PHOTO: iSTOCKPHOTO.COM

A SHORT GUIDE TO THE REPORT

CAETS ENERGY PROJECT

OPPORTUNITIES FOR LOW-CARBON ENERGY TECHNOLOGIES FOR ELECTRICITY GENERATION TO 2050

International Council of Academies of Engineering and Technological Sciences, Inc. (CAETS)

JUNE 2013

CAETS ENERGY PROJECT: OPPORTUNITIES FOR LOW-CARBON ENERGY TECHNOLOGIES FOR ELECTRICITY GENERATION TO 2050

The International Council of Academies of Engineering and Technological Sciences (CAETS) Working Group, (WG) on Low-Carbon Energy undertook a project entitled "*Opportunities for Low-Carbon Energy Technologies for Electricity Generation to 2050*". The report of the WG is focused on identifying promising initiatives to accelerate the commercial deployment of low-carbon energy (LCE) technologies for electricity generation and to highlight the engineering and financial risks to be overcome to facilitate the deployment of such technologies It is recognised that there are many additional factors that influence the development and deployment of electrical generation that are beyond the scope of this report (such as the need to obtain a social licence to implement LCE technologies). The WG report takes a global perspective on LCE technologies and the observations contained in the report are not necessarily applicable to any one nation. The key findings of the Working Group's investigation are given below.

KEY POINTS

Achieving a transition to a lower-carbon electricity generating system is technically feasible provided:

1. *significant investments are made to scale-up the development and deployment of LCE technologies (including carbon capture and storage (CCS)) for electric power generation by the end of this decade; and*
2. *consistent and significant government policy action is taken immediately.*

The following conclusions are relevant:

- *There is no single preferred LCE technology. Rather, the costs of different LCE technologies are expected to broadly converge over time. Hence a portfolio of technologies can be expected to be deployed.*
- *Promising initiatives in prospect for each LCE technology are identified, but significant technical and financial risks must be overcome for their widespread commercial deployment.*
- *Opportunities are identified where a number of LCE technologies may be integrated with either other LCE technologies or with fossil-fuel technologies to expedite their possible commercial deployment, including the lowering of greenhouse gas emissions of those fossil fuel technologies and delivering increased generating efficiency.*
- *Currently, most emerging LCE technologies do not have intrinsic commercial advantage over those technologies used today, so they will need sustained government support for research, development and deployment (RD&D).*
- *First-of-a-kind technologies have high risk and financial support is not readily available to support commercial deployment. There are opportunities for government support and this may include some form of subsidy (for example, cash or tax benefit).*
- *Even with support, major engineering challenges must be overcome to achieve a low-carbon electricity generating system.*
- *Substantial investments are required in new electricity generating plant. For example, it is estimated that US$ 6.4 trillion is required to be invested over a 10-year period for electric power generation technologies.*
- *Successful deployment of LCE technologies normally requires partnerships between research, industry and government. Appropriate public policy settings can make a clear difference in inducing innovation and the international diffusion of LCE technologies.*

It is not within the scope of this report to recommend either particular technology development strategies or electricity generation technology mixes; these subjects are clearly the province of individual nations. Recommendations for possible consideration include:

- *GHG reduction is a global issue – hence international RD&D collaboration should be supported with adequate resources, particularly in critical areas such as CCS.*
- *Governments and industry should work closely to ensure the strategic development and the acquisition of skills and resources for research, development, manufacture, deployment and possible international diffusion of LCE technologies.*

This report has been prepared as a resource for use by:

- *Those CAETS academies that may wish to engage with key stakeholders (including governments) in their respective countries about strategies that might be adopted to deploy LCE technologies for electric power generation as a means to achieve progress towards a low carbon environment.*
- *CAETS when it wishes to engage with relevant International organisations and inform them on:*
  - *the technical and financial feasibility of particular LCE technologies;*
  - *what are the promising initiatives that could be undertaken to accelerate their deployment; and*
  - *what are the risks to be addressed.*

This is an overview report and as such it contains general observations and technology assessments; it does not contain detailed technical appraisal of each of the LCE technologies.

The report considers nine LCE technologies that can be used for electric power generation; namely:

- Hydroelectric
- Biomass
- Solar Energy
- Gas
- Geothermal
- Coal
- Marine and Tidal Energy
- Nuclear
- Wind
- Carbon Sequestration*

*Carbon Sequestration is an enabling technology to achieve lower carbon emissions for fossil fuels.

Each of the low-carbon technologies is evaluated in the report under a common set of headings in the Technology Assessment section. In addition, the issues identified for each technology are then synthesised into general observations in a Technology Overview – Broad Findings section. Some of these observations are given below.

Many of the LCE energy technologies considered in this report have been in existence for years. They have formed a component of the electricity generation portfolio, but the majority of the world's electricity generation capacity is still provided by fossil fuels. While the proportion of electricity generated by LCE technologies is expected to increase significantly, it is expected also that fossil fuels will continue to be significant in the electricity generation in the short to medium term.

