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SUSPOWER AND ENGAS: TWO MAJOR EUROPEAN RESEARCH INFRASTRUCTURES IN THE GAS TURBINE AND ENERGY CONVERSION FIELDS

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ABSTRACT

Since the mid-1990's the European Commission (EC) has provided funding for transnational access schemes that open up existing major research facilities to outside users. In the current 6th Framework Program, two out of 14 funded projects – SUSPOWER and ENGAS – are of prime interest to the gas turbine community. SUSPOWER (KTH, Stockhom, Sweden) encompasses unique large-scale experimental facilities within the area of sustainable thermal power generation. Topics of key interest include high-temperature air combustion, catalytic combustion, gasification, aeroelasticity of turbine/compressor blades, film cooling aerodynamics, and stator/rotor interactions. ENGAS (NTNU, Trondheim, Norway) includes a complex array of specialized laboratories in the topic of environmental gas management. Relevant research topics include combustion of hydrogen and hythane, biomass gasification, CO_2 absorption and sequestration, membranes for hydrogen and CO_2 separation, gas storage in rock caverns, and hydrogen production and storage. This paper presents information on these projects along with a brief overview of previous EC transnational access activities as related to gas turbine research and development.

INTRODUCTION

Research and development activities in nearly all engineering disciplines remain highly dependent upon access to high-quality major experimental facilities. The gas turbine field is certainly no exception to this rule, owing to the many complex processes encountered at both component and systems levels. It can be worthwhile to explore the possibility of allowing access to already existing facilities by users outside the host institution, especially for the case of university-based research where proprietary issues are normally less of a concern. Here the philosophy is to enhance the utilization of otherwise latent resources, to ensure that such resources are maintained, and to encourage synergy effects between two or more international research teams.

During the past decade the European Commission (EC) has supported the joint utilization of existing major experimental facilities within a broad range of engineering and scientific disciplines. The EC currently funds two projects – SUSPOWER and ENGAS – that encompass significant existing experimental facilities in the gas turbine field. This paper contains information related to these projects and a brief overview of related EC-funded programs. Selected results from recent project activities will be presented, along with reflections on the successes and hindrances encountered to date. The intended audience includes researchers interested in learning more about European research infrastructures in turbomachinery and EC mobility programs, along with educators who view such opportunities as important elements of researcher training.

EC-FUNDED RESEARCH PROGRAMS

Every five years the European Commission launches new framework R&D programs in response to broader decisions made by European Union (EU) member-states. The overriding objectives of the 6^{th} Framework Program (FP6), stretching from 2002-2006 and with a budget of 1700 MEuro, are 'strengthening the scientific and technological bases of industry and encourage its international competitiveness while promoting research activities in support of other EU policies' [1]. Two main Thematic Areas are of main concern for the gas turbine community: Aeronautics and Space (1200 MEuro); and Sustainable Development, Global Change and Ecosystems (2300 MEuro including 890 MEuro for sustainable energy systems). Other broad areas include Structuring the European Research Area (2800 MEuro), which includes the Research Infrastructures (715 MEuro) activity. The EC describes this activity as follows [2]:

'The ability of Europe's research teams to remain at the forefront of all fields of science and technology depends on their being supported by state-of-the-art infrastructures. The term "research infrastructures" refers to facilities and resources that provide essential services to the research community in both academic and/or industrial domains. Research infrastructures may be "single-sited" (single resource at a single location), "distributed" (a network of distributed resources, including infrastructures based on Grid-type architectures), or "virtual" (the service being provided electronically).

Examples include singular large-scale research installations, collections, special habitats, libraries, data-bases, integrated arrays of small research installations, high-capacity/high-speed communications networks, networks of computing facilities, as well as infrastructural centres of competence which provide a service for the wider research community based on an assembly of techniques and know-how.

The overall objective of this activity is to promote the development of a fabric of research infrastructures of the highest quality and performance in Europe, and their optimum use on a European scale based on the needs expressed by the research community.'

