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CLEAN COAL TECHNOLOGY SALES PROSPECTS

Assessing the impacts of an EU CCT support programme

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Acknowledgement

This report covers Task 5 of the so-called CARNOT study carried out in charge of the Commission of European Communities Directorate General for Energy (DGXVII) under contract STR-1121-96-UK. The study has been co-ordinated by ETSU (UK) and the partners were FZ-Jülich and BSO (D), CIEMAT (E), and Novem (NL), with Hügli Pollock Read and ECN as sub-contractors. Task 5 has been contracted by Novem to ECN under number 7.7097.

Abstract

The CARNOT study assesses the possible impacts and prerequisites of an EU programme aiming at the support of Clean Coal Technology development, manufacturing and sales opportunities. It also includes an assessment of the organisational and institutional prerequisites of an intended CARNOT programme. The principal findings are synthesised in the main report and the implementation plan both issued by ETSU. Furthermore, the several participating institutes have published Task reports, being CIEMAT (Task 2), ETSU (Task 3), Hügli Pollock Read (Task 4), ECN (Task 5),and FZ-Jülich (Task 7).

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SUMMARY

Purpose and Scope

The CARNOT study assesses the possible impacts and prerequisites of an EU programme aiming at the support of Clean Coal Technology (CCT) development, manufacturing and sales opportunities. This report discusses the approach and results of Task 5 of the CARNOT study. Task 5 focuses on the estimation of the impact of a European CCT support programme on CCT sales volumes, kind of CCT technology sold, and volume of CCT manufacturing activities inside the EU up to 2010.

For this purpose CCT sales scenarios have been calculated. A distinction is made between a situation in which independent power producers (IPP) penetrate rapidly in the power markets of many countries and a situation in which this penetration builds up more slowly. A swifter penetration of IPPs on the various power markets is supposed to lead to less capital scarcity and consequently, more new generating power will be realised in the IPP High than in the IPP Low scenario, notably in some South- and East-Asian countries such as India, Indonesia, Pakistan, etc.

Economic Results

For both situations (IPP Low and IPP High) a variant *with* a CARNOT programme and a variant *without* a CARNOT programme have been calculated. Comparison of the results of the variants *with* and *without* CARNOT indicates an order of magnitude of the economic impacts of such a CCT support programme. For the entire time span studied, 1995-2010, the benefits regarding newly built capacity accrue to 7.5 to 8 billion ECU of additional production value in CCT manufacturing inside the European Union. An important part of this production concerns sales in Asian countries. The remainder will be in Central and Eastern Europe and inside the EU.

Since a CARNOT programme will come into effect not before 1999, the principal benefits are concentrated between 2000 and 2005. After that time, the benefits with respect to newly built coal power will gradually decrease, from just over 1 billion ECU annually down to a still significant 0.5 billion ECU annually. By approaching 2010 the decrease will continue, which can be attributed to the inevitable shift in manufacturing capacity towards the rapidly industrialising countries in Asia and to a lesser extent to Central and Eastern Europe as well. Please note that some of the latter countries will enter the European Union during the period 2000-2010.

The retrofit market is strongly dependent on policies, regulations and enforcement practices. Though more wealth will facilitate the implementation of retrofit projects, there are many local factors involved. Therefore, we decided that a distinction between IPP Low and IPP High was not useful. Just one scenario has been applied *with* and *without* CARNOT. The benefits from a support programme for CCT in retrofit projects are obviously smaller than for newly built capacity and are even much more concentrated in the early years of such a support programme. The extra production value for CCT manufacturing inside the European Union amounts to almost 300 million ECU annually between 2000 and 2005. Given the age structure of the global coal

power capacity the retrofit market is finite, at least for the kind of projects considered here. Consequently, the production value for CCT manufacturing inside the European Union drops to 6 million ECU annually after 2005. It is imaginable however that after 2010 an entirely new kind of retrofit will develop for the coal power built between 1995 and 2005. By that time the market conditions and the technology options will have changed so much that a completely new support programme will be needed. This notion applies to the market for new capacity as well.

The differences between the impacts of a CARNOT programme on the IPP Low and IPP High scenarios are not so large. In absolute terms the IPP High scenario generates a larger impact from a CARNOT programme (0.5 billion ECU more for the entire period). In relative terms the boost from a CARNOT programme is somewhat larger in the IPP Low scenario. IPPs will evaluate new CCT options somewhat different (with more emphasis on comprehensive costs) than utilities will do. Therefore, a CCT support programme should include a portfolio of instruments that can be tailored to crucial criteria in actual markets.

In the simulations for this study the market shares of EU based CCT manufacturers do not slide down under 40%. In case local manufacturers would develop even much stronger than assumed in this study, still significant benefits from a CCT support programme would remain, though with some shift from production effects inside the EU towards revenue transfers back to the EU. So, even in case of a market share that would drop to 20% of total sales in target markets, the benefits would accrue to 2.5 to 5 billion ECU.

Backgrounds

The impact of a CARNOT programme on CCT manufacturing inside the European Union is related to more cost effective and cost reducing designs of advanced clean coal technologies. As a consequence alterations in manufacturing processes may occur as well. In the default situation (without CARNOT) CCT manufacturers can only spend a limited amount on product research and development both aiming at higher performances and at lower unit costs. Despite these efforts still larger cost reductions can be derived from shifting production to selected export areas, provided that the basic conditions in these new host countries meet minimum standards regarding legal, economic, educational, and infrastructural aspects. The higher the standards are, the more advanced production can be transferred. So, in a situation without a CARNOT programme CCT manufacturing industries will tend to shift more production capacity towards selected expanding sales areas in order to remain competitive. A well focused comprehensive CCT support programme will slow down this process, provided it aims - among other things - on cost effective and cost reducing advanced clean coal technologies. As regards finance and marketing barriers Tasks 3 and 4 have put forward recommendations for those issues.

As regards newly built capacity five CCT options are considered, being:
- conventional pulverised coal with flue gas desulphurisation and low NO_x burners (PF),
- (ultra) supercritical pulverised coal with flue gas desulphurisation (FGD) and low NOx burners ((U)SCPF),
- atmospheric fluidised bed combustion (AFBC),

- pressurised fluidised bed combustion (PFBC),
- integrated coal gasification combined cycle (IGCC).

We assumed that AFBC and PFBC were predominantly used in small to medium scale plants (up to 100 MW), whereas the other options are assumed to be used for large scale facilities. Yet, in the future PFBC may be used for somewhat larger scales as well, while in some export markets there are simplified IGCC plants under construction of less than 100 MW.

Given the impending convergence of costs per kW of PF and SCPF, the latter technology seems to be the preferred one up to 2005, PF is decreasing and IGCC is just appearing (perhaps as commercial demonstration only). After 2005 IGCC is expected to play a more important role, being at least equal to that of (U)SCPF. As regards the small and medium sized plants AFBC will dominate before 2000. After that PFBC will gradually become more important and will even have a somewhat larger share in newly built capacity after 2005. If PFBC would succeed to penetrate the large scale market as well, then notably IGCC might suffer loss of market share.

Environmental results

The approach adopted for the impact assessment of a clean coal support programme was in the first place designed to illustrate how economic processes are affected. Therefore, the emphasis was on how and where CCT will be manufactured for a given market size. Within the boundaries of that approach the *simulated* impacts of a CARNOT programme on emission reduction are small. It is very likely however, that a CARNOT programme will contribute to the *acceleration of the uptake* of clean coal technologies and consequently will bring about accelerated reductions of emissions.

Considering that the economic impact oriented scenario construction has severely diluted the probable impacts of the promotion of CCT technologies, a second way of attributing the improvement of environmental performance has been applied. In this approach it has been assumed that in the absence of a CARNOT programme and given the capital limitations in a power market with low IPP participation Asian countries will continue to build just conventional coal power (PF + FGD) and AFBC. This means no SCPF, PFBC and IGCC will be installed in Asian countries in this variant. In that case a significant difference between a *with CARNOT* and a *without CARNOT* situation can be demonstrated. In fact this version of the environmental evaluation illustrates the risk of not staging a CCT support programme. In the case of a Low IPP scenario (implying less money available in target markets) the continued reliance on conventional technology turns out to become environmentally very unfortunate in the course of the next decade.

Even compared to the total EU emission levels, significant reductions are at stake. In the period 2006-2010 the annual emission reductions amount to 146,000 tons for SO_2, 290,000 tons for NO_x and 90 Megatons for CO_2. For example, these reductions equal approximately 2% of the EU NO_x emissions and almost 3% of the EU CO_2 emissions.

Remaining Aspects

Though the word 'coal' is used throughout the report, in fact other solid fuels are relevant as well. The share of other solid fuels is small compared to the total volume of the market for new power. However, in some countries and in the power market up to 100 MW other solid fuels can constitute important shares. The waste-to-energy market is currently building up inside the EU. Similarly, the ongoing massive urbanisation in many Asian countries will cause a transfer from landfill practices to better utilisation of urban waste, e.g. in waste-to-energy projects. In some rural areas, on islands, etc. adapted clean coal technology will enable clean and efficient ways to use local biomass. Please, note that these rapidly growing economies often have balance of payments deficits. Therefore, local fuels such as waste and biomass, just as indigenous coal, can attenuate these deficits.

The logistics of coal is always complicated and relatively expensive, unless minemouth power stations are used. In the fast growing Asian economies using indigenous coal, notably China and India, logistics is really becoming a bottleneck. To date most of the coal is transported by train. Given the rapid growth of industrial output there is increasing competition for rail and train capacity. In this situation the already large and still growing coal shipments are a heavy burden on the railway system and high opportunity costs due to crowding out of shipments with higher value added. The improvement of coal logistics, e.g. by constructing slurry pipelines coal logistics would enjoy lower unit costs, higher reliability and less environmental impacts. Another approach would be to reduce the losses of long range power transmission substantially and thereby making minemouth power generation more cost effective.

INTRODUCTION

The CARNOT study assesses the possible impacts and prerequisites of an EU programme aiming at the support of Clean Coal Technology (CCT) development, manufacturing and sales opportunities. This report discusses the approach and results of Task 5 of the CARNOT study. Task 5 focuses on the estimation of the impact of a European CCT support programme on CCT sales volumes, kind of CCT technology sold, and volume of CCT manufacturing activities inside the EU up to 2010. Special attention is given to the issue of global industrial dynamics with respect to coal (power) technology, notably clean coal technology (CCT). Furthermore, the impacts of the use of more advanced clean coal technologies on emission levels have been calculated as well.

In the CARNOT study 8 tasks have been distinguished. The overall co-ordination and the compilation of a main report and an implementation plan was organised in Task 8 (ETSU). Task 1 (ETSU) covered the organisation of the Forum meetings. The Forum was a consultative platform of representatives from the CCT manufacturing industry as well as from banks, consultancy and engineering agencies, and electric power companies. Task 2 (CIEMAT) synthesised the principal developments in CCT RD&D programmes inside and outside the EU and summarised the strong and weak points and key success factors in the programmes considered. Task 3 (ETSU) dealt with the barriers in finance of clean coal technology projects in export markets, while Task 4 (Hügli Pollock Read/Novem) surveyed the sales prospects of CCT, the role of EU based manufacturers in the global market, and especially discussed the barriers encountered in CCT sales activities in export markets. Task 6 (FZ-Jülich/BSO) calculated the direct and indirect employment impacts inside the European Union of a clean coal support programme. The results of Task 6 are closely connected to the results of Task 5. Task 7 (CIEMAT) aimed at the formulation of a communication plan. Annex A contains a further description of the eight tasks.

Next to new desk research as part of Task 5, the findings of Tasks 3 and 4 [1, 2], as well as Task 2 [3] have functioned as guidelines in shaping both the assumptions and the market process descriptions. The basic picture from which the study started is defined in the report Clean Coal Technology - Markets and Opportunities made by ETSU on behalf of IEA [4].

This report is composed of two main parts, discussing the market implications and the environmental implications respectively. Part 1, covering the market implications, consists of chapters 2 to 6, while Part 2, discussing emissions, consists of chapters 7 and 8. Conclusions and Recommendations are reiterated in chapter 9. More extensive information on input data used can be found in the Annexes B, C and D.

1. CURRENT SITUATION

1.1. Core Markets and Technologies

The primary focus of application of CCT is in the electric power industry. The expectation for coal based power within the EU can be summarised as predominantly a replacement market. Interesting export markets for power generation technology in general are China, India, South-East Asia, Latin-America, and Central and Eastern Europe. The market for expansion and upgrading in China and India is very large [4], but the competition and conditions of the local authorities imply that the resulting market share for CCT of European origin has a large uncertainty margin. Central and Eastern Europe constitutes a smaller market, but its nearness renders an advantage to EU manufacturers. The approach of European manufacturers of the Asian markets will often differ in many respects from the approach of the markets in Central and Eastern Europe.

The urgent need for power generation extension in combination with capital shortage in China, India, and many other developing countries, makes these countries very critical as regards investment costs. This is currently definitely a disadvantage for CCT, given the higher cost per kW [5,6,7]. It also means that these countries attach very high value to maximum availability in order to produce as many kWhs per year as possible, since latent power demand is so large. This is a second hurdle to be taken for selling CCT, as firm empirical proof of high availability has hardly started to accumulate [5]. Since the present capital shortage is increasingly being solved by engaging independent power producers (IPP) [8,9,10], the critical evaluation of investment cost and availability becomes even more crucial. On the other hand, the rapid economic growth has aggravated the environmental problems in China and India, notably in various growth pole cities, such as Shanghai. Therefore, as soon as project offers show acceptable investment costs and guarantee sufficiently high availability levels, environmental performance does become a selection criterion. In brief: *the customers look for an affordable and reliable technology that is as clean as possible.*

So, initially (until at least 2005) an enhanced penetration of CCT on the world market will mainly depend on:

- the speed of reduction of capital cost per kW of CCT,
- proven competitive plant availability through building track records,
- environmental regulation in the target countries.

Once CCT has obtained a foothold in the power generation markets, and capital cost reduction is achieved by selling larger numbers, environmental performance of various CCT options will become even more important, while fuel efficiency and maintenance and operation costs will receive increasing attention as well. The latter development will be also supported by maturing of the economies, which means that labour gets more expensive and the willingness to pay for environmental quality increases.

For Central and Eastern Europe the situation is different from the developing countries. Generally, there is no shortage of power generating capacity. There is however a urgent need to refurbish (coal) power stations in order to arrive at emission levels and fuel efficiencies that are compatible with the performance of (coal) power stations in EU countries. This need for compatibility is stimulated by the pre-accession process which takes place in Central and Eastern European countries that signed an accession treaty with the European Community. Actual access to the EU could speed up the aforementioned process. Furthermore, the liberalisation of electricity markets will increase the pressure on former CEE utilities to increase the fuel efficiency. Present EU member states have expressed their serious intentions to enlarge the EU within 10 years. Indirectly, through assistance programmes this has created a quasi-market for refurbishing of power stations in CEE countries. Obviously, EU based manufacturers have a multitude of advantages in this market.

All in all these considerations can be summarised in a hypothesis of a two stage process of market penetration of CCT for electric power applications, in which the stages are defined by what the customers are demanding:
1. a first phase primarily aiming at capital cost reduction and proven high availability (time indication -> at least until 2005; in the project this is further divided in 1995-2000 and 2000 - 2005).
2. a second phase primarily aiming at further improvement of the environmental performance, the fuel efficiency and, the operation and maintenance costs (time indication -> starting between 2005 and 2010; in the project this is further divided in 2005 - 2010 and 2010 - 2020, the latter only for tentative projections).

This two stage process hints at a technology support programme that initially puts more weight on cost reduction and maximum availability, while later on the environmental performance and the operational and maintenance cost could receive the most attention. Cost reduction will be mainly a matter of research while proven availability requires demonstration.

The discussion above concerns the new capacity to be built in target markets. Next to that market there is a retrofit market. Retrofit denotes a large range of activities spreading from what is in fact overdue maintenance through environmental modifications to total repowering of plants. In this report retrofit is especially identified as modifications of and additions to the power plant. Larger rehabilitation projects which often encompass substantial upgrading or even replacement of the boiler and/or the turbine are regarded as belonging to the new capacity market.

1.2. Other Items

The discussion above applies in the first place to the utilisation of coal and lignite, notably but certainly not exclusively in large scale power stations. However, the advances in clean coal technology extend beyond the use of coal and lignite. Especially, urban waste and biomass will be relevant and welcome additions to the range of input fuels. In the subsequent chapters it is assumed that notably power plants under 100 MW will be often fired (or co-fired) with non-coal solids.

The waste-to-energy market is currently building up inside the EU. Similarly, the ongoing massive urbanisation in many Asian countries will cause a transfer from landfill practices to better utilisation of urban waste, e.g. in waste-to-energy projects. In some rural areas, on islands, etc. adapted clean coal technology will provide clean and efficient ways to use local biomass. Please, note that these rapidly growing economies often have balance of payments deficits. Therefore, local fuels such as waste and biomass, just as indigenous coal, can attenuate these deficits. So, despite the fierce competition from natural gas, especially in smaller scale power plants (in which coal has diseconomies of scale) other solid fuels can be attractive even to IPPs. For example, the outsourcing of urban waste management could lead to the emergence of IPPs in the larger urban areas in Asia.

The logistics of coal is always complicated and relatively expensive, unless minemouth power stations are used. In the fast growing Asian economies using indigenous coal, notably China and India, logistics is really becoming a bottleneck. To date most of the coal is transported by train. Given the rapid growth of industrial output there is increasing competition for rail and train capacity. In this situation the already large and still growing coal shipments are a heavy burden on the railway system and high opportunity costs due to crowding out of shipments with higher value added. The improvement of coal logistics, e.g. by constructing slurry pipelines, coal power would enjoy lower unit costs for transportation, higher reliability and less environmental impacts. Another approach would be to reduce the losses of long range power transmission substantially and thereby making minemouth power generation more cost effective.

In the assessment of the development of preferences for CCTs in target markets the logistics have not been taken into account, since the choice of a clean coal technology and the way the manufacturing is organised is not linked to the logistics problem. However, significantly better coal logistics may be expected to influence the location of power plants and will contribute to a better competitive position of coal compared to natural gas.

2. GLOBAL TRADE AND INDUSTRIAL DYNAMICS

In chapter 2 is explained what the principal market areas are expected to be and what kind of (clean) coal technologies will be used in those market areas. The next step is to explain the various dimensions of competition that European clean coal technology (CCT) manufacturers have to deal with when they operate on these markets. Two elements stand out, being the share of global CCT sales that European manufacturers might obtain and the distribution of actual manufacturing activities over European locations and overseas locations. The development of global market shares of European CCT manufacturers has been studied in Task 4 [2]. This study makes use of that information and has focused more specifically on the second aspect mentioned above, being the distribution of activities over European and overseas locations. However, in addition to the market information based on [2] and [4], developments have been checked during an extra workshop with Forum members dedicated to industrial dynamics and location preferences in the CCT industry.

The remainder of this chapter has two sections. Section 3.1 briefly discusses the several elements of competitiveness as well as how this report perceives the competitive position of European CCT manufacturers in terms of shares in global sales up to 2010. The second section 3.2 explains the logic of shifting locational preferences depending on the maturity of technology at hand and depending on the industrial organisational options available. Obviously, the items are interrelated, since manufacturing location influences the price of a technology and hence its competitiveness.

2.1. Competition between Countries and across Technologies

Even if CCT would actually penetrate quicker than expected, e.g. due to cost reduction achieved in a CCT support programme, there are various filters that heavily influence the amount and the character of the benefits that might accrue to European manufacturers. In the framework of this study a manufacturer will be regarded European, if the manufacturing itself takes place in an EU country or when a significant part of the revenues of activities in the target country flows back to a manufacturing company in the EU.

Basically, there are two categories of filters, one category referring to the market share of European CCT in the global market and a second category referring to the economic organisation of the implementation of CCT in export markets. The first category will be termed as *European competitiveness* and the second category as *Industrial dynamics*. These categories are interrelated, since the competitiveness of European companies is influenced - among others - by the way they have organised their operations world wide.

The European competitiveness for CCT can be subdivided in:

- the position compared to traditional coal technology; in this study conventional pulverised coal (PF or PF+FGD, see below) is considered to be the reference technology.

- the position compared to non-European suppliers of CCT, in particular USA based and Japanese manufacturers.

Conventional pulverised coal (including DeSOx and DeNOx measures; 39% fuel efficiency) is taken as the reference technology. Utilities and certainly IPPs in export markets will only purchase more advanced CCT, if the alternative technology can generate electricity against competitive costs and/or if very cost effective emission reductions can be achieved. The position of coal in comparison to other (non-solid) fuels, notably natural gas, has been taken care of in a preparatory study by ETSU [4].

As regards the competitiveness of non-European competitors it is virtually impossible to give clear cut ratings. The relative positions depend on the export area, the kind of technologies involved and the size of the project. Furthermore, the world of CCT manufacturing gets more and more intertwined. Depending on licensed technologies, consortium co-operations and regional joint-ventures, CCT manufacturers will often be associates in one product-market combination and at the same time competitors in another product-market segment. This means that the distinction European vs. non-European gets somewhat blurred. Therefore, the definition of European CCT manufacturing has been defined as described above. It also means that the development of the market shares of EU based companies as derived from the survey carried out in Task 4 [2] will be used as an important guideline for the simulations in this Task, but not necessarily translate directly into model input or output of Task 5, since also other sources such as feedback from Forum members has been used.

