GEOSCIENTISTS MUST GET INVOLVED IN DEFINING CURRENT AND FUTURE DIRECTIONS IN ENERGY PRODUCTION AND IMPACT EVALUATION

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As the human population continues to grow, global demand for energy is certain to increase. The consequences of this increase in parallel with expectations for a higher standard of living pose many critical questions about the future of our planet. How much energy will be needed by more than 7 billion people in 2020? 2040? Where will this energy come from? How are we going to manage the impacts of resource extraction? Is there such a thing as sustainable, nonrenewable energy? What can be done to encourage energy conservation and increase efficiency?

To answer these questions and understand the impact of humans on Earth, the expertise of geoscientists will be critical. Our understanding of the geosphere, atmosphere, biosphere, and hydrosphere and the associated processes is needed to guide the public and other stakeholders in the myriad of challenges that we face. Geoscientists must take more active roles in leading energy-related conversations with decision makers in government and industry.

A déjà vu is emerging with the current increase in the production of unconventional hydrocarbons in North America. Senior geoscientists recall the past boom and bust cycles associated with hydrocarbons and have witnessed the environmental and social consequences that follow depletion of a local resource or a substantial drop in price. It will be interesting to see how our choices unfold in the coming years and whether the shale gas boom will lead to another boom/bust cycle.

This issue of *Elements* evaluates many of these broad, energy-related questions in regards to unconventional hydrocarbon extraction. The articles describe cutting-edge thinking and discuss challenges in the area of resource extraction and impact mitigation for both petroleum and natural gas extraction. They point to a number of areas where we can expect this type of resource extraction to potentially impact water, land, air, biota, and humans. While the specifics of these articles are largely focused on North America, many of the current and forthcoming lessons are certain to have global applications.

Over the years of my career in resource recovery and impact analysis, and more recently with unconventional hydrocarbons, I have made a number of observations related to extraction (for example, Chermak and Schreiber 2014). Resource-extraction projects always begin by defining economic, environmental, health, and social impacts, both positive and negative. There is a formal process in the US for evaluating impacts and mitigation strategies during resource-extraction activities, with the development of an Environmental Impact Assessment, a Social Impact Assessment, and a Health Impact Assessment (Vanclay 1999; NYS DEC 2009). The process promotes communications between industry, regulators, and stakeholders during planning for the extraction of a resource. Negative impacts can be thought of as project risks, and this concept is discussed in the following Perspective by Zoback and Arent. Their figure 2 highlights some of the potential risks posed by unconventional hydrocarbon extraction to water, land, the atmosphere, and the community.

In North America, each well needs to have a project plan that is communicated to all groups. The plan should include information such as the number and type of workers to be used, equipment, costs, recovery estimates, efficiency, schedule, and economics. Exploration, construction, operation, and closure activities should all be considered. Once the plan is defined and finalized, the project is then analyzed for impacts. If the plan is modified, the evaluation of the project needs to be updated. Pre- and postproduction monitoring requirements must also be determined (i.e. groundwater sampling) so that impacts can be assessed, mitigation proposed, and communication pathways identified. Geoscientists assume many roles in developing these plans, and critical areas such as resource recovery-percentage estimates and optimization are critical to accurately determining the economics of a project.

Economic impacts from the current North American unconventional hydrocarbon boom are substantial, and many are summarized by Blumsack (2014 this issue). The big winners in North America are currently the consumers, due to increased supplies, cheap natural gas prices, and new jobs, and the US economy, with increasing petroleum/gas production (EIA 2014).

Environmental impact analysis from a project plan is a well-developed process. Mitigation methods are chosen based on a cost/benefit/risk analysis of the project. These mitigation decisions can impact the economics of the project. As an example, a cost/benefit/risk analysis can be applied to wastewater disposal by comparing injection with treatment and discharge. Subsurface wastewater injection is significantly cheaper than treatment and discharge but carries higher risks.

An example of an atmospheric impact reduction in the US that was primarily caused by the switching from coal to natural gas in electricity generation can be seen in CO_2 emissions data. In 2012, CO_2 emissions were more than 12 percent below 2007 peak emissions (EIA 2014). The atmospheric emission data on methane release from unconventional gas extraction and use as compared to coal are still being collected and interpreted, but if unconventional hydrocarbon extraction and use can be conducted with minor methane release, this would be a positive change in the current US greenhouse gas emission situation.