Further, as most renewable technologies transform an energy source (e.g. solar) into electricity and, as the proportion of electricity generated by renewable technologies increases, it can be expected that this will facilitate the substitution of a number of current energy sources by electricity as an energy source (e.g. for transportation, heating and industrial processes) and thus increase the importance of electricity and electricity generation in the energy mix.

This report is concerned with electricity generation which forms part of a power system along with transmission, distribution and use. Traditional power systems are being challenged by the introduction of new LCE generation technologies including issues associated with integration, intermittency and storage. Further, locally distributed electricity grids are being developed and these pose separate challenges. These challenges are outside the scope of this report.

It is recognised that increased energy efficiency is perhaps the most cost-effective mechanism in the near term for achieving lower greenhouse gas emissions and lowering the need for new electricity generation capacity. The reason that such a strategy of increased energy efficiency is important for LCE power generation technologies is that it provides a window of additional time and opportunity for emerging technologies to mature and become more cost competitive. Nevertheless, energy efficiency is outside the scope of this report.

BACKGROUND

To achieve targets for GHG reduction there must be significant changes to energy sources and their production, distribution and use. As noted in a previous CAETS WG report on LCE for electric power generation: 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 (CAETS, 2010 - see Reference section p4). While the first CAETS WG report on Low Emissions Technologies concentrated on broad global issues, this second CAETS WG report focuses on promising initiatives to accelerate deployment and to identify the technological and financial risks that may hinder such deployment. Accordingly, there is a need for impartial and informed information on low carbon technologies to help facilitate improved understanding and decision-making associated with these technologies. This report is intended to contribute to the provision of such impartial and informed information on low carbon technologies.

Technology Overview

The report identifies many of the risks that must be addressed and the challenges facing industry and government that must be overcome in order to deploy LCE technologies at scale. In addition, the following observations are relevant:

Financial considerations

There are several fossil fuel, nuclear and wind technologies that are currently commercially viable. It is recognised that as a technology moves along the continuum of research, development and commercial deployment the type of risk tends to change. The first-of-a-kind commercial plant will normally have relatively high costs associated with it. As further commercial plants are installed, the level of learning results in increased understanding and improvements in the technology and a downward pressure on both the capital and operating costs. For example, even among renewable power technologies, the costs of photovoltaic (PV) installed systems in the United States fell by 22 per cent between 2007 and 2010 whereas the costs of other renewable options declined more gradually. These technology learnings (in conjunction with a price on carbon) are expected to result in broadly similar costs for different LCE electricity generating technologies over time, typically 25 to 40 years. As such it is expected that a mix of technologies will be deployed to generate the required future electricity demand.

Promising initiatives to accelerate deployment

Virtually all of the LCE power generation technologies considered will require some kind of substantial initiative – fundamental innovation, technology development, demonstration at market scale, market incentive, or other action – to change the course of deployment of these technologies throughout much of the world.

A number of the most promising possible initiatives that could have a profound influence on development and rate of adoption of LCE technologies are common to all such technologies, such as various mechanisms that place an actual or de facto price on carbon; expansion, improved control and efficiency of electric power transmission and distribution; and development and deployment of electricity storage or other mechanisms for dealing with generation variability common to many of the relevant emerging technologies. In addition, each technology has its own features that may limit the rate of commercial deployment. Some technologies require substantial continued development or fundamental innovation, despite being on a fast development track already, to reduce cost or mitigate performance risks and compete commercially with traditional generation options. Promising initiatives that will facilitate the development of each technology considered are identified in the report.

For example, given that fossil fuels represent about 67 per cent of the current world electricity generation, then CCS is important for the future viability of fossil fuels. While the individual components of the CCS chain are well known there are few commercial-scale operations that demonstrate the integrated process. A key technological challenge is to have demonstration plants that show the technology is operable at commercial-size scale and which can be used to help define the risks to deployment in other installations. An increasing carbon price trajectory over a 10 to 20-year period will assist the commercial viability of such plants.

Integration and combinations of technologies to accelerate deployment

There are many possible combinations of technologies that can lead to improved efficiencies and/or cost. Opportunities for each generation technology are identified where integration and combinations of technologies can accelerate investment and deployment. The report identifies where, for instance, one technology may reduce a constraint on the deployment of the other; alternatively, where an overall reduction in the carbon emissions can be achieved by the

utilisation of a combination of technologies (such as the use of CCS in conjunction with fossil fuel power generation plants).
An example of system integration is the use of pumped water storage. In periods where there is excess in electricity generation (e.g. from intermittent renewable sources) this excess can be used to pump water into storage and use this to generate electricity when there is insufficient generation from intermittent renewable sources. Similarly, solar thermal (e.g. linear Fresnel Reflectors) can be used to heat the feed water to a fossil-fuel boiler and this can reduce the carbon emissions from the generation of electricity.

Engineering challenges to deploy LCE technologies at scale

Many of the LCE technologies proposed for future use have been demonstrated in functioning test facilities, whether in laboratories or pilot plants; some are even at commercial scale. However, the transition from those early demonstrations to equipment at production scale, whether in terms of plant size or in large numbers of devices operating at smaller unit scale, can pose engineering or economic barriers as challenging as the development of the basic technology.

