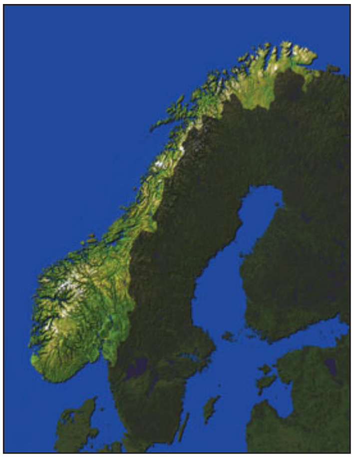

Deep geothermal ambitions in Norway

By **Arthur L. Robinson**
Feature Editor **Volker Oye**

Norway is blessed with abundant cheap hydroelectric power, limited only by occasional drought years and vast reserves of off-shore oil and gas that are sold on the European market in Rotterdam for national income rather than for domestic use. So the question arises: Why deep geothermal energy in Norway?

Geothermal energy derives from the heat in the interior of the Earth that slowly makes its way by convection and conduction toward the surface, where it is radiated into space. Drilling into the Earth to capture the heat can provide the power for applications from building heating to electricity generation. Currently, the best-developed sources are hydrothermal fields near hot spots where magma penetrates into the Earth's crust, as it does in Iceland. But the potential for geothermal energy is theoretically enormous. The International Energy Agency (IEA) estimates that the heat flowing into the top few kilometers of the Earth's crust is more than two million times the world's annual total energy consumption

There are two ways to tap this heat. Shallow (less than 500 m) geothermal energy is relatively well developed in more than 80 countries, but the comparatively low temperatures (below 50°C) away from hot spots mostly limit the applications to smaller scale heating, often based on heat pumps. Nonetheless, Kirsti Midttømme of Christian Michelsen Research AS in Bergen said, "shallow geothermal is and will be a major contributor to the Norwegian energy supply for at least the next 50 years."

Away from hydrothermal fields, to reach the higher temperatures suitable for large-area (district) heating and electrical-power generation requires drilling 3–5 km or more below the Earth's surface. This deep geothermal energy is renewable indefinitely, suitable for base-load electricity, and can be sited almost anywhere. But the deeper the bore hole the more hostile the high-temperature, high-pressure, corrosive environment. Moreover, Norway's geology is dominated by crystalline rock that is hard to drill through and generally has low permeability for hot fluid flow.

These features pose as-yet unsolved technological challenges and high costs, so there are no deep geothermal plants in Norway. "The high cost of drilling long-reach wells in hard rock formations is the showstopper for the widespread exploitation of deep geothermal energy," said Are Lund and Odd-Geir Lademo of SINTEF Materials and Chemistry.

Global climate change might provide an entrée. Norway has been ramping up a nationwide effort marked by joint government and industry investment to develop a comprehensive portfolio of clean and renewable energy sources with the goal of becoming carbon neutral by 2050 or sooner. To help raise geothermal's profile among energy alternatives, a consortium of industrial, academic, and research institutions established in 2009 the Norwegian Center for Geothermal Energy Research (CGER) in Bergen, hosted by Christian Michelsen Research. However, Energi21, an initiative established by the Ministry of Petroleum and Energy, published in 2011 an action-oriented energy plan with specific priorities, and but the plan did not place deep geothermal energy among its six priority areas.

Nonetheless, there are grounds for optimism, argues the chair of the CGER Board, Inga Berre of the University of Bergen. She points to a June 2012 white paper on Climate Efforts, which recommended that a "center for environmental-friendly energy research" dedicated to geothermal energy be established with government funding. Jiri Müller of the Institute for Energy Technology (IFE) in Kjeller explains the recommendation. "To start a research center for geothermal energy where major Norwegian players are united under one roof, we need substantial government funding," he said. Hopes rose in June 2012 when the Norwegian Storting (Parliament) agreed on a new climate policy for the coming years based on the white paper, but fell when no funding was forthcoming. Hopes rose again when the new government, elected in September 2013, supported the center and possible future funding.

One topic the proposed research center would certainly tackle is that of so-called enhanced geothermal systems (EGS). Since a large number of multimegawatt deep geothermal plants would be needed to make significant contributions to district heating and electricity, the plant sites cannot be limited to places where there are pre-existing fracture networks serving as reservoirs of hot fluid deep underground.