The Research Infrastructures Activity is subsequently comprised of various programs, most notably Transnational Access in the present context. In short the Transnational Access Program provides support to a single host institution in order to accommodate visits from European researchers (individuals or teams) located outside the host country. Typically such facilities are composed of well-established installations that have been employed for major experimental campaigns, and are accompanied by track records of significant research contributions and extensive international ties. Support provided via the Transnational Access Program can be seen as an enhancement to current activities; under this program EC financing represents no more than 15% in additional yearly turnover for each participant. Currently there are 14 funded facilities under this program. Three have energy relevance and two, SUSPOWER and ENGAS, include gas turbine technology. (Projects supported in the other FP6 programs do not have particular relevance to the energy engineering field.) Previous framework programs have featured a few projects of interest to the gas turbine community. As shown in Table 1, most of the facilities are linked to combustion or aerodynamics. University of Wales Cardiff, IFRF, and ENEL are also part of the EUROFLAM consortium [3], which includes training programs for young engineers and researchers.

Project funding with the Transnational Access Program covers the majority of costs related to equipment operation and maintenance, consumables, and staff support. Guest researcher travel expenses (excluding salaries) are also covered. Both SUSPOWER and ENGAS each receive around 250 kEuro per year in support for their activities related specifically to transnational access. (Note that this figure excludes normal research activities, and neither project subcontracts within this initiative).

OVERVIEW OF SUSPOWER

SUSPOWER features experimental facilities in the broad topic of sustainable thermal power generation and is supported by a staff of around 70 research and support personnel. Facilities are located in two 400 m^2 laboratory buildings at KTH's main campus have been grouped within the following three installations: Innovative Combustion; Gasification; and Gas Turbine Technology. More details can be found in Table 2. The facilities allow for in-depth, targeted research in specific areas while collectively enable the possibility of broad experimental programs involving several energy conversion steps. Coupling to numerical studies (either at detailed component level or system-level) is another important feature. These experimental facilities have been financed by the Swedish Energy Agency, Swedish Gas Turbine Center (GTC), Swedish Defense Research Agency, Swedish Steel Producers Association (Jernkontoret), EC Framework Programs, the New Energy and Industrial Technology Development Organization of Japan (NEDO), and others. Some examples of relevant projects run in parallel to SUSPOWER are given below:

Part Load Behavior and Partial Admission in Steam Turbines with Low Inlet Volumetric Flow – Swedish Energy Agency

Generic Studies on Energy-Related Fluid-Structure Interaction – Swedish Energy Agency

Aeroelastic Design of Turbine Blades II (ADTurB II) – EC

Development of Innovative Techniques for Compressor Aero-Mechanical Design (DITCAD) – EC

3D Nozzle: Compressible Flow with Shock, Turbulence, Transition, and Unsteadiness – Swedish Energy Agency

3-D Aerodynamics and Film Cooling in a Sector of an Annular Cascade – Swedish Energy Agency

Design and Off-design Optimization of Highly Loaded Industrial Gas Turbine Stages (DAIGTS) – EC

Catalytic Combustion of Gasified Biomass in Gas Turbines – Swedish Energy Agency

Synthesis Gas from Biomass through Pressurised Gasification II – Swedish Energy Agency

Clean Hydrogen-rich Synthesis Gas (CHRISGAS) – EC

Within the SUSPOWER project each visit begins by first submitting a proposal, which is then reviewed by the Users Selection Panel (comprised of three representatives from KTH and three international experts external to the project). Criteria include the novelty and impact of the proposed research, relevant education and/or research experience, dissemination plan, and existence of similar facilities in home country. Detailed planning and preparation commences once the project is approved. Each user is required to submit a final report, and additional publications (journal articles, conference contributions) are highly encouraged. The project homepage[1] is the primary information resource for potential users and others interested in the project. Short project descriptions will also be included in future updates of the CompEdu platform [4]. A total of 510 experimental days will be offered to external users for the 36 month period, and each visit is expected to encompass 15 experimental days.

