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Introduction to this special section: The role of geophysics in a net-zero-carbon world

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Human activities are changing the earth's climate, causing increasingly disruptive social and ecological impacts. These impacts can be reduced if global carbon dioxide (CO_2) emissions reach net zero in the near future. A net-zero-carbon world can be achieved by using energy more efficiently and responsibly; transitioning toward energy sources, products, and services that minimize greenhouse gas release; and implementing existing and novel technologies to remove and store CO_2 from the atmosphere.

The world's ever-increasing energy demand, climate change, and the continuing transition from hydrocarbon fuels to green energy sources are all factors that pose new challenges to the energy sector. The application of cutting-edge technologies and knowledge during injection and production activities in geologic reservoirs has never been more important than it is today. The transition toward green energy benefits from oil and gas state-of-the-art geophysical reservoir exploration, characterization, and monitoring techniques.

The process of burning fossil fuel that has increased the atmospheric concentration of CO_2 since the 19^{th} century is progressively being reverted. Depleted hydrocarbon reservoirs are now seen as ideal target sites for safe geologic CO_2 storage due to the combination of a massive storage capacity and proven seal integrity (Rutqvist, 2012). Consequently, injection of CO_2 into depleted reservoirs is a well-accepted leading mitigation strategy against climate change.

Injection of CO_2 is also a proven strategy for energy production, with a number of ongoing carbon capture utilization and storage (CCUS) projects around the world. In CCUS projects, CO_2 is used for enhancing oil recovery (Dooley et al., 2010) or generating energy from the heat gradient underground through enhanced geothermal systems (Randolph and Saar, 2011). Furthermore, beyond CO_2 storage, the physical properties of some of these reservoirs are suitable for storing energy in the form of hydrogen (Zivar et al., 2020). All of these strategies require the application of geophysical remote sensing techniques, such as reflection seismology and controlled-source electromagnetics, for accurate reservoir monitoring. Rock physics links large-scale geophysical data sets to the physical and mechanical properties of reservoir rocks. High-quality data from controlled flow-through tests in the laboratory allow us to improve our predictive tools for safe injection and production activities.

This special section highlights some of the pioneering geophysics work that demonstrates advancement toward the net-zero-carbon goal. Malenda et al. state that experimentation and rock physics is needed to improve our understanding of the coupled thermal-hydro-chemical-mechanical processes that occur in the reservoir as a result of CO_2-fluid-rock interactions. The authors present four applications to support the importance of experimental rock physics for short- and long-term solutions in the transition toward a decarbonized future, including natural gas development, enhanced geothermal energy for CO_2-reduced energy, CO_2 for storage, and manufacturing of green, geomimetic materials.

Fawad et al. concur with Malenda et al. about the importance of accurately defining input parameters for 3D geomechanical and flow simulation. They use seismic data to estimate elastic and petrophysical properties of three potential CO_2 storage reservoirs located in the Smeaheia area of the North Sea. This study shows the potential of seismic data to assess the mechanical and sealing integrity of the reservoir during CO_2 injection. The results are promising for the area studied in this case.

The energy transition is also leading to the development of new remote sensing technology to complement historical geophysical methods. Wilson et al. discuss the engineering challenges of applying fiber-optic cable technology for dynamic (4D) vertical seismic monitoring, using distributed acoustic sensing technology, in offshore transport and storage CCUS projects. They propose an ideal subsea fiber topology configuration that improves the quality of the collected 3D and 4D seismic images.

All in all, the authors in this special section address several aspects of the role of geophysics in the transition to a net-zero-carbon world. This section covers the importance of the scale of observation, experimentation and integration of results, and the use of historical and new remote sensing technology. It stresses the need for a combined mitigation-reutilization strategy to evolve efficiently and responsibly toward a decarbonized future. TLE

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