# can coal be clean?

## ‘Clean Coal’ Technologies
## & their potential impact on global warming

A Report for

## AID/WATCH

and

## Greenpeace Australia

Prepared by

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# Executive Summary

This report examines assistance provided by governments and other sources for the development of a range of 'Clean Coal' technologies and the potential for these to reduce greenhouse emissions. These findings are compared to alternative means of reducing greenhouse gas emissions, primarily Renewable Energy Technologies.

Although 'Clean Coal' technologies can cause a reduction in greenhouse emissions, the scope of the reduction is limited, as indicated by analysis of the potential in Asia, the fastest growing energy market in the world.

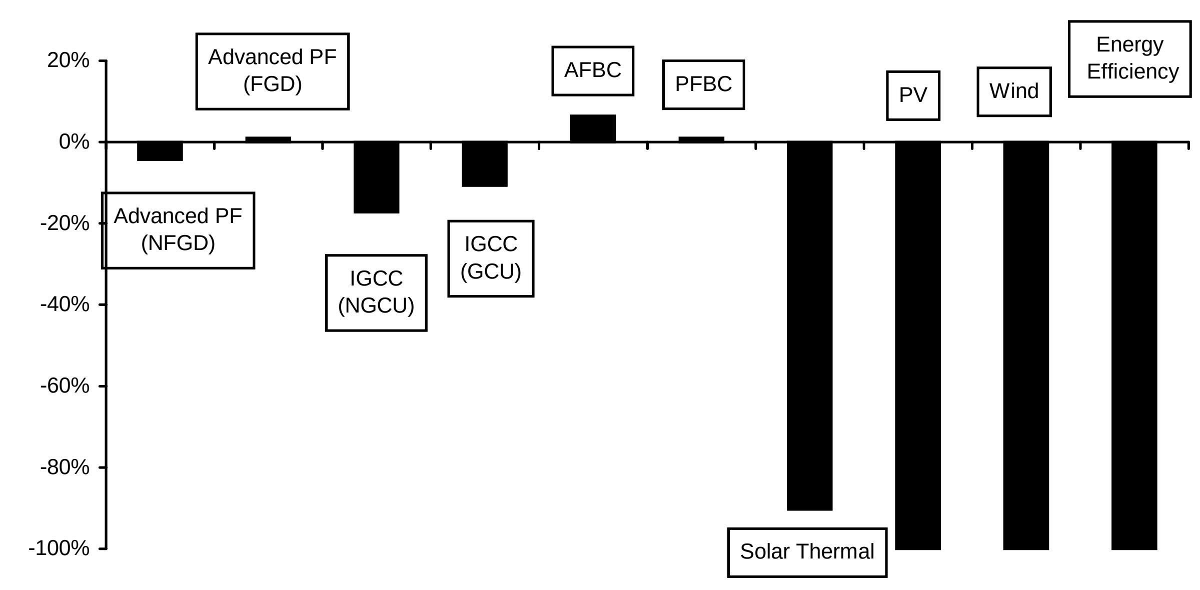
'Clean Coal' technologies can reduce greenhouse gas emissions as a result of:

- increased efficiency of coal combustion;
- increased quality of coal utilised;
- the capture and storage of $CO_2$ (decarbonisation of the fossil fuel cycle);
- reduced quantity of methane emissions released by mining activities, processing and storage of coal.

Reports indicate that 'Clean Coal' measures will have a negligible impact on the rate of growth in greenhouse gas emissions. Reductions in greenhouse gases related to coal mining and utilisation activities may be in region of 2.1%-3.6% between 1989 and 2000, while predicted emissions growth is over 50%.

In comparison, Renewable Energy Technologies offer a far greater potential to reduce emissions, as indicated in the following figure E1.

**Fig E1: Comparison of greenhouse gas reduction potential from electricity generating technologies.**



When the costs of supply options are taken into consideration, it is also evident that many Renewable Energy Technologies currently represent the most cost-effective means of reducing greenhouse gas emissions.

**Fig E2: Cost of $CO_2$ abatement, Fossil Fuel and Renewable Energy Technologies**

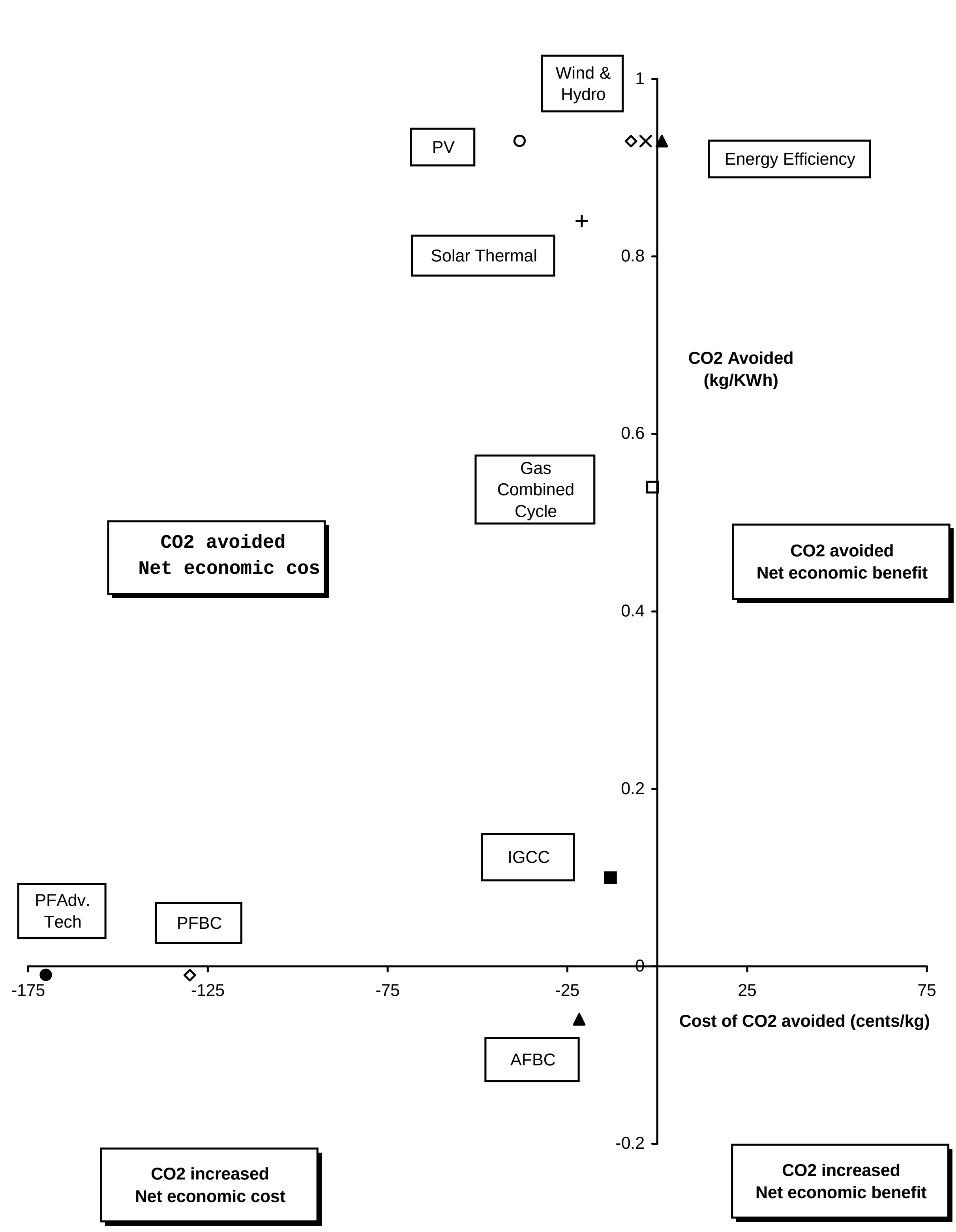


Figure E2. indicates that supply options fall into four categories:

1. *Increased greenhouse emissions:*

    PF Advanced Technology

    PFBC

    AFBC

2. *Small greenhouse emission reduction - Low cost of abatement*

    IGCC

3. *Medium greenhouse emission reduction - Low cost of abatement:*

    Gas Combined Cycle

4. *Large greenhouse emission reduction - Low cost of abatement:*

    All Renewable Energy Technologies

5. *Large greenhouse emission reduction - Economic benefits of abatement:*

    Energy Efficiency

Not only do Renewable Energy Technologies currently represent the least-cost option for reducing greenhouse gas emissions, it is evident that costs will be further reduced given sufficient market share to fully develop and utilise economies of scale.

In addition, Renewable Energy Technologies can provide considerable cost savings when compared to centralised grid supply of electricity because:

their small, modular nature enables a closer match between supply and demand;

they can often be located close to the point of use thereby reducing network costs.

On the basis of this analysis, it is evident that greenhouse reduction strategies should be focusing on the early advancement of Renewable Energy Technologies and the development of projects which utilise these sources.

However, Government policies in most major industrialised countries continue to provide very considerable support to 'Clean Coal' technologies, to the detriment of alternatives which offer substantially greater opportunities and benefits. Indeed, currently conventional energy technologies benefit from direct subsidies of more than $300 billion per annum worldwide

It is clear deep cuts in greenhouse gas emissions are feasible but will not occur without strong policy intervention by governments. It is also clear that a switch of policies towards providing support for Renewable Energy Technologies need not result in economic or social penalties.

**Section 1**

# ‘Clean Coal’ Technologies

## 1.1 Description

The term ‘Clean Coal’ is a general term used by the energy industry to describe a set of current and emerging technologies and processes which result in lower environmental impacts than those previously associated with coal mining, processing and utilisation.

‘Clean Coal’ technologies and processes can be divided into the four main elements of the energy generation cycle. These are:

### 1.1.1 PRE-COMBUSTION (INCREASED COAL QUALITY)

Improved methods of fuel extraction and preparation such as coal cleaning to remove ash and sulphur (sometimes called ‘coal benefication’) and the drainage of coal bed methane (CBM) which would otherwise be emitted into the atmosphere.

The use of coal with improved thermal or environmental qualities as a result of its composition.

### 1.1.2 DURING COMBUSTION

New combustion technologies with increased efficiencies and reduced emissions, such as pressurised fluidised bed (PFBC) and integrated gasification combined cycle (IGCC).

### 1.1.3 POST COMBUSTION

Technologies to remove undesirable emissions before flue gases leave the generation plant, such as flue gas desulphurisation (FGD) to remove SOx, and Selective Catalytic Reduction (SCR) to remove NOx. Processes to remove $CO_2$ are also being investigated.

### 1.1.4 WASTE TREATMENT

The treatment and disposal of waste products from mining, coal processing and utilisation, such as gypsum resulting from emission control processes, to reduce or minimise environmental impacts. This topic is not discussed in this report, since it has limited relevance to greenhouse gas emissions.

Investments in coal related technologies have occurred since the industrial revolution, primarily driven by economic considerations. However, with the enactment of the US Clean Air Act in 1970 began a new era of R&D activity aimed at reducing the environmental impacts caused by the use of coal as an energy sources. This can perhaps be seen as the genesis of what is now known as the ‘Clean Coal’ program.

Since the 1970s, many countries have implemented environmental regulations on emissions resulting from the mining and use of coal. ‘Clean Coal’ R&D is therefore a widespread response to these regulations with the aim of marketing coal technology as being environmentally sensitive. As such, ‘Clean Coal’ programs have been sponsored mainly by Governments, Mining Companies and Electricity Utilities.

The focus of this R&D has varied historically and regionally in recognition of different environmental priorities. Some of the key environmental issues include:

- emissions of NOx, SOx and particulates;
- land use and rehabilitation of mine sites;
- cooling water release;
- transport, storage and processing of residue materials;
- acid rain;
- methane emissions from mining activities;
- greenhouse gas emissions from coal combustion.

While all of these issues continue to be addressed through 'Clean Coal' programs, the growing concern about Global Warming and the increased pressure on those Governments which have signed the UN's Framework Convention on Climate Change (FCCC), has resulted in a larger emphasis on greenhouse gas emissions in recent years. For instance, the IEA Greenhouse R&D Program was established in 1991/2 as a separate initiative to the existing IEA Coal Research Program.

Not all elements of 'Clean Coal' programs have an influence on greenhouse gas emissions. The key areas of technology, or process, improvement which could lead to a reduction in greenhouse gas emissions include:

- increased efficiency of coal combustion;
- increased quality of coal utilised;
- the capture and storage of $CO_2$ (decarbonisation of the fossil fuel cycle);
- reduced quantity of methane emissions released by mining activities, processing and storage of coal;
- switching to less carbon-intensive fuels in generation; (eg, natural gas or renewables)
- improved end-use energy efficiency.

Most 'Clean Coal' programs acknowledge the option of switching to zero greenhouse gas emission sources, such as renewable energy supplies and end-use energy efficiency. However, since these industries are potential competitors to the coal industry, the viability of this option tends to be minimised and presented as complementary to other activities. However, renewable energy supplies and end-use energy efficiency do not have any direct link to the use of coal (or any other fossil fuel) as an energy source and therefore its potential impact on greenhouse emissions must be considered separately to those of a 'Clean Coal' program.

Therefore, in the following sections where the viability of 'Clean Coal' technologies and processes are discussed in more detail, end-use energy efficiency programs are not included. Discussion of the potential for renewable energy sources is included for comparative purposes, as an alternative to 'Clean Coal' technologies.

**Section 2**

# Increased coal quality

## 2.1 Characteristics

The quality of coal used can have an effect on the efficiency of the combustion process, thereby influencing the quantity of greenhouse gas emissions. In general, improvements to coal can be made by cleaning the existing coal stock or by replacing it with coal of a higher calorific value.

### 2.1.1 COAL CLEANING

The major benefits of coal cleaning include: [3]

- reduced transport volume and weight;
- reduced sulphur content leading to lower costs of $SO_2$ control or solid waste disposal;
- higher efficiencies and lower maintenance costs due to the removal of ash.

### 2.1.2 REPLACEMENT WITH HIGH QUALITY COAL

Australian coal has a lower ash content than many indigenous Asian coals, which results in higher thermal efficiencies during the combustion process, in the order of 1% [6], and reduced maintenance requirements. In addition, Australian coal has a lower sulphur content than many indigenous Asian coals which reduces desulphurisation requirements.

## 2.2 Greenhouse Gas Emissions

### 2.2.1 COAL CLEANING

An alteration in greenhouse gas emissions due to coal cleaning activities results from the change in the combustion efficiencies of the coal itself and a reduction in the quantities of coal transported from the washery to the power station, boiler or other plant.

In washed coal, the reduction of ash content will tend to increase the thermal efficiency of combustion, while any residual water content will lead to reduced efficiencies. The thermal efficiency of combustion has a direct impact on $CO_2$ emissions. Removing ash will also reduce the bulk of combustible materials which need to be transported, thereby reducing transport related $CO_2$ emissions.

While it had previously been assumed that washeries provided overall greenhouse benefits, a Report for AusAID in 1995 on the Moonidih coal preparation plant in India [20] concluded that emissions could increase in some circumstances. The report examined two cases:

- a washery to produce high quality coking coal to supply a local integrated steelworks;
- a washery to produce steaming coal with reduced ash content for electricity power stations.

Analysis of several scenarios showed that the residual moisture content of the washed coal had a significant impact on the overall efficiency of combustion and concluded that, in electricity generation plant, the use of washed coal could lead to an increase in emissions. In the case of the steelworks, the greenhouse benefits are likely to small. See Table 1, below.

| Table 1: $CO_2$ emissions resulting from the use of washed coal [20] | |
|---|---|
| **CASE STUDY** | **$CO_2$ REDUCTION** |
| COKING COAL FOR INTEGRATED STEELWORKS | 0.9% to 1.6% |
| STEAMING COAL FOR POWER STATION | 0.05% to -0.51% |

> *"It should be noted that the emission reductions estimated to be achieved in the steaming coal cases (electricity generation) are, at best, very small. The combination of the small emission reductions with the appreciable cost of building and operating coal washeries is likely that abatement cost per tonne of $CO_2$ will prove to be very high, i.e. washing power station coal in India seems likely to be a very expensive way of reducing greenhouse gas emissions. It is likely that larger and more cost effective emission reduction opportunities in the Indian electricity industry will be found beyond the fuel input stage, for example:*
>
> > *improved mechanical and electrical performance of power stations;*
> >
> > *reducing electricity transmission and distribution losses;*
> >
> > *improved system control;*
> >
> > *increased efficiency of customers' equipment."*

In these findings, this report is supported by the US Electric Power Research Institute (EPRI) who state that there is "*limited environmental benefit*" to be gained from coal cleaning activities in the Asia Pacific region [3].

The AusAID report also notes that its finding *"differ somewhat from those expressed in a previous Report (DPIE "Coal & Climate Change"* [6]), but appear consistent with similar, but confidential, work undertaken by Pacific Power:

> *"It is our understanding that Pacific Power has concluded that washing coal yields no greenhouse gas reduction benefit in electricity generation".* [20]

As a result a number of points are worth making:

> Reports, such as "*Coal and Climate Change*" [6], contain many assumptions which are often necessary due to the lack of data available, and in many cases the findings are highly sensitive to these assumptions. As shown in the above example, some of the conclusions regarding greenhouse impacts may prove to be ambiguous on closer inspection.
>
> In many cases data which would enable an accurate calculation of greenhouse impacts is currently held by sections of the coal industry. Clearly, as appears likely in the case of Pacific Power, such information may not be made publicly available when it runs contrary to the perceived interests of coal industry. However this does not serve the public good and, in the case of publicly owned utilities, Governments should ensure that information of this type is released.

#### 2.2.2 REPLACEMENT WITH HIGH QUALITY COAL

Use of higher quality coal will result in thermal efficiency improvements in the region of 1%. A comparison of $CO_2$ emissions also needs to account for differences in transport-derived greenhouse emissions, and therefore the net greenhouse impact will be somewhat site specific.

