PowerClean

STRATEGY FOR SUSTAINABLE POWER GENERATION FROM FOSSIL FUELS

Prepared by

PowerClean, CO_2NET and CAME-GT
EC Thematic R & D Networks

20 November 2004

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EXECUTIVE SUMMARY

Under the EU FP5, three R, D&D Thematic Networks (PowerClean, CO_2NET, and CAME-GT) were established to valorise the work being carried on throughout Europe into advanced power generation, carbon dioxide capture and storage, and gas turbine development. These networks have produced reports identifying the current state of the art, the important market factors, R, D & D needs, and a strategy for advancement. This report distils the findings of the three groups to produce a common strategy for the development of power generation in Europe over the next thirty years.

The prevailing view is that the future energy needs of the enlarged EU will be so significant that the full range of available fuels (including renewables, nuclear, natural gas and coal) will have to be utilised to meet the demand. For example, in EU-15 alone, the electricity sector will require some 550GW of power plant (90% of present capacity), to be built or re-powered between now and 2030 if new demand and replacement due to age are to be satisfied.

The other dominant consideration is the need to reduce CO_2 emissions to meet Europe's obligations regarding climate change. Short term commitments can be met through replacement of inefficient aging plant and by emphasis on more efficient energy use. For the longer term, however, carbon dioxide capture and storage (CCS) has been recognized as an important technology for achieving significant Green House Gas (GHG) reductions, particularly with the continued use of fossil fuels.

All major global projections suggest that fossil fuels will remain key for power generation and that global coal demand is expected to double by 2030. The IEA estimates that 4500 GW of new power plant will be required, of which 40% will be coal fired, with an investment value of €1450 billion. This is a huge market for which European industry must compete against the USA, Japan, and domestic suppliers within the target markets. Clean coal technologies (CCT) with higher efficiencies and better environmental performance, and carbon dioxide capture and storage are crucial for this competition and for the ultimate creation of near-zero-emission power plants.

Up to 2010, natural gas is projected to account for the largest share (~70%) of the increase in EU electricity production. As a result, some 27% of electricity should be produced from gas-based power generation and CHP plants in 2010. However, it is expected that between 2010 and 2020 this competitive advantage will disappear and that advanced coal technologies may account for the bulk of incremental electricity demand, the net result being stabilisation of the natural gas based share of electricity production at about the 2010 level.

For carbon dioxide capture, the approach to date has focussed on a range of options, all of which have some major technical issues to be resolved. There is now a need to take the more promising developments forward through large-scale demonstrations and deployment. In contrast, the options for CO_2 transport and geological storage are already understood and, while essential R&D remains to be done, purely technical issues surrounding storage seem unlikely to prove a major obstacle. Much more important is the non-technical barrier of obtaining political and public acceptance. Also, with foreseeable power plant designs, the cost of capture dominates the cost of the entire CCS chain (>80%).

Based on progress-to-date, the EU is well positioned to take action in CCT and CCS and to develop appropriate European Lighthouse Projects. Supporting these activities would be EU Networks of Excellence and cross-cutting thematic networks such as CO_2NET and PowerClean, as well as local and international centres of competence.

If consideration is given to economic and environmental issues and externalities, the development of clean fossil fuel-based power generation with CO_2 capture and storage must be a key part of EU energy policy. It will also be important to prepare for the introduction of hydrogen as an energy vector if that should prove to be a viable option. However, international competition will be very strong. USA initiatives such as the Carbon Leadership Forum, Clean Coal Plant Improvement Programme, and Futuregen demonstrate commitment in the area and are intended to ensure commercial advantage for the USA in world markets.

Many of the necessary developments are still at the pre-competitive R&D stage and the position regarding market drivers is extremely unclear. Because of this, EU industry is not yet in a position to fully support such initiatives. Consequently, the financial intervention of the EC is needed to support EU industrial competitiveness in this area. However, the EC Green Paper gives little mention to fossil fuel fired power generation, and this position is reflected in the strategic priorities of FP6, where fossil fuel R, D&D exists only in the context of the capture and storage of CO_2.

The inclusion of carbon dioxide capture and storage (CCS) measures inevitably incurs a penalty in the efficiency of power generation. This means that from a resource conservation and security of supply point of view CCS must be based on the most efficient conversion technologies. Thus, there are two interlocking strands to the development of zero-emission power generation systems:

- Significant increases in the efficiency of the underlying conversion technologies
- Development of the CCS technologies.

As a consequence of the above analysis, the shape of a coherent, integrated EU fossil fuel based power generation R, D & D programme can be seen as concentrating on:

- Emphasis on coal and gas, with co-utilisation of biomass and wastes
- Targeted towards achieving significant process efficiency improvements
- Integration of fuel switching/ co-firing and retrofitting of improvements
- Effective and integrated CO_2 capture and storage
- Development of key enabling technologies such as gas and steam turbines
- Production of hydrogen as a step towards a more diverse transport fuel system and H_2-based power production.

The role model would be the European Research Area, as put forward within the FP6 programme, but with a more comprehensive range of technical objectives.

A coherent, integrated EU fossil fuel based power generation R, D & D programme is required which:

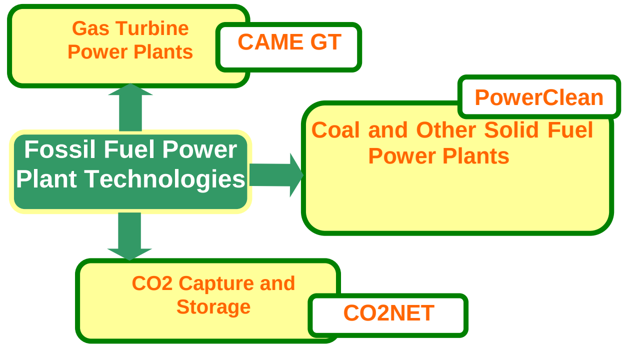
- **Emphasises coal and gas, with co-utilisation of biomass and wastes**
- **Is targeted towards achieving significant process efficiency improvements**
- **Integrates fuel switching/ co-firing and retrofitting of improvements**
- **Includes effective and integrated CO_2 capture and storage**
- **Develops key enabling technologies such as gas and steam turbines**
- **Includes production of hydrogen as a step towards a more diverse transport fuel system and H_2-based power production.**

The role model would be the European Research Area, as put forward within the FP6 programme, but with a more comprehensive range of technical objectives.

CONTENTS

1 INTRODUCTION

Under the EU FP5, three R, D&D Thematic Networks (PowerClean, CO_2NET, and CAME-GT) were established to valorise the work being carried on throughout Europe into advanced power generation, carbon dioxide capture and storage, and gas turbine development. These networks have produced reports (1, 2, 3, 4) identifying in each area the current state of the art, the important market factors, R, D & D needs, and a strategy for advancement. This report distils the findings of the three groups to produce a common strategy paper for the development of power generation in Europe over the next thirty years.



2 ENERGY DEMAND

In 2002, total world energy consumption was 9405 Mtoe. Oil was the largest contributor at 37.5%, primarily for transport applications, with coal following at 25.5%. For electricity production (9), coal was the major power generation fuel at 38.7%. It was used over twice as extensively as its closest competitor (hydro-power). Many countries (including members of the European Union) are heavily dependent on coal.

The IEA World Energy Outlook projection to 2030 (6) indicates an increasing worldwide demand for coal, oil and gas with nuclear and renewables at much lower levels. These projections are supported by the recent WETO study (5), which projects European and global energy demand and supply on the basis of a range of scenarios. The WETO reference case concludes that:

> *"More than half the total electricity production in 2030 will be provided by technologies that emerged in the nineties and afterwards like gas combined cycle turbines, advanced coal technologies and renewables. These two fossil fuel-based technologies are expected to largely replace conventional thermal power plants by the end of the projection period. The share of conventional coal in power generation is expected to decrease from 36 % in 2000 to 12 % in 2030 while the share of gas increases from 16 % to 25 % and advanced coal takes a share of 33 % in 2030."*

Thus, within the EU, coal presently plays an important role in the overall energy mix, primarily for power generation, while meeting current environmental regulations and standards. In the future, coal will have to maintain a key role, with enlargement of the Union further emphasising that position. At the same time, tightening regulations will require better solutions for achieving environmental compliance. Also, under the policies of nations like the USA, China and India, global dependence on coal is set to increase. Consequently, methods must be developed by which it and the other fossil fuels can be used cleanly, efficiently, and in a sustainable way.