One visit has been completed since the project commenced in November 2004 (S. Kakietek, Institute of Power Engineering, Poland). This study investigated oxidation of biomass and refuse-derived fuels in the HTAG facility with low oxygen concentrations. A brief summary is presented below (see S. Kakietek [5] for more information):

The ignition delay, mass loss, NOx emissions, and concentration of CO, CO_2 and O_2 for three different temperatures (1000°C, 800°C and 600°C) and three oxygen

[1] www.energy.kth.se/SUSPOWER

concentrations (5, 10 and 21%) were obtained for pelletized fuel samples with reaction times ranging from 15 to 300 seconds. It was shown that the differences in O_2 concentrations do not have a significant influence on mass loss as the oxidizer temperature levels were raised. NO_x emissions decreased as the concentration of O_2 was reduced, however an appreciable rise in nitric oxide levels was noticed when increasing the temperature of oxidizer from 800°C to 1000°C (approximately from 400 mg/Nm^3 to 1000 mg/Nm^3 for RDF pellets at 21% O2). This behavior is in agreement with general knowledge about NO_x emissions. However this phenomenon is not observed for low concentration of O_2, e.g. 10%. Here an increase in temperature from 800°C to 1000°C does not influence NO_x levels. This finding represents indicates a major advantage in high-temperature operation.

Beyond this study, six projects are planned to commence in early to mid-2006:

Fixed Bed Biomass Combustion in HiTAC Facility, M. Purvis and G. Lim, University of Portsmouth, UK. (HiTAC facility)

Experimental Study of Biomass and Plastics Co-gasification under Elevated Pressure, M. Vosecky, Institute of Chemical Technology Prague, Czech Republic. (Pressurized fluidized bed reactor)

Catalytic Combustion of Methane under Fuel-Rich Conditions, S. Cimino, Istituto Recerche sulla Combustione (CNR), Italy. (High-pressure catalytic combustion test facility)

Unsteady Aerodynamics and Aeroelastic Interactions in Turbomachines, A. Kalfas, Aristotle University of Thessaloniki, Greece. (Low-pressure test turbine facility)

Gasification of Sewage Sludge in a Pressurized Fluidized Bed, J. Sanchez, University of Zaragoza, Spain. (Pressurized fluidized bed reactor)

Measurements of HTAC Methane Combustion in Semi-industrial Scale for Validation and Verification of Numerical Models, A. Sachajdak, Silesian University of Technology, Poland. (HiTAC facility)

OVERVIEW OF ENGAS

Over the last 30 years NTNU and its technology transfer partner SINTEF have jointly developed a 38 million Euro research facility, consisting of 14 interlinked laboratories, where 600 people work towards cleaning up CO_2, NO_x, SO_x, other greenhouse gases, and pollutants from the oil and gas production processes and their utilization in industry, buildings and transport. A secondary thrust has been to cross-link this research with the development of clean new renewable energy technologies. This large group of individual rare, and unique, equipment, located in a net 8000 m^2 site, is driven by a dual research imperative:

1) More efficient energy systems
2) The cleanest (environmentally sustainable) attainable energy systems

Advances in both areas are based on state-of-the-art science and technology, developed in conjunction with some of the world's largest companies - General Electric, Rolls Royce Engines, Siemens, ABB, Exxon, Shell, Statoil, Hydro, Aker Kværner, Linde, Ford, Denso/Toyota, DaimlerChrysler, etc.

A brief description of each laboratory is given in Table 3. More details about each laboratories infrastructure can be found in the section below and on the project homepage[2]. The research infrastructure facilities are clustered along the entire technology chain from energy source to end user, as illustrated in the ENGAS Laboratory Road Map (see Figure 1).