Data on the social impacts to individuals and communities associated with unconventional hydrocarbon extraction are also being collected and assessed. Social impacts can be significant during the transformation of a rural environment into a temporary industrial setting. Decisions about the mitigation of impacts are being made by industry from the analyses of consultants and others, but these internal documents are often not publicly available or communicated to the public. This lack of communication prevents further evaluation and critical discussions with stakeholders to promote community engagement and understanding, and to manage expectations. There currently is little or no public/academic viewing of these documents, when they exist; thus there is little or no opportunity for lessons learned to be developed, and operators may be spending money on social impact mitigation without being very effective.

The state of Pennsylvania has recognized that some of the social impacts associated with unconventional hydrocarbon extraction were not being mitigated appropriately. A good example is road and infrastructure upkeep and maintenance. In response, the state implemented Act 13 in 2013. This oil and gas law essentially charges an "impact fee" to operators for drilling, and the fee is distributed back to the local government (http://stateimpact.npr.org/pennsylvania/tag/impact-fee/). The concept of sustainable development is still not very prevalent in North American unconventional hydrocarbon extraction but is fairly well developed in international resource-extraction activities. Investments in this approach are proving to be worth considering, for example, in areas such as schools, training, etc., to help obtain/maintain a social license to operate (Vanclay 2006).

Another important social aspect to unconventional energy extraction is the education of stakeholders. To value resources, the public needs to know more about the project plan and impacts. This communication is essential to building a better appreciation of what goes into supplying fuels for transportation or producing electricity. An understanding that impacts and impact mitigation are part of the resource development

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faults or into formations immediately above crystalline basement, in which case pressure changes in the injection zone might affect potentially active faults in basement.

Fundamentally, whether one is addressing the potential risks associated with earthquake triggering, contamination due to poor well construction, or methane leakage, the solutions come down to all of the stakeholders—oil and gas operators, regulatory authorities, utilities, and the public—being proactive about dealing with the associated environmental impacts. As we noted at the outset, switching from coal to natural gas for electrical power generation could have profound and far-reaching benefits; however, to realize these benefits, shale gas resources must be developed in an environmentally responsible manner.

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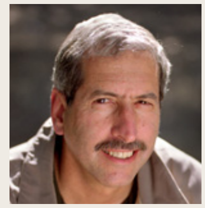

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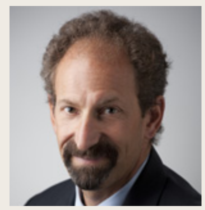

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process needs to be communicated. In these discussions, it is critical that stakeholders learn how they can obtain credible information.

What will the future of energy look like? This is a difficult question to answer. The growth in consumption is projected to be primarily in developing countries / emerging economies such as China and India. This is a critical point because significant steps toward reducing CO_2 emissions in the short term will require more conservation and increased efficiency as well as a faster transition from coal to natural gas in China and India. Ultimately, the high-growth energy consumers will have to transition rapidly to renewables for the largest potential reductions in greenhouse gas emissions and for a sustainable energy future. But it is difficult to say if this is a realistic expectation. As one looks to other energy opportunities, the role the nuclear option will have in supplying global energy is debatable.

From a global energy perspective, scientists and engineers generally agree that a technological breakthrough in renewable energy is necessary. The long-term goal is to reduce cost and increase efficiency such that a global-scale transformation from nonrenewable to renewable energy could occur. Such a breakthrough would give a truly sustainable energy future to us all. Still, impacts from renewable energy sources must be understood and managed.

It is poignant to consider a visionary statement by Thomas Edison that refers to nonrenewable versus renewable energy. During a discussion with Henry Ford and Harvey Firestone in 1931, Mr. Edison said, *"We are like tenant farmers chopping down the fence around our house for fuel when we should be using Nature's inexhaustible sources of energy—sun, wind and tide. I'd put my money on the sun and solar energy. What a source of power! I hope we don't have to wait until oil and coal run out before we tackle that."* At the present time, we are unfortunately nowhere close to attaining this vision. In 2013, the United States used approximately 91% nonrenewable energy and 9% renewable energy, while world use was estimated at 89% nonrenewable and 11% renewable energy (EIA 2014).

The expansion of natural gas production is upon us. Geoscientists are uniquely positioned to lead the effort to create a balance between extracting this resource and managing impacts. As a college professor to hundreds of undergraduates each year and as a parent, I cannot overemphasize how important it is for the geoscience community to engage in the discussion about how to balance global energy needs with environmental and societal needs. To transform the black box of energy extraction into an informed process, stakeholders, politicians, and the public need geoscientists to communicate their interdisciplinary insights. If we don't initiate these discussions, who will?

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