Although the DPIE report [6] finds that there are likely to be net greenhouse reductions from the replacement of inferior coal by high quality coal, it also concludes:

> *"It is likely that on balance these (Chinese) stations will be able to achieve higher overall thermal efficiencies by using Australian coal than would be possible with power stations of similar size using typical Chinese coal. However, the difference may not be great. It should also be borne in mind that, given the very rapid growth in demand for electricity in China, such new power stations, particularly if privately funded, as some are, could well be considered as additional to, rather than replacements of, stations which use Chinese coal. Thus it would be difficult to sustain a strong argument that supply of coal to these new coastal stations is a greenhouse gas reducing measure."*

Further, the scope for greenhouse gas reductions is dependent upon the available market for imported coal to areas with currently low quality indigenous supplies. In this regard, many of the potential markets in Asia have controls on imported coal in order to protect local employment and for reasons of supply security. So long as such barriers exist, the potential impact of imported coal as a greenhouse gas reduction measure will be limited.

### 2.2.3 LOW SULPHUR CONTENT COALS AND THEIR IMPACT ON GREENHOUSE EMISSIONS

One argument used by the Australian coal industry is that many Australian coals have a lower sulphur content than many overseas coals. Lower sulphur content is regarded as "cleaner" in the specific sense that their combustion leads to less emissions of sulphur dioxide (and other oxides of sulphur) and hence to lower levels of acid rain and acid pollution of waterways, agricultural land and urban areas.

The implication that low-sulphur coals are also "cleaner" in the sense of greenhouse gas emissions is a mirage, for two reasons.

Firstly, the quantity of greenhouse gas emissions during a coal combustion process is related to the carbon content of coal (amongst other factors), and is independent of the sulphur content.

Secondly, sulphur dioxide and trioxide emissions from coal combustion also form sulphate 'aerosols' in the atmosphere which tend to suppress the global warming effect from emissions of greenhouse gases like carbon dioxide, methane etc. Unlike carbon dioxide, which has a long-term global warming effect (over many centuries), the cooling effect due to sulphate aerosols last only a few days.

The cooling effect of sulphur aerosols has only recently been included in the global climate models used to predict global temperature rises due to greenhouse gas emissions. The inclusion of this cooling effect is the main reason that estimates of global average temperature rises for next century were revised downwards in the Summary for Policymakers of the Working Group I contribution to the 1995 Second Assessment Report of the Intergovernmental Panel on Climate Change [24a]. The only figure mentioned in the Summary for Policymakers is a mid-range "best estimate" of an increase in temperature of $2^oC$ by 2100. However, this estimate relies on an unrealistic doubling of sulphate aerosols over the next century.

In the Full Scientific Material, another set of scenarios is presented which assume that sulphate aerosols remain constant over the century:

> *"Taking account of increases of greenhouse gas concentrations alone (i.e. assuming aerosol concentrations remain constant at 1990 levels) the models project an increase in global mean temperature relative to the present of between 1 and $4.5^oC$ by 2100 for the full range of IPCC scenarios ... Incorporating possible effects of future changes of anthropogenic aerosol concentrations implied by the IS92 scenarios leads to lower projections of temperature changes of between $1^oC$ and $3.5^oC$ by 2100. In all cases these projections would represent a substantial warming of climate"* [24b]

In terms of the mid-range "best estimate", the temperature rise with constant sulphate aerosols is 2.4$^oC$ and with rising aerosols is 2.0$^oC$.

The question of which is the more realistic scenario is not addressed in the IPCC report. A doubling of sulphur aerosol emissions over the next 100 years ignores the environmental devastation that this would cause through acid rain. It also ignores the high likelihood that this will lead, even in the absence of any action in relation to greenhouse gases because of their climate impact, to sulphur emissions being reduced. Sulphur emissions are increasingly likely to be controlled in developing countries, as they already have been in developed countries, because of the local and regional environmental effects caused by acid rain (eg US Clean Air Act, European Convention on Long Range Transboundary Pollution). Stable or declining global sulphur emissions are likely as a result of the progressive decoupling of sulphur and $CO_2$ emissions in these regions, which is already an established phenomenon in developed countries. For example, there is already evidence that Japan is investing in China to reduce acid emissions, some of which fall on Japan.

Any efforts to reduce sulphur emissions have an immediate effect in the atmosphere because of the short lifetime of the sulphate aerosols.

The coal industry has taken comfort from the lower estimates of temperature rise, but has ignored or downplayed the reasons for it [30]. In reality, the lower estimates provide no joy for the proponents of "clean" coal and create instead a serious predicament for the industry.

By relying on a doubling of sulphur dioxide emissions, the lower temperature estimates imply a continued reliance on high sulphur coals without flue gas sulphur removal technologies.

If low sulphur coals are widely substituted for high sulphur coals and/ or flue gas sulphur removal technologies are increasingly widely applied, the constant sulphate aerosol/ higher temperature rise scenarios will be the more realistic.

Clearly, unlike other energy supply options and energy efficiency, coal combustion cannot be "cleaner" in both acid rain and greenhouse terms.

**Section**
**3**

# Combustion Technology

## 3.1 Characteristics

There are two major areas of direct coal consumption - in electricity generation plant and boilers/stoves as used by the industrial, commercial and residential sectors.

### 3.1.1 ELECTRICITY GENERATION

**Pulverised Fuel (PF)** technology is the conventional means of large scale electricity generation from coal. The major 'Clean Coal' combustion technologies for electricity generation include:

**Advanced PF** operating at 'supercritical' or 'ultrasupercritical' temperatures, using advanced component materials and including on/off cycling capabilities. [3]

Fluid Bed Combustion has the ability to use a wide variety of low quality fuels, with limestone generally being used as a component of the feedstock to reduce sulphur emissions [8]. In **Atmospheric Fluid Bed Combustion (AFBC)** electricity is generated in conventional turbine generators. [7] The **Pressurised Fluid Bed Combustion (PFBC)** process includes a pressurised boiler and a combined cycle. [9]

**Integrated Gasification Combined Cycle (IGCC)** involves burning coal to produce a gas stream which is fed into a gas turbine to generate electricity. The waste heat produces steam and this is used in a steam turbine to generate electricity. [8]

**Fuel Cells** are similar to continuously operating batteries; converting gaseous fuel (eg. gasified coal) directly into electricity without combustion through electrochemical reaction [7] [10].

**In Magneto Hydro Dynamic (MHD)** generators, very high temperature gases formed by burning fuel are expanded in a magnetic field to generate electricity.

The above list relates to new combustion technologies. However performance improvements can also be made to existing coal-fired plant. The application of such measures will depend on the age, maintenance regime and type of plant involved. In general the potential range of measures include: [3]

- replacement and upgrading of failed components;
- performance monitoring;
- predictive maintenance;
- retrofit control systems;
- operator training.

### 3.1.2 INDUSTRIAL/COMMERCIAL BOILERS, AND DOMESTIC STOVES

Coal is used by industries to generate process heat, eg. for the manufacture of bricks, cement, etc; in the commercial sector for space heating; and in both cases coal can be used to cogenerate heat and power. In the domestic sector, coal is mainly used for space heating and cooking.

New developments in boiler and stove designs have the potential to increase efficiencies over older technologies.

## 3.2 Status

At this stage, only some of the 'Clean Coal' technologies listed above can be considered 'proven' and commercially viable. Others are in a demonstration phase with pilot projects subject to further assessment and design modification before they become commercial propositions. There are also some technologies which are essentially experimental and will take a considerable amount of time before they reach the stage of becoming a realistic proposition. See Table 2.

In the development process, these phases are generally a continuum. Nevertheless, the following list provides a summary of the current status of each technology.

### 3.2.1 Currently Available Proven Technology

Pulverised Fuel (PF)

Advanced PF (eg. supercritical)

AFBC

Retrofit Improvements

Industrial/Commercial/Domestic scale boilers/stoves

### 3.2.2 Demonstration Stage (may reach proven status in 5-15 years)

Advanced PF (eg. ultrasupercritical)

PFBC

IGCC

### 3.2.3 Research Stage (commercial application not likely before 2015)

Fuel Cells

MHD

Since the speed at which technologies which are currently at the research stage reach commercial availability depends heavily upon the financing of further R&D, these may not be available until later next century. At this stage, therefore, their performance is entirely theoretical and it is not thought appropriate to include them further in this study.

## 3.3 Summary of Technology Characteristics and Status

Table 2, below, summarises the major existing and emerging technologies for electricity generation including current estimates of efficiency levels.

| Table 2: Summary of Existing and Emerging Electricity from Coal Technologies | | | |
|---|---|---|---|
| TECHNOLOGY | CHARACTERISTICS | STATUS | EFFICIENCY |
| PULVERISED FUEL (PF) | Current technology | Proven | 37.5% world standard [2]<br>38.8% [4] |
| ADVANCED PF | eg. supercritical, double reheat.<br>Limited by the development of new materials able to cope with ultrasupercritical conditions | Commercially available.<br>Further advances under development | 41% [4]<br>41% - 44% with environmental controls [2].<br>Projection for C21st 48%-50% |
| ATMOSPHERIC FLUIDISED BED COMBUSTION (AFBC) | Suitable for burning poor quality coal. Materials and operational problems still being resolved [2]<br>Desulphurisiation produces quantities of waste products. | Young technology, proven for small sizes [7].<br>150 units in US<br>Largest plant in operation = 165MWe [2]<br>350MWe under commission in Japan [2] | Similar or slightly lower than PF technology [2] |
| PRESSURISED FLUIDISED BED COMBUSTION (PFBC) | Suitable for burning poor quality coal.<br>Desulphurisiation produces quantities of waste products. | Experimental units in operation.<br>Largest plant in operation = 80MW Grimethorpe (UK).<br>Demonstration units in Spain Sweden Japan and USA [1] [4] | Potential over 40% [3]<br>42% [4] |
| INTEGRATED GASIFICATION COMBINED CYCLE (IGCC) | | Demonstration stage [1] [3]<br>6 demos being planned (95MW-370MW) [3] [11] | Current 41%<br>Next phase 43% [3]<br>43.5% [4] |
| RETROFIT TO EXISTING PLANT | Implementing heat rate improvement programs, monitoring ,etc [3] | Commercially available. | 3-5% improvement on older, inefficient plant [3]. |
| INDUSTRIAL, COMMERCIAL & DOMESTIC BOILERS | Design and control improvements | Proven | 15% improvement [5] |

## 3.4 Costs & Greenhouse Gas Emissions

The potential for greenhouse gas reductions through ‘Clean Coal’ combustion technologies is due to the increased efficiency of these plant over older combustion technologies, i.e. more electricity output is produced for the same amount of coal burnt.

Detailed data on the costs and $CO_2$ emissions associated with the major 'Clean Coal' technologies is provided in Appendix I [7] and summarised in Table 3 below [1].

Table 3: Summary of estimated costs and $CO_2$ emissions for coal combustion technologies [7]

| **Technology** | | **Total Cost (c/kWh)** | **$CO_2$ Emissions kg $CO_2$/kWh** |
|---|---|---|---|
| PF Black Coal | NFGD | 4.4 | 0.93 |
| Advanced PF Black Coal | NFGD | 4.5 | 0.89 |
| | FGD | 6.0 | 0.94 |
| AFBC Black Coal | | 5.7 | 0.99 |
| PFBC Black Coal | | 5.7 | 0.94 |
| IGCC Black Coal | N C U | 5.4 | 0.77 |
| | G C U | 5.7 | 0.83 |

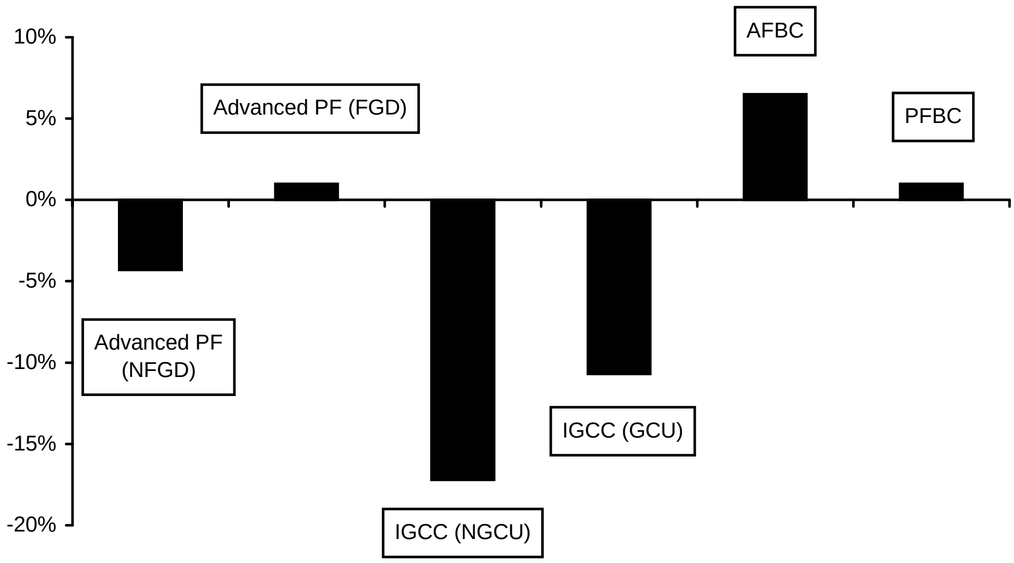
Notes: NFGD = No Flue Gas Desulphurisation; FGD = With Flue Gas Desulphurisation; NCU = No Clean Up; GCU = With Gas Clean Up

Assumptions: 25 year plant life; 8% discount rate

Figure 1 below illustrates the potential impact on greenhouse emissions if these technologies were used to replace a conventional PF plant, without flue gas desulphurisation, with an average efficiency (determined to be 35.9%) [7].

[1] Note, there is some variation between efficiency rates and costs quoted by industry. These are not necessarily inconsistent but generally reflect different operational and national circumstances, and economic assumptions.

**Fig. 1: $CO_2$ emissions for a range of combustion technologies using black coal, relative to Pulverised Fuel - Current Technology** [7]




The Energy Research and Development Corporation (ERDC) Report summarises these as follows: [7]

> *"the high efficiency clean coal technologies (IGCC and PFBC) do not offer very large reductions in carbon dioxide emissions.*
>
> *The impact of Gas Clean Up is again noticeable. Our calculations are showing significant penalties in cost and efficiency in the gas clean-up process."*

Figure 1 shows that, of the most viable emerging technologies, only some offer greenhouse benefits when compared to the base case. Indeed, if emission control processes are incorporated, only IGCC appears to reduce greenhouse emissions. In the context of increased environmental regulations in many parts of the world today, it is unlikely that new plant would be commissioned without such controls.

While greenhouse savings in the order of 10% may be available through the use of IGCC technology, it should be noted that the viability and reliability of such plant is still to be proven.

It is also relevant to note that overall greenhouse benefits will only occur if electricity produced by a new lower-emission plant replaces that produced by a less efficient plant. In the case where additional new plant is commissioned to meet increased demand, while overall emissions may be less than might have occurred (eg. if a conventional PF type of plant was installed) the level of emissions will still be growing.

**Section 4**

# $CO_2$ Capture technologies

## 4.1 Characteristics

Processes to capture $CO_2$ from fossil fuel power plants and then store the $CO_2$ are currently under investigation by numerous bodies around the world, with the IEA Greenhouse R&D Program being one of most significant programs.

Conventional, predominantly coal-fired, power plants produce flue gas streams with a $CO_2$ concentration around 15% by volume. The remainder of the flue gas is nitrogen (about 75%), some excess oxygen (a few %), water (about 6-10%), and trace impurities. Stack gases may be treated to remove particulates, SOx and NOx. The major challenge in $CO_2$ removal is its separation from nitrogen.

In general, $CO_2$ capture processes have significant energy requirements (the "energy penalty"), which reduce the plant's conversion efficiency and net power output, thereby increasing the amount of $CO_2$ produced per net kWh of electricity generated. As a result, analysis of these processes need to consider the net $CO_2$ avoided. [5]

### 4.1.1 CAPTURE - SCRUBBING THE $CO_2$ FROM FLUE GASES:

Removal of $CO_2$ from the flue gases involves physical or chemical separation processes: the use of the chemical solvent monoethanolamine (MEA) currently appears the most viable option [5].

This process would result in an energy penalty of about 35%, approximately doubling the generation costs of electricity. In addition, MEA plant would require about the same land area as the original power plant.[5]

There are in existence in the US a small number of MEA plant, currently used to remove $CO_2$ from other gas streams. [5]

### 4.1.2 CAPTURE - NITROGEN REMOVAL PRIOR TO COMBUSTION PROCESS:

An alternative to flue gas scrubbing is to remove nitrogen prior to combustion so that the final flue gases contain primarily $CO_2$ and water. This would involve the use of cryogenic air separation plant installed next to power plant to produce fairly pure oxygen stream for combustion.

This process also requires modification to existing coal handling and insertion processes and conversion to a pressurised boiler system. A separation plant has a relatively small land requirement. [5]

There is an associated energy penalty of approximately 30%, which would increase electricity costs by about 80%. Examples of this process are limited to test facilities [5].

### 4.1.3 OTHER PROCESSES

Amongst other processes for $CO_2$ capture are:

cryogenic fractionation

membrane separation

molecular sieves

The energy penalties of these are higher, and the net $CO_2$ reduction is lower than the processes described previously, so they are not likely to be competitive with these options.

Table 4, below, summarises the characteristics of these processes.

Table 4: Comparison of $CO_2$ capture technologies for existing coal-fired plant [5]

| | Energy Penalty<br>% | Nominal $CO_2$ Recovery<br>% | Net Reductions of $CO_2$ Emissions<br>% of base case |
|---|---|---|---|
| Base Case - No $CO_2$ Removal | 0 | 0 | 0 |
| Flue Gas scrubbing with Cogenerated Steam | 35 | 90 | 84.6 |
| Air separation - Flue Gas recycling | 30 | 100 | 100 |
| Cryogenic Fractionation | 75 | 90 | 60 |
| Membrane Separation | 63 | 80 | 46 |
| Molecular Sieves | 80 | 90 | 50 |

### 4.1.4 New Power Plant

It is likely that these processes could also be included in the design of new plant at a slightly lower additional cost.

> *"For example, a new plant could be designed to prevent air leakage if combustion in $O_2$ with flue gas recycle is used. For MEA, some modest cost savings would be achieved for a new plant verses a retrofit because the turbine could be designed originally to provide extraction steam." [5]*

The prospect of $CO_2$ capture from emerging technologies, particularly Integrated Gasification Combined Cycle (IGCC), has also been researched. IGCC technology involves the production of a pressurised synthesis gas (mainly CO and $H_2$). For $CO_2$ capture, the gas is reacted with steam in a shift reactor to produce $CO_2$ and $H_2$, with the $H_2$ being combusted to produce energy.

