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Taking the heat out of the burning-ice debate: Appendix B – SURVEY ANALYSIS

Gas Hydrates

A.T. Kearney Energy Transition Institute
June 2015

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Compiled by the A.T. Kearney Energy Transition Institute

Acknowledgements

A.T. Kearney Energy Transition Institute wishes to acknowledge Ray Boswell, Technology Manager, Natural Gas Technologies, U.S. DoE / National Energy Technology Laboratory and Robert L. Kleinberg, Schlumberger Fellow, Schlumberger Doll Research for their detailed review of this FactBook. The Institute also wishes to thank the authors of this FactBook for their contribution: Benoit Decourt, Romain Debarre, and Sylvain Alias.

About the FactBook – Gas Hydrates

The role gas hydrates may play as an energy resource is a controversial, polarizing subject. Therefore, a fact-based report has been developed by the A.T. Kearney Energy Transition Institute, presenting: key concepts; the status of exploration and production technologies; the status of research, development and demonstration (R,D&D); and the environmental and safety challenges associated with the potential exploitation of this resource. This publication aims at providing stakeholders with a balanced, unbiased assessment of gas hydrates and the tools to understand them properly.

The Institute performed a literature review and engaged experts in the gas-hydrate field. The Institute also analyzed patents from 50 offices worldwide, using the Thomson Derwent World Patents Index (DWPI) database, and conducted a survey of gas-hydrate stakeholders to present the state of R,D&D and a faithful picture of current thinking among academics and industry players involved in the field. Outcomes of the DWPI analysis and the results from the survey are available in separate documents referred to as Appendix A and Appendix B.

About the A.T. Kearney Energy Transition Institute

The A.T. Kearney Energy Transition Institute is a nonprofit organization. It provides leading insights on global trends in energy transition, technologies, and strategic implications for private sector businesses and public sector institutions. The Institute is dedicated to combining objective technological insights with economical perspectives to define the consequences and opportunities for decision makers in a rapidly changing energy landscape. The independence of the Institute fosters unbiased primary insights and the ability to co-create new ideas with interested sponsors and relevant stakeholders.

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The FactBook – Gas Hydrates Appendix B – Survey Analysis

About the Survey Analysis

In order to present a faithful picture of current thinking among academics and industry players involved in gas hydrates, the A.T. Kearney Energy Transition Institute launched a survey on gas hydrates. The A.T. Kearney Energy Transition Institute invited the subscribers of the Fire-In-The-Ice Newsletters to share anonymously their views on resource assessments and most readily produced type of accumulation, exploration and production challenges, environmental and safety challenges and development outlooks. The survey was launched on October 20th, closed on November 5th and collected responses from 56 participants. The full-results are presented in this document. The A.T. Kearney Energy Transition Institute expresses its gratitude to the National Energy Technology Laboratory (NETL), and more specifically to Ray Boswell and Karl Lang, for their support in distributing the Gas Hydrates Survey to the subscribers of the Fire-In-The-Ice Newsletter.

Key findings

There are clear areas of consensus among gas-hydrate experts regarding the most promising resources and technologies

- Most participants (69%) consider gas-hydrate deposits in sand-rich host sediments to be the most readily produced type of gas-hydrate accumulation.
- Almost all respondents (96%) believe that depressurization is likely or very likely to be suitable for producing this specific type of accumulation.
- 83% of respondents consider combining depressurization and thermal stimulation to be a promising strategy.

The development of gas-hydrate resources is still facing several challenges

- Production-related challenges are considered more severe than exploration and environmental hazards.
- Respondents view the most critical challenges as the geomechanical instability of reservoirs; the lack of understanding of reservoir properties; and slope instability.
- Methane leakage from onshore permafrost is considered the environmental hazard most likely to result from global warming, but leaks from deep-water accumulations are thought very unlikely to present a challenge in the near term.

