Geoscience education and workforce development for energy transition

Rasoul Sorkhabi

Driven by the gravity of global warming[1] and the need for national resilience against disruptions in resource supply chains[2], the transition from today's fossil fuel-dominated world to a low-carbon world with environment-friendly and secure energy supplies is at the forefront of public and policy debates, research and development (R&D) and international attention. This would necessitate an increase in the number of geoscience graduates who provide critical knowledge and skills for exploring and developing energy resources. However, according to the 2022 Geoscience Currents, a report published by the American Institute of Geosciences, student enrollment and graduates in geoscience programmes have sharply declined in recent years[3]. This decline is partly related to the COVID-19 pandemic but largely due to a slowdown in the oil and gas industry, which has historically hired a vast number of geology and geophysics graduates. The employment of geoscience graduates in the oil and gas industry has decreased from 40% for undergraduate and 70% for postgraduate degree programmes in 2013 to merely 6% in 2020 for both groups. As a result, many universities in the US and Europe have closed their petroleum geoscience and engineering programmes.

The slowdown in the petroleum industry has not only affected petroleum programmes in universities but has also decreased the total student enrollment in geoscience. Besides, and more importantly, the subsurface geoscience knowledge and skills required for developing technologies for energy transition have evolved in petroleum geology and geophysics for more than a century. In response to this issue, geoscience departments can revitalize and repackage subsurface geology, geochemistry and geophysics in the service of energy transition, which would also significantly resolve the daunting challenge of increasing student enrollments. Subsurface geoscience education in universities is crucial because the current decade is crucial for training the technical workforce for net-zero carbon technologies by 2040–50 (ref. 4).

To be part of the ongoing energy transition (and other environmental and societal needs of our time), geoscience departments should design new curriculums. This area of action is already overdue. Energy transition is a cross-disciplinary science of immense relevance to society. It is a dynamic and rapidly evolving field of research and development (R&D). This knowledge base needs to be packaged and translated for geoscience students through new textbooks and courses. For instance, an undergraduate geoscience course on energy transition would include subject areas like carbon capture and sequestration (CCS), critical minerals, water resources, geothermal and other renewable energies, hydrogen, energy storage systems, and environmental impact and life-cycle assessments of energy resources and technologies. These subject areas can then be expanded to independent courses for geoscience majors and postgraduate students (Figure 1).

The vast majority of skillsets in petroleum geology and geophysics, such as reservoir characterization, well logging, constructing three-dimensional structural or stratigraphic facies models, seismic and other geophysics imaging, can be directly transferred to R&D in energy transition.

Post-combustion carbon capture projects depend on storing the CO_2 stream in subsurface rock formations. These storage sites must be properly tested and selected; poor choices that result in CO_2 leakages will undermine the public confidence in this promising solution. The petroleum industry has long injected CO_2 into subsurface reservoirs for enhanced oil recovery. The skills of a petroleum geoscientist can thus be useful in CCS projects; these include identifying and mapping the extent and size of underground storage sites, characterizing the petrophysical properties of reservoir rocks, seal and trap integrity, forecasting fluid–rock interactions, and geophysical monitoring of CO_2 storages. Mineral trapping is another emerging method for CCS, whereby dissolved CO_2 reacts with fine-grained metal oxides (such as those in ultramafic rocks or mine tailings) to be deposited as carbonates.

Finding subsurface storage sites for hydrogen is even more challenging because it is the lightest and a highly reactive element, and no geologic analogue for subsurface hydrogen fields exists. Some geoscientists examine underground salt caverns as possible storage sites for hydrogen.

With geothermal gradients ranging from 15°C to 60°C per km, the Earth's crust is a gigantic heat machine. Iceland, sitting in an active volcanic terrain, is a geothermal success story; geothermal energy produces more than 25% of the country's electricity. Geothermal energy exists in underground hot rocks and fluids as dry steam (vapour-dominated) or wet steam (liquid-dominated). Geothermal systems require heat and permeability in subsurface rocks. Geologists working on geothermal fields construct 3D models incorporating lithology, stratigraphy, structures, crustal depth and geothermal profiles. A good example of how technology from the oil and gas industry can be utilized in developing geothermal fields is the FORGE project in

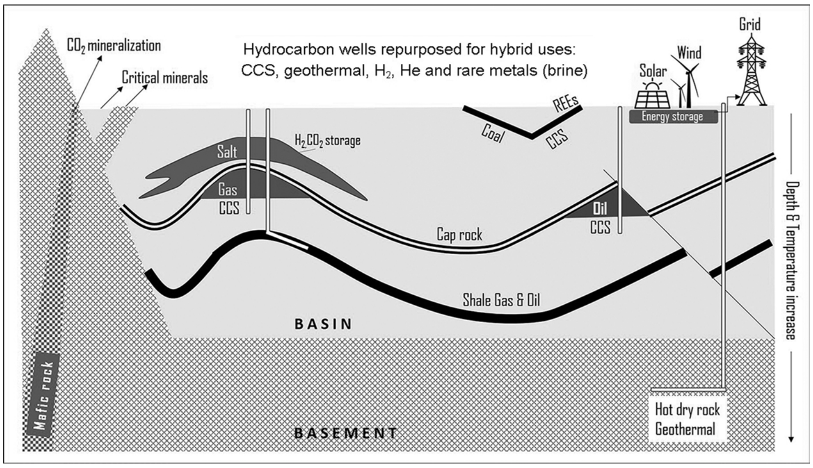

Figure 1. Subsurface petroleum and mining geoscience that can be applied in a number of ways to energy transition technologies.

central Utah, USA, in which hydrothermal fracturing is performed to create rock permeability necessary for fluid circulation[5]. Recently, attention has been given to abandoned oil and gas wells with high bottom-hole temperatures that can be retrofitted to geothermal power plants. In the UK, abandoned coal mines, which are located in many towns and are unaffected by seasonal temperatures, are considered a natural heat source.

