



Deployment of Low Emissions Technologies for Electric Power Generation in Response to Climate Change

NOVEMBER 2010

DEPLOYMENT OF LOW EMISSIONS TECHNOLOGIES FOR ELECTRIC POWER GENERATION IN RESPONSE TO CLIMATE CHANGE

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DEPLOYMENT OF LOW EMISSIONS TECHNOLOGIES FOR ELECTRIC POWER GENERATION
IN RESPONSE TO CLIMATE CHANGE
CAETS Working Group Report

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Project Background and Executive Summary

PROJECT BACKGROUND

The International Council of Academies of Engineering and Technological Sciences (CAETS) at its Council Meeting in Calgary, Canada, in July 2009 endorsed a project entitled *Evaluation of Strategies to Deploy Low Emissions Technologies for Electric Power Generation in Response to Climate Change*.

A CAETS Working Group was established comprising representatives of CAETS member academies. At a meeting in Tokyo on 2-3 March 2010, members of the Working Group:

- Presented reports of the status of energy and electricity generation and related developments in their countries;
- Formed the view that there is limited extant evidence to enable a systematic evaluation of technologies for electric power generation in response to climate change, other than levelised cost of electricity and real option values; and
- Identified key issues for the deployment of low emissions technologies.

Following that meeting, members of the Working Group prepared a report entitled: *Deployment of Low Emissions Technologies for Electric Power Generation in Response to Climate Change*. The report represents a joint effort to document the key technological issues being faced in the deployment of low-emission technologies for supplying electrical energy to meet the world's needs.

EXECUTIVE SUMMARY

There are massive technological and financial challenges involved in reducing greenhouse gas emissions from electricity generation while, at the same time, ensuring that sufficient electric power is available to meet the growing needs of the world. There are significant incentives and opportunities for CAETS to undertake collaborative work to facilitate the timely and cost-effective deployment of low-carbon generation technologies.

The primary challenge for the future of energy in a world combating climate change is that the global economy is predicted to grow four-fold by 2050, with commensurate benefits in improved standards of living, but the offsetting challenge that increased energy supply needed to support that growth must come from low-carbon-emission sources. Implementing low-carbon technologies on these scales will be costly, with high uncertainty and technical risk. Users will be paying a substantially higher price for the same service. The engineering challenge is also huge, to the extent that governments must provide strong leadership in technology development and deployment.

Financial modelling is a useful tool for evaluating critical energy generation and distribution infrastructure. A brief description is given of models that can be used to assess individual technologies and to aggregate a mix of technologies in response to demand scenarios. Because of the many potential low-carbon technologies and the variety of circumstances where they might be deployed, there is need for expert comment and evaluation of their technical and financial viability in order to inform public debate and government policy. This is a role that the engineering Academies around the world can undertake.

Electricity is increasingly being seen as the energy carrier of choice for transportation and there will be a movement towards an 'Electricity Economy'. The preferred means of road transport will most likely be the plug-in hybrid vehicle and electrical generation capacity will need to expand still further to meet this new market. To enable the increased use of low-emission technologies and to cater for the load-levelling potential of off-peak battery charging, the architecture of many existing grids will have to change, in particular with the introduction of smart grids.

With regard to the role of government, the relatively short timeframe, high risks and large costs involved in deploying new technologies mean that governments may need to take a leading role (for example, via policy development, regulation and funding support). At the basic R&D end of the development spectrum, there need to be further technical breakthroughs and cost reductions before renewable energy can supply a significant fraction of future energy needs. These will only be possible with continued long-term support by government. At the other end of the spectrum, innovative new technologies will need government support to continue to the demonstration and deployment stages, even though the decision to take a technology to that commercial stage is best made by the private sector. The global nature of energy and climate issues calls for more international cooperation, supported by governments, especially in the area of rapid deployment of low-carbon technology. Such international cooperation allows sharing of knowledge of the basic science and technology. Governments can also share the burden of investing in expensive demonstration projects. More efficient combustion technologies, carbon capture and storage, nuclear power and renewables will all have a place in future low-carbon electricity generation. There are also many opportunities for improved efficiency in the end-use of energy, both by industrial and domestic energy users. Global deployment of existing best practice in energy efficiency would deliver enormous reductions in carbon emissions without large development expenditure or risk.

The less-developed economies will show the fastest growth rates in energy requirements. Each country will probably develop its own portfolio of electricity-generating technologies drawn from a wider global set. They will be forced to rely for some time on fossil fuels but will improve energy-conversion efficiencies through new technologies. Many now rely heavily on biofuels and more efficient production of such fuels will need to occur. Smaller, distributed generation based on renewables will continue to be a feature of electrical energy supply in developing countries. Nuclear power will make an increasing contribution to the energy mix. Small reactors without on-site refuelling may be especially appropriate for the needs of developing economies.

Renewable energy sources will make an increasing contribution to global electricity supply. However, the potential of renewable energy, over at least the medium term, is inevitably limited by its variability and large land requirements. Dependence on topography and natural endowments means that the contribution of renewables to national energy requirements will vary from country to country. The overall global picture shows a continued reliance on fossil fuels, with some nuclear generation, over at least the medium term up to 2030.

The distributed and intermittent nature of many kinds of renewable energy generation introduces new demands on the design of the whole energy supply system (including transmission and distribution). Measurement and control – using information and communications technologies – will be carried out within so-called smart grids, with demand management an essential component. Such systems will rely heavily on the availability and implementation of appropriate standards for physical interfaces, communication protocols and common data formats. Because of the associated information flows, the introduction of these new technologies into the power supply system will raise a suite of new social issues and concerns to do with privacy and individual freedom.

COLLABORATION

One of the main **conclusions** of the CAETS Working Group is that CAETS has a major role to play in acting as a hub for international collaboration of engineers, technologists and scientists in the crucial matter of providing the world with secure, low-emission electricity at the lowest possible cost.

That collaboration should include efforts:

- to convey to governments and the public the serious dimension of the technical challenges ahead;
- to develop better ways for selecting the best generating technologies;
- to encourage further development in key technologies;
- to disseminate authoritative information about the benefits as well as the costs of competing electricity generating technologies; and
- to influence governments to provide the level of financial support to ensure technological success.

This CAETS Working Group report contains a number of **issues and recommendations** for future CAETS actions. These all involve collaboration between member Academies as well as with other bodies. There should be collaboration on communicating the huge challenge posed by the future need for secure low-carbon electricity, on encouraging government investment, on developing better financial evaluation models for different technologies, on publicly disseminating technically sound information on energy technology issues and on setting priorities for further technology developmen

DEPLOYMENT OF LOW EMISSIONS TECHNOLOGIES

Issues and Recommendations

1

ISSUE

The generation of electrical energy must expand to meet the growing demands of the world for more energy, especially in the form of electricity. A global revolution is needed in ways that energy is supplied and used. In the face of that growth, greenhouse gas emissions from electricity generation must nevertheless be reduced. Governments and the public need to understand and acknowledge the massive technological, engineering and financial challenges involved.

RECOMMENDATION

The members of CAETS should collaborate in the vital task of communicating these challenges globally.

2

ISSUE

While solutions to the problems of providing more electricity with lower emissions must reside in new technologies, the technological and financial risks involved are great. Accordingly, governments must provide strong leadership (for example via policy development and funding) to support further technology development and deployment.

RECOMMENDATION

CAETS should actively encourage and persuade governments to provide the required leadership, as well as communicate to both governments and the public the significant technical risks still to be overcome with technologies such as carbon capture and storage and geothermal energy.

3

ISSUE

There is limited sound, objective evidence to support systematic evaluation and selection of competing technologies for electric power generation in response to climate change.

RECOMMENDATION

As part of the strategy to advance knowledge in this field, CAETS should lead an international co-operative effort to assess and improve quantitative methodologies for determining financial and technical risks associated with deploying new electricity generating technologies.

4

ISSUE

There is a need for more informed public debate to enable formation of enhanced public policy.

RECOMMENDATION

Using its favourable position for enabling international collaboration, CAETS should lead and support the development and dissemination of authoritative information about electricity generating technologies in both its member countries and more broadly, in order to encourage informed public debate and public policy.

5

ISSUE

While every means of reducing carbon emissions should be pursued, there are several priority areas for further technology development.

RECOMENDATION

CAETS should encourage focus on:

- a. Improved efficiency of energy end use and means of promoting efficient usage globally;
- b. Basic research leading to technical breakthroughs and cost reductions in renewable energy;
- c. Advanced nuclear reactors, as well as small nuclear reactors suited to distributed generation;
- d. Research, development and commercialisation of carbon capture and storage technologies; and
- e. New technology for electricity distribution networks, especially to optimise systems to handle fluctuating renewable sources and loads from charging electric vehicles.

6

ISSUE

In view of the need for expanded use of nuclear energy for reducing emissions and meeting growing power needs, a global effort is required to ensure public understanding and resolution of major issues of concern in regard to safety and security of nuclear power generation.

RECOMMENDATION

CAETS should participate in this effort as well as cooperate in an exchange of experience in matters of safety and public attitudes in each country.

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Introduction

Dr Vaughan Beck FTSE – ATSE (Australia)

The Academies associated with this study all recognise the massive technological and financial challenges involved in reducing greenhouse gas emissions from electricity generation while at the same time ensuring that sufficient electric power is available to meet the growing needs of the world. There are significant incentives and opportunities for CAETS to undertake collaborative work to facilitate the timely and cost-effective deployment of low-carbon generation technologies.

CONTEXT FOR THIS STUDY

The issue of climate change is receiving considerable attention internationally. While governments are setting targets and providing funding support for low-emissions technology research and demonstration, it is clear that further and larger investments will be required to deploy these technologies at large scale. There is a need to accelerate the deployment of these technologies if target levels of greenhouse gases are to be met within the timeframe indicated by climate science. Current public policy reflects to varying degrees this need to accelerate technology deployment. However, governments in general do not seem to be sufficiently well informed on the practicalities of the implementation pathways.

As is noted subsequently in this report, very significant investments are required to ameliorate the effects of climate change, and in particular the rising levels of greenhouse gases. For example, in the energy field, significant investments are required in sectors such as transport, residential and commercial buildings, electricity generation and distribution, and industry. For the purpose of this study it was decided to focus on the issue of electricity generation, and in particular to identify the major issues that need to be addressed to allow the rapid deployment of low-emission technologies for electric power generation and distribution. It is recognised that while electricity generation is an important component in achieving reductions in the levels of CO₂ (other mechanisms are available such as demand-side contributions via end-use efficiencies or by alternative production technologies), there are other significant issues such as the cross-substitutions between energy sources (for example, liquid fuels and electricity) that could be a cost-effective way of CO₂ abatement.

BACKGROUND

As noted by the International Energy Agency (IEA)¹, the global economy is set to grow four-fold between now and 2050 and growth could approach ten-fold in some developing countries like China and India. Furthermore, some 1.6 billion people, most of them in rural and developing countries, have lack of access to electricity. This growth in the global economy promises economic benefits and huge improvements in people's standards of living, but also involves use of much more energy. Unsustainable pressure on natural resources and on the environment is inevitable if energy demand cannot be de-coupled from economic growth and fossil fuel demand reduced.

A global revolution is needed in ways that energy is supplied and used. Far greater energy efficiency is a core requirement. Renewables, nuclear power, and CO₂ capture and storage (CCS) must be deployed

¹ Energy Technology Perspectives 2008, Scenarios and Strategies to 2050, International Energy Agency IEA/OECD Paris, 2008.

on a massive scale, and low, or zero, carbon emissions transport developed. A dramatic shift is needed in government policies, notably creating a higher level of long-term policy certainty over future demand for low-carbon technologies, upon which industry's decision makers can rely.

The investment required to deploy these new energy generation technologies is massive. In addition to the significant financial risks, there are major technological risks associated with the deployment of technologies for electricity generation. Most of the targeted technologies remain largely unproven at commercial scale, the main exceptions being wind and nuclear. Not only are there substantial technological risks but also the timescales required to bring these technologies to commercial deployment are potentially several decades.

Secure, reliable and affordable energy supplies are fundamental to economic stability and development. The erosion of energy security, the threat of disruptive climate change and the growing energy needs of the developing world all pose major challenges to energy decision-makers.

These energy security concerns are compounded by the increasingly urgent need to mitigate greenhouse gas emissions, including those relating to energy production and consumption. About 69 per cent of all CO₂ emissions are energy related, and about 60 per cent of all greenhouse emissions can be attributed to energy supply and energy use (Intergovernmental Panel on Climate Change²). The IEA's *World Energy Outlook 2007*³ projects that unless current policies change, global energy-related CO₂ emissions will grow 57 per cent above 2005 levels by 2030. Oil demand will increase by 40 per cent. By 2030, fossil fuels will remain dominant, meeting 84 per cent of the world's incremental energy needs. The bulk of the new CO₂ emissions and increased demand for energy will come from developing countries. Even when the impact of policies and measures already under consideration is included, global CO₂ emissions will rise 27 per cent over current levels.

The United Nations Intergovernmental Panel on Climate Change (IPCC) has concluded that only those scenarios with a 50 per cent to 80 per cent reduction of global CO₂ emissions by 2050 compared to 2000 levels can limit the long-term global mean temperature rise to 2.0°C to 2.4°C (IPCC 2007). The dimension of the task of achieving such reductions has to be viewed in the light of energy's social and economic role.

Emissions for the 20 countries with the highest CO₂ emissions range from 6018 million metric tonnes of CO₂ for China to 303 million metric tonnes of CO₂ for Poland. On a per capita basis the range is from 1.2 tonnes of CO₂ per capita for India to 20.6 tonnes of CO₂ per capita for Australia⁴. The G20 nations contribute some 80 per cent of global CO₂ emissions (the G8 nations contribute some 45 per cent of global emissions)⁵.

Some insight into the challenge involved in reducing emissions can be found by examining energy intensities for various economies. Energy intensity of an economic activity is the amount of energy consumed to produce one unit of output, usually expressed in terms of the energy consumed per unit of GDP. Some energy intensities are listed in the Table⁶. Similar data are shown in a somewhat different form in the chart, which is a plot of IEA data for the year 2007 (from IEA Key World Energy Statistics

2 IPCC, 2007, Climate Change 2007: Mitigation of Climate Change: Contribution of Working Group III to the Fourth Assessment Report, Cambridge University Press, UK.

3 IEA, *Energy Balances of OECD Countries (2006 edition)* and *Energy Balances of Non-OECD Countries (2006 edition)*. See <http://earthtrends.wri.org/text/energy-resources/variable-668.html>

4 http://www.ucsusa.org/global_warming/science_and_impacts/science/each-countrys-share-of-co2.html

5 The Pittsburgh Summit, US Department of State, 2009; see <http://www.pittsburghsummit.gov/resources/129661.htm>

6 IEA, *Energy Balances of OECD Countries (2006 edition)* and *Energy Balances of Non-OECD Countries (2006 edition)*. See <http://earthtrends.wri.org/text/energy-resources/variable-668.html>

2009) for a range of economies, both individual and grouped. Each number is on a per capita basis. The per capita GDP is adjusted to express constant purchasing power and the per capita energy is based on total primary energy supply (TPES).

Energy Intensity of Different Economies

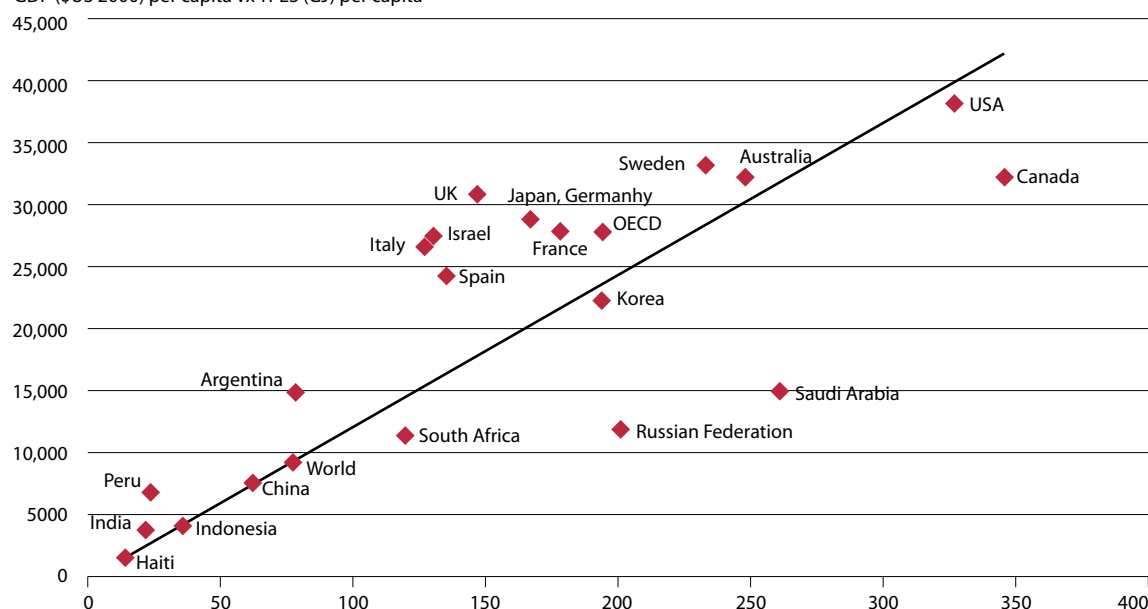
Energy Consumption per GDP at constant 2000 International \$

Country	Intensity, MJ/ \$ of GDP ⁷
Australia	7.8
Canada	10.6
China	8.2
Germany	6.0
India	6.0
Japan	5.5
Korea, Republic	10.3
UK	4.9
USA	7.9

The axes in the chart are chosen to emphasise that prosperity is a function of energy use rather than the converse. The trend line, which passes very close to the points for the largest economies, the USA and China, as well as for the world total, has a slope of \$122 per Gigajoule (GJ). This represents a global

Figure 1 GDP vs Energy Supply, both on a per capita basis, for a range of individual and grouped economies^{8,9}

GDP (\$US 2000) per capita vx TPES (GJ) per capita



average, equivalent to an energy intensity of 8.2 MJ/\$. The closer a point is to the line, the closer is that economy's energy intensity to the global average. Economies to the left of the trend line appear to have energy intensities lower than, and to the right higher than, the global average.

Energy intensity depends on many factors, including the structure or mix of activities in the economy and the relative values of different sectors, as well as the technical efficiency of energy use. More detailed

⁷ GDP is based on 2005 data, in units of constant 2000 international dollars adjusted for purchasing power parity.

⁸ Chart prepared by Dr T Biegler FTSE using data from IEA Key World Energy Statistics 2009.

⁹ IEA Key World Energy Statistics 2009, International Energy Agency, Paris 2009.

analysis is beyond the scope of this summary and in any event would need to take into account several uncertainties in the data. For example, exchange rates vary considerably over time, calculating purchasing power parity is complex and controversial, and the resulting factors to convert from the usual exchange rates can be large; for India for example the factor is over five.

Sectoral differences between economies, such as a preponderance of the more energy-intensive industries like metal production compared with less energy-intensive industries like the services sector, probably make the major contribution to these differences in energy intensity. While any particular economy might be able to reduce its energy intensity by, for example, closing down its aluminium smelters, there will be no impact on global emissions if production simply moves across national boundaries.

The chart is a convincing illustration of the fundamental direct association of wealth with energy usage. It is the combination of dependence of wealth creation on energy and the accumulated global impact of emissions that together constrain how far energy consumption might be reduced without adversely influencing global economic prosperity.

So, the world is faced with the task of reducing total carbon emissions at the same time as energy consumption continues to increase in order to drive increased global prosperity. The means available to reduce emissions comprise:

- further improvement of energy intensity via improved efficiency of energy use;
- energy conservation; and
- decarbonising economies by lowering the level of CO₂ emitted per unit of energy consumed.

Achieving these objectives will require both technology improvements and behavioural change. Considering the magnitude of the changes required there are massive challenges to be addressed and overcome in order to achieve target levels of CO₂.

Energy use is by far the predominant source of CO₂ emissions in the world, at some 69 per cent. Globally, electricity and heat account for around 44 per cent of energy sector emissions¹⁰, with manufacturing and construction, transport and other types of combustion each below 20 per cent. Electricity and heating comprise the largest source of CO₂ in every geographical region. From an analysis of global power generation plants, the Centre for Global Development has estimated that global power generation plants contribute some 26 per cent of global CO₂ emissions¹¹.

Clearly the introduction of low emission technologies for power generation will be an important strategy in a suite of strategies needed in order to reduce global dependence on fossil fuels, help combat climate change and improve energy security. The focus of this report is the identification of strategies to facilitate introduction of low emission technologies for electricity generation and distribution.

ESTABLISHMENT OF THE CAETS PROJECT

The Australian Academy of Technological Sciences and Engineering (ATSE) completed a preliminary study¹² that provided a view on the steps needed to accelerate the technology response to climate change in Australia. The study was restricted to stationary energy generation; capital costs only were considered. Subsequently, ATSE organised a three-day International Workshop in Melbourne from 31 March to

¹⁰ EU, an overview of global greenhouse gas emissions and emissions reduction scenarios for the future, European Parliament's Temporary Commission on Climate Change, February 2008

¹¹ Wheeler, D. and Ummel, K., Calculating CARMA: Global Estimation of CO₂ Emissions from the Power Sector, Centre for Global Development, Working Paper Number 145, May 2008

¹² Energy Technology for Climate Change: accelerating the technological response, ATSE Report December 2008. <http://www.atse.org.au/index.php?sectionid=128>

2 April 2009 that focused on the major challenges in accelerating technological change in electricity generation. ATSE invited to the Workshop representatives from five engineering academies – Japan, Germany, South Africa, United Kingdom and Canada. Representatives from these Academies (with the exception of the Canadian Academy of Engineering) joined an invited group of Australian delegates, experts in their fields, to contribute to the Workshop and to develop a Workshop Communiqué and report¹³.

Following this Workshop ATSE developed a draft proposal for the CAETS Council meeting in Calgary Canada during July 2009. This proposal was discussed and further developed in Calgary with those Academies that were represented at the Melbourne Workshop, plus the Canadian Academy of Engineering and the Indian National Academy of Engineering. The CAETS Council endorsed the project entitled: “Evaluation of Strategies to Deploy Low Emissions Technologies for Electric Power Generation in Response to Climate Change.”

ATSE subsequently convened a meeting of the CAETS Working Group (comprising those Academies who supported the proposal in Calgary plus the National Academy of Engineering of Korea) in Tokyo from 2 to 3 March 2010.

The representatives from the Academies who attended the CAETS Working Group meeting in Tokyo and who are responsible for this report are:

- acatech (Professor Dr Frank Behrendt);
- Australian Academy of Technological Sciences and Engineering (Dr Vaughan Beck* and Dr John Burgess);
- Canadian Academy of Engineering (Professor Robert Evans);
- Engineering Academy of Japan (Dr Kozo Iizuka**);
- Indian National Academy of Engineering (Professor Hanasoge S Mukunda);
- National Academy of Engineering of Korea (Professor Myongsook Oh);
- South African Academy of Engineering (Mr Willem du Preez); and
- The Royal Academy of Engineering (Professor John Loughhead).

(* Dr Beck was the convenor of the CAETS Working Group

** Dr Hideo Tanaka and Mr Yoshiaki Nishimura were also present at the Working Group meeting in support of Dr Kozo Iizuka.)

The host for the Tokyo meeting was the Engineering Academy of Japan, under the leadership of Dr K Iizuka. This was a very productive meeting and the structure and broad content of the WG report for CAETS was decided. Subsequently, the representatives from the Academies attending the WG meeting in Tokyo prepared sections of the draft report, in some cases with collaboration with others.

Dr Tom Biegler, a Fellow of the Australian Academy of Technological Sciences and Engineering, contributed to the editing of this report.

Please note that the various contributions to this report are the works of the individual authors and do not necessarily represent the views of the Academies of which they are members.

¹³ Electricity Generation: Accelerating Technological Change. International Workshop, ATSE, April 2009.
<http://www.atse.org.au/index.php?sectionid=128>

DEPLOYMENT OF LOW EMISSIONS TECHNOLOGIES

Section 1

CHALLENGES OF SWITCHING TO LOW-CARBON TECHNOLOGIES

The primary challenge for the future of energy in a world combating climate change is that the global economy will grow four-fold by 2050, with commensurate benefits in improved standards of living, but the increased energy supply needed to support that growth must come from low-carbon-emission sources. Reports from several learned Academies of engineering and technology as well as other sources emphasise the massive technological and financial risks involved. Implementing low-carbon technologies on these scales will be costly, with high uncertainty and technical risk. Users will be paying a substantially higher price for the same service. The engineering challenge is massive, to the extent that governments must provide strong leadership in technology development and deployment. Financial modelling is a useful tool for evaluating critical energy generation and distribution infrastructure. Because of the many potential low-carbon technologies and the variety of circumstances where they might be deployed, there is need for expert comment and evaluation of their technical and financial viability in order to inform public debate and government policy. This is a role that the engineering Academies can undertake.

Dr Vaughan Beck FTSE and Dr John Burgess FTSE – ATSE (Australia)

THE GLOBAL CHALLENGE

The International Energy Agency (IEA)¹⁴ notes that the global economy is set to grow four-fold between now and 2050 and growth could approach 10-fold in developing countries like China and India. The associated promise of economic benefits and huge improvements in people's standards of living will involve the use of much more energy. Unsustainable pressure on natural resources and on the environment is inevitable if energy demand cannot be decoupled from economic growth and fossil fuel demand reduced.

This growth will place significant pressure on the remaining oil and gas reserves. In recent years, fossil fuel prices have risen considerably and can be expected to rise further in the future. This raises concerns about energy security. Accordingly, achieving a reduced fossil fuel dependency in many countries becomes a key energy policy target. These energy security concerns are compounded by the increasingly urgent need to mitigate greenhouse gas emissions; about 69 per cent of all CO₂ emissions are energy related.

The United Nations Intergovernmental Panel on Climate Change has concluded that only scenarios resulting in a 50 to 80 per cent reduction of global CO₂ emission by 2050 compared to 2020 levels, can keep the long-term global mean temperature rise limited to 2.0°C to 2.4°C. The IEA developed two sets of energy technology scenarios to achieve reductions in CO₂ levels; namely, back to current levels by 2050 (ACT Scenarios) or a target 50 per cent reduction from current levels in 2050 (BLUE Scenarios). The IEA scenario analysis deals only with energy-related CO₂ emissions, which account for most of the anthropogenic greenhouse gas emissions. This summary considers just one IEA scenario; it is referred

¹⁴ International Energy Agency, Energy Technology Perspectives, Scenarios and Strategies to 2050, IEA/OECD Paris, 2008.

DEPLOYMENT OF LOW EMISSIONS TECHNOLOGIES

herein as the 50 per cent Baseline scenario (equivalent to the IEA BLUE Scenario). Details are given in the following table.

IEA Global CO₂ Emission Scenarios

Scenario	2005 CO ₂ Emissions, GT	2050 CO ₂ Emissions, GT
Baseline	27	62
50% Baseline	27	14

In the IEA Baseline case, energy-related CO₂ emissions are 130 per cent above the level in 2005 and oil demand is 70 per cent above the 2005 level. The 50 per cent Baseline case is an extremely challenging target and could require measures (with a cost up to US\$200/t CO₂).

SIGNIFICANT INVESTMENT REQUIRED

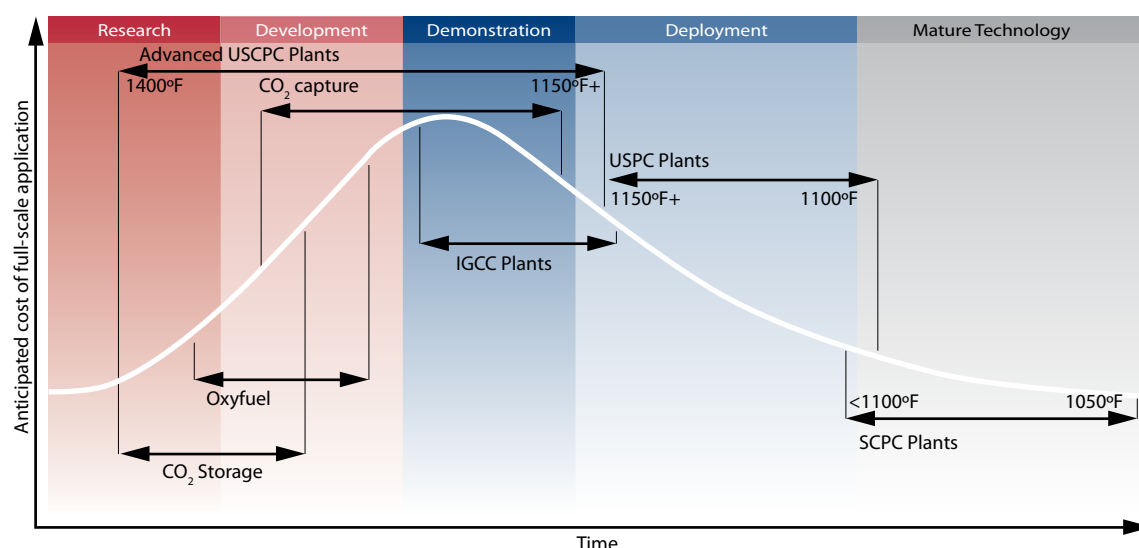
The development process required for the commercial deployment of low-emission technologies typically involves the following stages:

- research and development;
- demonstration;
- deployment; and
- commercialisation.

