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Finding a Greener Future Beneath the Surface of Petroleum Science and Engineering

Falling employment in the oil industry is shrinking university geoscience departments and closing petroleum engineering programs, but changes to the curriculum could make the field a leader in developing the workforce for the energy transition.

Even though oil prices have rebounded since the start of the COVID-19 pandemic, undergraduate enrollment in petroleum engineering has fallen by 75% since 2014, disrupting a long-standing trend linking petroleum program enrollments with oil prices. As recently as 2013, the oil and gas industry employed 40% of geoscience graduates with a bachelor's degree and 70% with a master's degree; in 2020, it hired just 6% of both sets. Facing reduced support from industry to boost the supply of workers and lower demand for degrees, colleges and universities in the United States, Canada, Australia, and the United Kingdom are combining or closing programs.

Although industry demand for expertise in fossil fuel extraction appears to be falling, subsurface geoscientists and engineers possess fundamental knowledge and skills related to the study of Earth's interconnected systems. Instead of shunting petroleum geoscience and engineering to a carbon-crusted past, the field should adapt. Subsurface science and technological capacity can and should be directed toward advancing the global transition to a low-carbon future. Geoscience has applications in mining, geothermal energy development, hydrogen management, carbon storage, and beyond—all of which will be needed to meet future global energy demand. And because geoscientists study the Earth as a whole—as an interlinked, complex, and evolving system—their knowledge will be essential in determining the safety and sustainability of future energy systems and climate interventions.

Rather than folding under the pressure of low enrollments, universities should instead support geoscience and petroleum engineering departments in developing curricula that focus on energy sustainability and environmental stewardship. Curriculum change can start with the development of core courses on research and development for the energy transition, like the ones we are developing for the Resilient Energy Education program at the University of Utah's Energy & Geoscience Institute. These courses emphasize interdisciplinarity, collaboration, and use-inspired research and education. The program's five core courses—geoscience for the energy transition; alternative energy technologies; carbon capture, utilization, and sequestration; energy management; and energy entrepreneurship, society, and policy—are designed for university students and professionals across energy industries to consider the most significant scientific, technical, and social impacts of the energy transition. Investment in these curricular shifts can create new pathways into geoscience and foster new opportunities for cross-sectoral research partnerships.

To see how geoscience can be part of the energy transition, consider how today's geoscientists are trained to explore, map, and visualize parts of Earth in 3D and to think of Earth's processes in 4D. They are systems thinkers, data analysts, and problem solvers. Geoscientists and engineers specialize in knowing how systems work and how they can be stimulated (for instance, through hydraulic fracturing); how attributes should be measured (by borehole analysis and wire logging); and how reservoir formations thousands of feet beneath the surface can be imaged and characterized. For example, the petroleum industry has spent decades developing techniques for injecting carbon dioxide into subsurface reservoirs for enhanced oil recovery, including identifying and mapping the extent and size of underground carbon storage sites, forecasting fluid-rock interactions, and monitoring site integrity. These and other tools developed to maximize hydrocarbon recovery are directly applicable to characterizing carbon dioxide storage sites for postcombustion carbon capture projects.

Similar skills are necessary for finding accumulations of natural hydrogen, which holds great promise as a zero-carbon fuel, but which is energy- and carbon-intense to manufacture. Here again, modeling techniques developed in petroleum geology can be applied to the question of where, under what conditions, and how much natural hydrogen exists underground. An extension of this challenge will be determining how to engineer subsurface storage sites for hydrogen, like underground salt caverns, depleted gas reservoirs, and depleted saline aquifers. Hydrogen is highly reactive, and few geologic analogs for subsurface hydrogen fields have been explored, so the hunt for accumulations and storage solutions brings entirely new opportunities for the field.

Another area of innovation that can build on the progress of the petroleum industry is the development of enhanced geothermal systems (EGS). The majority of US geothermal resources are inaccessible without the creation of EGS reservoirs. To detect the right conditions for development (underground hot rocks and fluids and permeable subsurface rocks), geologists working on geothermal fields construct detailed 3D models incorporating petrology and geothermal gradient. Other work occurring at the Frontier Observatory for Research in Geothermal Energy in Utah builds on innovative drilling and reservoir stimulation techniques for hydraulic fracturing to create rock permeability necessary for fluid circulation. There is even some possibility that petroleum engineers can help retrofit abandoned oil and gas wells to produce geothermal energy, which could circumvent the high up-front costs of drilling.