The EGS alternative is to pump water with some additives into the hot rock through injection wells to create a fracture network (hydraulic fracturing). Fluids injected thereafter are heated as they percolate through the network to neighboring production wells. Ultimately, the hot fluids pass through a heat exchanger on the surface before being re-injected into the Earth to be re-heated. Re-injection minimizes any environmental hazards associated with dissolved gases and toxic elements brought to the surface with the fluids.

Among several EGS demonstration projects dating back to 1977 in the United States, the United Kingdom, and Japan, the European Hot Dry Rock Project at

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https://doi.org/10.1557/mrs.2013.289 Published online by Cambridge University Press

Soultz-sous-Forêts in France was the most successful, creating the largest fractured rock reservoir and achieving the highest sustained flow rate of any project, thanks in part to carefully understanding the local geology, including natural fracture systems. The plant continues in operation today as an electricity producer.

While many problems remain, observers point to Norway's long history and consequently large investment in off-shore oil and gas drilling as a precious source of expertise, "The money is in the oil and gas industry, so the main technical development of the drilling industry will always come from the oil and gas sector," said Ólafur Flóvenz, director general of the Iceland GeoSurvey (ISOR). But owing to the generally greater depth, higher temperature, and harder rock associated with deep geothermal energy as compared to those typically encountered in the oil and gas industry, a simple one-to-one transfer of technology from one application to another will not do the job. "The advances in geothermal drilling will come from smart adaption of this technology into the geothermal industry," Flóvenz said.

To this end, many Norwegian companies, research institutes, and universities are doing the best they can to address the challenges of deep drilling, with cost reduction as the ultimate goal. For example, SINTEF is coordinating the NEXT-Drill Project, jointly funded by the Research Council of Norway (70%) and several industrial partners to develop technology for the new drilling tools and systems capable of achieving the high penetration rates required for cost-effective drilling.

Examples of unsolved problems are theoretical understanding of rock fracture mechanisms under deep-drilling conditions, drill materials hard enough to bore through Norway's rock, casing materials robust enough to tolerate corrosive environments, electronics (e.g., wide-bandgap semiconductors) able to withstand temperatures of 200°C or more encountered at multi-kilometer depths, sensing and control techniques accurate and fast enough to allow well drillers to carefully position neighboring wells, and numerical models able to predict where and how fracture networks can be created that allow ample fluid flow between injection and production wells.

The European Geothermal Hot-Dry-Rock Project enhanced geothermal systems plant in Soultz-sous-Forêts, France, produces thermal energy from fractured crystalline rock for electricity. It also serves as a platform for basic research and testing. Photo courtesy of Groupement Européen d'Intérêt Economique "Exploitation Minière de la Chaleur" (GEIE EMC).

Among these challenges, "rock fracture mechanisms involve multiple complex physical processes on several different length and time scales," said Alexandre Kane of SINTEF, the NEXT-Drill project manager, "and these affect the rate of penetration and drill-bit wear." Drill-bit research covers the gamut from traditional metallurgical approaches to atomic-scale solid-state physics. For example, researchers use dynamic indentation tests to investigate the influence of microstructure on drill-bit wear degradation and dynamic functional theory (DFT) and molecular dynamics to accurately model adhesion between interfaces.

One EGS feature, hydraulic fracturing (fracking) and the accompanying induced seismicity, poses a different kind of challenge. Volker Oye of NORSAR, a geoscience research institute in Kjeller, said, "Induced seismicity is a huge benefit because it can expand the fracture network sufficiently to extract a useful amount of heat, but it may also be a challenge when it comes to public acceptance." Indeed, a swarm of induced earthquakes in Basel, Switzerland, forced cancellation of an EGS project there in 2009 and stimulated about $7 million of damage claims.

Among the goals for all green technologies enumerated in the Energi21 report is "to cultivate internationally competitive expertise and industrial activities in the energy sector." Per Håvard Kleven of Kongsberg Devotek explains why, "We have enough nonpolluting electricity from our hydroelectric plants. We need more sources of revenue for times when oil and gas will not give us today's income." IFE's Müller spells out how deep geothermal can help: "The research establishment in Norway possesses enormous competence from off-shore petroleum activities, all of which are highly desired in overseas geothermal activities."

Among the several Norwegian firms following this path, IFE will develop and test new tracers for high-temperature and high-pressure geothermal fields in a new European Union project. And NORSAR is a partner in GEISER, a European project that aims to avoid induced seismicity. Bridging the gap between demonstrations and commercial projects, the Green Energy Group AS, headquartered in Oslo, is building a 25-MW prefabricated modular geothermal electrical power plant for the Kenya Electricity Generating Company, to be followed by a second 25-MW unit.