The mapping and extraction of critical minerals and rare-earth elements (REEs), both from primary conventional sources (rocks and ores) and unconventional secondary sources (existing mines and their wastes such as coal fines and fly ashes, mine tailings, waste streams and brines) is another area to which geoscientists can immensely contribute. The US Geological Survey has identified 50 minerals and elements critical to the country's economy, industries and national security[6]. The European Union, Japan and Australia have also assessed similar lists. Electrification lies at the base of the energy transition, but electric grids, electric vehicle (EV) batteries, wind turbines and solar panels all require massive amounts of critical minerals and REEs. According to the International Energy Agency[7], global demand for lithium, cobalt, nickel, copper and REEs will multiply by 2040. The US Bureau of Labor forecasts that workforce demand for mining in the country will increase by 10% by 2031 (ref. 8).

Natural gas, as the recent political conflict between Russia and Europe has demonstrated, is still a critical resource and will continue to be produced because it is cleaner than burning coal and oil, and is thus viewed as a bridge from today's fossil-fuelled civilization to a low-carbon world. Natural gas fields can also be used to produce hydrogen and (in some instances) helium. Indeed, the hybrid use of oil and gas wells for CCS, geothermal energy and mineral extraction is a cutting-edge technology.

Several 'geoengineering' fixes have been suggested to combat global warming. These suggestions range from iron fertilization of the oceans to stimulate phytoplankton production and hence seed up carbon dioxide absorption, injection of aerosols into the stratosphere to temporarily cool the climate, to installing mirrors in outer space to deflect sunlight. Such planetary-scale climate engineering ventures, however, need to be seriously assessed by the scientists.

Geoscience programmes have traditionally focused on outcrops and above-the-ground observations. With respect to climate change science, geoscientists are engaged in valuable research on climate change indicators and processes, both the geologic past and present. There is, however, even more space and funds for hardcore science and technology needed for energy transition. Funding agencies in North America and Europe are dedicating hundreds of billions of dollars in R&D in various areas of energy transition. For instance, the Congressional Bipartisan Infrastructural Deal and the Inflation Reduction Act grant the US Department of Energy to fund a large number of R&D projects and massive clean-energy buildouts. To tap into these grants and funds, however, geoscientists often need to collaborate with engineers. This is easier said than done. Geoscientists and engineers are trained with different cultures and mindsets. These cultural barriers need to be crossed through dialogue and collaboration. Such cross-disciplinary collaborations not only enrich geoscience and engineering skills but also attract more minds and money to geoscience departments, but also provide practical solutions for global warming and associated environmental problems.

Aside from applied research, geoscientists can bring certain intellectual skills to the table that help better understand climatic and environmental issues. Geoscience studies the Earth as a whole – an interlinked, complex and evolving system. Geoscientists are trained to explore, map and visualize parts of the Earth in 3D; they think of the Earth's processes in four dimensions and connect scattered dots and data to paint a big picture. These are valuable research tools, especially given that energy technologies to decarbonize the atmosphere are in a state of flux.

Geology as an independent modern science appeared in the 19th century during the Industrial Revolution, fuelled by coal and steam engines. Geoscience rapidly grew in the 20th century, which Daniel Yergin[9] has dubbed as the 'hydrocarbon age'. Geoscience has always been associated with natural resources and energy revolutions. Geoscientists and geoscience departments should partake in the historic energy transition of our time and be part of the solution. Applying subsurface knowledge and methods from the petroleum and mining industries to energy transition and environmental clean-up is urgently needed to train the necessary workforce and attract students to geoscience programmes.

Geoscience departments in universities and colleges need to embrace the subsurface knowledge and skillsets ingrained in the petroleum and mining fields in order to increase student enrollments and train the technical workforce required for energy transition to a low-carbon world.

1. IPCC, *Climate Change 2021: The Physical Science Basis*, The Workgroup 1. Contribution to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change, Geneva, Switzerland; https://www.ipcc.ch/report/ar6/wg1/
2. Jasiunas, J. *et al. Renew. Sustain. Energy Rev.*, 2021, **150**, 111476.
3. Keane, C. *et al.*, Status of recent geoscience graduates 2021. American Geosciences Institute, Alexandria, Virginia, 2022.
4. IEA, Net zero by 2050: a roadmap for the global energy sector, International Energy Agency, Paris, 2021.
5. Cornwall, W., *Science*, 2022, **377**, 252.
6. https://www.usgs.gov/news/national-news-release/us-geological-survey-releases-2022-list-critical-minerals (accessed on 15 May 2023).
7. IEA, *The Role of Critical Minerals in Clean Energy Transitions*, International Energy Agency, Paris, 2021.
8. Bureau of Labor Statistics, *Occupational Outlook Handbook: Geoscientists*, United States Department of Labor, Washington DC, USA, 2022; https://www.bls.gov/ooh/life-physical-and-social-science/geoscientists.htm
9. Yergin, D., *The Prize: The Epic Quest for Oil, Money & Power*, Simon & Schuster, New York, 2008.

Rasoul Sorkhabi is at the University of Utah's Energy and Geoscience Institute, Department of Civil and Environmental Engineering, and Department of Geology and Geophysics, Salt Lake City, UT 84108, USA.
e-mail: rsorkhabi@egi.utah.edu