In the area *Gas storage and transportation* research facilities are dedicated to elucidating the basic science and technology processes associated with making gas available for energy conversion through research on infrastructures purpose built for Multiphase Flow Technology analysis and Liquefied Gas technology. The Multiphase Flow Technology Laboratory has a 30-metre lab facility in NTNU complemented by a 1,000 metre two-phase flow and 200-metre three-phase flow reconfigurable facility off-site operated by SINTEF. The liquefied gas laboratory covers both liquid natural gas (LNG), liquid hydrogen (LH_2) and liquid carbon dioxide (LCO_2), and we have developed customized equipment and advanced computer codes to study thermodynamic and heat transfer properties of complex gas mixtures at low temperatures. We also have a new patented small scale LNG plant based on standard components from industrial refrigeration plants (compact heat exchangers and screw compressor) for novel research.

In the area *Power production with CO_2 capture* we operate a large group of strategic areas, like Combustion technology, including chemical looping; Process integration, including fuel cells, CO_2 absorption technology, Membrane technology (CO_2 selective membranes), and Ugelstad laboratory (surfactant chemistry). This means that both pre-combustion, post-combustion and oxy-fuel strategies may be studied. The Combustion Technology Laboratory includes test rigs for studying combustion of gas mixtures, equipment for testing low-NO_x gas burners and a laser diagnostic laboratory for measurements in non-reacting and combustion flows.

In the area *Efficient end use of electricity* research facilities support the development of new refrigeration and heat pump technology based on natural working fluids, with greenhouse gas management as main priority (own patented process).

In the area *Production, storage and transportation of hydrogen* we have a range of advanced equipment for research on catalyst/reactor systems for conversion of hydrocarbons to liquid fuels and hydrogen; reforming technology; hydrogen production by water electrolysis (PEM Cell); technologies for applying different hydrogen carriers (ammonia, methanol); hydrogen storage in hydrides, carbon nanofibres or as liquid.

In the area *Efficient end use of gas and hydrogen in transport sector* a suite of equipment supports research on gas motor technology with high efficiency and low emissions; fuel cells driven by gas from biomass and waste; fuel cell technology based on natural gas and different hydrogen carriers; energy efficient air conditioning pilot plants that utilize CO_2 as a working fluid.

[2] www.ntnu.no/engas/

In the *Renewable Energy* section facilities are dedicated to the development of technology that may make renewable energy sources like biomass and solar energy economically available. Equipment required for research on gasification of biomass and waste material; high temperature membranes for hydrogen separation; and how to integrate gasifier and fuel cell is provided as well as for new processes for direct production of solar cell silicon.

In the area *Storage, transportation and sequestration of CO_2* we handle storage and transportation by pipeline or ship (liquid CO_2); multiphase flow; process technology to avoid hydrate formation during injection, reservoir engineering and seismic to study and monitor CO_2 injection in oil reservoirs; rock mechanics to study storage of CO_2 in rock caverns, and technology related to study of sequestration of CO_2 in minerals.

By systematic team work NTNU and SINTEF have been able to establish ourselves as partners in the following projects in the 6th Framework Program:

Within Hydrogen/Fuel Cells

- FURIM (High temperature PEM Fuel Cells)
- NATURALHY (The "natural gas road" to the hydrogen economy)

Within CO2 Management

- ENCAP (Enhanced capture of CO_2)
- CASTOR (CO_2 from capture to storage)
- ULCOS (Ultra low CO_2 steel making)
- CO2GeoNet (Geological storage)
- DYNAMIS (Production of electricity and hydrogen with handling of CO_2)
- CO2Remove

Within Bioenergy

- NEXTGENBIOWASTE (Innovative demonstrations for the next generation of biomass and waste combustion plants for energy recovery and renewable electricity production)

Laboratory projects

- ENGAS Research Infrastructure

Users or user groups requesting access to ENGAS must submit a standard application form prior to the application deadline. ENGAS operates with two fixed application deadlines per year: 1 November (2005, 2006, 2007) and 1 April (2005, 2006, 2007). Besides background information about the group members and the installations to be used, the form contains a project description of maximum 2 pages, describing: aim of the project; methods to be used; expected results; collaboration with local scientists; and plans for publication. The applications will be assessed by a user selection panel composed of international experts in the field. The selection of proposals will be based on scientific merit, and priority will be given to users or user groups who do not have similar facilities in their home country and who have not used the ENGAS facilities previously.