The costs and technical risks associated with each of these stages are considerable. As an illustration, given below is a technology deployment curve for coal-fired electricity generation by a series of advances in combustion technology.

A report from the International Energy Agency (IEA, 2008) presents 17 technology roadmaps, each one outlining one technological approach that can be deployed to help achieve substantial reduction in emissions level by 2050. Each roadmap provides an overview assessment of the technology and the steps needed to accelerate their adoption on a commercial basis. It can be concluded from these roadmaps that implementing many low carbon technologies has high uncertainty and risk – including technological, economic, social and political risks.

In the Baseline scenario, total final energy consumption almost doubles between 2005 and 2050 because of increasing demand for goods, services and leisure activities that require energy as an input. This implies dramatic investment growth not only in energy consuming devices and processes but also in the energy



production and supply infrastructure that will be needed to service them.¹⁵ Total cumulative investment needs in the Baseline scenario are estimated to be US\$254 trillion between 2005 and 2050. Although extremely large in absolute terms, this is only 6 per cent of cumulative GDP over the period. Demand-side investments dominate, with US\$226 trillion invested in energy consuming technologies between 2005 and 2050.

In the 50 per cent Baseline scenario, the additional investment requirement over the Baseline scenario to 2050 is US\$45 trillion, which is an increase of 18 per cent over the Baseline. This represents an increase in the investment needs equivalent to 1.1 per cent of cumulative GDP between 2005 and 2050. The 50 per cent Baseline scenario requires additional investment of around US\$1.1 trillion per year between 2010 and 2050. This is roughly the current annual output of the Italian economy. A breakdown of the additional investment required for the 50 per cent Baseline scenario is given in the following table.

Additional Investment required in the 50% Baseline scenario compared to the Baseline, 2010 – 2050 (from reference 13 [IEA Energy Technology Perspectives 2008])

Energy sector/ strategy	US\$ trillion	% of total
Transformation ¹⁶	-0.6	-1
Power Plant	3.6	8
Transmission (electricity)	1.4	3
Distribution (electricity)	-2.1	-5
Industry	2.5	6
Transport	32.8	73
Residential	6.4	14
Services	1.0	2
Total	45.0	100

In the electricity sector, the 50 per cent Baseline scenario requires a significant increase in the investment in renewables, nuclear and CCS technologies as well as in the distribution network. The net investment required is US\$2.9 trillion. To encourage the adoption of low-carbon technologies, CO₂ reduction incentives are required. Such incentives could take a number of forms – such as regulation, pricing, tax breaks, trading schemes, subsidies or voluntary breaks. In the 50 per cent Baseline scenario the level of incentive needed continues to rise and the IEA estimates that it will reach a level of US\$200 per tonne of CO₂ saved by 2040 and will be in place in all countries, including developing countries. With less optimistic technology assumptions, notably in transportation, the marginal costs are expected to be much higher. Clearly, the additional investment needs (US\$45 trillion for the 50 per cent Baseline scenario) represent significant additional costs to end users.

The European Union Emission Trading System (ETS) has been operational since January 2005. The scope of this cap and trade system covers around 12,000 installations in 27 Member States which are responsible for around 2 Gt of CO₂ emissions each year. This amount represents 40 per cent of the EU's total greenhouse gas emissions. Europe's ETS is likely to raise the price of carbon in the EU from around €15 per tonne in June 2009 to €30 in 2013 and €40 by 2016, according to market analyst Point Carbon¹⁷.

ASSESSING THE CHALLENGES OF TECHNOLOGY DEPLOYMENT

Given below are examples of studies conducted by various Academies of Engineering to assess the challenges of technology deployment for mitigating climate change. These summaries reflect the approach taken by each Academy.

¹⁵ All figures in this Section are in US\$ 2005, evaluated at market exchange rates.

¹⁶ Energy efficiency and fuel switching in the end-use sectors

¹⁷ <http://www.endseurope.com/21466>

Royal Academy of Engineering

The Climate Change Act of 2008 committed the UK to at least 80 per cent reduction of greenhouse gas emissions by 2050. While there is a wealth of reports and studies on future energy systems and technologies, there is no clear and realistic overall picture of how these targets might be achieved and what such an energy system might look like.

The Academy has reported¹⁸ on possible energy scenarios that could meet the 2050 emissions reduction target. Four scenarios are explored. They describe the whole energy system (demand and supply) in broad terms and are illustrative rather than prescriptive, identifying the principal components of the system and contributing towards a better systems level understanding of the most salient issues. In general terms, the four scenarios adopted by the RAEng are:

Scenario 1 Level demand – Fossil fuel prioritised for transport

Scenario 2 Medium demand reduction – Fossil fuel prioritised for low grade heat

Scenario 3 Medium demand reduction – Fossil fuel prioritised for transport

Scenario 4 High demand reduction – Fossil fuel prioritised for transport

The procedure for generating each of the scenarios follows five basic steps:

1. Set the demand level of each category of energy demand relative to the current level.
2. Choose the primary sources of energy supply.
3. Balance supply and demand by adjusting the levels of supply.
4. Calculate the carbon emissions.
5. Repeat steps 2 and 3 until carbon emissions have reduces by 80 per cent.

The RAEng study shows that:

- There is no single ‘silver bullet’ that will achieve the required 80 per cent cuts in greenhouse gas emissions. Fundamental restructuring of the whole of the UK’s energy system will be unavoidable.
- Demand reductions across all sectors of the economy will be essential through a combination of increased efficiencies and behavioural change.
- The full suite of low-carbon energy supply technologies already available (or identifies as credible) will be needed, including nuclear, renewables and carbon capture storage brought together in a balanced way. There is a need to commit to new plant and supporting infrastructure now.
- The scale of the engineering challenge is massive, and currently beyond the capacity of the energy industry to deliver.
- To achieve the scale of change needed, industry will require strong direction from government. Current market forces and fiscal incentives will not be adequate to deliver the shareholder value in the short-term and to guarantee the scale of investment necessary in this time scale.

National Academy of Engineering

A report from the National Academy of Sciences and National Academy of Engineering¹⁹ assesses the potential over the next two to three decades of a range of technologies to increase sustainability, support long-term economic prosperity, promote energy security, and reduce adverse environmental impacts. The report found that, with a sustained national commitment, the US could achieve considerable energy-efficiency improvements, acquire new sources of energy supply, and effect substantial reductions in greenhouse gas emissions through the accelerated development and deployment of a portfolio of existing and emerging energy-supply and end-use technologies. Actions taken between now and 2020 to develop and demonstrate the viability of several key technologies will, to a large extent, determine the nation’s energy options for many decades to come.

¹⁸ Royal Academy of Engineering, *Generating the Future: UK energy systems fit for 2050*, March 2010

Some of the key findings of the NAS and NAE report follow:

- Increased adoption of energy efficiency technologies is the nearest-term and lowest-cost option for moderating US national demand for energy.
- While 70 per cent of electricity is produced by burning conventional fossil fuels (and coal-fired plants generate about half the electricity), several options have the potential to significantly change the mix over the few decades. These include: biopower, geothermal, nuclear, carbon capture and storage, and renewables. By 2035, the amount of energy provided by renewables could exceed the amount supplied by nuclear or coal with CCS.
- The US electric power transmission grid and distribution network urgently need to be upgraded to improve reliability, increase security, and expand the use of energy efficient technologies.

The report notes that: *Many emerging energy demand and supply technologies have significant barriers to their widespread adoption.* These barriers vary considerably by technology, including the slow turnover of infrastructure, limited resources, potentially higher costs, concerns about performance, and uncertainty about restrictions on greenhouse gas emissions. New energy supply options will be more expensive than fuels and electricity have been in recent years. In many cases, significant capital investments will be needed. Investments in the new technologies may be inhibited if investors are uncertain about future energy prices. Policies, such as those that set efficiency standards, support renewable energy, and encourage demonstration of CCS, evolutionary nuclear, and cellulosic ethanol technologies, can help overcome these barriers.

Australian Academy of Technological Sciences and Engineering (ATSE)

A number of technologies have the potential to replace conventional coal-fired generation technologies and need to be considered. Many of the technologies have significant negative issues associated with their commercialisation and have high investment costs. It is generally accepted that a portfolio approach is required for investment, since no one technology can provide the overall solution and each technology is at a different stage in its development. The challenge for both industry and government is to identify *a priori* which suite of technologies should be preferentially developed.

ATSE has assessed the financial viability of alternative generation technologies as a function of the uncertain variables involved using the calculation of both the Levelised Cost of Electricity (LCOE) and the Real Option Value (ROV). LCOE is the constant real price of electricity that a generator should receive for the investment to just earn the cost of capital employed. ROV is the value created by financial uncertainty and volatility and the time into the future when a technology is commercialised, assuming that a rational investor will not invest then if commercialisation earns less than the cost of capital. ROV may be greater than current net present value (NPV), and an alternative technology may thus have large future economic outcomes, even though it's current value in conventional accounting NPV terms could be negative. In other words, the technology's ultimate value is a combination of its current NPV and its ROV.

Real Option Values can be calculated using different methodologies. The Black-Scholes model²⁰ and the binomial model²¹ are two fundamental analytical models that may be used to calculate ROV using simplified assumptions. A Monte Carlo probabilistic financial modelling approach may also be employed, allowing greater flexibility. Following a review, ATSE decided to adopt the Monte Carlo model approach to calculate ROV for electricity generation option value assessment.

Uncertainties that are considered in the ATSE model include:

- capital and operating costs, and the timing of these costs for the technologies under consideration

19 National Academy of Sciences and National Academy of Engineering: *America's Energy Future: Technology and Transformation*, 2009. See www.nap.edu

20 Black, F. and M. Scholes (1973). The Pricing of Options and Corporate Liabilities. *Journal of Political Economics*, 81, 637-659.

21 Cox, J.C., Ross, S.A. and Rubinstein, M. (1979) Option pricing: a simplified approach. *Journal of Financial Economics*, 7: 229-263.

- and their probabilistic distributions;
- a variety of future scenarios for carbon and electricity pricing through emission trading or taxation schemes, and the associated uncertainties; and
- learning curves for the investment costs and operating efficiencies of each of the technologies, and their uncertainties.

ATSE has conducted an assessment of various technologies and has developed results for the ROVs and LCOEs. In conjunction with several selected broad energy scenarios, these results can be used to identify likely mix of technologies that can be deployed to meet prescribed emissions reduction targets.

The ATSE study²² has shown that low LCOE and high ROV are generally favoured by:

- low capital intensity (\$/MWh produced for export);
- high operating efficiency and low auxiliary electricity load;
- low CO₂ mitigation costs; and
- high capacity utilisation of the generating plant.

The ATSE study used Australian Government estimates for the price of carbon; namely a monotonic increase from about US\$25 per tonne CO₂ in 2010 to about US\$125 per tonne CO₂ in 2050. In the short to medium term, ATSE's work shows that, for Australia, efficient natural gas-powered combined cycle turbines, onshore wind and low capital-cost geothermal generation are the best financial options. The work also shows that in the longer term (2040) nuclear energy, low capital-cost efficient solar thermal plant and gas CCGT firing with carbon capture and storage could all become financially viable options. Some coal technologies with carbon capture and storage could also emerge as viable options, depending on favourable thermal efficiency and capital-cost learning curves and suitable low-cost CO₂ storage locations.

ATSE also has recently considered the policy and technology challenges associated with the stability of the electricity system arising from increasing usage of renewable energy sources²³.

Based on the above, the following observations and actions are relevant.

- A range of low-carbon technologies must be deployed in response to climate change targets.
- There are significant technological and financial risks to overcome to enable cost-effective and timely deployment of low-carbon technologies for electric power generation.
- The engineering challenge is massive.
- Governments must provide strong leadership in technology deployment.
- There is need for expert comment and evaluation of the technical and financial viability of potential low-carbon technologies that are being considered for deployment. This is to inform public debate and government policy and is a role that the engineering Academies can undertake.
- Financial modelling provides a convenient basis to evaluate critical energy generation and distribution infrastructure, and the consequences in terms of price and performance for society.

²² Burgess, J., *Option Values of New Energy Technologies for Climate Change*, Australian Academy of Technological Sciences and Engineering, September 2010

²³ ATSE, *Secure Electricity Systems for 2050*, Australian Academy of Technological Sciences and Engineering International Workshop, Sydney, March 2010

Section 2

THE ELECTRICITY ECONOMY

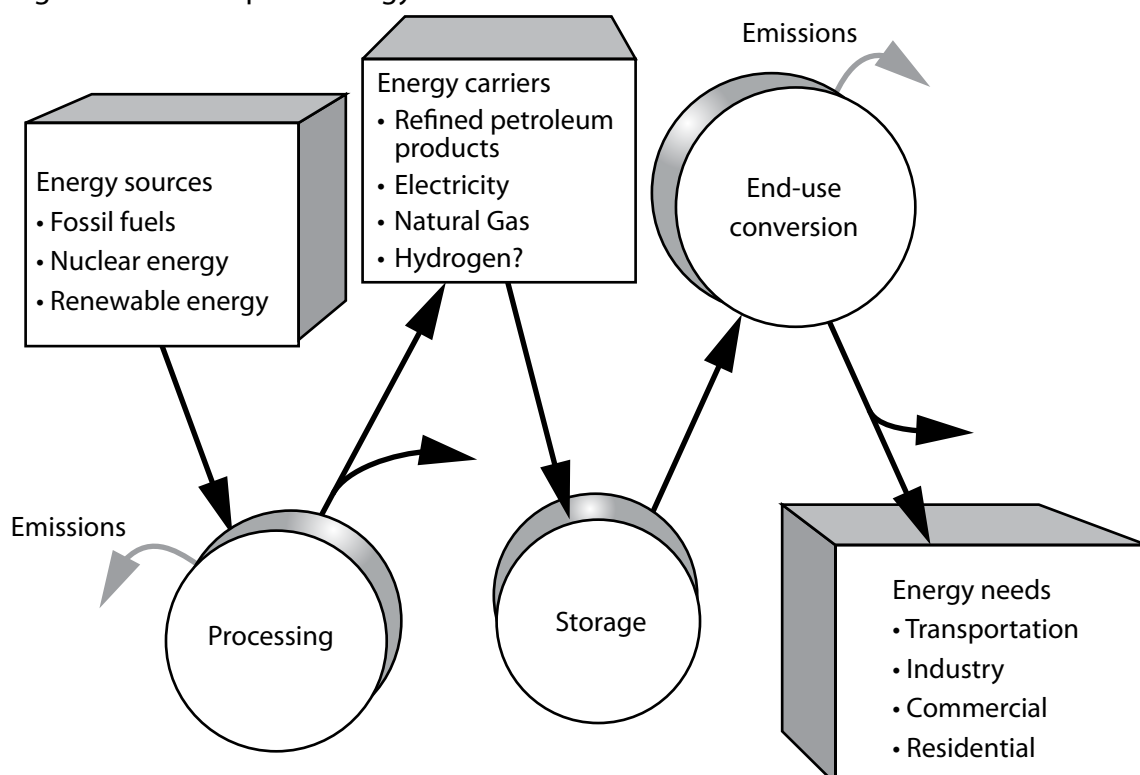
Analysis of complete energy conversion chains is necessary for selecting the best generating and end-use technologies for reducing global carbon emissions. Via such analyses, electricity is increasingly being seen as the energy carrier of choice for transportation and there will be a movement towards an 'Electricity Economy'. The preferred means of road transport will likely be the plug-in hybrid vehicle and electrical generation capacity will need to expand to meet this new market. To enable the increased use of low-emission technologies and to cater for the load-levelling potential of off-peak battery charging, the architecture of many existing grids will have to change and so-called "smart grids" introduced.

Professor Robert Evans FCAE – CAE (Canada)

TOWARDS THE ELECTRICITY ECONOMY

There are only three primary sources of energy that are used to provide all of our energy needs; fossil fuels, renewable energy, and nuclear fission. Fossil fuels currently account for nearly 80 per cent of the global demand for energy. When these fuels are used, whether in the form of coal for large electricity generating power plants, or as gasoline and diesel fuel for transport applications, essentially all of the carbon is converted into carbon dioxide. The challenge of reducing greenhouse gas emissions is therefore largely one of replacing fossil fuels with one of the other two primary sources of energy. In order to better

Figure 1 The complete energy conversion chain



understand how this might be done, the complete energy conversion chain [1] can be a powerful analysis tool for visualising how our energy use patterns can be changed.

A schematic of the generalised complete energy conversion chain is shown in Figure 1. The chain starts with the three primary energy sources, and ends with end-use applications such as building heating and cooling, transportation, and industrial processes. In between the primary source and the ultimate end-use are a number of steps in which the primary source is converted into an energy ‘carrier’, or is stored for use at a later time. To take a familiar example, in order to drive our car, we use a fossil fuel, crude oil, as the primary energy source. The crude oil is first converted in a refinery into gasoline, the energy carrier for this case, with some loss of energy availability, as indicated by the branched arrow joining the processing block to the energy carrier block in Figure 1. The gasoline is then stored in a fuel tank, ready for use by the engine in the final end-use conversion step, again with losses of energy availability as indicated by the branched arrow. This is, of course, just one example, but any use of energy can always be tracked through the complete energy conversion chain in this way. One important lesson to be taken from Figure 1 is that there are only 3 energy carriers that are of significance today; refined petroleum products, natural gas, and electricity. Hydrogen, often billed erroneously as an energy source of the future, is just a potential energy carrier.

Transportation is responsible for over 25 per cent of global energy demand and is one of the major consumers of fossil fuels primarily in the form of crude oil. Although carbon capture and storage techniques may become suitable for reducing greenhouse gas emissions from coal and natural gas used for electric power generation, they will not be applicable to transportation applications. The only way to reduce greenhouse gas emissions from the transportation sector is to switch from fossil fuels to another energy carrier.

Electricity is increasingly being seen as the energy carrier of choice for transportation, not only for electrified rail lines but with the advent of better batteries also for automobiles. In the past some proponents have claimed that the use of hydrogen as a transportation fuel would eliminate the production of any harmful exhaust emissions from vehicles. This is true for the vehicle itself, but if we consider the complete energy conversion chain, hydrogen is just an energy carrier, and would need to be ‘manufactured’ from one of the three primary energy sources. If produced from hydrocarbons, such as natural gas or coal, all of the carbon in the primary energy source would still end up as CO₂ at the point of hydrogen production.

If, on the other hand, the hydrogen was produced from a more sustainable primary energy source, such as renewable energy or nuclear power, then there would indeed be no production of greenhouse gases. The energy conversion chain for this case, from primary energy source to end-use, is illustrated by the schematic shown in Figure 2.

The first step in the chain is the generation of electricity as an initial energy carrier. The electricity would use electrolysis of water to produce hydrogen, which would then be compressed, or converted into liquid form, for storage on board the vehicle. An all-electric drive would power the vehicle, with a fuel cell

Figure 2 Energy conversion chain for a fuel cell vehicle

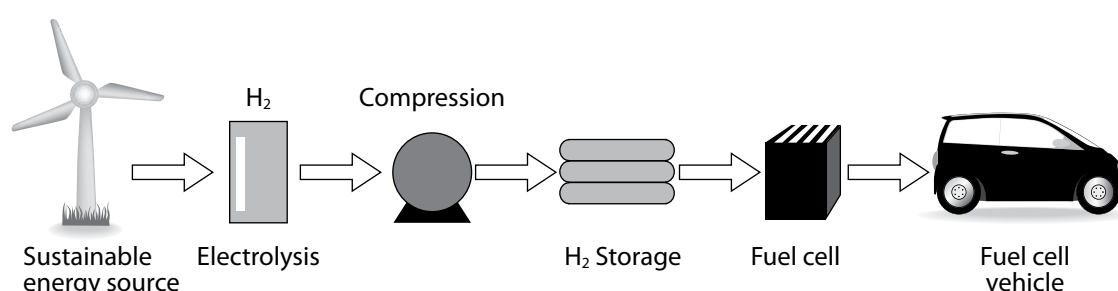
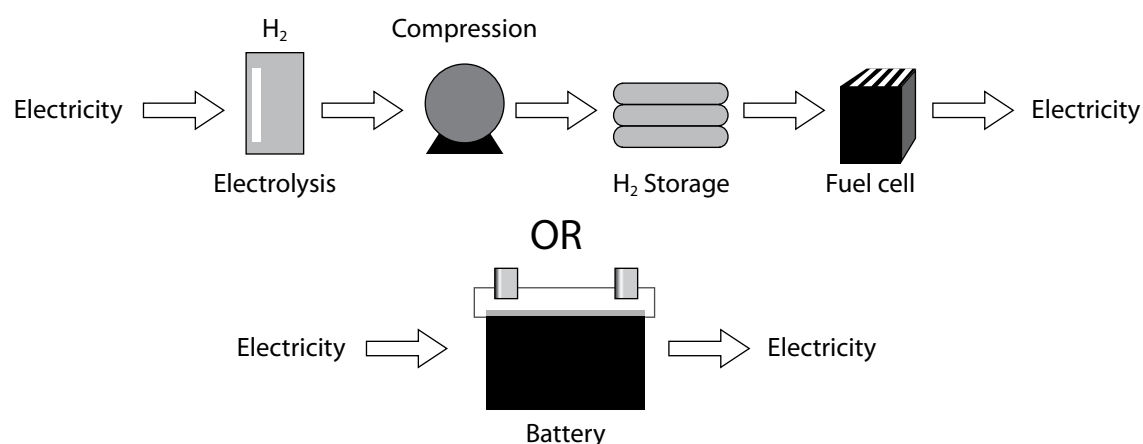


Figure 3 Alternative electrical energy storage concepts



generating electricity on-demand from the hydrogen. In this case the first energy carrier, electricity, is converted into hydrogen as a secondary carrier, and stored on board the vehicle. In other words, there is a “double conversion” into energy carriers, first from electricity into hydrogen, and then from hydrogen back into electricity again by the fuel-cell.

A battery electric vehicle takes a much simpler approach, with a battery used on board the vehicle to store the electricity directly. The two approaches can be summarised by comparing the partial energy conversion chains shown in Figure 3. This shows the two different approaches, starting from the point at which the primary energy source produces electricity, and ending where electricity is again used to power the vehicle’s electric traction motor. It can be seen that the equipment required for the fuel cell vehicle, including hydrogen production and storage, as well as the fuel cell, is really just an electrical energy storage device.

For each of the process steps shown in Figure 3 there is a loss of available energy associated with each step in the chain. To account for these energy losses we may assign an “in-out” efficiency value to each step in the two equivalent conversion chains. The efficiency for each of the steps for the complete hydrogen “electricity storage” process is estimated on the left-hand side of Table 1. With an assumed fuel cell efficiency of 50 per cent, the overall “in-out efficiency” for the hydrogen energy conversion chain is approximately 34 per cent. For the battery, there is only one step between the input to the energy storage and output to the vehicle, as shown on the right-hand side of Table 1, and since about 10 per cent of the input energy is normally lost in the form of heat during the battery charging process, we can assign an “in-out efficiency” of 90 per cent to the battery. This simple analysis indicates that if a battery with sufficient energy storage capacity to provide a reasonable vehicle range were available, then battery electric vehicles would be a very attractive option.

Table 1 Electrical storage ‘in-out’ efficiencies
Efficiency comparison of equivalent energy storage schemes

Hydrogen and fuel cell		Battery	
Electrolysis	75%	Battery	90%
Compression	92%	–	–
Fuel Cell	50%	–	–
Overall Efficiency	34%	Overall Efficiency	90%

Unfortunately, batteries are not yet able to compete with liquid fuels in terms of either energy density or specific energy, and pure battery electric vehicles will likely be suitable only in specialised short range applications for the foreseeable future.

Much of the recent development work on batteries has been driven by the successful introduction in the last few years of hybrid electric vehicles. Hybrid vehicles have been very successfully introduced into the market, initially in compact cars, but the technology is now spreading to larger cars and sport utility vehicles where the benefit of much greater fuel economy is particularly welcome. The current design of hybrid vehicles may be classed as “stand-alone” or “grid-independent” hybrids, because although they incorporate an electrical power train, and storage battery, they obtain all of their primary energy from the fuel carried on board the vehicle, and do not need to be plugged into the electrical grid to recharge the battery.

However, with the expected advances in battery energy density, and the desire to minimise the use of fossil fuels, these vehicles have set the stage for a transition to the next generation of vehicles, the so-called “grid-connected” hybrids, sometimes also referred to as “plug-in hybrids”. In this concept, the battery pack in an otherwise conventional hybrid vehicle will be much larger, and can be fully charged when not in use by being plugged into the electrical grid. The engine, however, will be smaller, and will still operate on some form of liquid fuel. In this way, the vehicle could operate for a significant range, perhaps somewhere between 50 and 100 km, as a completely electric vehicle, and would use the engine to re-charge the battery only when it was necessary to exceed this distance or perhaps when climbing steep hills. For commuters the vehicle would then be capable of operating as a pure battery electric vehicle for most trips. Studies [2] have shown that a plug-in hybrid vehicle with a 90 km range could provide up to an 85 per cent reduction in CO₂ emissions (depending on the source of electricity) for many drivers.

Of course once a significant shift from petroleum to electricity to provide transportation energy occurs there will need to be a significant expansion of electrical generation capacity. If the electricity used to charge the battery is generated primarily by sustainable primary energy sources, such as renewable energy or nuclear power, then road transportation would no longer be a significant factor in contributing to greenhouse gas production. An additional benefit to electric utilities of such a shift would be an improvement in load factor by spreading the electrical load more evenly over the course of a day. With many commuters plugging their cars in for recharging overnight, the increased electrical load, which is normally low at these times, would ensure that electrical generation capacity is better utilised. This “load-levelling” could provide a significant improvement to utility load factors, with the result being a reduction in electricity generation costs. The widespread adoption of electricity as the energy carrier of choice for transportation, together with a move towards a greater use of renewable and nuclear energy for electricity generation, will usher in the new “Electricity Economy”.

The transition to an electricity-based economy would also require a widespread strengthening of electric transmission and distribution systems. In many developed countries the major electrical transmission and distribution networks have been in place for many decades and there has been little new construction or modernisation of existing grids. Putting greater reliance on electricity as an energy carrier will put pressure on electrical utilities to build additional transmission and distribution capacity, and in some cases to strengthen regional networks that are better suited to distributed generation. Modernisation of electrical grids will need to incorporate better grid monitoring and control strategies in order to provide a better match between electricity generation and storage facilities on the one hand, and a highly-variable electricity demand structure on the other. Some of the techniques being considered for these so-called “smart grids” would include continuous load-monitoring with the ability to shed certain types of loads, or to re-schedule non-critical loads such as battery charging, at times when the overall demand for electricity is lower. Smart grid technology would also ensure integration and optimum utilisation of both intermittent and continuous generation capacity as well as any energy storage, such as hydroelectric reservoirs, that may be available on the system.

In countries with a very large land mass, such as the USA, Canada, Australia and the EU, inter-connected utilities may extend across several time zones or different climate regions. In these cases the electrical grid

may well benefit from a strengthening of ties between different regions, or even between countries, in order to take advantage of widely different demand patterns. For example, in North America there are quite good transmission connections on both the east coast and west coast between Canadian and US utilities, but only limited east-west connections in either country. In the west, the provincial utility BC Hydro exports substantial power to California, taking advantage of good north-south connections along the west coast. In the east, Hydro Quebec also exports large amounts of power south, primarily into New York State which experiences large electricity demands to serve the summer air conditioning loads. In this case the north-south connection is particularly beneficial since New York State has a summer-peaking system while Quebec has a winter-peaking system. In this case power-sharing from north to south makes much more efficient use of generation and transmission capacity in both jurisdictions. Consideration is being given to developing further connections (both East-West and North-South) [3].

There is a clear opportunity to expand this type of inter-regional synergy by strengthening east-west ties across both Canada and the USA. To date this has not been done, in part due to lack of east-west synchronisation and emphasis in the past on regional self-sufficiency. With increased electrical demands, however, it would make sense to expand electrical inter-connectivity throughout North America. This would facilitate a greater sharing of generation and transmission capacity, resulting in improved load factors. This type of greater inter-connectivity is also likely to be beneficial in other densely populated regions of the world such as Europe and Asia.

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See http://www.acad-eng-gen.ca/documents/NewsRelease_CPGTF.pdf.

DEPLOYMENT OF LOW EMISSIONS TECHNOLOGIES

Section 3

THE KEY TECHNOLOGIES AND THEIR PROSPECTS

More efficient combustion technologies, carbon capture and storage, nuclear power and renewables will all have a place in future low-carbon electricity generation. In the short term, replacement of old power stations with current best practice would produce immediate emission reductions. For practical application of renewables, governments and the public need accurate authoritative information from bodies like CAETS on the state of art of each technology. In the longer term, drastic reduction in emissions can be achieved with nuclear power and advanced reactor developed should be pursued. There are also many opportunities for improved efficiency in the end-use of energy, both by industrial and domestic energy users. Global deployment of existing best practice in energy efficiency would deliver enormous reductions in carbon emissions without large development expenditure or risk.

