

Creating a Global Research Capability Directory to Aid Advancements in Higher-Enthalpy Geothermal

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ABSTRACT

Next-generation geothermal has the potential to provide reliable, scalable, and clean baseload power globally. However, technological advancements, such as those that enable access to higher-enthalpy resources, are needed for these systems to reach their full potential as a cost-competitive bankable technology. Numerous research groups and industries worldwide are conducting research that can help with the development of higher-enthalpy geothermal systems, but there is no comprehensive overview of where these critical laboratory and modeling capabilities exist. Furthermore, many other research groups and industries possess relevant expertise in related fields that could accelerate the development of higher-enthalpy geothermal but may not realize its applicability to this technology. To address this challenge, we have conducted a first of its kind comprehensive global survey of research relevant to advancing higher-enthalpy geothermal capabilities, focusing on five key technical domains: resource characterization and/or modelling, drilling and well design, monitoring and instrumentation, reservoir creation and management, and surface engineering and power generation. Our survey was first distributed in Spring 2025, and we have begun to catalogue over 120 responses. The detailed survey captures specific equipment capabilities, including their maximum pressure and temperature, numerical modeling tools, and current as well as planned research activities. At the time of paper submission, we are actively collecting and validating survey responses and plan to finalize the development of the directory in mid-2026. The directory will include both a detailed overview of research capabilities by institutions around the world as well as country profiles. The directory will be continuously updated as we receive new survey responses, creating a one-stop shop for global research capabilities for higher-enthalpy geothermal development. It is hoped that this tool will create the conditions for collaboration and knowledge exchange that will accelerate the deployment of higher enthalpy geothermal while creating global visibility into research laboratories and gaps in capabilities. It is also expected that the benefits to higher-enthalpy geothermal development through cost reductions, efficiency gains, and technology improvements will aid in the advancement of lower enthalpy geothermal systems.

1. INTRODUCTION

Next-generation geothermal energy has the potential to provide reliable, scalable, and clean baseload power anywhere it is needed. In 2023, global geothermal energy use was 5 exajoules (EJ), which is less than 0.8% of the total global energy demand (IEA, 2024). This is partially due to conventional geothermal systems being geographically limited to regions with sufficient permeability to allow fluid to flow through hot rock that is concentrated near the Earth's surface. However, next-generation geothermal, such as enhanced and closed-loop geothermal systems, create the potential for geothermal power generation beyond these areas - allowing geothermal energy to be deployed on a truly global scale (Blankenship et al., 2024).

Lessons learned from the development and operation of lower-temperature geothermal systems are essential to advancing all sectors of the geothermal industry. This is especially true for higher-enthalpy geothermal systems, like superhot rock geothermal, a type of next-generation geothermal that focuses on higher-temperature reservoirs that allow water to be heated to greater than 400°C (CATF, 2022). The benefits of these high-enthalpy resources are sourced from the higher energy density and increase in thermal efficiency of the system. For example, production tests from the first Iceland Deep Drilling Project well (IDDP-1) indicated that the well was capable of producing up to 36 MWe, which is 5-10 times the energy output of a typical commercial geothermal well at lower temperatures (Friðleifsson et al., 2015). Given the high energy density of superhot rock geothermal systems, they are also expected to require a small environmental footprint (CATF, 2022). Most importantly, the high energy density of higher-enthalpy geothermal systems allows them to be more cost competitive. Once they reach Nth of a kind (NOAK) projects, superhot rock geothermal systems are expected to be cost competitive with other dispatchable generation technologies, including those in unsubsidized markets (CATF, 2023).

Although higher-enthalpy geothermal systems hold substantial promise, there are significant technological challenges that remain before they can be available anywhere they are needed (Hill et al., 2024). These technological challenges are concentrated in five primary areas of expertise: 1) resource characterization and/or modeling (Chhun et al., 2024), 2) drilling and well design (Pink and Pearce, 2024; Suryanarayana et al., 2024), 3) monitoring and instrumentation (Chhun et al., 2024), 4) reservoir creation and management (Cladouhos and Callahan, 2024), and 5) surface research in engineering and power generation (Brown et al., 2024). Coordinated research in these areas is essential to accelerating the deployment of higher-enthalpy geothermal resources (Hill, 2025). Importantly, technological improvements that aid the development of higher-enthalpy geothermal systems can also benefit the development and cost of lower-enthalpy systems through cost reductions, efficiency gains, and technology improvements (e.g., faster drilling to deeper depths).