The EU Energy Green Paper (8) projects that by 2030, the gap between energy demand and production for the EU will be becoming ever wider. Nuclear power will have decreased significantly compared to year 2000 levels while renewables will have increased to a corresponding degree but by nowhere near enough to deal with the energy shortfall. Once again, this is supported by the WETO report (5).

Additionally, the WETO coal case analyses the effects of improvements and future cost reductions in advanced coal based energy technologies. It compares its results with others by US-DOE, IEA and World Energy Council (WEC), and states:

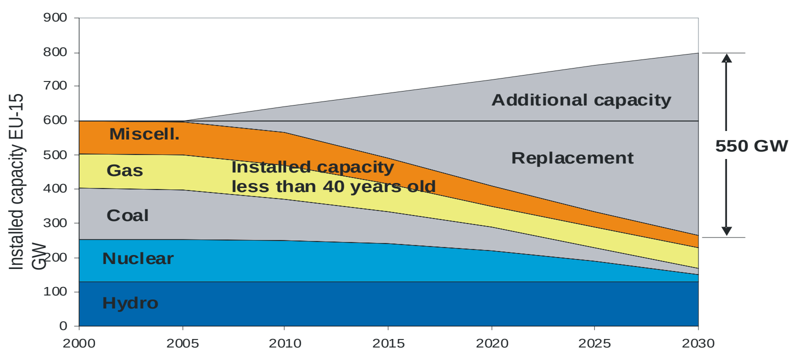
> *"All four scenarios point to an increase in world coal consumption over the next decades, with a total consumption of about 3 Gtoe in 2010. For the longer term, the WETO and*

WEC-IIASA projections show structurally higher coal consumption than the IEA and DOE projections for 2020 and the rise of coal continues in the 2020-2030 decade, with average growth rates higher than 2 %/year. In both cases, coal consumption reaches a level of more than 4.5 Gtoe in 2030, corresponding to a doubling from current levels."

EU demand for energy has been growing at a rate of between 1 and 2% per year since 1986. While industrial demand has been fairly stable, the transition to a service-oriented economy has increased demand for electricity, transport and heat from households and the tertiary sector has more than compensated. With enlargement of the Union, the pattern is likely to change. At present, the new member states are well behind in terms of energy conservation and there will need to be radical changes to achieve significant improvements. After the present phase, however, there will inevitably be a rapid surge in energy demand, especially since in the period leading up to 2010 their economies will be growing much faster than those of the other Member States (3 - 6%, as compared to 1-2% for the EU-15). This transition period should provide these countries with the opportunity of modernising their systems.

Another feature is the extent to which the new member countries are heavily dependent on coal, in contrast to many of the EU-15 countries. This means that their systems will be primarily fossil fuel based for many years to come. Ultimately, as these new member countries will be subject to the same drivers as EU-15, CCT must be attractive at some point.

Over the period to 2030, just in the EU-15, about 550 GW of new generation plant will have to be installed, to meet new demand, and to replace ageing power stations. This is a major engineering and economic challenge, involving the installation of new plant with a total capacity of about 90% of currently operating plant, and at a cost of approximately €400 billion. It presents two problems:



- The new plant that is to be built will itself have a lifetime of about forty years and so will be operating during the onset of the transition away from oil and gas, and with the associated price increases that will inevitably occur;
- The scale of operations, costs, and the need for reliability in the new plant, will make it difficult to accommodate the large-scale introduction of new, unproven and essentially small-scale energy technologies such as biomass, wave or tidal power.

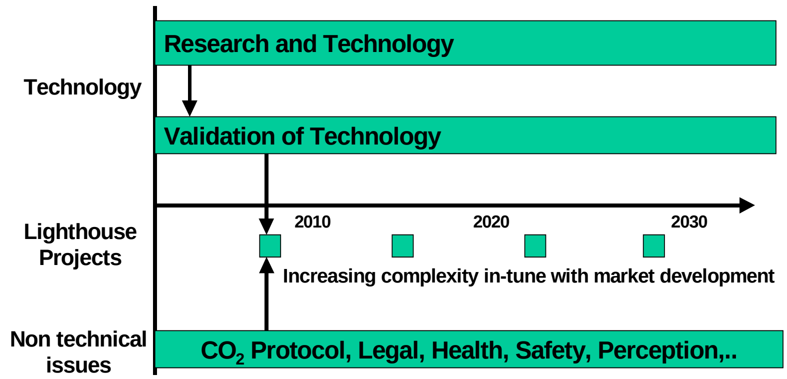
Consequently, it is an inescapable conclusion that a very large proportion of this new and replacement plant will have to be coal fired. However, such plant will need to achieve a much higher environmental performance than existing units in order to meet future EU environmental standards.

- **Fossil fuel demand is expected to increase significantly over the coming decades, with global coal consumption doubling by 2030**
- **Coal is expected to be preferred to gas for electricity production after the year 2020, but gas turbine technology will be critical for IGCC development**
- **EU-15 will require 550GW of new or refurbished power plant by 2030, and this requirement will be greatly increased by the needs of the new Member States**
- **A large proportion of this new and replacement plant will have to be coal fired. However, it will need to achieve much higher environmental performance than existing units.**

3 FOSSIL FUEL CARBON MANAGEMENT STRATEGY

3.1 Strategic issues for the continued use of fossil fuels

For fossil fuels to play a significant part in achieving a sustainable energy future, it will be necessary to define a carbon management strategy that is complementary to, and implemented alongside, those for other sources. In the EU, this means addressing issues that are pertinent to the different Member States as well as to Europe as a whole. Importantly, it also implies an international context both within the EU and externally.



First, the time frames to be addressed must run from now to 2030 and beyond. For example, because of the age-profile mentioned above, the plant replacement programme must be consistent and `in-tune` with the development of the market (subject to changes from increased liberalisation, greater privatisation and more de- or re-regulation) so that finances from the private sector can be brought to bear. This means that there will have to be some clear benefits to the industrial sector early on and during the implementation of the strategy.

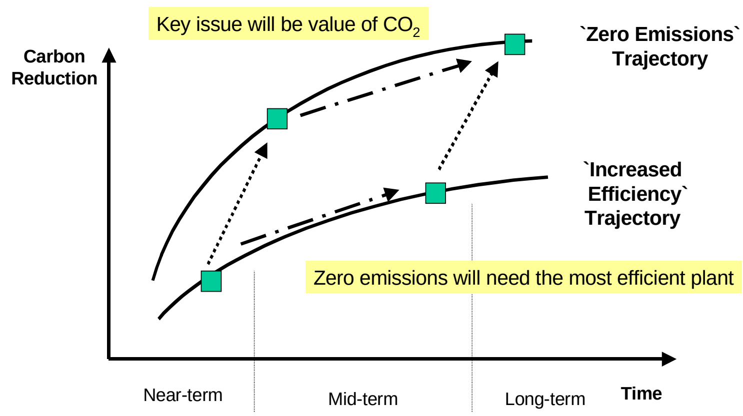
Second, the strategy needs to be broad in nature. Therefore, it needs to embrace increased efficiency and fuel flexibility in the short term, going to (near) zero emission technology involving CO_2 capture and storage in mid term, with a longer term link to hydrogen. It also needs to cover the associated issues of CO_2 transport and infrastructure

Third, the strategy needs to embrace all aspects of technology development, and deployment. It must therefore have elements that cover not only research and technology development system and component - validation but also deployment into the market place. In particular there must be a number of demonstrations (Lighthouse Projects) that provide strong visibility and public confidence that such technologies are possible and beneficial. To be fully successful, these Lighthouse projects must integrate the developing state-of-the-art fossil fuel power plant with the CO_2 capture and storage systems.