Dr Kozo Iizuka – EAJ, Dr. Hideo Tanaka – EAJ, & Mr. Yoshiaki Nishimura (Japan)

TECHNOLOGIES FOR ELECTRIC POWER GENERATION

There is no question that individual countries should decide on what is the best mix of power from various sources to fulfill their own needs for electricity as well as to reach the target for reduction of CO₂ emissions. The investment for lowering CO₂ emission may be directed towards high efficiency thermal power generation (with CO₂ capture and storage (CCS)), nuclear power and renewable energy.

(1) Thermal power generation

According to IEA statistics for 2007, global fuel use for electric power was 4.35 G tonnes in oil equivalent (TOE), in which 2.07 G TOE (48 per cent) was coal. As a result, improvement of the efficiency of coal-fired power plant may be the most effective means for decreasing CO₂ emissions globally in the short term. Switching to LNG-fired plant is also effective in decreasing CO₂ emissions. To enhance thermal efficiency, combined cycle with both gas and steam turbines has been successfully installed to realise a gross thermal efficiency exceeding 50 per cent. Further improvement of gas turbines is in progress. One example is the integrated coal gasification combined cycle system (IGCC) which will be operated with higher efficiency and lower CO₂ emissions. If all the present coal-fired power plants in the world were replaced by current best practice, their CO₂ emissions could easily be reduced by 10 to 30 per cent, possibly resulting in a reduction of more than 4 per cent of total global emissions. Substantial reductions in CO₂ emissions from fossil fuel power stations are possible with CCS technology. However, there are significant technological and financial risks to be overcome before this technology is suitable for commercial deployment.

(2) Nuclear power

Nuclear power can supply electric power with very low CO₂ emissions. The construction of advanced reactors and the development of small or medium scale reactors should be promoted. As a long-term project, fast breeder reactors should also be developed. Unfortunately, there are some sensitive problems concerning the construction of new nuclear power plants in many countries. Safety is the top priority in

introducing nuclear power and the security of nuclear fuel is also very important. These are significant concerns. Even so, drastic reduction of CO₂ emissions cannot be achieved without increased generation by nuclear power plants. CAETS should cooperate in the exchange of experience in matters of safety and public attitudes in each country.

(3) Renewable energy

Recently, the importance of renewable energy has become more widely appreciated. Interest in both conventional (hydroelectric) and enhanced geothermal power systems has been revived. In some countries or in some areas, small scale hydroelectric power may be most useful. Other renewables include photovoltaic cells, solar heat, biomass, wind, tide and wave power. Their introduction needs to be based on an evaluation of full life cycle costs and effects. Geological or climatic conditions at the installation site are often key factors in determining these effects.

The development of energy storage devices is a key issue for the efficient use of renewables. Further improvements in advanced batteries for such storage will help the efficient use of electrical energy.

Although it is not a primary energy source, hydrogen technology has been introduced and put into practical use, especially in conjunction with fuel cells. However its impact on reducing CO₂ emissions is largely dependent on the method of hydrogen production.

As described in other Sections, the current practical application of renewables often incurs higher costs. CAETS should continuously present accurate authoritative information on the state of art of each technology to policy makers and the public.

TECHNOLOGIES FOR EFFICIENT USE OF ELECTRICITY

According to the 4th IPCC report, the sectoral contributions to the global total of greenhouse gas (GHG) emissions from energy supply, industry, transport and residential and commercial buildings amount to 25.9 per cent, 19.4 per cent, 13.1 per cent and 7.9 per cent respectively. The rest is mainly from forestry and agriculture. In each sector, advanced key technologies for reducing CO₂ emission have been developed and are being deployed.

In the industry sector, the major sources of emission are the iron and steel, cement and chemical industries. According to the IEA Energy Technology Perspectives 2008, the average energy consumption for producing one tonne of iron, cement or sodium hydroxide in different countries ranges from 20 per cent to 50 per cent above best practice, depending on the particular industry. These figures indicate how far CO₂ emissions could be lowered simply by replacing less efficient plants with best practice.

In the business and household sector, improvement of the energy efficiency of buildings and appliances is important. An example of advanced technology for energy savings is the use of highly efficient heat pumps with a coefficient of performance (COP) greater than five for ventilation and hot water supply. Another example is the LED lamp for illumination. There are many other electric appliances and components developed and used for energy saving. At the same time, energy management systems are being introduced to minimise the input electric power in homes, in commercial buildings or even over a whole locality. The use of improved batteries with a larger capacity is an indispensable part of total energy savings.

Energy savings in IT devices and systems is also important, especially as these are expected to be sources of rapid increases in consumption of electric power in both advanced and developing economies. Savings can be introduced with individual pieces of equipment and in networks. A typical example is the development of data centers with much lower electric power consumption when a new cooling system is installed.

In the transportation sector, hybrid and electric cars are rapidly increasing in numbers and will comprise a significant share of the smaller car market in the near future. Fuel cells and hydrogen are related matters but will not be discussed here.

PROMOTION OF DEPLOYMENT OF HIGH-EFFICIENCY FACILITIES, EQUIPMENT AND SYSTEMS

Investment in new facilities, equipment and appliances with higher energy efficiency and lower CO₂ emissions should be encouraged by a social measures, or legal regulations if necessary. For the supply side, an example of voluntary schemes is the “Green Energy Certificate” now in operation in Japan. In this scheme, a Green Energy Certification Center issues a certificate to the supplier of low emission energy.

On the demand side, manufacturers of appliances are encouraged by the so-called “Top Runner System” to produce low emission products. In Japan, it is a legal requirement to identify and make public the performance of each product in a similar range and to recommend to manufacturers to match the product with the highest performance.

The practical application and dissemination of new technologies and their products should be promoted by various schemes on a voluntary or regulated basis. One example is Japan’s Carbon Footprint System (<http://www.oecd.org/dataoecd/3/33/42856130.pdf>) which involves labelling the amount of the life cycle emission of CO₂ on each product. CAETS should support the dissemination of such systems through collaboration in the assessment of emissions and in the best methods of promoting them publicly.

DEPLOYMENT OF LOW EMISSIONS TECHNOLOGIES

Section 4

THE ROLE OF RENEWABLES

Renewables will make an increasing contribution to electricity supply. However, the potential of renewable energy, over at least the medium term, is inevitably limited by its variability and large land requirements. Dependence on topography and natural endowments means that the contribution of renewables to national energy requirements will vary from country to country. The overall global picture shows a continued reliance on fossil fuels, with some nuclear, over at least the medium term, that is, up to 2030.

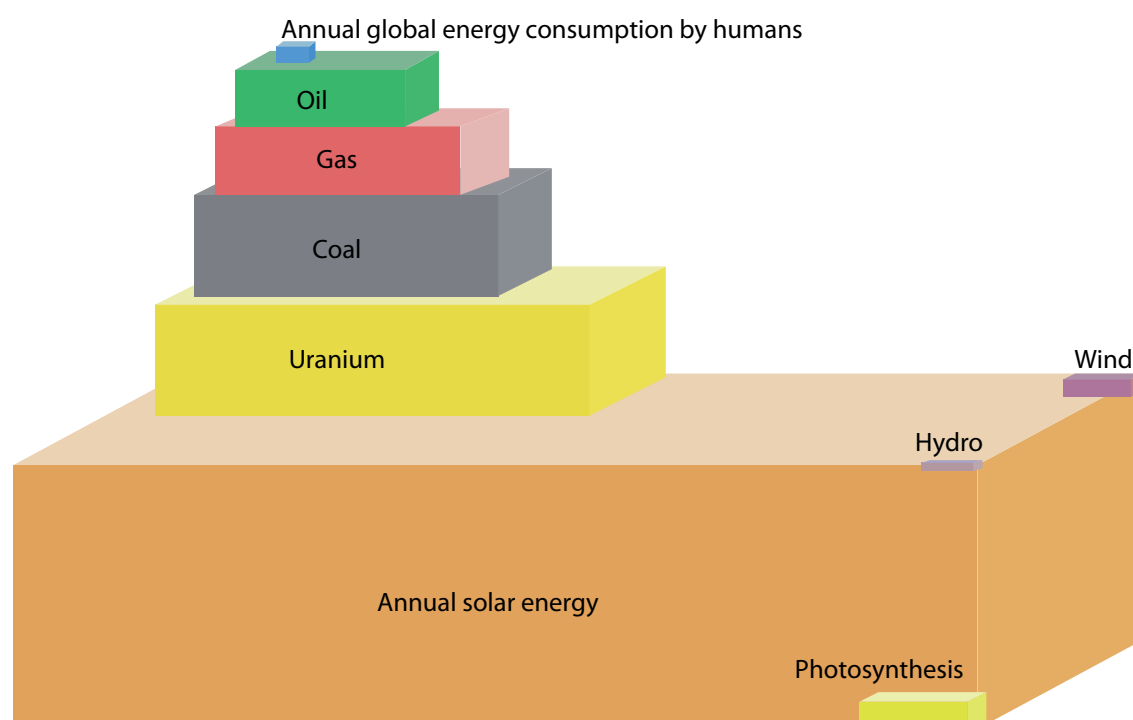
Professor John Loughhead FEng – RAE (United Kingdom)

POTENTIAL OF RENEWABLES

There is no dispute that the renewable energy potential of the earth considerably exceeds anthropogenic annual usage and will continue to do so for many years. However, in the IEA Energy

Technology Perspectives report of 2008 even the most aggressive carbon emission reduction scenarios for 2050 show total renewable contribution to energy supply as less than 40 per cent of the total. In the so-called ACT scenario this falls to less than 25 per cent. There are well-understood economic and engineering reasons for this.

Figure 1 Schematic diagram of total world energy resources in comparison with annual global energy consumption (top box)



Source: National Petroleum Council, 2007 after Craig, Cunningham and Saigo

LAND REQUIREMENTS FOR ELECTRICITY GENERATION

A typical combined-cycle gas turbine power station has a ‘power footprint’ (power supplied divided by total land occupied) of 8 – 20 kW/m². A coal-fired station will be around 3.5 – 10 kW/m², or perhaps 2.55 – 8k W/m² if it is fitted with CCS equipment. The equivalent figure for a solar PV installation is no more than 0.05 kW/m² in the most attractive locations and only half of that figure in places like Northern Europe. The enormous difference is caused by the power output of PV farm being controlled by the intensity of incident solar radiation, its variation through the day and complete absence at night, and the fairly low conversion efficiency of PV systems – typically 20 per cent maximum.

For wind the figures are of a similar scale on land, and given the correct topography can exceed solar availability. At sea the wind figures increase due both to typically stronger winds (the topography of the sea is more favourable than land), and to their more regular occurrence. Consequently countries with suitable littoral conditions are moving to deploy off-shore wind turbines, albeit it with some difficulties of installation and reliability arising from the challenging environment. For biomass growth the equivalent figure is typically 0.002 kW/m², as plants are even less efficient at converting incident energy, but can reach 0.007kW/m² in the case of sugar cane grown in South America. However, biomass of any type requires minimum availabilities of water, soil nutrients, and local climate conditions and so is notably location dependent.

As an example of the land requirements resulting from the large ‘power footprints’ of such renewable energy sources, in order to supply the “other renewables” element of the IEA 2050 scenario would at best require 625,000 km² of solar PV systems, an area roughly equivalent to the total area of France and its overseas territories.

By contrast gas or coal stations have an installation area dictated by machinery size. The difference in footprints between the two arises mainly from the common practice of storing several weeks supply of coal locally, as its transportation is a less reliable “batch” process than the continuous piped delivery of natural gas.

The major advantage of fossil fuels is that they are a highly concentrated form of stored energy, which of course originally was solar. It is predominantly that fact, coupled with easy availability, that makes fossil-based energy systems both a practical engineering solution and one whose costs are presently and historically below other options.

Nuclear systems have area requirements similar to fossil fuel systems, although their use is restricted primarily to large electricity generation and their economic performance (based on current practice for quantifying externalities) is probably materially inferior. However, compared with current renewable technologies, nuclear costs are at present lower.

There are however two renewable energy sources with much higher energy densities: high-head hydropower and geothermal energies in regions with magmatic penetration to the near-surface, such as Iceland and New Zealand (and for instance, there are unexploited hyro resources in Africa and Latin America). The first is the result of land topography coupled with appropriate climate conditions to assure sufficient regular rainfall, and results in a natural focusing of solar energy absorbed mainly by seas over large areas – essentially a short-cycle analogue to fossil fuel. Hydro-power was of course one of the earliest mechanical energy conversion systems and so potential sites internationally have been largely exploited. The second is fairly unusual and arises from local variations in thickness of the Earth’s geological crust, possibly due to tectonic movements, allowing hot core material to reach the surface. The global potential is small.

It is evident that the potential for indigenous renewable energy will depend upon local topography, climate, latitude, and water and land availability, so its exploitation and contribution to national energy needs will vary from country to country. However, save in comparatively low population density countries without significant urban developments, the demand for high energy density consumption will tend to restrict the ability of renewable energies to meet all needs

DENSITY OF ELECTRICAL ENERGY DEMAND

The majority of the world population (just) now lives in cities, and by 2050 about 6 billion of the 9 billion people projected to be alive will be in an urban area. The average density in urban areas is today between 3100 (high-income countries) and 6000 (low-income) persons for each square kilometre. As the general trend is to higher densities in urban areas, we may assume that the 2050 urban population will require about 1 million square kilometres of land, and use around 90 per cent of all energy consumed. If fully utilised for solar PV an area equivalent to the total city area could possibly provide 15 per cent of urban energy needs.

Based on these very approximate figures it is evident that the ‘energy density’ of renewable technologies as we can project them today is insufficient to meet local needs of urban populations by a factor of around 6. If we consider meeting power needs, which naturally vary from 20 to 100 per cent of maximum demand during 24 hours, then the difference is probably a factor of 20.

ENERGY SUPPLY SECURITY AND RELIABILITY

The trend to high density urban living, which is reflected in all projections for the period to 2050, is possible only because of the availability of reliable, cheap, clean and high density energy vectors, which today are essentially electricity and natural gas. Transport fuels are important to enable food to be provided, waste removed, and people to travel, but the majority of energy consumed is in the fixed infrastructure, industry, and dwellings in urban areas. In most cases the availability of the energy is assumed to be close to 100 per cent in the design of the city. Thus, lifts do not have secondary hand cranks for regular use, and air-conditioned buildings generally do not have opening windows. Industrial processes for modern technology are normally process-parameter sensitive and cannot tolerate disruption through power outages, while the suspension of a public transport service for even one hour can be highly disruptive in a social-work environment that is highly choreographed.

The security of today’s electricity supply is achieved through the provision of high capacity baseload generation connected through a network containing a high degree of redundancy. For the future, it is hoped that the growth of intelligent networks will allow tighter integration of electricity demand management with supply and effective use of a greater proportion of intermittent and renewable energy. However, as the energy density figures above highlight, this would require extensive use of remote solar farms, or similar, and substantial amounts of storage to balance power needs.

Given the identified need for continued dominant contribution of fossil fuel to the supply, it seems unlikely that there will be a rapid move away from the proven high-capacity baseload plants, which are the most efficient means of using these fuels. In the longer term, viable processes for carbon capture and storage will allow the continued use of fossil fuels to supply baseload electricity.

DEPLOYMENT OF LOW EMISSIONS TECHNOLOGIES

Section 5

NEW TECHNOLOGY FOR ELECTRICITY DEMAND MANAGEMENT

The distributed and intermittent nature of many kinds of renewable energy generation introduces new needs in the overall energy supply system (including transmission and distribution). Measurement and control using information and communications technologies will be carried out within so-called smart grids, with demand management an essential component. Such systems will rely heavily on the availability and implementation of appropriate standards for physical interfaces, communication protocols and common data formats. Because of the associated information flows, the introduction of these new technologies will raise a suite of new social issues and concerns to do with privacy and individual freedom.

Prof Dr Frank Behrendt, acatech and Ms Kristina Bogner – (Germany)

This contribution is based on an acatech paper on the “Internet of Energy (IoE)” by H.-J. Appelrath, Frank Behrendt, Kristina Bogner, Friedemann Mattern, Christoph Mayer, Markus Weiss.

The growing use of renewable energy sources does cause an increasing volatility in supply of electrical energy. Storage of electricity is available only on a small scale, leading to the necessity of more demand-side management (“follow the load” instead of “follow the generation”). To what extent a generation-dependent price structure will motivate customers to change their electricity-usage pattern remains an open question. Positive results from the US need to be validated in the EU and other regions.

Internationally, a common view is evolving that in the future energy supply systems (generation, transmission and distribution grids, usage) will need to be complemented by ICT (Information & Communication Technology) systems representing, not only extended versions of current measurement and control systems, but also forming also a basis for complete new business models in the energy sector. While the technologies for energy conversion, distribution, and usage increasingly do evolve in a concerted way, the corresponding ICT technology and its interaction with the energy infrastructure is still in an early phase of its development. This is closely related to the question: Which of these new technology components will offer a realistic basis to develop new business models allowing support of the vast investments needed in this sector?

In Germany, 16.1 per cent of electricity was generated from renewable sources in 2009. For 2020 this number is to be increased to 30 per cent. While this large amount of stochastically fluctuating supply of electricity poses a number of challenges in its own right, the situation becomes more complicated due to the fact that a significant number of coal-fired power plants will reach the end of their life-cycle in the upcoming decade. Moreover current Germany legislation requires phasing out of nuclear power until approximately 2021-22. This combination of changes in the energy-supply structure Germany’s may lead to a number of unwanted consequences with respect to the stability of Germany’s power grid.

A possible way to address the upcoming temporal and spatial disparity between the electricity generated and needed may be the introduction of so-called smart grids as a physical and logical foundation of demand-side management. While a generally accepted definition of this technological concept is currently not available there exists some agreement on its characteristic properties:

A smart grid is an electricity network that can intelligently integrate the actions of all users connected to it – generators, consumers and those that manage both – in order to efficiently deliver sustainable, economic and secure electricity supplies. A smart grid employs innovative products and services together with intelligent monitoring, control, communication, and self-healing technologies to

- better facilitate the connection and operation of generators of all sizes and technologies;
- allow consumers to play a part in optimising the operation of the system;
- provide consumers with greater information and choice of supply;
- significantly reduce the environmental impact of the whole electricity.

Smart grid deployment must not only include technology, market and commercial considerations, environmental impact, regulatory framework, standardisation usage, ICT and migration strategy but also societal requirements and governmental edicts (www.smartgrids.eu).

Keeping the concept of smart grids in mind, an “Internet of Energy (IoE)” can be described as follows: “The Internet of Energy (IoE) enables ICT-wise a simplified integration of new systems for energy conversion, distribution, and usage combined with new operational and business models by implementing a reliable, flexible, and system-wide communication and control technology leading to an increased economical and ecological efficiency as well as the operational reliability of energy systems.”²⁴

The IoE describes a complex ICT system forming the overall basis of a smart grid. Relevant components are:

- ICT hardware (smart meters, intelligent electronic devices, server) to be able to deal with the substantially increased load on the communication networks
- Software components and systems
- Communication devices
- The communication between all these systems
- All with an appropriate level of security and reliability.

This consequently means that all devices involved in energy conversion, distribution, and usage will be enabled to be integrated hard- and software-wise into the evolving communication infrastructure. This will allow these devices to access securely and reliably all data needed for their operation, and in turn to supply all data necessary to integrate the devices into the overall system. The challenge of achieving this far-reaching goal represents a significantly larger challenge than those of current ICT systems.

Relevant concerns and challenges of eEnergy development and the related introduction of the new technologies will raise a suite of new social issues. There are privacy and individual freedom concerns. The extent and quality of new services resulting from these new structures will strongly influence the degree of acceptance by both commercial and private customers. Such services may, for example, be attractive for traditional market actors being forced to evolve or change their business models driven by de-regulation or changing customer behaviour (attention to “green” topics). More possible new actors from other markets may find the energy sector attractive.

- Such new services may include the operation of virtual power plants. To consumers they will act like independent power producers of today, to producers they will be service providers coordinating and controlling electricity production capacities.

²⁴ Horenkamp, W. et al., “Dezentrale Energieversorgung 2020” (Decentralized energy supply structures), VDE/ETG-Studie, 2007

- Currently large customers already can profit from load-profile based advisory aiming at reducing their overall electricity bill – an IoE may open opportunities to extend such services to private households as well based on smart meters with a reasonable high time resolution
- Owners of transport grids have already started to buy, for example, forecast data on wind distribution and velocities and use them to predict the need for additional power plants depending on wind availability. Here service providers may be able to establish themselves in the market offering this kind of information based on various inputs the IoE may deliver from distributed devices integrated in the energy grid.
- The vast amount of distributed devices used in the renewable energy field (windmills, PV parks etc) will require regular as well as unscheduled maintenance. Remote diagnostic and maintenance scheduling are additional fields where new providers of services may be able to establish their business models. Here, experiences with similar services in the mobility sector could help to establish such kind of business.
- Some ideas in the field of e-mobility aim at allowing a car owner to exclusively recharge a battery with power from his or her home utility company, i.e., roaming for electricity. In this case a possible business model would be for a provider of services to organise the billing and payment procedures.
- Future tariffs will offer flexible structures not only to large industrial customers but also to households as a basis for an effective demand-side management. Innovative advisers may be able to offer an analysis of electricity usage profiles and based on this suggest new tariff structures.

Most of these and similar ideas and concepts rely heavily on the availability and implementation of appropriate standards. Without such standards for e.g. physical interfaces, communication protocols and common data formats the “real” internet would not have been as successful as it is today. An upcoming IoE requires a similar degree of standardisation. Work on this topic needs fairly rapid progress before “information islands” spread too widely and the potential advantages of merging the electrical grid and the Internet are lost.

Europe has the advantage of a very stable electricity supply, which is one of the best and most stable in the world. An over-hasty introduction of a smart grid without mature and 100 per cent secure energy distribution would, with the first minor failure, threaten loss of this one-time-opportunity for “greening our energy supply”.

DEPLOYMENT OF LOW EMISSIONS TECHNOLOGIES

Section 6

THE SPECIAL NEEDS OF DEVELOPING ECONOMIES

Each country will have a unique portfolio of electricity generating technologies drawn from a wider global set. Developing economies will show the fastest growth rates in energy requirements. They will be forced to rely for some time on fossil fuels but will improve energy conversion efficiencies through new technologies. More efficient production of bio fuel will occur. Smaller, distributed generation based on renewables will continue to be a feature of developing countries. This militates against rapid uptake of carbon capture and storage technologies when they become available. Nuclear power will make an increasing contribution to the energy mix. Small reactors without on-site refuelling may be especially appropriate for the needs of developing economies.

Mr Willem du Preez – SAAE (South Africa) and Professor H. S. Mukunda – INAE (India)

INTRODUCTION

The use of energy and the resulting level of economic activity and standard of living are very unevenly distributed among the world's countries and populations. Currently 80 per cent of the world's seven billion people have access to less than half the world's energy and some 1.6 billion are without access to electricity. The global economic development challenge for the 21st century is to improve the lives of the world's poor, a majority of whom will be living in developing countries and a majority of those in urban slums containing around 15 000 people per hectare.

Developing countries (and emerging ones as well) have a lower quality of life indicated by their lower human development index (HDI) compared to those of developed countries; HDI is directly related to amount of electricity per capita available. Solving the problems of achieving a low-carbon economy for developing countries in the coming years will need to address enhanced electricity supply to large segments of the population as well as making sure that the electricity generated has a low-carbon footprint. This issue it may be noted is different in the developed world where the essence is to change the electricity generation strategy to one with a low-carbon footprint.

INDIA – A LARGE, RAPIDLY DEVELOPING COUNTRY

The case of India is presented in some detail as being illustrative of the issues facing a developing country. With about 1.2 billion population and 220 million households, about 80 million households located in the rural areas continue to remain deprived of quality-of-life electricity for their inhabitants. Those living in metropolitan areas enjoy about 1000 kWh/capita/year while those in villages have 0 to 300 kWh/capita/year. In the coming years, one of the principal aims of development is to ensure that every household gets a minimum of electricity (about 300 kWh per capita). The broad geographical spread of population, a significant part of which is distant from the grid, makes India ideally suited to distributed electricity generation by renewable sources. This form of development does not contribute to significant carbon emissions.

Primary energy consumption in India is based 40 per cent on coal, 24 per cent on oil, 26 per cent on non-commercial sources (mainly biomass), 7 per cent on natural gas, 2 per cent on hydro power and less than 1 per cent on nuclear and other sources. The principal use of coal is in power plants and occurs at an average conversion efficiency of 30 per cent and best efficiency 37 per cent. The situation in the country is that most states are unable to meet the demand for electricity in both the domestic and industrial sectors. A significant base up to 15 per cent of fossil fuel is in-house generation and is the backbone of industrial activity. Significant additional capacity is planned to meet an economic growth rate of 8 to 9 per cent and these new power plants will have efficiencies close to 40 per cent. IGCC coal plants are still to be developed for Indian coal, which has a fairly high ash content (~ 45 per cent). Moving from this largely fossil based electricity to low-carbon solutions requires increasing the energy efficiency using IGCC.

The five most important sectors that contribute to India's carbon footprint are steel, cement, aluminium, paper and pulp, and fertilisers. The primary energy efficiency in the cement, aluminium and fertiliser sectors is comparable to best world practice but steel as well as paper and pulp have to make further improvements, which are currently in train.

Rural cooking uses biomass in very large quantities, around 450 million metric tonnes (*mmt*), which is comparable to coal usage but has low efficiencies and high emissions. Use of better technologies in this sector will help release more biomass for electricity generation and reduce GHG emissions mainly through far better combustion of prepared solid bio-fuel.

India has about 30 million hectares of waste land potentially available for oil-seed tree plantations for producing liquid bio-fuel for transportation. Oil-seed processing will leave residues of 75 to 80 per cent waste solids totalling 130 to 150 *mmt*. These will be used for producing pellets and briquettes suitable for distributed electricity generation.

Thus the future pathways for low carbon technology in India are (a) enhanced energy efficiency in major energy sectors like power, steel and paper and pulp, (b) growing oil-seed bearing plantations over a vast area of waste land to produce bio-oils for transport and waste material for distributed electricity generation. Such strategies are also relevant to many developing countries in Africa and south-east Asia.

FASTEST POPULATION AND ECONOMIC GROWTH EXPECTED IN DEVELOPING COUNTRIES

Because most developed countries have saturated in energy use per capita, whereas many developing countries are starting from a very low base, future growth will likely be inhomogeneous with faster growth taking place in developing than in developed countries. Energy demand growth in the 21st has been projected by numerous organisations, often in connection with the study of sustainable development and/or global climate change. Most projections, based as they are on hopeful projections of economic development, forecast massive growth in global demand for energy services over the next century. A "business as usual" approach will rely on fossil fuels to support this growth. Most projections in fact assume that fossil fuels will remain the dominant source of energy throughout the 21st century.

SUSTAINABLE ECONOMIC DEVELOPMENT

Increasingly over the past two decades, government attention has transcended simple economic development to seek sustainable economic development. While fossil fuel has dominated energy supply for over 200 years, its continuing expansion faces a potential collision among four trends affecting the pillars of sustainable development:

- continuing world population growth, primarily in developing countries where GDP/capita is currently low; coupled to

- economic growth, especially in developing countries, thereby requiring increased energy input per capita there and, as a result, vastly increased global energy usage overall.

The countervailing trends are:

- Increasing rates of consumption and competition for fossil energy resources, with shortfalls foreseen (except for coal) before mid-century; and
- Increasing ecological assault from emissions attendant to fossil fuel use, both locally (soot, smog, Hg) and globally (CO₂, CH₄).

With the above mentioned factors taken into account, exclusive dependence on fossil based energy to fuel the 21st century global economic development in a sustainable fashion will certainly not be possible. Nuclear energy will be required to fill a growing market share of world primary energy supply in the future because its large resource base and its avoidance of greenhouse gas emissions are favourable features for sustainable development.

Whereas until recently, nuclear deployments have been predominantly in developed countries, all projections forecast that by 2030 and thereafter the dominant energy capacity additions will occur in the currently developing economies due to two factors: greater population growth than in developed countries and higher economic and energy use per capita growth rates than in developed countries. For nuclear power to play a significant role in world energy growth, it must therefore be targeted to meet the needs of developing countries.

PORTFOLIO OF TECHNOLOGIES FOR DEVELOPING COUNTRIES

In considering the different compositions of the energy technology portfolios that will evolve over time for different countries, depending on their circumstances, the most significant difference will be between the needs of developing nations and developed nations. Emerging market conditions differ dramatically from the regulated electricity markets prevailing in developed countries during the previous half-century. When an extensive pre-existing grid is absent, when financing is tight, and when energy use per capita is initially low but growth rate is high, the economy-of-scale power plant configuration supported by indigenous fuel cycle service facilities becomes ill-suited to the customer needs. For many potential new customers, low initial buy-in cost and outsourced fuel cycle services could offer a much better way to meet their energy supply needs. Small nuclear reactors (see for example <http://www.iaea.org/NuclearPower/SMR/>) without on-site refuelling are an approach to provide a new architecture for nuclear energy, specifically designed to meet the needs of these emerging markets.

The very large capacities of base load electricity generation that will be required to meet the needs of the rapidly growing emerging markets can come from one of two technologies, namely coal with CCS and nuclear power (especially small reactors without on-site refuelling). The choice between them will be dictated by the following key factors:

- affordable unit generation cost and cash flow profile (including the cost of externalities);
- high level of safety on the basis of multiple inherent and passive safety features;
- maturity of technology and its reliability;
- security of energy supply (sustainability);
- near-zero carbon and pollutants emissions;
- waste management; and
- nuclear weapons proliferation resistance.