All in all it is assumed that the market shares of non-European manufacturers of OECD origin will not change significantly. Possible winners will be located in the main export markets, such as China and India. Yet, such local companies will often 'win' through the establishment of joint ventures with OECD based manufacturers and or will use licenses. In that sense EU based manufacturers will continue to play a role albeit on a different footing.

2.2. Industrial Dynamics and shifting Locational Preferences

When a technology matures the competitive edge moves from technological quality towards cost level. Maturity implies that there will be a lot of manufacturers that are able to produce the machinery, as knowledge about the construction has become common. Consequently, the level of technology as such is no barrier any more to entry of the market. In order to distinguish from other producers cost competition becomes a much more prominent feature (it doesn't mean that cost awareness was totally absent in earlier stages). For given levels of technological quality and advancedness different countries will show different minimum cost levels attainable. The more mature the technology is, the more likely it is that low wage countries have a cost advantage. Therefore, it seems logical for European CCT manufacturers to attempt to move manufacturing of maturing technologies to market areas with lower wage costs, provided minimum quality requirements can be met. Let's observe the main market areas for CCT.

The following areas are distinguished (between brackets area indication and estimated additional coal capacity in GW from ETSU CCT market assessment report [4]):

• EU + Norway and Switzerland	(W Eur.	10 - 20 GW)
• Central and Eastern Europe, Turkey	(CEE+FSU*	5 - 20 GW)
• China	(China	170 - 190 GW)
• India	(S Asia	60 - 70 GW)
• Other South and South-East Asia	(S Asia + E Asia	95 - 110 GW)
• Rest of the non-OECD world	(SCA, Africa, Middle East**	55 - 65 GW)
• Rest of OECD	(N Am., J, A, NZ	40 - 85 GW)

*) In the ETSU report [4] Turkey is included in the Western European group, however in terms of socio-economic conditions and political situation (a preaccession status similar to some CEE countries) it fits better in the CEE+FSU group.

**) The Middle East is only pro forma included, most of the capacity is expected in Africa.

The market areas listed above have different levels of accessibility for European CCT manufacturers. There are a number of reasons for this differentiation, such as:

- presence and strength of local competitors,
- degree of local technical competence and consequently tendency for low tech or high tech solutions,
- regulations regarding market entry.

The differentiation of market areas will be discussed below.

Cost levels of technologies as discriminating factor and options to alleviate cost barriers
Though cost competition will play a role in all export markets, the European manufacturers have an advantage of nearness and preferentially in the first two mentioned areas, while non-OECD Asia and Africa will be the major battle fields vis a vis competitors from other OECD countries. In order to convince a customer to buy CCT instead of traditional coal technology (TCT) the initial investment cost per kW should not deviate too much and/or should be compensated by reductions in other cost items (fuel, operation, maintenance). Furthermore, the availability should match those of TCT power plants. Generally, the clean coal technologies as currently built/tested in OECD countries are too expensive for China and India, let alone Africa, with the exception of AFBC. Cost reductions for CCT projects in such countries can be obtained via two ways:

1. *clever designs*, in which slight concessions to environmental performance enable significant cost reductions by skipping or simplifying components or simplifying the manufacturing process of components.
2. *clever project organisation*, in which for each component and for the logistics of the (final) assembly the most cost-efficient (sub-)contractor is engaged without compromising contractual quality obligations.

Ad.1 *Cost reduction through clever design*
There is a limited number of options to achieve cost reductions without affecting the environmental performance too much. The applicability is a matter of case-wise consideration depending on coal quality (or that of other solids), location, usefulness of by-products, etc. Design adaptations can have high cost reduction impacts in case of retrofit of existing power stations too. So, in terms of marketing and research strategy it will be attractive to investigate, assess and categorise the principal alternatives, under which conditions they can be applied and, what are actual suitable locations in target countries.

Cost reduction options are inter alia:
- use of air instead of oxygen in IGCC,
- limestone injection for FGD retrofitting.

Please note that clever design will enhance the opportunities for involvement of local manufacturers. An example of this approach is the construction of a commercial IGCC/CHP plant in India (60 MW adjacent to a cement factory; surplus power into public grid; air blown instead of pure oxygen [11]).

Ad.2 *Cost reduction through clever project organisation*
The number of options to (re)organise the manufacturing process is also large. Furthermore, preferences for particular solutions will change over time due to changes in economic (e.g. prices, wages), political (e.g. trade barriers, requirements to foreign direct investment, restrictions on capital movement), and technical conditions (e.g. quality performance levels of local manufacturers, logistic innovations).

The following options for international operations exist (which are not mutually exclusive) [12, 13]:
- trade (shipping product from Europe to target area),
- direct foreign investment
  - establishing a new subsidiary company in target country,
  - take over existing company in target country,
  - joint venture with local and/or other foreign companies,
- sub-contracting to local company,
- local production based on a license agreement with a local company.

The choice of one or more of the above mentioned options is often influenced by various kinds of barriers, intended and unintended, that are mainly caused by national or supranational agencies. Four main types of barriers may be distinguished, they are consecutively related to:
- trade (tariffs, quotas),
- direct foreign investment and participation (limits on profit retention; limits to ownership of local companies, etc.),
- financial markets (immature, volatile banks, convertibility, inflation, etc.),
- knowledge transfer (denying/underrating patent revenues, compulsory transfer, lack of copy protection, etc.).

Trade barriers can have either the purpose to protect local manufacturers or persuade manufacturers abroad to start up local manufacturing. Due to the recent world-wide trade agreements and the establishment of a new organisation, WTO (World Trade Organisation; successor of GATT), most countries generally tend to diminish trade regulation. However, at the same time more countries are flocking together in trade blocks (EU, NAFTA, MERCOSUR, ASEAN, CIS), while the markets of China and India are - potentially - so large that so far they can afford to stay on their own (and to some extent dictate their own terms of trade). Yet, at a global scale trade is growing faster than world production, which points at an ongoing trend of specialisation and co-operation.

Market size, negotiating experience of the customers and their special requirements will affect the importance of the barriers. The composition of power station consortia tends to become ever more international and intercontinental. Furthermore, the composition of consortia for similar power generation projects is not fixed. Changing commercial and technical opportunities lead to changes in consortia. In this respect the implicit assumption in the project as if entirely European CCT products can be sold to export markets is preferably abandoned and replaced by the assumption that European CCT manufacturers will take part in consortia with varying degrees of participation.

When shippings to another country become very large and frequent it gets worthwhile to consider the establishment of local production abroad. Substituting local production for trade gets more easily attractive the larger the commodity is. This certainly applies to energy technology. Usually many segments of power stations are manufactured locally if not on the spot [14; also acknowledged in the Forum]. In a free market situation the supplier(s) will just optimise their overall costs of manufacturing, assembly and logistics. Chances for local production will increase if:

- more than one project has to be implemented in the same country/area,
- the components used are not first of a kind,
- local manufacturers can meet (or be taught to meet) the quality standards without significant extra cost.

A shift towards local production will be often stimulated by national and local authorities in order to stimulate employment and enhance knowledge transfer. In most target countries the costs of local employment are considerably lower than in Europe. Therefore, most CCT suppliers will need modest encouragement to engage local manufacturing, perhaps with the exception of a few components embodying crucial patents. In some countries the availability of sufficient competent personnel and management still constitutes a problem. However, the impression exists that the competence level of manufacturing and engineering in developing countries is constantly improving [15].

Applying the above rules to practice means that, for example, the probability of significant local engagement in manufacturing for a CCT project in India is larger than in Vietnam. By the way, building - 'bricks and concrete' - is almost by definition a local affair.

Retrofit market

The discussion above has been focused on newly built capacity. By and large the same sort of mechanisms are active in the retrofit market. However two provisos could be made in this respect. First, retrofit projects are usually smaller than building new capacity, while on top of that the degree of customisation of retrofit should not be underestimated. The smaller size of the projects imply that the scale independent costs of foreign projects threaten the possibility to earn a margin. This implies that on one hand European manufacturers will be more keen on protecting key (patent) technology, while on the other hand as much as possible local input through outsourcing (sub-contracting) is necessary to protect the margin.

A second feature is that the current generation of retrofit technology (FGD, SCR, etc.) is meant to be built in a certain kind of coal power capacity. This stock is finite both in size and lifetime. Consequently, the retrofit technology included in this report can only be sold for a (relatively) limited period. This implies that the establishment of overseas manufacturing activities will be less attractive, unless a limited amount of investments is needed or flexible participation arrangements can be set up.

3. TOWARDS A METHODOLOGY

3.1. Overall Concept and Position compared to other Tasks

Having identified a collection of market features that influence the economic organisation and a number of technology options that contribute to simplified design, we can start to link the features influencing economic organisation to the identified CCT market areas and their present barriers/opportunities and the simplified design options to the various CCT options and their costs per kW and availability rating. This is indeed the purpose of Task 5 in the CARNOT project, organising the CCT supply and demand information in a way that is tractable and fit for use in quantitative estimations.

The available CCT options need to be screened on their applicability in the various market areas up to 2005 and after that time, given specific information and expectations on fuel quality, environmental regulation, etc. For each CCT - market area combination the most likely type of project organisation, including an indication of the share of local involvement, should be identified.

Having identified a collection of most promising product-market combinations for the medium (1995-2005) and long term (2005 - 2010) a qualitative backcasting can be constructed as regards the selection of critical issues in technology research and development for CCT. Supposedly, such R&D may include organisational aspects such as developing a handbook for contingent CCT project design under specific market conditions.

The main logic of activities in Task 5, also in relation to the activities of other tasks, is summarised in Figure 1 on the next page. Three major types of input information are required being 'economic organisation' (e.g. production and market shares), power market by area (expected GW by market area), 'CCT options and costs' (e.g. capital costs per kW per plant type). These boxes are indicated at the left hand side of Figure 1. The task number indications between brackets in the various boxes indicate the sources information is expected to come from. If Task 5 is (also) mentioned in Figure 1 it means that (part of) the information has to be processed within Task 5. Furthermore, information flows are not supposed to be one way, implying feedback to Tasks supplying information.

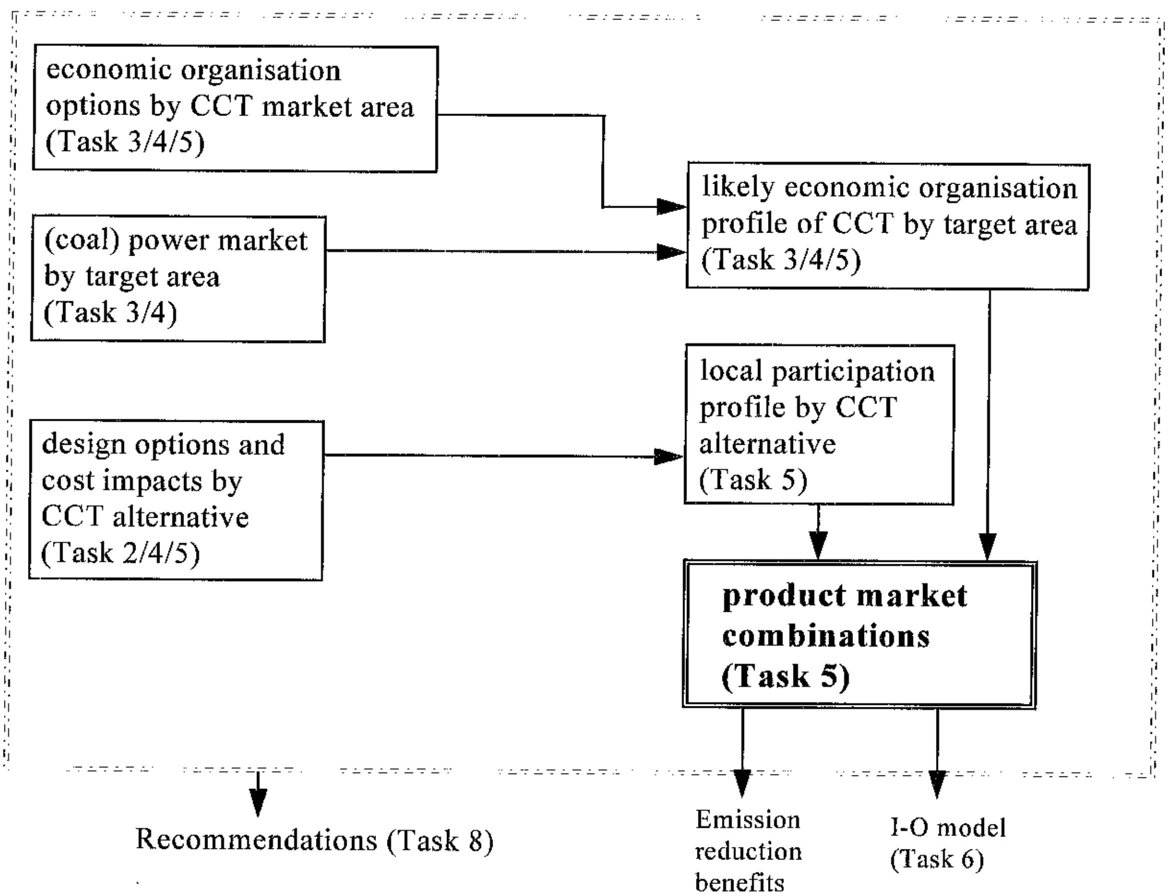

Figure 1 *Overview of approach Task 5*

3.2. Connections to Tasks 3, 4 and 6

The survey carried out in the framework of Task 3 and 4 has been reported in [2 and 1] and separately in [16] and has been discussed during the CARNOT project meetings. That survey constitutes the basis from which the market share developments of European manufacturers are assessed. In addition to this broad survey, encompassing a large number of CCT manufacturers, feedback was obtained during an extra Workshop in Utrecht, July 1997. This feedback concerned the rating of current and future CCT markets areas distinguished by CCT option and country.

Table 1 shows processed results regarding rating of barriers encountered by CCT manufacturers based on [1, 2, 16]. The rating per market area in Table 1 represents the weighed standardised sum of sample average ratings per criterion as collected in the survey of Task 3 and 4. Table 1 also indicates the principle barriers to be overcome in each market area. Please note that barriers may differ across market areas in absolute terms. Capital costs are an issue within the EU, but mainly for different reasons and to a less serious extent than for example in India. Furthermore, once capital cost issues and financing problems have been resolved, other *relatively* less prominent barriers can still be a major impediment. For example, the general level of understanding of EU manufacturers of commercial and institutional dynamics in India, though far from perfect, still is decisively better than in China. Yet, for the same token this situation may alter within five years. This element refers to social cultural elements in commercial operations and differs from the institutional barriers that hamper trade. Given the success of World Trade negotiations, trade barriers will generally decrease, despite the tendency to create regional trade blocks. Besides, establishment of industrial activities inside the trade block areas is often encouraged and thereby compensating to some extent for (remaining) trade barriers. Yet, deeply rooted differences in habits and norms and values will show much less convergence, consequently establishing new companies in such countries is more risky and will often require joint ventures with local counterparts.

Table 1 *Compound rating of barriers and principle barriers by market area*

Market Areas	*Relative Rating*	*Main Obstacles*
EU countries	1.00	capital cost, operational cost
East Asia	1.25	capital cost, finance
South Asia	1.26	capital cost, finance
China	1.30	capital cost, finance
Latin America	1.33	capital cost, finance
Central & Eastern Europe	1.34	finance, capital cost
Africa	1.42	capital cost, finance, political stability
CIS	1.48	capital cost, finance, political stability, institutional reform

Two barriers stand out, being capital cost and finance. Capital cost can be a problem for three reasons:

1. the country is poor and therefore, a power generation project is a heavy burden to the investment capacity of the country whatsoever (e.g. in Africa).
2. the country is experiencing rapid economic growth and consequently, capital is scarce as demand for capital for all kinds of investments is high (e.g. in Asia).
3. the power generation market is or is getting more competitive, which means that electricity suppliers are extremely keen on minimising costs of production (e.g. in EU).

The finance problem is obviously related to the capital cost issue, but is still something different. In very poor countries capital costs and finance problems are very closely connected. Therefore, not surprisingly, they are rated as equally grave obstacles in Africa. The finance problem in CIS and CEE is related to the transition of the economic system, which has created a very volatile money and banking system. Furthermore, unresolved aspects of property rights, and of liability aspects in trade increase risks for investments, notably foreign investments. In various Asian countries the money and banking system is already more developed. However, the large competition for capital reduces the transparency of the (financial) market and often requires a multitude of foreign and public funding organisations. It will be less risky than in the CIS, but takes more effort to organise. Latin America is in between these two positions.

Please note that CIS and Africa are the only two areas where political risks are regarded as significant. The stagnating and legally patchy transition (indicated as 'institutional barrier') in CIS even constitutes a fourth *major* risk according to the responding manufacturers. These latter risks can already be translated directly into preferences for industrial organisation types. EU manufacturers may be expected to avoid substantial investments in these countries. Therefore, the establishment of subsidiary companies or major joint ventures are unlikely options as long as the risks remain high. The political and legal unclarities also reduce the safe use of license agreements. So, depending on the required and available qualified labour as well as on costs of qualified labour, manufacturers may decide to source out the manufacturing or assembly of some components, provided alternative suppliers are available. Exports from EU countries are likely to take a large share of CCT power projects in these countries. Perhaps occasionally, a takeover of a local company could be attractive if the price is very attractive. As the share of exports from EU countries to these market areas for each project will continue to be large, EU consortia will have less leeway to reduce costs in competitive bidding for CCT projects, compared to some Asian or CEE countries that enable a larger share of local production. EU manufacturers should even count on competitive bidding of CCT manufacturers located in NICs after 2005/2010.

The elements capital costs and finance notably affect the overall sales volume of CCT and the composition of the sales portfolio distinguished by less and more advanced technologies. Furthermore, in as far as European manufacturers manage to offer comparable CCT options against lower unit costs and/or come up with efficient finance arrangements, their market share in the global CCT sales could increase. Yet, by and large the international power market is a buyers market, certainly in Asia. So, there is not much leeway for price setting. In some countries independent power producers (IPP) are allowed to enter the market and it is assumed these new type of actor will also enter other power markets in other countries, but the pace of market penetration is uncertain. IPPs are expected to be very costs sensitive and may prefer to use gas in small or medium size power stations constructed out of off-the-shelf technology. However, significant participation of IPPs could increase the amount of capital available for new power capacity and hence the total market would increase. Therefore, the penetration of IPPs might not be negative to CCT in all circumstances.

In principle environmental regulation is a very effective instrument to create or enlarge CCT markets. A lot of non-OECD countries may be expected to tighten their emission standards within 10 years. The reassessment of emission standards is mainly a political process, which is subject to national and international negotiations. The (direct) influence of European manufacturers will however be very modest. The European Commission and the EU members countries are participant in the Conference of Parties (COP III in Kyoto) on GHG reduction/Climate Change mitigation. Joint Implementation, nowadays officially indicated as Activities Implemented Jointly (AIJ), has been admitted as an important instrument in the COP III. In order to convince Developing Countries and NICs to reduce GHG emissions CCT activities could be a spearhead in AIJ programmes.

Direct regulation of emission standards for power plants is unlikely to be very conducive for EU manufacturers. It cannot be expected that countries are willing to tighten standards beyond the limit that would exclude its own (not so advanced) CCT industry from the market. AIJ may be helpful in this case, while also countries without own CCT industries will encounter less opposition for this reason.

Most other elements that influence the CCT market mainly influence the way the CCT market will be entered. The other elements comprise political stability, institutional framework, technology development, communication with the market and, information on export opportunities. For example, a European manufacturer will prefer exports over local (e.g. sub-contracted) production in case of market areas with high political risks. On the other hand in NICs licensed production could be a less favoured option because of risks for unauthorised copying of licensed products or processes (a combination of institutional framework and technology development). However, to date OECD manufacturers tend to be willing to allow licensed production in NICs, because of the risk of loosing the contract to a competitor and having nothing sold at all. This confirms the characterisation of *the Asian power market as a buyers market.*

As also explained in the main report and in the Task 4 report the study compares a situation WITH CARNOT with a situation WITHOUT CARNOT. This is the first distinction between scenarios. The second distinction is between a situation with a rapid penetration of independent power producers (IPPs) in the sales areas (IPP HIGH) and the situation with a slow penetration of IPPs (IPP LOW). The general understanding is that IPPs will be more critical on cost (both initial and operating) and therefore, more conservative with respect to CCT. Furthermore, the risk aversion of IPPs and gas background of some IPPs also implies a preference for natural gas over coal. Consequently, it could make a big difference whether IPPs play a prominent role in the construction of new power capacity.

The two stages, being distributing new megawatts over CCT alternatives and distributing sales by CCT alternatives over industrial organisation options and manufacturing locations, are distinguished in eight steps as shown in Figure 2. First, the amount of new coal capacity to be built in the various sales areas has to be defined (1). Subsequently, the share of new (coal) capacity built by IPPs will be estimated (2). These 2 items (1+2) together enable to produce expected amounts of MW in new coal capacity by market area by period distinguished by small (<100MW) and large units (3). In order to be able to calculate CCT sales by area by kind of contractor (utility or IPP) (7) we first need to know:

- capital costs and other costs (here focusing on fuel) per CCT option by sales area per period (4),
- than a likelihood is calculated for purchase of each CCT by market area by period (5).