Finally, it is essential that any strategy includes the non-technical issues linked to the deployment of the technology. In the case of CO_2 capture and storage in Europe, the North Sea has a tremendous potential but it will be essential to be sure that it can be stored in a safe manner and be accepted from an environmental point of view. This means considering the laws and conventions in light of this objective, very different from their original conception. Also there are health and safety issues, how the public views such technologies and, with the forthcoming CO_2 Emissions Trading (ET) schemes in Europe, the ability to monitor and verify the amount of CO_2 stored.

The value of CO_2 that is established under the ET scheme could have a significant impact on the market and greatly influence the routes taken to deploy the various technologies. For example, if the value of CO_2 is low, the impetus to invest in capture technologies could be limited and the emphasis would be on establishing `$CO_2$ capture ready` plant. This uncertainty in the future favours a `least regrets strategy` that means developing highly efficient fossil fuel use (in power stations for example). Such a route can only benefit zero emissions technology evolution as it will be essential to have the most efficient and cost effective components ready for application in such plant. Alternatively, if the value becomes high, there will be a substantial increase in the interest of near zero emission technology and its implementation, the economics now being substantially different. It is certain that the ET scheme will influence the development of the financial climate in which investment decisions will have to be taken.

It is important to stress that there are two routes to reducing CO_2 emissions from fossil fuel fired power stations. The zero-emissions route of carbon dioxide capture and storage is obviously the long-term target, but significant reductions can also be made, particularly in the shorter term, by increasing plant efficiencies. Additionally, because of the efficiency penalties associated with CCS, it is essential that CCS plants are based on the most efficient (and appropriate) underlying technology.



3.2 International aspects

The clean use of fossil fuels and its inclusion in carbon management strategies is becoming much more evident world-wide. In particular, the USA and Canada have been developing such strategies rapidly over the last 3-4 years (13) and have established leading positions, especially in the area of CO_2 carbon dioxide capture and storage where this has been recognized as a significant technology. More recently Australia has also developed and published a Technical Route Map for CO_2 Capture and Storage with a 30+ year timeframe extending out to the link to hydrogen, where it is recognized that fossil fuels will be the early source (14). This has been done by the newly formed Australian Co-operative Research Centre (CRC) for GHG called the CO2CRC.

Also in June 2003 the US DOE launched the Carbon Sequestration Leadership Forum (CSLF) with the result that 16 countries plus the EC are now signatories of the Charter (15). The aim of the CSLF is to promote the topic of CO_2 capture and storage and, if possible, establish a set of complementary `lighthouse projects` world-wide. To this end a Technology Route Map is being developed that is consistent with the aims and targets of the members. The US DOE project `Futuregen`, which was launched at the time of the CSLF and targets a demonstration of production of electricity and hydrogen, linked to CO_2 capture and storage, will be one of the early projects. This is being termed an `international commercial size test facility`, but it will actually be a showcase for US technology! Other early projects could well include those being developed by the Canadian Clean Power Coalition in Canada and the `Gorgon` Project (a large CO_2 injection project linked to LNG) together with power plant capture projects in Australia.

It is planned that the CSLF will have a greater interaction with the similar initiative also established in 2003 on Hydrogen, the International Partnership for a Hydrogen Economy (IPHE)and which involves 15 countries, many of which are in the CSLF.

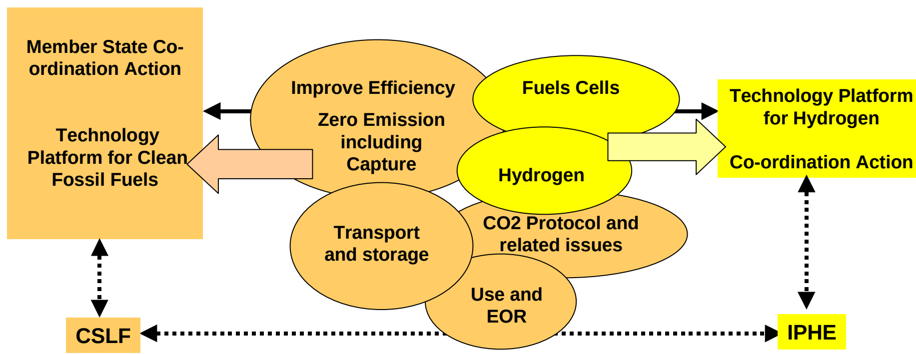
It is important to note that these activities have been developed in the context of a carbon management strategy that encompasses and builds upon the basis established on earlier work performed to improve plant, systems and component performance. All this has been underpinned through enabling technology development and research which remain important elements of an overall strategy.

3.3 European perspective

The EC, through the first part of FP6, has initiated several important capture and storage projects building on the early research work of FP5, one of the more important being involvement in the Norwegian Sleipner offshore storage project. Also several of the Member States are addressing the issue of carbon dioxide capture and storage and how it should fit into a carbon management strategy. However at present there are no commercial-size integrated demonstrations within Europe. Therefore, despite the research work being undertaken and the strong basis being established, this fact could well put Europe, especially its industry, in a detrimental position globally as the technology becomes ready for deployment. This will be true for the whole chain of CO_2 capture, transport and storage together with associated infrastructure issues – not forgetting the fossil fuel power generation technology itself.

In the coming decade, there will be a need for a limited number of complementary commercial sized `lighthouse projects`. It is likely that they will be of increasing complexity and that they will be international in composition. For a benefit to accrue to Europe, it is important that some of these are sited in Europe. Indeed, Europe has specific issues that will have to be addressed both in technical and non-technical ways, such as sub-sea storage in the North Sea initially linked to Enhanced Hydrocarbonl Recovery (EOR & EGR). However it is noted that involvement on a wider international scale will be beneficial at least in maintaining awareness of technology and lessons learned.

Also in order to get to a European programme of sufficient critical mass to be able to compete (or even collaborate) effectively world-wide, for example, with those of the US, it will be necessary to establish a mechanism by which various Member State programmes can come together with those of the Commission. An example of how this can be achieved is the FENCO (clean Fossil ENergy COalition) initiative covering the area of carbon management for fossil fuels. This Specific Supporting Action under the EC FP6 ERANET scheme is led by Germany and the UK (involving 15 EU countries) and could provide the focus for a synergistic approach between the Member States. This would be a major step in moving towards a critical mass EU programme in the area of carbon management associated with clean fossil fuels.



The basis for such an approach is already in place and consequently there is a clear opportunity for Europe to establish an integrated and co-ordinated approach to what will be one of the key areas in the transition to a sustainable energy future. Setting a structure for Europe around the theme of carbon management of fossil fuels with the long-term link to the vision of Hydrogen, also represents a major opportunity for Europe to play an important role in the international community. In addition, by establishing a critical mass programme pulling together actions in the EC and the Member States, there would be significant benefit to the industry and research base in Europe, enabling it to compete effectively on world markets.

One approach is to define a European Technology Platform complementary to the existing one on Hydrogen and Fuel Cells, with co-ordination actions involving the Member States. These would then form a natural alignment with the CSLF and IPHE initiatives world-wide.

- **European fossil fuel strategy requires a time horizon to 2030 and beyond**
- **The strategy must be broad in nature, embracing:**
    - **increased efficiency and fuel flexibility in the shorter term**
    - **near-to-zero emissions technology and CO_2 capture and storage in the medium term, and**
    - **Hydrogen production and use in the longer term**
- **Lighthouse Projects are required to provide strong visibility and public confidence that such technologies are possible and beneficial**
- **Establishment of a critical mass in R, D&D is crucial. This means that there must be a mechanism to pool resources throughout Europe**

4 STATE-OF-THE-ART

4.1 Carbon dioxide capture and storage

The need is to minimise emissions of CO_2 while maintaining very low levels of other pollutants. The options for carbon dioxide capture include post-combustion removal and integrated CO_2 separation within the process itself. Possible storage routes include depleted oil and gas wells (with potential for enhanced hydrocarbon recovery), deep saline aquifiers and deep unmined coal seams. Within Europe, the first RTD projects addressing the issues associated with CO_2 Capture and Storage (CCS) were initiated in the early 1990s, arising from the growing concern about global warming. The European Commission (EC) supported some preliminary RTD projects in the FP3 JOULE Programme, later followed by several significant projects within the 4th and 5th Framework Programmes.