$CO_2$ could be removed by using a physical absorbent (eg. Selexol) with a predicted energy penalty of between 13-20%.

## 4.2 $CO_2$ Sequestration

While there are some commercial applications for $CO_2$, these are far outweighed by the potential quantities available as a result of capturing emissions from power stations. For example, in US there is currently a market for only 2% (40 million tonnes) of $CO_2$ produced from power stations [5]. It is therefore unlikely that utilisation of $CO_2$ will become a major sequestration option.

All proposed storage options will be geographically dependent. They include:

Ocean disposal

Saline aquifers

Depleted gas reserves

Depleted oil reserves

Improved forestry/reforestation;

All of these options are largely untested and have considerable associated environmental uncertainties. For example, $CO_2$ disposal in deep waters will gradually exchange with surface layers and re-emit into the atmosphere; approximately 2000km2 of new forest would be required to absorb the $CO_2$ produced during the life of a 500MW coal-fired power station. [9]

## 4.3 Costs

Table 5: Projected cost of $CO_2$ capture and disposal [5]

| **Type of Power Station** | **PF** | **PF** | **IGCC** | **Coal Gasification - Fuel Cells** |
|---|---|---|---|---|
| Capture Technology | MEA | $CO_2$ Recycle | Shift + Selexol | Shift/Membrane |
| $CO_2$ Avoided (kg/kWh) | 0.37 | 0.93 | 0.76 | 0.49 |
| Cost of Capture (US$/tonne $CO_2$) | 37 | 35 | 18 | 21 |
| Cost of Capture (USc/kWh) [a] | 4.8 | 4.9 | 1.7 | 1.1 |
| Cost of Disposal (USc/kWh) [b,c] | 1.9-6.5 | 2.0-6.7 | 1.5-4.9 | 0.8-2.7 |
| Increase in cost of electricity [d] | 130-230% | 140-230% | 60-130% | 40-80% |

Notes:
[a] includes costs for compression (to over 100 bars)and dehydration;
[b] includes transportation costs;
[c] based on nominal range of US $15-50/tonnes $CO_2$ disposal;
[d] base electricity cost of US 5c/kWhe assumed for all cases.

## 4.4 Conclusion:

Considerable research is being undertaken into $CO_2$ capture and sequestration, however to date there is little evidence to suggest that it is a viable option for dealing with $CO_2$ emissions from power stations.

In a report on the research conducted by MIT on behalf of the US Department of Energy, Herzog [5] recently noted the following:

> *"$CO_2$ capture and sequestration should be viewed as an insurance policy. This mitigation strategy is an end-of-pipe option, while, in general, a pollution prevention strategy is preferred. Also, while $CO_2$ capture and sequestration does reduce atmospheric emission of $CO_2$, it increases total $CO_2$ production."*

> *"While the capture of $CO_2$ from power plant flue gas may be energy intensive and expensive, it is technically feasible."*

> *"The two leading candidates for sequestering large amounts of $CO_2$ are dissolution in the ocean or storage in underground reservoirs. However questions must be addressed before these sequestration options become viable. For ocean disposal, the most serious issues are environmental impacts and the effectiveness of sequestration. For land disposal, the issue of storage integrity is critical."*

**Section 5**

# Costs and subsidies for ‘Clean Coal’ Technologies

## 5.1 Costs

Costs for ‘Clean Coal’ combustion technologies are shown in Table 3 and Appendix I. Further calculation of costs on a levelised basis are included in Appendix II. These two sets of figures are broadly consistent.

## 5.2 Subsidies

‘Clean Coal’ technologies and processes have received considerable support over an extended period from Governments, Research and Development Bodies, and Industry organisations. This support includes the funding of R&D, the provision of ‘soft’ loans and direct funding for individual projects.

The scale of such funding means that many R&D activities and projects are jointly funded by a number of private and public organisations. In addition, Governments may have a range of departmental or agency initiatives through which to provide support. This complicates the task of calculating the overall scale of support. As a result, this section contains a number of examples of the larger programs which have been used, or are currently available, to develop ‘Clean Coal’ technologies and processes.

## 5.3 International Subsidies

### 5.3.1 DEVELOPMENT LOANS & OVERSEAS AID

The World Bank has extensive involvement in energy projects through a number of different programs. In 1991 the World Bank financed 20 projects in the energy sector, mostly in the electricity industry, at a total project cost of US$15 billion, providing US$3 billion in loans [6]. In 1993, the World Bank contributed US$400m to the construction of thermal power stations in India and plan to spend a total of US$1.2 billion over ten years for a total of 15 new coal-fired and 2 gas-fired plant. [21]

Funding for coal mining related activities primarily involve cleaner extraction processes, (it also includes structural reform assistance). A summary of recently approved projects is provided in Table 6.

| Table 6: World Bank funding, 1996/7 for coal mining related projects [13] | | |
|---|---|---|
| **COUNTRY** | **FINANCE FOR COAL MINING & RELATED ACTIVITES (US$)** | **WORLD BANK PROGRAM** |
| ARGENTINA | $30 m | IBRD |
| BOLIVIA | $11 m | IDA |
| INDIA | $63 m | IDA |
| MONGOLIA | $35 m (total $60.4 m) | IDA |
| RUSSIA | $25 m (total 30.8 m) | IBRD |
| RUSSIA | $500 m | IBRD |
| UKRAINE | 15.8 m (total 28.5 m) | IBRD |

The World Bank also has a specific 'Clean Coal' initiative. Examples of previous funding include provision of US$8.5 million for coal bed methane drainage at the Songzhao mine in China [6].

The Asian Development Bank (ADB) provided $1,792 million loans in 1995 to energy projects, 25% of which ($448 million) were targeted towards coal-related technologies. The 1996/7 ADB budget contains provision for 17% of loans to be used for a similar purpose. [12]

### 5.3.2 RESEARCH & DEVELOPMENT

The International Energy Agency (IEA) has two major programs which support 'Clean Coal' research; the Coal Research Program and the Greenhouse R&D Program. A large majority of the work undertaken under these programs relates directly to 'Clean Coal' technologies or programs, and a record of annual budgets is provided in Table 7.

| Table 7: IEA R&D Expenditure on 'Clean Coal' technologies [15] | | |
|---|---|---|
| **YEAR** | **IEA GREENHOUSE R&D PROGRAM** | **IEA COAL RESEARCH PROGRAM** (APPROX) |
| 1986/97 | na | £2,280,000 |
| 1987/98 | na | £2,150,000 |
| 1988/89 | na | £2,140,000 |
| 1989/90 | na | £2,120,000 |
| 1990/1 | na | £2,100,000 |
| 1991/2 | £550,500 | £2,000,000 |
| 1992/3 | £640,067? | £1,920,000 |
| 1993/4 | £726,600 | £1,970,000 |
| 1994/5 | £719,000 | £1,957,400 * |
| 1995/6 | £721,000 | £1,500,000 |
| **TOTALS** | **£3,357,167** | **£20,137,400** |

Notes: IEA Program income is derived from contributions from member countries plus sales of publications and contract work. All above figures represent members contributions only, except for (*) which includes approximately £290,000 of sales and contract income.

Further 'Clean Coal' R&D programs are funded directly by individual Governments, sometimes using IEA finance as co-funding. Major research programs are undertaken by the EC and the US, for example. Table 8 details annual expenditure by the US Department of Energy.

| Table 8: US Dept. of Energy ''Clean Coal' Program' [16] | | |
|---|---|---|
| **PROGRAM STAGES** | **DATE RELEASED** | **GOVERNMENT CONTRIBUTION** (US $ MILLION) |
| ROUND I | February 17, 1986 | 400 |
| ROUND II | March 18, 1987 | 536 |
| ROUND III | May 1, 1989 | 546 |
| ROUND IV | September 12, 1991 | 600 |
| ROUND V | May 4, 1992 | 600 |
| | Total Govt Contribution | 2,682 |
| | Industry and Other contributions | 4,018 |
| **TOTAL PROGRAM INVESTMENT** | | **US $6,700 million** |

## 5.4 Australian Subsidies

### 5.4.1 OVERSEAS AID

Australian overseas aid has provided support for energy projects, mainly in South-East Asia, through schemes administered by AusAID (formally AIDAB). In addition, 'Clean Coal' related technologies and processes have been supported by the Australian Government through Austrade and the Export Finance and Insurance Corporation (EFIC). Some of the projects which have benefited from these types of assistance are detailed in the DPIE report "Coal and Climate Change" [6].

It is estimated that in 1993/4, 5.6% of the country's total aid budget, i.e. A$78 million, was targeted at energy projects [6], the majority of which would have been coal related.

Examples of support provided by Australian Aid programs, the DIFF and EFIC schemes, are contained in Table 9 below.

| Table 9: Australian government funding of overseas coal related projects [6] [28] | | |
|---|---|---|
| **ACTIVITY** | **PRIVATE SECTOR COMPANIES** | **AUSTRALIAN GOVERNMENT FUNDING (A$M)** |
| **WASHERIES** | | |
| PIPARWAR, INDIA | White Industries Australia Ltd | $206.6m<br>(Austrade-EFIC, incl 61.5m DIFF) |
| DHANBAD, INDIA | Mineral Technologies Ltd | [no information available] |
| **GASIFICATION** | | |
| HENAN PROV. CHINA | CMPS&F Pty Ltd;<br>Energy Equipment Ltd | $31.5m (DIFF) |
| LIAONING PROV. CHINA | | $3.2 million (DIFF) |
| **UPGRADING INDUSTRIAL BOILERS** | | |
| VIETNAM | | $4.7 million (DIFF) |
| **LIGNITE MINING** | | |
| THAILAND | Kinhill Engineers Pty Ltd | $26m (AusAID) |

In the 1996 Budget, the Australian Federal Government ended the DIFF scheme. Overall overseas aid levels will be A$1,450.1 million for 1996/7 [17]. Major energy or related infrastructure projects are listed for the following countries:

- Indonesia
- Thailand
- China
- India
- Pakistan

### 5.5.2 RESEARCH & DEVELOPMENT

Funding of 'Clean Coal' R&D in Australia is divided between Federal and State Governments (through Departments and Agencies such as CSIRO), Industry bodies and private companies.

Table 10 below shows spending levels by Governments for the year 1988-89.

| Table 10: Australian Government R&D expenditure on 'Clean Coal' [17] | | |
|---|---|---|
| | **STATE GOVERNMENT R&D EXPENDITURE, 1988-89 (A$)** | **COMMONWEALTH GOVERNMENT R&D EXPENDITURE, 1988-89 (A$)** |
| COAL PROSPECTING & RESOURCE ASSESSMENT | 718,000 | |
| COAL EXTRACTION TECHNIQUES | 222,000 | 2,845,000 |
| COAL PREPARATION AND TRANSPORT | 1,793,000 | 3,448,000 |
| COAL COMBUSTION | 45,000 | 1,400,000 |
| OTHER COAL | 569,000 | 2,811,000 |
| TOTAL | 3,347,000 | 10,504,000 |

The Federal Government Co-operative Research Centre (CRC) program, initiated in 1991, has established a total of 62 centres, 9 of which relate to mining and energy research. Average annual Government support for these nine CRCs totals about $20 million. See table 11 below for further details.

| Table 11: Mining and Energy Co-operative Research Centres [22] | |
|---|---|
| **NAME OF CO-OPERATIVE RESEARCH CENTRE** | **GOVERNMENT FUNDING PER YEAR (AVERAGE FOR EACH OF 7 YEARS)** |
| CRC FOR BLACK COAL UTILISATION | $1.80m |
| CRC FOR MINING TECHNOLOGY AND EQUIPMENT (CMTE) | $3.24m |
| G.K. WILLIAMS CRC FOR EXTRACTIVE METALLURGY | $1.98m |
| CRC FOR NEW TECHNOLOGIES FOR POWER GENERATION FROM LOW-RANK COAL | $2.08m |
| AUSTRALIAN PETROLEUM CRC | $2.93m |
| A.J. PARKER CRC FOR HYDROMETALLURGY | $1.82m |
| CRC FOR AUSTRALIAN MINERAL EXPLORATION TECHNOLOGIES | $1.6m |
| AUSTRALIAN GEODYNAMICS CRC | $2.49m |
| CRC FOR LANDSCAPE EVOLUTION AND MINERAL EXPLORATION | $2.50m |
| TOTAL | $20.44m |

The CRC for Black Coal Utilisation, *whose "primary purpose is to support the marketing activities of coal producers*" [23], has a total budget of $39.4million over its seven year lifetime.

Since December 1992, the Australian Coal Association has been responsible for a national program of coal related R&D funding through the Australian Coal Association Research Program (ACARP), replacing previous Federal Government funded schemes (other than CRCs). ACARP works co-operatively with State and Industry research programs and is involved in Australia's participation in the IEA Coal Research and Greenhouse Gas R&D program.

To date, ACARP has committed A$33million to projects, raised through a levy of 5cents/tonne black coal produced, yielding an income of about A$9.5million per annum. Total project costs are estimated to be A$83million [22]. The type and distribution of projects supported by ACARP are shown in the following table.

Table 12: Analysis of ACARP program funding [22]

| | **No. Projects** | **ACARP A$millions** | **%** | **TOTAL A$millions** | **%** |
|---|---|---|---|---|---|
| Open Cut | 46 | 8.2 | 25% | 17.6 | 21% |
| Underground | 107 | 13.0 | 39% | 33.2 | 40% |
| Coal Preparation | 41 | 6.0 | 18% | 12.1 | 15% |
| Coal Utilisation | 34 | 5.8 | 18% | 20.2 | 24% |
| Total | 228 | 33.0 | | 83.1 | |

While data on industry expenditure is scarce, a report by ASTEC in 1994 [17] noted :

> *"About $45 million is currently spent by industry on coal research per year: some 60% of the total Australian coal R&D expenditure and over a third of the total energy R&D spending by Australian Industry."*
>
> *"BHP's coal R&D spending is $8.92 million per year. To this needs to be added the recently agreed additional $65 million over five years, with $5.92 million to be spent in 1992. This program focuses on mining, extraction and preparation. This totals $14.84 million for 1993."*

In view of the wide range of funding sources and the problem of identifying which research programs have coal-related applications, a complete picture can only be approximated. It is estimated that total current expenditure on coal related R&D is in the order of $80million per year from sources shown in Table 13 below.

| Table 13: Coal Industry Research in Australia, 1996 [22] | |
|---|---|
| **SECTOR** | **A$** |
| GOVERNMENT (CSIRO, UNIVERSITIES, CRC'S) | $20 million |
| COAL COMPANY PROPRIETARY RESEARCH | $15 million |
| COMPANY SPONSORED CO-OPERATIVE RESEARCH (ACARP, BHP SPECIAL RESEARCH PROGRAM, AMIRA, JCB, ESAA) | $30 million |
| MINING MANUFACTURERS | $15 million |
| TOTAL | $80 million |

In August 1996, the Federal Minister of Resources & Energy announced that the Government would spend an additional $1.2 million over four years to encourage the development of new mines, mineral processing and related infrastructure [25].

**Section 6**

# Costs and subsidies for Renewable Energy Technologies

Renewable sources of energy, including biomass and hydropower, contributed about 20% of the world's primary energy consumption in 1990 [24b].

A description of Renewable Energy technologies is contained in Appendix III, which also includes information relating to the Australian Renewable Energy Industry.

For the purposes of this report, medium and large scale hydropower has not been included as a renewable resource. This is because the flooding of ecosystems can in some circumstances result in considerable greenhouse emissions [28] as well as other substantial environmental damage. Particularly in developing countries, the construction of new dams and flooding of large areas of land usually causes considerable social dislocation.

## 6.1 Costs

While it is often believed that Renewable Energy sources are more expensive than conventional fossil-fuel sources, in many parts of the world Renewable Energy sources are already competitive. In particular, this occurs where Renewable Energy technologies have been encouraged to reach maturity, either through investment in R&D, or through the allocation of market share for a limited period of time, or mechanisms which remove cross-subsidies of electricity grid supplies.

Examples of such policies are a favourable weighting given to Renewables in power planning decisions by some US States, the Non Fossil Fuel Obligation in the UK, and the consideration of least cost alternatives to electricity network expansion in NSW, Australia.

These policies generally recognise that:

> Renewable Energy technologies will be cost-competitive, and in many cases could be lower than fossil-fuel alternatives, given sufficient market share to fully develop and utilise economies of scale;
>
> Fossil fuel technologies have benefited from considerable support over a long period of time;
>
> If environmental externalities were included in energy prices, most Renewable Energy technologies would already be competitive;
>
> Renewable Energy technologies can provide considerable cost savings when compared to centralised grid supply of electricity because:

- their small, modular nature enables a closer match between supply and demand;
- they can often be located close to the point of use thereby reducing network costs.

Where policies designed to assist the development of Renewable Energy sources have been in place, considerable cost reductions are already evident. For example, the record of prices paid in the UK for supplies through the Renewable Energy Tranche of the Non-Fossil Fuel Obligation (NFFO) demonstrate the considerable potential for such 'market-pull' initiatives over a small time period (see Table 14 below).