Carrying out long-duration production tests is viewed as the main pre-requisite for unlocking gas hydrates' commercial potential.

- Production tests should last between six months and one year in order to produce useful results, according to 44% of respondents.
- As many of 70% of participants believe gas hydrates will be produced economically within the next 20 years.
- The vast majority of respondents believe that Japan is the only country in which commercial-scale recovery will occur during this timeframe.

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1. Introduction

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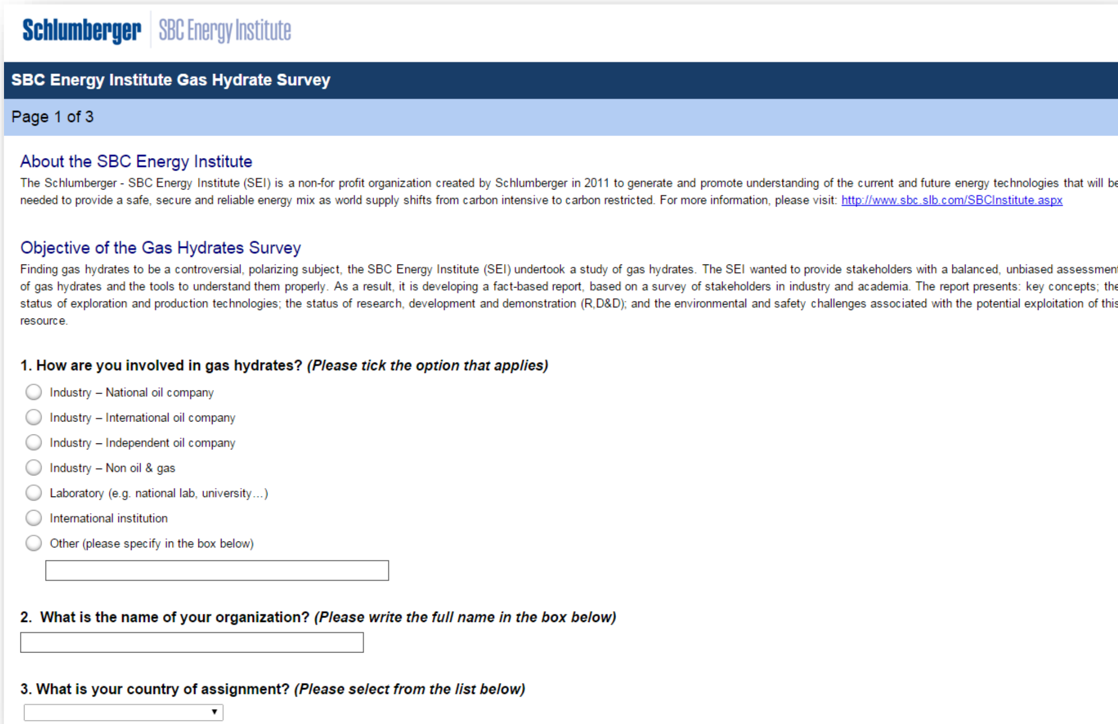
The A.T. Kearney Energy Transition Institute developed an online questionnaire, which was distributed to the subscribers of the Fire-In-The-Ice newsletter

Methodology – A.T. Kearney Energy Transition Institute Gas Hydrate survey



Schlumberger | SBC Energy Institute

SBC Energy Institute Gas Hydrate Survey

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About the SBC Energy Institute

The Schlumberger - SBC Energy Institute (SEI) is a non-for profit organization created by Schlumberger in 2011 to generate and promote understanding of the current and future energy technologies that will be needed to provide a safe, secure and reliable energy mix as world supply shifts from carbon intensive to carbon restricted. For more information, please visit: http://www.sbc.slb.com/SBCInstitute.aspx

Objective of the Gas Hydrates Survey

Finding gas hydrates to be a controversial, polarizing subject, the SBC Energy Institute (SEI) undertook a study of gas hydrates. The SEI wanted to provide stakeholders with a balanced, unbiased assessment of gas hydrates and the tools to understand them properly. As a result, it is developing a fact-based report, based on a survey of stakeholders in industry and academia. The report presents: key concepts; the status of exploration and production technologies; the status of research, development and demonstration (R,D&D); and the environmental and safety challenges associated with the potential exploitation of this resource.

