Hard Rock Reserves Institute

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Executive Summary:

Advances in production of oil and gas from unconventional reserves (shale rock) in the last few years have had a dramatic world impact. In the US that includes reduced CO2 emissions, progress towards energy independence (the US is projected to surpass Saudi Arabia as the world's largest oil producer by 2015 and is already leads in natural gas production), and resurgence in manufacturing. Global geopolitical ramifications involving Europe, Russia and the Middle East are equally profound. Improvements in hydraulic fracturing (fracking) are responsible, but concerns remain including possible groundwater contamination, long-term impact on low-carbon economy, and economic and social impact on regional communities.

These developments could be of huge consequence for UCM. It is estimated that the Monterey Formation, the on-shore portion of which is under Merced and the SJV, holds 40% of the hard rock reserves of the US. Development of this energy resource in a way that minimizes impacts on water, air, and ecosystems, and that realizes economic and social benefits for SJV, requires fundamental research in science and engineering, as well as research in economic and societal implications. Because the science and technology underlying unconventional petroleum recovery is untested over the long-term, much is unknown regarding its sustainability, economic viability, and impact on the development of non-carbon energy resources. The need for alignment of science, technology, and societal factors in both a regional and global context indicate that UCM could aggressively establish itself as an interdisciplinary research leader and "honest broker" in this space.

Description of the Initiative:

1. Background

a. Characteristics of a Viable Signature Focus Initiative at UCM

UC Merced's signature research areas, at least in the 2020 time frame, must be linked to its geographic / regional context to establish a competitive edge and to garner the necessary financial support. Of course that does not imply that UCM's research and the people it educates will only have regional impact, but rather is a pragmatic approach to exploiting any and all of the unique advantages we have.

The Sierra Nevada Research Institute (SNRI) is one example of a signature initiative that has been successful and has established an international identity for UCM. Another formally- established initiative is the Health Sciences Research Institute (HSRI) that will link to unique regionally-relevant public health and healthcare issues in an effort to build a distinctive program worthy of substantial external funding. Both initiatives have the potential to grow into very large scale Institutes (e.g. in the context of the $500M/10 yr Energy Biosciences Institute / EBI at UCB) Critical here is also the potential global impact of the research, since both the natural resources aspects of the Sierra and the health disparities in the San Joaquin Valley (SJV) have many global analogs and therefore wide-ranging potential impact.

Signature initiatives for our campus should ideally be focused on topics of a scale that can truly change the world. Access to larger supplies of natural gas can accelerate the substitution for coal-fired power plants and thereby continue the first substantial drop in CO2 emissions for many years. The prospect of much greater energy independency for the US and other nations that can adopt this bridging strategy on the pathway toward renewables will have huge, possibly unprecedented consequences on global peace

and prosperity.

b. US Petroleum and Shale Rock Reserves

The challenges of extracting oil and gas from shale rock about 2 miles below the surface of the earth are staggering. And even more challenging is to accomplish this with minimal or no impact on water, air, and ecosystems. As seen in Fig. 1, the implications of this energy resource on the US economy and the world scene are stunning. For example, since fracking started growing in 2006 the US supply gap has dropped by 5M barrels per day, resulting in about $0.5B per day or $180B per year reduction in what the nation pays for imported oil and gas (for reference, adding the CA poverty-line income of $23k per family of 4 to the estimated 9 million CA residents in poverty would cost $50B per year)