We also need to specify the preferences of industrial organisation for each type of CCT to be sold in a given market area (6). Combining the information resulting from 4/5/6/7 a distribution of sales of CCT by market area by period can be made for EU manufacturers (8). Yet, selling CCT plants to Asian customers does not ensure automatically a flow of money to the EU. It depends on the industrial organisation and on the degree of so-called secondary production effects. That means even if a plant is largely manufactured in the target market some components and services still have to be supplied by European branches of the consortium building the plant.

For the retrofit market steps 3 and 5 are not relevant, given the definition of retrofit projects in this study.

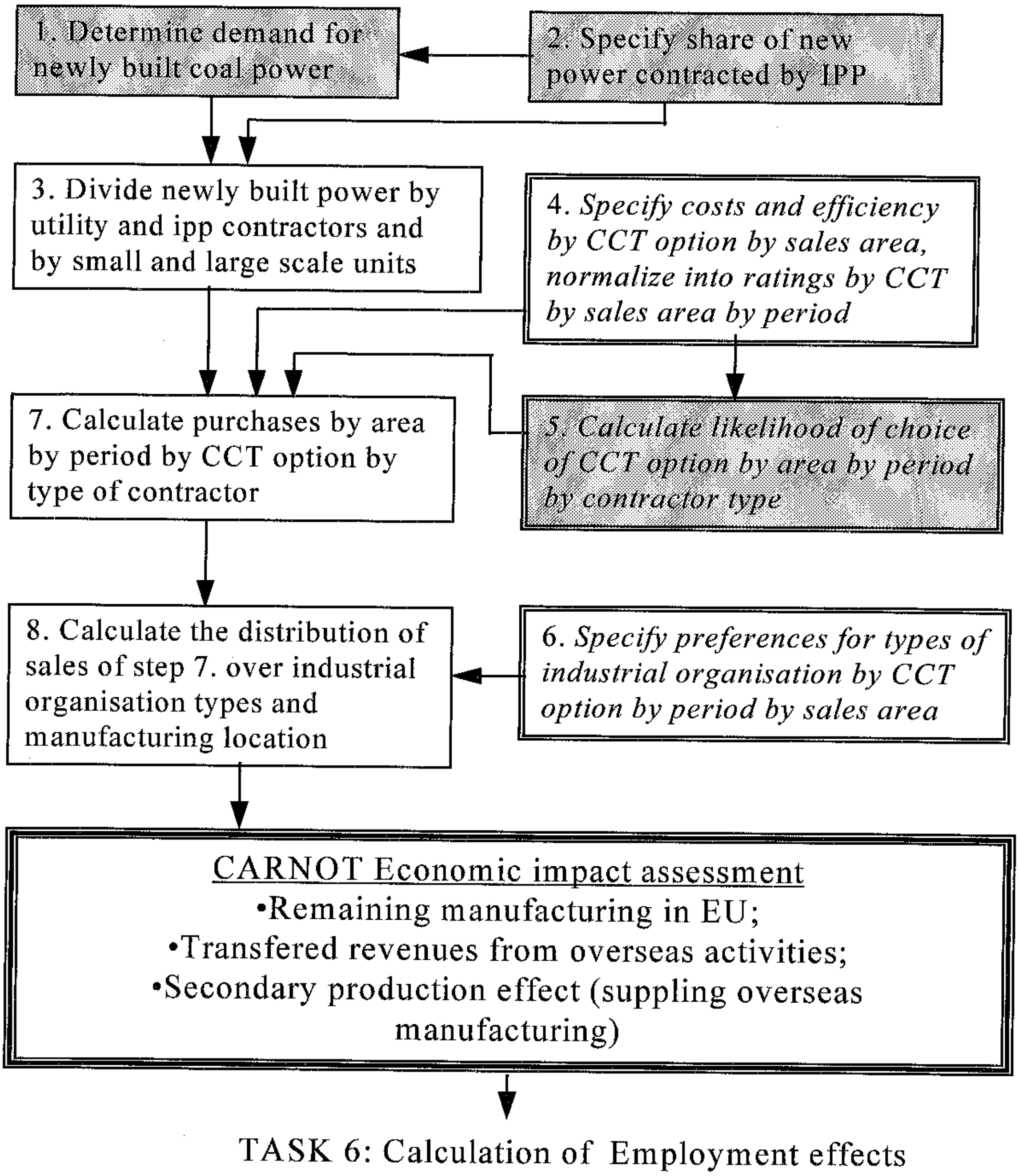

Figure 2 *Flow diagram of stepwise assessment of the share of European manufacturing in sales of newly built clean coal power units*

This means that three kinds of benefits are distinguished:
1. the production value of sold power plants to be manufactured inside the EU,
2. transferred revenues from overseas manufacturing (joint venture, licensing etc.) of EU based manufacturers,
3. the production value of supplied components manufactured inside EU but used in the assembly in overseas activities (as referred to in point 2).

In the next sections the stepwise assessment procedure will be shown as follows:

1. assessment of CCT market areas in terms of preferred/feasible/likely form of industrial organisation of a CCT product.
2. assessment of likelihood's of industrial organisation alternatives by CCT option by market area.
3. assessment of kW costs per CCT option in terms of:
   - current average (OECD) standard cost levels,
   - kW cost reduction possibilities by CCT option by market area, e.g. through more, local involvement and/or simplified designs.
4. market size by CCT and by market area for standard and alternative kW cost levels,
5. allowing shifts in market shares of CCT options due to different reductions.
6. overall assessment by and share of EU.

4. STEPWISE OPERATIONALISATION

4.1. Assessment of Markets and Industrial Organisation Options

Anterior to the explanation of the development of the market of new and retrofit capacity the next chapter will start with a qualitative assessment of the main export markets based on feedback from the workshop. This feedback served to fill in initial propensities in subsequent tables.

For the principle market areas a screening has been carried out what organisational options are more likely to appear, given the commercial, legal, institutional, social, cultural and technical circumstances in the distinct market areas. Obviously this gives an *average* picture that can be applied to provide a *rough estimate* of the incidence of organisational options for manufacturing, assuming that a sufficiently large number of projects will be implemented.

The assessment makes use of the rating of barriers by market area as obtained in the survey study [1, 2, 16] as well as additional information on market potential (size) and sales performance of EU manufacturers in the past few years. The assessment distinguishes for main components of a coal power plant, since the degree of technological complexity varies over these main components. Simply stated one may assume that higher complexity increases the chances for export from Europe (e.g. gas turbines), while less complexity increases the chances for local production (e.g. sub-contracting). The rating in this assessment stage is used for a next stage (see 5.3) in which for each CCT option the likelihood of preferred industrial organisation is indicated. The various shares of industrial organisation options by CCT denote different shares in revenue retention by EU manufacturers. Table 2 gives an impression of the market assessment *using preliminary figures.* Here the rating is shown for a utility. The same procedure is applied to IPPs, though resulting in slightly different ratings. Finally, retrofit (mainly for utilities) is regarded as a third category.

Since the available information is often patchy and contradictory a special workshop has been organised in July 1997 for which a selection of representatives of CCT manufacturers was invited. The operationalised approach and initial inputs and results have been shown and discussed in order to adapt inputs to a common understanding of the present market forces. Table 3 shows the changes in Table 2 due to the feedback from the workshop.

Table 2 *Market classification overview (original ratings)*

Indication of preferred industrial organisation by main component by market area

	capacity:	**client:**		
Project type	*New*	*Utility*		
pre.treat, burning	China	India	R of Asia	CEE+Tur.
export EU	0	-	-	-
new subs.	–	0	0	0
take over	-	-	-	+
joint venture	-	0	0	0
sub-contr	++	++	+	++
license	–	+	0	+

Project type	*New*	*Utility*		
conversion	China	India	R of Asia	CEE+Tur.
export EU	+	+	0	0
new subs.	–	0	0	0
take over	-	-	-	+
joint venture	-	0	+	0
sub-contr	+	+	+	+
license	–	+	-	+

Project type	*New*	*Utility*		
Clean-up	China	India	R of Asia	CEE+Tur.
export EU	+	+	+	+
new subs.	–	0	0	0
take over	-	-	-	+
joint venture	-	0	+	0
sub-contr	0	+	+	+
license	-	+	-	+

Project type	*New*	*Utility*		
Turn key	China	India	R of Asia	CEE+Tur.
export EU	+	+	+	+
new subs.	–	–	–	–
take over	-	-	-	-
joint venture	+	+	+	+
sub-contr	+	+	+	+
license	–	0	-	0

Barriers on organisational options

	China	India	R of asia	CEE+Tur.
on trade	**	**	**	*
on d.f.i.	***	**	**	**
on fin. asp.	**	**	*	**
on knowtrf	***	**	**	*
market - potential	large	large	medium	modest

coding industrial organisation:

++	often favourable
+	quite often reasonably favourable
0	not particularly favourable
-	often less favourable
–	generally unfavourable

coding barriers by market area:

***	strong
**	medium
*	modest
~	negligible

abbreviations industrial organisation alternatives:

export EU >>>>>>>>>	manufactured in EU, shipped to market
new subs. >>>>>>>>>	new subsidiary, new production establisment founded by EU company in target market
take over >>>>>>>>>	purchase of local (non-EU) company by EU manufacturer
joint venture >>>>>>>	expanded/new production facility in target market jointly owned by EU + local manufacturer
sub.contr. >>>>>>>>>	production/assemby of specific components mostly not involving massive knowledge transfer
license >>>>>>>>>>	production of specific essential components involving transfer of advanced commercially valuable knowledge

Explanation of main components of CCT and connection with Survey report table 7 'Key parts list'

abbreviation	*description*	*activities in table 7*
pre-treatment	washing, milling, etc.	civil works, component constr.
burning	boiler(s)	construction on site, engineering
conversion	turbine(s) generator(s)	component construction, electrical equipment
clean-up	NOx emission control	component construction
	SO2 emission control	engineering
	Fly-ash filter	
	etc.	

abbreviations for market areas (countries;regions):

China	mainland China
India	
R of Asia	Rest of Asia = ASEAN countries, Taiwan, Paskistan, Bangla Desh
CEE + Tur	Central and Eastern Europe, Turkey

abbreviations for trade barriers:

trade	shippings from EU to target market
d.f.i.	direct foreign investment (from EU into market area)
fin. asp.	financial aspects
knowtrf	knowledge transfer (including copying risks)
market potential	expected demand for new/retrofit coal power

Table 3 *Ratings after feedback from Workshop*

Project type		utility			
boiler	China	India	Asian NICs	R.of asia	CEE+Tur.
export EU	0	0	0	0	0
new subs.	-	-	-	-	-
take over	+	0	+	0	+
joint ventura	++	+	+	+	+
sub-contr	+	+	+	+	+
license	-	-	-	-	-

Barriers on organisational options					
	China	India	Asian NICs	R.of asia	CEE+Tur.
on trade	**	**	**	**	*
on d.f.i.	***	***	***	***	**
on fin. asp.	**	**	*	*	**
on know.trf	**	**	*	**	*
market - potential	large	large	medium	medium	medium

Project type		utility			
turbine	China	India	Asian NICs	R.of asia	CEE+Tur.
export EU	-	-	-	-	-
new subs.	-	-	-	-	-
take over	+	-	+	0	+
joint venture	+	+	+	+	+
sub-contr	+	+	+	+	+
license	-	-	-	-	-

Project type		utility			
FGD, etc	China	India	Asian NICs	R.of asia	CEE+Tur.
export EU	-	-	-	-	-
new subs.	+	+	+	+	+
take over	-	-	-	-	-
joint venture	+	+	+	+	+
sub-contr	+	+	+	+	+
license	+	+	+	+	+

Project type		utility			
Turn key	China	India	Asian NICs	R.of asia	CEE+Tur.
export EU	-	-	-	-	-
new subs.	-	-	-	-	-
take over	-	-	-	-	-
joint venture	+	+	0	0	0
sub-contr	-	-	-	-	-
license	-	-	-	-	-

4.2. Expected New Capacity and Share of IPP

In [4] an estimation of the market for coal power by export area has been made in the period up to 2010 (see also 3.2). This has been used as the basis for calculating the market potential for CCT technologies in the period 1995-2010 by market area. Based on these figures, which cover the entire period, estimates have been made for the consecutive periods 1995-2000, 2001-2005 and 2006-2010. This is shown in Figure 3.

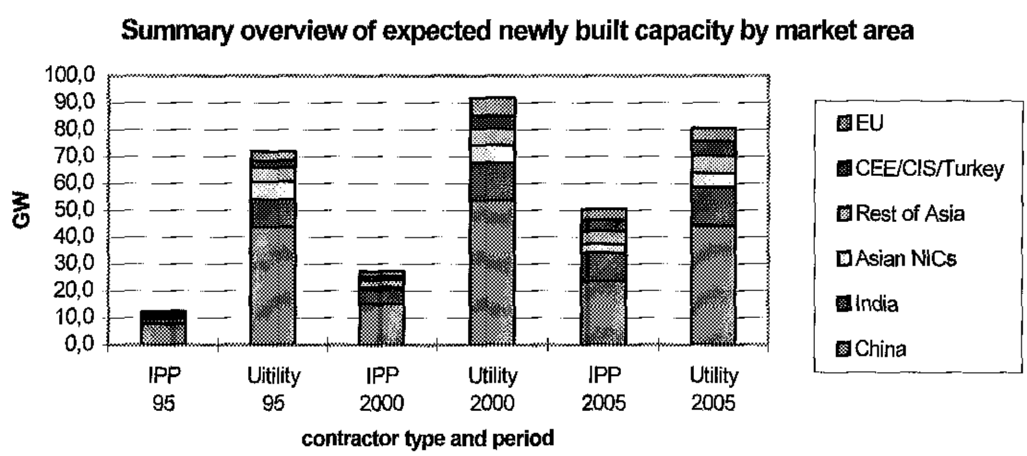

Figure 3 *Expected sales newly built capacity in IPP High Scenario*

These estimates by 5 year period take into account the expected GDP growth rates of the different export areas, a differentiation between large scale and small scale power given a total estimated need for new power, the possible influence of IPP and reforms in the energy and financial markets. The applied GDP growth rates are based on publications such as from IEA [17] and Financial Times-Energy [18].

The scenario distinguishes between a high and a low share of IPP in newly built power. Retrofit is assumed to be predominantly a utility activity. The development of IPP market shares in new power will vary over export areas. These variations inter alia depend on the indications of changing barriers, as discussed in the reports of Task 3 and Task 4, the feedback from the Workshop partners and other literature [3]. The possible emergence of IPPs in target markets cannot be predicted with high certainty. Therefore, a slow and a fast penetration trajectory for selected market areas has been formulated. The initial penetration is differentiated over countries and also the difference in pace between slow and fast penetration differs across countries (Figure 4). In some countries energy markets have been reformed already a great deal, consequently, there will be less difference between slow and fast penetration of IPPs.

The role of IPPs is important for the following reasons:

- its potential to enlarge the capital base available for power investments,
- the higher sensitivity to cost differentials between CCT options,
- the possibility it offers to gas companies to enter new markets and create a sales base by establishing gas fired power stations.

For both the high and the low IPP scenarios, a further distinction is made between cost reducing strategies either involving a CCT support programme (CARNOT), or depending on industrial strategies only (i.e. a higher tendency to shift production to target markets). An overview of applied penetration rates for IPP is displayed in Figure 4.

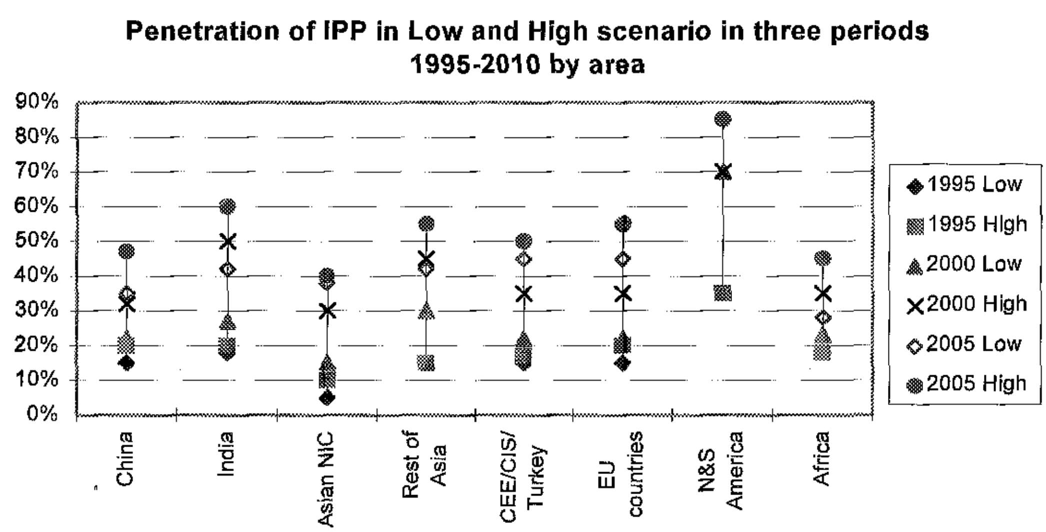

Figure 4 *Penetration of IPPs in two scenarios*

In summary the following four scenarios have been applied in the sales calculations:
1. IPP low with CARNOT (cost reduction through smart R&D),
2. IPP low without CARNOT (cost reduction through production relocation),
3. IPP high with CARNOT (cost reduction through smart R&D),
4. IPP high without CARNOT (cost reduction through production relocation).

The propensities to relocate and the favoured organisational options have been adapted to the feedback from the workshop, and the information produced in Task 3 and 4. Furthermore, the high and low IPP scenarios imply different power generation market conditions. This will be also reflected in the application of the limited versus the extended choice criterion (limited = capital costs only; extended = capital costs + fuel costs).

In summary the following steps have been applied for fine tuning the scenario:
1. the total amount of newly installed power an economy can afford: for India and Rest of Asia (except NICs) a low share of IPP is assumed to cause also a reduction of actually newly built capacity; China is assumed to move sufficiently quick towards market openness.
2. the share of IPP in new power has to be raised even up to or beyond 50% in India and Rest of Asia in order to prevent a growing lack of power; this coincides with a generally more open power market hence utilities will use decision criteria more similar to that of IPPs; in most of Europe, however, liberalisation will not necessarily imply very elevated levels of IPP participation (though lack of liberalisation or would-be forms will definitely reduce the chances for IPP);
3. if power markets are not much liberalised in India and Rest of Asia this will be just a part of a generally slow policy on opening domestic markets; consequently, western companies will also remain more reluctant to choose certain organisational options and basically may be forced - at the expense of risking lower sales - to retain a larger share of production in the EU despite the higher costs (without CARNOT) or even the more so (with CARNOT).

A full overview of all input data is provided in Annex B.

4.3. Likely Industrial Organisations by CCT Option

Based on the market - industrial organisation assessment and knowing by and large the technology input requirements by CCT option, a likelihood rating of industrial organisation options by market area can be made. Please note, a further distinction is made by sort of client of a power project, being a utility or an IPP. Table 4a and 4b show the ratings for one type of CCT for both the default situation (Table 4a; *with CARNOT*) and a situation where manufacturing shifts quicker to target markets in order to remain competitive (Table 4b; *without CARNOT*). In a market situation without a CCT support programme the EU based manufacturers will tend to shift more production towards the target markets as a way to cut costs. This is shown in Table 4a and 4b. The ratings are based on feedback we received during and after the workshop.

Table 4a *Share of the sales for an AFBC by type of industrial organisation (with CARNOT)*

Probability of project type			default			
AFBC	China	India	Asian NICs	R. of Asia	CEE+Tur.	EU
export EU	15%	15%	5%	20%	0%	100%
new subs.	0%	0%	5%	5%	5%	0%
take over	5%	5%	20%	5%	40%	0%
joint venture	10%	10%	25%	15%	30%	0%
sub-contr.	40%	40%	15%	30%	10%	0%
license	30%	30%	30%	25%	15%	0%

Table 4b *Share of the sales for an AFBC by type of industrial organisation (without CARNOT)*

Probability of project type			falling EU shares			
AFBC	China	India	Asian NICs	R.of Asia	CEE+Tur.	EU
export EU	8%	8%	5%	15%	0%	100%
new subs.	5%	5%	5%	0%	5%	0%
take over	10%	10%	20%	5%	40%	0%
joint venture	17%	17%	25%	10%	25%	0%
sub-contr.	30%	30%	15%	40%	10%	0%
license	30%	30%	30%	30%	20%	0%

4.4. Costs per kW by CCT Option and Implications for CCT Market Shares

Improving financial facilities is typically a measure that can be implemented fairly quickly, but can also be copied fairly quickly by competitors. On the other hand decreasing the cost per kW will render substantial and lasting competition advantages. This recipe is also emphasised as a major point of attention in [5]. That report indicates that an enhanced global penetration of CCT options requires a shift in research and development orientation from maximising environmental performance towards minimised costs per kW without significant deterioration of the environmental performance.