1. How are you involved in gas hydrates? ***(Please tick the option that applies)***

- Industry – National oil company
- Industry – International oil company
- Industry – Independent oil company
- Industry – Non oil & gas
- Laboratory (e.g. national lab, university…)
- International institution
- Other (please specify in the box below)

2. What is the name of your organization? ***(Please write the full name in the box below)***

3. What is your country of assignment? ***(Please select from the list below)***

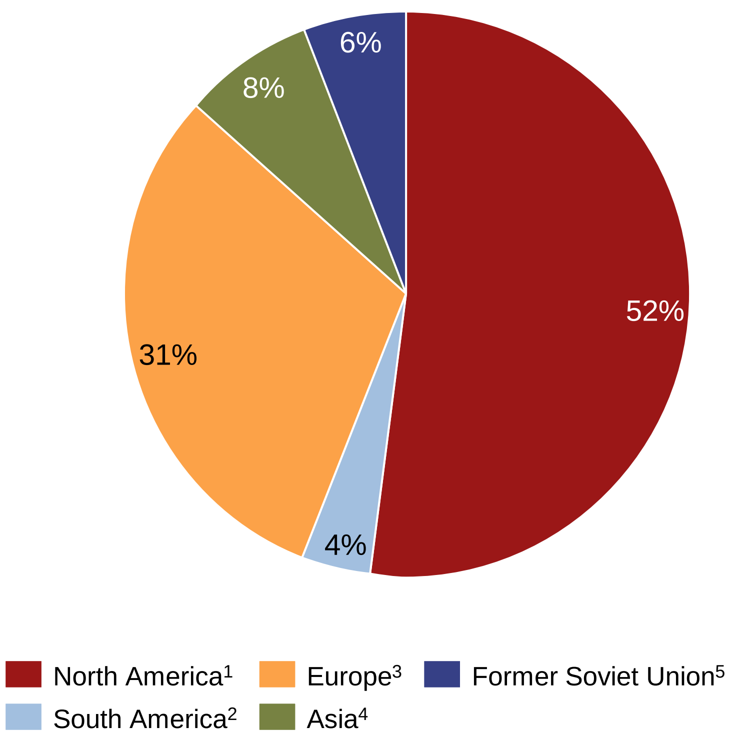
- The A.T. Kearney Energy Transition Institute Gas Hydrate Survey consists of a short online questionnaire, developed after an extensive literature review and interviews with leading academics and experts.
- The questionnaire was designed to preserve the anonymity of respondents. No IP address was collected. Participants could name their organizations if they wished, but this was optional.
- The survey was distributed to the subscribers of the quarterly Fire-In-The-Ice newsletter, managed by the National Energy Technology Laboratory (NETL) in the U.S.
- A.T. Kearney Energy Transition Institute asked participants to share their views on (1) resource assessments and most readily produced types of accumulation, (2) exploration and production challenges, (3) environmental and safety challenges and (4) the outlook for development.

1. Note: A.T. Kearney Energy Transition Institute for A.T. Kearney Energy Transition Institute; IP for Internet Protocol; NETL for National Energy Technology Laboratory.