2. SURVEY DEVELOPMENT AND GATHERING GLOBAL INPUT

Although the technological advancements for commercializing higher-enthalpy geothermal projects are achievable, substantial investment in research and development is required to better understand how to efficiently and cost-effectively develop higher-enthalpy systems in a variety of geologic settings. CATF (2025) identified a need for testing facilities at higher temperature and pressure conditions across all five of the primary areas of expertise listed above. To systematically map the global research capabilities relevant to this challenge, we are creating a global directory of research and laboratory capabilities. To start this process, we developed a comprehensive survey (<https://forms.office.com/Pages/ResponsePage.aspx?id=0zUMU1YcMkuc9SqW0WqBFUhSpH3qfDZHnH0bHvUdILFUMTIWMEdX MkU0Rlo2RVlQRUpMT0RJQTUxQy4u>) that was distributed directly to hundreds of research groups and industry partners from around the world. It was also shared across multiple listservs and social media platforms (e.g., LinkedIn). We encouraged three groups to complete the survey: 1) those currently conducting higher-enthalpy geothermal research, 2) those planning to conduct such research in the near-term, and 3) those whose research is not directly related to higher-enthalpy geothermal but could benefit its advancement. Importantly, the development of this resource is expected to benefit not only higher-enthalpy geothermal research, but also lower-enthalpy geothermal development. Individuals or groups with research capabilities relevant to higher-enthalpy geothermal development are encouraged to participate, including academic institutions, government entities, industry, etc.

The survey is designed to catalog global research and laboratory capabilities concentrated in five primary areas of expertise:

- Resource characterization and/or modeling
- Drilling and well design
- Monitoring and instrumentation
- Reservoir creation and management
- Surface research in engineering and power generation

For each primary area, respondents must first indicate their institution's overall research status ("Current", "Planned" or "Not Active"). Each area contains specific subareas of expertise (e.g., "water/Rock geochemistry" under "resource characterization and/or modeling") where participants again specify their research status ("Current," "Planned," or "N/A"). The survey then requests a description of relevant analytical or experimental capabilities, including numerical modeling tools or software used. For each capability listed, respondents must provide their maximum temperature and pressure and indicate whether both parameters can be controlled simultaneously. These data will all then be used to develop a free open-source directory to aid in inter-institutional collaboration and overall advancement of geothermal technology by offering a platform where researchers can find collaborators with complementary expertise and where private manufacturers and developers can find a facility that is able to provide the testing needed to derisk their operations.

3. PRELIMINARY TRENDS

At the time of submission, our survey has gathered initial responses from 121 research groups worldwide. The data compilation process involves a rigorous validation phase, including follow-up contact to clarify incomplete or ambiguous information. The preliminary analysis detailed in this paper is therefore based on a fully validated subset of 84 responses, with data from the remaining institutions still pending confirmation. Consequently, the findings presented here focus on initial insights from these 84 institutions.

Figure 1 illustrates the research status across the five key expertise areas, showing the number of institutions with "Current" or "Planned" research activities in each.