Observing costs per kW as decisive factor in the medium term this stage of the assessment identifies the costs per kW per CCT alternative per market area. In this case for some countries, notably India and the Rest of Asia, the difference between swift and slow penetration of IPPs (IPP High and IPP Low) is regarded to be symbolic for the degree of market openness in general. Therefore, the situation IPP High is using the standard cost levels derived from [2] for all target areas. When the penetration of IPPs is slow (IPP Low) cost levels will go down a bit slower in India and Rest of Asia. Table 5a depicts the IPP Low case, while Table 5b shows the IPP High case. For future years reduction of cost levels is based on reviews of different specialists in this field. For the situations with CARNOT and without CARNOT cost levels are assumed to be the same since the market is typified as a buyers market. Another small difference is that in IPP High the costs for IGCC are slightly lower (1180 USD/kW instead of 1200 USD/kW) for NICs and EU countries. The figures are based on a literature survey and desk research as well as feedback from the Workshop.

Table 6 displays the development of fuel efficiency by CCT option. The figures applied constitute a fair average expectation based on various publications (see Annex B)

Table 5a *Cost development per kW per CCT option in China and India (IPP Low)*

	kW costs China USD per kW				kW costs India USD per kW			
	95-2000	01-05	05-10	10-20	95-2000	01-05	05-10	10-20
PF+FGC	1150	1086	1086	1120	1150	1086	1086	1120
SCPF+FGC	1200	1081	1056	1070	1200	1092	1056	1070
AFBC	1120	1062	1042	1050	1120	1073	1042	1050
PFBC	1200	1116	1064	1050	1200	1133	1070	1050
IGCC	1540	1280	1140	1120	1540	1300	1146	1120

Table 5b *Cost development per kW per CCT option in China and India (IPP High)*

	kW costs China USD per kW				kW costs India USD per kW			
	95-2000	01-05	05-10	10-20	95-2000	01-05	05-10	10-20
PF+FGC	1150	1086	1086	1120	1150	1086	1086	1120
SCPF+FGC	1200	1081	1056	1070	1200	1081	1056	1070
AFBC	1120	1062	1042	1050	1120	1062	1042	1050
PFBC	1200	1116	1064	1050	1200	1116	1064	1050
IGCC	1540	1280	1140	1120	1540	1280	1140	1120

Table 6 *Fuel efficiencies by CCT option - all countries*

	fuel efficiency - all countries efficiency of alternatives			
	1995-2000	2001-2005	2005-2010	2010-2020
PF+FGC	0.39	0.39	0.39	0.39
SCPF+FGC	0.45	0.47	0.48	0.49
AFBC	0.40	0.41	0.41	0.41
PFBC	0.44	0.45	0.46	0.47
IGCC	0.45	0.48	0.51	0.53

Altogether five CCT options are distinguished. Pulverised coal fitted with flue gas desulphurisation (FGD) is regarded as the reference technology.

PF+FGD	pulverised coal + flue gas desulphurisation
SCPF+FGD	Super critical pulverised coal + FGD
AFBC	Atmospheric fluidised bed combustion
PFBC	Pressurised fluidised bed combustion
IGCC	Integrated coal gasification combined cycle

For retrofit the following technologies are distinguished (please note the definition of retrofit as applied in this report - see section 2.1):

FGD	Flue gas desulphurisation
S(N)CR	Selective (non)catalytic reduction
Combustion modifications	Mainly Low NO_x burners
Particulates/Ash	Cyclones, Filters such as electrostatic precipitators (ESP)
Pre treatment	washing, blending and grinding of coal or other solid fuels

4.5. Overall Position of EU Manufacturers by CCT Option and by Market Area

The analysis in the previous stages is merged in the last stage to show expected sales in a standard and in alternative scenarios. Next to a breakdown by market areas and CCT options, distinctions are made between industrial organisation options and market shares of local producers, EU based manufacturers and other (non-EU) competitors.

For each scenario the impact on EU sales can be analysed. This can provide indications for :

- the robustness of certain developments,
- the minimum reduction of costs per kW needed to enhance penetration of one or several CCT options,
- a ranking by size of the minimum reductions by CCT option,
- sensitivity of potential clients (markets) to adaptations in the industrial organisation,
- sensitivity of potential clients (markets) to cost reduction by CCT option.

Table 7 shows normalised relative cost indicators based on the figures displayed in Tables 5 and 6. These indicators are necessary to perform calculations in the next step, which is shown in Table 8, CCT choice probabilities. In Table 8 is shown what the probability is to choose one of the large scale CCT options (SCPF and IGCC) in comparison with the default (PF+FGC). For small size capacity (AFBC and PFBC) AFBC is taken as the reference choice. So, please note that AFBC is supposed to compete only with PFBC on the market for capacities under 100 MW (in practice the borderline is somewhere between 100 and 150 MW). Though PFBC might become capable to compete to some extent also in the medium size plant market, we decided to make this clear distinction, since further refinement would possibly blur the message from the results, while still being not essentially different.

Table 8 shows the situation where the choice criterion 'capital cost+fuel cost' is applied (i.e. for IPPs in all situations and for both IPPs and utilities in IPP High after 2000). Alternatives may have higher or lower probabilities to be chosen depending on the rating of their initial investment cost or weighed rating of investment cost + fuel efficiency by country.

Table 7a *Cost indicators normalised based kW costs*

	kW costs only China				kW costs only India			
	95-2000	01-05	05-10	10-20	95-2000	01-05	05-10	10-20
PF+FGC	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
SCPF+FGC	0.71	1.04	1.25	1.44	0.71	0.96	1.25	1.44
AFBC	1.24	1.20	1.39	1.68	1.24	1.11	1.39	1.68
PFBC	0.71	0.81	1.18	1.68	0.71	0.72	1.13	1.68
IGCC	0.10	0.27	0.68	1.00	0.10	0.24	0.65	1.00

Table 7b *Cost indicators normalised based kW costs and fuel efficiency*

	kW + fuel costs China				kW + fuel costs India			
	95-2000	01-05	05-10	10-20	95-2000	01-05	05-10	10-20
PF+FGC	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
SCPF+FGC	1.04	1.51	1.81	2.09	1.04	1.42	1.81	2.09
AFBC	1.20	1.24	1.42	1.63	1.20	1.17	1.42	1.63
PFBC	0.99	1.14	1.58	2.14	0.99	1.04	1.53	2.14
IGCC	0.24	0.57	1.27	1.83	0.24	0.52	1.23	1.83

Table 8 *Probability of choosing a CCT option by market area by period on the basis of capital cost + fuel cost*

	China				India			
	95-2000	01-05	05-10	10-20	95-2000	01-05	05-10	10-20
PF+FGC	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50
SCPF+FGC	0.60	1.00	1.00	1.00	0.60	1.00	1.00	1.00
AFBC	0.92	0.95	1.00	1.00	0.92	0.87	1.00	1.00
PFBC	0.47	0.83	1.00	1.00	0.47	0.61	1.00	1.00
IGCC	0.00	0.02	0.97	1.00	0.00	0.01	0.95	1.00

Considerations such as plant availability, the need to get acquainted with new technology, etc. are not explicitly included as arguments in the applied formula, but the specification allows 'room' for other considerations, hence probabilities do not jump directly from 0% to 100% and vice versa. The way the formula works out is shown in Figure 5. The horizontal axis depicts the quotient of the costs of the default CCT (PF+FGC) and one alternative (SCPF+FGC or IGCC) and for AFBC versus PFBC. The quotient is smaller than 1, if the costs of the default are lower than the alternative. Consequently, the likelihood to select the alternative over the default gets lower than 50%. For example, when using the line depicting the results of formula 'Logit 1', it shows that if the default CCT is 2.5% cheaper (0.975 on x-axis) the likelihood to choose the alternative CCT has decreased towards 26%. Conversely, if the alternative CCT is 2.5% cheaper (1.025 on the x-axis) the likelihood to select the alternative has risen to 80% according to line 'logit 1'. Figure 1 depicts three similar lines. Each line represents different levels of supposed responsiveness. The Logit 1 line has been used in the calculations for utilities and Logit 3 (the steeper curve) has been used for IPPs, since IPPs are assumed to be more responsive to cost differentials.

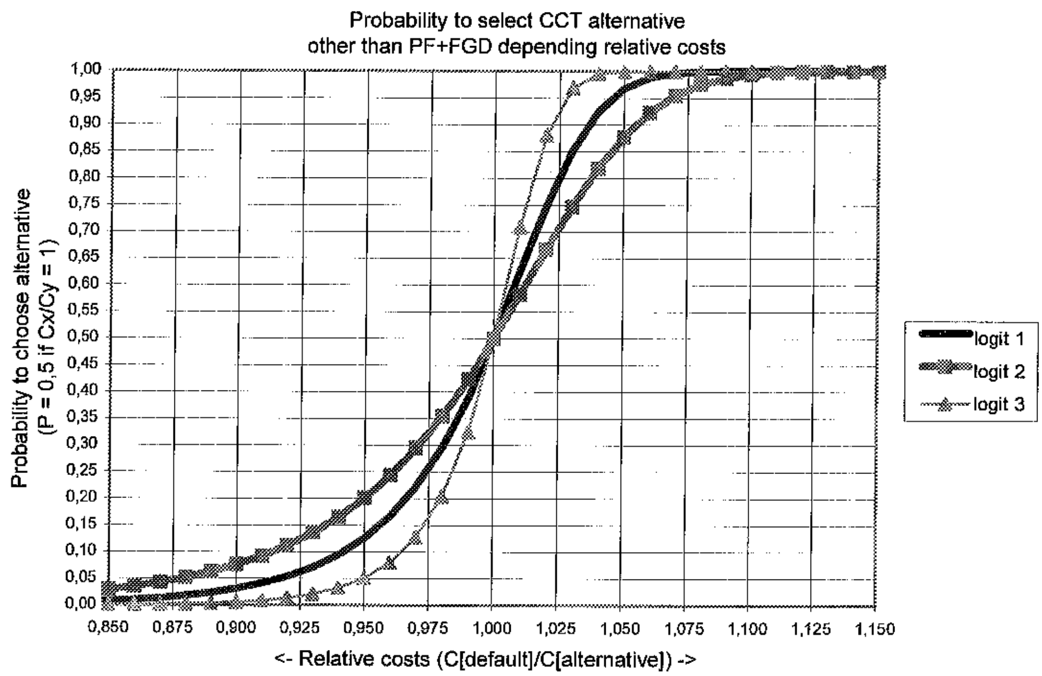

Figure 5 *Sensitivity of CCT choice to relative costs*

5. RESULTS

This chapter will first highlight the main results in terms of sales of newly built capacity and retrofit by EU manufacturers. Subsequently the calculated economic impact of a CCT support programme will be discussed. Please note that in this study only the differential impact of a CCT support programme on EU based sales and its direct impact on levels of CCT production value are discussed. The overall impact on the economies of EU countries both in terms of value added an in terms of employment creation are discussed in the report about Task 6 (FZ-Jülich). The assessment of environmental benefits of a CCT support programme are discussed in chapters 7 and 8 which are in Part 2 of this report.

5.1. Sales for New Capacity

In the Low IPP scenario the market for new coal power amounts to 289 billion ECU, while in the High IPP scenario the market could achieve a size of 307 billion ECU from 1995 to 2010. As set out in chapter 3 and mentioned earlier in the report of Task 4 these figures do not comprise the Americas and Africa. EU based coal power manufacturers are involved in 41% to 43% of the sales, depending on the scenario. The scenario variants including a CCT support programme (*with CARNOT*) have both a slightly higher share than the variants without a CCT support programme. Table 9 below gives an overview. The column 'EU prod' refers to the part of sales that has to be manufactured in the EU. The column 'EU trf' denotes production overseas in which the EU is involved through subcontracting, licensing, joint ventures and subsidiaries. In other words these figures represent the part of the sales that creates manufacturing abroad. Please note that these figures are substantially larger in the cases without a CCT support programme. Yet, even in the case of production abroad some parts have to be supplied by EU based companies. This aspect is termed 'secondary production effect'. Furthermore, a part of the net revenues of production overseas may be transferred back to the EU. These two elements, secondary production effect and revenue transfer are shown in the last column of Table 9. Since the overseas production is larger in the 'without' scenarios the secondary production effect and the transferred revenues will be larger as well. However, this compensates only a fraction of the loss of production value due to a larger share of overseas production.

Table 9 *Summary of sales results by scenario*

New Capacity	Sales in million ECU			
Scenarios:	Global sales	EU prod	EU trf.	EU rev.trf.
Low IPP *without CARNOT*	288,682	52,238	67,472	6,811
Low IPP *with CARNOT*	288,682	60,321	62,841	6,260
High IPP *without CARNOT*	307,616	58,348	70,166	7,247
High IPP *with CARNOT*	307,572	66,938	65,235	6,661

Figure 6 shows the effects of comprehensive production (EU prod) and secondary production+transfer revenues (EU trf.rev.) combined for the entire period (1995-2010) taken together. On annual basis the activity base for manufacturers inside the EU amounts to an average of 3.7 billion ECU up to 4.5 billion ECU.

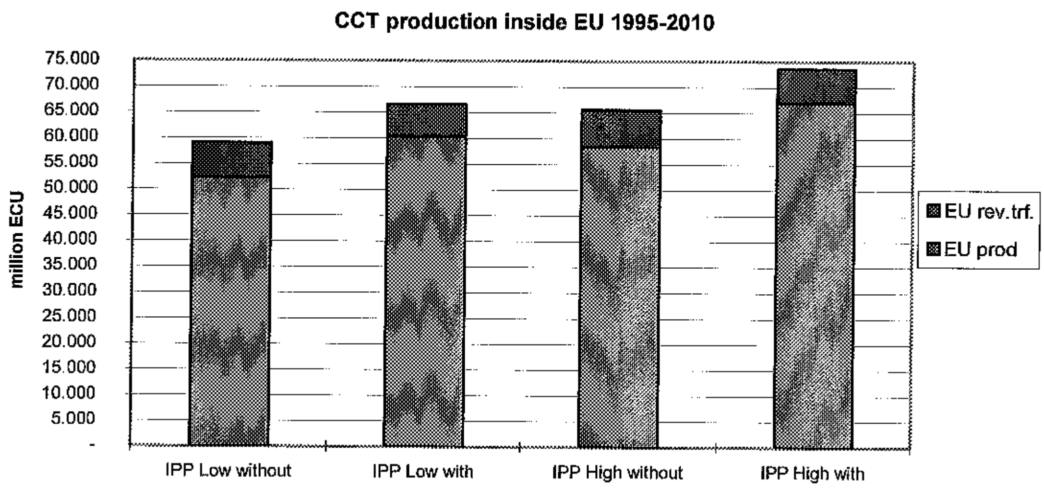

Figure 6 *Manufacturing activities in EU based on global sales*

Table 10 *Annual production value of CCT manufacturing inside EU and secondary production effect in EU and transferred revenues to EU due to overseas activities*

	CCT manufacturing inside EU in mln. ECU 92				EU supplies overseas/transferred revenues in mln ECU 92			
years	IPP Low without C.	IPP Low with C.	IPP High without C.	IPP High with C.	IPP Low without C.	IPP Low with C.	IPP High without C.	IPP High with C.
1995	2010	2010	2846	2846	277	277	265	265
1996	2010	2010	2846	2846	277	277	265	265
1997	2010	2010	2846	2846	277	277	265	265
1998	2010	2010	2846	2846	277	277	265	265
1999	2010	2010	2846	2846	277	277	265	265
2000	2010	2010	2846	2846	277	277	265	265
2001	3632	4727	3529	4671	504	431	561	486
2002	3632	4727	3529	4671	504	431	561	486
2003	3632	4727	3529	4671	504	431	561	486
2004	3632	4727	3529	4671	504	431	561	486
2005	3632	4727	3529	4671	504	431	561	486
2006	4403	4925	4726	5302	526	488	570	528
2007	4403	4925	4726	5302	526	488	570	528
2008	4403	4925	4726	5302	526	488	570	528
2009	4403	4925	4726	5302	526	488	570	528
2010	4403	4925	4726	5302	526	488	570	528

Since the market increases over time the figures are in fact much lower in initial years than later on in the first decade of the next century. The calculated annual flow is depicted in Table 10. Please note that these annualised figures depict a smoothed average, while actual power sales will show ups and downs.

So, these annualised figures are meant to give an impression of the *average* volume of activities in EU CCT manufacturing companies. As it is assumed that CCT support measures will not come into effect before 1999, the differential impact between a situation *with* and *without* a support programme will start to build up from 2001 onwards. The knife-edge evaluation behaviour of IPPs implies that in the period 2001-2005 a high IPP penetration results in a slightly lower impact of a support programme compared to the IPP Low situation. However, this is compensated in the last period (2006-2010) when advanced CCT technologies have experienced further cost reductions. Last but not least, it is good to realise that the money flows as depicted in Table 10 form the basis of the calculations made in Task 6.

5.2. Retrofit Sales

The retrofit market is much in smaller terms of sales volume. It is estimated to be approximately 10% of the new capacity market. The retrofit market is strongly dependent on policies, regulations and enforcement practices. Though more wealth will facilitate the implementation of retrofit projects, there are many local factors involved. Therefore, we decided that a distinction between IPP Low and IPP High was not useful. Just one scenario has been applied *with* and *without* CARNOT. Given the age structure of the global coal power capacity the retrofit market is finite, at least for the kind of projects considered here. Consequently, the production value for retrofit manufacturing drops to a mere 5% of its earlier level after 2005. Therefore, given the start of a CCT support programme not earlier than 1999, the impact of such a programme on the retrofit market is confined to 7 years. It is imaginable, however, that after 2010 an entirely new kind of retrofit will develop for the coal power built between 1995 and 2005. By that time the market conditions and the technology options will have changed so much that a completely new support programme will be needed. This notion applies to the market for new capacity as well. Table 11 summarises the results. The column headings have the same meanings as in Table 10.

Table 11 *Summary of retrofit sales results*

Retrofit	Sales in mln. ECU			
Scenarios	Global sales	EU prod	EU trf.	EU rev.trf.
without CARNOT	26,704	16,581	4,444	480
with CARNOT	27,750	18,113	4,167	449

5.3. The Impact of a CCT Support Programme

The idea behind a CCT support programme tested here, was the reinforcement of the competitiveness of EU based manufacturing, notably through enhancing the capability of producing good value for money clean coal technology. As explained in chapters 3 and 4 as well as in the reports on Task 3 and 4 both the financial and marketing barriers should be lowered and cost-effectiveness oriented R&D and demonstration should be supported. This should facilitate a longer continuation of large scale CCT manufacturing in the EU. Table 12 focuses on this effect based on the differential sales discussed on the previous sections. The first column 'D(EU prod)' represents the differential effect on manufacturing inside the EU. The second column 'D(EU trf.)' denotes the differential impact on production overseas as far as EU based companies are involved. The third column 'D(EU rev.trf.)' displays the differential impact on secondary production and transferred revenues. Finally the last column gives the overall balance, i.e. the CARNOT effect, attributable to a support programme over the entire period 1995-2010. As regards newly built capacity the CCT manufacturing inside the EU would increase by 8 billion to 8.6 billion ECU depending on the scenario. For retrofit the impact is rated at 1.5 billion ECU. However, since overseas production reduces the revenues and secondary production effect reduces as well. This causes a deduction from the original impact of 550 to 590 million ECU for new capacity and 32 million for retrofit. All in all the CARNOT effect accrues to 7.5 - 8 billion ECU for new capacity and 1.5 billion for retrofit.

Table 12 *Summary of differential impact of a CCT support programme*

New capacity	D (EU prod)	D (EU trf)	D (EU rev.trf)	CARNOT effect
IPP Low	8,083	-4,632	-551	*7,532*
IPP High	8,589	-4,931	-586	*8,004*
Retrofit	D (EU prod)	D (EU trf)	D (EU rev.trf)	CARNOT
1 scenario	1,532	-276	-32	*1,500*

Since a CARNOT programme will come into effect not before 1999, the principal benefits are concentrated between 2000 and 2005. This is shown in Figure 7. After 2005 the benefits with respect to newly built coal power will gradually decrease, from just over 1 billion ECU annually down to a still significant 0.5 billion ECU annually. By approaching 2010 the decrease will continue. This can be attributed to the inevitable shift in manufacturing capacity towards the rapidly industrialising countries in Asia and to a lesser extent to Central and Eastern Europe as well. Please note that some of the latter countries will enter the European Union during the period 2000-2010.