Finally, the mapping, exploration, and extraction of critical minerals and rare earth elements (REEs)—both from conventional sources such as rocks and ores and unconventional ones including existing mines, mine tailings, waste streams, and brines—offer additional research opportunities that build on innovations in mineral exploration and extraction. Minerals such as lithium and bromine are critical to high-tech supply chains, including for solar panels, wind turbines, and electric vehicles. Deployment of renewable energy infrastructure is already creating global competition over mineral access. Geoscientists and engineers are well equipped to drive innovations in mining techniques that respond to increased REE demand.

Petroleum geoscience and engineering bring more than theoretical and quantitative knowledge and practical application to the energy transition; they also offer a model for a tightly coupled innovation system between academia and industry. For nearly a century, subsurface science and engineering in the petroleum industry have driven innovation in energy exploration. What's more, this innovation system has focused significant resources on technological developments to reduce the financial and industrial risks of high-cost, dangerous exploration activities. This work, in turn, influenced the development of geoscience and engineering programs in universities close to oil and gas basins, such as those in Texas, Oklahoma, and California.

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These established relationships could be re-engineered to drive similarly rapid innovation in the technologies of the energy transition.

But as well positioned as petroleum engineering and geoscience are to lead in preparation of a new energy transition workforce, attracting talent to the field will require retooling some aspects of geoscience's culture. The field's tight association with the petroleum industry—once seen as a gateway to a profitable future, now often identified as the primary contributor to climate change—is deterring students more likely to be inspired by environmental concerns. In the American Geosciences Institute's 2021 report *Vision and Change in the Geosciences: The Future of Undergraduate Geoscience Education*, the authors recommend that "a crucial first step to increasing geoscience enrollments is significantly improving the public's perception of the geosciences, by promoting it as highly relevant to societal and environmental issues and an economically viable, innovative career."

Subsurface science and engineering have lagged behind other scientific and technical fields in terms of racial, ethnic, and gender diversity for decades. Universities will need to create a culture that welcomes a more diverse group of students and prepares them to seek employment across a wide variety of industries. The National Science Foundation has made targeted investments in approaches to addressing the notable lack of diversity in geoscience compared to other fields with programs like the Directorate for Geosciences EMpowering BRoader Academic Capacity and Education (GEO-EMBRACE) and Geoscience Opportunities for Leadership in Diversity (GOLD-EN). And the US Department of Energy's Reaching a New Energy Sciences Workforce (RENEW) program is creating new pathways to support basic energy research and training at institutions historically underrepresented in its Office of Science portfolio. But expanded federal support for geoscience and engineering will only go so far in ensuring a long-term future for the discipline if students and professionals do not see university programs reflect their values on diversity and sustainability.

Another space for change is toward more collaborative and interdisciplinary work, and geoscience and engineering education together should be preparing students for future research that moves outside traditional boundaries and comfort zones. Interdisciplinary research is often easier said than done because scientists and engineers are trained differently and think in different cultures. But today's colleges and universities should build on the fields' interdisciplinary foundations to lead in this work. One way to cultivate interdisciplinarity in the field is to map how contributions from geoscience can advance the United Nations' Sustainable Development Goals, as a recent report from UNESCO and the American Geophysical Union has done. Grappling with energy and environmental issues on a global scale will require new approaches that can be pioneered at universities and research institutes, which offer a platform to bring sciences and engineering together.

Without forgetting its long history, we believe it is time for subsurface science and engineering education to look to the future—and to redefine its connections to society. In many ways, orienting petroleum geology and engineering curricula toward informing the energy transition is a return to the disciplines' acceleration after the First and Second World Wars, when these fields contributed to the rapid development of new energy resources to meet changing societal needs. Today we again have an opportunity as a community to appeal to a new generation of students interested in employing the skillsets of subsurface geoscience and engineering to shape the trajectory of global energy evolution.

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