Table 14: Comparison of prices paid for UK Renewable Energy Resources between 1990 to 1994.

| | **NFFO1 (1990)** | **NFFO2 (1991)** | **NFFO3 (1994)** | **% increase/ (decrease)** |
|---|---|---|---|---|
| Capacity (MW) | 152 | 472 | 627 | 313% |
| **Technology Band** | **Contracted price (p/kWh)** | | | |
| Wind | 10.0 | 11.0 | large 4.8<br>small 6.0 | large -52%<br>small -40% |
| Hydro | 7.5 | 6.0 | 4.9 | -35% |
| Landfill Gas | 6.4 | 5.7 | 4.0 | -38% |
| Waste | 6.0 | 6.6 | 4.0 | -33% |
| Energy Crops | - | - | 8.7 | - |

A further order of between 400-500MW is expected in early 1997 and a similar amount in 1998, to reach the target of 1500MW of commissioned capacity by the year 2000. The UK regulator, OFFER, has recently stated that:

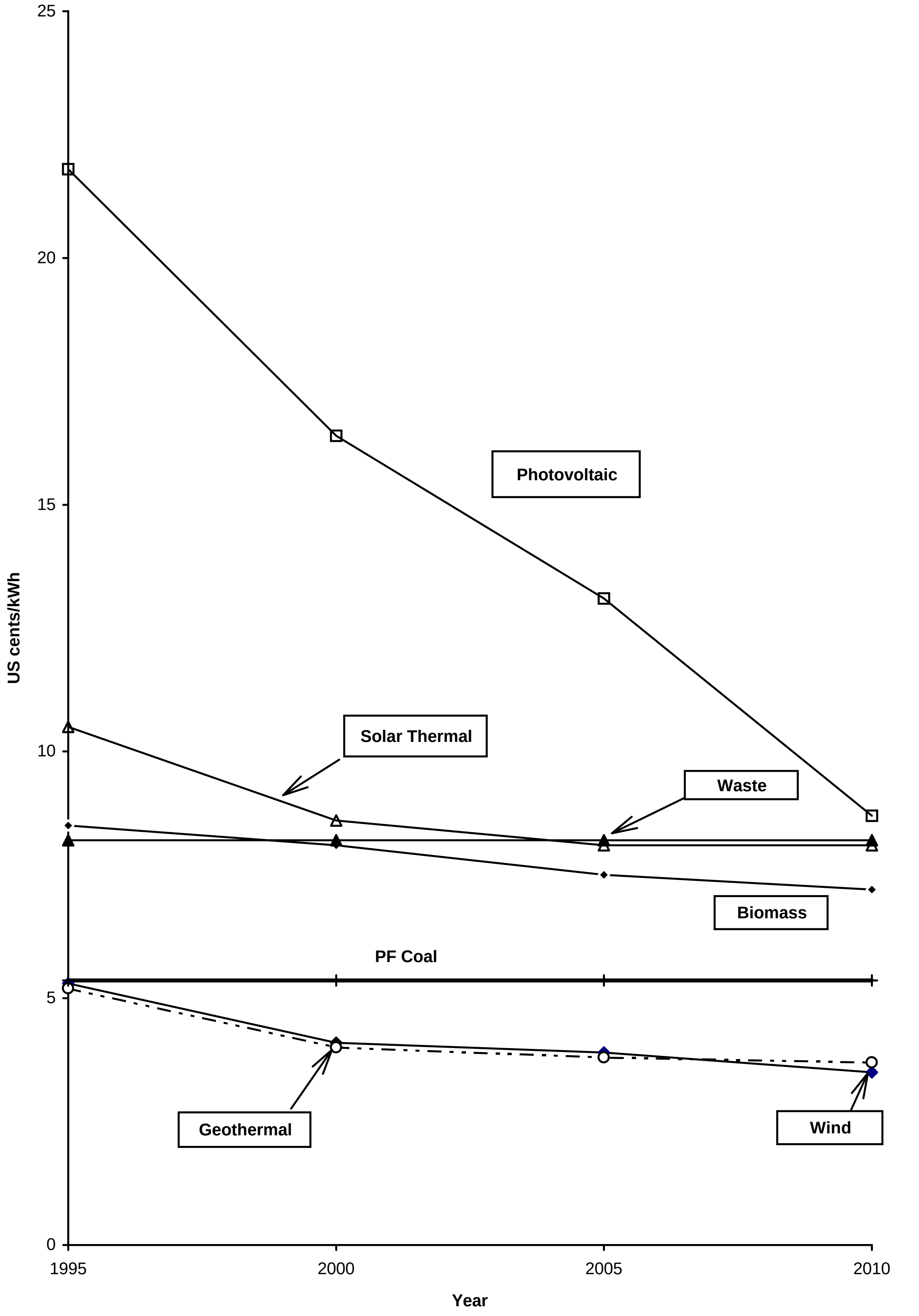
> *"Experience suggests that further convergence of bid prices to market prices can be expected in the next order"* [26]

Similar cost trends have been experienced in the US, where the market for Renewable Energy sources is most developed, and Dept of Energy forecasts (see Table 15 and Fig. 2) show that further cost reductions are likely. These costs do not include additional overall cost reductions to energy supply as a result of network benefits (See Appendix IV for the full DoE report).

Table 15: US Dept of Energy Projected Levelized Cost Estimates for Renewable Energy Technologies [19]

| **TECHNOLOGY** | **COST (1993 US ¢/KWH)** | | | |
|---|---|---|---|---|
| **YEAR** | **1995** | **2000** | **2005** | **2010** |
| WIND | 5.3 | 4.1 | 3.9 | 3.5 |
| GEOTHERMAL | 5.2 | 4.0 | 3.8 | 3.7 |
| BIOMASS | 8.5 | 8.1 | 7.5 | 7.2 |
| PV | 21.8 | 16.4 | 13.1 | 8.7 |
| SOLAR THERMAL | 10.5 | 8.6 | 8.1 | 8.1 |
| WASTE TO ENERGY | 8.2 | 8.2 | 8.2 | 8.2 |

**Fig 2: US Dept of Energy estimates of Renewable Energy costs , 1995-2010**. [19]



As noted previously in this report, there are a variety of costs (cited in reports) for electricity generated by fossil-fuel and Renewable Energy sources. This generally reflects national circumstances such as fuel and labour costs, different operational conditions (availability, etc), and assumptions regarding discount rates and plant life spans. In Appendix II, the levelised costs of a range of energy supply options have been calculated on an equal basis to enable comparison. The input costs are more reflective of countries such as Australia where there is only a fledgling Renewable Energy Industry, and hence the overall costs are different from those in the US.

Table 16 below summarises the results for electricity generation from Renewable Energy technologies.

Table 16: Costs of Renewable Energy Generating Technologies

| **TECHNOLOGY** | **TOTAL COST OF ELECTRICITY SUPPLY (A CENTS/KWH)** | | |
|---|---|---|---|
| | **High** | **Low** | **Average** |
| HYDRO | 11.8 | 2.8 | 7.3 |
| GRID CONNECTED PV | 50.1 | 29.8 | 39.9 |
| SOLAR THERMAL | 30.1 | 13.8 | 22.0 |
| WIND FARMS | 15.5 | 6.9 | 11.2 |
| BIOMASS COGEN | 4.0 | 2.8 | 3.4 |
| LANDFILL GAS | 8.6 | 1.8 | 5.2 |
| ENERGY EFFICIENCY | 4.8 | 1.6 | 3.2 |

## 6.2 Subsidies for Renewable Energy Technologies

In comparison to the fossil-fuel industry, support for Renewable Energy Technologies is small. For example:

1.4% of World Bank lending for energy projects goes to Renewable Energy projects [21];

0.8% of World Bank lending for energy projects goes to Energy Efficiency projects [21];

Less than 10% of IEA member governments' support is for renewable energy technology.

*"Fortunately, many of the promising technologies for reducing emissions, such as fuel cells and most renewable energy technologies, require relatively modest investments in R&D….As a result it should be feasible, even with limited resources for R&D, to support a diversified portfolio of options*." [24b]

In the UK, the Renewable Energy levy (part of NFFO) is equivalent to 1% of customer electricity prices. The remaining 9% of the NFFO supports the nuclear energy industry [26];

In Australia, there is only one CRC for the entire Renewable Energy Industry, with Government funding of $10m over seven years (see Table 17a). This should be compared with the nine Fossil Fuel Industry CRCs which receive a total of $184m of Government support over a similar period.

In total, major government-funded R&D programs for Renewable Energy Technologies receive approximately $14m per year (see Table 17a). Commonwealth and State governments also contribute around $9m per year for commercialisation programs.

**Table 17a: Major Committed Expenditure on Renewable Energy R&D in Australia [27]**

| PROGRAM | TOTAL FUNDS AVAILABLE (A$M) | PERIOD SPREAD OVER (YEARS) | ANNUAL FUNDS AVAILABLE (A$M) |
|---|---|---|---|
| ENERGY RESEARCH & DEVELOPMENT CORPORATION | 11.3 [2] | 3 years | 3.8 |
| COMMONWEALTH CRC | 10.0 [3] | 7 years | 1.4 |
| NSW FUNDING FOR PACIFIC SOLAR | 26.0 | 3 years | 8.7 |
| TOTAL | $47.3m | | $13.9m |

**Table 17b: Major Committed Expenditure on Renewable Energy Commercialisation Programs in Australia [27]**

| PROGRAM | TOTAL FUNDS AVAILABLE (A$M) | PERIOD SPREAD OVER (YEARS) | ANNUAL FUNDS AVAILABLE (A$M) |
|---|---|---|---|
| COMMONWEALTH RENEWABLE ENERGY PROGRAM | 4.8 | 4 years | 1.2 |
| NSW RENEWABLE ENERGY PROGRAM (SEDA) | 8.8 - 12.3 | 3 years | 2.9 -4.1 |
| QLD RENEWABLE ENERGY PROGRAM | 13.5 | 3 years | 4.5 |
| TOTAL | $27.1m | | $8.6m - $9.6m |

Unlike the case for 'Clean Coal' Technology, government investment in Renewable Energy Technology is likely to comprise a large proportion of the total R&D investment, and without market-making mechanisms there will be little opportunity to raise further funds through measures such as a levy on technology sales (eg. in the case of ACARP).

It appears likely, therefore, that Renewable Energy Technology in Australia receives something approaching one quarter of the R&D funding available for 'Clean Coal Technologies' ($80m p.a.).

[2] Current commitments

[3] A further $5million is promised, though not committed.

**Section 7**

# Comparison of $CO_2$ savings potential

## "Clean Coal" Technologies vs Renewable Energy Sources

This analysis of the potential for a range of energy sources to reduce greenhouse gas emissions relies primarily upon data provided by two previous studies.

the DPIE report *"Coal and Climate Change"* [6]; and,

the Intergovernmental Panel on Climate Change *Report "Impacts, Adaptations and Mitigation of Climate Change: Scientific-Technical Analysis"* [24b]

While the scope of these studies are different, they are adequate for comparative purposes and enable some broad conclusions to be drawn.

### 7.1 The scope for $CO_2$ reductions through 'Clean Coal' Technologies

The Asia-Pacific region has the highest predicted energy, and electricity, growth rate in the world in the period up to the year 2000, is heavily dependent upon the use of coal as a primary fuel, and has examples of older style technology in use. It is therefore likely that this market would be one where 'Clean Coal' technologies could have the largest impact, in terms of the number of potential applications, efficiency improvements and greenhouse savings.

The DPIE report *"Coal and Climate Change"* [6] analyses these opportunities in the Asia-Pacific region. The following data is taken from this report.

Tables 18, 19 & 20 show estimated Electricity and Greenhouse Gas emission projections for this region in a scenario where there is little or no constraint upon consumption and where there is little or no attempt to alter the type of fuel used to generate electricity. In these projections, there is a very high degree of reliance upon coal.

Table 18: Estimated Electricity Generation in Asia-Pacific (TWh) [6]

| ENERGY SOURCES | 1995 | 2000 | 2010 |
|---|---|---|---|
| COAL | 1410 | 2135 | 3470 |
| GAS | 380 | 520 | 963 |
| HYDRO POWER | 460 | 610 | 1170 |
| GEOTHERMAL | 10 | na | 70 |
| NUCLEAR | 315 | na | 950 |
| NEW AND RENEWABLE ENERGY | na | 1.5 | 6 |

| Table 19: Estimated emissions of $CO_2$ and Methane in Asia-Pacific, 1989 [6] | | | |
|---|---|---|---|
| SOURCES | $CO_2$ EMISSIONS (MT) | SOURCES | METHANE EMISSIONS (KT) |
| ALL INDUSTRIAL SOURCES | 3468 | COAL, OIL AND GAS | 17500 |
| COAL COMBUSTION | 2474 | COAL MINING | 14900 |

Clearly, of all the energy related emissions, those associated with the mining and utilisation of coal are the most significant in this region, accounting for 74% of $CO_2$ emissions and 85% of methane emissions.

Assuming no alteration in the quality of fuels and combustion technologies, the projected increases in $CO_2$ and Methane emissions in Asia-Pacific countries, related to the use of coal, are shown in Table 20 below.

This indicates a 57% increase in $CO_2$ emissions and a 43% increase in methane emissions between 1989-2000.

Table 20: Projected coal related $CO_2$ and Methane emissions in selected Asia Pacific Countries [6]

| | **CARBON DIOXIDE (MT)** | | **METHANE (KT)** | |
|---|---|---|---|---|
| **COUNTRY** | INCREASE 1989-2000 | TOTAL IN 2000 | INCREASE 1989-2000 | TOTAL IN 2000 |
| CHINA | 900 | 2,900 | 6,000 | 19,000 |
| INDIA | 420 | 880 | 1,600 | 3,400 |
| INDONESIA | 50 | 60 | 70 | 82 |
| THAILAND | 30 | 40 | n.a. | n.a. |
| ALL OTHERS | 40 | 70 | n.a. | n.a. |

In assessing the major opportunities for greenhouse gas reduction in the Asia-Pacific region, the DPIE report [6] makes an assessment of the potential for all major 'Clean Coal' technologies and processes. Some of the issues raised by the report relating to the application of these technologies and processes are discussed below.

#### 7.1.1 EXPORT OF HIGH QUALITY AUSTRALIAN COAL TO ASIA-PACIFIC

The report notes that the importation of coal in China, Thailand and India is strictly controlled by their respective Governments, thereby limiting the potential application of this activity unless national policies alter.

#### 7.1.2 BENEFACTION OF INDIGENOUS COALS

See earlier comments, Section 2.2.1.

#### 7.1.3 IMPROVED EFFICIENCY OF COAL FIRED POWER STATIONS

Many of the study countries have already implemented maintenance programs and efficiency improvements to existing plant, with the result that the savings potential was found to be less than might have been expected.

> *"….the availability of Chinese thermal power stations is broadly similar to that of more developed industrialised countries…."*

> *"Because Indonesian coal fired power stations are very modern, there is little or no opportunity to improve efficiency by plant renovation."*

#### 7.1.4 NEW COAL FIRED POWER STATIONS

The report notes that the development of new power stations to meet growing demand *"will have the effect of increasing emissions in absolute terms".* It is also true that new coal fired power stations will increase emissions in relative terms, compared to some of the alternatives described, particularly end use energy efficiency and renewable energy sources.

> *"We therefore conclude that participation in the supply of new black coal fired power stations, while potentially extremely important in both economic and commercial terms, is not a measure which would unambiguously, or in all circumstances, reduce greenhouse emissions."*

#### 7.1.5 CONCLUSIONS

Above mentioned data limitations means that the DPIE report has to make assumptions, not only about the greenhouse savings potential of individual measures, but also the scope for applying these in each country. Nevertheless, the report states that the overall estimates *"show much, but not all of the potential*". This estimates are provided in Table 21.

Table 21: Total Potential Emission Reduction from Selected Measures [6]

| MEASURE | COUNTRY | ANNUAL CARBON DIOXIDE REDUCTION (MT) | ANNUAL METHANE REDUCTION (MT) |
|---|---|---|---|
| IMPORTED COAL | India | 2.3 Mt. | na |
| COAL BENEFACTION | India | 2.1 Mt. | na |
| POWER STATION EFFICIENCY | India | 6.3 Mt. | na |
| INDUSTRIAL BOILER EFFICIENCY | China | 81 Mt. | na |
| METHANE DRAINAGE | China | 0.35 Mt. | 0.14 Mt. |

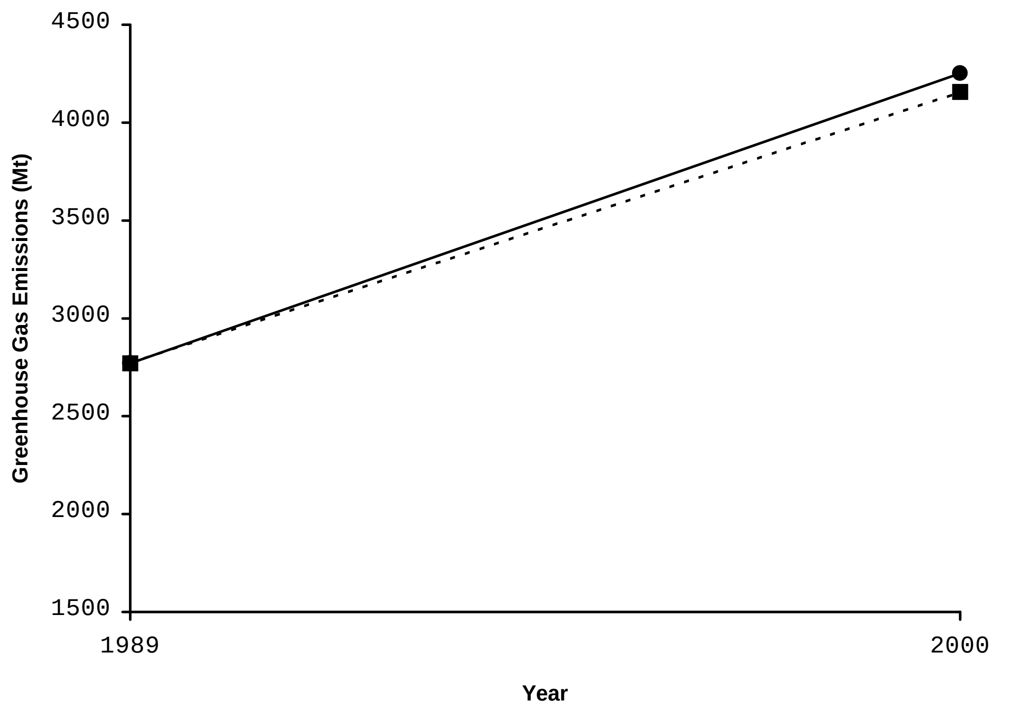
The impact of these measures on greenhouse gas emissions in the Asia-Pacific region up the year 2000 (i.e. using data in Table 19, 20 & 21) is shown in Table 22.

This demonstrates that these savings are extremely small (2.1%-3.6%) compared to total emissions associated with coal mining and utilisation activities. Considering the subsequent information contained in [20], even this estimate may be optimistic.

Greenhouse reductions will be even less significant compared to total greenhouse gas emissions from each country.

Figure 3. illustrates these findings and shows that these 'Clean Coal' measures will have a negligible impact on the rate of growth in greenhouse gas emissions.