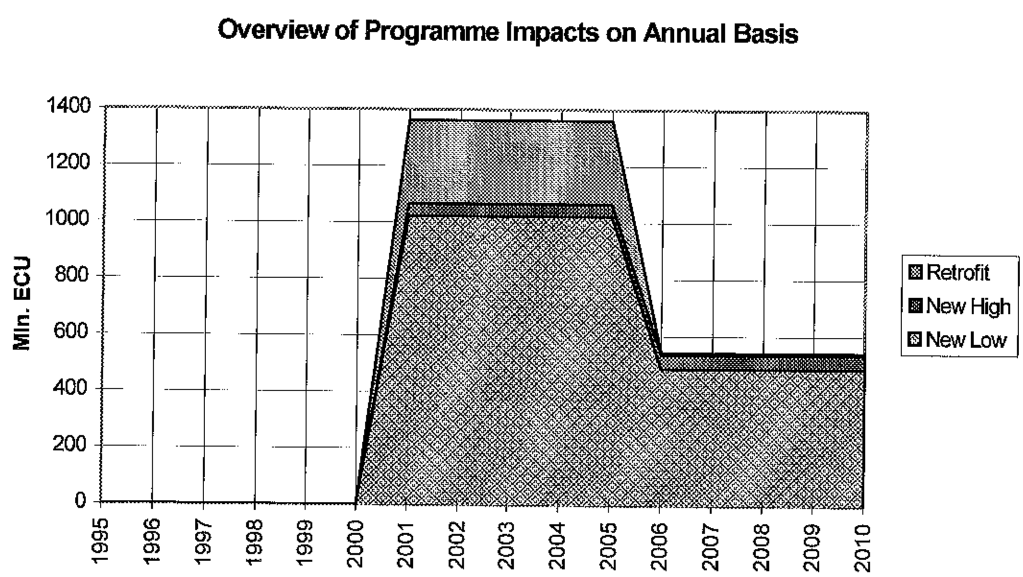

Figure 7 *Net impact per year of a CCT support programme*

The benefits from a support programme for CCT in retrofit projects are obviously smaller than for newly built capacity and are even much more concentrated in the early years of such a support programme. The extra production value for CCT manufacturing inside the European Union amounts to almost 300 million ECU annually between 2000 and 2005, while it is only a mere 6 million after 2005. The reason for this concentration in time is related to the age structure of the global coal power capacity as is explained in section 8.2.

It is imaginable, however, that after 2010 an entirely new kind of retrofit will develop for the coal power capacity built between 1995 and 2005. By that time the market conditions and the technology options will have changed so much that a completely new support programme will be needed. This notion applies to the market for new capacity as well.

The differences between the impacts of a CARNOT programme on the IPP Low and IPP High scenarios are not so large. In absolute terms the IPP High scenario generates a larger impact from a CARNOT programme (0.5 billion ECU more for the entire period). In relative terms the boost from a CARNOT programme is somewhat larger in the IPP Low scenario. IPPs will evaluate new CCT options somewhat different (with more emphasis on comprehensive costs) than utilities will do. Therefore, a CCT support programme should include a portfolio of instruments that can be tailored to crucial criteria in actual markets.

In the simulations for this study the market shares of EU based CCT manufacturers do not slide down under 40%. In case local manufacturers would develop even much stronger than assumed in this study, still significant benefits from a CCT support programme would remain, though with some shift from production effects inside the EU towards revenue transfers back to the EU. So, even in case of a market share that would drop to 20% of total sales in target markets, the benefits would accrue to 2.5 to 5 billion ECU.

The dynamics of market shares by target area are the result of a multitude of influences, i.e. the share of IPP, the attainable cost level in every country through overseas production, the attainable cost levels of CCTs in EU, notably the degree of convergence in cost levels between less and more advanced CCT options. Table 13 provides an overview of the differences between the scenarios. For the EU 'home' market a default rate of 100% is used. Please note that the figures in Table 13 refer to gross market shares, that is including overseas production. In other words it shows the part of the global sales in which the EU manufacturing is involved. Table 14 provides an overview of the development of total EU related sales and the part actually produced in the EU.

Table 13 *Market shares of EU based sales (include. overseas production)*

		1995-2000	2001-2005	2006-2010
China	IPP Low without C.	39	38	39
	IPP Low with C.	39	42	40
	IPP High without C.	42	38	39
	IPP High with C.	42	41	40
India	IPP Low without C.	39	41	39
	IPP Low with C.	39	42	40
	IPP High without C.	42	38	39
	IPP High with C.	42	41	40
Asian NICs	IPP Low without C.	30	30	30
	IPP Low with C.	30	30	30
	IPP High without C.	29	30	30
	IPP High with C.	29	30	30
Rest of Asia	IPP Low without C.	39	41	39
	IPP Low with C.	39	42	40
	IPP High without C.	42	38	39
	IPP High with C.	42	41	40
CEE CIS	IPP Low without C.	26	25	28
	IPP Low with C.	26	25	28
	IPP High without C.	26	25	28
	IPP High with C.	26	25	28

Table 14 *Shares of EU, EU-but-overseas and non-EU manufacturing*

	IPP low without CARNOT	IPP low with CARNOT	IPP high without CARNOT	IPP high with CARNOT
Other	59.5%	59.5%	56.9%	56.9%
EU prod	15.8%	15.8%	21.7%	21.7%
EU overseas	24.7%	24.7%	21.4%	21.4%
Other	58.0%	55.7%	58.9%	56.5%
EU prod	17.9%	23.3%	16.3%	21.5%
EU overseas	24.0%	21.0%	24.9%	21.9%
Other	58.3%	57.4%	58.5%	57.6%
EU prod	19.8%	22.1%	19.6%	22.0%
EU overseas	21.9%	20.5%	21.9%	20.4%

5.4. Market Developments by Technology

As regards newly built capacity five CCT options are considered, being:
- conventional pulverised coal with flue gas desulphurisation and low NO_x burners (PF),
- (ultra) supercritical pulverised coal with flue gas desulphurisation and low NO_x burners ((U)SCPF),
- atmospheric fluidised bed combustion (AFBC),
- pressurised fluidised bed combustion (PFBC),
- integrated coal gasification combined cycle (IGCC).

We assumed that AFBC and PFBC were predominantly used in small to medium scale plants (up to 100 MW), whereas the other options are assumed to be used for large scale facilities. Yet, in the future PFBC may be used for somewhat larger scales as well, while in some export markets simplified IGCC plants are under construction of less than 100 MW.

Given the impending convergence of costs per kW of PF and SCPF, the latter technology seems to be the preferred one up to 2005. PF is decreasing and IGCC is just appearing (supposedly as commercial demonstration only). After 2005 IGCC is expected to play a more important role, being at least equal to that of (U)SCPF. As regards the small and medium sized plants AFBC will dominate before 2000. After that, PFBC will gradually become more important and will even have a somewhat larger share in newly built capacity after 2005. If PFBC would succeed to penetrate the large scale market as well, then notably IGCC might suffer loss of market share.

Figures 8, 9 an 10 provide an impression of the development of market shares distinguished by technology option, by kind of purchaser (utility or IPP) and by production location. The label extension 'production' represents production inside the EU, while the extension 'transfer' refers to production predominantly realised overseas in the target market, though with involvement of EU based companies.

The graphs demonstrate that the local content, i.e. what is made in target markets, is larger when the technology is more conventional. Furthermore, over time the share of local content of - nowadays - more advanced clean coal technologies increases. The other scenarios show similar developments that only differ in absolute size and speed of the changes. Indeed, since the figures only represent prospective calculations instead of observations the graphs should primarily be interpreted as depicting a process and providing an impression of the order of magnitude of markets.

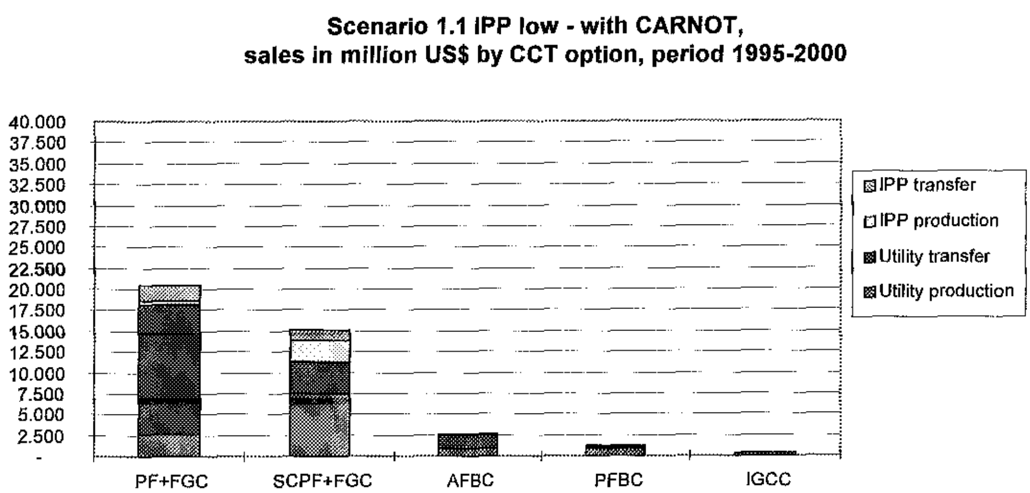

Figure 8 *Overview of market shares by technology*

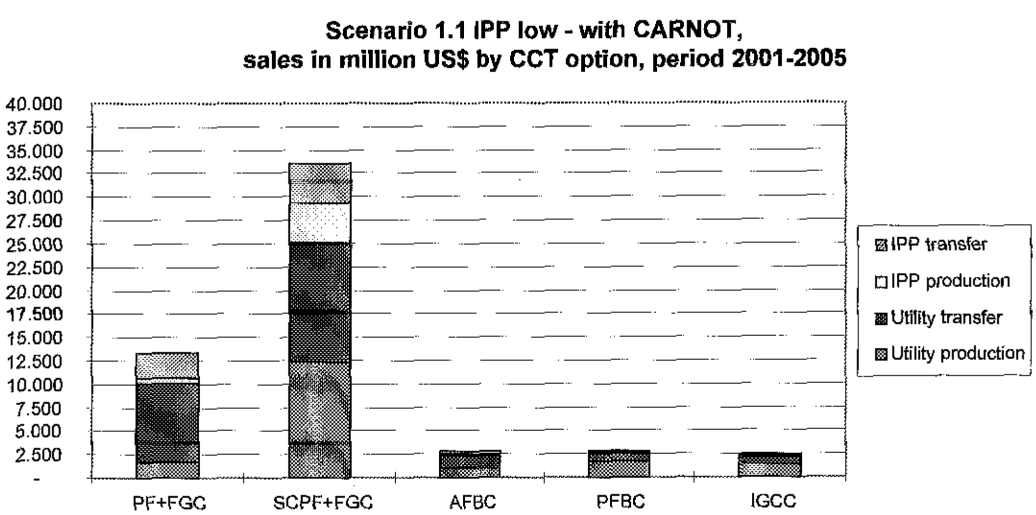

Figure 9 *Overview of market shares by technology*

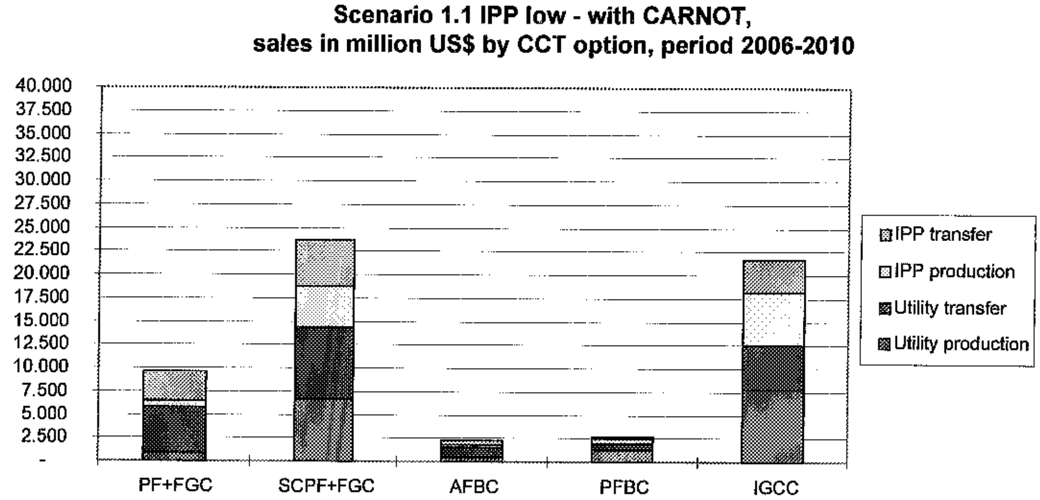

Figure 10 *Overview of market shares by technology*

6. ENVIRONMENTAL CHARACTERISATION OF CCT OPTIONS

For five clean coal technology (CCT) options estimates of investment cost, SO_2, NO_x, and N_2O emissions, and generating efficiencies of four clean coal technologies have been collected and evaluated. The five CCT options considered are:

- conventional pulverised coal fitted with flue gas desulphurisation and low NO_x burners and (optional) scrubbing installations (PF).
- (ultra) supercritical pulverised coal fitted with flue gas desulphurisation and low NO_x burners and (optional) scrubbing installations ((U)SCPF).
- atmospheric (circulating) fluidised bed combustion (CFBC).
- pressurised fluidised bed combustion (PFBC).
- integrated coal gasification - combined cycle (IGCC).

A conventional pulverised coal fired power plant with supercritical steam conditions, and a net generating efficiency of 42.5%, is used as reference. This coal fired power plant is equipped with flue gas desulphurisation and low-NO_x technology, just as in case of the coal fired power plant with Ultra supercritical Steam Conditions (USC). Therefore, the emissions of SO_2, NO_x and N_2O in g/GJ are the same as for advanced pulverised coal (USC).

For the period 2000-2010 moderate cost reductions (USD 50/kW_e) are assumed for all of the clean coal technologies, except for CFBC. The reason is that CFBC is regarded as a mature technology with little prospect for further efficiency improvement and cost reduction after 2000. The reference coal fired power plant could also become marginally cheaper in the timeframe considered (2000-2010), for instance because of cost reductions in flue gas desulphurisation.

CFBC and PFBC could have the same investment cost (USD 1.100/kW_e) in 2010. Because of the superior environmental performance (emissions, generating efficiency) of PFBC compared to CFBC, PFBC would probably have a competitive edge over CFBC at that time. Pulverised coal fired power (based on USC) is assumed to be slightly more expensive (USD 1.150/kW_e), although it is somewhat more efficient than PFBC. IGCC could be favoured for its higher efficiency compared to USC based pulverised coal fired power, despite its higher investment cost (USD 1.270/kW_e in 2010). The reference coal fired power technology with a constant net efficiency of 42.5% is assumed to remain slightly less expensive (in USD/kW_e) than advanced pulverised power based on USC.

Figure 11 presents the SO_2, NO_x, and N_2O emissions of the clean coal technologies. SO_2 and NO_x emissions do not show large differences, although IGCC seems to be superior in this respect. Emissions of N_2O are relevant, as N_2O is a harmful greenhouse gas. N_2O emissions are much larger for CFBC and PFBC than for the two other clean coal technologies.

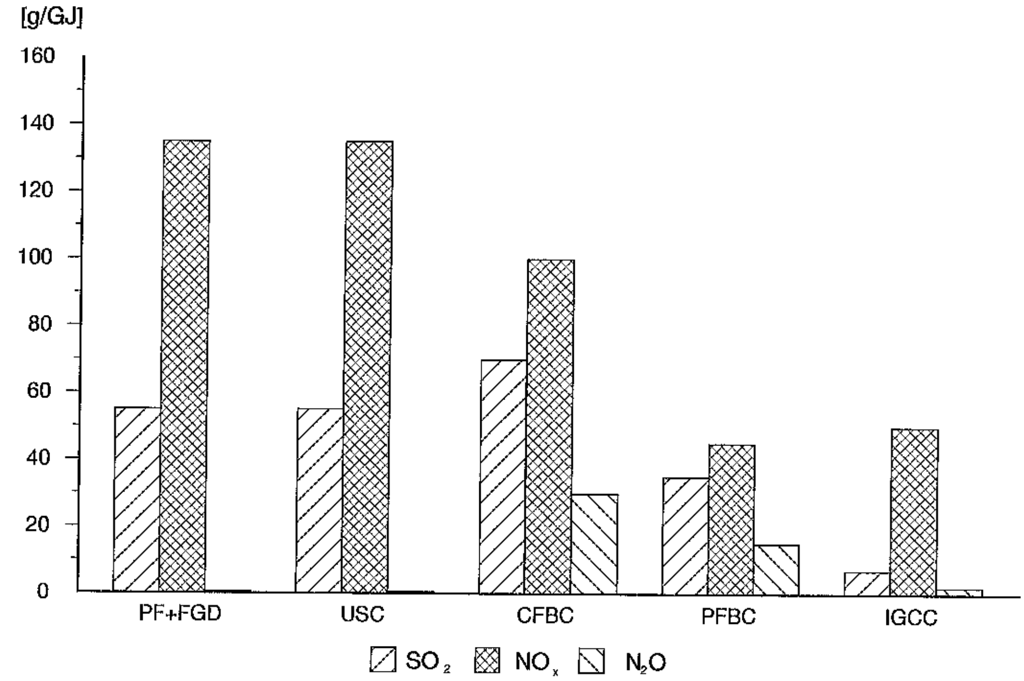

Figure 11 *SO_2, NO_x, and N_2O emissions (g/GJ) for clean coal technologies*

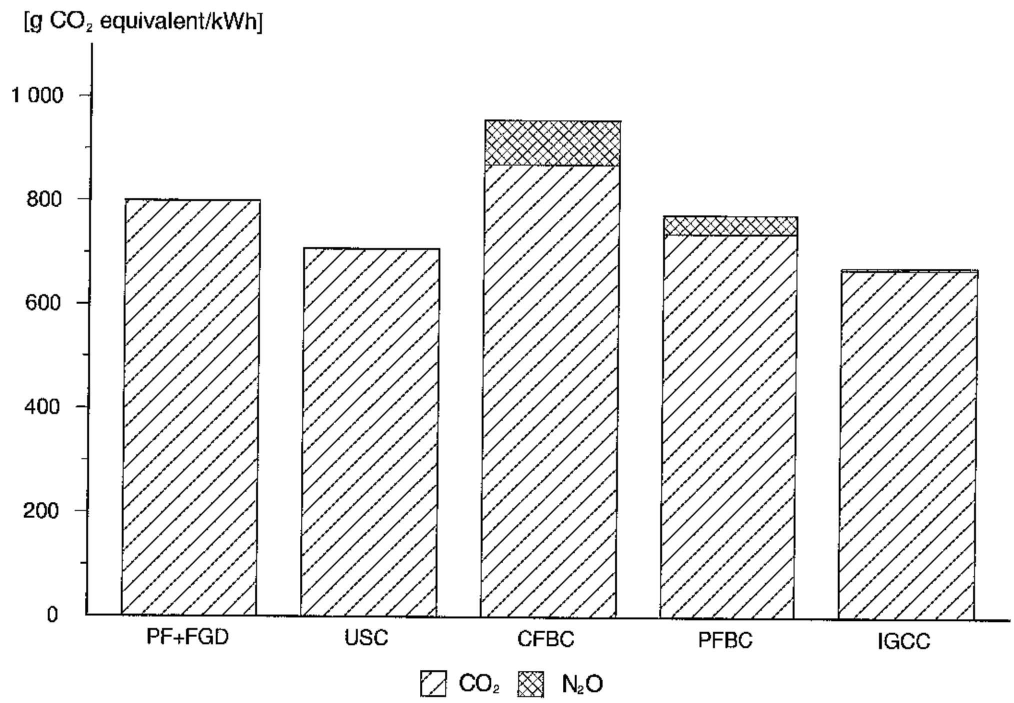

Figure 12 *CO_2 equivalent emission (g/kWh) for clean coal technologies in year 2000*

CO_2 equivalent emissions are presented in Figure 12. The figures refer to the CO_2 emission from coal, and from the use of limestone or dolomite for desulphurisation. For IGCC alternative desulphurisation processes are used, which do not cause direct CO_2 emissions. Besides, N_2O expressed as CO_2 equivalent is taken into account in Figure 12. It should be noted that N_2O is 310 times more powerful as a greenhouse gas than CO_2, taking a time horizon of 100 years.

Today, USC based pulverised coal fired and IGCC are the only technologies with lower greenhouse gas emissions than conventional pulverised coal fired power. CO_2 equivalent emissions of CFBC and PFBC are higher than for conventional pulverised coal fired power, because of a lower generating efficiency (CFBC) and/or higher N_2O emissions (CFBC and PFBC).

7. RESULTING ENVIRONMENTAL BENEFITS FROM CCT OPTIONS

7.1. Introduction

Environmental benefits from clean coal technologies arise primarily from reduction in two types of emissions:

- SO_2 and NO_x emissions, which are acidifying emissions,
- Greenhouse gases, mainly CO_2, but also N_2O (as `CO_2 equivalent').

In the sections 8.2 and 8.3 the focus is on these two types of emissions. In section 8.4 results from scenarios with a low or a high share of IPPs are presented.

7.2. SO_2 and NO_x Emissions

Clean coal technologies are characterised by specific SO_2 and NO_x emissions (in g per GJ of coal). Some options have potential for large reductions of SO_2 and NO_x emissions, e.g. IGCC. Pulverised coal fired power (conventional or advanced) is assumed to be equipped with flue gas desulphurisation (FGD), but not with selective catalytic reduction (SCR). SCR has the potential to reduce NO_x emissions by approximately 80%. However, other NO_x reduction options in the energy economy could be more cost effective. Therefore, SCR is not considered mandatory for new pulverised coal fired power. For that reason NO_x emissions from pulverised coal fired power are not particularly low, compared to e.g. PFBC and IGCC.