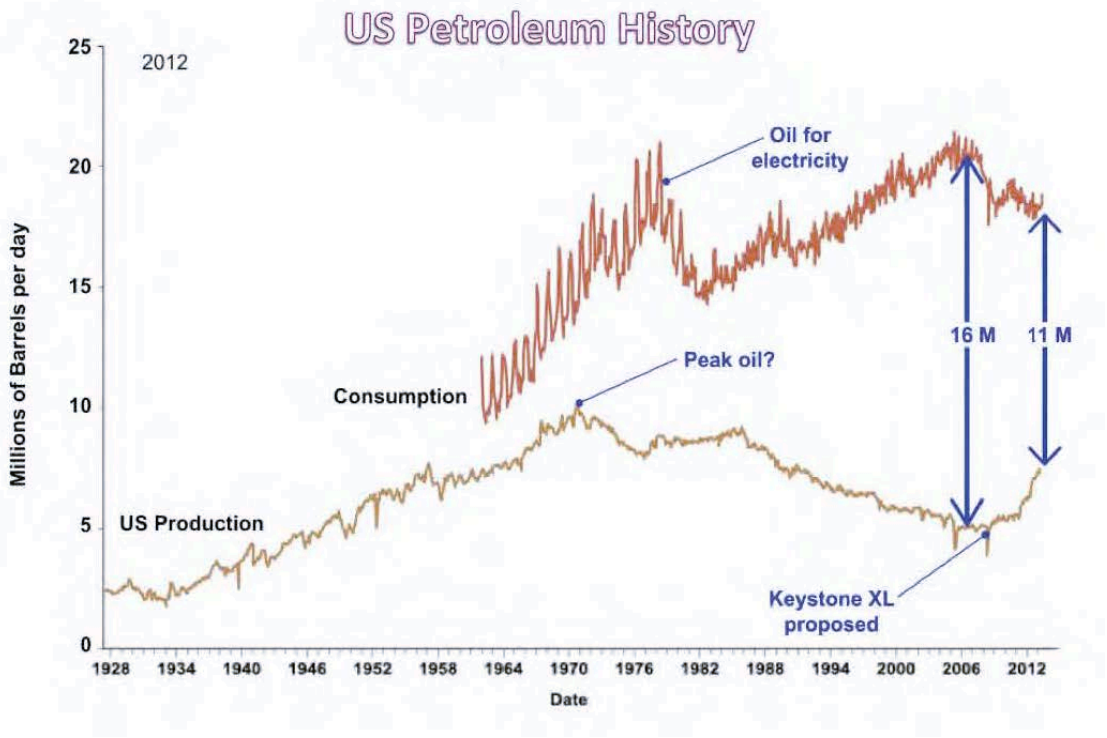

Figure 1. US petroleum history - consumption and production. Graph courtesy of Dr. Roger Aines, Lawrence Livermore National Laboratories, data derived from US Energy Information Agency (EIA).

The Petroleum-bearing shale in the Monterey Formation has unique challenges among the dozen fields in the US which will make production quite challenging. But with an estimated five times the reserves of the Bakken and Eagle Ford fields in North Dakota and Texas, respectively (which are responsible for the majority of the increase since 2006 shown in Fig. 1), there will likely be sustained pressure to utilize these resources as a bridge to a low-carbon economy. So the question at hand is, what role, if any, should UCM play in this dialog?

2. Intellectual Drivers and Research Questions:

a. Extraction Processes

The efficient and environmentally-sound extraction of fossil fuels from hard rock reserves poses significant challenges in science and engineering, and brings significant political and social impacts. Current extraction processes have evolved empirically over the years, and do not have the scientific basis required to optimize extraction, reduce risks and mitigate environmental impacts. If the risk/reward ratio

is deemed adequate, effective communication to policy makers and the public are critical.

Research challenges in the physical sciences include 1) rock and fracture mechanics, 2) organic geochemistry, 3) mineral surface chemistry, surface wetting, and fluid flows through fractures at high pressures and temperatures , 4) nanoparticle engineering and particle-laden fluid flow, 5) materials engineering, 6) advanced controls, including fractional order modeling, 7) multiscale stochastic modeling, and 8) sensors. The Monterey Formation is a particularly challenging target in comparison with other U.S. oil shale reserves. It is a heterogeneous rock formation that is structurally complex as a result of California's complex tectonic history, and much of the organic carbon is trapped in highly silicified shales. Economic development of petroleum and gas from rocks of this composition at elevated temperatures and pressures at depth will require advances and innovation in both science and engineering aspects of the extraction and recovery process in addition to addressing questions surrounding environmental impacts. An important consideration for environmental mitigation is that hydraulic fracturing or other unconventional extraction could be done in the SJV at depths well below groundwater aquifers.

b. Environmental Impact, and the agriculture/water/energy nexus

Leakage of hydrocarbons, chemicals and additives that are used in hydraulic fracking into groundwater aquifers are a major environmental concern. While there is conflicting data on the impact on groundwater, at the very least there is a real danger of contamination. UC Merced already leads in many areas related to groundwater sensing and modeling, and that expertise will be crucial here. Extraction processes could have significant air quality impacts in a region that is already significantly impacted, and eventual exploitation of this resource may also bring pressure for increased refining capacity in CA.