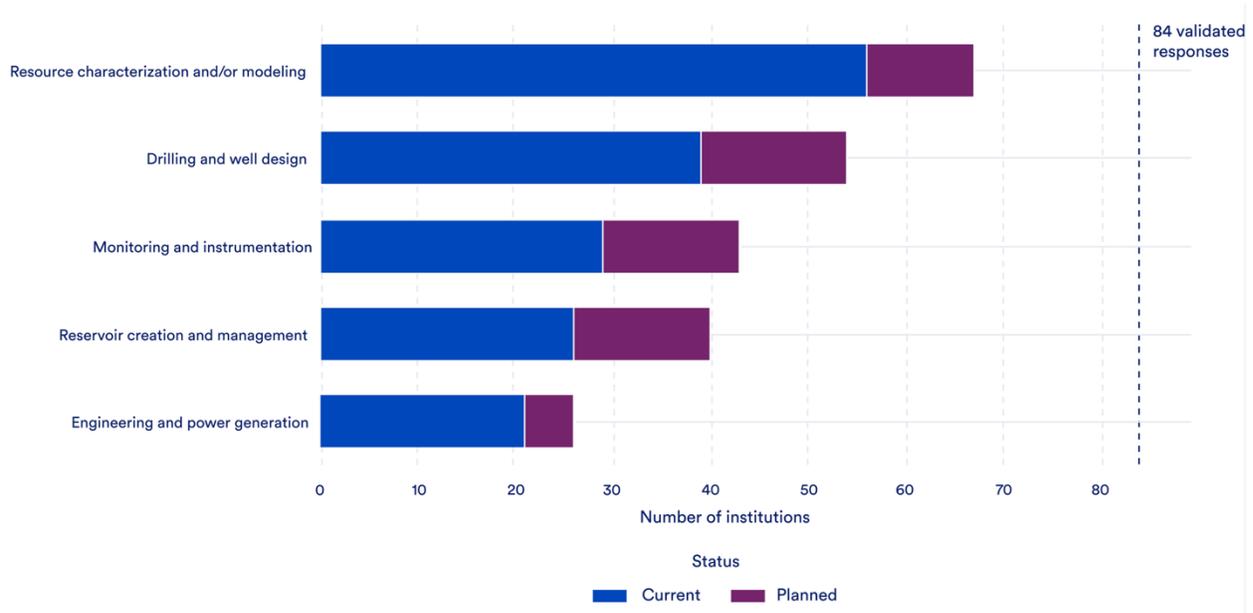


Figure 1. Number of institutions with either current or planned capabilities in each of the five primary areas of expertise. Number of validated responses is 84.

This current distribution, as noted in Figure 1, indicates that, while resource characterization and modeling, in addition to drilling and well design, appear relatively mature among surveyed institutions, there appears to be a need to expand research in power generation system engineering and reservoir management to accelerate higher-enthalpy geothermal commercialization. It should be noted that these results likely reflect geographical sampling bias, as our survey outreach was limited to institutions within our existing professional networks and those with publicly available research profiles in geothermal.

Figure 2 identifies the 10 countries with the largest number of institutions in the dataset; for each country, a stacked bar chart breaks down the number of responding institutions by their type (e.g., academia, industry, government, etc.).

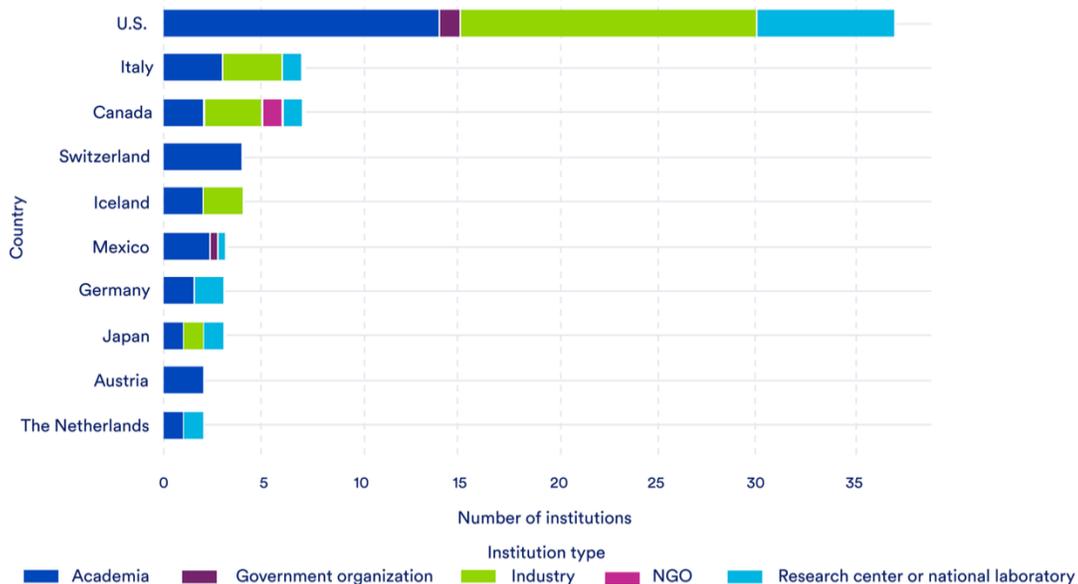


Figure 2. Breakdown of the 10 countries with the largest number of institutions included in the dataset by institution type.