In most of the regions considered - China, India, and other Asian countries - reduction of SO_2 and NO_x emissions has not such a priority to ensure IGCC and PFBC to be favoured solely because of their low SO_2 and NO_x emissions. However, in heavily polluted and/or densely populated areas in China, India, and Eastern Europe, reduction of these emissions could become so important, that IGCC and PFBC become favoured options indeed. In a number of Asian countries numerous people each year become victim of heavy air pollution: recent evidence shows that in India as much as 50.000 people each year die from air pollution, caused by emissions from traffic, industry, and power generation.

7.3. Greenhouse Gas Emissions

The main greenhouse gas is CO_2. It has been shown that emissions of N_2O are far from negligible for CFBC and PFBC, considering that the global warming potential of N_2O is 310 times that of CO_2 (time horizon 100 years) [41]. With the inclusion of N_2O as a greenhouse gas, the most efficient clean coal technologies - advanced pulverised coal and IGCC - are getting a competitive edge over CFBC, PFBC and conventional pulverised coal. Considering the development potential of advanced pulverised coal and IGCC, these options could become favoured indeed, if global warming becomes more dominant as a selection criterion. Yet, in the quantitative evaluation procedure used for the results in chapter 6 these considerations have not been included, in order to prevent us from producing overly optimistic market prospects for the advanced CCT options.

7.4. Emission Scenarios for CCTs

A number of scenarios have been developed which show different developments of clean coal technologies in the world regions considered. The main differences between scenarios are related to the proportion of utilities and IPPs and the production settlement strategies of EU-based CCT manufacturers in the timeframes considered. In order to have a clear unfiltered picture of the sales differences, it followed from the initial assumptions that for a given market situation the industrial strategies would more or less attempt to compensate for a possible absence of a CCT support programme. Consequently, for a given market situation approximately the same power generation mix would be installed regardless of the existence of a CCT support programme. This has been done since the prime aim of the study was to show the economic rationale of a CCT support programme. The consequences of this choice are that the variants *with CARNOT* and *without CARNOT* do not show much difference in emission levels. Therefore, only the scenarios *with* CARNOT are considered here. In Annex C the results of the scenarios *with* CARNOT are presented, in terms of MWs and percentages of clean coal technologies for the main world regions and for each of the time periods considered (Tables C.1-C.3), and as emissions of SO_2, NO_x, and CO_2 (Tables C.4-C.6).

Considering that the economic impact oriented scenario construction has severely diluted the probable impacts of the promotion of CCT technologies, a second way of attributing the improvement of environmental performance has been applied. In this approach it has been assumed that in the absence of a CARNOT programme and given the capital limitations in a power market with low IPP participation, Asian countries will continue to build just conventional coal power (PF + FGD) and AFBC. This means no SCPF, PFBC and IGCC will be installed in Asian countries in this variant. In that case a significant difference between a *with CARNOT* and a *without CARNOT* situation can be demonstrated. An overview is shown in Table 15.

Table 15 *Emission consequences of absence or presence of CCT support programme*

CARNOT Effect Version 1		SO_2 [t/y]	No_x [t/y]	CO_2-eq. [mln t/y]
Low IPP	2001-2005	2,848	6,868	5
	2006-2010	3,832	9,257	7
High IPP	2001-2005	2,667	6,424	5
	2006-2010	5,008	11,492	7
	NL 1996	136,000	489,000	229
	EU 1990	14,252,000	13,606,000	3,286
CARNOT effect/NL emission		*3.7%*	*2.4%*	*3.2%*
CARNOT effect/EU emission		*0.0%*	*0.1%*	*0.2%*

CARNOT Effect Version 2		SO2 [t/y]	Nox [t/y]	CO2-eq. [mln t/y]
Low IPP	1995-2000	7,296	14,943	8
	2001-2005	38,619	80,284	41
	2006-2010	146,438	290,380	90
CARNOT effect/NL emission		*107.7%*	*59.4%*	*39.4%*
CARNOT effect/EU emission		*1.0%*	*2.1%*	*2.7%*

The impacts shown in version 1 depict the very strict interpretation tied to economic impact oriented scenario formulation. In order to make the differential emissions more easy to interpret the emission levels of the Netherlands and the 15 EU countries together have been added. In fact the message from this is that even in a typical buyers market in which a *given power mix* may be expected to be purchased, a CCT support programme including cost effectiveness R&D would still mean a slight beneficial impact for the environment. Yet, the second version of the evaluation illustrates the risk of not staging a CCT support programme. In the case of a Low IPP scenario (implying less money available) the continued reliance on conventional technology turns out to become environmentally very unfortunate in the course of the next decade. Even compared to the total EU emission levels, significant reductions are at stake.

It should be noted that the market for each clean coal technology is defined as the MWs to be delivered by Europe based industries, including the share of local manufacturing industries in the region concerned.

From the Tables D.1-D.3 in Annex D the following conclusions can be presented :
1. The major market for clean coal technology is `Asia exclusive of NICs', which includes China, India, and a large part of the rest of Asia. The market shares of clean coal technologies within China, India, and the rest of Asia (exclusive of Asian NICs) is more or less comparable. For each of the periods considered, this part of the world represents over 80% of the total. Asian NICs, Eastern Europe and Turkey, and the EU are relatively minor markets compared to `Asia exclusive of NICs'.
2. In the first period considered (1995-2000) the share of more or less advanced technologies (advanced pulverised coal, PFBC, IGCC) is rather limited in case of the `low IPP' scenario. However, advanced pulverised power could capture a large share of the market in case of the `high IPP' scenario.

3. After 2000 the differences between 'low IPP' and 'high IPP' become less pronounced. In the period 2001-2005 advanced pulverised power becomes the dominant option in all of the regions, and irrespective of the share of IPPs in power generation. The other advanced technologies, PFBC and IGCC, show an increasing market share in the period 2001-2005. The share of AFBC marketed by EU industry declines marginally.
4. In the period 2006-2010 the main options of choice are advanced pulverised coal and IGCC, with conventional pulverised coal as the third substantial option. The remaining 8% of the market is equally divided between AFBC and PFBC. In this timeframe the differences between 'low IPP' and 'high IPP' are marginal.

These results have consequences for SO_2, NO_x, and CO_2 emissions, as shown in the Tables D.4-D.6 in Annex D.

8. CONCLUSIONS AND RECOMMENDATIONS

This report focused on the market dynamics underlying the sales prospects of clean coal technology as well as the possible consequences of emission levels for given compositions for newly installed coal based power. However as this report constitutes one element in a larger series of tasks aiming at the provision and testing of a sound rationale for a clean coal technology support programme, the conclusions and recommendations presented here have been formulated with an eye to the entire study context.

The postulated hypothesis of a drift of clean coal technology (CCT) manufacturing activities from EU countries to new key markets, such as China , India and Central and Eastern Europe, has been confirmed by the Forum members as well as by actual observations in the market. Yet, the speed with which CCT manufacturing activities will build up elsewhere in stead of in the EU can be significantly influenced by proper support instruments. This report has demonstrated that CCT options to be sold in Asia and Central and Eastern Europe should be excellent in terms of cost-effectiveness rather than environmental performance proper. In other words the emerging target markets will show an increasing demand for *clean* coal technologies, but the cleanliness should be *affordable*. This will have implications for research, development and demonstration programmes for CCTs.

Provided that an RD&D programme focusing on cost-effective CCTs is implemented, while also the financing and marketing barriers are reduced, a significant net economic benefit could accrue to the EU and EU based CCT manufacturers. The accumulated impact of an effective CCT support programme has been estimated at the order of magnitude of 8 billion to 9.5 billion ECU for the entire period 1995-2010, including both newly built power and retrofit projects. These figures do not include possible sales to non-European OECD countries, Africa and Latin America.

Taking into account that the absence of CCT support programmes might lead to a much slower introduction of advanced CCT options in the target markets, notably Asia, moderate but still significant emissions reductions can be expected.

The influence of IPPs or in more general terms the influence of liberalisation of energy markets on technology choice is not purely detrimental to the penetration of CCTs. As regards fuel choice, notably in the case of small scale power plants there is a strong competition from natural gas. Yet, given the limited possibilities to enlarge energy imports due to balance of payments restrictions, countries with important indigenous coal reserves will continue to use coal in substantial quantities, especially in (large scale) power plants. Given a continued presence of coal for power generation IPPs may be expected to get more interested in advanced CCTs as soon as these technologies become more competitive, notably through lower costs per kW. Indeed once CCT is seriously considered as an option, IPPs might even show a swifter switch towards CCTs than more traditional power companies. Clearly, what remains a problem is how to get the CCTs as soon as possible within the margin of competitiveness and how to finance this transitional pre-commercial period.

One important element in this precommercial period is the implementation of commercial scale demonstration projects of cost-effective CCTs in the target markets. This will speed up the learning curve in manufacturing and operation and facilitate the attaining of cost-effectiveness goals. This point has also been emphasised in Tasks 3 and 4.

Originally the tightening of environmental standards has been advocated as a possible way to enhance the market conditions for CCTs. However, it has been explained in the Forum that such an approach should be utilised with utmost care. A too ambitious tightening of standards could raise costs so much that eventually less CCT is bought or a dual approach of partly advanced CCT and partly non clean coal technology is followed.

The following list below summarises the principal conclusions and recommendations.

Conclusions and Recommendations

- R&D aiming at *affordable CCT* is crucial.
- in as far as IPPs don't avoid coal, higher shares of IPP are neutral or positive, certainly in the medium to long run.
- stagnant re/deregulation of power markets leads to slower shift towards advanced CCT, since less efficient power markets will require more capital per project or is less able to mobilise sufficient capital.
- demonstration projects will be an important vehicle to move advanced CCT into market, it is especially necessary to accelerate uptake of advanced CCT by risk averse IPPs.
- utmost care should taken with regard to the encouragement of tightening environmental standards, any tightening of standards preferably follows the speed of cost reduction of CCT.
- a CCT charter fostering some openness, JI elements and license protection seems worthwhile.

Remaining Aspects

Though the word 'coal' is used throughout the report, in fact other solid fuels are relevant as well. The share of other solid fuels is small compared to the total volume of the market for new power capacity. However, in some countries and in the power market up to 100 MW other solid fuels can constitute important shares. The waste-to-energy market is currently building up inside the EU. Similarly, the ongoing massive urbanisation in many Asian countries will cause a transfer from landfill practices to better utilisation of urban waste, e.g. in waste-to-energy projects. In some rural areas, on islands, etc. adapted clean coal technology will enable clean and efficient ways to use local biomass. Please, note that these rapidly growing economies often have balance of payments deficits. Therefore, local fuels such as waste and biomass, just as indigenous coal, can attenuate these deficits.

The logistics of coal is always complicated and relatively expensive, unless minemouth power stations are used. In the fast growing Asian economies using indigenous coal, notably China and India, logistics is really becoming a bottleneck. To date most of the coal is transported by train. Given the rapid growth of industrial output there is increasing competition for rail and train capacity. In this situation the already large and still growing coal shipments are a heavy burden on the railway system and high opportunity costs due to crowding out of shipments with higher value added. The improvement of coal logistics, e.g. by constructing slurry pipelines coal logistics would enjoy lower unit costs, higher reliability and less environmental impacts. Another approach would be to reduce the losses of long range power transmission substantially and thereby making minemouth power generation more cost effective.

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ANNEX A. PROJECT STRUCTURE[1]

The project was wide ranging in its scope with many different areas of activity to be considered. As a result, the project was divided into individual tasks divided amongst the members of the consortium. The eight inter-related project tasks can be summarised in terms of specific objectives as outlined below:

Task 1: European Clean Coal Technology Forum
The objective of this task was to develop a point of contact with clean coal technology developers, manufacturers, users, exporters, and financiers by establishing a European clean coal forum. This forum provided an essential method for obtaining feedback from industry for input to the project. (*Co-ordinated by ETSU*)

Task 2: Success Factors in Clean Coal Programmes
The task objective was to review and analyse past and present coal programmes in order to recommend the best structures and procedures for stimulating the COMMERCIALISATION of the leading European technologies. The work focused mainly on European Union and Member State coal programmes, along with those in the USA and Japan. (*Carried out by CIEMAT*)

Task 3: Investment, Regulatory and Institutional Barriers
The objectives of this task were to identify all major non-technical barriers to the take-up of EU CCTs, to identify activities to reduce these barriers. A focus on finance mechanisms and their application in EU and world-wide markets. (*Carried out by ETSU*)

Task 4: Export Markets and Options for Penetration
This study determined a priority list of target markets outside of the EU and quantified the export potential, identified market opportunities and to provided recommendations to enhance market penetration. (*Carried out by Hügli Pollock Read/Novem*)

Task 5: Economics and Emissions
Assessment and quantification of the economic and environmental benefits for EU countries of the new Programme was undertaken in this task. The estimation of benefits was constructed from quantitative indicators, based heavily on a range of underlying data and qualified assumptions. (*Carried out by ECN/Novem*)

Task 6: Socio-economic and Environmental Benefit Analysis
An analysis of the socio-economic and environmental benefits of increased investment in clean coal technologies due to the Programme activities was completed within the objectives of this task. By reviewing existing studies, creating and applying 'simple' computer-aided input-output models a number of scenarios were examined and the expected benefits were calculated. (*Carried out by FZ-Jülich*)

Task 7: Communications Strategy
The development of an appropriate communication strategy to demonstrate that clean coal technologies are cost-effective and environmentally acceptable. The identifica-

[1] This text is taken from the European Integrated Clean Coal Programme - Implementation Plan, ETSU, February 1998.

tion of decision-makers or persons capable of influencing decisions on energy technology investments formed an integral part of the task, along with an analysis of effective communication media. (*Carried out by CIEMAT*).

Task 8: Implementation Plan
This task integrates the recommendations of the above tasks into a comprehensive implementation plan which will facilitate the initiation the Programme. In addition the recommendations from individual tasks were examined taking account of EU energy policy issues. (*Carried out by ETSU*)

ANNEX B. DATA FOR SALES ASSESSMENT

B.1 Expected GW per target market and IPP shares

Expected new capacity (GW)	1995-2000		2001-2005		2006-2010	
IPP Low	IPP	Utility	IPP	Utility	IPP	Utility
China	7.7	43.9	15.2	53.8	23.8	44.2
India	2.2	10.2	5.1	13.9	10.4	14.4
Asian NICs	0.3	6.6	1.2	6.6	3.2	5.2
Rest of Asia	0.9	5.2	2.6	6.1	4.7	6.6
CEE/CIS/Turkey	0.5	2.6	1.4	4.8	4.3	5.3
EU	0.6	3.4	1.8	6.5	4.0	4.8
Total by period	*12.3*	*71.9*	*27.3*	*91.7*	*50.4*	*80.5*

IPP low	%IPP of new capacity		
Andersen Con	1995	2000	2005
China	15%	22%	35%
India	18%	27%	42%
Asian NIC	5%	15%	38%
Rest of Asia	15%	30%	42%
CEE/CIS/Turkey	15%	22%	45%
EU countries	15%	22%	45%
N&S America	35%	70%	85%
Africa	18%	23%	28%

Expected new capacity (GW)	1995-2000		2001-2005		2006-2010	
IPP High	IPP	Utility	IPP	Utility	IPP	Utility
China	10.3	41.3	22.1	46.9	31.9	36.0
India	2.8	11.1	12.6	12.6	19.5	13.0
Asian NICs	0.7	6.2	2.3	5.4	3.4	5.1
Rest of Asia	1.0	5.7	5.1	6.3	8.1	6.6
CEE/CIS/Turkey	0.5	2.5	2.2	4.0	4.8	4.8
EU	0.8	3.2	2.9	5.4	4.8	4.0
Total by period	*16.1*	*70.1*	*47.2*	*80.6*	*72.5*	*69.4*

IPP high	%IPP of new capacity		
Andersen Con	1995 >>>	2000>>>	2005>>>
China	20%	32%	47%
India	20%	50%	60%
Asian NIC	10%	30%	40%
Rest of Asia	15%	45%	55%
CEE+Turkey	17%	35%	50%
EU countries	20%	35%	55%
N&S America	35%	70%	85%
Africa	18%	35%	45%

Small scale power (<100 MW) in GW				
IPP High	1995 >>>	2000 >>>	2005 >>>	Total
China	4.6	5.8	5.2	15.6
India	1.2	1.9	2.3	5.4
Asian NIC	0.7	0.8	1.1	2.6
Rest of Asia	0.6	0.9	1.4	2.9
CEE/CIS/Turkey	0.4	0.7	1.0	2.1
EU countries	0.7	1.4	0.9	2.9
Total Small Scale	8.3	11.5	11.8	31.5

Small scale power (<100 MW) in GW				
IPP Low	1995 >>>	2000 >>>	2005 >>>	Total
China	4.8	6.1	5.6	16.5
India	1.1	1.6	2.0	4.7
Asian NIC	0.7	0.9	1.1	2.7
Rest of Asia	0.6	0.7	1.1	2.4
CEE/CIS/Turkey	0.4	0.8	1.0	2.2
EU countries	0.7	1.5	0.9	3.1
Total Small Scale	8.3	11.7	11.7	31.6

B.2 Probability by type of industrial organisation

Probability of project type **default**

AFBC	China	India	Asian NICs	R.of Asia	CEE+Tur.	EU
export EU	15%	15%	5%	20%	0%	100%
new subs.	0%	0%	5%	5%	5%	0%
take over	5%	5%	20%	5%	40%	0%
joint venture	10%	10%	25%	15%	30%	0%
sub-contr	40%	40%	15%	30%	10%	0%
license	30%	30%	30%	25%	15%	0%
	100%	100%	100%	100%	100%	100%

PFBC	China	India	Asian NICs	R.of Asia	CEE+Tur.	EU
export EU	50%	50%	20%	40%	15%	100%
new subs.	0%	0%	0%	0%	0%	0%
take over	5%	5%	10%	0%	15%	0%
joint venture	15%	15%	15%	20%	40%	0%
sub-contr	25%	25%	40%	30%	20%	0%
license	5%	5%	15%	10%	10%	0%
	100%	100%	100%	100%	100%	100%

IGCC	China	India	Asian NICs	R.of Asia	CEE+Tur.	EU
export EU	50%	50%	20%	40%	15%	100%
new subs.	0%	0%	0%	0%	0%	0%
take over	5%	5%	10%	0%	15%	0%
joint venture	15%	15%	15%	20%	40%	0%
sub-contr	25%	25%	40%	30%	20%	0%
license	5%	5%	15%	10%	10%	0%
	100%	100%	100%	100%	100%	100%

PF+FGD	China	India	Asian NICs	R.of Asia	CEE+Tur.	EU
export EU	5%	5%	0%	5%	5%	100%
new subs.	0%	0%	5%	0%	0%	0%
take over	10%	10%	10%	10%	25%	0%
joint venture	40%	40%	25%	40%	40%	0%
sub-contr	25%	25%	40%	25%	20%	0%
license	20%	20%	20%	20%	10%	0%
	100%	100%	100%	100%	100%	100%

SCPF+FGD	China	India	Asian NICs	R.of Asia	CEE+Tur.	EU
export EU	50%	50%	5%	50%	5%	100%
new subs.	0%	0%	0%	0%	0%	0%
take over	5%	5%	10%	5%	20%	0%
joint venture	10%	10%	40%	10%	40%	0%
sub-contr	20%	20%	25%	20%	25%	0%
license	15%	15%	20%	15%	10%	0%
	100%	100%	100%	100%	100%	100%

Probability of project type **falling EU shares**

AFBC	China	India	Asian NICs	R.of Asia	CEE+Tur.	EU
export EU	8%	8%	5%	15%	0%	100%
new subs.	5%	5%	5%	0%	5%	0%
take over	10%	10%	20%	5%	40%	0%
joint venture	17%	17%	25%	10%	25%	0%
sub-contr	30%	30%	15%	40%	10%	0%
license	30%	30%	30%	30%	20%	0%
	100%	100%	100%	100%	100%	100%

PFBC	China	India	Asian NICs	R.of Asia	CEE+Tur.	EU
export EU	35%	35%	20%	30%	10%	100%
new subs.	0%	0%	0%	0%	5%	0%
take over	5%	5%	10%	5%	25%	0%
joint venture	25%	25%	15%	25%	30%	0%
sub-contr	25%	25%	40%	25%	15%	0%
license	10%	10%	15%	15%	15%	0%
	100%	100%	100%	100%	100%	100%

IGCC	China	India	Asian NICs	R.of Asia	CEE+Tur.	EU
export EU	35%	35%	20%	30%	15%	100%
new subs.	0%	0%	0%	0%	0%	0%
take over	5%	5%	10%	5%	15%	0%
joint venture	25%	25%	15%	25%	40%	0%
sub-contr	25%	25%	40%	25%	15%	0%
license	10%	10%	15%	15%	15%	0%
	100%	100%	100%	100%	100%	100%

PF+FGD	China	India	Asian NICs	R.of Asia	CEE+Tur.	EU
export EU	0%	0%	0%	0%	0%	100%
new subs.	5%	5%	5%	5%	5%	0%
take over	10%	10%	10%	10%	25%	0%
joint venture	40%	40%	25%	40%	40%	0%
sub-contr	25%	25%	40%	25%	20%	0%
license	20%	20%	20%	20%	10%	0%
	100%	100%	100%	100%	100%	100%