**Fig 3: Impact of 'Clean Coal' measures in Asia-Pacific region**



| Table 22: Impact of greenhouse reduction measures, Asia-Pacific region, 1989-2000 | | | |
|---|---|---|---|
| | CHINA | INDIA | TOTAL |
| $CO_2$ emissions in 1989 (Mt.) | 2000 | 460 | 2460 |
| Increase in $CO_2$ emissions 1989-2000 (Mt.) | 900 | 420 | 1320 |
| Reduction in $CO_2$ emissions due to proposed measures (Mt.) | (81) | (10.7) | (91.7) |
| % Reduction relative to 1989 $CO_2$ emissions | (4%) | (2.3%) | (3.7%) |
| Net $CO_2$ emissions in 2000 (Mt.) | 2819 | 869.3 | 3688.3 |
| % INCREASE IN $CO_2$ EMISSIONS, 1989-2000 | 41% | 89% | 50% |
| Methane emissions in 1989 (kt) | 13,000 | 1,800 | 14,800 |
| Increase in Methane emissions 1989-2000 (kt) | 6,000 | 1,600 | 7,600 |
| Reduction in Methane emissions due to proposed measures (kt) | (140) | 0 | (140) |
| % Reduction relative to 1989 Methane emissions | (1%) | (0%) | (1%) |
| Net Methane emissions in 2000 (kt) | 18860 | 3,400 | 22260 |
| % INCREASE IN METHANE EMISSIONS, 1989-2000 | 45% | 89% | 50% |
| Total Greenhouse Emissions ($CO_2$ equivalents) | | | |
| Greenhouse emissions in 1989 (Mt) | 2273 | 498 | 2771 |
| Increase in Greenhouse emissions 1989-2000 (Mt) | 1026 | 454 | 1480 |
| Reduction in Greenhouse emissions due to proposed measures (Mt) | (84) | (10.7) | (94.7) |
| % Reduction relative to 1989 Greenhouse emissions | (3.6%) | (2.1%) | (3.4%) |
| Net Greenhouse emissions in 2000 (Mt) | 3215 | 952 | 4157 |
| % INCREASE IN GREENHOUSE EMISSIONS, 1989-2000 | 41% | 91% | 50% |

## 7.2 The scope for $CO_2$ reductions through Renewable Energy Technologies

The IPCC model, "Low $CO_2$-emitting Energy Supply Systems for the World (LESS)", has been constructed to investigate the potential for achieving deep reductions in emissions in the long-term.

> *"By the year 2100, the global commercial energy system will have been replaced two to three times - providing many opportunities to change system performance through the use of various new technologies at the time of investment, both for capacity expansion and replacement."* [24b]

The model examines six scenarios, each containing a different mix of energy supply sources:

Case 1: The reference scenario

Case 2: Emphasises energy efficient power generation from fossil fuels (with efficiencies reaching 66% by 2095)

Case 3: Liquefied hydrogen from natural gas, biomass & electrolytic sources is used in fuel cells; for transport, and solar and wind power become highly competitive.

Case 4: As case 3 except compressed hydrogen instead of liquefied hydrogen.

Case 5: As case 4 but greater use of biomass

Case 6: As case 5, but greater exogenous end-use energy intensity .

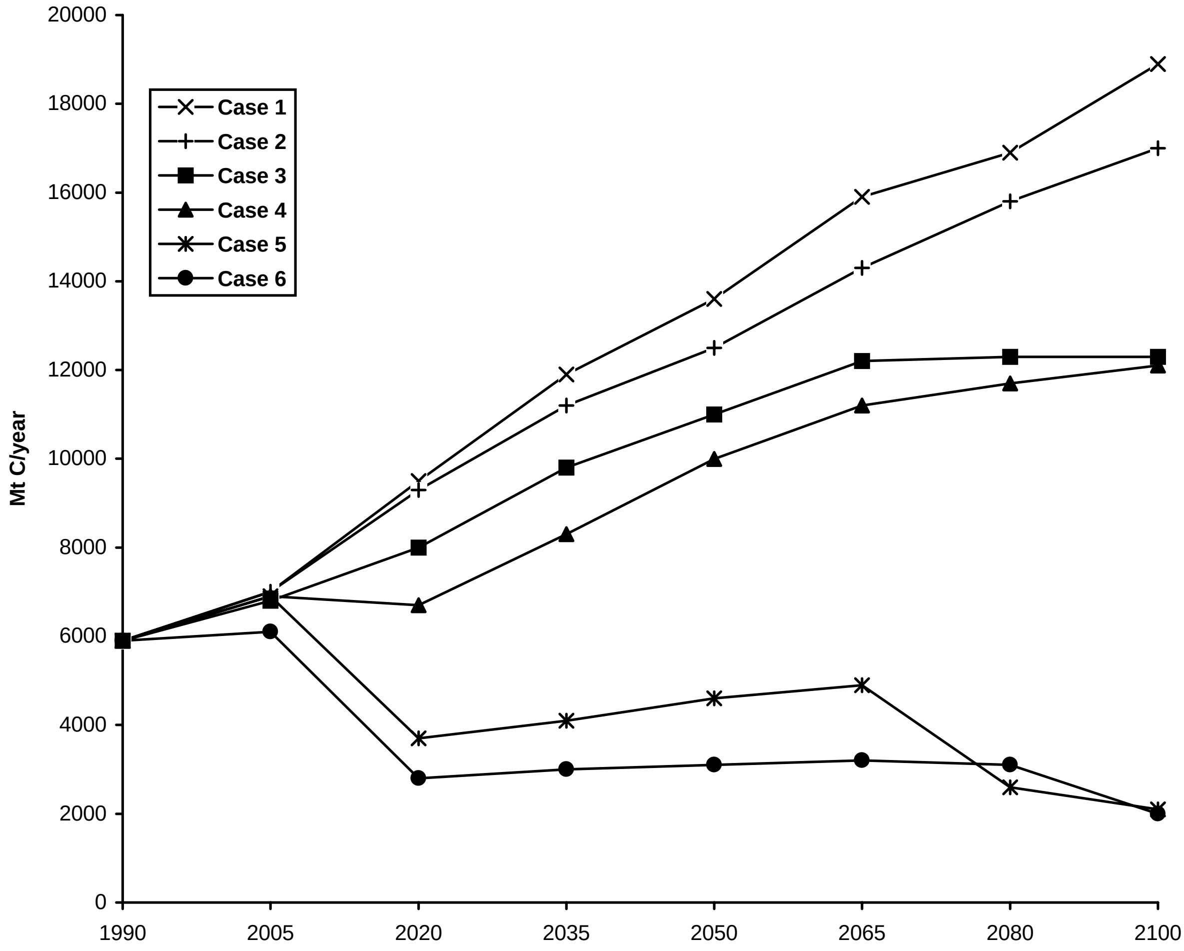
The impact of these scenarios are shown in Fig. 4.

Table 23, below, shows that deep cuts in greenhouse gas emissions are feasible as a result of switching to renewable energy technologies and increased energy efficiency (approximately equivalent to Case 6 above).

**Table 23: Maximum potential greenhouse gas reductions: results of LESS model [24b]**

| | Industrialised Countries | Developing Countries | World |
|---|---|---|---|
| $CO_2$ emissions, Gt C in 1990 | 4.39 | 1.86 | 6.25 |
| $CO_2$ emissions, Gt C in 2100 | 0.78 | 1.00 | 1.78 |
| % change in $CO_2$ emissions | -82% | -46% | -72% |

**Fig 4: Low $CO_2$-emitting Energy Supply Systems for the World (LESS)** [24b]




The IPCC notes that these greenhouse gas reductions may not result in economic costs. However, such a scenario is only possible if driven by policies aimed at stimulating investment in low-greenhouse intensive technologies.

> *"This [the LESS model] shows that if the assumed technological characteristics are realised, deep reductions could be achieved without economic penalty. What is needed is a technology policy that facilitates the development and commercialisation of Greenhouse Gas friendly technologies that offer the potential at maturity of being competitive under market conditions with fossil fuel technologies."* [24b]

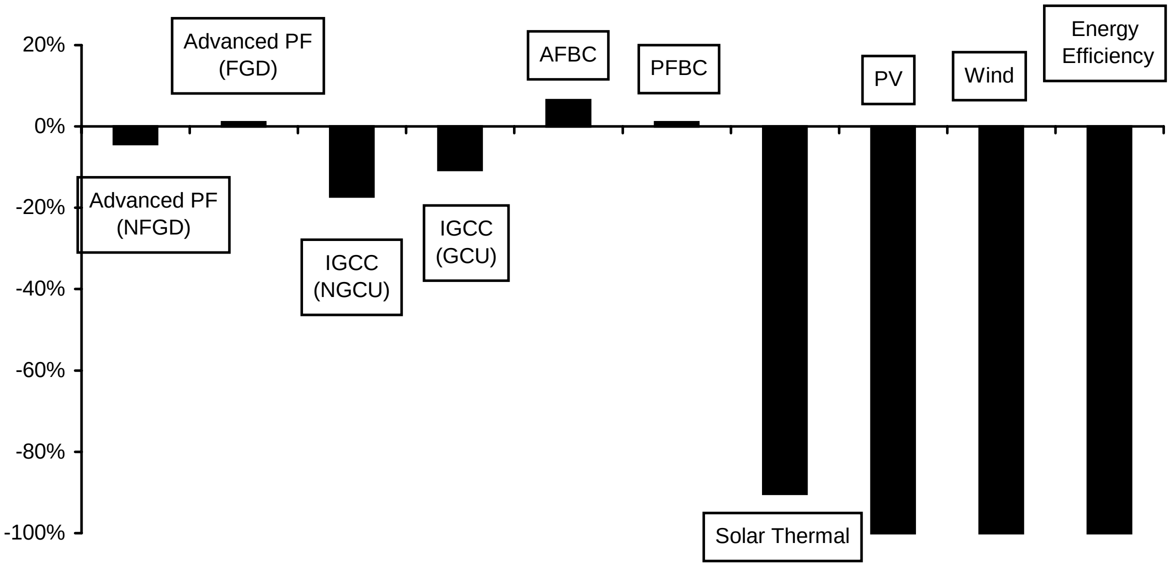
> *"Costs for energy services in each LESS variant relative to costs for conventional energy depend upon relative future energy prices, which are uncertain within a wide range, and on the performance and cost characteristics assumed for alternative technologies. However, within the wide range of future energy prices, one or more of variants would plausibly be capable of providing the demanded energy services at estimated costs that are approximately the same as estimated future costs for current conventional energy. In a LESS scenario, substantial reductions in $CO_2$ emissions would result from the deployment of advanced energy supply technologies, along with more efficient energy-using equipment. Such outcomes appear to be possible given adequate time (several decades) and an economic climate and public- and private- sector policies conducive to the needed innovations."* [24b]

## 7.3 Conclusion

### Comparison between 'Clean Coal' and Renewable Energy technologies

Fig.5, below, illustrates the potential of considerable greenhouse benefits available through Renewable Energy technologies, in comparison with 'Clean Coal' technologies.

**Fig 5: Comparison of greenhouse gas reduction potential from electricity generating technologies.**




When the costs of supply alternatives are taken into consideration, it is also evident that many Renewable Energy Technologies currently represent the most cost-effective means of reducing greenhouse gas emissions.

In the following Table 24, all alternatives are compared to an existing conventional Pulverised Fuel coal-fired power station without Flue Gas Cleanup. Since the Renewable Energy options have zero or slight emissions of NOx and SOx, these are compared to 'Clean Coal' technologies with Gas Cleanup/Desulphurisation.

A negative cost of $CO_2$ saved, in the final column, indicates that $CO_2$ will be increased, not reduced. In the case of energy efficiency, the bracketed result indicates that not only is $CO_2$ reduced, but also that it is a lower cost supply option that the reference case.

| Table 24: Cost and scope of $CO_2$ reductions | | | | | |
|---|---|---|---|---|---|
| TECHNOLOGY | LEVELISED COST<br>cents/kWh | $CO_2$ EMISSION COEFFICIENTS<br>kg $CO_2$/kWh | POTENTIAL TO AVOID CO2 EMISSIONS<br>kg $CO_2$/kWh | NET ECONOMIC COST<br>c/kWh | COST OF $CO_2$ REDUCED (OR INCREASED)<br>cents/kg |
| REFERENCE CASE (PF BLACK COAL NFGD) | 4.4 | 0.93 | 0 | 0 | 0.0 |
| ADVANCED PF + FGD BLACK COAL | 6.1 | 0.94 | -0.01 | 1.7 | -170.0 |
| IGCC BLACK COAL + GCU | 5.7 | 0.83 | 0.1 | 1.3 | 13.0 |
| AFBC BLACK COAL | 5.7 | 0.99 | -0.06 | 1.3 | -21.7 |
| PFBC BLACK COAL | 5.7 | 0.94 | -0.01 | 1.3 | -130.0 |
| GAS COMBINED CYCLE | 5.11 | 0.39 | 0.54 | 0.71 | 1.3 |
| HYDRO | 7.33 | 0 | 0.93 | 2.93 | 3.2 |
| SOLAR THERMAL | 22 | 0.09 | 0.84 | 17.6 | 21.0 |
| WIND | 11.2 | 0 | 0.93 | 6.8 | 7.3 |
| GRID-CONNECTED PV | 39.9 | 0 | 0.93 | 35.5 | 38.2 |
| ENERGY EFFICIENCY | 3.2 | 0 | 0.93 | -1.2 | (1.3) |

This Table is represented in Figure 6, below. This shows that the technologies can be divided into the following categories:

1. *Increased greenhouse emissions:*

   PF Advanced Technology

   PFBC

   AFBC

2. *Small greenhouse emission reduction - Low cost of abatement*

   IGCC

3. *Medium greenhouse emission reduction - Low cost of abatement:*

   Gas Combined Cycle

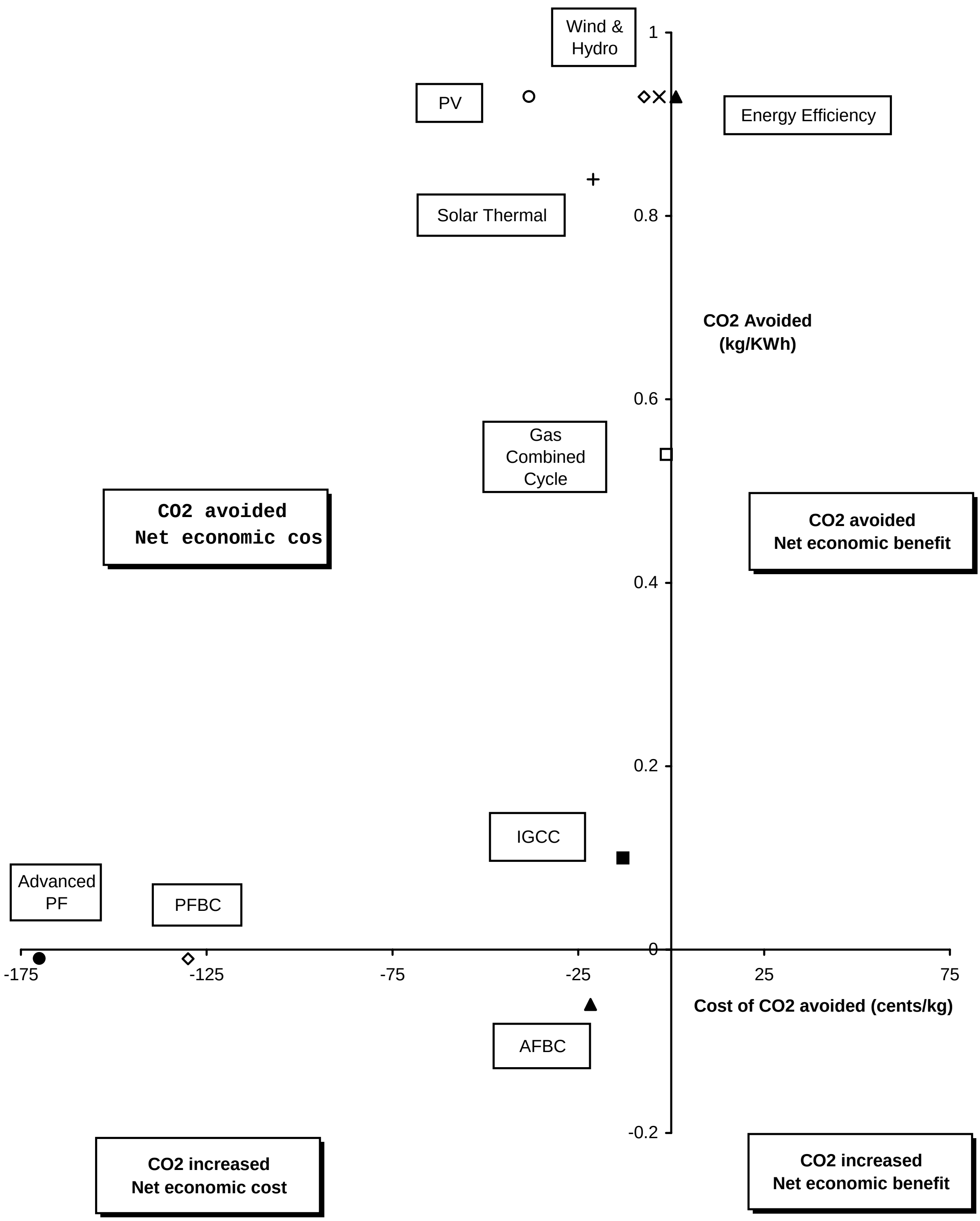
4. *Large greenhouse emission reduction - Low cost of abatement:*

   All Renewable Energy Technologies

5. *Large greenhouse emission reduction - Economic benefits of abatement:*

   Energy Efficiency

Fig 6: Cost of $CO_2$ abatement, Fossil Fuel and Renewable Energy Technologies



On the basis of this analysis, it is evident that greenhouse reduction strategies should be focusing on the early advancement of Renewable Energy Technologies and the development of projects which utilise these sources.

However, as noted previously in this report, Government policies in most major industrialised countries continue to support 'Clean Coal' Technologies to the detriment of alternatives which offer substantially greater opportunities and benefits. Indeed, currently conventional energy technologies benefit from direct subsidies of more than $300 billion per annum worldwide [24b].