Of particular note is the project to monitor the injection of up to 1 million tonnes of CO_2 per year into a saline aquifer on the Statoil-operated Sleipner field in the North Sea. This was begun in 1996 and was the first environmentally driven CCS project. From it, several EC/industry (SACS) RTD projects were initiated. This put Europe in a leading role when it came to the storage element of environmentally-driven CO_2 abatement. Other key projects include: GESTCO (geological storage potential in 8 European countries), CO_2STORE (monitoring at Sleipner and application of the experience to onshore sites in the GESTCO countries) and NASCENT (the study of naturally occurring CO_2 seepage). In addition, the European Commission has supported RTD activities relating to capture cost reduction (as part of the industry-based Carbon Dioxide Capture Project led by BP) and European participation in the Canadian Weyburn oil field enhanced oil recovery (EOR) RTD project. The CO_2NET Thematic Network was created as a forum for European collaborative efforts and knowledge transfer.

Most of the CO_2 storage effort thus far has focused on aquifers and disused gas fields with minor work on coal beds and other options. While these storage options are very important and have the largest attached storage volumes, it is imperative that attention is also directed at the major current and past petroleum provinces in Europe. Obviously the oil industry is keen to deploy any commercially (and environmentally) attractive techniques such as EOR to the producing North Sea oil fields. From a societal point of view there is, however, a larger picture to consider, i.e. the timely exploitation of additional North Sea oil resources, while also considering the potential for subsequent CO_2 storage after commercial oil field operations have ceased. This has not hitherto been a priority RTD topic and the time window is narrow, 10-15 years. The proper use of active and old petroleum fields throughout continental Europe - not least in the new member countries - is also an outstanding issue.

The new EU CO_2 projects, under the first round of FP6applications are large (budget of €15 to 20 million for the Integrated Projects) and cover four of the main areas of priority: pre-combustion capture (ENCAP), post-combustion capture (CASTOR), geological storage (CO_2SINK) and a scientific Network of Excellence (CO_2 GeoNet). As such they will contribute significantly to maintaining a high European profile within the field of CCS and will form a significant springboard for the future.

At present there are no commercial electricity generation plants in the world using CO_2 separation and capture technologies, but there is a large international interest in its development and demonstration. The USA and Canada in particular are already fully committed to the development of these technologies. With the its strong industrial base in power engineering and oil and gas production, EU industry could win a substantial share of the very large potential global market for carbon dioxide capture and storage technology. However, as is noted below, it is imperative that EU industry is positioned to ensure that it can take full advantage of all aspects of such a market opportunity, which will include the need for an integrated approach for advanced power generation systems.

The drive for reduced oil-dependence and pollution in the transport sector has created support for the development of the “Hydrogen Economy”. The difficulty with this concept is that hydrogen is not a fuel, and must be manufactured from other sources. While there has been much interest in hydrogen from renewable sources, there are inadequate such resources available to make a significant impact.

In contrast, coal gasification and natural gas reforming are established routes for producing hydrogen and there is large potential for the concept of multi-faceted hydrogen-producing IGCC plants. If such high efficiency units were established with integral CO_2 capture and storage they would represent a major step towards the establishment of hydrogen as an energy vector in the EU economy.

Recently, the European Commission has announced the Quickstart Initiative for the Hypogen Programme. This aims to demonstrate hydrogen and power production from fossil fuels (for example through coal based IGCC or natural gas reforming). The fact that such an initiative is being considered is an important fact in itself and importantly could form the framework for a major action covering all aspects (both technical and non-technical) in the development of a path to successful deployment. It is evident that such a pathway for coal/IGCC must include the equally important step of improving the technology components in such a way as to achieve overall optimisation and integration of the system.

- **The options for carbon capture include either post-combustion control, or integrated CO_2 removal within the process itself**
- **Possible storage routes include depleted oil and gas wells (with the potential for enhanced oil recovery), deep saline aquifiers and deep unmined coal seams**
- **The EU has launched four carbon dioxide capture and storage projects under FP6: pre-combustion capture (ENCAP), post-combustion capture (CASTOR), geological storage (CO_2SINK) and a scientific Network of Excellence (CO_2 GeoNet)**
- **Processes developed for carbon capture are the natural basis for producing hydrogen as the feedstock for the Hydrogen Economy**

4.2 Advanced fossil fuel energy technologies

It is essential to realise that the proposed technology options have the potential to achieve high standards of environmental performance, and that CO_2 capture and storage is likely to be more cost effective when applied to coal fired plant rather than to natural gas plant. However, it is also important that costs are considered and presented on a level playing field basis. For example, various studies have suggested that the cost of CO_2 avoided for a large scale modern, advanced coal fired plant with CO_2 capture and storage (CCS) is comparable to or lower than for a typical biomass fired unit or many other forms of renewable energy.

As has been discussed already, the global market for advanced coal fired technology is very significant and there will be major opportunities for EU industry, provided that the necessary technology has been developed and proven. Initially, this means technologies with higher efficiencies, better environmental performance and higher availabilities. Over the medium to long term, such systems must be equipped with CO_2 capture and storage technology, integrated with the advanced fossil fuel power plant in such a way as to minimise the penalties on efficiency and availability.

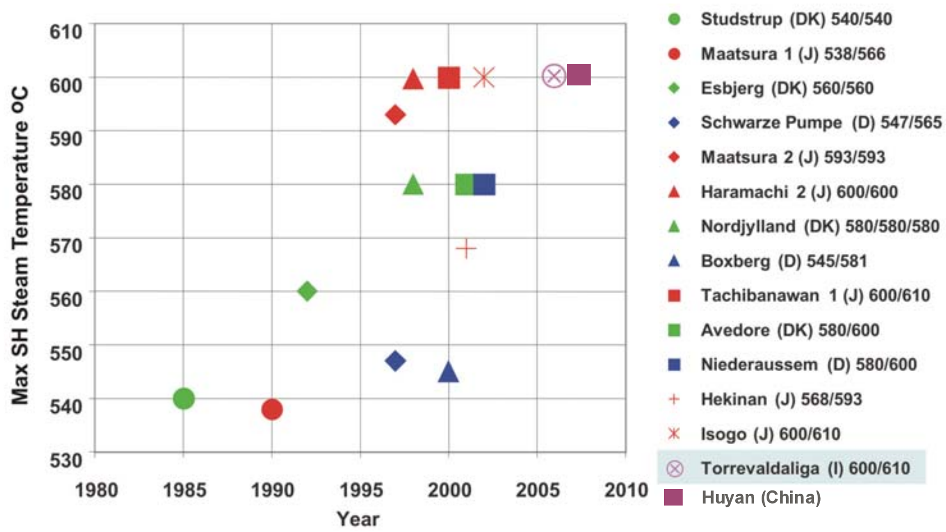
This will require a major R, D&D drive if EU industry is to take an international lead in the development and deployment of carbon dioxide abatement technologies within the fossil fuel fired power generation sector. To achieve this goal, it will be necessary both to enhance the energy and environmental performance of the existing key fossil fuel technologies and at the same time develop, establish and integrate the CO_2 capture and storage techniques.

Thus, it is essential that the development of CCTs with higher efficiencies and better environmental performance is recognised as a key enabling step for the medium to long-term creation of near-zero-emissions power plants. Various coal-based technologies are being developed in Europe that could in due course offer the necessary performance. These are still at the pre-competitive R&D stage and the lack of clearly defined market drivers means that EU industry would need support to take such technologies forward to the demonstration of commercial prototypes. Previously, support would have been provided via the European Commission Framework Programme. However, while support can be provided for CO_2 capture and storage under FP6, the necessary complementary R, D&D for the advanced CCTs to be established and then integrated with such systems are not included.

By contrast, the EU's major industrial competitors, the USA and Japan, both have long-term visions that include coal with advanced CCTs as a major part of the overall technology mix for a sustainable energy future. Most importantly, the exploitation of such CCTs within the global export market is seen as a key policy objective in both countries. Consequently, when both EU energy/environmental needs and industrial competitiveness are considered, there is a very real danger that, unless the current EC policies are modified, then not only will the European Union fail to achieve a sustainable energy future but there will also be a severe and major setback for the EU power generation equipment industry, which could end up severely disadvantaged compared to its major competitors.