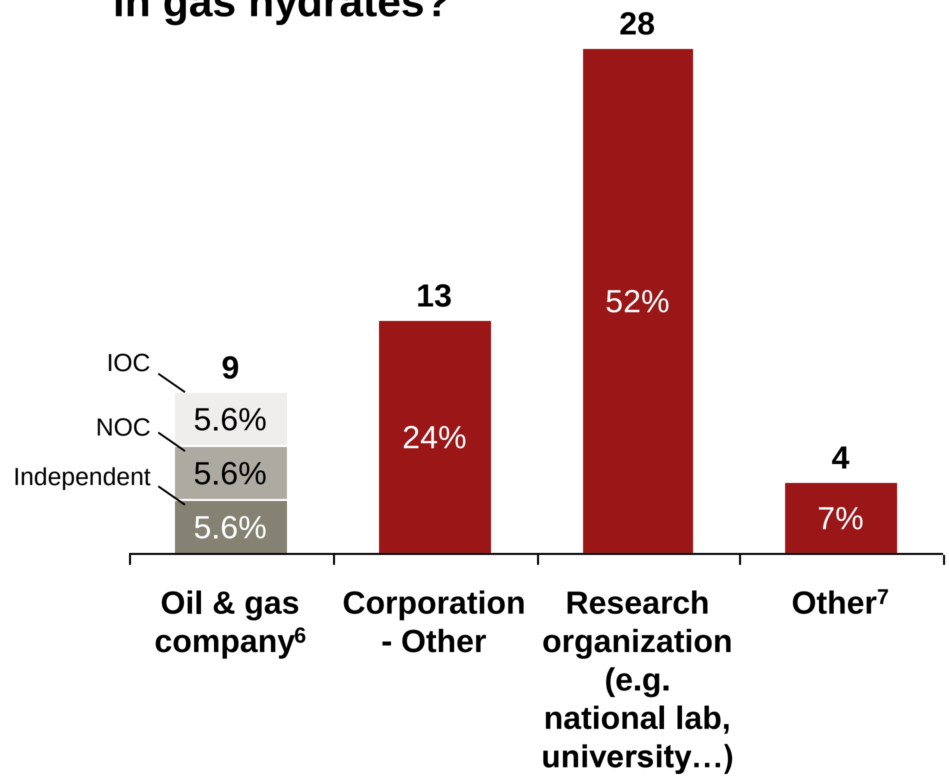
A total of 56 participants from a variety of countries and professional backgrounds took part in the survey

Involvement in the Gas hydrate sector

In which country are you based?



In what capacity have you been involved in gas hydrates?



1. Includes 25 in the United States and 2 in Canada; 2. Includes 2 in Brazil; 3. Includes 7 in the United Kingdom, 3 in Germany, 2 in France, 2 in Norway and 1 in Spain; 4. Includes 1 in China, 1 in India, 1 in Korea and 1 in Bangladesh; 5. Includes 1 in Bulgaria, 1 in Uzbekistan and 1 in Russia; 6. IOC for International Oil Companies and NOC for National Oil Companies; 7. Includes 2 international institutions, as well as 2 energy industry publishers.
Source: A.T. Kearney Energy Transition Institute analysis