Equally important are questions related to the agriculture/water/energy nexus for which UCM's neighborhood is the living lab. For example, there an estimated 4M acre-feet of currently-unusable water (with dissolved salts from irrigation and subsequent evaporation) under the SJV. Research questions that UCM would be positioned to answer could be related to using such contaminated water for fracking, using some fraction of the fuels obtained to desalinate the water and recycle for agricultural usage, or even for other forms of manufacturing to positively impact the regional economy.

c. Local Political Implications

The political dialog on fracking within the region and the state of CA is already in full force. The governor's recent decision on fracking was disliked by people on both sides of the issue and is a continuing source of debate. The precise locations where Monterey Shale resources might be produced and how production would impact the tax revenues of local cities and counties will be contentious. There are significant research questions here for UCM faculty and students, in terms of equity, communication and public awareness, political process, etc.

d. Regional Economic Implications

History has not proven that access to natural resources has benefitted to local citizens of region. With the poverty issues of the SJV we could become a living lab for how the created wealth can be distributed widely for positive economic impact to accelerate the transformation from poverty to prosperity in the region (see Blum Center UC Merced). The southern SJV has historically been a petroleum-producing region; although convention petroleum production has declined over the last 25 years, it remains an economic driver in Kern County. The agricultural economic base in the SJV has led to much greater economic disparities than the petroleum industry because of the demand for unskilled farm labor compared with more skilled, higher paid workers in petroleum.

e. Global Geopolitical Implications

The implications of the US becoming a net energy exporter are profound. The relationship of the US with for example OPEC is changing drastically. The advances in production technology driven by the US private sector will also have huge implications for the relationship between Russia, members of the former Soviet Union, and Europe. Exporting science and technology improvements in low-impact,

unconventional petroleum recovery could have large implications in China, by reducing their extraction and burning of coal. Related considerations will be a dominant factor in changing international relations research in future years.

f. Informatics and Data for Democracy

The analytics required to understand the implications on economics, environment, and social welfare of impending decisions are huge. This issue could be an excellent case study for using data to support the democratic process (See CITRIS). This will generate significant opportunities for scholarship and community engagement around an issue that should be deemed crucial for many of UC Merced's students and stakeholders. And the learning will apply globally.

3. Campus and Initiative Metrics:

a. Graduate Education and Research

A majority of the graduate groups and all three Schools will be needed to make this a successful signature initiative. In fact it is rare to find a topic that has such a broad impact and requires contributions from aspects of the academy. There are many exciting and fundamental Ph.D. topics, all linked to an area of inquiry that will impact and therefore muster enormous financial resources. The potential global implications are equally large, and the demand for professional and research graduate degrees from internationals will be substantial.

b. Undergraduate Education

The impact of decisions related to shale resources in the SJV will have a direct impact on many of the UG students attending UCM. With such a connection to the vitality of communities in the region while simultaneously being a global "game changer", degrees and electives related to this topic should be a magnet for the UCM student culture. It is possible that a broad minor could be developed for the topic.

4. Partners:

There are a number of natural partners for this initiative, most of whom we have relationships or have made preliminary contacts in this context. These include: the National Labs (LLNL and LBL), regional economic development associations, environmental groups, oil companies, supplier chains to the industry, and utilities. In addition, all existing campus ORUs, (CITRIS, SNRI, HSRI, ERI), the proposed Centers for Theory and Computation and for Environment and Sustainability, and the MIST program are well aligned.

5. Resources:

To be a major player in this domain will require a substantial fraction of UC Merced's 2020 faculty to be academically involved. A faculty/PI team of the scale (say 60) of large Institutes might draw 30 of our existing faculty and require hiring another 30 faculty to existing groups/units by 2020. The concomitant investment, with start-up and salary and benefits and facilities, would be roughly $100M. We would expect to raise $100M from private and industry sources, and another $100M from regional, state, and federal sources.

6. Peers:

Peers in the proposed domain would be universities with Petroleum Engineering and related programs, Penn State and UC Boulder who have won recent awards to study fracking; Colorado School of Mines, and other western state universities such as Wyoming and Montana have programs in geoscience, geological engineering; We do not propose to create a new major at the present time. Rather, we propose to have interdisciplinary participation in this initiative be the UC Merced signature, and have specialties within existing majors that allow targeted coursework and research related to hard rock reserves.