Pulverised Fuel Plant

Worldwide, the most commonly used coal-fired technology is based on pulverised fuel (PF) plant. The state of the art efficiency in Europe is >45%, based on supercritical steam plant operating at about 600^oC. Also, techniques have been established to control acid gas pollutants such as NO_x and SO_2.

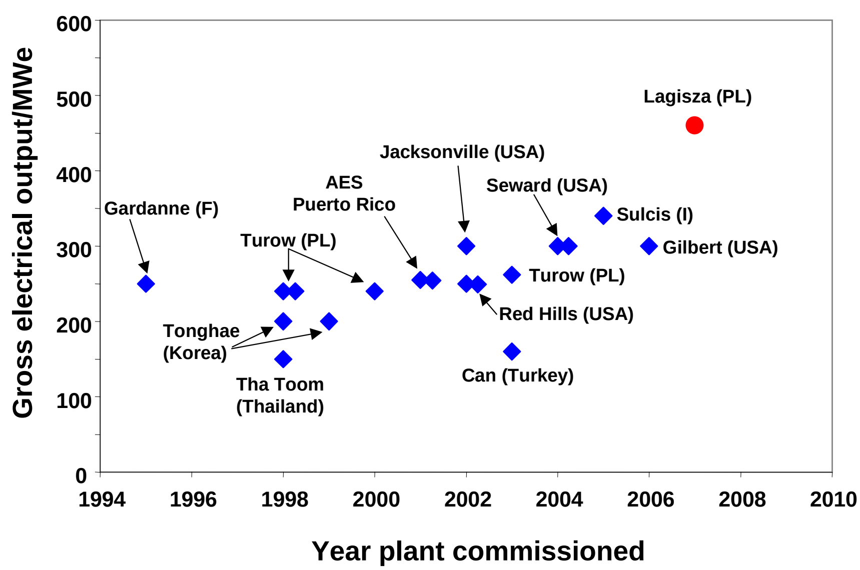


In a market context, European companies have historically built over 50% of the world's power plants. Plants with the latest supercritical technology have been installed in Denmark and Germany, and, in Italy, Enel is at the final approval stage for the installation of 3 x 660 MWe PF boilers, designed for 270 bar, 600/610 °C, today the most advanced steam conditions in Europe. Thus Europe is at the forefront of this development, both in the materials and plant development areas. Thanks to earlier EC and ECSC support, the EU is on a par with Japan, and 20 years ahead of the USA.

The EU R&D target is to achieve 50 – 52% in new ultra-supercritical plant operating at 700^{o}C and very high pressures. This evolution represents a striking 45% increase in efficiency from the present fleet performance, with corresponding reduction in CO_2 emissions. However, the limitations of the FP6 scope of work means that such R, D&D can no longer receive significant support from the EC, and it is difficult to see how it can progress towards the demonstration of a commercial prototype.

Circulating fluidised Beds

Circulating fluidised bed combustion systems offer an alternative to PF plants, with the advantage of being able to utilise low grade, variable quality coal, plus biomass and wastes, and still achieve high environmental performance at lower cost. Of the technologies considered, this appears to offer the best route for co-firing as a means of CO_2 mitigation. New plants with supercritical steam parameters can offer overall net efficiencies in the 43-45% range depending on fuel and condenser conditions. The first supercritical unit is being established in Poland. As yet, such systems cannot offer the economy of scale of the larger PF plants. However, even so, the market potential is very significant, particularly in developing nations such as China and India. Ultimately, the introduction of larger units with advanced steam conditions should enhance that market potential on a worldwide basis.

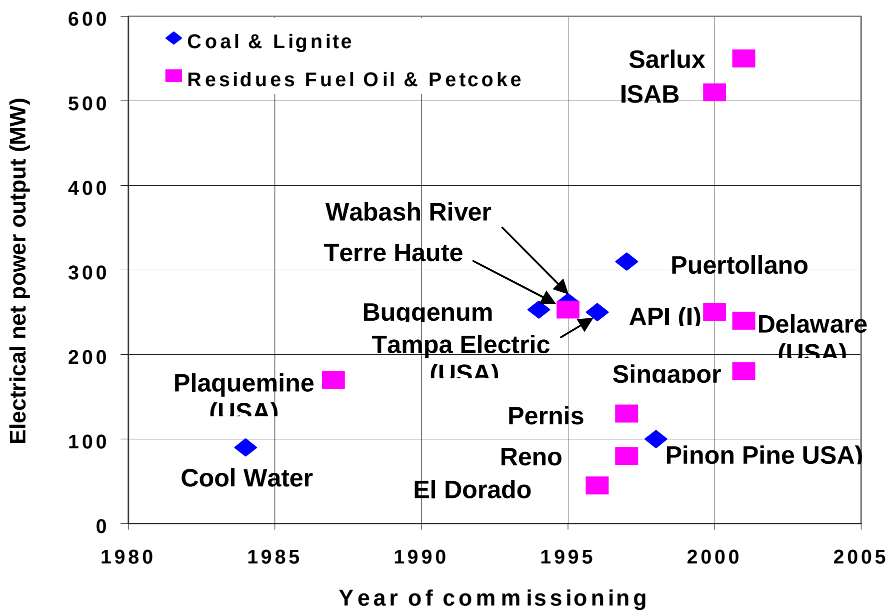


European companies are very active in this area. Thus Electricité de France (EdF) has established a substantial R, D&D programme on CFBC centred on the Carling (125 MWe) and Provence (250 MWe) power stations. It is also investigating the scale-up of CFBC to 600 MWe in a single boiler unit. There has been significant effort by manufacturers such as Lurgi and Foster Wheeler to develop the technology further, to achieve a breakthrough in utility solid fuel power generation by high efficiency Circulating Fluidised Bed (CFB) technology with supercritical (SC) steam parameters.

Under the Third and Fourth Framework Programmes, support was provided for the development and demonstration of CFBC technology and multi-partner collaborations from member countries of the EU were encouraged. Under FP5 and FP6, there has been no funding for either development or demonstration. Some R&D funding is available via the ECSC for multi-partner activities.

IGCC
In Europe, gasification technologies and gasification combined cycle systems have been developed to the large-scale pilot stage with funding from industry, nation states and the European Commission.

Two variants of the entrained bed concept have been demonstrated at the commercial prototype scale at Buggenum and at Puertollano, with part funding from the EC Thermie Programme. Both plants operate reasonably reliably with efficiencies of over 42% (LHV) and the Puertollano unit is widely regarded as the state of the art operational technology. Optimisation studies carried out under EU non-nuclear energy R&D programmes have demonstrated that the efficiency of the Puertollano type concept could be increased to over 50% using world-market coals by implementing simple design changes based on conventional available technologies, including the use of a state of the art gas turbine. That said, work is needed to resolve technical issues and to build customer confidence.



Beyond this, significant R&D is needed to achieve higher efficiencies. However, because of the oxygen-fed nature of the process, it is the coal-based technology best suited to linking with CO_2 capture technologies. Consequently it is the technology of greatest potential when a near zero emissions power plant concept is considered. Ultimately, coal gasification and the use of IGCC could lead to efficiencies of about 60%, with the prospect of near complete capture and storage of the CO_2. If this target were achieved, it would represent a 66% improvement over present technology, and would result in a 40% reduction in CO_2 emissions – close to the long-term European target.

Coal-Biomass Co-utilisation
The other R&D area where some limited support is provided via the FP6 biomass programme, is the co-utilisation of renewables with coal. There are a number of synergetic relations between coal and renewables, essentially combustible materials such as biomass (and waste), which suggest that coal plant might provide the route by which large scale biomass energy plants could develop.

Essentially, and except in special circumstances, biomass plant is small in scale. The fuel supply is diffuse, and must be concentrated and transported to the power plant. This limits the size of the plant to that matching the locally available fuel resource. Because of the small size and the low calorific value of the fuel, biomass combustion/gasification is inherently inefficient and suffers large energy losses. By contrast, coal plant is large in scale and coal has a high calorific value. Thus, coal plant is more efficient and suffers lower energy losses. The co-combustion of biomass with coal provides the scale of operation that would allow biomass to be used efficiently. It could also help to solve part of the problem of reducing coal-related environmental emissions by substituting coal with biomass.