The top 10 countries shown in Figure 2 reveal distinct patterns in the types of institutions represented within the dataset. Responses from academia are the most widely distributed type, appearing across all top 10 countries and accounting for the largest percentage of institutions overall based on current validated responses. Research centers and national laboratories also show a consistent presence across these 10 countries, reflecting their important role as intermediaries between academic research and industrial applications, which is critical

to technology development. In addition, the dataset includes responses from private industry in five of the top 10 countries, with industry participation occurring at proportions broadly comparable to academia within those countries.

Table 1 shows the distribution of the five areas of expertise and the associated research status among validated survey responses. Resource characterization and/or modeling emerges as the most developed area among survey respondents, with 67% of institutions currently working in this field, followed by drilling and well design (46%) and monitoring and instrumentation (35%). However, engineering and power generation presents the largest research gap among survey respondents, with only 25% of institutions currently active and 69% with no current activity. This is followed by reservoir creation and management (31% active, 52% with no activity). Notably, drilling and well design shows the highest future momentum, with 18% of institutions planning to initiate research in this area.

Table 1: Distribution of the areas of expertise among survey respondents

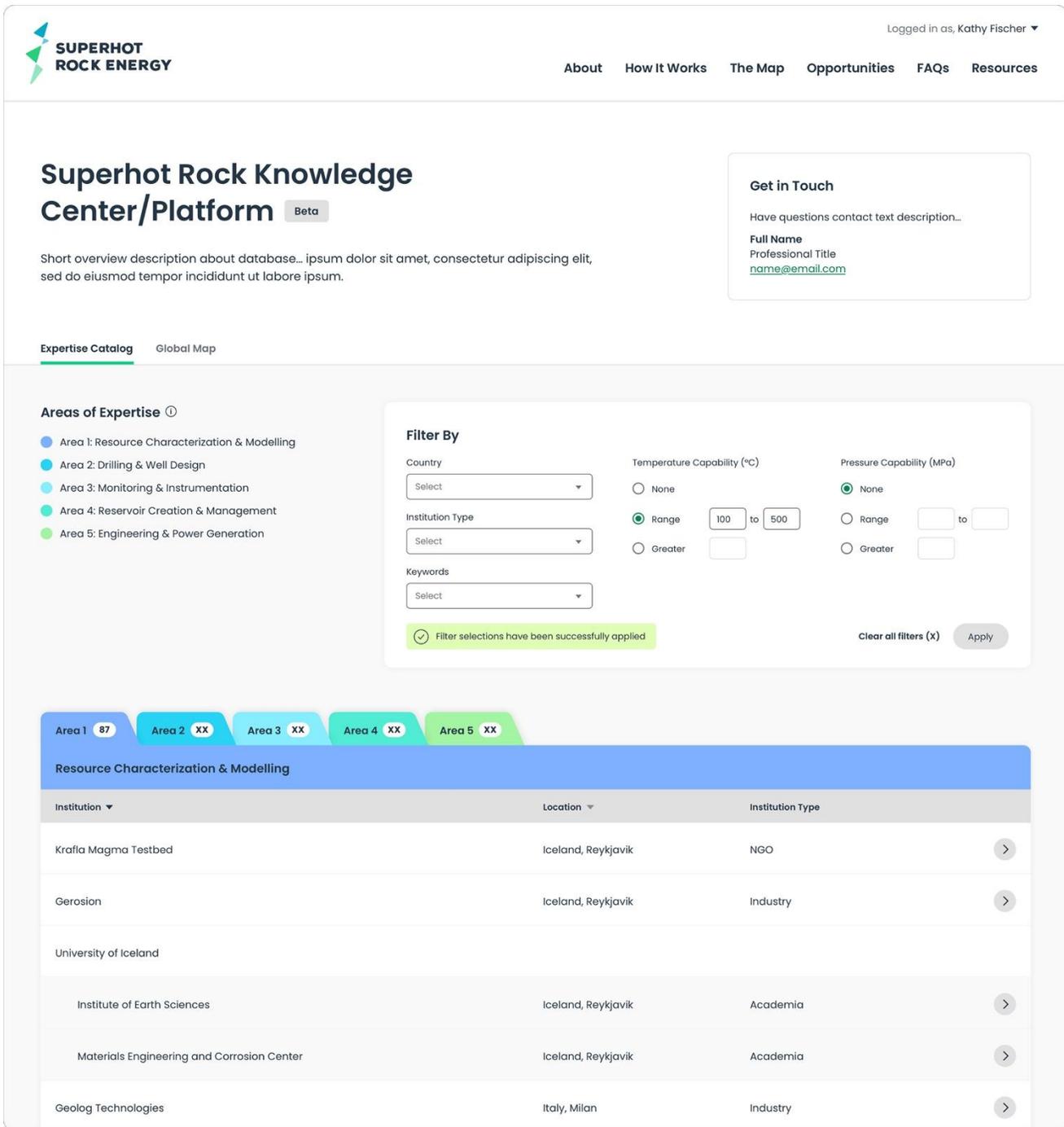
Area of Expertise	Number of Respondents		Percentage of Respondents	
	Current	Planned	Current	Planned
Resource Characterization and/or Modeling	56	11	67	13
Drilling and Well Design	39	15	46	18
Monitoring and Instrumentation	29	14	35	17
Reservoirs Creation and Management	26	14	31	17
Engineering and Power Generation	21	5	25	6