CUSTOMER NEEDS

Four main categories of customer needs are identified:

- villages and towns in off-grid locations;
- industrial installations in off-grid locations;
- cities in developing countries; and
- in a more distant future, perhaps, merchant plants for non-electric energy services.

Off-grid villages and towns require a standalone energy infrastructure, which includes electricity and perhaps desalination and/or district heating. Small power plants with low staffing levels are preferred and low staffing skill level may be desirable in some cases. The truly massive future growth in energy demand will be for the support of cities throughout the developing world; that is where energy infrastructure deployments could dominate throughout the 21st century.

The projections for massive energy demand growth in cities of the developing world can be understood as the product of population growth, rural-to-urban demographic migration, and economic development.

The financial conditions faced by many developing cities may favour small initial capital outlay, with incremental additions deployed as population grows, as energy input per capita increases, and as a city becomes wealthier. To accommodate rapid growth but shortage of initial financing, a “just-in-time” capacity growth plan would be appropriate. Therefore, small reactor plants must be designed to be easily expandable into clusters comprising ever larger power installations.

COAL FIRED POWER GENERATION WITH CCS

A lot of research and development as well as demonstration of the technology remains to be done before it can be commercially deployed on a large scale. The indications are currently that CCS will add seriously to the cost of electricity generation from coal, which may as a result be substantially higher than the cost of electricity from nuclear generation. A further disadvantage as far as developing countries are concerned is that the cost of CCS is very dependent on economies of scale. This feature is contrary to the small and distributed nature of many of the energy requirements in the developing markets.

SMALL NUCLEAR REACTORS WITHOUT ON-SITE REFUELLING

For small reactors without on-site refuelling, the observed common business strategy is to tailor the offering specifically to meet the needs of certain customers by providing a standardised turnkey plant that is:

- easily transported and installed;
- designed with a high level of safety on the basis of multiple inherent and passive safety features;
- pre-licensed (standardised design certification) in the supplier country;
- provided with vendor-supplied front and back end fuel cycle services, including waste management; and
- designed with a long (many years) whole-core refuelling interval with a potential for refuelling equipment to be brought to the site by the refuelling team, or with entire reactor module change-out.

The above-mentioned special features of small reactors without on-site refuelling make them compatible with proposed future institutional means to centralise fuel cycle facilities at only a few locations worldwide. Moreover, component accounting could be performed on entire cores during shipment and operation deployment of such reactors.

Section 7

ROLE OF GOVERNMENT IN LOW-CARBON TECHNOLOGY DEVELOPMENT

The decision to address climate change has created the need for long-term strategic development of new low-carbon technologies. The relatively short timeframe, high risks and large costs involved mean that governments need to take a leading role. At the basic R&D end of the development spectrum, renewable energy can only supply a significant fraction of future energy needs if further technical breakthroughs and cost reductions occur. These will only be possible with continued long-term support by government. At the other end of the spectrum, innovative new technologies should continue to the demonstration and deployment stages through government support, even though the decision to take a technology to that commercial stage is best made by the private sector. The global nature of energy and climate issues calls for more international cooperation, especially in the area of rapid deployment of low-carbon technology. International cooperation allows sharing of knowledge of the basic science and technology and governments can share the burden of investing in expensive demonstration projects.

Professor Myongsook Oh – NAEK (Korea)

LOW CARBON ENERGY TECHNOLOGY DEVELOPMENT AND GOVERNMENT LEADERSHIP

The need for the development of low carbon energy technologies presents enormous challenges to both government and the private sector because of

- short timeframe for deployment – new technologies need to be ready for large-scale deployment in the next 20 years;
- high cost involved – low-carbon technologies such as carbon capture and storage (CCS) will require very large investments;
- high risk and large uncertainties – the need for technology development is not market driven, and there are higher risks and market uncertainties than for other types of technologies; and
- no simple technological solution available – new technology development with low carbon emissions is the best response to higher energy costs and climate change. However, there are no simple technological solutions for this task.

A competitive industry, for which the primary concern is to ensure that investors receive a return on their investment, tends to invest in projects with a short-term gain. Very few companies can withstand a mid- to long-term return on investment. For private companies to invest in a new technology, certainty about market conditions is important to foster commercial development, including commercial scale demonstrations. The current risk/return profiles of most of the low-carbon technologies preclude significant investment by private companies.

In industry, profits are often realised through economics of scale, where the decreased per-unit cost is achieved as output increases. Economics of scale tend to occur in industries with high capital costs where those costs can be distributed across a large number of units of production. In the energy industries, where the initial capital investment requirements are extremely high, large scale investments are crucial for generating profit. However, it is not likely that companies will make large investments where there is high risk and large uncertainties.

The urgency, high risk and uncertainties in low-carbon technologies make it difficult for corporations to undertake serious research and development (R&D) efforts or carry out demonstration projects. In order to address the necessary technology development, governments must take a leading role in basic R&D efforts as well as associated demonstration and deployment. Well planned and managed major government programs are required to design and develop new technology, to set a direction for R&D, to determine what technologies to demonstrate and deploy, and to facilitate private sector investment.

GOVERNMENT ROLE IN BASIC R&D

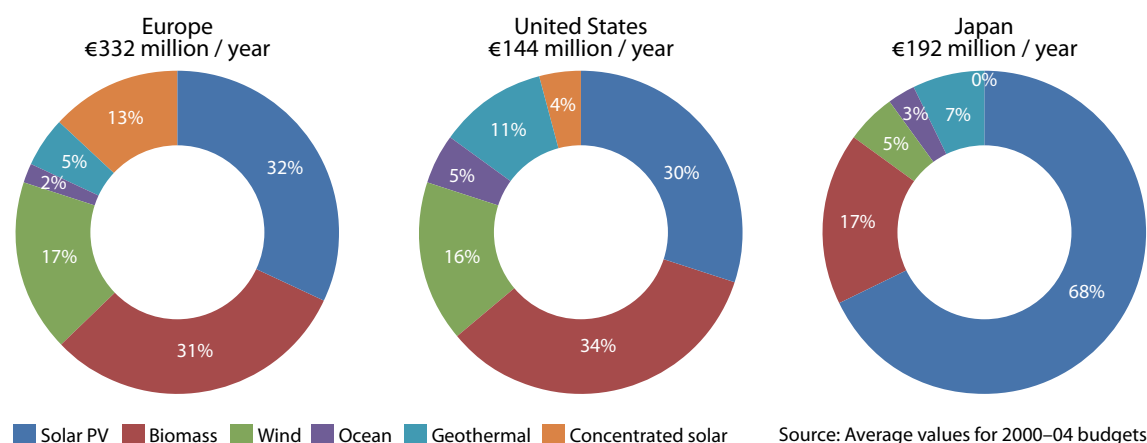
Industrial R&D is part of a firm's competitive activities and therefore private sector R&D is often focused on bringing new products or existing products to market at a lower cost and with better quality. Since government programs are less subject to the competitive pressures induced by the market or by the investors, government programs are compelled to put more effort into generating new ideas and exploring ideas fully, and not dropping an idea after a short investigation because it may not appear economically attractive. Especially in the area of low-carbon energy technologies, various options must be explored and structured R&D plans developed to determine the effectiveness, costs, and environmental and social effects of each option.

Government has been playing a crucial role in the development and distribution of renewable energy technologies. The share of corporate R&D in some of the relatively mature technologies, such as wind energy, bio-fuels and crystalline silicon photovoltaics (PV) is increasing, but other technologies such as other types of PV, concentrating solar power, hydrogen and fuel cells still remain in the basic R&D stage. For renewable energy to supply a significant fraction of future energy needs, technical breakthroughs and cost reductions are required. For example, PV technology has the potential to supply a major fraction of the world's electricity needs in the long term, but the contribution to the electricity supply before 2030 is expected to be less than 1 per cent²⁵. Even though the crystalline silicon system is well into the market, this was only possible through government support via various routes such as feed-in tariffs. For PV to be market competitive, a series of huge leaps in technological breakthroughs has to be made to reduce the cost, through developing new systems and new materials such as dye-sensitised cells and organic photovoltaics. These technical breakthroughs will only be possible with continued long-term support by government.

In the process of government R&D planning, however, decision makers tend to select the technology that has the more reliable outcome. For example, one can compare R&D budgets in renewable energies in the US, the European Union (EU), and Japan as shown in Figure 1. Even though the development priorities are different, Europe and the US placing a comparable degree of priority on PV, biofuel and wind energy, while Japan concentrates its efforts on PV, the general categories of technologies being developed are very similar. Governments need to expand the portfolio and spend more of their funds to explore and develop new and innovative ideas.

²⁵ The state and prospective of European energy research – Comparison of commission, Member and non-member state's R&D portfolios, European Commissions (2006)

Figure 1 Comparison of key renewable energy research portfolio structures



One such effort is found in the US Department of Energy’s Advanced Research Projects Agency – the Energy Program, which is set up to support the generation of new and innovative ideas and high risk basic research. The goal of ARPA-E is to create transformational new energy technologies and systems by focusing on high-risk, high-payoff concepts in reducing fossil energy dependence, reducing energy-related gas emission, and improving energy efficiency²⁶. ARPA-E’s plans to fund transformational technology R&D efforts both in early stages, focusing on drawing a discovery or invention out of the laboratory, and in late stages, developing immature technologies to the point that all the key technical risks have been reduced for the final stages of development. The first round of 37 projects was funded in October 2009.

GOVERNMENT ROLE IN DEMONSTRATION AND DEPLOYMENT

It is important that R&D, in the full range of potential innovative new technologies, continues to the demonstration and deployment stages through government support. Even though the decision to put a technology in demonstration and deployment for commercial use can be better made by the private sector, the decision is often impeded by the large investment needs and uncertainties of the operation and the market. When the technology is the first of its kind such as CCS, the level of uncertainties tend to increase several-fold along with the cost. Only government support and leadership can bring such technology to demonstration and generate the knowledge needed for commercialisation.

Landsberg et al.²⁷ cautioned that a commitment to demonstrate or commercialise a technology, especially at a large scale, is a decision that runs a risk even for the government. The demonstration technology must not be selected for the sole reason that a large amount of R&D funding has been spent. The projects that are judged to be too expensive to deploy should also be excluded. Demonstration projects have to be selected with great care based on expert advice on economic as well as technological merits.

GOVERNMENT ROLE IN COMMERCIALISATION

The decision to commercialise a technology must be market-driven in most cases. In the low-carbon technologies, however, climate issues and environmental and social benefits override market issues. In commercialisation, involvement of the private sector is important in order to move the technology at the right time and at the right pace. Government must create stimulating environments for the private sector to invest by establishing financing options, risk-share arrangements, market incentives, as well as supporting policies such as a carbon tax.

26 http://www.semi.org/en/Press/CTR_029643

27 http://www.semi.org/en/Press/CTR_029643

INTERNATIONAL COOPERATION

Energy and climate issues are not a concern only of one country or region but a concern shared by the world. More international cooperation is needed in the area of climate and energy issues, especially in the area of rapid deployment of low-carbon technology. Through international cooperation, the knowledge of the basic science and technology is shared, and governments can share the burden of investing on large demonstration projects.

CONCLUSIONS

There are many technologies that are, or might be, available for reducing emissions of CO₂ in the course of electric power generation and its use. The various learned Academies that comprise members of the engineering and technology professions contain the highest levels of expertise that will be needed for the objective evaluation, selection and deployment of these technologies. As a result, there are significant incentives and opportunities for CAETS to undertake collaborative work to facilitate the timely and cost-effective deployment of low-carbon generation technologies.

There are massive technological and financial challenges involved in reducing greenhouse gas emissions from electricity generation. These reductions need to occur in an environment where the electric power needs of the world are bound to increase. Energy conversion chain analysis is critical to strategies for improving efficiency of energy use. The likely outcome is that electricity will displace fossil fuels for transportation and that electricity will increasingly become the energy carrier of choice, including potentially for road transport. In other words, there will be a movement towards an 'Electricity Economy'.

Various reports, including several from individual Academies of engineering and technology, say that implementing low-carbon technologies will be expensive and involve high uncertainty and risk. In some cases uncertainty and risk will deter deployment. Users will pay a substantially higher price for the same service. The analysis of costs and risks will be an important contribution to future technology selection and deployment.

The current risk/return profiles of some technologies preclude significant investment by private companies. Certainty about market conditions is important to foster commercial development, including commercial-scale demonstration. The global nature of the required response to climate change, the technology risks involved and the long timeframes for technology development all indicate the need for government involvement and support for the long-term strategic development of new low carbon technologies. It is important that research and demonstration continues on the full range of potential innovative new technologies through government support.

Despite the common global objective of reducing emissions, each country will draw differently on the available portfolio of technologies. Developing economies will actually show the fastest growth rates in energy requirements. They will be forced to rely for some time on fossil fuels but will have great scope for improving on energy conversion efficiencies through new technologies.

The overall global technology outlook is that more efficient combustion technologies, carbon capture and storage, nuclear power and renewables will all have a place in future low-carbon electricity generation. More efficient production of biofuels will occur. There will be national variations of the proportions that each technology contributes but the global picture indicates a continued reliance on fossil fuels, with some nuclear, over at least the medium term, that is, up to 2030. Nuclear power will make an increasing contribution to the energy mix and there will be a particular need for small nuclear reactors.

It needs to be recognised that the inherent low density of renewable power generation will restrict its deployment due to its mismatch with an increasingly concentrated demand. The high intensity of generation from fossil and nuclear fuels is well suited to engineering supply systems and this represents a substantial barrier to adoption of alternatives.

Intermittent renewable energy sources like wind and sun pose special problems for electricity grids. To deal with these, the architecture of many existing grids will have to change. Classical networking technology could be complemented by an “Internet of Energy” as a controlling element. This will rely heavily on the availability and implementation of appropriate standards. There will be an additional layer of complexity to electrical energy supply, which must be designed to ensure that the reliability of electrical grids is not put at risk. Some issues to do with individual privacy need to be addressed early in discussions of such smart grids.

Most studies conducted by the member Academies have, along with IEA, identified that reducing demand for energy, especially via improved efficiency of end-use, is the most cost-effective and immediately deployable means of reducing carbon emissions to combat climate change, and is applicable internationally. Global deployment of existing best practice in energy efficiency can deliver major reductions in carbon emissions. Demand reduction measures should start with deployment of best practice and best available technologies. From a system engineering viewpoint there is a strong case for urging that each development or deployment of a low-carbon electricity supply capacity should be accompanied by complementary demand reduction measures.

COUNTRY REPORTS



AUSTRALIA

Introduction

Australia had 50.8 GW capacity of grid-connected generation in 2009 [1] and its current electricity energy generation profile is given in Appendix 1 [2]. Australia's national inventory of greenhouse gas emissions was an estimated 537 Mt CO₂-e (million tonnes of carbon dioxide equivalent) in 2009 [3]. This is a decrease of 2.4 per cent compared with the corresponding period for the previous year. Electricity production contributed some 202 Mt CO₂-e in 2009. Australia emits some 20 tonnes of CO₂-e per person per year. This is one of the highest rates for developed countries and is comparable to that of Canada and the USA.

Australia's low-emissions technologies

By 2050, Australia's low-emissions generation portfolio will probably include most or all of the following proven technologies: clean coal; carbon capture and storage (CCS); oil; natural and coal seam gas; biomass and biofuels; nuclear; geothermal; solar (photovoltaic and thermal); wind; waves and tides; small scale distributed energy systems; energy storage; and far better end use energy management. The share of each in Australia's low-emissions future will, like all such countries, be a matter for intelligent research policies, international collaboration on the accelerated development of commercial IP and of course economics – including the price of carbon and other externalities. It must be noted that present Australian government policy does not permit consideration of domestic nuclear power although uranium oxide (yellowcake) is permitted for export. This position may change in the future.

Australian energy policies, programs, responsibilities and implementation

Ministerial responsibility is devolved to four specialist departments, each with its own bureaucracy.

The Australian Government has proposed an Emissions Trading Scheme; however, this has not yet been enacted by Parliament.

At the time of writing, a Commonwealth Energy White Paper is still under preparation. Significant ATSE input is being provided through externally funded specialist ATSE reports and focussed ATSE workshops. The latter, in which key politicians, senior bureaucrats and policy makers as well as international contributors are invited to explore and debate policy issues, are proving especially valuable in this process. ATSE is increasingly being recognised as a source of credible, apolitical, independent high level expertise.

Australian low-emissions policy framework

The Australian policy support framework relevant to low-emission technologies currently includes the following overarching policies and supporting targets:

- A medium-term target of 20 per cent national energy from renewable (i.e. low-emission) sources by 2020 (equivalent to an additional 45,000 GWh per annum (~ 25 MWe installed at 20 per cent capacity factor). This important target is facilitated by legislation. Renewable Energy Certificates (RECs) each worth 1 MWh are issued to producers of solar hot water, solar PV and on- and off-grid wind power systems. Energy retailers are required to purchase a prescribed number of RECs. The

REC system was originally implemented to encourage an additional 9,500 GWh of RE generation per year by 2010. RECs will now play a greater role in the above 2020 target which requires 45,000GWh/a to be delivered through the new Solar Credits Program.

- A long-term notional target of 60 per cent (the figure of 80 per cent has been canvassed) CO₂ reduction from 2000 levels by 2050.
- Numerous Commonwealth and State programs targeting sustainable energy RD&D with grant support including:
 - Generation 2 Biofuels program
 - Domestic solar PV and hot water
 - Roof insulation (as part of the economic stimulus program)
 - Energy efficiency program (more to follow)

Australia's RD&D policies and programs

Before commenting on Australia's position in each of the above domains it is first useful to present an overview of the prevailing policy environment. The Australian Government in 2009 committed an additional \$4 billion to Clean Energy Technologies over nine years. Most importantly the Australian Government's Clean Energy Initiative (CEI), launched in 2008, has funded major program elements:

1. CCS Program

A\$2.4 billion to demonstrate large-scale integrated CCS projects including gasification, post-combustion capture, oxy-firing, CO₂ transport and storage, including establishment of the \$A100 million per year Global Carbon Capture and Storage Institute (GCCSI) – see 4 below.

2. Solar Program

A\$1.6 billion to demonstrate large-scale solar power stations including solar thermal, PV and energy storage technologies including establishment of the \$A100 million Australian Solar Institute (ASI) – see 5 below.

3. Australian Centre for Renewable Energy (ACRE)

A\$465 million to promote commercialisation of renewable energy technologies through private investment.

In addition there are a number of very tightly focused programs, for example the A\$15M Generation 2 Biofuels Program with other programs at both federal and state level to foster specific opportunities.

4. Global Carbon Capture and Storage Institute (GCCSI)

The GCCSI, funded to A\$100M per year by the Australian Government, aims to:

- accelerate commercial deployment of CCS;
- become a key voice in climate change debate;
- facilitate global CCS RD&D co-operation;
- deploy projects and build confidence in CCS technologies where fossil fuels are part of the national energy mix; and
- encourage global collaboration to inspire confidence and make CCS commercial reality where it is appropriate.

5. Australian Solar Institute (ASI)

The ASI, which received A\$100M by the Australian Government (as part of a \$150M Energy Innovation Fund over four years), aims to:

- enhance collaboration between Australian and international researchers in solar energy;
- support RD&D of Australian solar thermal and solar photovoltaic technologies;

- provide an initial A\$15M for three foundation projects:
 - crystalline silicon pilot production line – University of NSW;
 - solar thermal generation – CSIRO Newcastle; and
 - solar research facility – Australian National University.

Selected Australian low-emission technologies RD&D programs

This Country Report concludes with a number of examples of the leading RD&D activities current in Australia focussed on the further development of commercially attractive low-emissions technology. As noted elsewhere, and reiterated here, Australia sees international cooperation in this domain as essential if these and related technologies are to become widely taken up by industry for universal deployment.

1. Clean coal technologies

CSIRO Pullenvale in Queensland is centre to the Low Emissions Electricity and Competitive Coal for Australia (LEECC) program. This supports a high quality RD&D team focused on low-emissions electricity and competitive coal markets for Australia in view of the huge potential for GHG reductions. The quality of the research work, the growing strength of national (and international) collaborative research links and the substantial industry support are testament to the quality of the research team and the importance of its work. However definitive estimates of the installed and operational technology costs for CO₂ capture to final storage remain to be demonstrated. The imposition of externality costs (through some form of international carbon tax or trading regime) is expected to become a reality if climate change indicators continue to support response policies embodying economic instruments.

The ‘clean coal’ RD&D initiative is thus of huge importance to Australia’s coal industry, not only to meet domestic emission reduction targets but also to seek export opportunities for technologies to other economies. Key elements of the RD&D program include:

- Coal gasification – using the reaction of coal with oxygen and steam to create a mixture of carbon monoxide and hydrogen (syngas). Gasification is also used to produce chemicals, liquid fuels and hydrogen from hydrocarbon feedstocks and associated research includes aspects of coal conversion behaviour, reactivity, and slag formation and flow. Gasification is a key enabling technology for advanced, high-efficiency, low-emission power generation.
- Integrated Gasification Combined Cycle (IGCC) – syngas for generation. Costs of IGCC are higher than conventional technology and further cost reductions are still needed.

This RD&D provides a sound basis for hydrogen energy systems and CO₂ capture and storage, essential to development of near-zero-CO₂ emission technologies. Specific RD&D projects include:

- Pressurised Entrained Flow Reactor (PEFR) – to measure high pressure, high temperature coal conversion reaction processes;
- coal and char reactivity – to explore gasification reactions at high temperatures and pressures to provide data for process design and optimisation;
- coal slag flow evaluation – to examine the flow behaviour of PEFR slag, particularly temperature and composition for optimum viscosity. Strategies for gasifier operation and coal selection, blending and fluxing derive from this research;
- syngas cleaning – developing innovative technologies to overcome limitations in existing advanced but unreliable coal gasification processes, including advanced techniques for cleaning candle filters and gas cleaning using agglomeration and sorbent techniques;
- syngas processing – RD&D into the water gas shift (WGS) reaction between carbon monoxide and steam which generates carbon dioxide and hydrogen (syngas). This is a key step in hydrogen and liquid fuel energy systems, also in production of high pressure CO₂ streams suitable for capture and storage; and
- oxy-firing.

2. Carbon capture and storage (CCS)

Australia relies upon coal for over 80 per cent of its domestic electric power generation and also for massive exports. With the high level of investment in coal mining, coal for power generation and coal for export, it is inconceivable that by 2050 coal will not still remain a cornerstone of power generation. If low emissions targets are to be attained the twin technology thrusts of clean coal and CCS must be high RD&D priorities.

Given that coal is perceived as 'dirty', inevitably involving combustion to carbon dioxide, it is understandable that very considerable RD&D effort is already deployed in the clean coal domain. Here the 'holy grail' must be the reduction or even total removal and subsequent permanent storage of the carbon dioxide (and other unwanted pollutants such as particulates) by improved combustion processes, by better control and management of the combustion process and by capture of the carbon dioxide produced. Carbon dioxide removal may be via its transformation into a raw material for the production of transport biofuels, or its treatment and transfer to permanent underground storage.

Australia's Carbon Dioxide Cooperative Research Centre (CO2CRC) is one of the world's leading collaborative research organisations focused on carbon dioxide capture and geological sequestration, or geosequestration, to reduce emissions to the atmosphere of the greenhouse gas carbon dioxide. More than 100 researchers in Australia and New Zealand are collaborating to develop safe and economical CO₂ geosequestration technologies that will make deep cuts in Australia's greenhouse gas emissions. The CO2CRC has three main research programs. Further detail can be obtained via the links to the CO2CRC website listed below:

- capture of CO₂ – aiming to demonstrate technologies that will reduce the costs of capturing CO₂ by 75 to 80 per cent;
- storage of CO₂ – studying sedimentary basins and identifying regions and sites in Australia and New Zealand best suited to safe, deep sub-surface storage of CO₂; and
- demonstration and Pilot Projects and Regional CO₂ Strategies – demonstrating that geosequestration is a viable option for Australian CO₂ mitigation.

3. Solar photovoltaics (PV)

The leading Australian PV RD&D programs are:

- University of New South Wales (UNSW). The UNSW remains a world leader in thin film PV module RD&D, achieving the world's highest efficiency of 25 per cent. Government and industry support has been considerable. Current work includes construction of the Roth & Rau pilot PV line. Technologies under active research at UNSW include:
 - Laser doping selective emitter (LDSE) to achieve lower costs and moderate efficiencies;
 - Patterned etching of dielectrics for high efficiency cells to achieve lower costs; and
 - Passivated emitter and rear locally diffused cell (PERL) to achieve the world's highest PV cell efficiency at 25 per cent.
- Australian National University (ANU). The ANU's leading edge 'SLIVER cell' technology is state of the art has been developed with considerable Government support from previous programs. It has strong industry support as it moves towards commercialisation. The technology dramatically reduces the silicon content of conventional wafer cells and promises efficiencies of 18 to 20 per cent at much reduced cost.
- Solar Systems. Solar Systems, a private company, is a world leader in concentrated PV using dense array converter technology. While PV is expensive, steel and glass are not. The sun's radiation is concentrated 400 times onto the high efficiency PV cell by means of large tracking paraboloidal mirrors. Government program support has been significant but the company is currently in financial difficulty.

4. Solar thermal (STG)

Australia's principal proponent in solar thermal technology development is CSIRO. The Newcastle based RD&D group has secured \$3.35 million in funding under the Commonwealth Government's Asia Pacific Partnership for Clean Development and Climate (APP). This program aims to demonstrate solar-enriched fuels for electricity and transport application. This funding has been supplemented by a commitment of \$7.5 million from the Queensland government towards the construction of the world's first multiple solar tower demonstration project aimed to demonstrate that solar thermal production of solar-enhanced fuels for electricity production can become a cost competitive source of renewable energy.

5. Geothermal exploitation

The deep technology known as hot fractured rock (HFR) is particularly attractive for Australia. The Cooper Basin in South Australia has some of the world's hottest dry rocks at 200°C to 270°C some 3 to 5km below the surface. At that depth, these are the hottest rocks on earth outside volcanic zones. The granites have natural radiogenic minerals producing their own heat, trapped by overlying insulating rock – in effect a natural nuclear reactor. Granites are effective heat sources but must be made permeable to water through fracturing, a complex technology. Australia's main RD&D effort, with very significant Government program support, is aimed at overcoming the problems of very deep drilling, associated hot rock fracturing and efficient heat recovery.

6. Nuclear energy

The sole Australian nuclear research centre is ANSTO, Lucas Heights. Nuclear energy related RD&D undertaken or in hand includes:

- Synroc high level waste (HLW) encapsulation
- High temperature creep resistant materials for Gen IV reactors
- Neutrons for the hydrogen economy
- Titanium for solar cells research
- OPAL research reactor

7. Oil and gas

Australia has limited Government funded RD&D in low-emission technologies related to oil and gas. However there is an increasing focus on coal seam methane (CSM) recovery for power generation.

8. Biomass and biofuels

The primary RD&D activities, apart from biofuels, lie in the co-firing of biomass wastes with coal. Large scale power station co-firing demonstration projects are operational.

9. Second generation biofuels

The 'food versus fuel' challenge of first generation biofuels (ethanol and biodiesel) and the very limited success, and indeed several failures, of substantial investments in plant and production have shifted the Australian RD&D focus strongly to second generation biofuels (G2B) using feedstocks derived from non-food resources. The Government's Generation 2 Grant Program funded to \$15 million, part of its \$500 million Renewable Energy Fund, like all such support funding requires matching contributions from applicants.

Grants awarded in 2009 under this scheme have supported three promising approaches to second generation transport biofuels:

- Production of biodiesel from microalgae using carbon dioxide from power station flue gas, microalgae culture, harvesting, extraction of lipids, refining and conversion to biodiesel and utilisation of non-lipid biomass.

DEPLOYMENT OF LOW EMISSIONS TECHNOLOGIES

- Production of biodiesel from agricultural wastes (sugar cane bagasse, mallee biomass and other sources) by pyrolysis, refining and utilisation of biochar.
- Production of ethanol from sugar cane bagasse through the use of patented yeast strains for fermentation followed by refining and utilisation of lignin.