Burning coal and biomass together overcomes the uncertainty about what level of distributed small scale generation can be tolerated on a grid system before instabilities and control problems become a serious problem. There are, however, some technical uncertainties since the high alkali content of some biomass materials can cause excessive fouling of boiler internals under certain conditions. Thus it is essential to ensure that the co-firing of coal and biomass can be introduced successfully on a technical and economic basis.

- **The three main candidate Clean Coal Technologies are ultra-supercritical PF (AD700), circulating fluidised bed combustion, and IGCC**
- **These technologies are the basis on which future carbon capture and storage technologies should be built**
- **There is a very large world market for clean coal technologies**
- **IGCC is the basis for the development of the hydrogen economy**
- **Europe is a world leader in the development of all three technologies, and is extremely well placed to take advantage of their development**

4.3 Turbomachinery and enabling technologies

For the future of advanced power generation, including both CCTs and CCS, the key enabling technology will be turbo-machinery. Both gas and steam turbines, together with the generator, represent critical elements of current and future systems and have the potential to increase further the overall process efficiency. In particular, the gas turbine, with its high efficiency and flexibility in terms of operational loads and fuels, needs to be noted. The performance of steam turbines is closely linked to the higher temperature and pressure cycles considered above, where efficiency improvements remain one of the most important developments.

In the 1990s, gas turbine combined cycle power generation systems became the favoured generation technology for base load operation due to a number of technical and market driven factors. De-regulation of electricity supply regimes together with the growth of independent power producers and merchant power suppliers resulted in a demand for electricity at lowest cost. The increasing maturity of gas turbine technologies allowed them to meet this need. Wherever natural gas is available, gas turbine combined cycle power plant has dominated the orders for new electrical generation capacity and there has also been increasing demand for gas turbines for industrial use in integrated electricity and steam cycles and other co-generation fields. In addition, use for shaft power and pumping applications increased significantly. Globally, in the late 1990s, gas and steam turbines for combined cycle operation represented over 60% of the annual new generation orders.

Gas turbines will be the key prime mover for all power systems based on natural gas and for gasification-based technologies where the fuel is a producer gas or hydrogen. Fuel flexibility will become increasingly important as natural gas becomes more expensive. The ability to handle alternative fuels such as poorer quality natural gas, industrial process gas, and gasification products of coal and bio-fuel will become increasingly important.

The development of gas turbine technologies was supported within EC FP4 and FP5, including the establishment of the thematic network CAME-GT that formed a useful forum to bring together the industry and the research base. Also it was possible to establish a limited amount of technology transfer between the aero-engine development work supported by the EU and the industrial gas turbine industry, despite the very different load cycle. These developments primarily targeted basic technologies such as aerodynamics, heat transfer, combustion, materials, and instrumentation and controls. A number of projects were also supported that evaluated novel cycles including integration of alternative energy sources within the gas turbine cycle. However under FP6 there has been no direct support and also the network will be discontinued after 2004, thus creating a gap for Europe in an increasingly accepted key technological area for the future.

It should be noted that the industrial development of gas turbines follows a defined approach, with new turbines being introduced into the market in a timed cycle. Thus, opportunities to demonstrate new technologies on new platforms occur only in limited “windows of opportunity”. It is therefore beneficial that governmental development and demonstration funding cycles are in phase with those of business. While this co-ordination has been successfully achieved in the USA, the “arms length” policies now followed in Europe – as indicated by the lack of direct support in FP6 - are resulting in mismatched scheduling, with adverse impact on EU industry business opportunities.

- **Development of the hydrogen economy depends critically on ensuring adequate supplies of fairly pure hydrogen. For the foreseeable future, this will have to come from fossil fuels.**
- **The primary enabling technology for advanced power generation will be the gas-turbine. The key issues here will centre on efficiency and fuel flexibility. Gas turbines will be required to handle a mixture of fuels from natural gas, through gasification products of coal and biomass, to hydrogen.**
- **Another key issue is the need to ensure that R&D expenditure is in phase with the windows of opportunity that arise from the business cycle and the appearance of natural market drivers.**

5 R, D&D NEEDS

The key requirements for improving the competitiveness of fossil fuel fired power generation technologies are

- to reduce fuel consumption through increased efficiency,
- to capture CO_2 from the process, and then
- to transport the CO_2 and
- store it safely in suitable geological structures.

These subjects are linked, and choices made in one area depend critically on advances made in the others. Of key importance is the need to establish a critical mass of research, industrial and end-user interests to ensure that an R, D & D programme is capable of making the transfer to demonstration and from there to commercialisation.

5.1 To optimise the performance of existing CCTs

R, D & D needs must be considered within the vision of technology development and deployment set out above, but also reflecting uncertainties arising from externalities and funding availability issues since funding support will always be constrained. The role of direct industry R&D and the need for support through the European Research Area both need to be considered.

In overall terms, there is a need to consider the R, D&D necessary to improve the economics of the CCTs of major interest within Europe, to improve thermal efficiency, reduce environmental impact, and reduce capital and operating costs, while improving plant availability. The timescale is to be able to offer such optimised technologies within a period of some 10-15 years in order to maximise opportunities within both EU and global markets.

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Ultra-supercritical PF combustion

The driving force for this technology is to reduce CO_2 emissions through advanced steam cycles. In the short to medium term (5-10 years), the aim is to achieve very high efficiency with advanced ultra-supercritical steam cycles while ensuring that novel components using new materials of construction can achieve acceptable reliability at economic cost. Within the EU context, the AD 700 project is a classic example of this type of activity, and, with input from all major EU equipment manufacturers and several end users represents a viable ERA approach. It has been the subject of a significant EU cooperative R&D programme involving 39 companies from 12 Member States. However, the limitations of the FP6 scope of work means that the AD700 project can no longer be supported.

In order to progress some aspects of the R&D, a consortium of EU utilities and manufacturers has gained funding from the Research Fund for Coal and Steel for the testing of materials for evaporator and superheater components on an existing power plant. There are also materials development activities within the COST 522 and COST 536 programmes. Ultimately, however, if EU industry is to maintain its competitive position compared to Japan and the USA, funding must be available within FP7 so that the project can progress towards demonstration of a commercial prototype.

It is also essential that any demonstration is backed up by a clear unambiguous, level playing field, techno-economic analysis in order that the cost of electricity can be truly established. Such an approach must also cover competing technology variants.

Circulating fluidised bed combustion

There has been significant effort by various manufacturers to develop the technology further, to achieve a breakthrough in utility scale solid fuel power generation. The drivers are to establish larger, 600-800 MWe, units with advanced supercritical steam cycles so that higher efficiencies can be obtained. A further increase in efficiencies to 50% will be the target through the use of advanced steam conditions, adapting the advances being developed for PF boilers under projects such as AD 700. Such units will need to be demonstrated to ensure that there are no materials issues not already dealt with in ultra-supercritical PF systems.

Proposals have been prepared by major EU industrial companies to advance the state of the art through a multi-partner development programme aiming at developing a highly competitive system. This includes the integration of a 20% substitution of coal by renewables (biomass), which can reduce CO_2 emissions by a further 20-25%. As a result, the new advanced characteristics and advantages of CFBC technology could be fully utilised, enhanced further and transferred to the wider power generation industry. Again this represents an IP-type initiative for a technology demonstration, which should be considered within the ERA context. This too will need financial support from the European Commission within FP7 if the EU competitive position compared to the USA is to be maintained.

IGCC

IGCC is already recognised as a very clean coal based technology that other CCTs cannot match, although emissions legislation worldwide does not yet require such standards to be met. However, availability problems with the existing large units still have to be fully resolved. In overall terms, the prime area for development is the integration of the various components to ensure a lower capital cost for the system. With regard to the components themselves, for entrained flow systems the issues include materials to ensure greater reliability, especially refractories, improved dry feeding, particularly for mixed feedstocks, improved fire-tube cooler designs with regard to minimising deposition and corrosion. Linked to all of this is the development of gas turbines to fire the fuel gases that will arise from different gasification units, particularly hydrogen which will be the prime fuel produced when CO_2 capture is undertaken.

