KSCE Journal of Civil Engineering (2011) 15(4):607-610
DOI 10.1007/s12205-011-0101-8

www.springer.com/12205

Energy Geotechnology

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Received August 31, 2010/Accepted February 16, 2011

Abstract

Energy consumption is closely correlated with quality of life. A 1% annual increase in power production is required to sustain current trends, and a 2% annual increase will be needed to satisfy anticipated growth in the developing world. On average, 85% of all primary energy comes from fossil fuels; this carbon-based economy faces limitations in reserves and climate-change implications. Energy Geotechnology must play a central role in the development of a sustainable energy strategy. Geotechnology is intimately involved in all energy resources, including fossil fuels (petroleum gas and coal), nuclear energy, and renewable sources (wind, solar, hydroelectric, geothermal, biofuels, and tidal energy). While wind and solar energy are surface processes that require limited geotechnical engineering, subsurface geo-storage is a viable alternative to bridge the time-gap between production and demand peaks. Geotechnical engineering is required to manage energy-related waste, ranging from fly ash to CO_2 emissions and nuclear waste. Furthermore, geotechnical engineering can contribute to geo-environmental remediation, the design of new facilities in view of life-cycle needs and decommissioning, and geotechnical construction methods that reduce the embodied energy in infrastructure projects. Education programs must be restructured to prepare the next generation of geotechnical engineers to address the needs in the energy sector.

Keywords: *carbon dioxide, climate change, education, embodied energy, energy geotechnology, fossil fuel, geo-storage, sustainability, waste*

1. Introduction

The importance of energy remains unnoticed in our daily lives until national and international events highlight the complexity and brittleness of the energy system. Consider for example, the oil embargo (1973), nuclear accidents (Three Mile Island on March 28, 1979, and the Chernobyl disaster on April 26, 1986), massive power failures or blackout events (the August 18, 2005 blackout in Indonesia affected 100 million people, and the northeast blackout in the USA on August 14, 2003 affected 55 million people), the failure of fly ash impoundments (e.g., in Tennessee on December 22, 2008), and the explosion of BP's Deepwater Horizon (Gulf of Mexico, April 20, 2010).

There is an increased realization in the energy sector and among governments worldwide that we are advancing towards a much more critical situation, which will have profound long-lasting effects unmatched by short-term events such as those listed above. Fossil fuels are at the center of this conundrum, due to our carbon-based economy, the known limited reserves, their impact on climate, and sustainability considerations.

Energy consumption per capita varies by more than three orders of magnitude among countries. Many countries, particularly in Africa, have an energy consumption lower than 100 W/person, while nations in the developed world exceed 4000 W/person; in particular, the USA consumes energy at the rate of 11000 W/person. The 100 W/person mark is of particular interest because this is equivalent to a healthy diet of 2000 calories per day, i.e., the energy required to sustain our bodies. It is not surprising then, that countries with very low energy consumption also exhibit very high infant mortality rate and very low life expectancy. Indeed, the critical relevance of energy in our lives is readily demonstrated by the correlation between quality of life indicators and power consumption.

Population growth is also correlated to energy consumption: the lower the power consumption, the higher the population growth rate. If we consider the population growth and the increasing power consumption per person in most countries, then the predictions for energy requirements in the near future are staggering. The current global power consumption is about 16 TW. To sustain current trends, we need to increase power production by 1% every year. If we promote growth in the developing world to attain an adequate quality of life, a 2% per year increase in power production is needed worldwide. For reference, a 1% increase per year is equivalent to an addition of

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160 large nuclear power plants to the system every year; in contrast, less than 500 nuclear power plants have been built in the world since the beginning of the nuclear era in the late 1950s.

The analysis of energy consumption provides other important observations. Consider the USA: 85% of all primary energy comes from fossil fuels. Petroleum satisfies 37% of the energy needs, and most of it is used for transportation; unfortunately, today's transportation system is the most inefficient energy component in developed countries.

2. An Earth-Centered Perspective

The high dependency on fossil fuels makes us wonder about the origin of gas, coal and petroleum. The earth is 4.5 billion years old. Bioactivity started approximately 3.5 billion years ago and played a critical role in trapping CO_2 from the atmosphere (fueled by solar energy), converting carbon into organic matter, and releasing the oxygen back into the atmosphere. The accumulation of organic matter, starting about 600 million years ago, led to the formation of fossil fuels. In contrast to these lengthy formation processes, our consumption of fossil fuels took-off with the Industrial Revolution, approximately 200 years ago, and the anticipated reserves are sufficient to satisfy our current needs for another 100 to 200 years. Therefore, the era of fossil fuels will be, at most, 400 years long.

In addition to the dramatic contrast in time-scales, we also need to consider the length scales in the various processes involved. Burning fossil fuels reverses the carbon cycle by releasing CO_2 back into the atmosphere. This thin layer of gas (most of its mass is within 10,000 m of the earth's surface) is responsible for the earth's thermal balance because it governs the reflection and entrapment of solar energy, hence the concern for the observed correlation between CO_2 concentration in the atmosphere and climate change. In fact, many anticipate that climate change will limit the use of fossil fuels before reserves are depleted.