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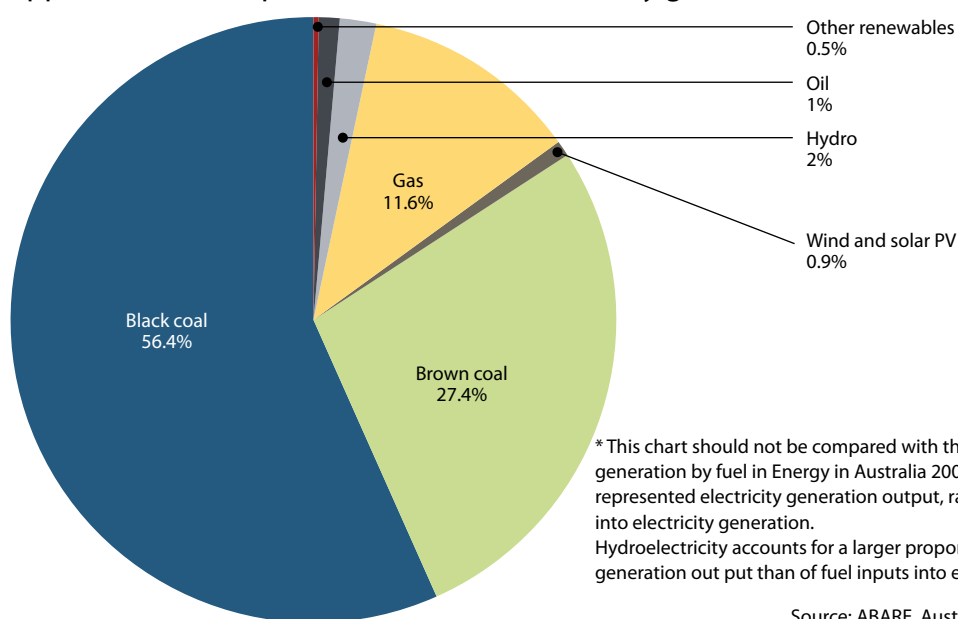
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Appendix 1 Fuel inputs into Australian electricity generation, 2006-07*





CANADA

Introduction

Canada is one of the most energy intensive countries on the planet. There are reasons for this, of course, including the climate in much of the country with long winters and a sparse population with long travel distances between communities. With substantial fossil fuel resources and large hydroelectric power capacity, energy prices in Canada are amongst the lowest in the world, which also contributes to high consumption rates. And, finally, Canadian industry tends to be focussed on the development of primary resources, which is often very energy intensive. Nevertheless, there is substantial potential for improving energy efficiency in order to reduce per capita energy consumption. The remainder of this paper provides a brief introduction to the electricity sector in Canada and outlines a strategy for reduction of greenhouse gas emissions from electrical generation.

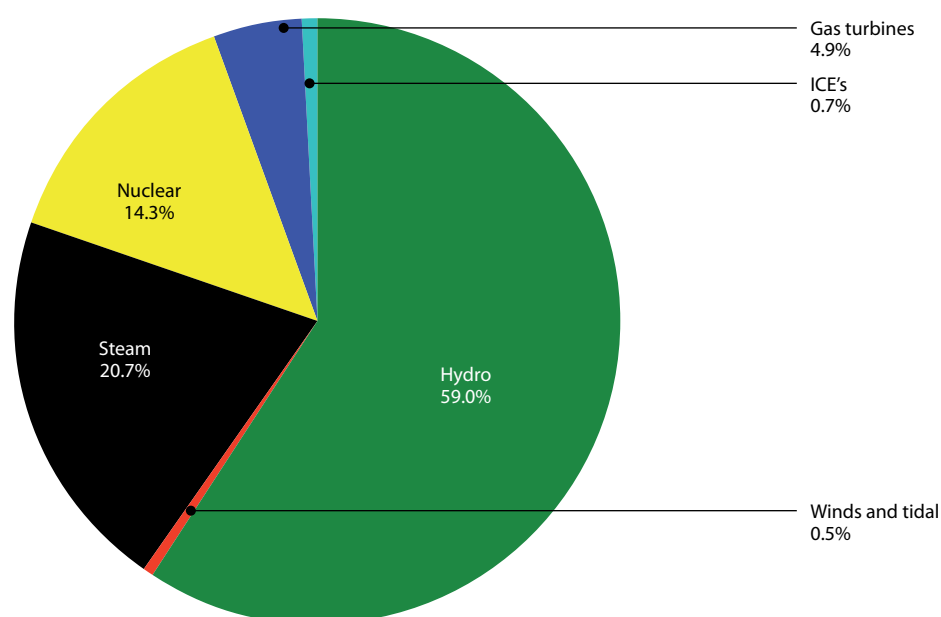
Electricity Generation in Canada

The distribution of primary sources for electricity generation in Canada is shown in Figure 1. It can be seen that nearly 60 per cent of all generation comes from hydroelectric power sources. The country is clearly fortunate to have such large reserves of hydroelectric generation capacity, which makes it second only to China in the amount of hydroelectric energy that is produced annually. Taken together with over 14 per cent of generation from nuclear power, nearly 75 per cent of Canadian electricity production is achieved without producing greenhouse gas emissions.

Canada is a federation, made up of 10 provinces and the three territories of Nunavut, the Northwest Territories and the Yukon. Energy production is a provincial and territorial responsibility, while overall national energy policy is a federal responsibility. Provincial and territorial responsibility includes electricity generation, and the sources of generation vary significantly by province, which can be seen from Figure 2. Hydroelectric generation tends to be concentrated in the provinces of British Columbia, Manitoba, Ontario, Quebec and Newfoundland. In the case of Ontario, which has the largest population

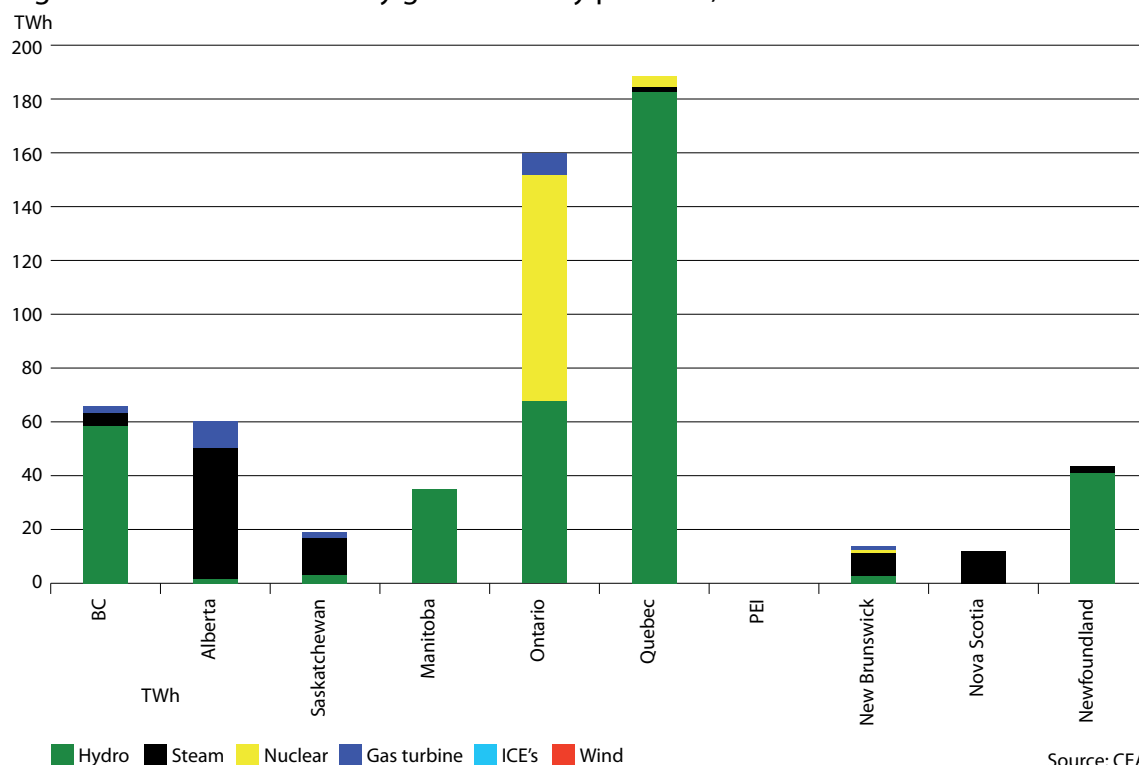
Figure 1 Canadian Electricity Generation by Source - 2007

Total generation = 617,470 GWh



Source: CEA

Figure 2 Canadian electricity generation by province, 2007



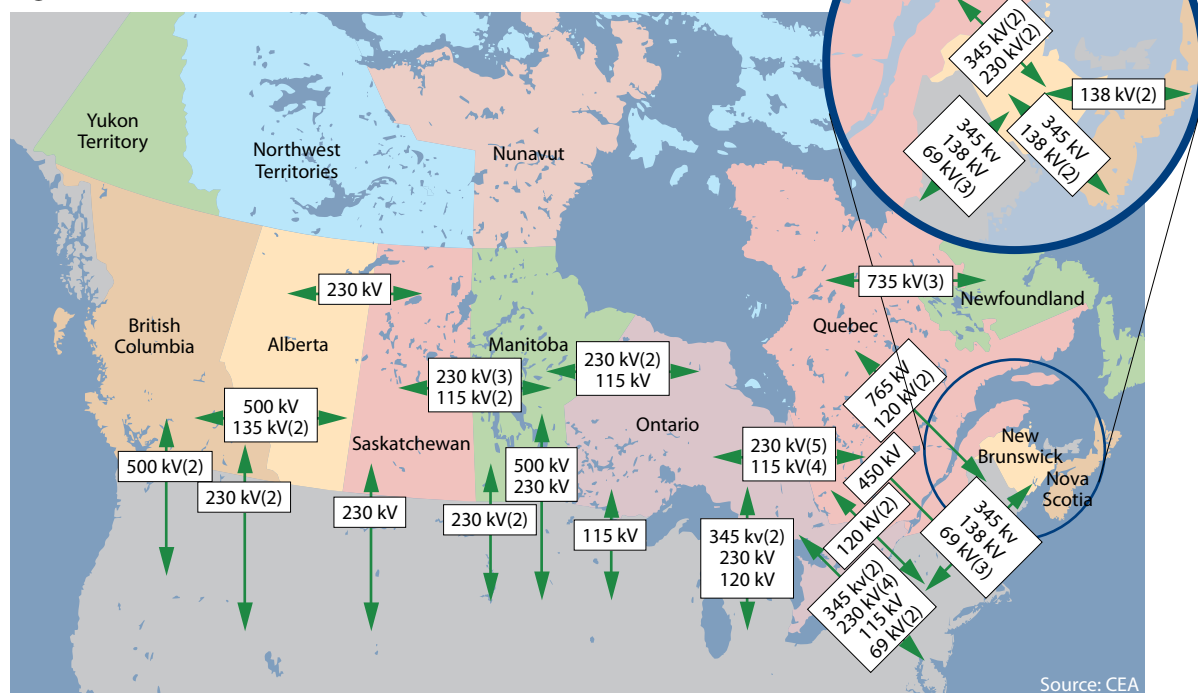
Source: CEA

of any province, nearly all of the potential sites for hydroelectric generation have been developed, while substantial new potential still exists in the remaining four hydroelectric producers. The provinces of Alberta, Saskatchewan and Ontario also rely on significant levels of coal-fired generation, and to a lesser extent so do the maritime provinces of New Brunswick and Nova Scotia. The major hydroelectric producing provinces of Quebec, British Columbia and Newfoundland also export significant amounts of hydroelectric power to the United States. Although wind power is being slowly developed in several provinces, this resource only makes a minor contribution to current Canadian electricity generation. As can also be seen from Figure 2, although nuclear power makes a substantial contribution to electricity generation in the country it is primarily concentrated in Ontario, with much smaller capacity in Quebec and New Brunswick. All of the current nuclear generation is obtained from Canadian developed CANDU reactor systems.

Since Canada is a very large country, and each province tends to be self-sufficient in electricity generation, there is only limited interconnectivity East-West between provinces. There are, however, good connections North-South between most provinces and the United States, as can be seen in Figure 3. In most cases these ties have been built as the result of international power exchange treaties, with most of the export power flowing south to the US from Canada. On the West coast, for example, the provincial utility, BC Hydro exports substantial power down the coast to California, taking advantage of good North-South connections along the US West coast, as well as two 500kV and two 230kV connections across the border between British Columbia and Washington State. In the East, Quebec also exports large amounts of power South, primarily into New York State which experiences large electricity demands to serve the summer air conditioning loads. In this case the North-South connection is particularly beneficial since New York State has a summer-peaking system while Quebec has a winter-peaking system. In this case power-sharing from North to South makes much more efficient use of generation and transmission capacity in both jurisdictions.

Canada at present has more electrical connections with the USA than it has among all the provinces. Several new major interconnections (both East-West and North-South) are being considered by various

Figure 3 Transmission connections from Canada to the US



planning authorities [1].

Policies for Reducing Greenhouse Gas Emissions

As can be seen from the summary above, nearly 75 per cent of the electricity produced in Canada is generated without any greenhouse gas emissions. The focus on further reductions in GHG emissions must therefore be in those provinces, such as Alberta, Saskatchewan, Ontario, New Brunswick and Nova Scotia which currently rely on coal-fired generation for much of their electrical power. Development of clear policies and procedures for increasing the percentage of sustainable electricity generation is complicated by the fact that there are 14 different policy and regulatory jurisdictions involved, including the federal government, ten provinces and three territories. These complications are clearly illustrated in Table 1, which summarises recent statements from the federal government and most of the provinces outlining the greenhouse gas emission targets that each jurisdiction has proposed. For example, in response to the recent Copenhagen accord, the Government of Canada has announced a target for GHG reductions of 17 per cent below 2005 levels by 2020, which is in line with a similar statement from the United States government. The federal government argues, with some justification, that in order for Canada to remain competitive its GHG targets must be in line with those of the US which is by far Canada's largest trading partner. It can be seen from Table 1, however, that several provinces have announced targets which are substantially higher than those of the federal government. It remains to be seen how all of these targets may (or may not) be aligned in the years to come.

Strategies for Reducing Greenhouse Gas Emissions

There are substantial new resources of hydroelectric generation available in several provinces, particularly British Columbia, Manitoba, Quebec and Newfoundland & Labrador. In addition, Canada has a well-developed capability for designing and building CANDU nuclear power plants. Any strategies for further reductions in GHG emissions from the electricity sector will very likely rely on further developments of these two established technologies. In addition, since wind-power has now reached the stage of mature technology, wind will likely account for a small, but increasing, contribution to new electricity generation in Canada. Although tidal power is being examined on both coasts, since the state of development is still at a very early stage it will likely be some time before ocean energy makes any

Table 1 Canadian greenhouse gas targets

Canada	17% below 2005 levels by 2020
British Columbia	20% below 2007 levels by 2020 80% below 2007 levels by 2050
Alberta	14% below 2005 levels by 2050
Saskatchewan	20% below 2005 levels by 2020
Manitoba	Below 1990 levels by 2012
Ontario	15% below 1990 levels by 2020
Quebec	20% below 1990 levels by 2020
PEI	???
New Brunswick	to 1990 levels by 2012
Nova Scotia	10% below 1990 levels by 2020
Newfoundland	???

significant contribution to Canada's electricity generation. The major barriers to development of new large hydroelectric and nuclear generation capacity in Canada will be primarily financial and political, rather than technological. With substantial hydroelectric potential in several provinces, one strategy could be the construction of new large-scale hydro plants in these provinces with the objective of displacing coal-fired power in other provinces. This would require additional transmission power across the country, however, which at the present time is severely limited by very weak East-West transmission capability and a lack of electrical synchronisation across the country. In some cases utilities might prefer any new large scale generation to be directed primarily for export to the US using the well-established North-South transmission corridors. In order to counter this tendency and direct new generation towards displacing coal-fired power in Canada there would have to be a major initiative to expand and strengthen East-West transmission capacity in Canada. This topic is the subject of a separate CAE study, which will be published in the near future.

Summary

Canada is fortunate to have nearly 75 per cent of its electricity produced without any greenhouse gas emissions. This fraction could be expanded by building new hydroelectric and nuclear capacity, and by building a new cross-Canada transmission capability with strong inter-provincial connections. The barriers to reducing GHG emissions from electricity generation in Canada are primarily financial and political, rather than technological. Better integration and coordination of the various GHG targets and energy policies across the country could enable Canada to make a significant contribution to the reduction of GHG emissions from electrical generation.

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GERMANY

The decline in Germany's primary and final energy consumption

For a number of reasons Germany's primary energy consumption has decreased in the past two decades, both on a per capita as well as on a GDP basis. This trend contains some one-off effects resulting from Germany's reunification but is also a consequence of continued efforts to increase energy efficiency in both private households and transportation as well as in industrial processes and power generation.

Figure 1 Primary energy usage in GJ/per capita (PEV/Einwohner) and GJ/1,000€ (PEV/BIP, in year 2000 prices) for the period 1990 to 2008

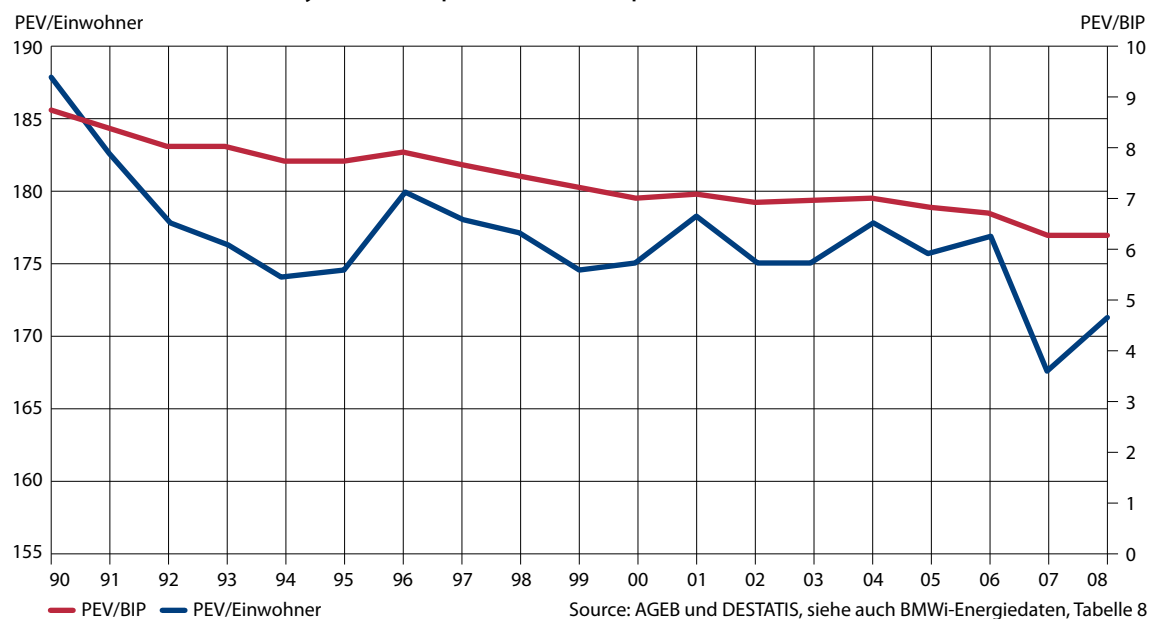
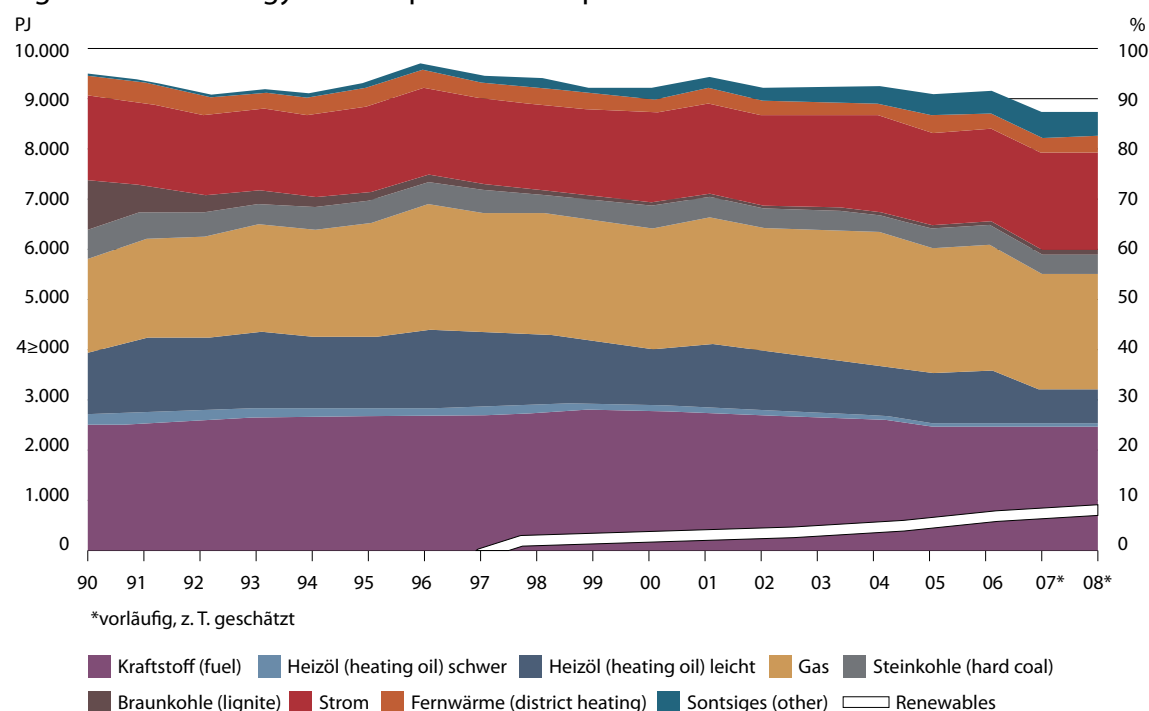
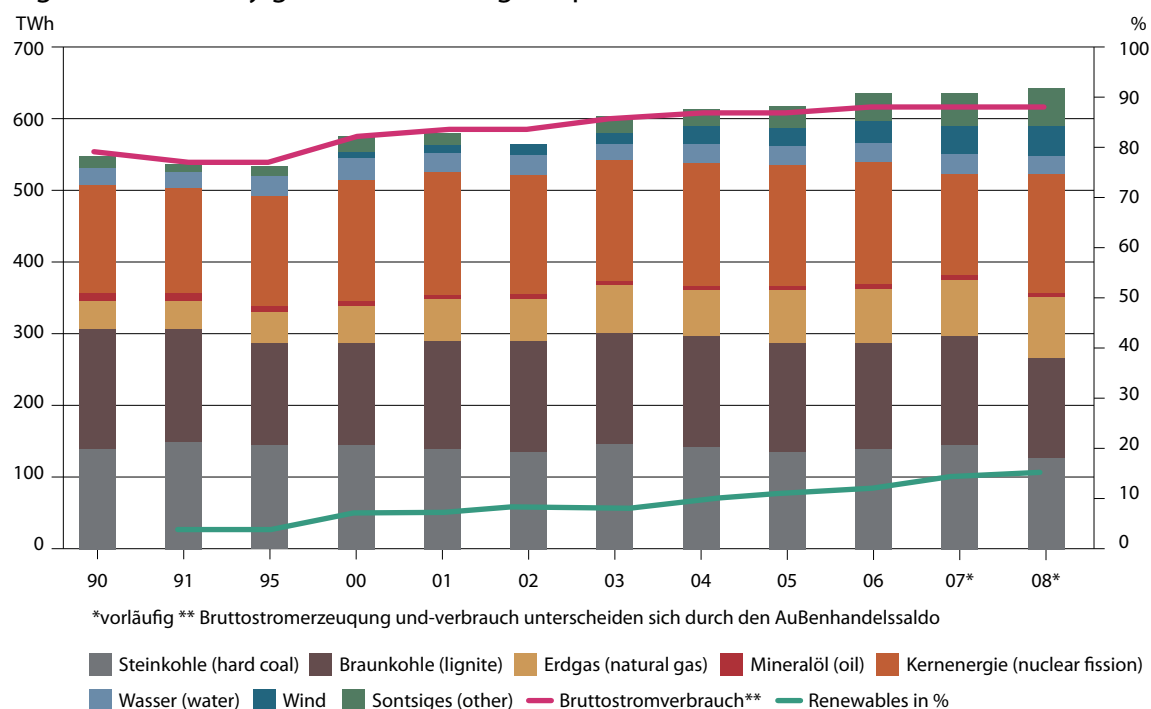


Figure 2 Final energy consumption for the period 1990 to 2008



Germany's final energy consumption has also been gradually decreasing over the last two decades (see Figure 2). The current situation is still dominated by fossil fuels, with a steady increase in the share of renewable energy sources, up from 2.9 per cent of final energy consumption 1997 to 9.4 per cent in 2008.

Figure 3 Electricity generation during the period 1990 to 2008



Source: BDEW, siehe auch BMWi-Energiedaten, Tabelle 22

Increasing role of electricity in the energy mix

The overall contribution of electricity to final energy consumption has been steadily increasing over this period of time. One of the driving forces behind this observation has been the increasing contribution of renewable energies, where mainly electricity is generated as final form of energy. This increase is also consistent with expectations of an “electrified society” in the long-term future, driven both by a continued increase of renewables in the energy mix and a strong increase in nuclear power usage.

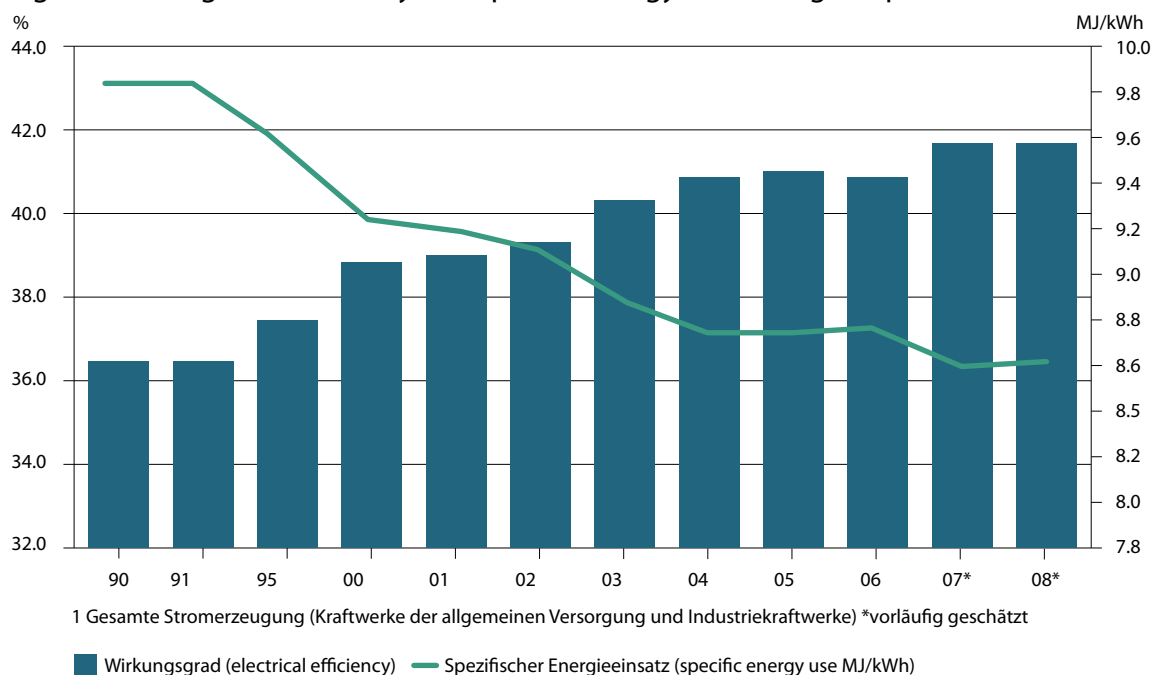
The changes in Germany with respect to the technologies for generation of electricity are shown in Figure 3. Renewables contribute roughly 16 per cent of electricity generated while about 29 per cent is of nuclear origin.

The combined heat and power (CHP) sector is still dominated by natural gas and hard coal. These systems contribute about 12 per cent towards the overall generation of electricity, with a political aim of 25 per cent in the upcoming decade.

Emissions of greenhouse gases especially CO₂ are closely coupled to the overall efficiency of power stations. This efficiency has been increased significantly by two means: retrofitting of older systems, together with a substantial quantity of newly built power plants, especially in eastern Germany (the former GDR). This one-off effect is easily seen in the very steep decrease in the specific use of energy over the first decade, as shown in Figure 4, which shows both the increasing efficiency and the continuing decline in the specific input of primary energy.

While there is good progress in Germany in relation to power plants and heat usage in industrial applications (reduction by 3.2 per cent per annum), the industrial sector still offers significant potential

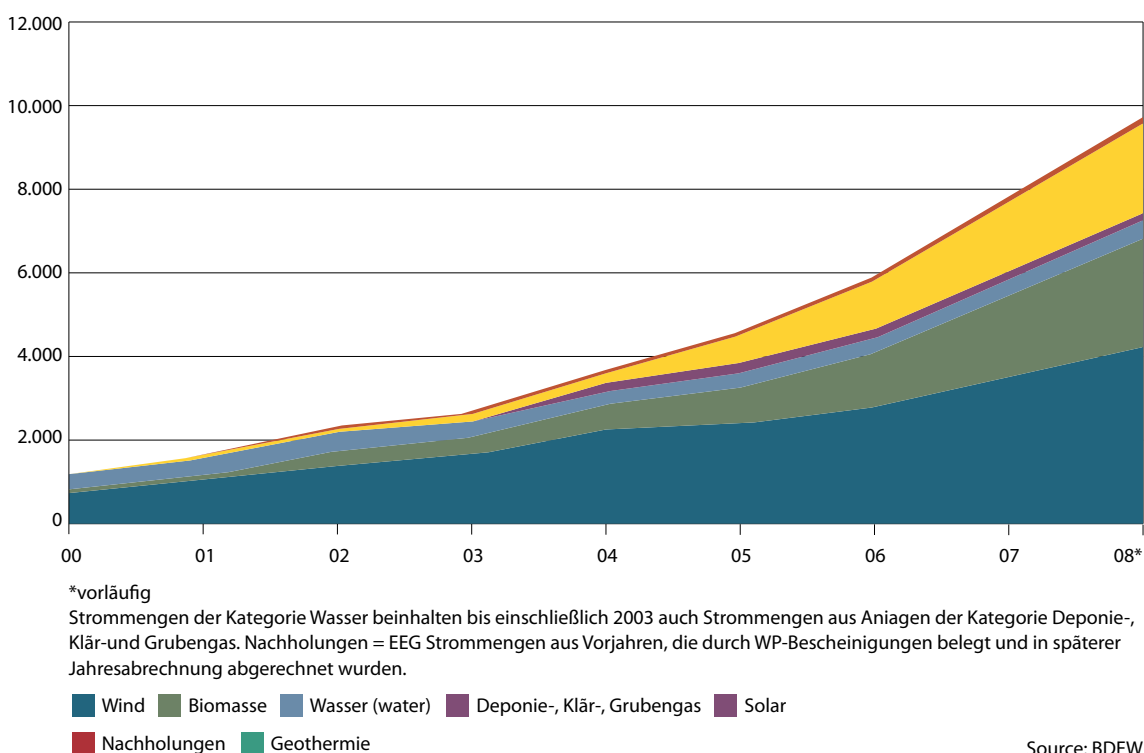
Figure 4 Changes in efficiency and specific energy use during the period 1990 to 2008



Source: Berechnungen von EEFA nach AGEB und DESTATIS, siehe auch BMWi-Energiedaten, Tabelle 8

for improvement in the field of electrical energy efficiency per gross production value (presently reducing by 0.9 per cent per annum). Energy efficiency is often less than optimal because capital and operating costs are often considered in separate investment budgets and life-cycle costs are not properly evaluated in the acquisition process. Consequently if industrial electrical energy usage and greenhouse gas emissions are to be further reduced, this issue must be addressed quickly and carefully.