Seven visits have been completed since the project started in April 2004.

REFLECTIONS ON PROGRESS TO DATE

Establishing selection criteria and administrative procedures for accommodating users at each site was found to be relatively straightforward. The existing EC-funded research infrastructures have served as excellent examples in this context, and both KTH and NTNU have previous experience in hosting guest researchers. Implementation of approved projects has also been trouble-free once scheduling issues have been resolved. A low proposal turnout has been the primary obstacle in the first year of operation despite information campaigns via well-established formal and informal contacts. Obviously more work needs to be done to utilize these and other resources to a fuller extent. For example the SUSPOWER team will offer a list of preliminary project proposals from year two onwards. Such information should help potential users to see how the facilities can be employed for new research, as the possibilities may not be obvious at first glance.

Measuring the impact of the completed visits is somewhat difficult at this time as both projects are in a start-up phase. Research quality is deemed to be relatively high; for example results from the first SUSPOWER visit were presented at an international symposium on high temperature air combustion and gasification [8]. Many past and upcoming projects are linked to researchers located in the new European-member states (e.g. Poland, Czech Republic). Access to this type of advanced equipment is usually more limited in these countries, so it is clear that these projects are positive in terms of resource utilization. Open research is emphasized with each visit, so the results will contribute to the gas turbine community both within and outside Europe. Inevitably new or stronger ties are made between collaborating institutions.

Even though the Transnational Access Program is not intended specifically for education or training purposes, there are side benefits in this area as well. Several colleagues have expressed an interest in involving their students in these projects as a way to enhance their research work. Experienced graduate students could certainly qualify for such a project. Of course students with little research experience may not be fully prepared to work in such a setting where knowledge of key experimental equipment and procedures is vital. In some cases this can be overcome by inviting the advising professor or other senior staff to work with the student first-hand. For instance this would allow young graduate students to participate in experimental work at an early stage in their careers, in particular for cases where relevant equipment is not available at the home institution. Beyond this both projects will likely have a positive impact on educational programs at both KTH and NTNU. Guest lectures can be arranged in conjunction with visits (both at undergraduate and graduate levels), not to mention the many benefits attained from informal contacts. As mentioned previously, user-visits will be cataloged in the CompEduHPT platform and will thus be available to a much broader audience.

CONCLUDING REMARKS

With the addition of SUSPOWER and ENGAS, access to a broad range of research infrastructures in the energy field has been improved significantly. A majority of the facilities featured in these projects have direct relevance to the gas turbine community, so research visits should have a positive influence in terms of advancing research and development. The work performed within the projects is also expected to shed light on the technologies' significance in future sustainable energy solutions. Hopefully EU support for research infrastructure programs will continue in the next framework program as their benefits are deemed to be substantial for all parties involved.

ACKNOWLEDGMENTS

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Table 1: List of previously EC-funded research infrastructures with gas turbine relevance (obtained from EC [6-7]).