Although the results detailed in Table 1 contain some sampling bias, it also shows the areas of expertise that will require further research and development to advance higher-enthalpy geothermal technology and subsequently benefit the development of lower-enthalpy geothermal systems through material cost reductions, increased efficiency, and technology improvements. Research gaps in the areas of expertise shown in Table 1 can be correlated with Clean Air Task Force's gaps assessment synthesis report (CATF, 2025) and technology roadmap (Hill, 2025). This cross correlation can be used to document the research areas that are most needed for the advancement of higher-enthalpy geothermal and compare them with the areas that most lack research, as noted in Table 1. This comparison is an ongoing area of research that will be important to identify the most critical gaps in research capabilities.

4. CREATION OF THE KNOWLEDGE CENTER: AN OPEN-SOURCE DIRECTORY TOOL

Using the data gathered through the survey, we are developing an interactive online platform, currently in a prototype testing form, that provides access to the collected data. This online platform is being created to benefit geothermal advancement in three main ways: 1) creating the conditions for collaboration and knowledge exchange, 2) creating global visibility into research laboratories and procurement, and 3) bridging the gaps across technology maturity and research capabilities to unlock the pathways to innovation. The online platform contains two primary sections.

The first is a catalog dashboard (Figure 3), which allows users to navigate through an expertise catalog or to a global map, view the catalog of institutions by areas of expertise (e.g., resource characterization and/or modeling or drilling and well design), and filter the data for temperature and pressure of the capabilities, country, institution type, and keywords.



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Figure 3. Example view of the catalog dashboard, which is divided into four main areas from top to bottom: 1) overview of the tool, 2) expertise catalog and map navigation tabs, 3) expertise key and filter window, and 4) catalog table.

They can then select a given institution to see more information on the institution’s primary areas of expertise (Figure 4), subareas of expertise (Figure 4), and capabilities (Figure 5). Users can also see whether the institution is currently researching a subarea of expertise or plans to in the near-term.

The screenshot shows a web interface for 'SUPERHOT ROCK ENERGY'. At the top right, it says 'Logged in as, Kathy Fischer'. A navigation menu includes 'About', 'How It Works', 'The Map', 'Opportunities', 'FAQs', and 'Resources'. Below the header, there is a 'Back to catalog' link and the institution's name: 'University of Iceland, Institute of Earth Sciences'. A box on the right lists 'Materials Engineering and Corrosion Center' in Reykjavik, Iceland, with a 'View profile' link. A tabbed interface shows 'Expertise' selected, with sub-tabs for 'Overview', 'Projects', and 'References'. On the left, 'Areas of Expertise' are listed: 'Resource Characterization & Modelling' (highlighted), 'Drilling & Well Design', 'Monitoring & Instrumentation', 'Reservoir Creation & Management', and 'Engineering & Power Generation'. The main content area is titled 'Resource Characterization & Modelling' and includes a description and a table of 'Expertise Subareas' and 'Capabilities'. The table lists seven subareas, all marked as 'Active'. At the bottom right, it notes 'Profile last updated Month XX, 2025'.