It is clear from the IPCC report [24b] that the LESS scenario, offering deep cuts in greenhouse gas emissions, will not occur without strong policy intervention by governments. It is also clear that a switch of policies towards providing support for Renewable Energy Technologies need not result in economic or social penalties.

**Section 8**

# References


[1] OECD/IEA. 1995. *IEA Clean Coal Technologies*, 1995

[2] OECD Coal Industry Advisory Board, 1995. *Industry Attitudes to steam cycle clean coal technologies - survey of current status*.

[3] Preston, Dr G. T. 1993 *Improved coal Technologies for the Asia Pacific 21st Century* Economic Development IEA second International Conference on the Clean…

[4] Kunito, A & Takahashi M, 1993. *The Clean & Efficient use of coal and lignite*…….

[5] Herzog, H. *$CO_2$ mitigation Strategies: Perspectives on the capture and sequestration option*. Energy & Environment Vol 7, 1996 Issue 2.

[6] Commonwealth of Australia, 1994. *Coal and Climate Change - Opportunities for Australian Industry to Contribute to Reducing International Greenhouse Gas Emissions*, report for the Department of Primary Industries and Energy. Economic and Energy Analysis Pty Ltd and Sinclair Knight Merz, October 1994.

[7] ERDC, 1992. *Advanced Generation Options for the Australian Electricity Supply Industry and their Impact on Greenhouse Emissions*, a report for ERDC and ESAA prepared by Ewbank Preece Sinclair Knight, January 1992.

[8] Electricity Commission of NSW, 1989. *Electricity Development and Fuel Sourcing Plan - Strategic Plan*, July 1989.

[9] McIntosh, M. (ABB Power Plants Ltd), 1994. *Pressurised Fluid Bed Combustion*, presentation to Pacific Power forum 'Energy for Life', Sydney, February 1994.

[10] Badwal, S., Foger, K., Murray, M. (CSIRO), 1992. Fuel Cells: A Clean Alternative Energy Technology of 21st Century, presentation to the Gippsland Basin Symposium, Melbourne, June 1992.

[11] Hart, J., 1995. *Pursuing Sustainable New Greenhouse Responses*, article in ESAA Magazine, September 1995.

[12] AID/Watch, 1996. *A Review of the Asian Development Bank's Energy Sector,* prepared by Aviva Imhof on behalf of NGO Working Group on the ADB, April 1996.

[13] EGRET, 1996. *Draft Report of the Expert Group on Renewable energy Technologies*.

[14] World Bank, 1996. *Annual Report 1995/6*, located on the World Bank web site.

[15] IEA, 1996. Data located on the IEA web site.

[16] DoE, 1996. Data located on the DoE web site.

[17] Australian Science and Technology Council, 1994. *Energy Research and Technology in Australia, occasional paper No. 28*.

[18] Australian Coal Industry Council, 1994. *Study of the Australian Black Coal Industry*, November 1994.

[19] DoE, 1996. *The True Cost of Renewables*, National Renewable Energy Laboratory.

[20] Economic & Energy Analysis, 1995. *Greenhouse Gas Quantification: Moonidih Coal Preparation Plant Project, India*. Report prepared for AusAID, September 1995.

[21] Greenpeace 1996. *World Bank Factsheet No 5*.

[22] Australian Coal Research Ltd, 1996. *Latest Developments in Australian Coal Mining Research*. Presentation to NECET.

[23] Graham, R, 1996. *Clean Coal Technology for the Future*. Presentation at the 1996 Australian Coal Conference, 19-23 May 1996.

[24a] Houghton, J.T., L.G. Meira Filho, B.A. Callander, N. Harris, A. Kattenberg and K. Maskell, 1996. *Climate Change 1995: The Science of Climate Change*. Contribution of Working Group I to the Second Assessment Report of the Intergovernmental Panel on Climate Change, Cambridge University Press, Cambridge.

[24b] Watson, RT., Zinyowera, MC., Moss RH., Dokken, DJ., 1996. *Climate Change 1996: Impacts, Adaptations and Mitigation of Climate Change: Scientific-Technical Analysis*. Contribution of Working Group II to the Second Assessment Report of the Intergovernmental Panel on Climate Change, Cambridge University Press, Cambridge.

[25] Commonwealth of Australia, 1996. *Support for Minerals Regional Projects. Press release from Dept. Primary Industries and Energy*, 21$^{st}$ August 1996.

[26] OFFER, 1995. *Renewable Energy and Price Convergence*. A speech given by Professor Littlechild to the Parliamentary Renewable and Sustainable Energy Group. November 1995.

[27] Greenpeace 1996. *1996 Major Review of the National Greenhouse Response Strategy*. Greenpeace submission to the Intergovernmental Committee on Ecological Sustainable Development. May 1996.

[28] Paligaru, C. 1992. *The Export of Australian Coal Mining Technology to India: A Case Study*. Paper for the Asian Studies Association of Australia 9$^{th}$ Biennial Conference, University of New England, 6-9 July 1992.

[29] New Scientist, 1996. *"Trouble bubbles for Hydropower"* by Fred Pearce, New Scientist, 4$^{th}$ May 1996.

[30] Michaels. Dr P., 1996. *A World Without Coal - The Alternative Perspective*. Presentation at the 1996 Australian Coal Conference, 19-23 May 1996.

[redacted]

**Section 9**

# Terminology

| | |
|---|---|
| ACARP | Australian Coal Association Research Program |
| ADB | Asian Development Bank |
| AFBC | Atmospheric Fluid Bed Combustion |
| ASTEC | Australian Science and Technology Council |
| $CO_2$ | Carbon Dioxide |
| CRC | Co-operative Research Centre |
| DIFF | Development Import Finance Facilities |
| DPIE | Department of Primary Industry and Energy |
| EFIC | Export Credit Insurance Facilities |
| EPRI | Electric Power Research Institute |
| ERDC | Energy Research and Development Cooperation |
| FGD | Flue Gas Desulphurisation |
| GCU | Gas Clean Up |
| IEA | International Energy Agency |
| IGCC | Integrated Gasification Combined Cycle |
| IPCC | Intergovernmental Panel on Climate Change |
| LESS | Low CO2-emitting Energy Supply Systems |
| MEA | Monoethanolamine |
| MHD | Megneto Hydro Dynamic |
| NCU | No Clean Up |
| NFFO | Non Fossil Fuel Option |
| NFGD | No Flue Gas Desulphurisation |
| NOx | Nitrogen oxides |
| OECD | Organisation of Economic Cooperation and Development |
| PF | Pulverised Fuel |
| PFBC | Pressurised Fluid Bed Combustion |
| PV | Photovoltaic Cells |
| SRC | Selective Catalytic Reduction |
| SOx | Sulphur oxides |

## APPENDIX I: COST OF COAL COMBUSTION TECHNOLOGY [7]

| | PF Black Coal Advanced Tech. | | PF Brown Coal Advanced Tech. | | IGCC Black Coal | | IGCC Brown Coal | | ACFB Black Coal | PFBC Black Coal |
|---|---|---|---|---|---|---|---|---|---|---|
| | NFGD | FGD | NFGD | FGD | N C U | G C U | N C U | G C U | | |
| Size (gross) | 1320 | 200 | 1320 | 200 | 1684 | 1666 | 1574 | 1490 | 150 | 150 |
| (net) | 1227 | 184 | 1214 | 182 | 1470 | 1448 | 1381 | 1298 | 140 | 146 |
| Efficiency % (new) | 38.9 | 36.8 | 30.6 | 29.0 | 44.0 | 40.6 | 42.7 | 36.9 | 34.8 | 36.7 |
| (average) | 37.6 | 35.5 | 29.8 | 28.2 | 43.3 | 40.0 | 41.5 | 36.3 | 33.8 | 35.5 |
| Capacity Factor | 75 | 75 | 75 | 75 | 75 | 75 | 75 | 75 | 75 | 75 |
| Capital Cost ($/kW) | 1540 | 2300 | 1990 | 2730 | 1960 | 2030 | 2000 | 2230 | 1890 | 2000 |
| Cost of Electricity (c/kWh) | | | | | | | | | | |
| Capital + IDC | 2.4 | 3.5 | 3.1 | 4.3 | 3.3 | 3.4 | 3.3 | 3.7 | 2.9 | 2.9 |
| O + M | 0.8 | 1.0 | 0.9 | 1.0 | 1.0 | 1.0 | 1.1 | 1.2 | 1.3 | 1.3 |
| Fuel | 1.3 | 1.4 | 0.9 | 0.9 | 1.2 | 1.3 | 0.6 | 0.7 | 1.5 | 1.4 |
| Total Cost (c/kWh) | 4.5 | 6.0 | 4.8 | 6.1 | 5.4 | 5.7 | 5.0 | 5.6 | 5.7 | 5.7 |
| kg $CO_2$/kWh | 0.89 | 0.94 | 1.1 | 1.2 | 0.77 | 0.83 | 0.82 | 1.0 | 0.99 | 0.94 |

| | | |
|---|---|---|
| Notes: | NFGD = No Flue Gas Desulphurisation<br>FGD = With Flue Gas Desulphurisation | NCU = No Clean Up<br>GCU = With Gas Clean Up |
| Assumptions: | 25 year plant life | 8% discount rate |

## APPENDIX II: LEVELISED COSTS OF ELECTRICITY GENERATING TECHNOLOGIES [8% discount, 25yr]

| Technology | Options | Discount Rate [%] | Typical Capacity [kW] | Capacity Factor [%] | Capital Investment Costs: Capital Costs [$/kW] | Capital Investment Costs: Life of system [yrs] | Capital Investment Costs: levelised costs [cents/kWh] | Overheads & Maintenance Costs: Annual costs [% of capital] | Overheads & Maintenance Costs: levelised cost [cents/kWh] | Fuel Costs: Levelised cost [cents/kWh] | Total Cost of electricity supply: Levelised costs [cents/kWh] |
|---|---|---|---|---|---|---|---|---|---|---|---|
| ***Coal Fired Generators [1]*** | | | | | | | | | | | |
| Coal Thermal | Option 1 - High | 8% | 500000 | 40% | 2000 | 25 | 5.35 | 3% | 1.71 | 3.60 | **10.66** |
| | Option 2 -Low | 8% | 500000 | 80% | 1500 | 25 | 2.01 | 2% | 0.43 | 0.97 | **3.41** |
| PFBC | Option 1 - High | 8% | 500000 | 40% | 2000 | 25 | 5.35 | 3% | 1.71 | 2.40 | **9.46** |
| | Option 2 -Low | 8% | 500000 | 80% | 1500 | 25 | 2.01 | 2% | 0.43 | 0.72 | **3.15** |
| IGCC | Option 1 - High | 8% | 500000 | 40% | 2000 | 25 | 5.35 | 3% | 1.71 | 2.40 | **9.46** |
| | Option 2 -Low | 8% | 500000 | 80% | 1500 | 25 | 2.01 | 2% | 0.43 | 0.72 | **3.15** |
| ***Gas Fired Generators [2]*** | | | | | | | | | | | |
| Gas Thermal | Option 1 - High | 8% | 250000 | 30% | 800 | 25 | 2.85 | 2.00% | 0.61 | 7.20 | **10.66** |
| | Option 2 - Low | 8% | 250000 | 70% | 500 | 25 | 0.76 | 1.00% | 0.08 | 2.70 | **3.55** |
| Gas Turbine | Option 1 - High | 8% | 50000 | 5% | 700 | 25 | 14.97 | 1.00% | 1.60 | 6.17 | **22.74** |
| | Option 2 - Low | 8% | 50000 | 25% | 400 | 25 | 1.71 | 0.50% | 0.09 | 2.57 | **4.37** |
| Gas Combined Cycle | Option 1 - High | 8% | 250000 | 50% | 1000 | 25 | 2.14 | 1.00% | 0.23 | 4.80 | **7.17** |
| | Option 2 - Low | 8% | 250000 | 80% | 700 | 25 | 0.94 | 0.50% | 0.05 | 2.08 | **3.06** |
| Gas Cogeneration [3] | Option 1 - High | 8% | 100000 | 70% | 1200 | 25 | 1.83 | 3% | 0.59 | 3.09 | **5.51** |
| | Option 2 - Low | 8% | 100000 | 80% | 800 | 25 | 1.07 | 2% | 0.23 | 1.35 | **2.65** |
| ***Other*** | | | | | | | | | | | |
| Coal-Bed Methane [4] | Option 1 - High | 8% | 100000 | 40% | 700 | 25 | 1.87 | 1.00% | 0.20 | 1.03 | **3.10** |
| | Option 2 - Low | 8% | 100000 | 60% | 400 | 25 | 0.71 | 0.50% | 0.04 | 0.43 | **1.18** |
| Hydro | Option 1 - High | 8% | 50000 | 20% | 2000 | 25 | 10.69 | 1% | 1.14 | 0.00 | **11.84** |
| | Option 2 - Low | 8% | 50 | 40% | 1000 | 25 | 2.67 | 0.50% | 0.14 | 0.00 | **2.82** |
| Grid Connected PV | Option 1 - High | 8% | 100 | 18% | 8000 | 25 | 47.53 | 0.50% | 2.54 | 0.00 | **50.07** |
| | Option 2 -Low | 8% | 100 | 22% | 6000 | 25 | 29.17 | 0.20% | 0.62 | 0.00 | **29.79** |
| Solar Thermal [5] | Option 1 - High | 8% | 1000 | 16% | 3600 | 25 | 24.06 | 2% | 5.14 | 0.93 | **30.12** |
| | Option 2 - Low | 8% | 1000 | 21% | 2400 | 25 | 12.22 | 1% | 1.30 | 0.26 | **13.78** |
| Wind Farms [6] | Option 1 - High | 8% | 2000 | 21% | 2500 | 25 | 12.73 | 2% | 2.72 | 0.00 | **15.45** |
| | Option 2 - Low | 8% | 2000 | 36% | 2100 | 25 | 6.24 | 1% | 0.67 | 0.00 | **6.90** |
| Biomass Cogen [7] | Option 1 - High | 8% | 10000 | 70% | 2300 | 25 | 3.51 | 1.20% | 0.45 | 0.00 | **3.96** |
| | Option 2 - Low | 8% | 10000 | 80% | 1900 | 25 | 2.54 | 0.80% | 0.22 | 0.00 | **2.76** |
| Landfill Gas [8] | Option 1 - High | 8% | 5000 | 40% | 1500 | 25 | 4.01 | 4% | 1.71 | 2.88 | **8.60** |
| | Option 2 - Low | 8% | 5000 | 65% | 900 | 25 | 1.48 | 2% | 0.32 | 0.00 | **1.80** |
| Demand-side Management [9] | Option 1 - High | | | | | | | | | | **1.58** |
| | Option 2 - Low | | | | | | | | | | **4.80** |

## NOTES & SOURCES FOR APPENDIX II

Notes:

[1] Typical values for black coal used = $1.0/GJ (low) and $3.0/GJ (high)

[2] Typical costs of Gas used = $3.0/GJ (low) and $6.0/GJ (high).

[3] Assumes a large thermal load in addition to electricity output.

[4] Fuel costs assumed = $0.5/GJ (low) and $1/GJ (high)

[5] Solar Thermal with gas back-up. Max gas contribution = 15%, minimum = 10%

[6] For Wind Farms: Option 1 is for wind speeds of 5.5 m/s; and Option 2 is for wind speeds of 7 m/s.

[7] Assumes a large thermal load in addition to electricity output. Cost of biomass is assumed to be zero

[8] Some commercial landfill plant may be required to purchase fuel. Fuel costs assumed = $0/GJ (low) and $2/GJ (high)

[9] The cost of DM programs has been taken from the cost of the Queensland program (Low) and the SECV program (High).
The Queensland program is estimated to cost $63 million over ten years and reduce demand by a cumulative total of 650MW.
It is assumed that an average of $6.3 m will be spent to yield average savings of 65MW each year.
At a capacity factor of 70%, the levelised cost is therefore $1.58 cents/kWh.

*General:* Land costs have not been included for any technology

*Sources:*

DASETT, 1991. The Application of Solar Thermal Technologies in reducing Greenhouse Gas Emissions.

Ewbank Preece Sinclair Knight, 1991. Advanced Generation Options for the Australian Electricity Industry, Phase 1. ERDC Report 78.

International Energy Agency, 1993. Projected Costs of Generating Electricity from Power Stations for Commissioning in the Period 1995-2000

DASETT, 1991. The Role of Photovoltaics in reducing Greenhouse Gas Emissions.

DASETT, 1991. The Role of Wind Energy in reducing Greenhouse Gas Emissions.

ERDC, 1994. Biomass in the Energy Cycle, Strategic Industry Research Foundation.

Commonwealth of Australia, 1992. Renewable Electricity for Australia - discussion paper No 2.

Pacific Power, 1992. Electricity Development and Fuel Sourcing Plan.

SECV, 1993. Demand Management Annual Report. September 1993.

CADDET, 1995. Renewable Energy Newsletter, February 1995.

ERDC, 1994. Photovoltaics in Australia, McLennan Magasanik Associates, November 1994.

Wilkenfeld & Associates, 1994. The Impact of the Proposed Redbank Power Station on Greenhouse Gas Emissions, and Comparison with Other Means of Meeting Projected Energy Needs. Report for Environmental Defenders Office.

## APPENDIX III:

## BACKGROUND INFORMATION ON RENEWABLE ENERGY TECHNOLOGIES, MARKETS AND COSTS [13]

Some renewable energy is used in each State of Australia, the types vary depending on the available resources. For example Tasmania has abundant hydro resources which supply nearly all of its electricity supply.

In this chapter, the technologies have been classified by renewable primary energy source and its application. For each technology the report will consider the technology and its use.

## SOLAR ENERGY

### WATER HEATING

Solar water heating is mainly used domestically. The most popular models have a large flat plate some four square metres in area. Water from a hot water storage tank is usually circulated by natural thermosiphon action through the solar collector where it is heated and returned to the tank. Solar energy contribution varies depending on the location of the unit. Typically it varies from approximately 45% in Tasmania through to 90% in Darwin with 75% in Perth and Sydney. Commercial water heating is achieved by manifolding of multiple domestic units or by the installation of commercially designed large volumes storage systems. A number of Australian interests have been developing concentrating solar systems for hot water production.

Domestic solar water heaters are installed in some 350,000 or 6% of Australian households (ABS 1992). In Western Australia 25% of households have a solar water heater, while in the Northern Territory the figure is 37%. However, less than 4% of households in New South Wales, Queensland, South Australia and Victoria have a solar system installed. Solar hot water system use in Australia has been static since the mid 1980's.