Name	Host or Coordinator	Duration	Major equipment and website
Facility for Aero-thermodynamic and Propulsion Studies (FAPS)	CNRS (France)	1996-2000 2000-2003	Low-density plasma wind-tunnels, Low-density and non-rarefied hypersonic wind-tunnels, Vacuum chambers for studies relative to jets and plumes, Installation for studying spacecraft electric propulsion, Large-size subsonic wind-tunnel, High- and low-pressure combustion chambers, Turbulent combustion installations, Shock tubes for chemical kinetic studies, Laser and spectroscopy installations. http://www.cnrs-orleans.fr/~webaero/faeps/
International Flame Research Station (IFRF)	IFRF Station B.V. (Netherlands)	1996-2000 2000-2003	Semi-industrial scale experimental research equipment (boilers, industrial heaters) for study of flames, liquid fuel sprays, pulverized coal; emissions performance in boilers and other conversion processes; advanced measurement techniques and numerical modeling. http://www.ifrf.net/
ENEL Production – Research	ENEL SpA (Italy)	1996-1999 2000-2003	Large semi-industrial and demo scale combustion facilities; pollutant formation in furnaces, boilers, and gas turbine combustors; combustion characteristics like atomization and flame stabilization; renewable fuels; gasification and pyrolysis; advanced laser diagnostic instrumentation such as 2D LDA, PIV and 2D PDA systems; major computational facilities. http://www.euroflam.net/enel.html
University of Wales Cardiff, Cardiff School of Engineering (CAREER)	University of Wales Cardiff (UK)	1996-2000 2000-2003	Range of rigs up to 2 MWt that caters for biomass, solid, liquid and gaseous fuel consumption using a range of combustion techniques such as swirl, cyclonic and sprays; novel fuels; gasification and pyrolysis; advanced laser diagnostic instrumentation such as 2D/3D LDA, PIV and 2D PDA systems; species analysis with on- and off- line equipment. http://www.euroflam.net/uwc.html
Access to Lund University combustion centre	Lund University (Sweden)	2001-2005	High Pressure Combustor Facility; Fully equipped optical engines; Fire spread facilities; Laser/detector equipment; Gas turbine according to the HAT (=Humid Air Turbine) concept; Small/medium size burners. http://www.forbrf.lth.se/lsf/

Table 2: Description of SUSPOWER experimental installations

Facility	Description
High-temperature air combustion semi-industrial test facility (HiTAC) (2001)[1]	Unique HiTAC research furnace in Europe (500 kW, inner dimensions 3.5 m x 2.2 m x 2.2 m). Extremely flexible operation including recuperation. Fully instrumented with 120 thermocouples, water-cooled heat flux probe, and flue gas sampling with connected gas chromatograph (GC). Accompanying research-scale furnace available for complementary studies such as optical measurements.
High-pressure catalytic combustion test facility (2003)	Unusually high, industrially representative pressure levels (35 bar). Various catalyst configurations can be tested at pressures up to 4 bar. Unique one-pass tubular humidifier allows for absolute humidity levels up to 30%. 100 kW fuel capacity.
High-temperature air and steam gasification (HTAG) test facility (2002)	Preheating up to 1300°C possible, a very uncommon level for gasification equipment. Fuels include woody biomass and (plastic) wastes. GC and other diagnostic equipment included tar analysis via solid phase adsorption (SPA) method.
Pressurized fluidized bed reactor (1985, continuously upgraded since then)	Sole bubbling fluidized bed (BFB) research unit in Europe which can handle pressures over 10 bar; very suitable for syngas production and upgrading. High fuel flexibility; previous tests have been conducted with biomass, black liquor, and coal. Fuel feed rates up to 3 kg/hr.
Low-pressure turbine test facility (2004)	One-of-a-kind facility for studying detailed blade/flow interactions at full scale. Annular flow channel, transonic flow conditions. Controlled simulation of flutter via unique oscillation actuator. Instrumented for time-resolved pressure measurements on blades, hub and casing. Determination of aeroelastic stability at design and off-design conditions. Tip diameter 980 mm, radius ratio 1.25, axial chord (root) 55mm, inlet angle 45 deg, outlet angle 70 deg, inlet Mach number 0.1-0.44, outlet Mach number: 0.67-0.99, Reynolds number 320000-520000. Blade oscillation: bending (flex, chordwise) 0-6.5 deg, torsion 0-9 deg, combined torsion and bending (at a phase angle of 90 deg), reduced frequency 0-0.5. High frequency pressure measurements and laser velocimetry available.
VM100 transonic wind tunnel facility (1998)	Very flexible facility for investigations in fundamental fluid mechanics (boundary layers, shocks) along with flows in full-scale annular sector cascades with blade cooling. Flow rates up to nearly 5 kg/s at 4 bar. Typical Reynolds number ranges from 500000 to 5000000. Powerful, rare laser equipment (3-D L2F) available.
Cold flow test turbine[2] (1989, upgraded 1999)	Unique full-flow facility for studying fluid dynamics of turbine blading (1-3 stages). Unsteady wall and traversing pressure profiles can be measured. Mass flow rates over 4 kg/s at 4 bar, rotational speeds up to 9000 rpm. Number of stages 1-3, min. inner diameter 280 mm, max. outer diameter 500 mm.