Figure 5 Annual costs (€ million) as a result of the EEG feed-in tariff



Source: BDEW

The role of renewables in decreasing overall greenhouse-relevant emissions

One means by which Germany tackles the overall reduction of emissions connected with supply of electrical energy is the strong promotion of renewable energy. Legislation in this field is based on the so-called EEG (Renewable Energy Law) introduced in 2000. Here preference is given to electricity generated from renewable sources by making it mandatory for grid operators to accept the electricity feed-in from these sources and by defining specific prices per kWh depending on technology and year of construction (for a period of 20 years). The additional costs are added to the price per kWh and paid by the customers (see Figure 5). This add-on today represents roughly 10 per cent of the price per kWh.

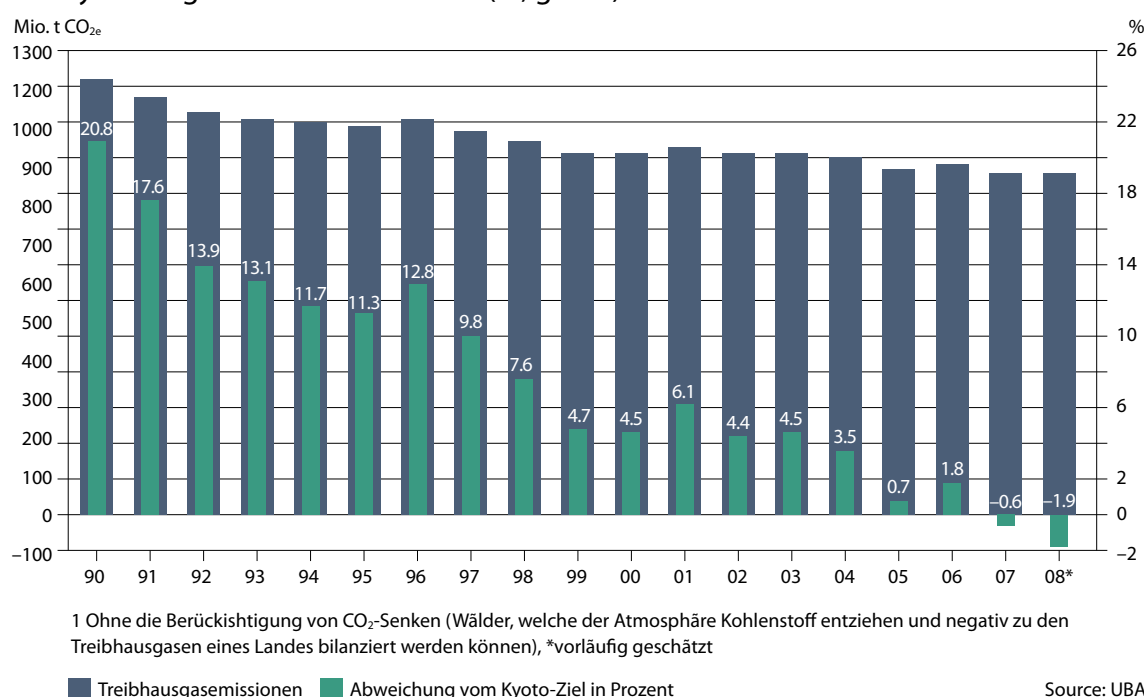
While photovoltaics are only responsible for a very small part of the overall generation of electricity the amount of money spent via the feed-in tariff is significant. Especially in the years 2008 and 2009 much more PV elements were installed than expected due to a fast drop in prices of the equipment compared to the amount paid via the tariff. This will result now in a burden to the consumers for the upcoming two decades. In 2010 a strong adjustment of the feed-in tariff for PV will be implemented.

Future development of greenhouse-gas emission measures

Within the Kyoto protocol Germany accepted the obligation to reduce its emissions of greenhouse gases by 21 per cent in 2012, with 1990 as the year of reference. The intermediate goal for 2008 was exceeded by 1.9 per cent (see Figure 6).

Most GHG emissions (85 per cent or 799 out of a total of 945 million tonnes CO₂ in 2006) are related to energy conversion processes. Power plants contribute 46 per cent, transportation 20 per cent, industry 15 per cent, households 13 per cent and various other sources 7 per cent to this total of 799 million tonnes of CO₂. While energy-related reconstruction within the former GDR helped a lot in the early part of this reduction effort, in more recent years the decrease has become slower – the low-hanging fruit has been harvested already. Future goals in this field should be set very carefully and should not assume that the reduction rates of the early years will be maintained in the future.

Figure 6 missions of greenhouse gases (million tonnes CO₂, blue) and deviation from the Kyoto target on an annual basis (% , green)



Conclusion

Germany has been successful in reducing GHG emissions related to the generation of electricity in the last two decades. The numbers achieved are in part a result of one-off effects caused by Germany's reunification. Because 85 per cent of the GHG emissions are energy-related and the large inventory of power plants has already undergone significant refurbishment in recent years, further decreases in these emissions will be slower. No single field of application or technology will dominate the future approaches to this problem. To find an economically reasonable package of measures we need tools allowing reliable, full life cycle evaluation of various technology paths.

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INDIA

Deployment of Low Emission Technologies for Electric Power Generation in Response to Climate Change – Indian Perspective

Climate change and global warming caused by greenhouse gases (GHG) are considered the biggest threat to our planet and sustainable energy (SE) with low emission technologies for electric power generation has come to centre stage. Now that the Kyoto Protocol is revisited with pressure on India and China to limit emissions the challenge is compounded for these economies. While sustainable energy is a necessity, achieving it and making it viable from technological, economical and social view point is a typical Indian challenge. Technology development encompasses research, development and deployment (RD&D) and the policy should facilitate this route effectively to meet the energy needs of the citizens in a sustainable manner. We must exploit all energy sources. Prioritisation and eliminating some is not desired. Each expert thinks that his area must get priority.

India has most of the energy sources, both conventional and renewable. It is a paradox that while conventional energy is available but not sustainable, renewable energy is sustainable but not available in the context of quantities and economies. The effort must focus on making conventional energy sustainable and to facilitate the maximum availability of renewable energy. Manifestations of energy, central to quality of life, are electricity, heat and motion whose sustainable delivery has become imperative. Current status in this front projects mixed signals. India plans to increase the generating capacity from the current level of 160GW to 1300GW by 2050 (in 40 years) to meet the needs of its growing population and economy. This is a gigantic and challenging task compounded by the need to achieve the goal with reduced emissions.

From Indian context following issues are relevant:

- grid-fed systems;
- off-grid systems; and
- energy efficiency.

India has made considerable efforts towards low carbon technologies for power generation. "The Integrated Energy Policy" document of the Planning Commission brought out in 2008 lists many specific recommendations to achieve this goal; some of these are being pursued. It states: "To ensure adequate supply of energy India will have to pursue all available fuel options and forms of energy, both conventional and non-conventional/renewable". India cannot have the luxury of omitting any form of energy since as per the statement of the late Dr Homi Bhabha: "No POWER is costlier than 'No POWER'".

India has launched the solar mission with a target of 20GW from solar energy by 2020. India has also embarked on a special rural electrification program (RGGVY) aimed at total electrification of villages across the country. India perhaps is the only country to have a separate ministry for new and renewable energy sources (MNRE) aimed at exploiting renewable energy in a coordinated manner. Ministries of power, oil and gas, atomic energy, coal, railways etc. deal with different aspects of energy. The public sector undertaking such as National Thermal Power Corporation (India) (NTPC), National Hydroelectric Power Corporation Ltd (India) (NHPC) and National Petroleum Council (NPC) are respectively dealing with conventional energy such as thermal, hydro and nuclear power. Central Electricity Authority coordinates power generation, transmission and distribution. Power Grid Corporation of India (PGCIL) is responsible for the national electricity grid. National Energy Fund of Rs. 1000 Crores to support R&D in energy is being proposed. Such a fund must be created soon with a proper management structure to disburse and manage the funds at the national level.

It must be emphasised that the technology adaptable to India must be India-Centric, and that it may be at variance with those required for developed countries. India may need global support in developing such technologies suitable for developing countries.

Grid-fed systems mainly use conventional energy sources such as fossil fuels, (coal, oil, gas etc) large hydro and nuclear. The challenge is to make such power generation with less carbon emissions. Clean coal technologies are talked about but not yet implemented. Clean coal technologies (ultra supercritical and coal gasification) are the areas being pursued. CO₂ capture, storage and utilisation should be addressed. India is blessed with abundant coal but the major drawback is in its ash content (40 per cent plus) and excessive amount of alpha quartz content. These two parameters pose challenge for designing ultra super critical plants or Integrated Gasification Combined Cycle (IGCC) technology. Since these challenges are very unique to India, efforts are currently devoted to designing an India centric ultra super critical plants using appropriate metallurgy and also IGCC plants using most suited gasification technology. These are currently at a conceptual stage and collaboration at the global level will be necessary to quickly build these plants. Even in case of carbon capture and storage, the nature of Indian geology (sedimentary rock verses basaltic) and thickly populated land mass would necessitate the design of safe high pressure storage of CO₂ in geological formations and in the areas which are prone to secondary seismic activities.

Nuclear Energy has many local issues with global restrictions. The recent Indo-US Nuclear deal may give impetus to nuclear energy with free flow of technologies and equipment. India has its leadership position in sodium cooled fast reactors and thorium based reactors with respective closed fuel cycles; a robust answer to sustainability with nuclear energy. Continuous efforts are needed to make nuclear energy sustainable and acceptable. While the bulk of the large hydro systems are exploited, there is a considerable scope for small hydro units feeding to the grid. Renewable energy also can be a partner in this venture as a wind, solar, bio and hydro energies can produce electricity to feed to the grid. We may aim at about 10 per cent renewable energy penetration into the grid. These are found to pose new technological problems. Considerable study is required on grid interface with renewable energy.

The transmission system is another area of concern with high transmission losses. Smart grid can be a useful technology to pursue. Indian Grid condition is hazardous in that it inhibits renewable energy penetration. Grid interface issues must be deeply studied. Transmission losses are a local bane. Smart Grids are perhaps imperative.

Off grid decentralised systems mainly using locally available renewable energy sources is very attractive in the Indian context. Off grid decentralised power generation is relevant to India compared to developed countries. Technologies in this front are not yet fully mature. Wind, small hydro, bio and solar energies couple with energy from waste can be used for such applications to energise rural and remote locations.

Off-grid systems need to be made economical with a sound business model. Mini, micro, pico hydro systems for both grid fed and off grid systems have many technology, environment gaps to be bridged. India has thousands of pico hydro sites with unit sizes from 1-20kW in Western Ghats and Himalayan ranges from J&K to Arunachal. Synergising hydro programs between India, Bhutan, Nepal and Bangladesh may help energy availability in the region. But technologies must be indigenous and adoptable.

India is giving considerable emphasis on energy efficiency through Bureau of Energy Efficiency (BEE) under the ministry of power. Several policy formulations for industry, commercial and domestic consumers are evolving. Energy Efficiency has many local factors relating to conservation in the transportation, industry, commercial, and domestic fronts - BEE is concerned with local factors. Transportation is a major sector with heavy drain on energy sources. Integrated transport planning with efficient vehicles can be the priority. Energy and information technologies can be combined to achieve the goal. Smart buildings, building codes, fuel cells, battery technology etc can be relevant. Electric and hybrid vehicles can also be considered for urban transportation.

It is strongly felt that for some of the above schemes to succeed we need to work out suitable business models to make the system attractive to the users. New technologies must be economically viable with suitable carbon imprint.

Emissions are a global problem needing global solutions through local actions. International synergy is required in developing technologies and adaptations for the Indian context. Some of the international schemes such as Global Environmental Facility (GEF), European Union (EU), Asia-Pacific consortium, United Nations Development Programme (UNDP), United States Agency for International Development (USAID), S&T agreement between India and some leading countries such as Canada, Australia, Israel, Japan, USA etc. need to be suitably oriented towards the above technology development efforts for needs of developing countries such as India. Energy resource data need to be updated. There is an urgent need to update the data bank on available resources on both conventional and renewable energy in India such as coal deposits, wind potential, hydro potential, solar PV and thermal potential and bio energy (waste and mass) in various forms. Nearly 30 per cent of India's non commercial primary energy supply is derived from combustibles and wastes. The potential waste assets of India include agro (150,000 MW) municipal (urban) (3000 MW), plantation (20,000 MW) and waste lands (33+ million hectares). Solar Thermal and Solar PV systems need considerable local adaptation. The relevant issues for such forecasting are energy resources - identification, data, extraction, energy conversion and energy transmission. Energy utilisation and storage, other peripheral sources such as geothermal, ocean, and hydrogen energy are to be assessed.

India has ambitious plan for building Solar Thermal Energy plants, both through photovoltaic and thermal route. Micro climatic conditions due to dust and other contaminants in India result in distortion of solar radiation resulting in Indian design of solar plant being more expensive than say in Mediterranean/California desert where the solar availability is more than 28 per cent compared to 21 per cent in India. The challenge which is being addressed in India is to maximise the solar energy conversion while maintaining low costs. There are several innovative ideas which are integrated and this coupled to low cost manufacturing in India would perhaps make these targets realised.

Last, but not the least, competency building is a critical area wherein necessary skills and expertise need to be developing for creating new technologies and their deployment. Competency building and education in the upcoming areas have become priority. Education through the university system needs to reorient to meet new challenges. To create national level expertise in different areas of science and engineering an interdisciplinary group on sustainable energy (IGSE) be created in all IITs and IISc with a Chair or

coordinator in each Institute with a mandate to carry out science and engineering research jointly with other institutes and stake holders. This would be a virtual group. Liberal funds need to be allotted for their operation.

There are some areas of concern to be addressed. Solar energy is still the most expensive form of energy and cannot be sustained for long unless the prices are brought down to manageable levels. Nearly half of the existing population of India do not have access to grid electricity. Our aim is to provide at least one unit of electricity per day per family. This requires considerable planning and execution. In most of the places in India the electricity is available not more than four hours per day. To energise all the existing lines on 24X7 basis is a major challenge that requires massive expansion of generating capacity mostly through conventional energy. Renewable energy requires considerable use of land and water. This requires coordinated planning among all stakeholders. There are many uncertainties on bio energy- biofuels and biogas. Biomass energy security/availability etc. need more clarity. Considerable studies are required for biomass and bio fuels through new plantations. Law of the land environment clearance etc. need a re-look. Major stake holders to pursue technology development efforts are Government funding agencies (national and international), academia, industry, and utilities/ user agencies. Industry participation in manufacturing needs to be strengthened and R&D efforts need to be strengthened. It is essential to identify the role of each in implementing a viable program. Synergy among all the stake holders is essential. Global synergy in developing suitable technologies for each country and region considering local needs and resources is imperative. Global synergy (international cooperation) is confined to just importing some units and not on technology development tailor-made to local needs. The typical synergy drivers for the effective utilisation of Indian energy resources in totality are:

- co-existence of multiple resources;
- processing similarities and co-processing compatibility;
- interdependency of resources processing;
- locational dependency;
- co development prospects; and
- complementary nature of utilisation.

National technology mission programs can be planned for science and engineering involving academia, industries /utilities and energy agencies. Specific mission programs for following areas/technologies are planned:

- a) integrated gasification combined cycle (IGCC) and coal-to-liquid (CTL) technologies – Indian coal blended with pet coke and biomass;
- b) carbon capture and sequestration;
- c) underground coal gasification;
- d) ultra supercritical technology for Indian coal (operating parameters: 300kg/m² & 700°C);
- e) solar thermal systems: combined heat power and cooling;
- f) wind and solar (PV), energy for power generation both in grid fed and off grid (hybrid) mode. Considerable efforts are required for harnessing wind energy in India both for grid-fed and off-grid systems. We have an estimated 100GW of wind energy. Roof-top windmills may be innovations to pursue;
- g) grid interface of renewable energy – wind, solar, bio, hydro;
- h) municipal solid waste for energy conversion to heat and electricity;
- i) thermal energy storage;
- j) renewable energy for off-grid power generation for remote communities in decentralised distributed generation (DDG) mode using Micro (smart) grids;
- k) energy efficiency and conservation in domestic, commercial, transport and industrial sectors;
- l) technologies for electric vehicles (EV) and plug-in hybrid vehicles (PIHV); and
- m) other renewable energy systems – hydrogen (fuel cells), geothermal, ocean: studies on relevance of technologies and applications.

Quality control of sustainable energy equipment, components and systems is essential for successful field installations and ensure lasting performance. Equipment and systems for sustainable energy need stringent quality control for reliable and durable operation under field conditions. Suitable testing centers must be established and augmented to meet global standards. India is pursuing a high growth trajectory and its energy needs are going to grow multi-fold in the next decade. Strong technology development platform coupled to favourable policy support and competent manpower would be essential to meet this mammoth challenge. The technology platform will rest on a tripod of (a) energy efficiency and waste to energy conversion technologies, (b) clean coal technologies and nuclear technologies and (c) renewable solar-wind-biomass-geothermal technologies and, a golden triangle of academia-research-industry is gearing itself in building a strong framework for meeting the challenges outlined in this report.

The Indian Energy Resources can be grouped into 4 categories based on their availability, utilisation for energy generation and technological inputs required for their commercialisation:

Group 1: Oil, bio-fuel, biomass-to-liquids (BTL), coal-to-liquid (CTL), gas-to-liquid (GTL), shale and tar sands.

Group 2: Coal, biomass, natural gas (NG), coal bed methane (CBM), gas hydrates, H₂

Group 3: Distributed Resources viz., low grade coal and gas, urban wastes, solar, wind and geothermal

Group 4: Nuclear, hydrogen, water.

The governing strategies for the groupings are:

Group 1:

- imported oil replacement;
- ultra supercritical coal technology for Indian coal;
- development of alternative or co-liquid fuels;
- acquisition of clean technologies for coal, gas and biomass based; and
- liquid fuel generation.

Group 2:

- clean coal gasification through IGCC;
- large-scale biomass gasification; and
- crude oil replacement with natural gas.

Group 3:

- coal-gas-biomass compatible co-firing technology;
- location proximity of processing facilities;
- multi-resources adaptability; and
- viable distributed energy resources systems based on urban wastes.

There is a strong need to work out an India centric strategy for development of low emission technologies for creating future grid and off-grid power generation capacities in India.

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JAPAN

Introduction

It is well known that Japan has very few primary energy resources and has to import them to the extent of more than 80 per cent (96 per cent if nuclear fuel is included) to fulfill the domestic demand for energy. This situation makes Japan very sensitive to energy security and has encouraged her to develop advanced technologies for energy conservation and their deployment in products and manufacturing processes. As a result, Japan can claim to have achieved the highest-class efficiency of energy use per capita among industrialised countries.

In the mean time, reduction of greenhouse gases (GHG) is another element to be considered in energy supply. The Japanese government promulgated the Basic Law on Energy Policy in 2002 to attain the energy security and environmental requirements relying on market principle and then formulated action plans to develop innovative technologies for energy and to move towards the so-called low carbon society.

The EAJ used to organise a special group to investigate energy and resource issues in this country and to formulate recommendations or statements to the nation from time to time. In 2008, a working group on eco-innovation was established to carry out investigations on possible scenarios for realising sustainability from the point of view of energy and the environment. A preliminary report of its activity was reported at the CAETS annual meeting in Calgary in 2009.

Here, the present perspective of our government on Japan's energy is presented together with the methodologies for determining the best mix of various energy sources. Then the views of the electric power industry are presented. Finally, comments and proposals from the EAJ's working group on eco-innovation are presented.

Present status and the long-term outlook of the energy supply and demand

In May 2008, the Advisory Committee for Natural Resources and Energy of the Ministry of Economy, Trade and Industry (METI) announced the long-term energy supply and demand outlook. It provides the following three model cases based on the extent of development and introduction of energy technologies:

■ Case I – Current status case (Technology Frozen Case)

Technology frozen case assumes that, starting with the conditions in the fiscal year (FY) 2005, no new energy-related technology will be introduced and that the efficiency of appliances will remain unchanged, although it reflects the anticipated effects of the replacement of obsolete appliances with ones that were available as of FY 2005.

■ Case II – Continuous effort case

Continuous effort case assumes that the efficiency of appliances and facilities will continue to be improved through the enhancement of existing energy-related technologies.

■ Case III – Maximum introduction case.

Maximum introduction case assumes that the government will do everything short of using the force of law against consumers and companies in order to diffuse, to the maximum possible extent, costly appliances and facilities whose efficiency is notably superior due to the use of the most advanced technology commercially available.

In order to implement these assumptions and estimate the demand and supply, we need to use some macro framework assumptions as the basis of the calculation. These are as follows. In fact, the original estimation in 2008 was re-considered in August 2009 to accommodate the rapid change of the economic and environmental situation and the revised figures are shown here:

1. Overall population and working population are assumed to continue declining from the peak levels of FY2004, namely 127.77 million and 66.54 million respectively.
2. Yen to US dollar exchange rate is assumed to stay around ¥110/US\$.
3. Energy prices in 2005 dollars are assumed to change over the FY2020-2030 as follows:
Oil: \$121 to \$169/bbl;
LNG: \$330 to \$565/t;
Coal: \$63 to \$63/t.
4. The growth rate of real gross domestic product is assumed to remain at 1.3 per cent during the period of 2005 to 2020 and 1.2 per cent through 2020 to 2030.

Then, for each model case, the consumption of energy in FY2020 and 2030 was estimated sector by sector and was balanced with energy supply from various sources based on minimum CO₂ emissions realisable by the introduction of new technologies. As for electric power, the well-known method based on linear programming (LP) was used to minimise the total cost of plant construction and operation in the nation. Capacity conditions and scheduled retirement of existing units were also taken into account. The detailed calculation is shown in the report from the Institute of Energy Economics, Japan: Optimal Power Generation Mix Model. It should be noted that, in the outlook for the total energy supply, the amounts of nuclear power and new renewable energy are fixed according to government policy and are not included in the above calculation.

The results in the estimated outlook are summarised in Tables 1 and 2, in which the CO₂ emission originating from energy supply is seen to decrease to 27 per cent of the GHG in FY2005.

Table 1 Energy consumption (Past and future/estimated)

Fiscal Year	2005	2020			2030		
Assumed case	Real	I	II	III	I	II	III
Final Consumption *	413	421	401	375	424	391	346
Industry (%)	44	43	45	47	42	46	50
Non-industry (%)	32	35	34	32	36	33	30
Household (%)	14	14	14	14	16	14	14
Commercial, etc (%)	19	21	20	18	21	19	16
Transport (%)	24	22	22	21	22	21	20

* Giga L in crude oil equivalent

Table 2 Primary energy supply (Past and future/estimated)

Fiscal year	2005	2020			2030		
Assumed case	real	I	II	III	I	II	III
Domestic supply	588	627	596	563	637	590	515
Oil (%)	43	36	36	34	35	35	33
LPG (%)	3	3	3	3	3	3	3
Coal (%)	21	20	20	19	21	20	18
Natural gas (%)	15	18	17	16	18	16	14
Nuclear power (%)	12	16	17	18	17	18	21
Hydroelectric (%)	3	3	3	3	3	3	4
Geothermal (%)	0	0	0	0	0	0	0
New energy sources (%)	3	3	4	5	5	5	7

* Giga L in crude oil equivalent

As a result of the general election in August 2009, a new cabinet lead by the Democratic Party came into operation. The above outlook may therefore be reconsidered in the near future.

Electric power sources in Japan

The following explanation is based on the brochure “Electricity Review Japan” issued by the Federation of Electric Power Companies of Japan.

In Japan, most of the electric power is supplied by 10 privately-owned regional electric power companies, who are responsible for providing local operations from power generation to distribution and supplying electricity to their respective service areas. They also work together to ensure a stable supply to customers nationwide by exchanging or providing electricity in order to cope with emergencies resulting from accidents, breakdowns or summer peak demand. To ensure the smooth operation of power exchange, extra-high voltage transmission lines link the entire country.

For security of energy supply, the electric power companies have been diversifying power sources since the oil crisis. At the same time, they are now asked to move to lower CO₂ emission facilities. Electricity demand in Japan is assumed to increase annually by 0.9 per cent on average up to 2017. As a result, electric companies will be developing power generation facilities with a total capacity of 29.83GW by that year, 41 per cent of which will be accounted for by nuclear power. For the utilisation of coal with less CO₂ emissions, combined-cycle generating plants with both gas and steam turbines have been installed. Various efforts are continuing in order to develop and use integrated coal gasification combined cycle (IGCC) power generation. Another effort to decrease CO₂ emissions is to increase the share of LNG-fired thermal power.

As for renewable energy, electric power companies are firmly committing to a renewables portfolio standard (RPS) system promulgated by the government since April 2003. According to this system, each electric power company has to generate or purchase designated amount of “new energy” power or its equivalent.

The liberalisation of the electric power market in Japan is rather slow but steadily advancing. Since April 2005, power producers and suppliers have been allowed to sell electricity to high voltage users whose demand exceeds approximately 50kW.

As well as electricity suppliers, various measures are provided for energy saving by manufacturers and consumers. One is the ‘top runner’ program applied to 21 products, in which the energy efficiency of the best product is recommended from those of the same class. The second is the Eco Leaf Program, in which LCAs for the products are certified and registered by a third party, with a special label on the product. A third example is the Carbon Footprint Program, started in 2008.

Implementation of Low emission technologies and systems

In the FY2008, the EAJ carried out an extensive survey of eco-innovation and reported the results at the CAETS Convocation in Calgary in 2009. Throughout the study, the key technologies and systems to be developed and implemented for mitigating climate change were identified and evaluated. Details of these technologies and systems cannot be included here but the topics investigated are listed below:

(1) Energy supply:

- Solar cells and batteries
- Highly efficient thermal power generation (exemplified by the integrated coal gasification combined cycle)
- Next-generation nuclear power plant

(2) Energy consumption (Energy conservation)

- Steel industry
- Green chemistry
- Electric cars

- Eco-buildings

- Green IT

(3) Materials recycling

(4) Social systems

- Intelligent traffic systems

- Energy management systems

- Tele-working

The present state of the art and the effectiveness of each technology or system were analysed and evaluated and the barriers to their implementation in the society were identified. These are mainly to do with cost of practical application but some other reasons were noted including inadequate level of technology or products and lack of the understanding by the public. Observations on common problems in the realistic implementation of these technologies and systems were summarised as the conclusions of the study and recommendations for solving these problems were formulated. The main points of the recommendations are as follows:

- The government should demonstrate a long-term vision of eco-innovation for the future society.

- The government should give accurate information on eco-innovation to all the sectors in the country.

- The barriers to the implementation of new technologies and systems should be identified and removed, often with government support.

- Open innovation based on interdisciplinary collaboration should be promoted. The government should encourage this by deregulation and other appropriate means.

- Appropriate measures must be provided to transfer eco-technology to developing countries through joint research and training.

- Standardisation of eco-products and their methods of evaluation must be promoted.

Some of the above topics could be jointly discussed by the members of the CAETS working party in the near future.

Conclusion – Future activity of CAETS Working Party

In this report, Japan's energy policy and plans for electric power supply are introduced, with an outlook for a low GHG-emission society. The recent activity of the EAJ on these topics is summarised and its conclusions are suggested as possible topics for future CAETS activity concerning environment and sustainability.

Although it is not described above in detail, the EAJ regards nuclear energy as the most important technology to be developed and deployed to overcome both the problems of future shortages of fossil fuel and of climate change. For the promotion of nuclear power generation, there are, unfortunately, three issues in Japan: absolute safety, certainty of security, and public understanding. The EAJ could well take the initiative in helping to solve these complex problems.