Solar energy also is used widely in Australia for swimming pool heating and 50,000 systems were estimated to be in use in 1994. These are commonly plastic strips mounted directly on a roof. Thermal electricity

A wide range of solar thermal power generation technologies are under development around the world. These include systems where sunlight from a large field of mirrors is focused on a central receiver, where the heat is used to produce electricity; smaller, dispersed systems each unit of which operates as a separate collector; and solar ponds which effectively collect and store low grade heat. Dispersed systems typically use a concentrator in the shape of a parabolic dish or trough. Systems typically use a Stirling cycle engine or a steam engine to transform the heat into electricity.

The major commercial solar thermal installation totals some 350 MW of solar thermal power plants in southern California. In Australia, the ANU has a demonstration site (the big dish) and previous demonstration sites were at Meekatharra and White Cliffs. A feasibility study is underway for a 2 MW solar thermal demonstration plant at Tennant Creek in the Northern Territory which would use multiple dishes based on ANU technology This would have a nominal capacity of 4MW (2MW would be solar powered).

Solar thermal electricity is a potential supplier of base-load power, if a reliable and cost-effective storage system is developed, or in conjunction with gas. Alternatively it can be used in a fuel-saving or time-of-day capacity boost (to match, for example, an air-conditioning load profile).

### THERMOCHEMICAL

Solar thermochemical generation is based around capturing and storing the sun's energy through chemical reactions. For example, methane (CH4) can be reformed into higher energy constituents, thereby storing the sun's energy and providing a 40% higher energy fuel. These higher energy fuels can then stored and used for, for example, base-load electricity generation.

Development of solar thermochemical processes for methane and ammonia is proceeding at CSIRO and ANU respectively. Such technologies are not in commercial application anywhere in the world yet, although work on them is proceeding overseas.

### PHOTOVOLTAICS

Solar energy can also can be used to generate electricity directly using a photovoltaic cell. They are usually composed of wafers of crystalline silicon similar to those used for the production of silicon chips for the computer industry. Commercially available crystalline silicon photovoltaic cells convert sunlight into electricity with an efficiency of up to 16%. In the laboratory, PV cell efficiencies of around 25% have been achieved. Photovoltaic modules are now standard commercial product, with high reliability.

Photovoltaic systems are used in rural and remote areas to provide electricity for a wide range of applications including household power supplies (RAPS), telecommunications (eg microwave repeater stations), navigation beacons, water pumps, electric fences, corrosion protection and for marine applications.

Telecom is presently Australia's largest user of photovoltaics with over 8,000 photovoltaic systems being used to provide power for their telecommunications network and individual subscribers phones. Solar water pumping is now used in many remote locations throughout Australia.

In Kalbarri, WA, photovoltaics are being used to supplement electricity supply at the end of the grid. This is a 20KW system which is currently the largest grid connected system in Australia. Photovolatics may be particularly useful in areas where the peak electricity demand is driven by air-conditioning in the summer, as this demand corresponds with the peak production from photovoltaics.

Some demonstration photovoltaic systems have been added to the grid in urban areas. Most of these have received considerable government subsidy, but urban photovoltaics has the potential to be a major market.

There are increasing numbers of stand alone photovoltaic systems used to power lights and other small energy uses in urban areas. These can be cost-efficient where a grid connection would be expensive due to the cost of putting underground wires though concrete carparks etc.

Overseas use of photovoltaics includes RAPS, rural communities and some grid connected applications. Many of these overseas applications have been government supported demonstrations rather than fully commercial applications. The largest grid connected PV system is some 3.3MW at Serre in Italy.

Increasing volume production of photovoltaic modules and the attendant cost reductions are continually widening the market and driving real costs down. Peaking power plants using PV greater than 100 kW will begin to show scale economies with the present product.

The major difficulty for PV electricity generation is the high (but declining) cost of PV modules and the resulting high cost of electricity. PV has, in common with all solar, the problem of intermittency.

Assuming that business continues to develop at the same rate experienced in the last decade (15% annually on average), annual shipments of PV modules are expected to reach 630 MW world wide in 2010. The two largest markets are expected to be solar home systems in developing countries and grid-connected, mainly building mounted systems in industrialised counties, according to Photovoltaics in 2010 (1995 Directorate of Energy of the Commission of the European Communities).

### BUILDING HEATING, COOLING AND LIGHTING

Space heating is responsible for more than a third of residential final energy use (ANZEC 1990) and a quarter of commercial sector final energy use (Energy Efficient Strategies 1994). Utilisation of winter solar radiation in conjunction with energy efficiency measures such as insulation, infiltration control (draughtproofing) and energy efficient heating equipment has the potential to reduce this energy requirement by 50 to 90%. Artificial lighting requirements can also be reduced. When savings on the capital cost of heating and cooling equipment are included, cost measures vary from a net reduction to a modest increase in construction cost, and they result in a large lifecycle energy and financial savings. Buildings constructed with these features typically are referred to as passive solar or solar-efficient buildings. Greenhouses also use solar energy for heat.

While the design principles have been known for decades, it is only in recent times that passive solar houses have become popular in southern Australian markets. They are still not the 'normal' house design. As customer demand in this region has increased, some building firms are now offering energy efficient housing options.

In the commercial sector, solar building design is rarely used. Indeed the common use of large areas of poorly orientated, unshaded glazing tends to lose large amounts of heat in the winter and collect large amounts of solar energy in the hottest weather, when it adds to cooling loads and air-conditioning costs. The utilisation of solar energy (including daylight) in commercial buildings is complicated by factors such as high internal heat loads from equipment and lighting and the need to avoid glare on computer screens. While the potential for solar energy to cut commercial heating and lighting consumption is substantial and the principles are understood, much work is still required to exploit this potential in practical applications. Nevertheless, important niche markets are being developed, including tourist accommodation and some low-rise office developments.

The development of user-friendly computerised design tools and the introduction of performance codes for commercial and residential buildings (e.g. the National House Energy Rating Scheme) may encourage clients and their building suppliers to adopt solar passive design principles and active solar heating, cooling and daylighting products.

Certainly there is great scope for widespread adoption of passive solar and energy efficient design principles into all new Australian commercial and residential buildings, and as renovations of the considerable existing stock of buildings is undertaken.

There is, potentially, even greater scope for Australian companies to take proven passive solar and energy efficient building technologies to our neighbouring countries. The demand for building stock in these countries is very high, as is their energy demand growth.

### PROCESS HEAT

Solar energy can be used as a heat source by industry for a wide range of industrial processes. To achieve temperatures in excess of 80(C, more complex solar technology is required than is needed for most solar dryers or solar hot water systems. Typically these higher temperature solar systems concentrate the sun's energy using mirrored reflectors and/or use absorbers enclosed within an evacuated tube. Solar process heat has been demonstrated at Campbelltown Hospital in NSW.

### DRYING

Traditionally, a range of crops have been dried by leaving them exposed to the sun and the wind. However such practices also leave the crops susceptible to damage from wind-blown debris, and rain can result in crops having to be left to dry for prolonged periods.

A variety of solar dryers for fruit crops such as sultanas, prunes and tomatoes are under development. The simplest version involves a modification to the traditional drying racks used to dry sultana grapes. Approximately 5-10% of the growers producing sultana grapes in Victoria are now using these dryers. Solar controlled drying leads to a higher quality product and extends the overseas market for Australian crops such as Five Crown sultanas. Dryers are also being developed for grain, hay, and timber.

## WIND

Current commercial applications of wind power fall into either the RAPS system scale or much larger grid connected (wind farm) systems. Both the technologies and their economics are very different for these applications.

Major wind farm developments have occurred in California and in the world generally where some 1700 MW and 4000 MW respectively have been installed, primarily with government incentives. Major installations are now taking place in several European countries; notably the United Kingdom, the Netherlands and Germany. World installations are expected to reach 10,000 by the year 2000 (Flavin and Lennsen 1994). Australia's only wind farms are 2.5 MW at Esperance 2.5 MW (Ten Mile Lagoon and Salmon Beach).

At the RAPS scale, small wind turbines are being used in Australia to meet the electricity needs of some rural houses not connected to an electricity grid. Wind turbines can also represent an economically viable option for remote communities using diesel generators to meet their electricity needs. Over the past decade, wind turbines have been installed in several remote communities including Esperance in Western Australia, Coober Pedy in South Australia, Cocos Islands in the Indian Ocean and Flinders Island in Bass Strait.

Water pumping windmills have been used extensively in Australia for the past 130 years. The use of windmills has declined significantly since the 1950s as a result of major extensions to the electricity grids in rural areas. In many instances, water pumps powered by photovoltaic cells are being used in preference to windmills, particularly in inland areas where wind conditions are generally poorer than in coastal regions.

## HYDRO

Large scale hydro electricity is a well established technology which presently meets some 15 Terawatt-hours (TWh) or 11% of Australia's electricity needs. The vast majority of this electricity is produced by hydro-electric schemes in Tasmania and the Snowy Mountains area of south eastern Australia.

Although most of the promising sites for large hydro schemes in Australia and internationally have either been developed, or face opposition on environmental grounds, there are many sites where small hydro power plants could be installed.

Mini and micro hydro systems provide an efficient means of generating power where a reliable source of running water is available. Micro hydro systems are used in RAPS where an electricity supply of a few kilowatts is required. They are particularly suited to applications in neighbouring countries with high mountains and all year rainfall in locations where rugged terrain and thick vegetation often makes it difficult, expensive and environmentally inappropriate to extend grid based power to small rural communities. Mini hydro systems provide electricity from dams such as that proposed on the Ord River dam.

A portable run of river mini hydro system which can pump water and/or generate electricity from any river of suitable depth and flow rate has been developed by an Australian company. The system consists of a water turbine attached beneath a twin-hulled support vessel which can be moored at a suitable location. The advantage is that unlike conventional mini hydro systems, being portable it does not necessitate the building of sluices or laying of any permanent pipework.

## BIOMASS

Biomass is a flexible feedstock capable of conversion into solid, liquid and gaseous fuels which can substitute for fossil-based fuels for relatively small-scale investment. In Australia, biomass from urban and rural waste materials and crops such as forestry plantations is used as a fuel for heating houses, providing process heat for industry, generation of electricity and production of transport fuels. The study 'Biomass in the Energy Cycle' has made an attempt to quantify the availability of biomass that could be utilised on a sustainable basis.

| **Type of Residue/Waste** | **Quantity Available for Energy Use/Year** (‘000 tonnes) | |
|---|---|---|
| Cereals | 30,000 | |
| Bagasse | 3,000 | |
| Woody Weeds | 300,000 | (this is the total available) |
| Forestry/Sawmill Waste | 30,000 | |
| Urban Waste | 1,000 | |
| Cotton Waste | 1,650 | |
| Rice Husks | 160 | |
| Dung | 1,000 | |

Of this waste, in the order of 50,000,000 tonnes of residue and waste could be utilised now. There is considerable discussion in the farming community of growing trees on degraded and salinated land to produce wood, fodder and energy. This could increase the potential supply by another 10,000,000 tonnes.

### HEATING

Wood heat is used in a quarter of Australian households. Up to 5% also use it for cooking during part of the year. Wood heat is also used to a lesser extent in the wood and paper products industries. In recent decades, R&D and technological development, in which Australia has established itself as a world leader, have transformed the open fire (5-15% efficient) into a highly efficient range of appliances (up to 75% ) which also have significantly reduced emission levels. In some urban areas there is concern about local air quality as a result of emissions from wood stoves.

Wood heating is extensively used where there are good supplies of cheap wood. Studies, such as investigating the viability of growing trees on degraded land and growing trees irrigated with effluent, are being undertaken to enable biomass production to play a positive role in the rural environment.

The sugar industry generates in the order of 40MW of electricity and 100-200 MW of heat. Recent studies have indicated that with modifications to the boilers and upgrading of the turbines up to 400MW of electricity could be generated. There is about 50MW of co-generation power from waste paper and other garbage. The timber industry and other agricultural (eg rice industry) and livestock industries probably generate 5000-10000MW of heat from biomass. There are eight companies now manufacturing biomass combustors and gasifier/combustors for industries in Australia and overseas.

Internationally the most used renewable energy is biomass for cooking and heating. Approximately 60% of all households rely on biomass for cooking an heating and half the rural industry in most developing countries use wood and agricultural residues to process food, minerals and timber products and dry crops. The installed capacity is well over 100,000 GW thermal.

#### ELECTRICITY

Waste wood from forestry and sawmill operations could also represent a cost effective option for producing power for isolated rural communities. Crops residues are another potential energy source. Bagasse (the residue from milling sugar cane) currently meets 2.1% (ABARE 1995) of Australia's energy needs. It is presently burnt by sugar mills to meet their needs for process heat and electricity. In early 1995 plans were announced for the establishment of bagasse-fuelled power plants at five sugar mills in Queensland. The power plants will have a combined capacity of 49 MW. Other proposals could result in a total installed capacity of 200MW - up to 7.5% of Queensland's electricity requirements. Crop residues such as rice husks and cotton trash could provide electricity in rural areas at the extremities of the grid with net system benefits.

Rubbish dumps or landfills contain large amounts of organic matter. As time passes some of this organic matter is converted into methane and other gases by bacterial action. This methane can be used to power an engine to generate electricity for sale to the electricity grid, reticulated in natural gas pipelines or used as a source of heat for applications adjacent to the landfill (brick works, heated swimming pools). Major landfill gas developments have occurred or are planned in most States.

Sewage treatment plants that use biogas to generate electricity to meet their own energy requirements have been in operation in a number of major metropolitan centres (eg. Melbourne, Adelaide, Brisbane) for many years. Potentially, there is scope to produce more biogas from sewage treatment works and sell the excess energy to electricity utilities. There is now 50MW being produced from landfill and sewage gas and 150kW being produced from animal waste.

#### LIQUID FUELS

Biomass resources can also be used to produce alternative transport fuels to petrol and diesel. For example, many crops such as sugar cane and wheat can be fermented to produce ethanol (alcohol) suitable for use in motor vehicles. Ethanol is produced on a large scale for use as a vehicle fuel in some countries, most notably in Brazil and the USA from sugar cane and corn respectively, with the assistance of government subsidies.

Fuel ethanol production is currently supported by the Commonwealth by exemption from petroleum products excise together with a bounty. Fuel grade ethanol is presently being produced from wheat starch and effluent in Nowra by the Manildra Group and is being sold as a blend with petrol. Trials of ethanol blends in diesel fuel are being undertaken by a number of organisations.

A major project will probably be undertaken to commercialise state of the art technology for the production of ethanol from lignocellulose fuels. Increase in the production of ethanol will come from an expansion of existing plants and the installation of other plants to convert dairy waste. However, the high cost of useable biomass, limits the use of fuel ethanol.

## TIDAL

The quality of tidal resources depends on the tidal range and is very sensitive to local coastal conditions such as the depth and length of bays or estuaries. Conventional tidal schemes operate in much the same way as hydro electric schemes in that the rise and fall of the tide enables water to be trapped behind the barrage (dam) and fed through water turbines. This is a major civil engineering exercise in which a dam must be constructed across a tidal channel. As a result, tidal power plants have been constructed in regions of the world where there are good tidal resources in close proximity to a sizeable electricity market. Tidal power plants have been constructed in France, China and Canada.

Australia's best tidal resources are located in the north west regions of the continent where variation in height between low and high tide can be in excess of 10 metres. However costs would be in the order of double that of coal fired generation. In addition, this is region of very low population density and access to inexpensive natural gas. Transmission costs would be high due to the distance to major energy users. Environmental concerns have also been voiced regarding large scale tidal energy developments in the Kimberly region.

Two tidal power studies are currently being undertaken in northern Australia. The Northern Territory Power and Water Authority is looking at the use of tidal power for remote communities. The cost of transmission to users would be low and the facility would be providing electricity to a market with relatively high costs by Australian standards. This project involves the use of a stream mounted water turbine (Tyson turbine) which would be located in the tidal currents. Tidal Energy Australia, is looking at a potential 30MW project at Cape Keraudren on the North West Coast of Western Australia.

## WAVE POWER

The commercial use of wave power throughout the world is presently confined to small scale applications in areas which have traditionally relied upon high cost sources of electricity such as diesel generators. It is not used in Australia. However, surveys have shown that southern Australia has excellent wave energy resources.

## GEOTHERMAL

Conventional sources of geothermal energy depend upon the natural occurrence of hot water or steam. At Portland, in western Victoria, hot bore water is used for water heating at the municipal swimming pool, and also for space heating at the hospital and police station. In the Great Artesian Basin region of central Australia, there are many bores which discharge water at high enough temperatures (above 80oC) to operate a heat engine. Although these resources are not appropriate for large scale electricity generation, they can be used to generate electricity for remote homesteads and communities in this area.

The generation of electricity using very large reserves of energy trapped in hot dry rocks at distances from three to five kilometres below ground is being investigated. Despite lack of success of overseas attempts to tap this type of energy in their region, Australia's hot dry rock reserves appear better suited to exploitation.

## GENERAL COMMENTS ON MARKETS AND COSTS

Investment in the renewable energy industry can provide a stimulus for innovation throughout the economy and so support the development of a dynamic and successful Australian economy into the future. However, private enterprise may not initially find investment in such an industry attractive, because of the high risks due to high start-up costs.

The Australian renewable energy industry has an annual turnover of about $250 million, of which $100 million is exported. It has considerable strengths including the commercial production of solar water heaters, RAPS systems, small wind turbines, biomass fuelled technology and consultancy services, as well as internationally respected research efforts. The renewable energy industry has the potential to provide significant local employment, as well as substantial foreign income from export sales.

## Markets

Rising incomes in potential markets, especially in developing countries, will increase demand for energy services. Energy demand in developing countries is growing at a rate estimated at around seven times that of OECD countries. Some of this increasing demand is in markets where renewable energy is the most cost effective form of energy. Each year, the South East Asian region is installing the equivalent of Australia's current installed energy generation capacity annually (i.e. 30,000MW). Assuming that 1% of this could be supplied by renewable energy, the potential annual market is 300MW.

It is estimated that two billion people around the world are still without any access to electricity. A vast majority of these live in rural and remote communities in developing nations. In India there are 85,000 villages without electricity of which 35,000 are not expected to be connected to the grid in the foreseeable future.

