Engineering 3 (2017) 436–438

Contents lists available at ScienceDirect

Engineering

journal homepage: www.elsevier.com/locate/eng

Topic Insights

Contemporary Research in Energy Science and Engineering

Chris Greig

Professor, The University of Queensland

1. Introduction

Energy is vital to any modern economy, as it enables the provision of lighting, cooking, heating and cooling, transportation, and the industrial production of most goods required by society. Access to modern energy services that are reliable and affordable is therefore a priority for societies, governments, and industries the world over. In 2015, the United Nations [1] reported that over 1.25 billion people living in the world's wealthiest countries enjoy the social, economic, and population health benefits that are made possible by the widespread provision of modern energy services. At the same time, more than 3 billion people in poorer countries lack access to adequate energy services to meet even their most basic requirements [2].

China provides a recent exemplar of a nation's transition from energy impoverishment to widespread access. This is best illustrated by the three-fold rise in primary energy consumption that occurred between 2000 and 2016 [3], which powered a near 10-fold increase in GDP [4]. However, environmental consequences came along with the tremendous social and economic benefits of this transition, bringing into question the sustainability of such transitions.

2. Energy transitions and sustainability

The provision of modern energy services has been underpinned by low-cost, abundant fossil fuels that are energy dense, transportable, and storable, and that may be readily converted into useful energy carriers such as electricity and fuels for cooking, heating, and transportation. In 2016, fossil fuels accounted for over 85% of total global primary energy use, with an even greater contribution of 87% in China [3].

This utilization of fossil fuels has resulted in serious environmental consequences, particularly in relation to air pollution, which is associated with particulates in flue gas, and in relation to climate change, which is associated with the carbon dioxide (CO_2) emissions inherent to combustion. Although serious air pollution issues are avoidable with modern technology, the production and emission of CO_2 present a great challenge to the utilization of fossil fuels.

As a result, much of the recent focus of energy-related research is driven by the pressing need to decarbonize the energy economy. For engineers, the focus is on designing low-carbon energy systems that will allow a rising global population access to reliable and affordable energy services without contributing to climate change.

This research can be considered under four primary categories:

- Energy security;
- Reducing CO_2 emissions associated with fossil fuel utilization;
- Zero-carbon energy systems; and
- Energy-economy systems analysis.

2.1. Energy security

Energy security is central to the economic resilience of nations. Resource depletion and a reliance on imports represent threats to ongoing energy security. Engineers look to enhance energy security through alternative technologies that are not reliant on scarce resources. Renewable energy offers such alternatives. Several of the articles in this issue reference energy security, and a majority focus on renewable energy and CO_2 emissions reduction.

Two articles in this issue, while not related to renewable energy, are specifically focused on opportunities to enhance energy security in China. The article by Wang and Huang, titled "The recent technological development of intelligent mining in China," reviews the latest developments in coal mine automation and covers intelligent machines, information technology, and real-time data processing and automation, all of which can enhance the productivity and efficiency of coal mining with positive outcomes for China's energy security. The article by Liu et al., titled "Particle size and crystal phase effects in Fischer-Tropsch catalysts," is motivated by China's reliance on oil imports and on the relative abundance of coal over oil in China. This research aims to improve the efficiency and reduce the costs of the conversion of synthesis gas from coal, natural gas, or biomass into transportation fuels.

2.2. Reducing CO_2 emissions associated with fossil fuel utilization

There are three ways to reduce emissions from fossil fuels. The first is to increase the efficiency of production and conversion from primary energy resources to energy carriers for productive use. These efforts are largely driven by the private sector, and particularly by engineering, construction, and manufacturing firms working in the sector.

The work of engineering academicians is more focused on carbon capture and storage (CCS) in various configurations. The article by Cook in this issue, titled "CCS research development and deployment in a clean energy future: Lessons from Australia over the past two decades," articulates the role that CCS may play in reducing

http://dx.doi.org/10.1016/J.ENG.2017.04.026

emissions. It also discusses the likelihood that this technology will be necessary to meet global emissions reduction targets and outlines the challenges for deployment and the need for international collaboration.

Geologists and petroleum engineers are focused on research to assure the cost-effective long-term storage of supercritical CO_2 in geological reservoirs. Chemical and mechanical engineers tend to focus on technologies to increase the efficiency and reduce the costs of separating CO_2 from industrial gas streams, such as those from coal- and natural gas-fired power plants, blast furnaces for iron and steel production, and cement manufacture.

Although most current carbon-capture plants utilize amine adsorption to separate out CO_2, membrane technology is considered to be an emerging opportunity to reduce the costs and energy consumption associated with CO_2 capture. The article by Brinkmann et al. (this issue), titled “Development of CO_2 selective poly(ethylene oxide)-based membranes: From laboratory to pilot plant scale,” reports encouraging results from their demonstration of a flexible polymer membrane.

2.3. Zero-carbon energy systems

A number of renewable resources, as well as nuclear energy, offer (near) zero-carbon energy services. Wind, solar, hydro, geothermal, tidal and wave and, in some cases, biomass energy resources offer such opportunities, especially for electricity generation.