3. Energy Geotechnology - Contributions to this Issue (shown in parenthesis)

A sustainable worldwide energy strategy must incorporate Energy Geotechnology (Fragaszy *et al*., 2011). Table 1 presents a summary of all energy resources including fossil fuels (petroleum gas and coal), and nuclear and renewable sources (wind, solar, hydroelectric, geothermal, biofuels, and tidal energy), along with a brief listing of associated geotechnical engineering involvement.

"Classical geotechnology" is involved in the static and dynamic design of foundation systems for all energy infrastructure components, ranging from nuclear power plants and wind mills (both onshore and offshore), to the foundations of transmission towers and offshore platforms in the petroleum industry (Cassidy, 2011). Classical geotechnology has also played a critical role in the design and construction of hydroelectric projects during the 20th century; we note, however, that the worldwide capacity of hydroelectric energy is nearly saturated, and environmental restrictions add further limitations. Therefore, a small number of new hydroelectric energy projects are anticipated in the future.

The utilization of alternative energy sources is still very limited, but this sector is growing rapidly. There is a wide range of geotechnical needs in the developing renewable energy sector (Yun *et al*., 2011). Obviously, geotechnology plays a central role in geothermal system design, construction and optimal operation (Johnston *et al*., 2011). Biofuels offer great promise as an 'almost' carbon neutral fuel, but issues related to water demands, land usage, energy efficiency and competition with food production need to be carefully addressed. Wind and solar energy are surface processes that require limited geotechnical engineering (apart from foundation systems). However, a critical concern regarding

Table 1 Energy Geotechnology (Refer to the papers in this special issue for a comprehensive discussion of geotechnical tasks in the various energy sectors.)

FOSSIL FUELS (C-BASED)			RENEWABLE			NUCLEAR
Petroleum	Gas	Coal	Wind	Solar	Geothermal	
Fines & clogging, sand production, borehole instability, EOR, heavy oil & tar sand	Hydrates, low-T LNG storage, hydraulic fracturing, optimal extraction	Characterization, subsurface response, mine excavation and instability, gas recovery	Off/onshore foundations, periodic loading		Drilling, fracure formation, heat transfer, piles, optimization	Engineered soils, decommission, leak detect and repair, long-term behavior and monitoring
Geological Storage						
CO_2 Sequestration			Energy Storage			Waste Storage
Geoenvironmental Remediation						
Efficiency and Conservation Energy efficient construction technology Embodied energy in infrastructure projects						

Note: Hydroelectric: global capacity almost saturated
Biofuels: water, land use, energy efficiency, and food impact
Tidal: at selected locations only

the use of wind and solar energy is the need for massive energy storage that is capable of bridging the time gap between production and demand peaks; subsurface storage is a viable alternative (Pasten and Santamarina, 2011).

Typical downhole geotechnical problems with petroleum production are fines migration and clogging (akin to filter criteria), sand production, shale instability (akin to clay phenomena), enhanced oil recovery (akin to unsaturated soils), and various new needs related to the production of heavy oil and tar sands (Dusseault, 2011). There are complementary geotechnical difficulties in gas recovery from unconventional reservoirs (Lee *et al*., 2011a). The case of methane hydrate is of particular interest given the large amount of carbon trapped in hydrate bearing sediments around the world and the challenges associated with gas production from this resource (Lee *et al*., 2011b). Many countries have large coal reserves; their safe and economical production requires adequate site and material characterization, the development of optimal extraction strategies, the implementation of robust monitoring systems, and the reliable prediction of surface implications; these are inherently geotechnical tasks (Note: unfortunately, coal is not covered in this special issue).

Vast amounts of waste are produced by the energy sector (Yeboah and Burns, 2011). There are substantial impoundments of fly ash near power plants; the complex behavior of these materials and the consequences of impoundment failures are prompting the reassessment of current regulations that may have pronounced effects on current practices. The use of fossil fuels generates CO_2, and today's emission of CO_2 into the atmosphere is unsustainable, leading to the current research emphasis on carbon capture and geological storage (Espinoza *et al*., 2011). We must also address nuclear waste disposal: there is not an operating disposal site for commercial waste anywhere in the world. The design of nuclear waste disposal facilities, able to perform as required for the next ten thousand -to one million years-, is a formidable geo-technical task (Kim *et al*., 2011).

There are two other important potential contributions of geotechnical engineering to the energy sector. One is in the area of geo-environmental remediation and the design of new facilities in view of life-cycle needs and decommissioning. The other is the development of geotechnical construction methods that can reduce the embodied energy in infrastructure projects (Soga *et al*., 2011).

4. Conclusions

Energy Geotechnology is a new frontier for the geotechnical engineering field, with unprecedented relevance to a critical worldwide challenge. Indeed, Energy Geotechnology is an integral part of the development of a sustainable energy strategy.

As described in the articles included in this issue, the technical questions are fascinating and require multi-scale analyses, consideration of large-spatial and long-time scales, and the detailed assessment of hydro-chemo-thermo-bio-mechanical coupled processes.

The next generation of engineers will require the proper education to address the needs in Energy Geotechnology.

Acknowledgements

We are very grateful to the KSCE Journal of Civil Engineering for undertaking this topic, and to all authors for their contributions to this special issue. We are indebted to the U.S. Department of Energy, the Goizueta Foundation, and the National Research Foundation of Korea for their support. Any opinions, findings, conclusions, or recommendations expressed herein are those of the authors and do not necessarily reflect the views of funding organizations. C. Barrett edited the original manuscript.

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