In the annual CAETS meeting in Delft in 2008, the EAJ proposed establishment of a working group to coordinate the studies being made by member academies on environmental and sustainability issues. The EAJ considers that the present Working Group organised by AYSE is a good example of the realisation of that proposal and is pleased to be collaborating with the group. For the future, the EAJ hopes that further such activities on other topics will follow the current project.

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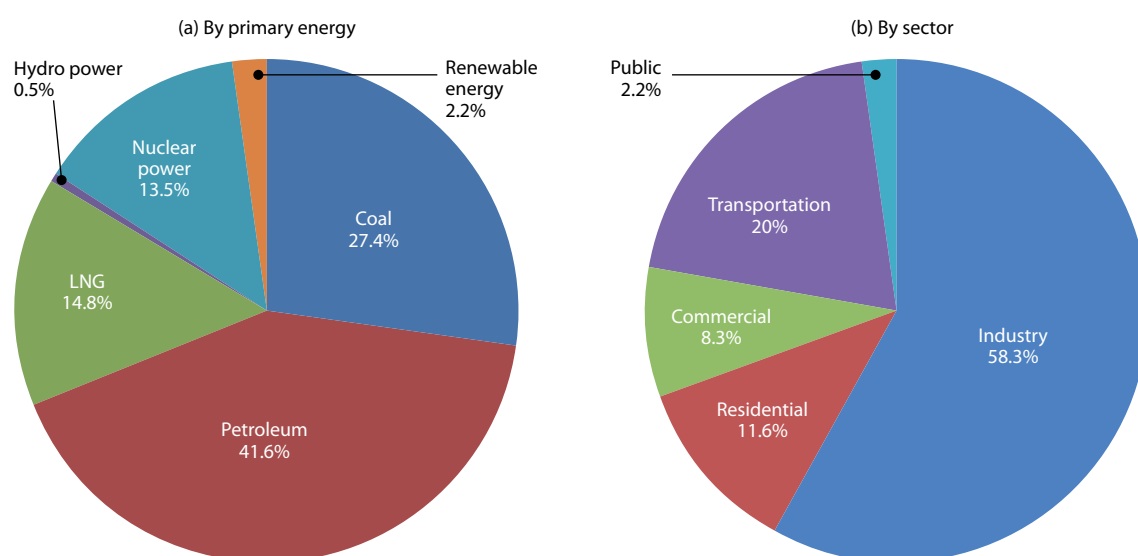
KOREA

Current energy status in Korea

Korea's total primary energy consumption was 234 million TOE in 2007, ranked ninth in the world, and 241 million TOE in 2008 [1,2]. With limited energy resources, Korea depends on imports for most of its energy needs. The overseas energy dependency in 2008 was 96.4 per cent. Energy accounts for 32.5 per cent of total imports and 15 per cent of GDP. The very high overseas energy dependency and large share of total imports make Korea very vulnerable to energy crises, with the price of energy having a significant impact on the Korean economy.

Energy consumption according to primary energy sources is shown in Figure 1. In 2008, petroleum provided the largest share of Korea's energy with 41.6 per cent of the energy consumption. Coal was the second largest, providing 27.4 per cent, followed by liquefied natural gas with 14.8 per cent and nuclear power and hydropower with 13.5 per cent and 0.5 per cent, respectively. The renewable energy portion was low at 2.2 per cent. Energy consumption by sector shows that almost 60 per cent of the energy was consumed by the industrial sector. The transportation sector consumed 19.6 per cent of the total, and the residential and commercial sectors 11.6 per cent and 8.3 per cent, respectively.

Figure 1 2008 Energy consumption in Korea: a) by primary energy and b) by sector

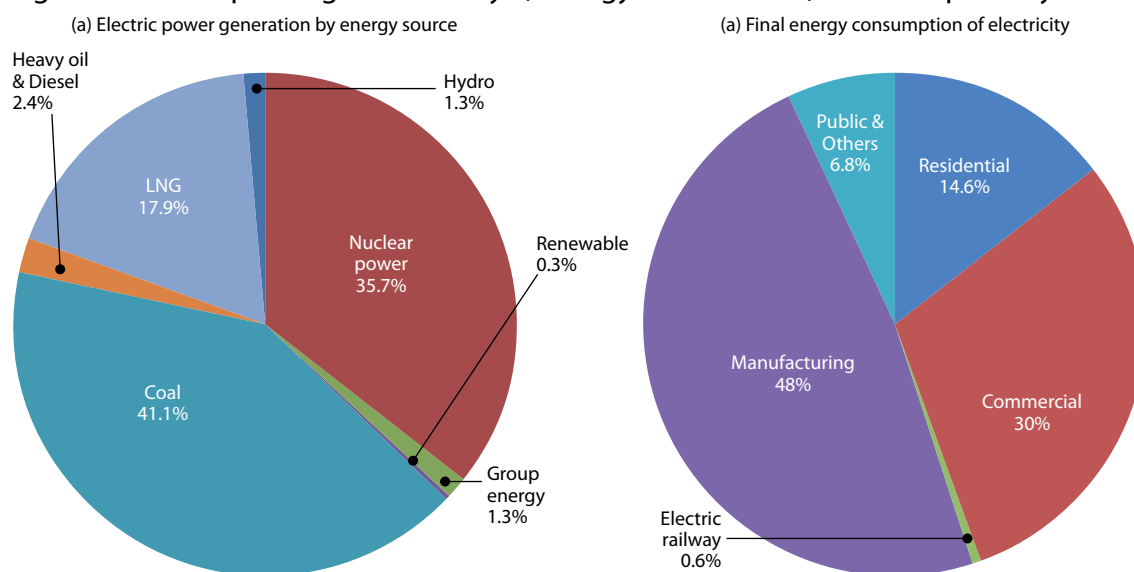


In the power generation sector, the total generating capacity in Korea was 77,652 MW, and the gross generation of electricity was 447 million MWh. As shown in Figure 2 (a), Korea gets 60 per cent of its electricity from conventional thermal sources, mostly coal (41.1 per cent) and natural gas (17.9 per cent), with a small amount coming from heavy oil and diesel. The share of nuclear power has been increasing over the last 20 years, showing a share of 35.7 per cent in 2008. The renewable energy fraction was 0.3 per cent. Figure 2(b) shows the final energy consumption of electricity. Again, the industrial sector consumes the largest fraction of electricity at 48 per cent. Commercial and residential sectors consume 30 per cent and 14.6 per cent, respectively.

The New National Vision - Low Carbon Green Growth

'Low Carbon, Green Growth' is Korea's new vision, presented by President Lee Myung Bak on August 15, 2008, the 60th anniversary of the founding of the Republic of Korea. President Lee defined green growth as a "new national development paradigm which creates a new growth engine and jobs with green

Figure 2 Electric power generation by a) energy source and b) consumption by sector



technology and clean energy”. With this vision, Korea aims to be one of the seven greenest nations by 2020 and in the top five by 2050.

The First Basic National Energy Plan (2008-2030)

Shortly after presenting the “Low Carbon Green Growth” vision, the National Energy Committee, in which the president serves as chairman, announced The First Basic National Energy Plan (2008-2030), which will provide support for Low Carbon Green Growth from the energy sector, and presents a long term energy vision to strategically prepare for the post-petroleum era [3,4]. It is a long term energy plan with a 20-year timeframe and will serve as the highest level policy in energy, giving the principles and directions for all other energy related policies. The plan also includes a projection for energy demand, a strong reduction goal, and a long term energy mix that accounts for the policy goals for environment, efficiency, and energy security. Some of the specific goals listed in the basic plan include (1) a 46 per cent increase in national energy efficiency, (2) a reduction of fossil energy dependence from 83 per cent to 61 per cent in 2030, (3) an increase in the portion of renewable energy sources in the national energy mix from 2.4 per cent in 2008 to 11.5 per cent in 2030, and (4) a strengthening of the role of nuclear power to account for 33 per cent of Korea’s total power generation facilities and 48 per cent of its power generation capacity.

The National Strategy for Green Growth

In order to establish a national strategy for “Low Carbon Green Growth,” the Presidential Commission on Green Growth was established in February 2009. In July 2009, the National Strategy for Green Growth was announced along with the first five-year (2009-2013) plan [5]. The National Strategy for Green Growth is the highest level government plan on green growth and sets policy objectives for 2050 and performance indicators for 2020. It defines three main policy objectives and a 10 key policy agenda. The three main objectives are (1) mitigation of climate change and energy independence; (2) creation of new engines for economic growth; and (3) an improvement in quality of life and enhanced global leadership.

In order to take action on the agenda set out in the National Strategy in a more systematic and consistent manner, the government set out the first part of the five-year implementation plan, which has an ambitious investment plan of 2 per cent of GDP annually, totaling \$86 billion between 2009 and 2013. This level of investment is twice the amount recommended by the Green Economy Initiative advocated by the United Nations Environment Program. By doing so, Korea hopes to boost its global market share in the green technology area from the current 2 per cent to 10 per cent within 10 years.

The 2020 mitigation target for GHG

Another significant initiative under the Low Carbon Green Growth vision was to determine the 2020 mitigation target for GHG. The Korean government went through a year-long process for this. In August 2009, after a 10-month study, the government presented three mitigation scenario options of 21 per cent, 27 per cent, and 30 per cent reduction from the Business As Usual (BAU) scenario. These reduction levels correspond to an 8 per cent increase, unchanged, or a 4 per cent reduction from the 2005 GHG emission level. On November 17, 2009, immediately before the Copenhagen meeting, the government decided that it would cut its GHG emissions by 30 per cent from the BAU scenario by 2020, the highest level proposed. As a non-Annex I country, Korea's target-setting was voluntary, and was considered to show the government's commitment to the reduction of GHG.

Through this process, Korean industries insisted that the reduction of GHG by 4 per cent from 2005 levels is an overly ambitious target [6]. Korea's key industries consume almost 60 per cent of the nation's energy. This is much higher level than those of the US, Japan, and the EU. Korea's GHG emissions have almost doubled in the last fifteen years (1990 to 2005) and its economic structure is still heavily dependent on energy-intensive industries such as steel, petrochemicals, automobiles, and electronics. In particular, the steel and petrochemical industries consume 11.5 per cent and 27 per cent of the nation's energy while claiming the highest energy efficiency in their fields. Any drastic reduction of GHG emissions will put a heavy burden on these industries.

2010 Action Plan

At the beginning of 2010, the Ministry of Knowledge Economy announced the 2020 National GHG reduction master plan [7]. The plan considers the year 2010 as the first year to execute the plan to meet the mid-term goal of the BAU 30 per cent reduction. It aims to set detailed reduction goals and timelines for all industrial sectors and business categories by the second half of the year. Some of the contents of the plan are as follows:

- Correlate the energy management system with sectoral and industrial allocations, and develop an energy-GHG management system. During 2010, the energy management system will be applied to 46 business locations, in which the energy consumption is greater than 0.5 million TOE, and will be extended to businesses that consume more than 50 thousand TOE in 2011.
- Enact legislation for emission trading and run a model trading scheme.
- Expand financial and tax support to promote the GHG reduction business and plant and equipment investments by private corporations.
- Establish support systems for medium and small companies and high energy consuming corporations which are unfavorably positioned to deal with climate change issues.
- Develop a forceful energy savings plan to keep energy consumption growth under 3 per cent (a 4 million TOE reduction). In the industrial sector, energy management systems will be applied to 10 categories of industries: steel, petroleum, cement, petrochemicals, automobiles, machinery, electronics, pulp, textile, and power generation. In the residential sector, a building management system will be introduced for high energy consuming buildings. New buildings in the public sector will be required to have the highest level efficiency. In the transportation sector, detailed reduction plans for GHG emission from automobiles are in preparation.

GHG Reduction in Electricity Generation

Korea's power sector is represented by the Korean Electric Power Corporation (KEPCO). KEPCO is a market-based public company in which the Korean Development Bank and the Korean Government together have more than 50 per cent of the shares. KEPCO has 10 subsidiaries, including six power generation companies.

With the prospect of GHG regulations and the government's strong push for "Low Carbon Green Growth," KEPCO established a new vision in 2008 for 2020 and formed a mid-to-long term strategy to become a global utility leader as well as a leader of green growth [8]. Four major mid-to-long term strategies are (1) leading green technology, (2) expanding business markets, (3) driving global business, and (4) advancing innovation and efficiency.

In the green technology area, KEPCO selected eight strategic green technologies in consideration of their appropriateness and technological merits. The eight green technologies are: Integrated Gasification Combined Cycle (IGCC), Carbon Capture and Storage (CCS), Smart Grid, export-oriented power plant, HVDC, superconductor technology, infrastructure for charging electric vehicles, and smart green home systems. KEPCO plans to secure new growth engines through development of these eight technologies, and to improve its profit model. Some of the current activities include a 300 MW IGCC plant scheduled for operation at the Korean Western Power Company, and carbon capture using dry sorbent and circulating fluidised beds, which is scheduled to be pilot-tested at the Korean Southern Power Company.

To reduce CO₂ emissions, KEPCO will increase the share of nuclear power to 41 per cent (based on facility) by 2030, and continuously expand new and renewable energy facilities through the Renewable Portfolio Agreement (RPA) with power generating companies. RPA is an agreement between the government and nine energy-related public organisations, including KEPCO and its six power generating companies [9]. The agreement was made to elicit voluntary investment in new and renewable energy. According to the agreement, the nine participating organisations should submit a detailed action plan to the government and, in turn, the government should provide administrative and financial support. Through RPA, the renewable energy facilities in KEPCO subsidiaries are expected to increase to 700 MW in 2011. The efforts to reduce indirect GHG emission from power use are on-going through systematic demand-side management and by boosting efficiency of transmission and distribution. KEPCO is also pushing ahead with a clean development mechanism (CDM), and it already has registered 18 projects at the UN as of 2008, securing 0.53 million ton/yr of carbon emissions.

Summary

In 2008, Korea imported 96 per cent of its energy, and its fossil energy dependence was almost 80 per cent. Korean industries consume almost 60 per cent of the nation's energy, while the share of renewable energy remains very low. All these data indicate that Korea is not well positioned to face the prospect of GHG regulation in 2013. However, Korea is aggressively dealing with challenges by making "Low Carbon Green Growth" a new vision for the nation. The new vision emphasises green growth as a new paradigm for the nation's sustainable development and green technologies as a new growth engine. Since the new vision was presented in August 2008, "green" became the catch phrase of the country with every corporation and organisation setting its own green vision. The power generation sector, KEPCO, with more than 60 per cent of its facilities using thermal power, is facing challenges to reduce its GHG emissions to meet the 2020 GHG reduction goal of 4 per cent below the 2005 level.

KEPCO's green vision includes an increase in nuclear power and the development of eight core green technologies.

Korean energy-intensive industries are voicing concerns about the government's unilateral goal setting, and Korean environmentalists are criticising the government's approach of green equaling low carbon, despite many problems with nuclear power. And yet, it is clear that Korea is going forward with the "Low Carbon Green Growth Vision." It may take some time to put in place all the necessary regulations, staged energy savings and GHG reduction targets and to obtain public acceptance of the new paradigm. Since the announcement of the new vision, a consensus is forming that green growth is a timely concept, and

investment in green technologies by the top 350 companies is increasing. Korea is certainly showing signs of advancing towards a greener nation

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SOUTH AFRICA

Introduction

Electricity generation in South Africa is today dominated by coal fired power stations, which contribute a large percentage of South Africa's greenhouse gas emissions. The government and the state owned electricity supply utility, Eskom, have accepted that the risks of global warming are real and that South Africa should take action to restrict the emission of carbon dioxide and other greenhouse gasses. Significant change in the coal-fired energy sector will be required to substantially reduce emissions.

The government has set a target long-term average growth rate for the economy of 6 per cent per annum in real terms. South Africa has a very energy intensive economy with mining, metallurgical and manufacturing industries, transportation, and other sectors requiring large amounts of electrical energy to enable their operations. It has been estimated that in order to support a 6 per cent annual growth rate of the economy, the electricity generating capacity of the country has to grow at a rate of 4.4 per cent per annum. Funding and executing a long-term construction program that will create sustainable and affordable generating capacity growth at the required rate and in the very large quantities required is a huge challenge.

Timely decisions on fuel choice – what type of power plants to build and when to build them – are critical to keep the lights on, limit power price increases and manage carbon emissions.

This report will examine the expected future electricity demand growth in South Africa and the current and emerging low-carbon technologies that may be available to meet the demand.

South Africa's current and projected electricity needs

Eskom's long-term electricity demand forecast for South Africa has been revised to incorporate the expected impact of the recent economic downturn. A critical aspect of this forecast is predicting the timing and speed of the recovery as well as the growth trajectory thereafter. Three demand forecast scenarios have been prepared, reflecting different expected electricity demand growth trajectories (a high growth of 3.6 per cent average, a

moderate growth of 2.9 per cent and a low growth of 1.9 per cent). The three scenarios follow a similar pattern of growth with the initial recovery indicating strong growth before tapering off to a long-term average growth.

Eskom's installed generation capacity in 2009 was about 42 GW (42 000MW). With the high growth rate (3.6 per cent) scenario this is expected to increase to about 80 GW by 2025. With the moderate growth (2.9 per cent) scenario, 80 GW should be reached by 2030.

If we assume a long-term average growth rate of 2.5 per cent over the period 2025 to 2050, the installed generating capacity in 2050 will be about 148 GW, which means a growth of about 68 GW over the period. In addition to this, provision will have to be made for replacement of the existing fleet of power stations that will reach the end of their operating lives during this period, i.e. a further 38 GW in addition to the demand growth of 68 GW. The total new build requirement over the period 2025 to 2050 will then be 106 GW, or an average of more than 4 GW per year over the 25 years.

Responding to Climate Change

The main element of Eskom's strategy to reduce its greenhouse gas emissions is diversification of the generation mix to lower carbon-emitting technologies. They are assessing all available options to make significant cuts in greenhouse gas emissions in the longer term.

The amount of CO₂ that Eskom emits will increase in the short to medium term as the coal-fired projects currently being executed come into commercial operation over the next seven years or so. Their intent is to reduce their relative CO₂ (Mt CO₂/MWh) footprint until 2025 and thereafter to continually reduce absolute emissions in support of national and global targets. Eskom is also considering the installation of up to 20 GW of nuclear capacity by 2025 which would make a major contribution towards meeting Eskom's target of reducing the contribution of their fossil fuel fired generation to below 70 per cent by 2025.

After 2025 Eskom's existing power stations will reach the end of their lives and will be replaced with more advanced, lower-carbon emission technologies. This will provide a further major opportunity to change the energy mix and reduce absolute emissions. It so happens that 2025 is about the time that important new low-carbon emitting technologies such as Carbon dioxide Capture and Storage (CCS), Fourth Generation nuclear power plants and Concentrating Solar Power (CSP) with energy storage can be expected to become commercially available.

Renewable energy sources for power generation

Renewables currently represent a small fraction of total electricity generation. Conventional hydroelectric power is the largest source of renewable electricity in South Africa, generating about 2 per cent of the electricity produced by Eskom in 2008.

The hydroelectric potential in South Africa is very limited and the full hydroelectric potential has almost been exploited already. Substantial imports of hydroelectric power from neighbouring and central African states are likely to occur in the medium term future. Renewables which have not received much attention in South Africa include wave, tidal and geothermal energy.

South Africa has sufficient renewable energy resources to significantly expand the amount of electricity generated from them. Solar in particular, followed by wind, offers the greatest potential among the domestic renewable resources. However, the resource bases for wind and solar energy are not evenly distributed, spatially as well as temporally, and they are more diffuse compared to fossil and nuclear energy sources. Although the size of the resource base is impressive, there are many technological, economic, and deployment-related constraints on using sources of renewable energy on a large scale.

For any country, the penetration and average capacity factor of intermittent generation sources that can ultimately be reached depends on natural characteristics such as the prevalence and distribution of favourable wind generating sites and the size and characteristics of the national transmission network. Favourable wind generating sites are found only in a limited number of regions in South Africa and are often located far from major electricity load centres. Typical numbers globally for both penetration and average capacity factor are about 20 to 25 per cent, but they could be less for South Africa.

The ultimate solution required to deliver the reliability of supply required from renewable sources will be based on storage systems able to store intermittent energy inputs and release continuous and reliable energy on demand. A lot of research and development is being done using a range of technologies to develop suitable energy storage devices.

The cost of concentrating solar power systems with heat storage is today still very high. Because of the potential of this technology to make solar power available as dispatch-able electrical power, there will definitely be huge investments in research and development into the technology. In the longer term this may turn out to be a technically and economically viable option for low-carbon emission electricity generation, including base load electricity. It will then play a major role in electricity generation worldwide and specifically in South Africa with our large solar resources.

Clean Coal Technologies

A cost effective and readily available option to reduce CO₂ emissions per unit of electricity generated is to increase the generating plant's efficiency, so that less coal is burned per MWh generated. A number of options are available for high efficiency power generation which significantly reduces emissions of CO₂. Eskom is currently constructing two new pulverised coal power plants of 4800 MWe generating capacity each. These are both supercritical steam plants with expected efficiencies of about 40 per cent. The average efficiency of Eskom's current fleet of coal-fired power stations is about 33 per cent. Eskom also intends to increase the average efficiency of its current fleet.

Integrated coal gasification combined gas turbine-steam cycle (IGCC) uses partial oxidation of coal with oxygen as the oxidant to produce a synthesis gas (syngas) consisting mainly of CO and H₂. As with combustion technologies, higher efficiency results in lower emission per MWh. Eskom is working on a project to do underground coal gasification (USG) in situ, using steam and oxygen to turn the coal into carbon monoxide and hydrogen.

Carbon Capture and Storage

One of the pulverised coal plants currently under construction has been designed as "Carbon Capture and Storage Ready". This means that when CCS technology becomes commercially available it would be quicker and less expensive to implement the technology on this plant than it would be otherwise.

Research on geosequestration is ongoing in several parts of the world. The main potential appears to be deep saline aquifers and depleted oil and gas fields. In both, the CO₂ is expected to remain as a supercritical gas for thousands of years, with some dissolving. Given that rock strata have held CO₂ and methane for millions of years there seems no reason that carefully chosen ones cannot hold sequestered CO₂. However, the eruption of a million tons of CO₂ from Lake Nyos in Cameroon in 1986 asphyxiated 1700 people, so the consequences of a major release of heavier-than-air gas are potentially serious.

In South Africa a project has been launched to develop the "South Africa CO₂ Storage Atlas." This project will look at identifying existing geological formations for possible future storage of CO₂.

Nuclear Energy

Electric utilities worldwide are expressing increased interest in constructing new nuclear plants. Reasons cited include the need for additional base load generating capacity; growing concerns about greenhouse gas emissions from fossil-fuel plants; volatility in natural gas prices; favourable experience with existing nuclear plants, including improvements in reliability and safety. No major R&D is needed for expansion of nuclear power through 2020 and, likely, through 2035. Nonetheless, the high cost of construction of new nuclear plants is a major concern and the experience with the number of new plants that could be built before 2020 will be critical to assess the future viability of the nuclear option. If these plants are not built on time and on budget, or if the electricity produced is not cost competitive, few additional new plants are likely to follow, at least for a while.

Second generation nuclear power

The nuclear power plants currently operating across the world were built with technology developed in the 1960's and 1970's and are referred to as generation 2 reactors. In the intervening decades, ways to make better use of existing plants have been developed, along with new technologies that improve safety and security, decrease costs and reduce the amount of generated waste – especially high level waste.

Third generation nuclear power

The next generation of nuclear reactors, also referred to as evolutionary nuclear plants, are currently being developed in several countries. The first type of third generation advanced reactors has been operating in Japan since 1996. Late third generation (3+) designs are now being built.

Third generation reactors have a standardised design for each type to expedite licensing, reduce capital cost and reduce construction time. Improved design features include a simpler and more rugged design, higher availability and longer operating life, further reduced possibility of core melt accidents (a thousand times less than with second generation plants), resistance to serious damage that would allow radiological release from aircraft impact, and higher burn-up to reduce fuel use and the amount of waste. The greatest departure from second-generation designs is that many incorporate passive or inherent safety features which require no active controls or operational intervention to avoid accidents in the event of malfunctioning, and may rely on gravity, natural convection or resistance to high temperatures. Another departure is that some will be designed for load following.

Fourth generation nuclear power.

One basic problem with generation 2 and generation 3 thermal reactors is that more than 99 per cent of the uranium fuel ends up “unburned” (not fissioned). In addition to “throwing away” most of the potential energy, the long-lived nuclear wastes (plutonium, americium, curium, etc.) require geological isolation in expensive repositories.

There are two compelling alternatives to address these issues, both of which will be needed in the future. The first is to build reactors that do not allow appreciable slowing down of the neutrons in the core thereby keeping them “fast”. These fast reactors can virtually completely “burn” the uranium. Moreover, they can burn existing long-lived nuclear waste, producing a small volume of waste with half-life of only decades, thus largely solving the long-term nuclear waste problem.

The other compelling alternative is to use thorium as fuel in thermal reactors. Thorium can be used in ways that practically eliminate build-up of long-lived nuclear waste.

During the development of the commercial light water reactor (LWR) technology, little emphasis was given to issues of nuclear waste. Today the situation is very different. If nuclear energy is to be used widely to replace coal, issues of waste, safety, and proliferation become paramount.

The Integral Fast Reactor (IFR) concept, which was developed and has been built and tested in the USA, keeps neutrons “fast” by using liquid sodium metal as a coolant instead of water. IFRs also make fuel processing easier by using a metallic solid fuel form. IFRs can burn existing nuclear waste making electrical power in the process. All fuel reprocessing is done within the reactor facility (hence the name “integral”) and many enhanced safety features are included and have been tested, such as the ability to shut down safely under even severe accident scenarios.

The Liquid-Fluoride Thorium Reactor (LFTR) is a thorium reactor concept that uses a chemically-stable fluoride salt for the medium in which nuclear reactions take place. This fuel form yields flexibility of operation and eliminates the need to fabricate fuel elements. This feature solves most concerns that have prevented thorium from being used in solid-fuelled reactors. The fluid fuel in the LFTR is also easy to process and separate useful fission products, both stable and radioactive. LFTR also has the potential to destroy existing nuclear waste, albeit with less efficiency than in a fast reactor such as IFR.

Both the IFR and LFTR operate at low pressures and high temperatures, unlike today’s LWRs. Operation at low pressure alleviates much of the accident risk with LWRs. Higher temperatures enable more of the reactor heat to be converted to electricity (40 per cent in IFR, 50 per cent in LFTR and 35 per cent in LWR). Both IFR and LFTR have the potential to be air-cooled and to use waste heat for desalinating water.

Both IFR and LFTR are 100 to 300 times more fuel efficient than LWRs. The actual figure depends on the design parameters of a specific thermal reactor that is being compared with a fast breeder reactor. These design parameters include the fresh fuel uranium enrichment level, fuel burn-up, spent fuel enrichment level and whether a once-through or a reprocessing fuel cycle is being used. It also depends on the tails assay of the uranium enrichment plant from which the fuel came. In addition to solving the nuclear waste problem, they can operate for several centuries using only uranium and thorium that has already been mined.

A lot of research and development work remains to be done before Generation 4 technologies will become commercially available. It could take anything from 20 to 40 years, depending on the urgency with which it is pursued. In the light of the wide acceptance of the seriousness of global warming, the large uncertainties about the technical and economic viability of CCS, and the inherent limitations of renewable technologies, it would very strange if the rate of development of Generation 4 systems is not drastically increased in the immediate future.

Conclusion

Electricity generation technologies for the future have to meet three conflicting requirements: reduce greenhouse gas emissions to low levels; keep the price of electricity affordable; and generate enough reliable power to support the country’s rapid economic growth. Given the historical facts around electricity generation in South Africa and the socio-economic realities of the country both today and in the future, it is clearly going to be an enormously difficult task to satisfy all three requirements. Actually it is not realistically possible and major compromises will have to be made in deciding on the best way forward.

In South Africa specifically, there are very few options amongst existing and emerging energy-supply technologies, only three in fact, that can be used for low-carbon emission base load power generation:

- coal-fired power generation with CCS;
- nuclear power generation; and
- CSP with energy storage.

For any option to be a solution, it needs to be technically and economically feasible and be available on the right timescale. If one considers the three above options against these criteria, the situation is, to say the least, challenging in the extreme.

Coal with CCS will require a lot more development and demonstration before its technical feasibility, specifically with South Africa's geological characteristics, is established. The actual cost with commercial scale application will become known when the first commercial plants are in operation. The initial indications are that CCS will add about 70 per cent to the cost of electricity generated from coal. Despite the great urgency with which the development work is now approached internationally, the complexity and huge difficulty of the task make it unlikely that commercial operation will begin before 2025.

In the case of CSP with energy storage, there is little doubt that the technical feasibility will be demonstrated. Because of the diffuse nature of solar energy, there is a big question mark against the economic feasibility of the technology. This uncertainty discourages investments in the development of the technology, causing it to be stretched out in time.

That leaves nuclear power, where the technical feasibility is well established and the technology is available today. The economic feasibility is still in some doubt. However, with the expected wide-scale international deployment in the immediate future, and the design improvements in the third and especially the fourth generation reactors, there is reason for optimism that the future economic feasibility of commercial nuclear power will be acceptable.