SCPF+FGD	China	India	Asian NICs	R.of Asia	CEE+Tur.	EU
export EU	25%	25%	5%	30%	5%	100%
new subs.	5%	5%	5%	5%	0%	0%
take over	5%	5%	10%	5%	25%	0%
joint venture	20%	20%	20%	20%	40%	0%
sub-contr	20%	20%	30%	20%	20%	0%
license	25%	25%	30%	20%	10%	0%
	100%	100%	100%	100%	100%	100%

B.3 Cost and efficiency levels of CCT options

CCT type	kW costs China 95-2000	01-05	in USD 05-10	kW costs India 95-2000	01-05	in USD 05-10
PF+FGC	1150	1086	1086	1150	1086	1086
SCPF+FGC	1200	1081	1056	1200	1092	1056
AFBC	1120	1062	1042	1120	1073	1042
PFBC	1200	1116	1064	1200	1133	1070
IGCC *	1540	1280	1140	1540	1300	1146
average cost	1160	1086	1076	1160	1095	1079

CCT type	kW costs Asian NICs 95-2000	01-05	in USD 05-10	kW costs Rest of Asia 95-2000	01-05	in USD 05-10
PF+FGC	1150	1120	1120	1150	1086	1086
SCPF+FGC	1200	1120	1100	1200	1092	1056
AFBC	1120	1100	1080	1120	1073	1042
PFBC	1200	1150	1120	1200	1133	1070
IGCC *	1540	1320	1180	1540	1300	1146
average cost	1160	1123	1119	1160	1095	1079

CCT type	kW costs CEE+Turkey 95-2000	01-05	in USD 05-10	kW costs EU / OECD 95-2000	01-05	in USD 05-10
PF+FGC	1150	1098	1098	1150	1120	1120
SCPF+FGC	1200	1086	1062	1200	1120	1100
AFBC	1120	1073	1048	1120	1100	1080
PFBC	1200	1121	1064	1200	1150	1120
IGCC *	1540	1287	1140	1540	1320	1180
average cost	1160	1095	1080	1160	1123	1119

	fuel efficiency - all countries			
	efficiency of alternatives			
CCT Type	1995-2000	2001-2005	2005-2010	2010-2020
PF+FGC	0.39	0.39	0.39	0.39
SCPF+FGC	0.45	0.47	0.48	0.49
AFBC	0.40	0.41	0.41	0.41
PFBC	0.44	0.45	0.46	0.47
IGCC	0.45	0.48	0.51	0.53

B.4 Overview of Results by Scenario Variant

1.1

Scenario:	**IPP low**	**differentiated prices**	**Criterion:**	**Capital cost only LDCs**
		***without* CARNOT**		**Capital cost and fuel efficiency**

1995-2000 UTILITIES	Total Sales in mln. USD	of which by EU: prod.	trf.rev.	**1995-2000 IPPs**	Total Sales in mln. USD	of which by EU: prod.	trf.rev.
PF+FGC	51,551	2,666	15,495	PF+FGC	6,123	464	1,821
SCPF+FGC	22,685	7,474	3,765	SCPF+FGC	7,639	2,729	1,099
AFBC	6,590	888	1,592	AFBC	455	62	110
PFBC	2,130	899	218	PFBC	251	90	24
IGCC	734	283	95	IGCC	5	2	0
	83,690	*12,210*	*21,166*		14,473	*3,347*	*3,054*

2001-2005 UTILITIES	Total Sales in mln. USD	of which by EU: prod.	trf.rev.	**2001-2005 IPPs**	Total Sales in mln. USD	of which by EU: prod.	trf.rev.
PF+FGC	28,898	1,659	8,448	PF+FGC	9,254	543	2,721
SCPF+FGC	55,792	12,416	12,657	SCPF+FGC	18,463	4,313	4,089
AFBC	5,907	916	1,503	AFBC	866	135	219
PFBC	5,280	1,686	786	PFBC	757	247	111
IGCC	4,908	1,376	761	IGCC	454	130	70
	100,785	*18,053*	*24,156*		29,793	*5,369*	*7,211*

2006-2010 UTILITIES	Total Sales in mln. USD	of which by EU: prod.	trf.rev.	**2006-2010 IPPs**	Total Sales in mln. USD	of which by EU: prod.	trf.rev.
PF+FGC	16,832	898	4,913	PF+FGC	10,608	703	3,053
SCPF+FGC	32,713	6,676	7,749	SCPF+FGC	20,654	4,377	4,832
AFBC	4,485	427	1,181	AFBC	1,563	248	399
PFBC	4,748	1,201	774	PFBC	1,606	493	253
IGCC	29,330	7,712	4,801	IGCC	21,054	5,660	3,483
	88,108	*16,915*	*19,418*		55,485	*11,481*	*12,019*

1.2

Scenario:	IPP low	differentiated prices	Criterion:	Capital cost only	LDC's
		with CARNOT		Capital cost and fuel efficiency	

1995-2000 UTILITIES	Total Sales in mln. USD	of which by EU: prod.	trf.rev.	1995-2000 IPPs	Total Sales in mln. USD	of which by EU: prod.	trf.rev.
PF+FGC	51,551	2,666	15,495	PF+FGC	6,123	464	1,821
SCPF+FGC	22,685	7,474	3,765	SCPF+FGC	7,639	2,729	1,099
AFBC	6,590	888	1,592	AFBC	455	62	110
PFBC	2,130	899	218	PFBC	251	90	24
IGCC	734	283	95	IGCC	5	2	0
	83,690	*12,210*	*21,166*		14,473	*3,347*	*3,054*

2001-2005 UTILITIES	Total Sales in mln. USD	of which by EU: prod.	trf.rev.	2001-2005 IPPs	Total Sales in mln. USD	of which by EU: prod.	trf.rev.
PF+FGC	28,898	2,192	8,430	PF+FGC	9,254	710	2,715
SCPF+FGC	55,792	16,738	10,016	SCPF+FGC	18,463	5,696	3,245
AFBC	5,907	1,034	1,434	AFBC	866	153	210
PFBC	5,280	1,919	631	PFBC	757	280	88
IGCC	4,908	1,610	595	IGCC	454	151	55
	100,785	*23,494*	*21,106*		29,793	*6,991*	*6,314*

2006-2010 UTILITIES	Total Sales in mln. USD	of which by EU: prod.	trf.rev.	2006-2010 IPPs	Total Sales in mln. USD	of which by EU: prod.	trf.rev.
PF+FGC	16,832	1,044	4,908	PF+FGC	10,608	794	3,049
SCPF+FGC	32,713	7,847	7,038	SCPF+FGC	20,654	5,084	4,402
AFBC	4,485	469	1,157	AFBC	1,563	262	391
PFBC	4,748	1,299	710	PFBC	1,606	523	232
IGCC	29,330	8,343	4,353	IGCC	21,054	6,093	3,169
	88,108	*19,003*	*18,166*		55,485	*12,756*	*11,244*

2.1

Scenario:	IPP high	differentiated prices	Criterion:	Capital cost only
		without CARNOT		Capital cost and fuel efficiency

1995-2000 UTILITIES	Total Sales in mln. USD	of which by EU: prod.	trf.rev.	1995-2000 IPPs	Total Sales in mln. USD	of which by EU: prod.	trf.rev.
PF+FGC	33,867	2,270	9,999	PF+FGC	8,017	608	2,380
SCPF+FGC	39,438	13,174	6,034	SCPF+FGC	10,002	3,547	1,456
AFBC	5,164	818	1,243	AFBC	596	81	144
PFBC	3,414	1,247	347	PFBC	329	118	32
IGCC	455	155	46	IGCC	6	2	1
	82,337	*17,665*	*17,669*		18,950	*4,356*	*4,013*

2001-2005 UTILITIES	Total Sales in mln. USD	of which by EU: prod.	trf.rev.	2001-2005 IPPs	Total Sales in mln. USD	of which by EU: prod.	trf.rev.
PF+FGC	25,251	1,272	7,408	PF+FGC	15,976	778	4,711
SCPF+FGC	48,933	9,927	11,637	SCPF+FGC	31,800	6,548	7,511
AFBC	5,109	750	1,315	AFBC	1,452	210	375
PFBC	4,644	1,423	726	PFBC	1,339	409	210
IGCC	4,505	1,211	728	IGCC	864	232	140
	88,441	*14,583*	*21,814*		51,431	*8,177*	*12,947*

2006-2010 UTILITIES	Total Sales in mln. USD	of which by EU: prod.	trf.rev.	2006-2010 IPPs	Total Sales in mln. USD	of which by EU: prod.	trf.rev.
PF+FGC	14,472	734	4,219	PF+FGC	15,183	853	4,435
SCPF+FGC	28,129	5,640	6,664	SCPF+FGC	29,552	6,193	6,930
AFBC	3,896	362	1,026	AFBC	2,202	324	565
PFBC	4,131	1,026	678	PFBC	2,258	677	358
IGCC	25,361	6,583	4,171	IGCC	30,412	8,084	5,009
	75,989	*14,345*	*16,758*		79,607	*16,130*	*17,298*

2.2

Scenario:	IPP high	differentiated prices	Criterion:	Capital cost only
		with CARNOT		Capital cost and fuel efficiency

1995-2000 UTILITIES	Total Sales in mln. USD	of which by EU: prod.	trf.rev.
PF+FGC	33,867	2,270	9,999
SCPF+FGC	39,438	13,174	6,034
AFBC	5,164	818	1,243
PFBC	3,414	1,247	347
IGCC	455	155	46
	82,337	*17,665*	*17,669*

1995-2000 IPPs	Total Sales in mln. USD	of which by EU: prod.	trf.rev.
PF+FGC	8,017	608	2,380
SCPF+FGC	10,002	3,547	1,456
AFBC	596	81	144
PFBC	329	118	32
IGCC	6	2	1
	18,950	*4,356*	*4,013*

2001-2005 UTILITIES	Total Sales in mln. USD	of which by EU: prod.	trf.rev.
PF+FGC	25,251	1,855	7,388
SCPF+FGC	48,933	14,681	8,760
AFBC	5,109	879	1,241
PFBC	4,644	1,675	556
IGCC	4,505	1,470	546
	88,441	*20,561*	*18,491*

2001-2005 IPPs	Total Sales in mln. USD	of which by EU: prod.	trf.rev.
PF+FGC	15,976	920	4,706
SCPF+FGC	31,800	7,730	6,798
AFBC	1,452	225	367
PFBC	1,339	437	190
IGCC	864	251	127
	51,431	*9,562*	*12,189*

2006-2010 UTILITIES	Total Sales in mln. USD	of which by EU: prod.	trf.rev.
PF+FGC	14,352	813	4,189
SCPF+FGC	27,894	6,533	6,015
AFBC	3,896	398	1,006
PFBC	4,131	1,109	623
IGCC	25,689	7,281	3,831
	75,963	*16,134*	*15,665*

2006-2010 IPPs	Total Sales in mln. USD	of which by EU: prod.	trf.rev.
PF+FGC	15,075	933	4,409
SCPF+FGC	29,341	7,147	6,246
AFBC	2,202	344	554
PFBC	2,258	722	328
IGCC	30,701	8,911	4,576
	79,577	*18,057*	*16,112*

ANNEX C BACKGROUND DATA EMISSIONS ASSESSMENT

Circulating Fluidised Bed Combustion

Circulating Fluidised Bed Combustion (CFBC) is an efficient and environmentally benign power generation option. A range of fossil fuels, such as coal, lignite, and oil residues can be used, as well as wood-based fuels and waste: peat, bark, wood dust, sawdust, agricultural waste, sludge from paper mills and de-inking plants, municipal sludge, waste paper, and RDF (Refuse Derived Fuel). The technology is proven, and the market leader in this technology supplied over 100 CFBCs until 1996 [1, 2].

Process description
A CFBC unit uses a water-cooled combustion chamber and a refractory-lined hot cyclone to recirculate hot bed material, mainly inert ash. The bed material, fuel, and limestone are suspended by air provided from the fan systems. Combustion takes place in a hot, turbulent fluidised bed environment that contains a relatively low concentration of combustibles. Almost 100% combustion is achieved by recirculating any solids remaining until they are burned. A reaction between limestone and sulphur takes place in the combustor at a temperature of 870EC to control SO_2 emissions (90% desulphurisation). Because of the low combustion temperature, NO_x emissions are at much lower levels than achievable with conventional technologies. From the convection zone, flue gases pass through a particulate collection system to the stack via induced draft fans [3].

Technological challenges
CFBC is a mature technology. CFBCs for CHP (Combined Heat and Power) or for sole power production are in operation or under construction all over the world. Rated power is modest (up to 250 MW_e [4])and SO_2 and NO_x emissions are relatively low. There are few technological challenges ahead.

Options regarded
CFBC technology can be applied to new power plants or to repowering, as has been shown in the US, Germany, and Poland [5, 6]. Because the market for repowering is limited in time, only new CFBCs are regarded.

One of the disadvantages of CFBC, the low power rating, would disappear if CFBC would be scaled up to 400 MW_e [7] or 600 MW_e [8, 9]. Thus, two options are regarded, current CFBC technology and technology of year 2000, with unit sizes of 250 MW_e and 400 MW_e respectively.

Characteristics
Two types of CFBCs - current technology (the CFBC plant near Gardanne, France) [4,9] and technology of year 2000 - are presented in Table C.2.1.

Table C.2.1 *Characteristics of Circulating Fluidised Bed Combustion*

Parameter	Unit	Current CFBC technology	Future CFBC technology (2000)
Steam pressure	bar	163	163
Steam temperature	EC	565	565
Unit size	MW_e	250[1]	400
Net efficiency	%	38.8	39
Investment cost	USD/kW_e[2]	1,150	1,100
SO_2 emission[2]	g/GJ	70	70
NO_x emission[3]	g/GJ	100	100
CO emission	g/GJ	65	65
N_2O emission[4]	g/GJ	20-60	20-60
Particulates emission[5]	g/GJ	50	50

1 This is the rated power of the CFBC plant near Gardanne (France) [4,9].
2 Based on 90% desulphurisation for coal containing 0.9% sulphur.
3 Without Selective Catalytic Reduction (SCR).
4 Measured at CFBC plant at Rauma (Finland) [3].
5 Electrostatic Precipitator (ESP); 50 g/GJ complies with Finnish regulations [1].

Source: [1-9].

Incremental scale-up could result in a modest reduction of investment cost towards 2000. The projected investment cost in 2000 is substantially lower than the level (USD 1.300/kW_e) which comes up from the ETSU study on behalf of DTI and IEA [10], and far below the level (USD 1.420/kW_e) in an IEA Coal Research study of earlier date [11]. This disparity seems to be mainly due to a different view on potential cost reduction.

Residues from CFBCs - ash mixed with gypsum and unreacted dolomite - have a relatively low value. Research in Canada indicates that such residues may readily be turned into an analogue of lightweight concrete, or palletised into artificial gravel for use as aggregate [12].

[2] The US$ of 1992 is used as reference (US$ 1 = ECU 0.775).

Pressurised Fluidised Bed Combustion

Introduction

Pressurised Fluidised Bed Combustion (PFBC) is an efficient and clean option to generate power from a broad variety of coals, from hard coal to lignite, and with sulphur contents up to 7%. Demonstration PFBCs have been built in the US (Tidd), Spain (Escatran), Japan (Wakamatsu, Karita), and Sweden (Värtan) [13]. Commercial PFBCs are under construction in Germany [14] and Japan [15]. So-called Pressurised Circulating Fluidised Bed (PCFB) technology is to be demonstrated in the US [16].

Process description

Particulates of solid fuels mixed with hot bed material (mainly ash), resting on a perforated plate (fixed bed), can be suspended, if the fluid (gas or liquid) flows at sufficiently high velocity up through the plate: the solids are in the `fluid bed' condition. In particular, gas-solids systems behave in a bubbling, turbulent, fluid-like fashion, with a physical appearance resembling a boiling liquid. Because of the very high rates of heat transfer and the degree of mixing, coal combustion in fluid beds takes place at relatively low temperatures (860EC instead of 1300EC in conventional boilers). SO_2 emissions are reduced by direct addition of limestone or dolomite, whereas the low combustion temperatures reduce NO_x emissions. Slagging, fouling, and corrosion are much less severe than in conventional coal fired power plants.

This process takes place at pressures considerably higher than atmospheric conditions; hence the term `Pressurised Fluidised Bed Combustion'. The high-pressure combustion gases drive the gas turbine, increasing the efficiency of the plant (based on combined-cycle operation).

Current PFBCs based on bubbling beds are considered as proven technology. Plants of this kind are under construction at Cottbus in Germany (repowering, 80 MW_e) and Wakamatsu in Japan (360 MW_e). Future PFBC technology could be based on a circulating bed system (PCFB, or Pressurised Circulating Fluidised Bed).

A more radical improvement could involve a front end pyrolysis or partial gasification step, as outlined in [17, 18]. Such a technology - e.g. the `British Coal Topping Cycle' - would require some ten years for commercialisation. The PCFB project planned at Lakeland (Florida) includes a second stage with use of the gas from partially gasified/carbonised coal in a high-temperature gas turbine. The second stage has a time schedule beyond the year 2000 [16]. Because of the relatively long lead times involved this option is disregarded.

Technological challenges

Demonstration PFBC plants - e.g. the ones at Escatran (Spain), Tidd (US), and Wakamatsu (Japan) - can be considered as first generation PFBCs. They experienced various problems, such as ash blockage in the cyclone ash-removal system, and their availability was poor. However, while these plants had numerous problems with early operation, solving the problems and continuing with successful operation has lent experience and confidence to PFBC commercialisation [18]: for instance, maximum availability of the

Tidd plant was 55% in 1994, before the plant was shut down, whereas current PFBC plants can be expected to have availabilities of 80% or more.

One of the lessons learned from the demonstration plants is that a reliable hot gas cleanup (HGCU) plant is indispensable to commercial deployment of PFBC. HGCU is necessary because cyclones are not capable of cleaning 100 percent of the ash from the combustion gas before it enters the gas turbine. The presence of ash in the gas requires ruggedised gas turbines, limiting the performance of the combined cycle. Furthermore, ash that does make it past the cyclones requires electrostatic precipitators (ESP) at the stack to meet particulate emissions. Capturing particulates early in the cycle eliminates the need for secondary cyclones and stack gas ESPs, in addition to permitting a wider selection of gas turbines [18].

The basic design for HGCU is a ceramic barrier filter system. A filter pressure vessel houses hundreds of ceramic filter elements, called candles, which collect ash on their surface while allowing the gas to pass through. Periodic backpulses of compressed gas from a single-pulse nozzle cleans the fly ash collected on the surface of the filter elements. Early tests with such HGCU systems at the Tidd (US) and Wakamatsu plants (Japan), and at Ahlstrom Pyropower in Finland revealed several problems with ash 'bridging' between candles and with broken candles. Nowadays, HGCU systems are more reliable, although more experience is needed with different fuel types before HGCU is ready for commercialisation [18].

Options regarded

First generation PFBCs are commercially available, as witnessed by orders from Germany and Japan. For the German Cottbus plant PFBC was judged to be the best option, since it is a proven, yet innovative technology that permits maximum use of the local brown coal both efficiently and with low impact on the environment [14]. In Japan (Karita plant) PFBC is welcomed because of the flexibility PFBC offers in the choice of alternative coal resources in the world [15]. First generation PFBCs are characterised by a relatively high generating efficiency of 42-44% (based on LHV, Lower Heating Value), low SO_2 and NO_x emissions, and relatively low capital cost.

Second generation PFBC with HGCU technology is on the brink of commercialisation. Some specialised components (especially related to HGCU) have undergone long-term testing. Not only the hot gas cleaning system of second generation PFBC is more advanced and efficient than presently applied cyclones, but also the generating efficiency is slightly higher (up to 46%) than for PFBC technology of today. It has been noted that advanced PFBC - Pressurised Circulating Fluidised Bed (PCFB) technology, based on partial gasification, HGCU, and a high-temperature gasturbine - is disregarded, as it cannot be commercialised before 2005.

Characteristics

The options considered - first and second generation PFBC - differ with respect to gas cleaning system, the type of gas turbine applied, and hence the generating efficiency. Their characteristics are presented in Table C.2.2.

Table C.2.2 *Characteristics of Pressurised Fluidised Bed Combustion*

Parameter	Unit	First generation PFBC (1997)	Second generation PFBC (2000)
Steam pressure	bar	246	246
Steam temperature	EC	566/593	566/593
Unit size	MW_e	360	400
Net efficiency	%	44	46
Investment cost	USD/kW_e	1,200	1,150
SO_2 emission[1]	g/GJ	35	35
NO_x emission[2]	g/GJ	45	45
CO emission	g/GJ	19	19
N_2O emission[3]	g/GJ	15	15
Particulates emission	g/GJ	7.5[4]	2[5]

1 Based on 95% desulphurisation for coal containing 0.9% sulphur.
2 Without Selective Catalytic Reduction (SCR).
3 Estimate.
4 Based on cyclones.
5 Based on Hot Gas Cleanup (HGCU).

Source: [14-18].