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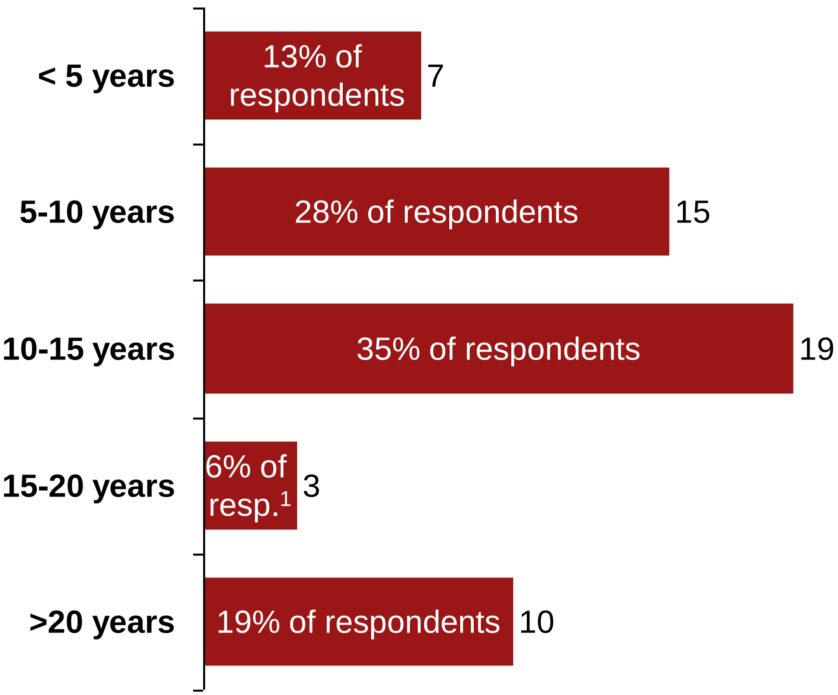
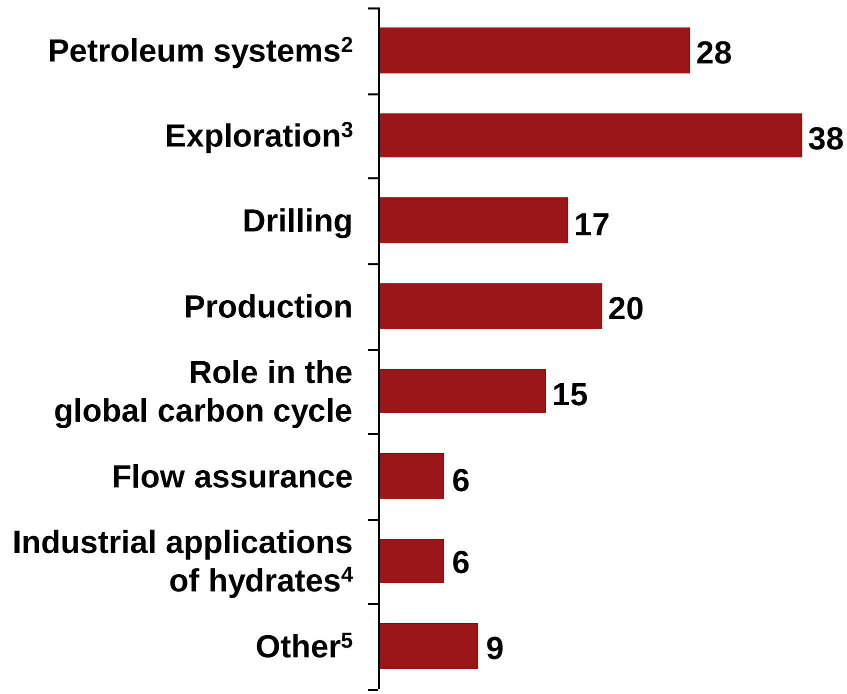
Respondents' expertise covers the full range of gas-hydrate related subjects and 87% of them have been involved in gas hydrates for more than five years

Experience in the Gas hydrate sector

For how long have you been involved in gas hydrates?



What is/are your main area(s) of focus regarding hydrates?



1. Resp. For respondents; 2. Gas-hydrate structure, formation process; 3. Laboratory and field characterization; 4. e.g. transportation; 5. Other includes: "monitoring", "research", "teaching", "economics of gas hydrate production", "all potential development in the US".
Source: A.T. Kearney Energy Transition Institute analysis