As noted in the previous section, the efficiency of the Puertollano concept could be increased to over 50% using world-market coals by implementing fairly simple design changes based on conventional and available technologies, including the use of a state of the art gas turbine. Beyond this there would need to be significant R&D to achieve higher efficiencies. However, it must be stressed that it is the coal-based technology best suited to integral CO_2 capture. Hence, it is the technology of greatest potential when a near zero emissions power plant concept is considered.

It is evident that this vision is recognised in the USA and Japan, with the USA and others committing large-scale funding to demonstrate coal fired IGCC for hydrogen production and CO_2 capture and storage. In the USA, within the Futuregen programme, such a system will be based on US technology, *with the expectation that the USDoE will gain a significant return on its investment from increased export sales by US companies*. Consequently, if Europe wishes to remain competitive for the supply of the technology that appears to offer the best option for near zero emissions power plant then designs must be established with efficiency and availability targets such that it will be credible to integrate CO_2 capture systems.

While aspects of the near zero emissions technology development are included within FP6, FP7 must support the equally important steps to take forward the IGCC technology itself so that an overall integrated system can be established. Thus at present there is a limited amount of work being undertaken within FP6, within the ENCAP project, which is examining IGCC designs to optimise the shift reaction for hydrogen production. More recently the European Commission has announced the Quickstart Initiative for the Hypogen Programme.

5.2 For near-to-zero emissions technologies

The considerations as set out in the previous section are equally applicable here, based on the need to develop and establish near zero emissions technologies by 2020-2030 (which will be based on fossil fuel power generation technologies currently under development). This is set within the definition of the technology development and deployment vision outlined earlier, but also reflecting the uncertainties arising from funding availability and externalities issues since funding support will always be constrained. Again the role of direct industry R&D and the need for support through the European Research Area both need to be considered, from which will arise a listing of R, D&D topics that could best be covered within an ERA type of structure.

Post-combustion capture of CO_2 from combustion processes

The driver here is to minimise emissions of CO_2. The options include either post-combustion control, or integrated CO_2 removal within the process itself. Thus for PF systems, and in principle CFBC systems, the preference is for removal of CO_2 at the stack as a relatively dilute component of the flue gas. For CFBC systems, the current smaller size of CFBC compared to PF makes CO_2 removal less economically attractive.

In terms of R&D priorities, these include the need to demonstrate the removal of CO_2 from a PF plant at a significant scale. At the same time there is a need to develop less energy intensive removal schemes than amine-based chemical scrubbing. This work forms part of the strategic priorities for FP6 and R&D is included within the CASTOR project. However, further emphasis needs to be given to integration of the combustion process with the CO_2 capture stage in order to minimise efficiency losses and potential plant flexibility/availability problems for both PF and CFBC systems.

Oxy-combustion to enhance post CO_2 capture

The aim with regard to oxy-fuel combustion is to establish a more concentrated stream of CO_2. This technique is far from proven both technically and economically. Issues include combustion control, the effects of a concentrated CO_2 gas stream on corrosion of boiler heat transfer surfaces, slagging and fouling. The development of lower cost, less energy consuming oxygen separation systems is also a key requirement (that is also applicable to IGCC). This R&D activity forms part of FP6 within the ENCAP project, but again, overall system integration and related issues will need to be considered for both PF and CFBC applications.

Chemical looping combustion

While the EU focus must be on the existing technologies best suited for subsequent near zero emissions development and application, it is appropriate to consider future innovative possibilities that might be worthy of significant funding in due course. One such prospect, which also links to CFB technology opportunities, is chemical looping combustion (CLC), development of which started under the FP5 Grace project.

The CLC principle is to stage the traditional combustion process into two separate reaction phases involving a looping solid metal oxide reactant. Thus, it can lead to the direct concentration of CO_2 in an enclosed reactor unit, thereby avoiding the need for an air separation process. In principle it should be applicable to boilers and gas turbine power cycles, offering high flexibility in the use of fuels, although, the most suitable fuels appear to be natural gas and coal.

Under FP6, the Commission is supporting some preliminary activities, within the ENCAP project, which include investigations of carrier stability and integration into a CFB CLC concept. Should the research be successful and should the techno-economic assessments be positive, it would then be appropriate to consider further financial support for some form of pilot plant activities, after which, larger-scale trials and demonstrations might be appropriate.

Pre-combustion CO_2 capture

IGCC, as noted previously, should be highly suited to integrated CO_2 separation as it produces a fuel gas that is rich in H_2 and CO, which can be converted to H_2 and CO_2 using the so-called water shift reaction. The higher pressure operation and greater concentration of CO_2 would facilitate the separation and capture of the CO_2, but there is then a need to ensure that the gas turbines can utilise hydrogen as the fuel gas while still meeting all necessary performance requirements. The underlying need is for IGCC to become established, which under current market conditions will be difficult even though ultimately this appears the more promising route for CO_2 capture. However, consideration needs to be given to support its development in the ERA context of CO_2 capture and storage.

There is scope for R&D on some of these issues within FP6 (within the project ENCAP). However, it is evident that a greater technology development, demonstration and deployment programme will be required. For example, the prospect of a CO_2-capture side-stream on the Puertollano or Buggenum IGCCs needs to be explored. Ultimately, full-scale demonstration of an advanced EU IGCC concept will be needed as a technology showcase for subsequent global exploitation. The recently announced EC Quickstart Initiative for the Hypogen Programme is a powerful driver in this regard.

Multi-function IGCC

Coal gasification is an established route for producing hydrogen and there is considerable potential for multi-faceted hydrogen-producing IGCC plants. If high efficiency units were established with integral CO_2 capture and storage, they would represent a major step towards introducing hydrogen into the EU energy system and elsewhere. This is, in part, the rationale for Hypogen, which is designed to encourage the development of the infrastructure, networks and knowledge needed to launch a genuine hydrogen economy.

Thus, there is a primary need is to ensure that EU gasification technology for power generation can advance significantly so that Europe can achieve the necessary reductions in greenhouse gas emissions while EU industry can challenge effectively in a global market. At the same time it is essential to recognise the timing implications for market opportunities and the financial constraints even within a European Research Area.

Consequently a phased approach is proposed based on the initial need to move the system optimisation forward through R&D on a 5-10 year timescale. This could include:

- Gasifier component development, including improved materials of construction and improved feeding and handling systems.
- Ancillary component development, including lower cost air separation units.
- Gas turbine development to ensure the efficient use of hydrogen rich fuels (already covered to some extent within FP6 as part of the project ENCAP).
- Complementary design and optimisation studies, with integration of CO_2 capture.
- Associated techno-economic studies, including the global market possibilities.

It is also important to be alert to opportunities that might arise, which could allow the timings to either be advanced or for additional funding to be introduced. For example, it is known that the World Bank/GEF will support the 400 MWe Yantai IGCC demonstration project in China both to accelerate the application of the technology in China (and elsewhere) and also to assist the long-term goal of H_2 production/CO_2 capture as a first significant step towards zero carbon dioxide emissions. Consequently there may be a prospect to carry out a side-stream experiment on this plant if the EU options are not available for whatever reason.

Ultimately, there is a need to establish a commercial prototype demonstration of a European IGCC technology that can achieve the performance required by the market. Such a unit will need to demonstrate reduced energy use and capital cost with improved operational flexibility. There will need to be integrated CO_2 separation from fuel gas that has undergone a hydrogen shift stage. Alongside this, gas turbines are required that can use hydrogen as the fuel gas while still meeting all necessary performance requirements. It might well be particularly important to demonstrate the multi-function capability of IGCC for the co-production of hydrogen and power from fossil fuels. This would require the plant to be designed to produce electricity, heat and synthesis gas. As such, the plant must be located near an industry that could use the synthesis gas to produce high value chemical by-products, such as ammonia and methanol.

This offers the prospect of clean power with provision of hydrogen, which is seen as a key requirement for the future EU energy economy. The timing for this activity is probably 15 years and upwards.