Back to catalog

University of Iceland
Institute of Earth Sciences

Other groups/labs at institution:

Materials Engineering and Corrosion Center
Reykjavik, Iceland
View profile

Overview Expertise Projects References

Areas of Expertise

- Resource Characterization & Modelling
- Drilling & Well Design
- Monitoring & Instrumentation
- Reservoir Creation & Management
- Engineering & Power Generation

Resource Characterization & Modelling

Optional short description about this area of expertise... lorem ipsum dolor sit amet, consectetur adipiscing elit, sed do eiusmod tempor incididunt ut labore.

Expertise Subareas Capabilities

Coupled Process Modelling	Active
Exploration, Appraisal, Site Selection	Active
Geological Modeling	Active
High-Performance Computing (HPC) for Coupled or Multiphysics Simulations	Active
Reservoir Modeling	Active
Water Resource Management	Active
Water/Rock Geochemistry	Active

Profile last updated Month XX, 2025

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Figure 4. Example view of the institution profile with a focus on the expertise subareas. Institution profiles will include information such as the institution’s location, type, areas of expertise, capabilities, planned or ongoing projects, references, and contact information.

SUPERHOT ROCK ENERGY Logged in as, Kathy Fischer ▾

[About](#)
[How It Works](#)
[The Map](#)
[Opportunities](#)
[FAQs](#)
[Resources](#)

[← Back to catalog](#)

University of Iceland

Institute of Earth Sciences

Other groups/labs at institution:

Materials Engineering and Corrosion Center
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[View profile](#)

Overview **Expertise** Projects References

Areas of Expertise

- Resource Characterization & Modelling
- Drilling & Well Design
- Monitoring & Instrumentation
- Reservoir Creation & Management
- Engineering & Power Generation

Resource Characterization & Modelling

Optional short description about this area of expertise... lorem ipsum dolor sit amet, consectetur adipiscing elit, sed do eiusmod tempor incididunt ut labore.

Expertise Subareas **Capabilities**

Capability 1

Description	High temperature U-tube reactor systems for superhot fluid-mineral interaction
Max Temperature (°C)	800 <small>Custom note about temp placed here if applicable...</small>
Max Pressure (MPa)	50
Ability to Adjust T & P Simultaneously	Yes

Capability 2

Description	High temperature cells for in-situ work on superhot fluid properties
Max Temperature (°C)	600 <small>Custom note about temp placed here if applicable...</small>
Max Pressure (MPa)	200
Ability to Adjust T & P Simultaneously	Yes

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Figure 5. Example view of the institution profile with a focus on the institution’s capabilities.

The second section is a global map (Figure 6), which allows users to select any country that has at least one institution contained within the database that is currently or planning to conduct research that can aid in commercializing higher-enthalpy geothermal systems. The interactive map shows countries in a relative color scale, where deeper shades indicate a higher number of institutions with research capabilities and a paler shade indicating a lower number of institutions with research capabilities within the directory.