Chair of IEA's geothermal collaboration (IEA-GIA) Chris Bromley of New Zealand's Institute of Geological and Nuclear Sciences sums it all up: "Norway has a reputation for developing creative solutions to energy technology challenges, and we are convinced that its current expertise in deep drilling, seismicity, well completion, and fluid-flow tracing will, over time, lead to innovative and cost-effective ways of accessing the heat that can be found at depth virtually anywhere." □

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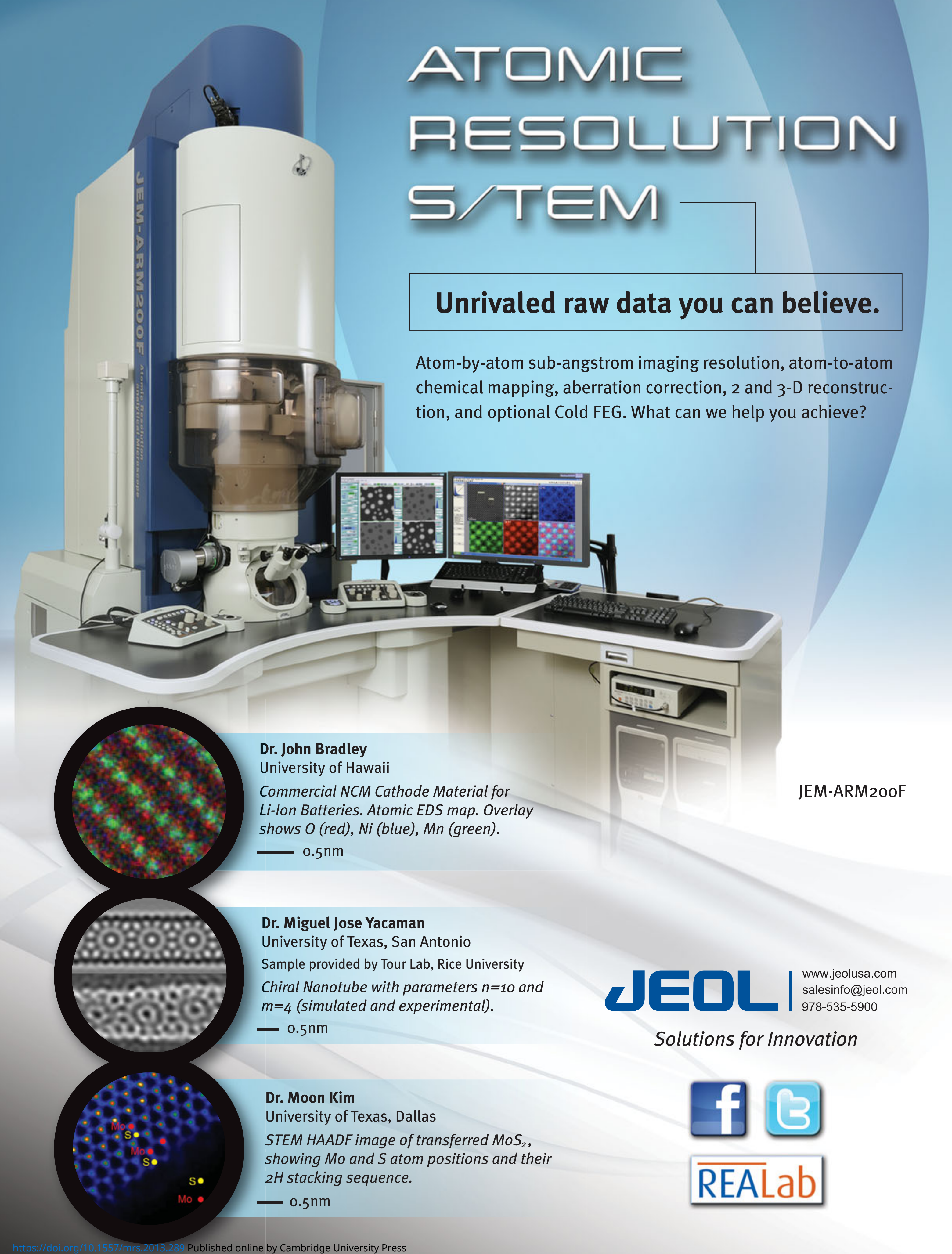

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