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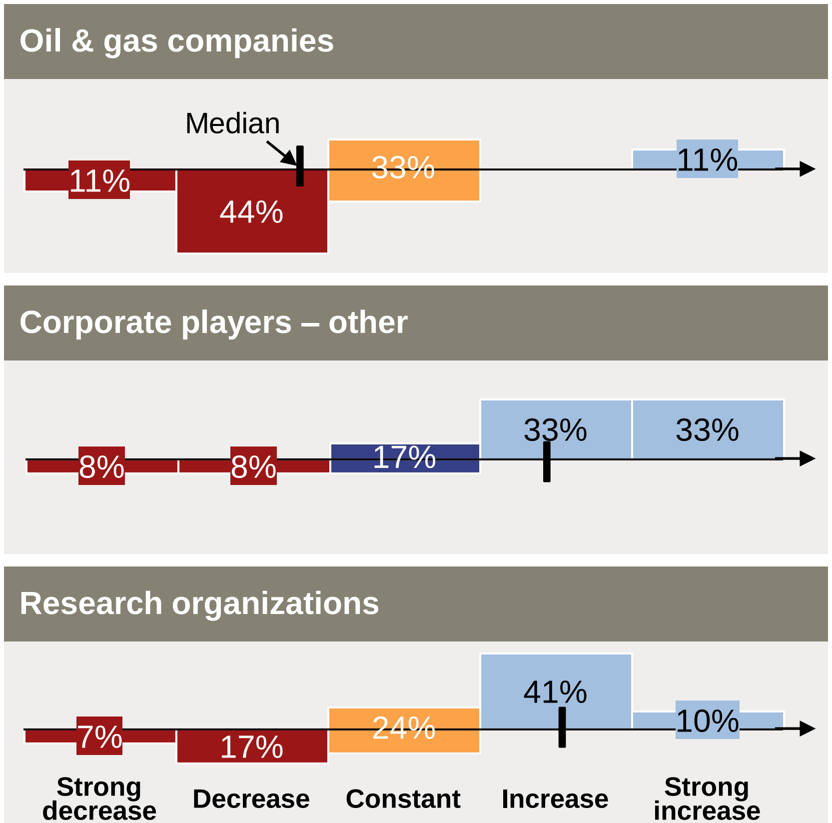
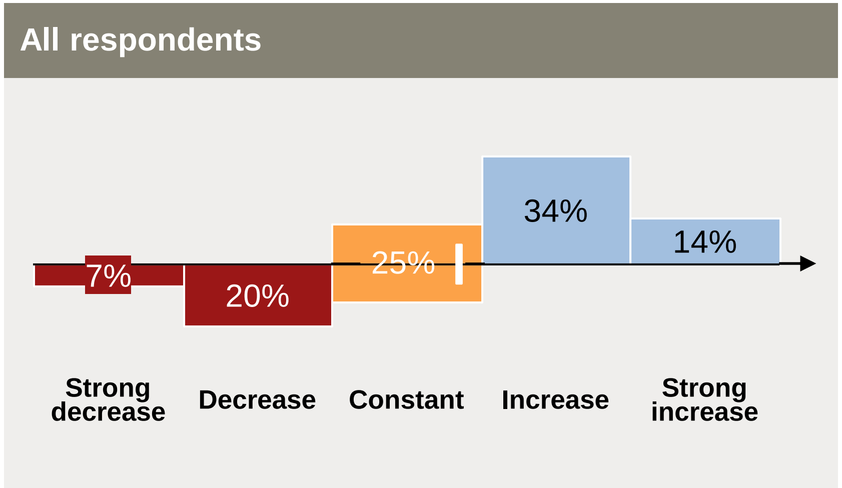
Involvement in gas hydrates seems to be growing among research organizations and international institutions, but decreasing among oil & gas companies

Organization involvement

How has your organization's involvement in gas-hydrates Research, Development and Demonstration evolved over the past decade?