Hydro and nuclear power currently provide the highest (near) zero-carbon contributions to global electricity generation at 16% and 10.5%, respectively, followed by wind (3.8%) and solar (1.4%), with the remainder (biomass, geothermal, and tidal and wave power) contributing a total of 2.3% [5].

The outlook for renewable electricity, especially wind and solar, appears stronger than the outlook for nuclear power, because the former is driven by strong public support and financial incentives. Wind and solar energy also enjoy strong support in the research sector. The combination of incentives, manufacturing scale, and research outcomes has led to very significant reductions in the costs of wind and solar generation capacity; accordingly, most forecasts see very significant expansion of solar and wind generation [5]. There are two solar power generation technologies, solar photovoltaic (PV) and solar thermal; solar PV has provided the major contribution to deployment thus far.

Wind power, especially onshore applications, is a mature technology with current innovation focused on increasing the scale of wind turbines and on control methods to enhance power capture and manage load shedding when necessary. The article by Yuan and Tang (this issue), titled “On advanced control methods toward power capture and load mitigation in wind turbines,” surveys recent developments in multivariate control approaches to optimize power capture and load reduction, which can be required to balance power systems with variable wind resources.

The majority of solar PV technology deployment relies on silicon-wafer-based solar cells. The projected rapid uptake of solar energy has the potential to expose limitations associated with a lack of flexibility and form factor, along with vulnerabilities in materials supply chains. Significant research effort is focused on potential alternatives to silicon-wafer-based PVs, with most attention being on thin-film PVs that comprise very thin coatings of $Cu(In,Ga)Se_2$ (CIGS) semiconductors on a glass or polymer substrate. In this issue, the paper by Sun et al., titled “Review on alkali element doping in $Cu(In,Ga)Se_2$ thin films and solar cells,” and the paper by Powalla et al., titled “Advances in cost-efficient thin-film photovoltaics based on $Cu(In,Ga)Se_2$,” trace the development history and benefits of CIGS solar cells along with the improvements that have been achieved in their performance over time.

The key challenge for wind and solar energy is that they are variable in supply and produce electricity intermittently, with negative consequences for the reliability and cost of systems as the penetration of these renewables increases [6,7]. Energy storage has become an area of much attention for researchers, policy makers, and power utilities in an effort to resolve these intermittency issues.

Energy storage technologies involve the conversion of electricity to potential energy in the form of, for example, elevated water storage (pumped hydro), compressed air in subsurface porous reservoirs, kinetic energy in the form of mechanical fly wheels, or chemical energy. The focus of most energy storage research is on storing electrochemical energy in batteries, capacitors, and fuel cells.

Pumped hydro is currently the most scalable and affordable energy storage option [7]. The article by Zuo and Liu (this issue), titled “Flow-induced instabilities in pump-turbines in China,” summarizes the role of pumped storage hydro in China and examines some of the performance issues associated with hydraulic instabilities that are negatively impacting the performance of pumped-hydro installations.

2.4. Energy-economy systems analysis

Energy systems analysis is a field of study that involves the development and modeling of energy systems and the analysis of their economic competitiveness. Such studies can be focused on a specific technological opportunity or on the integrated assessment of sectoral, regional, national, or even global energy transitions.

A small number of research groups around the world work on integrated assessment studies connecting energy, environmental trends, and the broader economy. The article by Chen (this issue), titled “An empirical study on China’s energy supply-and-demand model considering carbon emission peak constraints in 2030,” exemplifies such studies. This article projects a technology and fuel mix for primary energy, with trajectories for key population, GDP, energy elasticity, and shifts in economic structure (primary, secondary, services, industry sector, etc.) for China, given its international commitments to climate mitigation.

3. Summary

Energy services are vital to any modern economy, and underpin both human wellbeing and economic productivity. To date, modern energy services have been supplied by fossil fuels, resulting in serious environmental consequences—particularly in relation to climate change, which is due to greenhouse gas emissions.

In this issue, we review contemporary energy-related research with an emphasis on China. Much of recent engineering research has focused on designing and improving the performance of low-carbon energy systems. These cover both renewable energy technologies and emissions reduction from coal-fired generation using CCS. A number of papers also focus on the system-level energy security challenges and economy-wide assessments of energy transitions associated with emissions reduction commitments.

References

[1] United Nations Department of Economic and Social Affairs, Population Division. World population prospects: The 2015 revision. New York: United Nations; 2015.
[2] International Energy Agency, World Bank. Sustainable energy for all 2017—Progress toward sustainable energy. Washing, DC: Wold Bank; 2017.
[3] BP p.l.c. BP statistical review of world energy. London: BP p.l.c.; 2017.
[4] World Bank data of China [Internet]. Washington, DC: The World Bank Group, c2017 [cited 2017 Aug 5]. Available from: http://data.worldbank.org/country/china.

[5] International Energy Agency. World energy outlook 2016. Paris: International Energy Agency; 2016.
[6] International Energy Agency's Energy Technology Systems Analysis Programme, International Renewable Energy Agency. Renewable energy integration in power grids: Technology brief. 2015.
[7] International Energy Agency. The power of transformation: Wind, sun and the economics of flexible power systems. Paris: International Energy Agency; 2014.