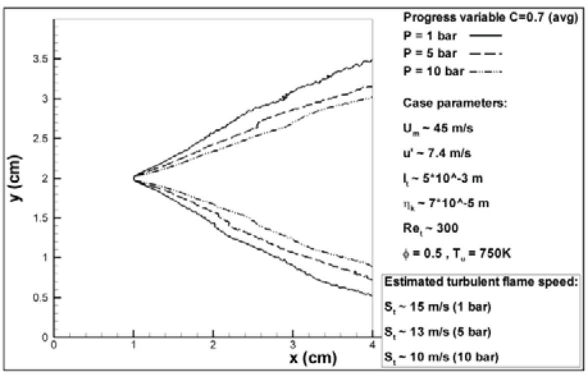
In order to achieve a high efficiency, a high turbine inlet temperature is required in standard gas turbines. As a result, there arise high NOx emission levels and higher life cycle costs. These problems are mitigated with a sequential combustion cycle, wherein the compressor delivers nearly double the pressure ratio of a conventional one. Within the auspices of WP4.1 in the DECARBit project, the goal of Alstom CH is to develop design guidelines for a lean-premixed sequential burner (SEV burner) for $H_2$-rich combustion. These can only be procured, if there is a hardware configuration allowing a wide range of trade off studies. Thus, defining a suitable hardware configuration was the target of the first phase.

In the 2nd year, the potential of current ALSTOM state-of-the-art SEV technology was assessed as well as a modified SEV burner when applied to $H_2$-rich fuels. The modified SEV hardware demonstrated successfully combustion with up to 47%vol $H_2$ at realistic GT conditions. As such, the concept shows promise for further trade off investigation and further optimisation for improved performance.

The experimental testing of new concepts is a fundamental phase in new burners development process. Performing tests on syngas fuelled burners requires a fuel system able to store and mix a wide range of fuels, as well as a large air flow at high pressure. The Sesta test facility, owned by Enel, has been used since the 90's by the world's main gas turbine manufacturers for experimental activity on prototype combustors at flow rates and pressures of full scale condition. The facility includes a fuel storage and mixing system able to supply a wide range of combustible mixtures. The air flow rate is supplied by an intercooled two stages compressor, with a maximum air flow rate of about 42 kg/s.

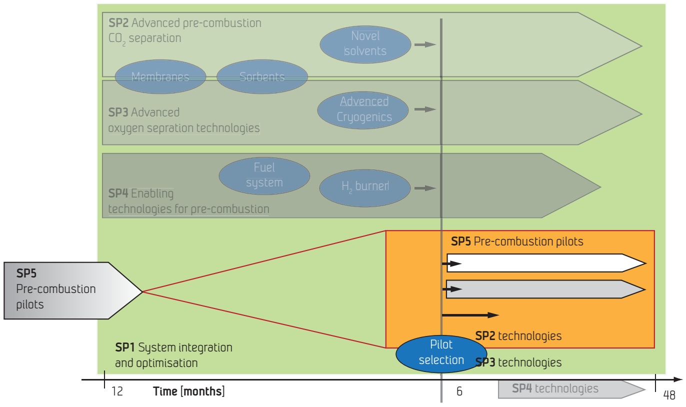
State-of-the art DNS direct numerical simulations.



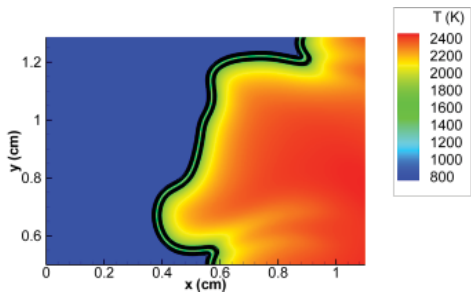



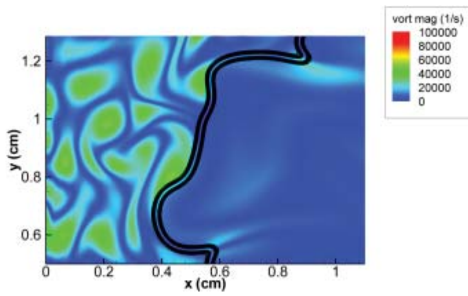

## SP5 Pre-combustion Pilots

DECARBit has now passed the first two years and will during 2010 enter into the second phase, where pilot testing of selected technologies will be the main part of the work. The three sub-projects that will progress with pilot testing are SP2 (Pre-combustion separation), SP3 (Oxygen separation) and SP4 (Hydrogen combustion) which all have during the first two years performed studies on various technologies within the pre-combustion $CO_2$ capture route. In the second phase, the main part of the work will be done within SP5 (Pre-combustion pilots). The actual technologies to be pursued during phase II of DECARBit will be selected following a thorough application process, in which the partners will need to describe their planned pilot testing in detail based on the results from phase I. The evaluation of these proposals will be performed by the "Technical and Exploitation Advisory Committee" under the leadership of Prof. dr. Klaus Hein which will result in a recommendation to the DECARBit board. It is expected that the project will pursue 3-5 selected technologies for pilot-scale testing during phase II.




DECARBit entering the second pilotphase of the project.

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