The emissions shown in Table C.2.2 are based on projections for the Cottbus power plant, except for SO_2 (based on 95% desulphurisation of reference hard coal) and N_2O. In the next few years commercial deployment of a reliable hot gas cleanup (HGCU) plant is one of the key objectives. It is estimated that capital cost could come down from USD 1.200/kW_e in 1997 to USD 1.150/kW_e in 2000. As for CFBC the level of investment costs is lower than the ETSU estimate (USD 1.300/kW_e) in [10]; this could be due to different assumptions with respect to unit size. However, the investment cost level (USD 1.150/kW_e in 2000) fits well with that of an earlier IEA Coal Research study [11], viz. USD 1.200/kW_e for a PFBC plant of the same size.

Ash from a PFBC plant comes in three streams with the same composition: as granular bed material (20-50%), as fly ash from the cyclones (45-70%) and as filtercatch from the final back-end filter (2%). Residues have a relatively low value, although utilisation as synthetic gravel is possible. The IEA urges research on recycling of PFBC waste [19].

Pulverised coal fired power plant

Introduction

A large proportion of European electricity demand is met by (conventional) coal fired power plants. Until a few years ago coal fired power plants had generating efficiencies of 40%. Today Ultra supercritical Steam Conditions (USC) enable efficiencies of 45% and more. The main characteristics of such advanced plants will be elucidated in brief.

Process description

Recently built coal fired power plants are mostly based on supercritical steam conditions, for instance 250 bar/535EC/563EC [20]. The net generating efficiency of such power plants is about 42.5% [21].

The best available technology for coal fired power is USC technology, with typical steam parameters like 290 bar/580EC/580EC [22, 23]. Basic to this technology is the use of 9% Cr steel for thick-walled sections and high-pressure turbine [23] [24]. The generating efficiency of an advanced pulverised coal fired power plant, such as the one to be commissioned in Denmark in 1998[3], is 47%, based on cooling with sea water. For river cooling an efficiency of 46% is achievable [25].

Technological challenges

Going from supercritical to ultra supercritical steam conditions (generally from 250 bar to approximately 300 bar), requires use of well defined steel types (9% Cr) for thick-walled sections and high-pressure turbine. This is state-of-the-art today (at least in developed countries).

Options regarded

Existing coal fired power plants have subcritical or supercritical steam conditions. However, ultra supercritical steam conditions can be applied today. Therefore, only USC boilers are regarded, notably a USC power plant as built today (Denmark), and a somewhat more advanced type (technology of year 2000).

Characteristics

The aforementioned net generating efficiency of 46% (river cooling) is considered as representative of current USC coal fired power plants. A slightly higher efficiency of 48% (river cooling) is regarded as representative of the technology in year 2000 (this type of power plant is on the drawing board today).

Investment cost depends on the location (existing power plant or greenfield), environmental regulations and corresponding abatement technology for SO_2 and NO_x, and rated power. Investment costs of power plants based on supercritical steam conditions range from USD 1.250/kW_e [20] to as high as USD 1.650/kW_e [21]. USC based power plants could be competitive with supercritical coal fired power plants [26, 27].

[3] Nordjyllandsvaerket power plant under construction at Aalborg, Denmark.

It seems that USC based power plants (net efficiency 46%) could be built at a cost less than USD 1.200/kW_e [28]. The investment cost figures of Table 1.3 include cost of flue gas desulphurisation (FGD) and low-NO_x technology (not Selective Catalytic NO_x Reduction, SCR).

Table C.2.3 *Characteristics of pulverised coal fired power plant based on Ultra supercritical Steam Conditions (USC)*

Parameter	Unit	Technology 1997	Technology 2000
Steam pressure	bar	290	290
Steam temperature	EC	580/580	580/580
Unit size	MW_e	400	400
Net efficiency	%	46.0	48.0
Investment cost	USD/kW_e	1,250	1,200
SO_2 emission[1]	g/GJ	55	55
NO_x emission[2]	g/GJ	135	135
CO emission[3]	g/GJ	5	5
N_2O emission[3]	g/GJ	0.5	0.5
Particulates emission[4]	g/GJ	2	2

1 Based on 92% desulphurisation for coal containing 0.9% sulphur.
2 Without Selective Catalytic Reduction (SCR).
3 Representative figures reported in [29]
4 Based on 99.75% efficient Electrostatic Precipitator (ESP).

Investment cost figures of USD 1.250-1.200/kW_e (Table C.2.3) are of the same order of magnitude as the level which comes up from the ETSU study [10] for supercritical pulverised coal fired power with flue gas desulphurisation and without SCR (approx. USD 1.275/kW_e). However, they are far below the level predicted in an earlier IEA Coal Research study [11] (approximately USD 1.600/kW_e), presumably due to a conservative view on cost reduction for pulverised coal fired power in that study.

Integrated Coal Gasification Combined Cycle

Introduction

Integrated Coal Gasification Combined Cycle (IGCC) is an advanced power generation option based on hard coal or lignite. Demonstration IGCCs have been or are being built in the US, the Netherlands (Buggenum), Spain (Puertollano), and Germany. Key parameters of such advanced plants will be elucidated in brief.

Process description

The heart of the installation is the gasifier with syngas cooler. The gasifying agent is oxygen from the air separation unit. Fly ash is separated from the syngas, and recycled to the gasifier. Part of the nitrogen from the air separation plant is used to pressurise the milled coal particles (in case of the plants at Buggenum and Puertollano). After separation of the fly ash, halogens and other dissolvable components are washed out. After that, the gas is lead through an HCN/COS-convertor and desulphurised, by separation of H_2S and subsequent conversion into sulphur. This enables a very high degree of desulphurisation (98-99%). Also NH_3 and HCN are separated. Clean syngas is diluted with nitrogen from the air separation unit and with steam, to reduce the NO_x emission. The remaining NO_x is thermally related, as chemically bound nitrogen (NH_3 and HCN) has been separated before. Therefore, the NO_x emission is relatively low. The diluted syngas is burned in a gas turbine as part of a combined cycle [30].

Technological challenges

Several demonstration plants have been or are being built today. In 1994 an IGCC was commissioned at Buggenum, the Netherlands. The Demkolec plant has a rated power of 253 MW_e and a net efficiency of 43%. Investment cost was NLG 850 million (currency of 1989), which equals USD 2,000/kW_e today (USD of 1992) [30]. The 315 MW_e Elcogas plant at Puertollano (Spain), commissioned in 1996, has a net efficiency of 45%. Investment cost of a `commercial' IGCC of the Puertollano type could be USD 1.646/kW_e [31, 32]. A demonstration 360 MW_e lignite fired IGCC (KoBra) for the Goldenberg-Werk (Germany) will be commissioned in 1997. Rheinbraun developed the gasification technology. Its net efficiency is projected at 45% [25]. Investment cost is USD 2,280/kW_e. In the US an IGCC demonstration project - the 262 MW_e Wabash River (Indiana) plant - was completed in 1996 [33]. Its net generating efficiency is 45%. Total installed capital cost for the project is USD 1.600/kW_e (investment cost is relatively low because it is a repowering project).

Net generating efficiencies of demonstration IGCCs are broadly comparable (43-45%). Table C.2.4 shows their SO_2, NO_x, and particulates emissions.

Table C.2.4 *SO_2, NO_x, and particulates emission of demonstration IGCCs (g/GJ)*

	Buggenum	Puertollano	Wabash River
SO_2	<25[1]	<10[2]	<10
NO_x	60	60	35
Particulates	<1	<3	<3

[1] Based on 98% desulphurisation for coal containing 0.9% sulphur.
[2] Based on approximately 99% desulphurisation.
Source: [30-34]

A number of technological improvements is needed, before IGCC can enter the stage of commercialisation. One of them is hot gas cleanup. Conventional desulphurisation equipment requires complex heat regeneration in order to minimise energy losses. High-temperature desulphurisation increases the generating efficiency, meanwhile reducing the size of the major pressurised components in the gasifier section (i.e. the syngas cooler). Reduction in size and height of the gasification island can also be achieved by an optimised coal milling and drying system and a modified slag lockhopper system [34]. Such advanced IGCC technology is assumed to be commercially available around 2000.

Options regarded

Two options for IGCC are regarded. One is the type of IGCC plant as has been built at Puertollano (technology 1997). Alternatively, technology of year 2000 could be applied [35]. Such an advanced IGCC would possibly incorporate a novel (high-temperature) desulphurisation process.

Characteristics

Advanced IGCC technology enables a net efficiency of approximately 50%. Investment cost of such IGCCs will be much lower than the investment cost level of demonstration IGCCs. Cost reduction can be realised by application of advanced gas turbines with higher efficiencies, economies of scale (commercial size is 400 MW_e or more), etc. Investment cost is assumed to come down from USD 1,650/kW_e for a commercial 'Puertollano' IGCC to USD 1,320/kW_e for IGCC technology of year 2000 (Table C.2.5).

Table C.2.5 *Characteristics of Integrated coal Gasification Combined Cycle (IGCC)*

Parameter	Unit	First generation IGCC (1997)	Second generation IGCC (2000)
Steam pressure	bar	125	170
Steam temperature	EC	510	570
Unit size	MW_e	315	454
Net efficiency	%	45.0	50.5
Investment cost	ECU/kW_e	1.650	1.320
SO_2 emission[1]	g/GJ	7	7
NO_x emission	g/GJ	60	50
CO emission[2]	g/GJ	10	10
N_2O emission[3]	g/GJ	2	2
Particulates emission	g/GJ	<3	1

1 Based on 99% desulphurisation for coal containing 0.9% sulphur.
2 Representative figure (25 mg/m3) for a gas fired combined cycle plant [39].
3 Representative figure (<5 mg/m^3) for a gas fired combined cycle plant [36]
Source: [30-39].

IGCC technology is rather expensive compared to conventional coal fired power, mainly due to the high level of integration. Presumably, investment cost can be reduced by some 20% compared to the level of 'Puertollano', if advanced gas cleanup and the most advanced type of gas turbines are applied. Investment cost in 2000 - USD 1.320/kW_e - is marginally lower than the average of eight IGCC projects and design studies normalised to 500 MW_e, viz. USD 1.400/kW_e (USD 600/kW_e of which is attributed to the combined cycle, and USD 800/kW_e to the gasifier section) [37].

The level of USD 1.320/kW_e for year 2000 is substantially lower than the estimate of USD 1.700/kW_e by ETSU in [10]. This can be due to differences in state-of-the-art assumed for future IGCCs. This investment cost level (USD 1.320/kW_e) is also far below the level predicted in an IEA Coal Research study [11], viz. USD 1.745/kW_e for a comparable entrained flow gasifier combined with a so-called Class III gas turbine. It should be noted that investment cost of an air blown fluidised bed gasification IGCC is estimated at only USD 1.430/kW_e (unit size 240 MW_e) in the latter study.

ANNEX D RESULTS OF EMISSION ASSESSMENT

Table D.4.1 *Clean coal technologies with CARNOT, 1995-2000,; capacities installed*

Region	Option	IPP low		IPP high	
		[MW]	[%]	[MW]	[%]
Asia exclusive of NICs	PF+FGC	40,477	66.8	27,520	45.4
	SCPF+FGC	14,649	24.2	27,446	45.3
	AFBC	4,522	7.5	3,446	5.7
	PFBC	935	1.5	1,998	3.3
	IGCC	24	0.0	203	0.3
		60,609	100	60,613	100
Asian NICs	PF+FGC	.865	30.6	2,711	44.1
	SCPF+FGC	3,383	55.5	2,849	46.3
	AFBC	259	4.3	349	5.7
	PFBC	324	5.3	217	3.5
	IGCC	267	4.4	23	0.4
		6,099	100	6,150	100
CEE + Turkey	PF+FGC	1,706	61.8	1,129	41.2
	SCPF+FGC	684	24.8	1,243	45.3
	AFBC	308	11.2	228	8.3
	PFBC	61	2.2	132	4.8
	IGCC	1	0.0	9	0.3
		2,760	100	2,741	100
EU	PF+FGC	1,130	28.0	1,566	38.8
	SCPF+FGC	2,050	50.7	1,775	43.9
	AFBC	325	8.0	426	10.6
	PFBC	392	9.7	260	6.4
	IGCC	143	3.5	12	0.3
		4,040	100	4,040	100
Total	PF+FGC	45,179	61.5	32,926	44.8
	SCPF+FGC	20,767	28.3	33,313	45.3
	AFBC	5,414	7.4	4,451	6.1
	PFBC	1,713	2.3	2,607	3.5
	IGCC	435	0.6	248	0.3
		73,508	100	73,545	100

Table D.4.2 *Clean coal technologies with CARNOT, 2001-2005; capacities installed*

Region	Option	IPP low		IPP high	
		[MW]	[%]	[MW]	[%]
Asia exclusive of NICs	PF+FGC	25,887	32.1	28,418	32.2
	SCPF+FGC	44,874	55.7	49,950	56.5
	AFBC	3,976	4.9	3,930	4.5
	PFBC	3,159	3.9	3,247	3.7
	IGCC	2,727	3.4	2,833	3.2
		80,622	100	88,377	100
Asian NICs	PF+FGC	2,078	30.3	2,099	30.6
	SCPF+FGC	3,765	54.9	3,826	55.7
	AFBC	394	5.7	368	5.4
	PFBC	362	5.3	338	4.9
	IGCC	264	3.8	234	3.4
		6,864	100	6,865	100
CEE + Turkey	PF+FGC	1,591	28.7	1,635	29.5
	SCPF+FGC	3,044	54.9	3,114	56.1
	AFBC	373	6.7	345	6.2
	PFBC	327	5.9	285	5.1
	IGCC	206	3.7	169	3.0
		5,541	100	5,547	100
EU	PF+FGC	2,240	26.8	2,279	27.2
	SCPF+FGC	4,356	52.1	4,454	53.2
	AFBC	783	9.4	726	8.7
	PFBC	706	8.4	655	7.8
	IGCC	282	3.4	254	3.0
		8,368	100	8,368	100
Total	PF+FGC	31,795	31.4	34,431	31.5
	SCPF+FGC	56,039	55.3	61,343	56.2
	AFBC	5,527	5.3	5,368	4.9
	PFBC	4,554	4.5	4,524	4.1
	IGCC	3,478	3.4	3,489	3.2
		101,393	100	109,156	100

Table D.4.3 *Clean coal technologies with CARNOT, 2006-2010; capacities installed*

Region	Option	IPP low		IPP high	
		[MW]	[%]	[MW]	[%]
Asia exclusive of NICs	PF+FGC	18,081	20.8	19,924	20.7
	SCPF+FGC	32,435	37.3	35,764	37.1
	AFBC	3,667	4.2	3,734	3.9
	PFBC	3,631	4.2	3,689	3.8
	IGCC	29,256	3.4	33,229	34.5
		87,070	100	96,340	100
Asian NICs	PF+FGC	1.517	20.5	1.427	19.4
	SCPF+FGC	2,830	38.2	2,661	36.1
	AFBC	471	6.4	468	6.4
	PFBC	484	6.5	480	6.5
	IGCC	2,103	28.4	2,326	31.6
		7,405	100	7,362	100
CEE + Turkey	PF+FGC	1.624	19.1	1.657	19.5
	SCPF+FGC	3,147	37.0	3,195	37.6
	AFBC	449	5.3	427	5.0
	PFBC	447	5.2	426	5.0
	IGCC	2,843	33.4	2,792	32.9
		8,510	100	5,547	100
EU	PF+FGC	1.768	20.1	1.653	18.9
	SCPF+FGC	3,527	40.1	3,299	37.7
	AFBC	438	5.0	438	5.0
	PFBC	444	5.0	441	5.0
	IGCC	2,621	29.8	2,941	33.3
		8,795	100	8,745	100
Total	PF+FGC	22,990	20.6	24,661	20.4
	SCPF+FGC	41.940	37.5	44,919	37.1
	AFBC	5,025	4.5	5,066	4.2
	PFBC	5,002	4.5	5,036	4.2
	IGCC	36,822	32.9	41.262	34.1
		111.780	100	120,944	100

Table D.4.4 *Clean coal technologies with CARNOT, 1995-2000; emissions of SO_2, NO_x, and CO_2, based on capacities installed (Table A.1)*

Region	Option	IPP low			IPP high		
		SO_2 10^3 t	NO_x 10^3 t	CO_2 10^6 t	SO_2 10^3 t	NO_x 10^3 t	CO_2 10^6 t
Asia without NICs	PF+FGC	113	278	194	77	189	132
	SCPF+FGC	38	93	64	71	174	121
	AFBC	18	25	27	13	19	20
	PFBC	2	2	4	3	4	10
	IGCC	0	0	0	0	0	1
		170	398	289	165	387	284
Asian NICs	PF+FGC	5	13	9	8	19	13
	SCPF+FGC	9	21	15	7	18	13
	AFBC	1	1	1	1	2	2
	PFBC	1	1	2	0	0	1
	IGCC	0	1	1	0	0	0
		16	37	28	17	39	29
CEE + Turkey	PF+FGC	5	12	8	3	8	5
	SCPF+FGC	2	4	3	3	8	6
	AFBC	1	2	2	1	1	1
	PFBC	0	0	0	0	0	1
	IGCC	0	0	0	0	0	0
		8	18	13	7	17	13
EU	PF+FGC	3	8	5	4	11	8
	SCPF+FGC	5	13	9	5	11	8
	AFBC	1	2	2	2	2	2
	PFBC	1	1	2	0	1	1
	IGCC	0	0	1	0	0	0
		8	24	19	11	25	19
Total	PF+FGC	126	310	216	92	226	158
	SCPF+FGC	54	132	92	86	211	147
	AFBC	21	30	31	17	25	26
	PFBC	3	4	8	4	6	13
	IGCC	0	1	2	0	1	1
		204	477	349	200	468	344

Table D.4.5 *Clean coal technologies with CARNOT, 2001-2005; emissions of SO_2, NO_x, and CO_2, based on capacities installed (Table A.2)*

Region	Option	IPP low			IPP high		
		SO_2 10^3 t	NO_x 10^3 t	CO_2 10^6 t	SO_2 10^3 t	NO_x 10^3 t	CO_2 10^6 t
Asia without NICs	PF+FGC	72	178	130	79	195	142
	SCPF+FGC	111	273	198	124	303	220
	AFBC	15	22	23	15	22	22
	PFBC	5	7	15	5	7	16
	IGCC	1	6	13	1	6	13
		205	485	378	224	533	413
Asian NICs	PF+FGC	6	14	10	6	14	11
	SCPF+FGC	9	23	17	9	23	17
	AFBC	2	2	2	1	2	2
	PFBC	1	1	2	1	1	2
	IGCC	0	1	1	0	1	0
		17	41	32	17	41	32
CEE + Turkey	PF+FGC	4	11	8	5	11	8
	SCPF+FGC	8	18	14	8	19	14
	AFBC	1	2	2	1	2	2
	PFBC	1	1	2	0	1	1
	IGCC	0	0	1	0	0	1
		14	33	26	14	33	26
EU	PF+FGC	6	15	11	6	16	11
	SCPF+FGC	11	26	19	11	27	20
	AFBC	3	4	5	3	4	4
	PFBC	1	1	3	1	1	3
	IGCC	0	1	1	0	1	1
		21	48	40	21	49	40
Total	PF+FGC	89	218	159	96	236	172
	SCPF+FGC	139	340	248	152	373	271
	AFBC	21	31	32	21	30	31
	PFBC	7	10	22	7	10	22
	IGCC	1	7	16	1	7	16
		258	606	476	277	656	512

Table D.3.6 *Clean coal technologies with CARNOT, 2006-2010; emissions of SO_2, NO_x, and CO_2, based on capacities installed (Table A.3)*

Region	Option	IPP low			IPP high		
		SO_2	NO_x	CO_2	SO_2	NO_x	CO_2
		10^3 t	10^3 t	10^6 t	10^3 t	10^3 t	10^6 t
Asia without NICs	PF+FGC	51	124	91	56	137	100
	SCPF+FGC	79	195	143	88	215	158
	AFBC	14	20	22	14	21	20
	PFBC	6	8	17	6	8	18
	IGCC	9	61	133	10	69	151
		159	408	406	173	449	449
Asian NICs	PF+FGC	4	10	8	4	10	7
	SCPF+FGC	7	17	13	6	16	12
	AFBC	2	3	3	2	3	3
	PFBC	1	1	2	1	1	2
	IGCC	1	4	9	1	5	11
		14	41	35	14	34	35
CEE + Turkey	PF+FGC	5	11	8	5	11	8
	SCPF+FGC	8	19	14	8	19	14
	AFBC	2	2	3	2	2	3
	PFBC	1	1	2	1	1	2
	IGCC	1	6	13	1	6	13
		16	39	40	16	40	40
EU	PF+FGC	5	12	9	5	11	8
	SCPF+FGC	10	21	16	8	20	15
	AFBC	2	2	2	2	2	3
	PFBC	1	1	2	1	1	2
	IGCC	1	5	12	1	6	13
		17	42	41	16	41	41
Total	PF+FGC	64	158	116	69	169	124
	SCPF+FGC	103	252	185	110	270	199
	AFBC	19	28	29	20	28	29
	PFBC	8	10	24	8	10	24
	IGCC	11	76	167	12	9	187
		205	525	522	219	563	564

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