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UNITED KINGDOM

Introduction: Low emission technologies in the UK

The evolution of the UK's historical generating mix is shown in Figure 1. This has been driven primarily by access to and economics of fuel sources, initially the UK's coal deposits, and from the 1960s by increasing exploitation of natural gas reserves from the North sea fields, facilitated by the privatisation of the electricity industry. Substantial changes are anticipated in the next few decades, mainly due to a UK

Figure 1 Historical trends in UK electricity generation technologies

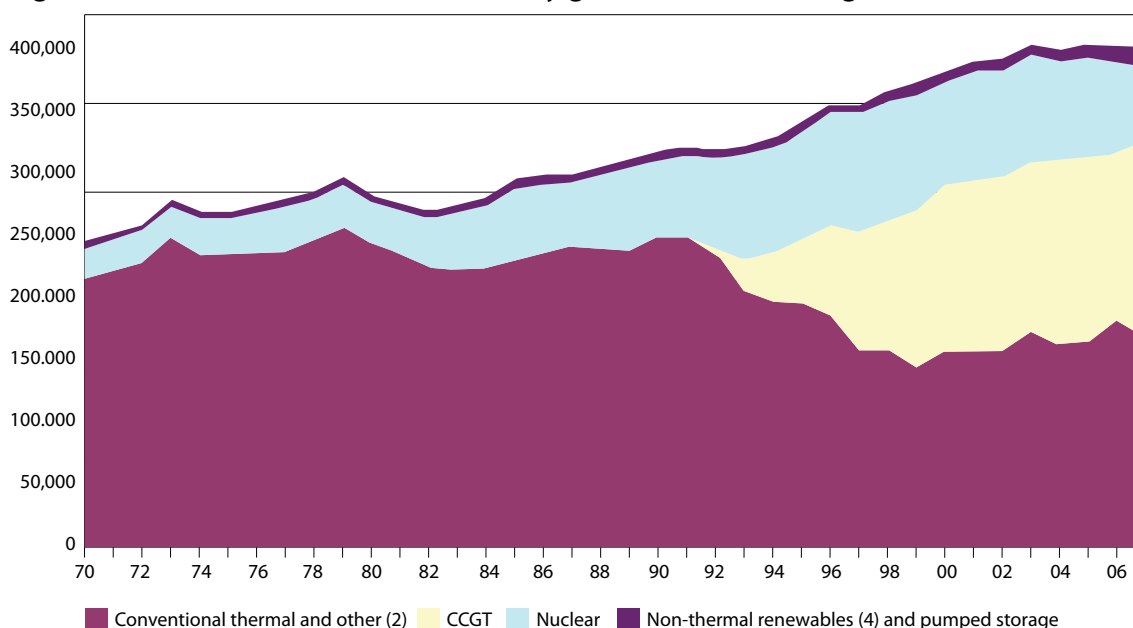
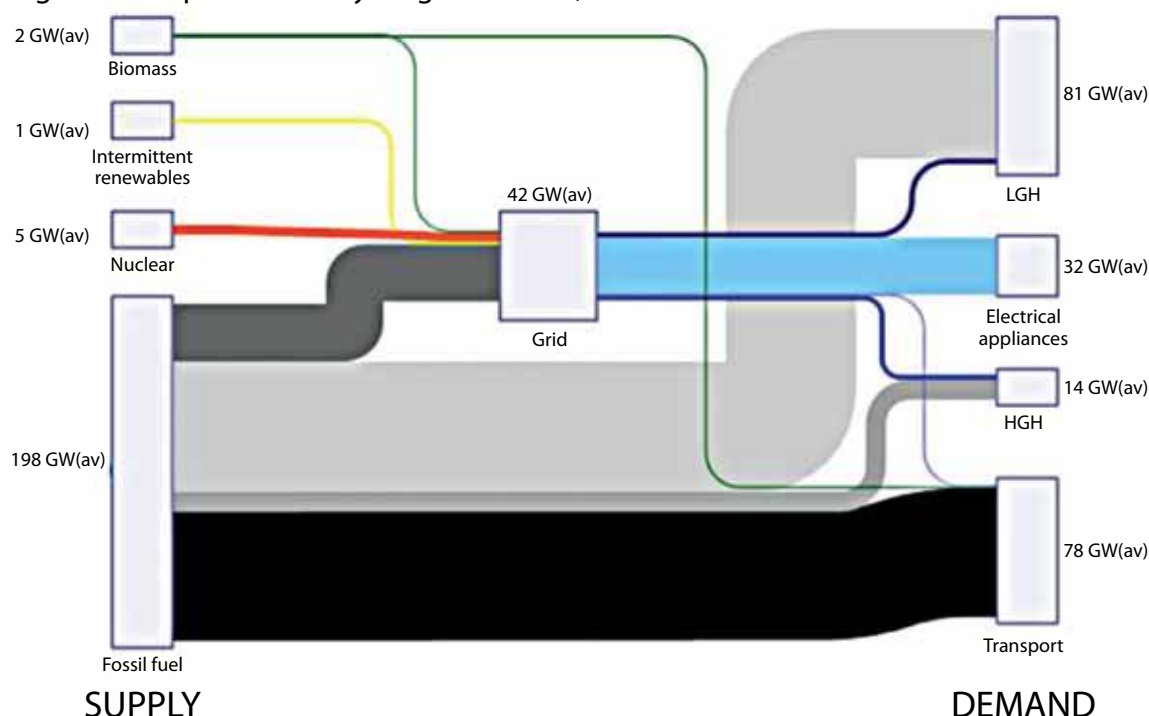


Figure 2 Simplified Sankey diagram for UK, 2008



Government commitment to reduction of carbon emissions: a target of 34 per cent by 2020, and 80 per cent by 2050, against a baseline of 1990.

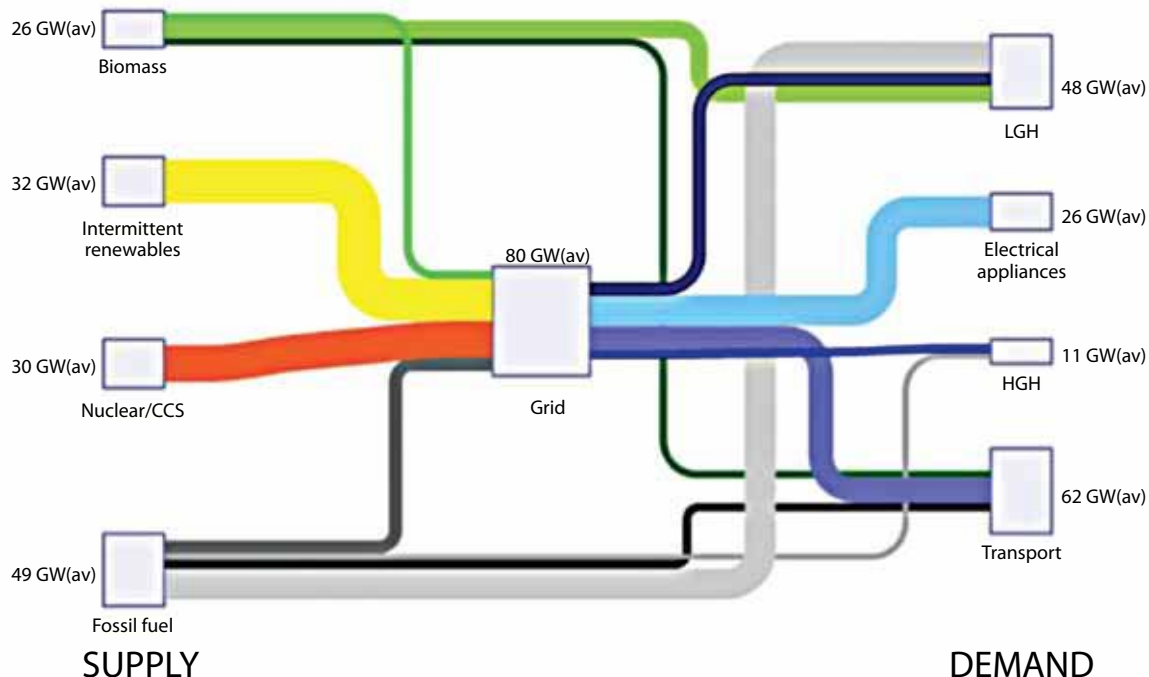
Technologies presently foreseen (there is always the possibility of new options through innovation or scientific discovery) to increase in use are wind energy, mainly off-shore, carbon capture and storage systems, biomass, solar photovoltaic, solar thermal, domestic heat pumps, nuclear fission, small scale co-generation, wave and tidal, and active network management. The latter would facilitate both improved energy efficiency and stable integration of stochastic sources. Presently electrification of transport is also favoured, which will increase the demand for electricity, and is thought to offer the possibility of large-scale distributed storage to assist network management. The impact of these various technological changes can be seen in the following highly simplified Sankey diagrams for UK energy flows expressed as yearly average GW supplied, Figure 2 representing the position on 2007 and Figure 3 a possible scenario for 2050 assuming success in demand reduction and adoption of electric transport.

Two important aspects to note are the substantial increase in electricity consumed, and the continuing dominance of fossil and nuclear sources in supplying it, in spite of aggressive deployment of renewable sources.

UK Energy Policy and Implementation

Lead responsibility lies with the recently created Department for Energy & Climate Change, with substantive participation of Department for Transport, Department of Communities & Local Government (domestic dwellings), Department of Business & Enterprise (industrial processes and industrial development), and HM Treasury (economic growth and impacts). Policy is defined in a series of White Papers on Energy (latest 2007) and Low Carbon Transition (2009). DECC also leads on early-stage deployment support (Environmental Transformation Fund) while RD&D is financed by the UK Research Councils, Technology Strategy Board, the Carbon Trust, and the Energy Technologies Institute (a public-private body with six industrial partners who heavily influence its programmes).

Figure 3 Sankey diagram for possible UK 2050 scenario: demand reduction and transport electrification



UK RDD&D Support and Priorities

The UK Research Councils' Energy Programme spends around £100M per year in universities, on a wide range of energy technologies, including nuclear fission and fusion. TSB funds around £35M of applied research into generic carbon abatement technologies by industry or academic industry consortia. ETI's budget is £60M annually, directed to industry-led consortia for development and demonstration of devices for deployment in the UK in the 2020-2030 timeframe. Finally the ETF is focused on early deployment support of low-carbon technology at about £100M per annum.

Full-scale demonstration of CCS will be supported through three schemes: a UK Government grant for one site, UK grants for a further three sites funded by a levy on electricity consumers, and an EC grant for a fifth system as part of the European economic recovery package. The UK schemes cover the additional capital and operating costs of usually one shaft-line, or about 300MWe, while the European scheme is at similar but lower levels.

Deployment incentives

These are mostly 'market correction' mechanisms designed to fit the UK competitive electricity supply system. A Renewables Obligation working through Certificates (ROC) requires each supplier to deliver ROCs for a specified proportion of power, which increases each year. An ROC is awarded for each MWh generated from renewable sources and can be traded. A fossil generator unable to purchase sufficient ROCs must pay a 'buy-out' price which also increases annually; currently it is £36.99/MWh. ROCs are now 'banded' to give higher returns to earlier stage technologies and lower returns to mature technologies by a simple multiplying factor from 0.5 to 2. Additionally the UK participates in the European Emissions Trading Scheme, which covers all generators and large industrial carbon emitters. This ETS is a 'cap-and-trade' scheme, but initially provided too generous allowances resulting in a high cap and low price. The current phase of the scheme has addressed this, but prices have proven volatile and as yet the scheme is not driving change in generating systems.

Very recently a feed-in tariff has been announced for small generators, particularly domestic scale. This offers a payment for every kWh generated from renewables, even if used by the generating entity, with a slightly higher sum if fed to the grid. The payment is essentially the ROC buy-out price, or around three times the retail price of electricity.

Priority Programmes

CCS: Demonstration at full scale is planned for five sites, using a range of pre- and post-combustion technologies. At each site the CCS element will be a single shaft-line of a multi-machine installation, permitting direct performance comparisons plus the potential to more rapidly retrofit a successful technology to the rest of the site. In parallel, extensive work is underway on assessment of storage sites, all under the North Sea. Transport of captured CO₂ is to be undertaken by the capturing site but development of shareable systems and pipelines is a specific objective.

Offshore wind: Development of effective construction, commissioning and maintenance systems, to meet aggressive deployment targets. Concurrently R&D is underway on novel design concepts for high reliability, high performance, lower cost machines for 'over the horizon' deployment.

Biomass and biofuels: R&D for 2nd and 3rd generation systems of biomass processing. A new Bioenergy Research Centre is now in place pursuing more efficient biomass production technologies with particular emphasis on reduced environmental impact, notably water demand and land quality, and higher energy capture.

Solar PV: R&D on thin film and excitonic systems, novel substrates, and efficiencies.

Fuel Cells and Hydrogen: PEM and SOFC systems have been brought close to commercial exploitation stage, and some 35,000 fuel cell-based domestic co-gen systems are to be trialled in the coming three years. R&D continues with a focus on cost reduction, enhanced durability, and increased specific performance. Parallel R&D into hydrogen focuses on improved storage systems, both solid state and pressurised, and generation from non-fossil sources.

Marine: 2MW unit size tidal stream systems are in demonstration, so R&D is directed to improved performance and operation, as well as new concepts to achieve substantial cost reduction. Wave energy remains an attractive potential resource but as economically viable generators are still to be proven R&D prioritises the development of more resilient, durable, and lower cost designs, of which several have emerged that show some promise.

Nuclear Fission: Future reactor systems will be procured from international developers but design licensing and all aspects of the fuel cycle and waste handling will be UK activities. Both require further development of knowledge, and reinforcement of skills base, which is the subject of recently enhanced funding levels.

Networks: Enhancing the capability of electricity networks is critical to exploiting effectively many of the new energy sources, or the efficient and flexible deployment of conventional systems. R&D thus focuses on capacity enhancement of existing infrastructure, flexible offshore connection and interconnection technologies, fault current limiters, 'smart' distribution networks, communications and control systems for load demand participation, energy storage systems for medium and small scale use, and virtual storage systems based on participative connected batteries.

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BIOGRAPHIES

WORKING GROUP

Dr Vaughan Beck FTSE – ATSE (Australia) Executive Director – Technical, ATSE

Vaughan Beck is Executive Director - Technical with the Australian Academy of Technological Sciences and Engineering (ATSE) and is responsible for the Academy's research projects and the development of policy advice to government in areas such as climate change, energy, water and education.



Dr Beck has a diploma and a degree in mechanical engineering, a master degree in structural engineering and a PhD in fire safety and risk engineering.

In 1989, Dr Beck was appointed as a Visiting Professorial Fellow at the Warren Centre of Advanced Engineering at the University of Sydney where he led a team of some 70 fire safety professionals. His research into building fire safety systems, and the program of reform that he led in Australia, was adopted in Australia and subsequently in a number of overseas countries. In 1991, Vaughan was appointed as Professor and foundation Director of the Centre for Environmental Safety and Risk Engineering at Victoria University. He was subsequently appointed as Pro Vice Chancellor (Research) at the university.

Vaughan has been awarded the W H Warren Medal by Engineers Australia and the John J Ahearn Presidents Award by the Society of Fire Protection Engineers.

Dr John Burgess FTSE – ATSE (Australia) Chief Investigator, ARC-Funded ATSE Energy Project

John Burgess is a chemical engineer. He has had wide experience in research, both in industry and academia. He was part of the management team of a BHP before the Billiton merger and in this role was Vice President Safety, Environment and Research. He has been a member of government and industry advisory and company boards and has received the highest national accolade for the chemical engineering profession in Australia, the Chemeca Medal. He has also been awarded an honorary Doctor of Engineering.



John is a Fellow of ATSE and has recently analysed and reported the capital costs required to create a portfolio of new technologies to satisfy Australia's energy requirements to 2050 in the context of strong CO₂ reduction targets. He is also now working on a new ATSE project examining the financial option values of these new technologies.

Professor Robert L. Evans FCAE – CAE (Canada) Professor of Mechanical Engineering at The University of British Columbia

Robert Evans is Professor of Mechanical Engineering at The University of British Columbia (UBC). He obtained a BAsC degree in mechanical engineering from UBC, an MASc from the University of Toronto and his PhD from Cambridge University. Dr. Evans previously served as Head of the Department of Mechanical



Engineering, as Associate Dean of Applied Science, and as founding Director of the Clean Energy Research Centre at UBC. He is a Fellow of the Canadian Academy of Engineering, the Institution of Mechanical Engineers, and the Society of Automotive Engineers. Dr Evans is the author of *Fueling Our Future: an Introduction to Sustainable Energy*, published by Cambridge University Press, which was short-listed for the 2007 Donner Prize for the best book on public policy published by a Canadian author. The book is also available in Chinese and is now being translated into Turkish and Arabic.

Professor Dr Frank Behrendt – acatech (Germany)

Professor Dr Frank Behrendt, born 1959, studied chemistry at RWTH Aachen and Heidelberg University. He got his PhD in 1989 from Heidelberg University for his work on modelling of diffusion flames including detailed chemical reaction mechanism. Additional research on catalytic ignition and combustion including extended research stays at the Chalmers University of Technology (Gothenborg, Sweden) and the Combustion Research Facility (Sandia National Laboratories, CA, USA) led to his habilitation at Stuttgart University in 1999.



Since 2001 he has been Full Professor for Energy Process Engineering and Conversion Technologies for Renewable Energies at the Berlin Institute of Technology (TU Berlin). His scientific work focuses on the experimental investigation of two-phase flows exemplified by the gasification of biomass in various types of reactors. These experiments are complemented by modelling and simulation efforts as well as their economical and ecological evaluation.

In 2007 he became Speaker of the Innovation Centre Energy being responsible for the coordination of all energy-related research at TU Berlin.

In the same year Behrendt was elected as member of the German Academy of Science and Engineering (acatech). Within acatech he is the deputy speaker of the thematic network Energy & Ressources.

Professor Hanasoge S. Mukunda – INAE (India)

Advisor, ABETS, CGPL, Indian Institute of Science

Professor Hanasoge S Mukunda holds a bachelor degree in Mechanical Engineering, Aeronautical Engineering and a PhD, both from the Indian Institute of Science. He served as a faculty member of the Aerospace Engineering Department, Indian Institute of Science for 34 years and is currently an Advisor to the Advanced Bioresidue Energy Technology Society.



His research is related to combustion processes in which he has supervised over twenty PhD theses and published over hundred peer reviewed papers. Over the last 25 years he has provided leadership in the modern technologies of solid fuels including biofuels. The technology for converting the solid fuels into clean gaseous fuels for use in reciprocating engines as well as gas turbines has been researched, developed and systematically perfected. The applications include gasifier stoves for cooking and semi-industrial applications, thermal and electrical applications over a wide power range, a few kWe to a MWe. These technologies have been licensed to several Indian manufacturers as well as those in Japan, Switzerland and Brazil. A number of applications including rural energy supply, institutional and industrial electric and thermal needs have been serviced with this technology which is of global relevance and of immediate importance to all oil importing countries, whether it is for taking care of the needs of isolated habitats, grid linked villages or industries without grid supply. As a member of International Science Panel on Renewable energy under ICSU he contributed to the biomass based energy segment of the report.

A fellow of Indian Academy Sciences, Indian National Academy of Engineering, and Aeronautical Society of India, he has received many national awards in aerospace science and technology as well as energy.

Dr Kozo Iizuka – EAJ (Japan)

President, Japan Association for Metrology Promotion

Dr. Kozo Iizuka is the President of Japan Association for Metrology Promotion and the Research Adviser to National Metrology Institute of Japan (NMIJ) of the AIST. He graduated from the University of Tokyo in 1953 and immediately joined the former National Research Laboratory of Metrology (NRLM, presently a part of the NMIJ), where he engaged in research on standards of hardness and other properties of materials as well as precision measurements of geometrical forms and dimensions. He received the degree of Doctor of Engineering from the University of Tokyo in 1972. He was appointed to Director General of the NRLM in 1983 and to Director General of the Agency of Industrial Science and Technology (AIST), MITI, in 1986. After resigning from the latter position in 1989, he moved to the Vice-President of Japan Society for Promotion of Machine Industry and then to Kubota Corporation in 1991, where he was the Vice-President from 1998 to 2000. He has been active in international activities and was appointed to President of Human Frontier Science Program (HFSP) Organization, a granting institution for bio-science, from 1995 to 2000, to Vice-President of the International Committee of Weights and Measures (CIPM) from 1996 to 2001, and to President of the International Measurement Confederation (IMEKO) from 1997 to 2000. He served in the Japan Industrial Standards Committee from 1996 to 2005 as the Vice-Chair and also in many national advisory and reviewing committees.



He is one of the founding members of the Engineering Academy of Japan and served on the Board of Directors from 1992 to 1995 and on the Committee of International Affairs from 2000 to 2006 as the Chair. He was elected as a member of the Board again in 2007 and was appointed as one of the Vice-Presidents. He is now a special adviser to the Committee of International Affairs.

Professor Myongsook Oh – NAEK (Korea)

Department of Chemical Engineering, Hongik University

Myongsook Oh is a professor of Chemical Engineering Department at Hongik University in Seoul. She obtained a BS degree in chemical engineering from the University of California at Berkeley, and ScD from Massachusetts Institute of Technology (MIT). Before joining Hongik University, Dr Oh was associated with Lawrence Livermore National Laboratory (LLNL) and Texaco, Inc in the US.



Starting from her ScD thesis on softening coal pyrolysis, she worked on the conversion of fossil fuels for over 30 years. At LLNL, Dr Oh's research was focused on oil shale retorting, coal pyrolysis, and the vitrification of nuclear wastes. After joining Texaco, her focus became the gasification process of various carbonaceous feeds such as coal, petroleum coke, spent tires and etc, concentrating on the transformation of inorganics. She has continued working on the gasification process in Korea, providing leadership in gasification slag rheology, refractory corrosion and trace elements emission. In 2004, she served as Chairwoman for a society for gasification research.

The other area that Dr Oh devotes her effort is to develop women in engineering program and educational contents. With her colleagues, she introduced the concept of engineering education for women (EEW). For the past five years she organised and chaired the EEW session in the annual conference of Korean Society of Engineering Education (KSEE). She also serves as chairwoman of the society for EEW research, and organises quarterly meetings. She authored several articles on EEW as well as research

papers. She is also very active in the professional societies of women: she served as a vice president in Women in Science, Engineering and Technology, Korea, vice president in National Women Professors Association, chairwomen in Women's Committee in Korean Institute of Chemical Engineers (KIChE) and WISE mentoring fellow.

She also served several government committees such as Energy Technology Advisory Committee and New and Renewable Energy Committee in the Ministry of Commerce, Industry and Energy, Korea. She is an active member of in ACS, KIChE, KSIEC, ASEE, and KSEE. She is a member of the National Academy of Engineering of Korea (NAEK).

Mr Willem du Preez – SAAE (South Africa) Consultant, Nuclear Engineering, ELMER Group

Willem du Preez received the BScBEng. degree in electrical engineering from the University of Stellenbosch in 1959 and the MSc(Eng.) degree in nuclear engineering from the University of Pretoria in 1961. He joined the South African Atomic Energy Board in 1962 and was seconded to the Oak Ridge National Laboratory in the US for two years practical training in nuclear engineering.



Willem returned to South Africa at the end of 1963 to work at the Atomic Energy Board's research establishment at Pelindaba. He held various engineering positions, ending as Head of the Control and Instrumentation Division.

In 1970 he was appointed by the Uranium Enrichment Corporation of S.A. as Head of the Control and Instrumentation Division. He participated in the engineering, procurement, construction and operation of UCOR's high enrichment uranium enrichment plant (Y-Plant) and held the positions of Engineering Manager, Manager : Y-Project and Manager : Y-Plant.

Willem was appointed as a Director by the BKS Group of Consulting Engineers and Project Managers in 1979 where he was responsible for the engineering and project management of various industrial projects.

Willem was a founder shareholder of the Pretoria based company Integrators of System Technology (Pty) Ltd. ("IST"). He became an Executive Director of IST in 1987 and was Chairman of the Board of Directors from 1992 to 1997. The company is active in the development and manufacturing of high technology products in the electrical power generation, nuclear power, industrial and military fields.

In 2005 Willem joined Pebble Bed Modular Reactor (Pty) Ltd where he was Project Manager of a project to industrialise PBMR's fuel manufacturing technology for commercial application. He is currently a Consultant in Nuclear Engineering at the ELMER Group in South Africa.

Professor John Loughhead FREng FCGI FRSA – RAE (UK) Executive Director, UK Energy Research Centre

John Loughhead is Executive Director of the UK Energy Research Centre and previously was Corporate Vice-President of Technology and Intellectual Property for the Alstom group, spending 11 years at its head office in Paris, during his career in industrial research and development.



He has been active in industrial energy systems research for the past 30 years, developing new generation and conversion technologies, electrical network systems, power electronics and control products, and energy efficient devices. This included time as MD of a contract R&D business which also undertook specialist manufacturing. He has extensive international and European experience,

and is currently co-chair of the Implementation Committee of the inter-governmental IPHE, a member of the European Advisory Group on Energy, the Executive of the European Energy Research Alliance, and the Energy Committee of the Agence Nationale de Recherche.

In his present role he has extensive interaction with UK Government bodies linking with energy policy development and new technology deployment, and is also a non-exec on the MoD R&D Board. He served as a member of the EPSRC Council, and Chair of its User Panel.

John is a graduate in Mechanical Engineering from Imperial College, London, where he also spent five years in computational fluid dynamics research. He is a Fellow of the Royal Academy of Engineering, a Chartered Engineer, a Fellow and Past-President (2008) of the Institution of Engineering and Technology, and Fellow of the Institution of Mechanical Engineers, the City and Guilds Institute, and of the Royal Society of Arts, and holds Honorary appointments as Professor of Engineering Cardiff University and Fellow of Queen Mary University of London.

SUPPORTING AUTHORS

Kristina Bognar – (Germany)

Kristina Bognar, born 1983, studied Media Studies/International Business at the University of San Francisco in 2002-03 and then moved to the Berlin Institute of Technology (TU Berlin) to complete her studies in the field of Engineering Economics. She received her diploma degree in 2008 with a thesis entitled “Desalination based on Renewable Energy Sources”.



As co-owner of a company she focused on R&D for integrating renewable energy systems for domestic purposes, increased energy efficiency, and energy storage. Later she worked as R&D Assistant at the Society and Technology Research Group of DaimlerChrysler in Berlin on alternative powertrains. In 2007 she joined the staff of Michael Cramer, MEP, member of the Committee on Traffic and Environment in Brussels.

Since 2009 Kristina Bognar has worked at the Department of Energy Engineering at the Berlin Institute of Technology (Chair of Energy Process Engineering and Conversion Technologies for Renewable Energy) as staff scientist. Her work is focussed on self-sufficient energy infrastructure including seawater desalination for islands and remote areas based on renewable energies.

Dr Hideo Tanaka – Japan

Dr Hideo Tanaka is Executive Director, TEPCO Research Foundation. He graduated from Keio University with BS degree in 1971, and with MS degree in 1973. He received PhD from Tokyo Metropolitan University in 1995.



He joined Tokyo Electric Power Co in 1973. He has been working on R&D on application of smart technology to power network operation and analysis.

He is also serving as Visiting Professor at Tokyo University of Agriculture and Technology. His major in the university is energy resources and environment.

He is a member of the Engineering Academy of Japan and is serving as Vice-Chairperson of Committee for Public Relations in the academy.

Mr Yoshiaki Nishimura – Japan

Yoshiaki Nishimura, born 1954, is Senior Staff at Planning Group of Central Research Institute of Electric Power Industry (CRIEPI) in Japan and is working on international research cooperation in the field of electricity. He obtained BA degree in nuclear physics from International Christian University (ICU) in Tokyo and M.A. in environmental science from Hokkaido University.



Before he joined CRIEPI in 1992, he had experienced various jobs including consultancy works on meteorological issues at private companies, management of technical cooperation projects at WMO headquarters in Geneva, field works at WMO/UNDP technical cooperation project in Jamaica, and advisory works as Special Assistant in the field of global environment at the Permanent Mission of Japan to the UN in Geneva.

At CRIEPI he has been working on research and management mainly in the field of environmental science and engineering for electric power industry. He also served as a scientific officer at Science and Technology Agency of Japan to promote various national and bilateral scientific projects, and as a leader of the Working Group of the Central Electric Power Council for evaluation of CCS technologies.

Mr Martin Thomas AM FTSE – ATSE (Australia) {Author of Country Report for Australia}

Martin Thomas has had a lifetime career in energy consulting, concluding as a Principal of Sinclair Knight Merz. Later he was founding Managing Director of the Cooperative Research Centre for Renewable Energy, ACRE. Former roles include Deputy Chairmanship of Australian Inland Energy, Chairmanship of Alecto Energy Plc; non-executive Directorships of the Tyree Group and EnviroMission and Advisor to the Board of ZBB Energy. He has also served as Chairman of industry association Austenergy, the NSW Electricity Council and the Sydney 2000 Olympic Energy Panel.



He is currently Chairman of Dulhunty Power Limited (ASX:DUL) and the Asia Pacific International College (APIC).

He is a past President of the Institution of Engineers, Australia and of the Australian Institute of Energy and a past Vice-President of the Australian Academy of Technological Sciences and Engineering of which he now chairs the Energy Forum. In 2008 he was awarded the Peter Nicol Russell Memorial Medal, the highest award of Engineers Australia.

In 2006 Martin Thomas served as a member of the then Prime Minister Howard's Uranium Mining, Processing and Nuclear Energy Review taskforce known as UMPNER.