Source: A.T. Kearney Energy Transition Institute analysis

2. Gas hydrates today

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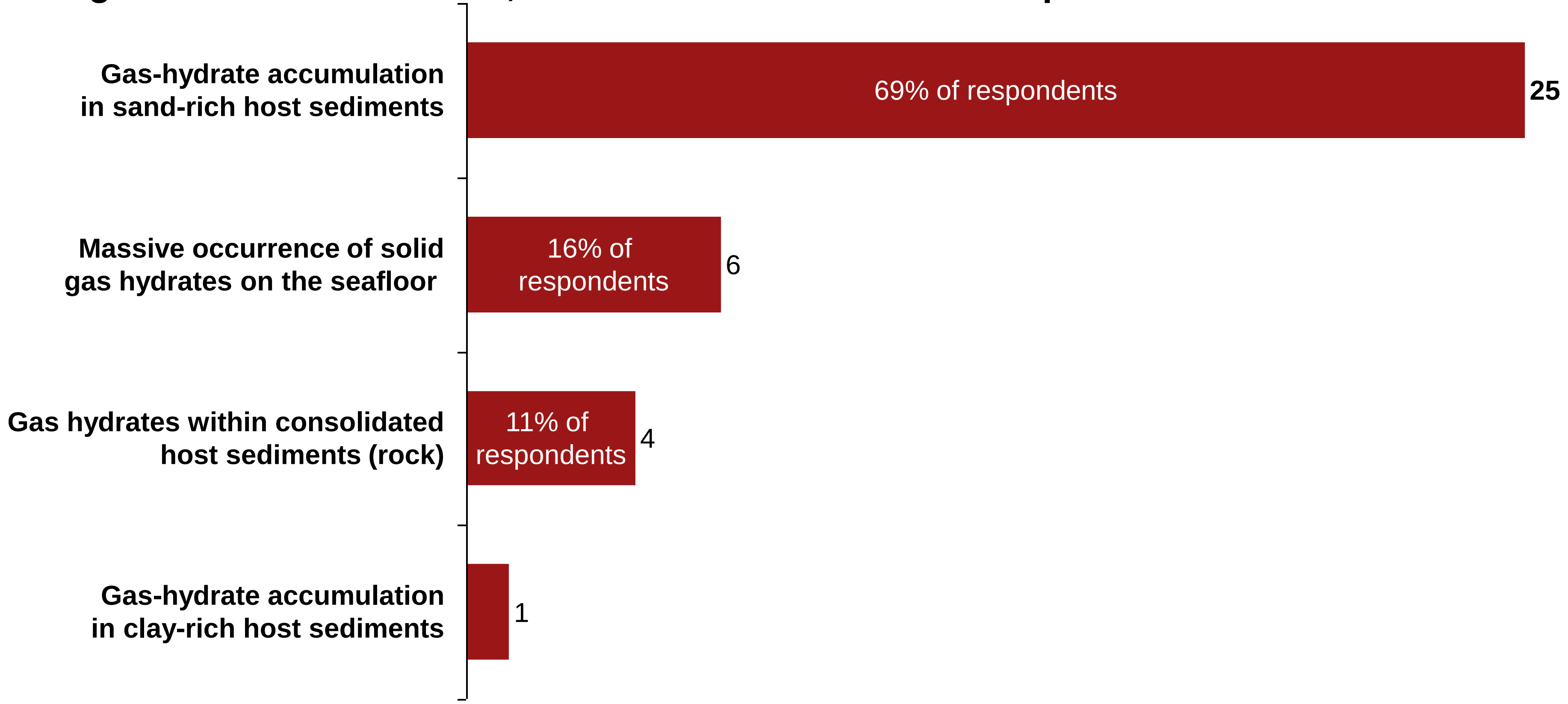
69% of respondents consider gas-hydrate accumulations in sand-rich host sediments to be the most readily produced type of gas-hydrate accumulation

Most readily produced type of Gas hydrate deposit

In your opinion, what is the most readily produced type of gas-hydrate accumulation, taking into account technical, economic and environmental parameters?