It is considered that for most of the technologies evaluated here the engineering challenges can be overcome to realise deployment at scale. However, marine and tidal energy technologies face probably the greatest engineering challenges for deployment at scale. Apart from the technical and development barriers still to be overcome, the reliable installation, connection to the network, operation and maintenance will require a large engineering effort and an associated infrastructure including both ships and ports. Manufacture and delivery in volume of what are likely to be large heavy devices, up to 10 tonnes per kilowatt, implies a substantial and sophisticated industry with heavy delivery capabilities.

FUTURE PERSPECTIVES

Achieving a transition to a lower-carbon electricity generating system (comprising a mix of different LCE technologies) is technically feasible provided that: significant investments are made to scale-up the development and deployment of LCE technologies by the end of this decade; consistent and significant government policy action is taken immediately; that significant challenges and risks in the engineering and technological, environmental, social and financial domains are addressed and resolved; and that effective partnerships are developed between research, government and industry stakeholders.

REFERENCE

CAETS 2010, *Deployment of low emission technologies for electric power generation in response to climate change,* Working Group Report, September 2010, International Council of Academies of Engineering and Technological Sciences; see: http://www.caets.org/cms/7122/9933.aspx

WORKING GROUP MEMBERS

The representatives on the CAETS Working Group are listed below:

- Australia - Australian Academy of Technological Sciences and Engineering
  Dr Vaughan Beck (Chair)
- Canada - Canadian Academy of Engineering
  Professor Robert Evans
- Germany – acatech
  Professor Frank Behrendt
- India - Indian National Academy of Engineering
  Dr Baldev Raj
- Korea - National Academy of Engineering of Korea
  Professor Myongsook Oh
- South Africa - South African Academy of Engineering
  Professor Philip Lloyd
- UK - The Royal Academy of Engineering
  Professor John Loughhead
- United States of America
  Dr Maxine Savitz

CAETS MEMBER ACADEMIES

National Academy of Engineering (ANI) Argentina
www.acadning.org.ar

Australian Academy of Technological Sciences and Engineering (ATSE)
www.atse.org.au

Royal Belgium Academy of Applied Sciences (BACAS)
www.kvab.be

Canadian Academy of Engineering (CAE)
www.acad-eng-gen.ca

Chinese Academy of Engineering (CAE)
www.cae.cn

Croatian Academy of Engineering (HATZ)
www.hatz.hr

Engineering Academy of the Czech Republic (EA CR)
www.eacr.cz

Danish Academy of Technical Sciences (ATV)
www.atv.dk

Technology Academy Finland (TAF)
www.technologyacademy.fi

National Academy of Technologies of France (NATF)
www.academie-technologies.fr

German Academy of Science and Engineering (acatech)
www.acatech.de

Hungarian Academy of Engineering (HAE)
www.mernoakademia.hu

Indian National Academy of Engineering (INAE)
www.inae.org

The Engineering Academy of Japan (EAJ)
www.eaj.or.jp

The National Academy of Engineering of Korea (NAEK)
www.naek.or.kr

Academy of Engineering (AI), Mexico
www.ai.org.mx

Netherlands Academy of Technology and Innovation (AcTI.nl)
www.acti-nl.org

Norwegian Academy of Technological Sciences (NTVA)
www.ntva.no

Slovenian Academy of Engineering (IAS)
www.ias.si

South African Academy of Engineering (SAAE)
www.saae.co.za

Real Academia de Ingenieria (RAI), Spain
www.real-academia-de-ingenieria.org

Royal Swedish Academy of Engineering Sciences (IVA)
www.iva.se

Swiss Academy of Engineering Sciences (SATW)
www.satw.ch

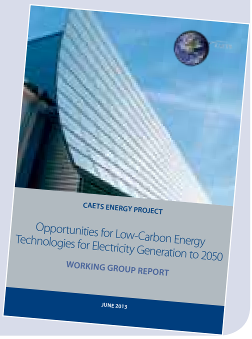
Royal Academy of Engineering (RAEng), United Kingdom
www.raeng.org.uk

National Academy of Engineering (NAE), United States
www.nae.edu

National Academy of Engineering of Uruguay (ANI)
www.aniu.org.uy

CAETS

William C. Salmon, P.E.
112 Pleasant Grove Road
Locust Grove, Virginia 22508
cell +1-703-527-5782
caets@nae.edu
www.caets.org



- CAETS is the International Council of Academies of Engineering and Technological Sciences, Inc. It consists of those national academies of engineering and technological sciences that have satisfied an agreed set of criteria for membership. It was established in 1978 and was incorporated as a charitable non-profit corporation in the District of Columbia (US) in 2000. Its Articles of Incorporation, Bylaws and Operating Procedures set down its objectives and governance arrangements. These documents and its membership and achievements are posted on the CAETS website, www.caets.org. A list of CAETS member Academies is given on this page.
- A complete copy of the CAETS Working Group Report *"Opportunities for Low Carbon Energy Technologies for Electricity Generation to 2050"* can be found on the CAETS website.
- The views contained in the Working Group report are not necessarily endorsed by each member Academy of CAETS.