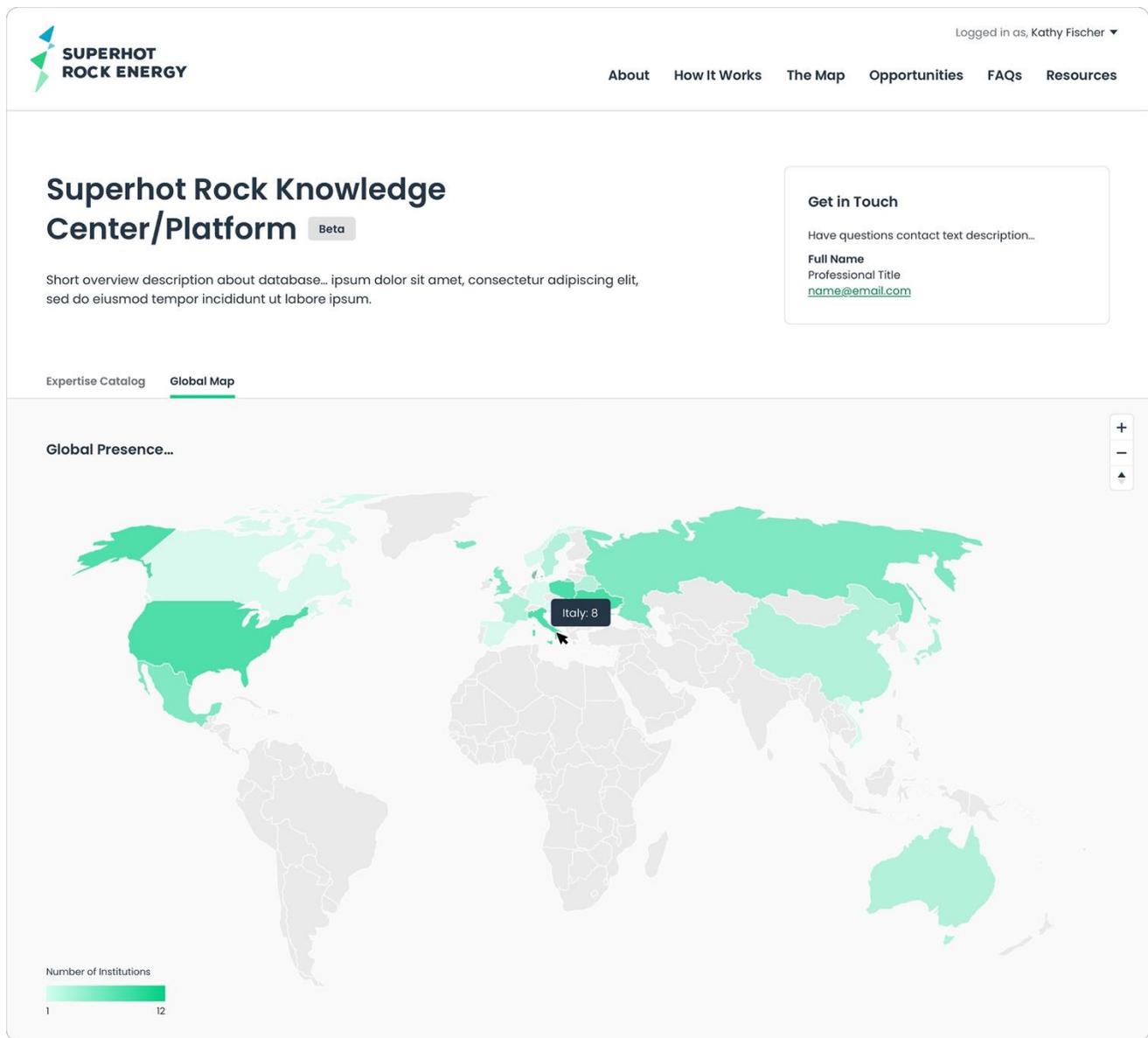
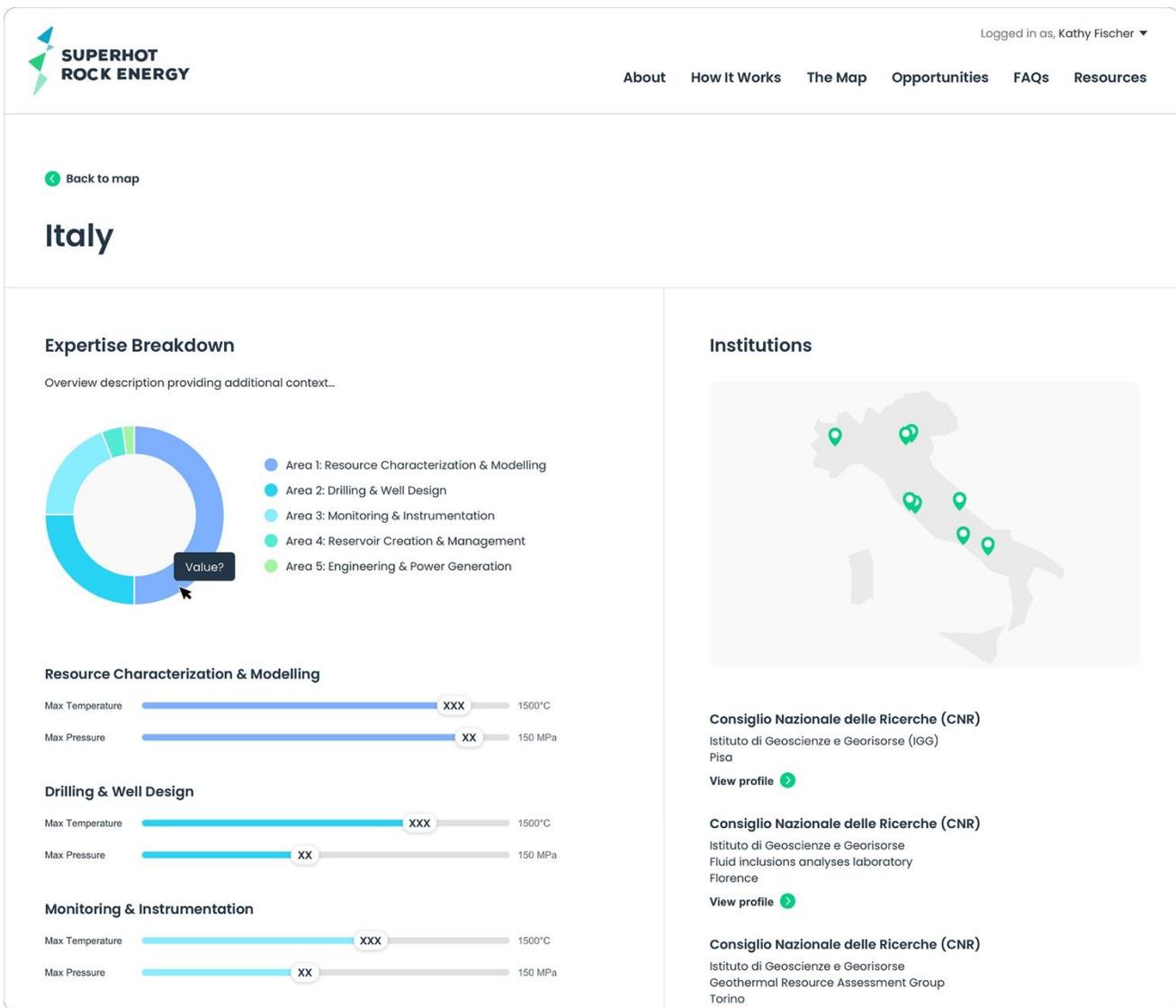


