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Review

Key questions, approaches, and challenges to energy today

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ABSTRACT

This perspectives article is intended to highlight global energy needs and solutions with a focus on catalysis. Market dynamics are discussed along with today's major energy resource options and emerging energy resources versus petroleum with a particular focus on those topics where catalysis can offer real impact: shale gas, biomass, and solar. Petroleum, NG, and coal continue to dominate the energy resources for most nations with the percentage of renewables growing but accounting, in total, for a much smaller share of the energy pie. Other natural resources, such as land, geology, and water do impact energy options. Over the last few years, shale gas has had a big impact on the available energy resources. Renewables will take increasing amounts of the energy pie, but this is going to depend on the region and in nations, such as the USA and China, which have a long term supply of any one of the big three energy resources: NG, petroleum, and/or coal. There have in the past and will continue to be roles for catalysis and new materials in the big three and in renewables with many new opportunities arising because of the recent development of vast fields of shale gas wells producing at regionally competitive prices.

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1. Scope of this assessment

Energy is certainly one of the biggest businesses in the world [1], and it offers a growing opportunity for catalytic solutions to meet the escalating global demands. Energy is also vital to the world's chemical industry. More than 95% of all manufactured products rely on chemistry and ~90% of all our chemical processes rely on catalysts to improve production efficiency [2]. To most manufacturers, energy often is a major part of their costs. In the USA, industry consumes about 31% of the energy resources [3]; the chemical industry accounting for ~10% of global energy demand or 30% of total industrial energy demand [4]. Energy intensive businesses include petroleum refining, NG conversion, power generation, transportation vehicles, emissions controls, chemicals production, aluminum production, and increasing applications of biomass conversion and solar devices. Totaling the sales for the number of companies involved in energy intensive businesses easily amounts to many trillions of US dollars. For each one of us, energy impacts our lives in many ways every day. This manuscript seeks to look at the broader picture of meeting future global energy needs with catalytically driven solutions while being sensitive to energy resources [5]. The intent in this perspectives manuscript is to provide an overview, not a detailed review of key energy options,

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with a focus to options beyond traditional petroleum resources, and to highlight the issues and identify major opportunities for catalysis R&D in the future.

2. Energy is a big business opportunity

The resources for energy vary around the world depending on any nation's natural resources. The distribution of energy sources within the USA in 2011 is shown in Fig. 1. Globally, fossil fuels make up a dominant part of the energy supply for most developed nations, with renewables generating a lot of interest for environmental and sustainability reasons, of which biomass conversion makes up almost half of the renewable energy resources in the USA [6]. Sixty percent of the world's energy needs are expected to be met by traditional hydrocarbon fuels, but the world is not standing still. Developing nations thirst for increasing amounts of new energy and seek to sustain their economic growth by using increasing amounts of energy. In 2012, China and India accounted for 90% of the net increase in global energy consumption [7]. By 2040, experts predict [8] that there will be a 56% increase in world energy demand, 90% of that increase coming from developing nations. Where will this energy come from in a world completing for limited fossil fuels? Economic forecasts predict decades ahead of continuing tight supply and high demand for energy and its dependent products. This demand presents a great opportunity for catalysis. This continued demand for energy will come from global businesses that include petroleum refining, natural gas (NG) conversion, power generation, transportation vehicles, emissions controls for a cleaner atmosphere, chemicals for enhancing the quality of life, and new businesses being created to meet that demand, such as biomass conversion and solar power generation. A recent report issued jointly by the IEA, Dechema, and the International Council of Chemical Associations [2] predicts that by 2050 catalysts and related process improvements could reduce the energy intensity of 18 major chemical products by 20–40%.