There is a need to develop and establish near zero emissions technologies by 2020-2030. These will be based on CCTs currently under development. The key areas are

- **Post-combustion capture of CO_2 from combustion processes**
  - **Oxy-firing to enhance CO_2 capture**
  - **Chemical looping combustion**
- **Pre-combustion capture of CO_2 for IGCC applications**
- **Multi-function IGCC based on the need to accommodate multiple feed streams and to produce a range of outputs which could include electricity and hydrogen.**

5.3 For turbo-machinery and enabling technologies

Turbomachinery, both gas and steam turbines, will remain key elements of advanced power generation systems into the future. The performance of steam turbines is closely linked to the higher temperature and pressure cycles considered in the RTDD needs of CCTs. It is noted that efficiency improvements remain one of the most important areas.

Gas turbines cover a wide range of applications and sizes. Therefore any development strategy must take into account the driving forces that determine the technical needs. For the larger gas turbines, as appropriate to power generation systems, the major driving force is cost of electricity. Efficiency, reliability and availability all contribute to this.

	Current	**2006**	**2012**	**2020**
Efficiency GTCC %	58	60	65	75
Availability %	92	94	95	96
Reliability %	97	98	99	99
Cost of Electricity (c/kWh)	0.040	0.038	0.037	0.036
NOx ppvm	25	9	5	1
CO2 cost (€/t CO_2)	50	30	20	10
Efficiency with CO_2 %	47	55	60	72
Cost of Electricity with CO_2 mitigation	0.077	0.061	0.051	0.040

Targets have been set as shown in the Table for the development of gas-turbine technologies to meet this challenge. The R&D needs to meet these targets can be summarised as:

- Materials development to raise metal and surface temperatures
- Improvement of near wall cooling technologies; manufacturing techniques and validation
- Development of modelling and simulation techniques
- Improvements in combustion kinetics and acoustics
- Development to allow the use of low calorific value gases and of hydrogen
- improvements in wet compression, sealing technologies, and robust performance

The key enabling technology is the gas turbine. Here the development issues include:

- **Materials development to raise metal and ceramic surface coating temperatures**
- **Improvement of near wall cooling technologies; manufacturing techniques and validation**
- **Development of 3D aerodynamic codes and validation through testing**
- **Improvements in combustion kinetics and acoustics, with validation through testing**
- **Development to allow the use of low calorific value gases and of hydrogen**

5.4 For CO_2 storage

Here, there is a broad range of requirements, which includes studies to guide the selection of suitable storage sites, specification of operating conditions, and establishment of high integrity methods for final closure of an injection site. There is also a requirement for sensitive and cost effective long-term monitoring techniques to confirm that the stored CO_2 is behaving as expected. Finally there is a need to demonstrate storage to establish full confidence in the practical application of the technology.

The technology of CO_2 storage in deep unmineable coal seams is still in the development phase, so applied research programmes, as well as field demonstration projects, are required to address the existing knowledge gaps.

For CO_2 storage in oil and gas reservoirs, there is an economic need to define ways to maximise the value of produced hydrocarbon resources and CO_2 storage and provide economic optimisation. Injection & Separation Facilities for use in offshore applications need to be lighter and cheaper. Corrosion control, the integrity of old well stock and long-term well sealing all need to be investigated both to prevent CO_2 leakage and to cope with ultimate well abandonment. Other areas include subsurface modelling, phase behaviour and injectivity, and surveillance, safety and monitoring.

For storage in aquifers, the R, D & D needs to centre on three areas: material and equipment development (well completion, CO_2 injection, monitoring and measurement), subsurface process understanding (storage mechanism in aquifers, flow paths, chemical changes in rocks and fluids, time scales over which these processes act), and development of modelling and prediction tools.

Here, there is a broad range of requirements, which includes studies to guide the selection of suitable storage sites, specification of operating conditions, and establishment of high integrity methods for final closure of an injection site. One example is the development of new cements with high CO_2 tolerance

There is also a requirement for sensitive and cost effective long-term monitoring techniques to confirm that the CO_2 is behaving as expected.

Finally there is a need to demonstrate storage so that the process can be fully understood in practice.

5.5 Lower capture rate CCS strategies

If carbon dioxide capture and storage were to be adopted in some form on current power plant technologies, a number of CO_2 emission reduction opportunities could become available before the 2020 – 2030 timeline presently envisaged.

Thus, if a less-than-near-zero emission policy was acceptable as an interim measure, it should be possible to install systems delivering part-capture with a lower energy efficiency penalty. This might provide a more economic route in the mid-term, while complete capture options are being engineered

CCS could be adopted earlier on current plant, with a lower impact on operating efficiencies, if a lower CO_2 capture criterion of say 50% was acceptable

6 CONCLUSIONS

Europe faces significant challenges to establish a sustainable energy use and management policy while meeting environmental standards and ensuring security of supply. The future energy needs of the enlarged EU will be so significant that the full range of available fuels (including renewables, nuclear, natural gas and coal) will have to be utilised on an environmentally acceptable basis to meet the demands. All of the recent major economic projections suggest that fossil fuels must remain a key factor for power generation, and hence that new power plants must include advanced CCTs with carbon dioxide capture and storage technologies so that ever-tighter emissions limits can be met. It is also essential that EU industry is in a position to exploit such advanced CCTs within a global context against what will be very significant competition from other OECD countries and elsewhere.

Consequently, when full consideration is given to economic, environmental issues and externalities, a key part of EU energy policy must be to ensure that coal, oil and natural gas can provide a sustainable part of the overall EU energy mix. At the same time, the EU power plant manufacturing and supply industry needs to remain competitive such that it can take advantage of the major global opportunities for new and replacement power plant. This requires the continuing advancement of existing CCTs together with an associated and major effort to ensure that the related near-zero emission technologies can be developed and established on an attractive economic basis. This approach offers the vision of maintaining a fossil fuel based technology, for which there will be the benefit of efficiency and environmental improvements plus lower costs with the existing technology options. At the same time, this will provide the base on which the related near-zero emissions technologies can be established subsequently in a cost effective, credible manner. Alongside this is the need to further improve the efficiency performance of large gas turbines, both for use in gas fired combined cycle plant but also for use in advanced coal based IGCC systems, with particular reference to the use of coal as a transitional fuel for the establishment of the future hydrogen economy.

Since many developments are still at the pre-competitive R&D stage, and the market drivers are not clearly defined, EU industry needs support to take forward these initiatives. Thus it is essential that the European Union provides positive action to support the EU power industry in working together on a Europe-wide basis to establish the clean use of coal and other fossil fuels, with the ultimate aim to ensure cost effective near zero emissions power plant. The role model would be the European Research Area and it is suggested that there is a strong need to put together an integrated approach combining the inputs of EU industry, the various national programmes and the European Commission. While some individual aspects of the R&D are being funded within FP6, it is essential that the scope of FP7 is enlarged so that all the key enabling steps, both for advanced CCTs and near zero emissions power plants including CO2 capture and storage and its link to hydrogen production, can be taken forward on an ERA basis within an integrated programme.

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9 THE R, D & D THEMATIC NETWORKS

PowerClean

PowerClean has the objectives of encouraging collaboration, co-operation, and exchange between EC supported research projects and researchers, helping to maintain the technical and industrial content of future European energy-related research, and contributing to identifying future research priorities for clean power generation.

The 52 members include the leading industrial, academic and independent research centres throughout Europe, and the whole spectrum of interest from laboratory R&D, through manufacturing to final users are represented. Further details can be found on the web site at http://www.powercleannet.net.

CO_2NET

CO_2NET is intended to provide a think-tank of expertise and information for policy-making and to facilitate decision-making at European and national level. Its activities are to facilitate research collaboration and map European centres of excellence, to develop a database on RTD projects, skills and IPR, and to assess and define R&D strategy in areas related to CO_2 capture and storage.

There are 64 member organisations in 18 countries. Further information is available at http://www.co2net.com.

CAME-GT

The Thematic Network for Cleaner and More Efficient Gas Turbines (CAME-GT) provides a platform for the review and dissemination of information generated within European funded gas turbine research and technology demonstration projects. The members of the project are the leading European gas-turbine manufacturers, together with representatives of the new accession countries.

Further information is available from http://www.came-gt.com.