Figure 6. Example view of the global map, which includes an interactive map allowing users to click on a country to open that country’s profile.

When users select a country, they are taken to a country profile (Figure 7). The country profile provides an expertise overview for the country that includes the country’s relative research contribution to each of the primary areas of expertise. Additionally, the country view shows the maximum temperature and pressure of capabilities for each of the primary areas of expertise. Users can also see a list of each of the institutions with research capabilities in each country. From there, users can go directly to the institution profile.



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Figure 7. Example of the country profile view, which shows the country’s overall expertise and a list of institutions within that country.

5. CONCLUSIONS AND NEXT STEPS

The development of higher-enthalpy geothermal systems, such as superhot rock geothermal, holds substantial potential to provide reliable, always available, clean firm power anywhere it is needed. However, before this potential is fully realized, research is needed to allow the technology to move past the field research and pilot demonstration phases to commercial demonstration and full-scale deployment. To help streamline the research process, we created a survey to gather input from researchers and industry around the world who are conducting research that can aide in the advancement of higher-enthalpy geothermal systems. The details of this survey were used to create a prototype of a free online, open source, global directory of research capabilities, which is planned to be released in mid-2026. It is hoped that this tool will create the conditions for collaboration and knowledge exchange that will accelerate the deployment of higher enthalpy geothermal while creating global visibility into research laboratories and procurement. We are continuing to gather input from a global array of researchers and industry to include in the directory. Future forms of the directory may include additional features, such as tools for collaboration and an overview of research capabilities that are lacking on a global scale. It is also expected that the benefits to higher-enthalpy geothermal development through cost reductions, efficiency gains, and technology improvements (e.g., drilling faster and deeper) will aide in the advancement of lower enthalpy geothermal systems.

ACKNOWLEDGEMENTS

This work would not be possible without engagement from the research institutions who dedicated time to filling out the survey used to create the database, and for their continued engagement in response to any questions we had about their survey input. The Knowledge Center was also greatly improved by multiple in person engagement sessions where participants provided important input on the tool.

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