[1]Year of construction

[2]Shared ownership with SIEMENS Industrial Turbines AB.

Table 3: Brief description of ENGAS laboratories

Facility	**Description**
Multiphase Flow Technology Lab	Fundamental studies related to transport of oil-water-gas mixtures in pipes. Several test sections (3-6 cm diameter, 17m long, 7m high) are instrumented with impedance probes, pressure censors and moving camera for characterization of steady and transient flow conditions
Refrigeration Technology Lab	Several rigs and test facilities are available for conducting research within liquefied gas technology (LNG and LH_2) and refrigeration and heat pumps using CO_2 as refrigerant (CFC-HFC-free technology).
Combustion Technology Lab	The laboratory provides opportunity to conduct both fundamental and practical combustion studies in small and large-scale facilities like boilers, furnaces and combustors. Several optical diagnostics (e.g. lasers) and advanced gas diagnostics techniques (e.g. FT-IR) are available.
Energy Process Technology Lab	The laboratory is equipped with several rigs and test facilities for doing research within thermal processes for energy conversion. The multi-fuel reactor is a small scale reactor designed for fundamental studies of pyrolysis, gasification and combustion of biomass and waste materials.
Gas Motor Technology Lab	The laboratory is equipped for product verification, testing and development for marine and land-based industries. Typical examples of work carried out include: large scale testing of gas engines (extensive auxiliary equipment available); advanced experimental studies of combustion process with different fuels.
Absorption Technology Lab	The laboratory has a substantial activity in the field of CO_2 (and also other acid gases) removal from exhaust gas, process gases and natural gas. Technologies associated with absorption of CO_2 into physical and chemical solvents using conventional absorption towers or new membrane contactors are studied both experimentally and with rigorous modeling tools.
Membrane Process Laboratory	Experimental studies of reactors and technology utilized in chemical looping. Development of high temperature membranes for hydrogen separation and high temperature CO_2 selective membranes
Membrane Technology Lab	Develop technology to improve membrane separation of gases => Membrane material development; Capture of green house gases (CO_2 , VOC, SF6); Upgrading of bio-gas, Purification of aggressive gases; Simulation of integrated membrane processes
Chemical Engineering Lab	Develop technology for catalytic conversion of hydrocarbons to hydrogen; Production and utilization of carbon nanofibres; Storage of hydrogen; TEOM-laboratory (Tapered Element Oscillating Microbalance) suitable for studying uptake of gases in porous structures
Electrochemical Technology Lab	Develop improved hydrogen and fuel cells technology, including application of various hydrogen carriers (ammonia, methanol), hydrogen storage in metal hydrides and carbon materials, and hydrogen production by water electrolysis
Reservoir Technology Lab	Develop technology to improve planning and monitoring of CO_2 injection projects, utilising reservoir engineering, seismic and high performance computing and visualisation (Cave tech.)
Gas Storage Technology Lab	Develop technology to handle gas storage in rock caverns, utilizing equipment and models for rock stress measurements. The laboratory has equipment for doing measurements of mechanical and physical properties of rocks.
Mineral Technology Lab	Develop technology to handle mineral sequestration of CO_2. The laboratory has comminution equipment and equipment for particle characterisation which are of particular interest in the context of CO_2 sequestration on minerals.
HelioSi Laboratory	Develop technology to reduce costs in production of silicon for solar cells, including Clean room laboratory for casting multi crystalline pure silicon by direct solidification; Equipment for cutting and slicing; Metallographic characterization of dislocation density, grain size and texture