The Asian Development Bank projects that some US$40 billion of renewable energy systems will be installed in the 1990s in the Asian Pacific region (Egan 1995). It estimates a potential RAPS market in rural Asia to be approximately 8,000 MW. India has a forecast shortfall in generating capacity of 28,000 MW by 2000 and China 86,000 MW by 2000, an enormous potential export market for Australia in our own region. Indonesia is intending to install 50MW of photovoltaic rural electrification in the next 5 to 7 years backed by AusAID, World Bank and Asian Development Bank (Utami 1995). Major initiatives are occurring in India. The Rajasthan Government has entered into agreements for the provision of solar derived electricity at buy back rates ranging from 9c - 15c Australian over the 20 year life of the agreement.

At present the overseas market in developing countries is heavily driven by development assistance. Any changes in aid policy by Australia or competing nations may affect overseas markets. The World Bank plans to increase funding allocated to renewables from 0.1% in 1994 to over 14% by 1997 in its Asia Power Sector.

In both developed and developing countries, increased concern for the environment is expected to be a major incentive for the increased use of renewable energy. Concerns over air pollution from open air burning of biomass and pollution from dumping wastes are expected to lead to an increase in the use of biomass technologies which produce energy from waste. Energy production from fossil fuels has created localised environmental problems (eg. acid rain, photochemical smog) in some areas, especially those using high sulphur coal or densely populated. Renewable energy use may provide a way of reducing some local pollution problems.

## Costs

Research groups in Australia believe that they have developed solar technologies which will be capable of producing electricity for around 5 cents/kWh (Anderson, 1994). A group of Commonwealth, State and Territory Government agencies are conducting a major feasibility study to establish a 4 MW solar thermal demonstration plant based on technology developed at the Australian National University. The ANU is also working on improved solar cells as is Pacific Solar (a joint venture between Pacific Power and Unisearch developing a multilayer, thin film silicon cell based on University of NSW research).

Attaining such cost levels would put solar power within reach of coal-fired electricity which presently costs around 4 cents/kWh in Australia (ERDC, 1992). However, it should be noted that generation costs alone may not provide a true indication of the competitiveness of renewables. Intermittent sources of energy require back-up generating capacity from conventional power plants and/or energy storage facilities. However, dispersed renewable energy technologies which are located closer to point of use than centralised generators have additional value to an energy supply system.

Biomass power plants will also benefit from advances in gasification and gas turbine technology as these developments are expected to lead to a reduction in the cost of and improvement in the efficiency with which electricity is generated from small (ca. 1 to 10 MW) biomass power plants.

Another advance which may occur involves the production of transport fuels from woody materials. With the appropriate technological developments, it may be possible to use these comparatively low cost feedstocks to produce ethanol or methanol at a cost competitive with petrol and diesel derived from crude oil costing US$25/barrel (Wyman et al, 1993). Current price of crude oil is US$15-20 /barrel.

Generation costs for new wind energy farms have reduced significantly over the last 10 years. Unit energy costs of US 4 - 5 cents/kWh are being claimed for new farm developments. Current costs are in the order of US 6-8 cents/kWh (Thompson 1995).

Increased energy efficiency of appliances can open new markets for renewables. This is because, if the energy requirements are low, they can be more cheaply supplied by renewables and this cost may be less than the cost of the conventional alternative, such as connecting to the electricity grid. This market is currently developing in areas such as parking meters and outdoor lighting.

Advances in renewable energy technology will not occur in isolation from other energy-related technologies. Recent developments in coal-fired power plants aim to minimise the costs associated with increased levels of environmental protection (Weinberg, 1993). Recent advances in the combined cycle natural gas technology aim to improve efficiencies from 40% to 60%.

Many of the developments in energy technology are applicable to both renewable and non-renewable energy options. For example, power plant technology being developed primarily for use with fossil fuels (eg. gas turbines, fuel cells, fluidised bed combustors) could also be applicable to renewable energy options.

There is also a wide range of storage technologies under development (eg. compressed air, batteries, flywheels, super-conducting magnetic storage, super capacitors) which could be used for levelling loads on the electricity grid to make more effective use of the existing generation and transmission system. Many of these technologies also could be used to store energy from renewable sources that are available only intermittently (eg. solar, wind). Water storage dams already perform this role in hydro electric schemes. Improvements in storage technology will also improve the prospects for using electric vehicles and, in turn, increase opportunities for using renewable-based electricity in the transport sector.

The price of renewable energy's competitors could be influenced by significant upward pressures on crude oil prices with possibly, some flow on to natural gas and other fossil fuel prices over the next 25 years. However, the world-wide availability of fossil fuels is unlikely to have a major bearing on the use of fossil fuels over the next 25 years. Based on present production rates, there are sufficient resources of coal to last over 200 years. The corresponding values for natural gas and crude oil are in the region of 60 and 40 years respectively (BP, 1994). There are likely to be substantial additional resources still to be discovered. However the potential for serious market disruption cannot be totally eliminated.

Energy markets can be divided into four on the basis of their use of renewables:

- Renewables are cost effective and used.
- Renewables are cost effective but not used due to market failures.
- Renewables would be cost effective if externalities and other market failures are taken into account.
- Renewables are not cost effective at present.

Existing markets for renewables are in market 1, the prospective markets for renewable are in the markets 2 and 3. Some markets in 4 should become accessible to renewables as the cost effectiveness of renewables improves due to technological development and scale effects. They will then move into one of the other categories of the market.

Most, but not all, renewable energy technology systems are capital intensive but have low running costs. Cost effectiveness of renewable energy technology systems must be evaluated against alternatives on a life-cycle basis. The economics for energy delivery from such systems are highly sensitive to the perceived risk associated with the technology, the discount rate, and the delivered energy price.

The cost effectiveness of renewable energy technologies depends on where they are used. This influences the price and availability of the renewable resource used and the price of alternative energy supplies. For example, some biomass wastes can cause pollution if dumped, so where this is an issue, using this waste biomass for energy production will significantly reduce disposal costs.

Some renewable energy technologies such as photovoltaic panels are modular in nature. This allows easy expansion as customers' needs grow and may reduce initial capital expenditure, thus improving the cost effectiveness of these technologies.

APPENDIX IV

**The True Cost of Renewables**

## The True Cost of Renewables: An Analytic Response to the Coal Industry's Attack on Renewable Energy

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## Preface

One intended result of federal investments in renewable energy research and development (R&D) programs is the adoption and use of renewable energy technologies in the energy marketplace. Insights into the nature of energy markets can help to assure that the technologies being developed are compatible with these markets.

In April 1995, the Centre for Energy and Economic Development (CEED), a coal industry lobbying group, issued a report critical of the role that renewable energy technologies can play in future power sector markets. Both the National Renewable Energy Laboratory (NREL) and the U.S. Department of Energy (DOE) felt that it was important to respond to the CEED report by examining its basic assumptions regarding renewable energy and fossil-fuel-based technologies and future power markets. This report documents the NREL analysis that refutes many of the CEED report's key findings.

NREL's Analytic Studies Division (ASD) supports the long-range planning of the overall federal renewable energy R&D program, both at NREL and DOE, by conducting analyses on aspects of energy market competition that are relevant to the present and future deployment of renewable energy technologies. ASD reports on these efforts to DOE and NREL managers, as well as external utility sector stakeholders, to enhance their awareness of competitive and institutional factors that may affect the successful deployment of renewable energy technologies in the marketplace.

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## Introduction

In April 1995, the Centre for Energy and Economic Development (CEED), an umbrella organisation of pro-coal interests, released a report entitled “Energy Choices in a Competitive Era: The Role of Renewable and Traditional Energy Resources in America's Electric Generation Mix.” The report purports to show that a very modest growth in the use of renewable energy in the U.S. power sector would entail unaffordable costs for the nation's electricity ratepayers.

The National Renewable Energy Laboratory (NREL) was commissioned by the U.S. Department of Energy (DOE) to review the assumptions contained in the report, which was prepared for CEED by Resource Data International, Inc. (RDI). The NREL analysis finds that the conclusions of the CEED/RDI study are based on faulty data and assumptions regarding the comparative economics of coal and renewable energy development. After correcting these errors, NREL finds that a modest growth path of renewable resource development would essentially cost the nation little more than projected electricity market costs for coal-fired generation, even before considering the environmental benefits that would accompany this development.

## The True Cost of Renewables

The CEED/RDI study claims that a modest increase in the contribution of nonhydro renewable energy sources, from 2% of total electricity supply today to 4% in 2010, will cost the nation $52 billion "above today's most competitive power alternatives." NREL estimates that the extra cost of renewables development would be $1.9 billion over 15 years, or an average of just more than $100 million annually --; less than one-tenth of 1% of the total annual revenue of the U.S. electric utility industry. In fact, the NREL analysis shows that certain renewable energy technologies, such as geothermal and wind, are projected to become “more economic” than coal during this period.

Why the big difference? First, the CEED/RDI analysis relies on data that overstate the cost and performance advantages of coal-fired plants. The NREL analysis used coal data from the Electric Power Research Institute (EPRI), the national research and development (R&D) organisation for the electric utility industry, and from the U.S. Energy Information Administration (EIA), the statistical arm of DOE. This change alone reduces the CEED/RDI renewables cost by $8.6 billion.

Second, the CEED/RDI analysis employs unjustifiably high cost estimates for renewable energy technologies and assumes no improvement in technology costs and performance throughout the 15-year analysis period. This assumption is contrary to recent market experience, which has seen several utilities contract for cost-effective renewable energy power. In addition, this assumption runs counter to the last 15 years of history, which has witnessed dramatic improvement in renewable energy technology costs and performance. Many energy analysts expect these improvements to continue(1). For its analysis, NREL substituted renewable energy cost data from DOE, which are more representative of current market costs and which account for expected future technology improvements. This substitution accounts for a further reduction of $31.6 billion from the CEED/RDI estimate.

Finally, the CEED/RDI analysis assumes a fixed market share for renewable energy technologies. It does not consider comparative economics or the ability of renewable energy industries to supply the market. The NREL analysis assumes a more orderly development path for the renewables industries. This final difference reduces the CEED/RDI estimate by another $9.9 billion, leaving a total "above-market" cost estimate of only $1.9 billion over the next 15 years. Furthermore, because renewable energy technologies will become more, not less, cost competitive, nonhydro renewables could be reasonably expected to supply a much larger fraction of the future power market than the 4% assumed by CEED/RDI.

## Energy Subsidies

The CEED/RDI study implies that renewable energy technologies can only be competitive with massive public subsidies, stating that "advocates for renewable energy technologies are increasingly heading to public policy forums as they fail to make their case in the open market" (page 16).

However, what CEED/RDI fail to note is that coal and other fossil fuels historically have been and continue to be the recipients of massive public subsidies. A recent paper by the Congressional Research Service (CRS) summarises the findings of several energy subsidy studies, including a 1992 study by DOE's EIA(2). These studies have consistently found that public subsidies given to fossil fuels far outweigh incentives available for renewables development. Indeed, CRS notes that the most recent of these analyses found that "because the great bulk of incentives support mature fossil and nuclear equipment, the existing subsidy structure markedly distorts the marketplace for energy in a direction away from renewables."

Most recently, the federal government has contributed nearly **$3 billion** to the development of new coal-burning technologies through the Clean Coal Technology Program, while the renewable energy industry is today fighting to maintain a $300 million annual federal R&D budget for all renewable energy technologies combined(3). And RDI itself, in another recent analysis, estimates that ratepayers nationwide will incur costs of **$14.8 billion** because of above-market, long-term coal contracts between electric utilities and coal producers(4).

## Environmental Impacts

While CEED/RDI expend great effort to ascribe negative environmental impacts to renewables, they conveniently ignore the costly environmental impacts associated with the combustion of fossil fuels. For example, because of fossil-fuel-based emissions of sulphur dioxide and nitrogen oxides, electricity ratepayers will be required to pay **$4 billion or more per year** to clean up emissions under the Clean Air Act Amendments of 1990(5). The spectre of additional emissions control requirements (e.g., for control of air toxics and fine particulates, not to mention carbon dioxide), as well as environmental taxes, potentially creates additional cost burdens.

The prospective environmental cleanup costs of fossil-fuel-based plants are never considered up front when generation investment decisions are made; only later are ratepayers presented with these costs.

## The Reliability of Renewable Energy Systems

To further discredit renewables, the CEED/RDI report states that many renewable energy systems are inherently unreliable. In fact, using traditional utility reliability criteria as a gauge, the reliability of renewables projects is generally comparable to that of conventional utility generating plants. For example, the availability of newer wind plants has improved to 95% or greater on average(6). And photovoltaics systems are highly valued in remote applications specifically for their high reliability compared with the reliability of diesel generation and stand-alone battery systems.

CEED/RDI point to the capacity factors and dispatchability of renewable projects as reliability issues. However, the majority of renewable technologies can operate in base load or are otherwise dispatchable; geothermal units can have capacity factors greater than 90%. For comparison, the average capacity factor for all operating coal-fired power plants in the United States was 60% from 1990 to 1994(7). Solar- and wind-based projects, without storage, typically have capacity factors of 20% to 30% because they operate only when the sun shines or the wind blows.

However, the plant capacity factor is not as important as whether the plant generates its predicted output, that is, the output level upon which the economic decision to build the plant was based. Also, utility plants are dispatched based on production costs, and because many renewables have low production costs, renewables tend to be dispatched whenever the output is available to displace the power produced from units with higher production costs.

When power from intermittent resources is not available, other generators on the system must be called upon to supply the power. At low penetration levels, this situation is much like the normal utility system response to load fluctuations. At higher penetration levels, a utility might have to provide additional dispatchable capacity to compensate for both normal load fluctuations and the output variations of intermittent generators. A recent NREL review of this topic suggests that intermittent generation levels of at least 10% can be accommodated with no adverse system impacts(8). Already today, wind generation provides up to 7% of the system load, and has supplied about 5% during peak hours, on the Pacific Gas and Electric system with no adverse effects(9). These intermittent penetration levels are far above the contributions examined in the CEED/RDI study. In fact, research shows that intermittent penetration levels above 10% are also entirely feasible, with any technical limits being a function of the specific utility system characteristics(10).

## The Impact of Electricity Competition

Finally, CEED and RDI state that with "open and direct competition" in electricity markets, renewable energy use is likely to decline because it will be priced out of the market. On the contrary, the renewable energy industry welcomes truly open and fair competition as a boon to renewables development(11). This is because true competition will provide electricity customers with the ability to choose from an expanded number of electricity suppliers offering alternative services, ones that will include renewables. This situation is akin to shopping at a supermarket where customers base their purchases, in part, on product differentiation and perceived value. A large segment of the American public has consistently supported greater development of renewable energy sources, and utility surveys are also revealing customer preferences for renewables(12). At the same time, a growing market will ensure continued improvement in the economics of renewable energy technologies.

However, the electric industry is just now beginning its experiment with more competitive market structures. In addition, the existing system of energy subsidies will continue to distort energy market decisions. To the extent that truly fair and competitive markets cannot be obtained, public policies and regulation may still be required to assure that the public interest is factored into market outcomes. And even in a perfectly competitive market, market failures, such as accounting for the uncosted environmental impacts of different energy resources and assuring adequate provision of public goods, will continue to exist. A properly functioning competitive market should provide ample development opportunities for renewables. We won't really know until effective market tests are performed.

## Endnotes

[1] See, for example, the discussion on renewable energy in DOE's recent National Energy Policy Plan, which notes that "During the last 15 years, intensive work by industry and the Department of Energy's national laboratories has steadily increased the reliability of renewable energy systems while dramatically lowering their costs. These systems are gradually becoming commercially competitive with conventional power sources" (“Sustainable Energy Strategy: Clean and Secure Energy for a Competitive Economy”, July 1995, page 44). An analysis of energy futures performed by Shell

International notes that renewables costs will continue to fall as production increases. Thus, the key question for renewables is not whether costs will be lowered but "the speed at which market opportunities will appear, to enable renewables to move down their cost curves" (E.J. Grunwald, "Energy in the Long Term," Shell International Petroleum Co. Ltd, undated). And even the CEED/RDI report acknowledges that "renewable energy has made important advances in lowering costs" (page 2-5).

[2] F. Sissine, "Renewable Energy: A New National Commitment?" Congressional Research Service, January 5, 1995.

[3] U.S. General Accounting Office, “Ways to Strengthen Controls Over Clean Coal Technology Project Costs”, GAO/RCED-93-104, March 1993.

[4] Presentation by Thomas Feiler, RDI, to the National Association of Regulatory Utility Commissioners, July 25, 1995.

[5] M. Hoske, "Phase I Compliance Plans Emphasize Flexibility," “Electric Light & Power”, August 1993.

[6] C. Weinberg, "Wind Energy and the Electric Utility Industry," “Proceedings of Windpower '90”, American Wind Energy Association, 1990.

[7] North American Electric Reliability Council, “Generating Unit Statistics 1990-1994”, June 1995.

[8] Y. Wan and B. Parsons, “Factors Relevant to Utility Integration of Intermittent Renewable Technologies”, National Renewable Energy Laboratory, NREL/TP-463-4953, August 1993.

[9] D. Smith and M. Ilyin, "Wind Energy Evaluation by PG&E," “Proceedings of the Ninth ASME Wind Energy Symposium”, 1990.

[10] Wan and Parsons, “Op Cit”.

[11] Edwin Mansfield, in his classic microeconomics textbook (“Microeconomics: Theory and Applications”, Third Edition, W.W. Norton and Company), describes the four conditions that define the model of a perfectly competitive market:

- The product of any one seller must be the same as the product of any other seller;
- Each participant in the market, whether buyer or seller, must be so small, in relation to the entire market, that it cannot by itself affect the market price of the product;
- All resources must be completely mobile; each resource must be able to enter and leave the market, and switch from one use to another, very readily; and
- Consumers, firms, and resource owners must have perfect knowledge of the relevant economic and technological data.

[12] See, for example, B. Farhar, “Trends in Public Perceptions and Preferences on Energy and Environmental Policy”, National Renewable Energy Laboratory, NREL/TP-461-4857, February 1993 and D. Moskovitz, "'Green Pricing': Customer Choice Moves Beyond IRP," “The Electricity Journal”, October 1993.