What is intriguing about Fig. 2, showing the status of various energy resources over the past 65 years [9], is the dramatic upturn since about 2008 in natural gas, crude oil, biomass, and other renewables due largely to technology advances over the last 5 years. Importantly, the sources of the energy marketplace differs by sector, that is the transportation market sector has and will continue to rely largely on petroleum, while those in the industrial sector are shifting their feedstocks (such as coal to either NG or solar for electricity generation; or switching to biomass or NG for specialty chemicals production).The big three, petroleum, coal, and natural gas, today continue to dominate the world's energy resources and have for more than 40 years. Global energy consumption by fuel in 2010 was 12,477 million tons oil equivalent, of which oil was 33%, NG 24%, coal 30%, and renewables 1.9% [7]. The global reserves of these fossil fuels are substantial. While renewables (encompassing biomass) have grown considerably in the last few years, their overall contribution on a global scale is small, but becoming more important in meeting the growing energy demand worldwide as long as regional prices for energy resources permit (This will grow from 16 TWy/year in 2009 to 28 TWy/year in 2050 [10]) (Terawatt-years, TWy). Ernst & Young LLP reported that in 2012, renewables accounted for 50% (13.1 MW as wind technology; 3.3 MW as solar PV) of the newly added energy in 2012 [11]. The projected growth of energy demand over the next century will be met increasingly by renewables (solar, wind, biomass, geothermal, waste conversion, hydroelectric, and ocean (currents, tides, and waves)). New growth in carbon-free renewables will depend on further improvements in technology, cost breakthroughs, legislation, and subsidies that give renewables an added cost advantage.

While solar offers huge energy resources (Fig. 3), it may take decades for solar technology to compete competitively on price compared to fossil fuel alternatives (primarily petroleum, coal and NG); the latter two will strive to satisfy new energy demand in this transition to renewable fuels. Solar has a potential (Fig. 3) of providing 500 terawatts (TW, a trillion watts; 1 TW-hr can power 85,000 homes) of practical power generation versus 5–7 TW from biomass, 2–4 TW for wind, and <2 TW for tidal and hydroelectric (practical) [12,13]. One hour of sunlight corresponds to ~14 TW/yr.) (Current efficiencies in biomass-based technology would require 30% of earth's land mass to produce 20 TW). A recent NREL/DOE report suggests, optimistically, that the cost of renewable energy (vs. NG fired power plant) becomes quite competitive in the western USA by 2025 [14]. Certain states (California, Arizona, and Nevada – have a solar advantage; Idaho – a geothermal advantage; Montana, Wyoming, and Colorado – a wind advantage) could have surpluses of un-subsidized, renewable energy by focusing development on each region's most productive renewable resources (depending on transmission costs, population center demands, and new technology developments).

Fig. 4 shows energy costs for selected chemical products. Not surprisingly, energy costs of very endothermic processes (NH_3, ethylene, propylene) or those based on other feedstocks produced from endothermic processes (synthesis gas, naphtha cracking, etc.) reveal high energy costs [15]. Shale gas is now impacting this picture since ethane and propane are often low cost byproducts of shale gas recovery.

3. Catalysis in energy R&D

Catalysis is only one large part of the R&D efforts in energy. Applications for new catalysts and catalytic processes emerge in the many different sources of energy (coal, biomass, nuclear, solar, oil, and natural gas (NG)); many of which demand catalysts for emissions control, transportation vehicles, improved devices (photovoltaics (PV), and fuel cells), and processes for both chemicals and fuels production. Source limitations or customer demand are creating entirely new businesses in storage to capture energy for off-peak use. Then there are the products that use the energy (chemicals, agriculture, and transportation) which will rely on catalytic solutions. Specific energy R&D topics include fuel cells, photovoltaics, electrochemical energy conversion/storage, biomass conversion, storage of energy as a chemical (such as H_2), batteries for off peak storage, solar splitting of water, photocatalytic conversion of chemicals, water purification, and feedstocks (coal, NG, etc.) for energy generation. One critical topic that bridges almost all of these is water, since fresh water supplies and quality often are limited around the globe. Here too catalysis has an impact via purification processes such as wet air oxidation, ozonation, enzymes, H_2O_2 production and treatment processes, photo disinfection, and even indirectly via the production of the plastic pipe used for transporting water over large distances.

4. Petroleum

Much has been said about this vital energy resource over the 20th century and its continued dominance as a major energy resource into the 21st century. That is not to be the focus of this manuscript; rather it is to contrast petroleum with alternative, greener and ultimately more sustainable energy resources and point to distinguishing characteristics of those resources. Many of us personally have experienced the dramatic growth in petroleum prices from the 1960s through to 2010. As a commodity resource, petroleum is subject to a great deal of market as well as political forces. For decades demand has been high because of the lack of