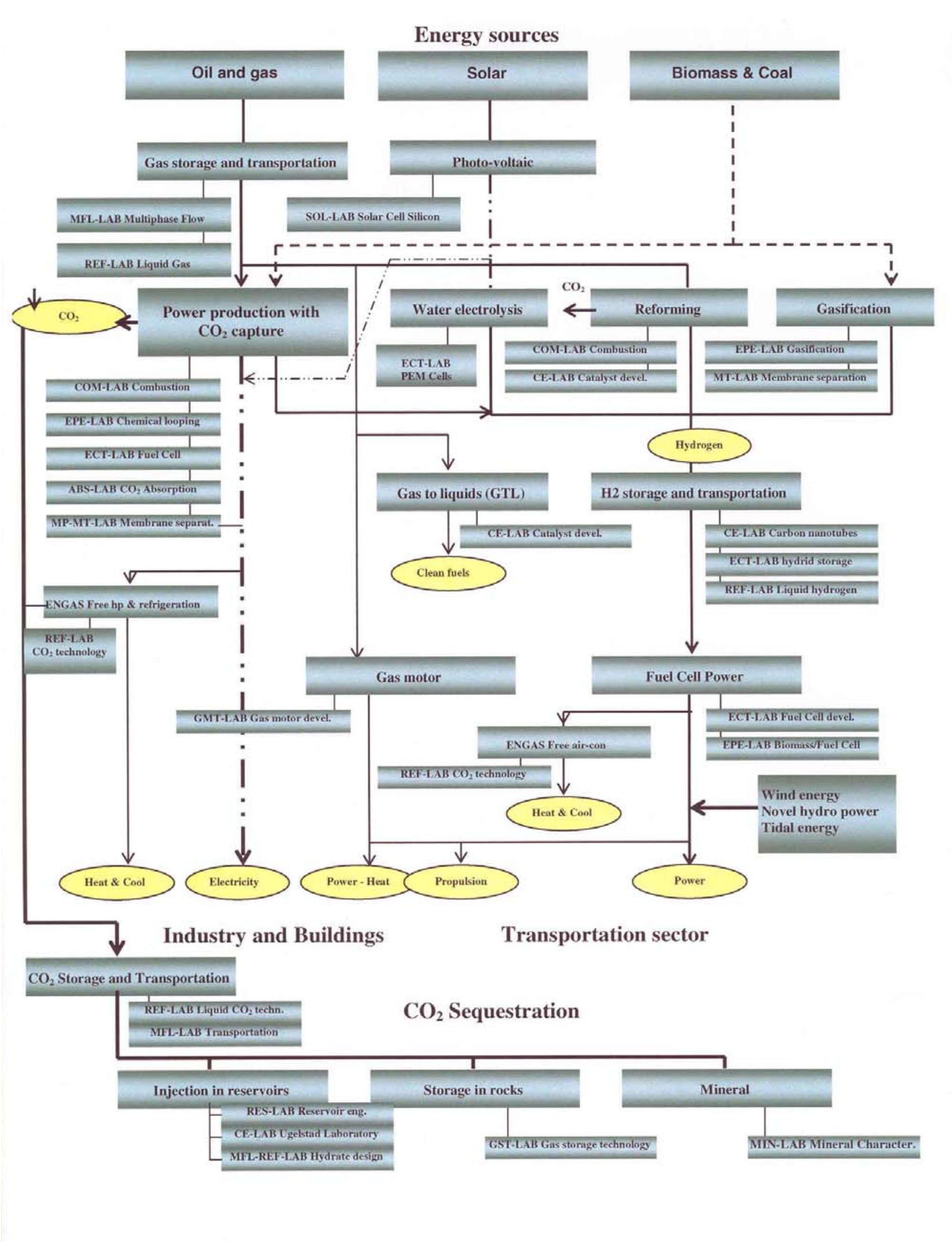

Figure 1: ENGAS Laboratory Road Map