Source: A.T. Kearney Energy Transition Institute analysis

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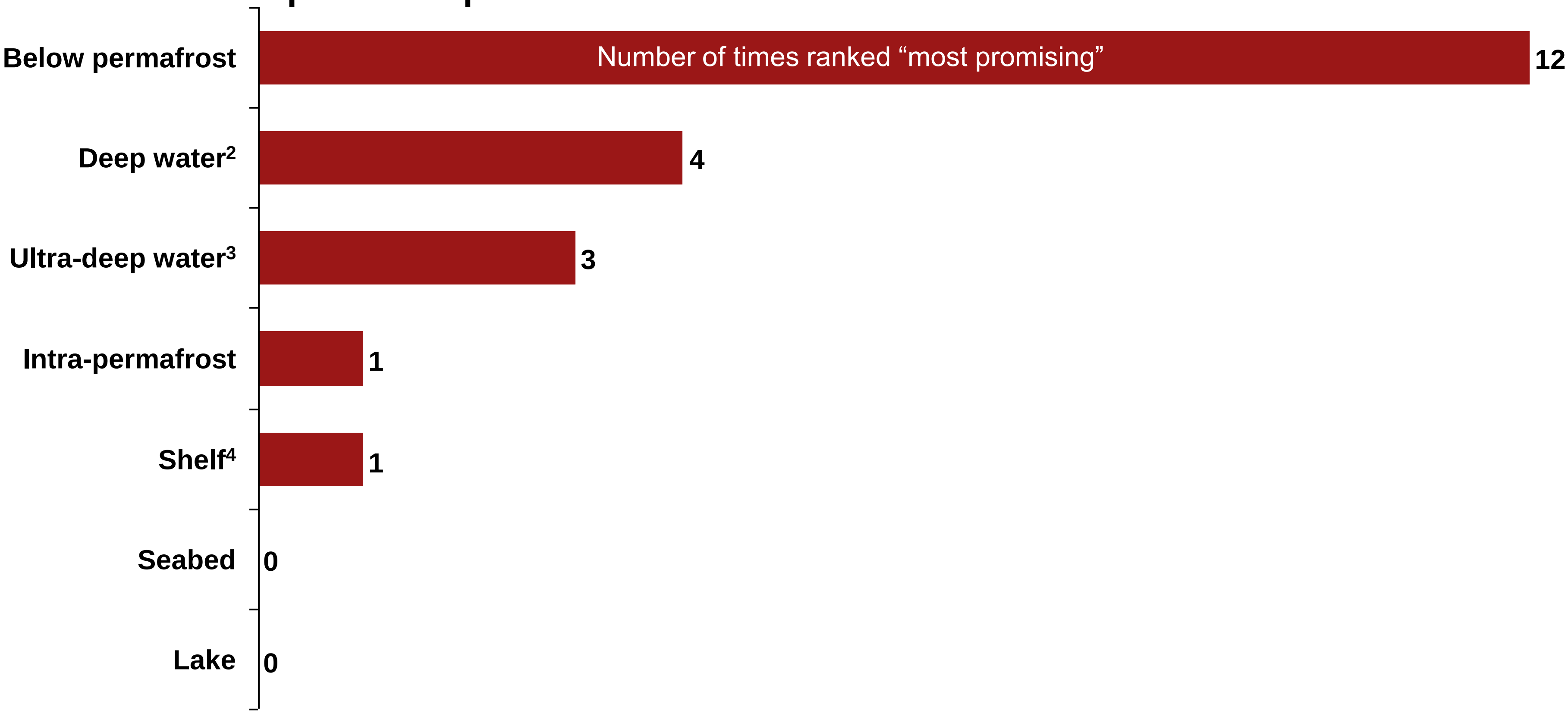
Deposits located below the permafrost are considered the most promising type of gas-hydrate accumulation in sand-rich reservoirs

Attractiveness of different gas-hydrate targets in sand-rich host sediments

In your opinion, how promising is each deposit target for the type of accumulations you identified in the previous question?[1]



1. From a possible seven options, respondents selected the four most promising and ranked them 1 to 4, with 1 being the least promising deposit target and 4 being the most promising; 21,000< water depth <5,000 ft; 3water depth > 5,000 ft; 4water depth < 1,000 ft.

Source: A.T. Kearney Energy Transition Institute analysis

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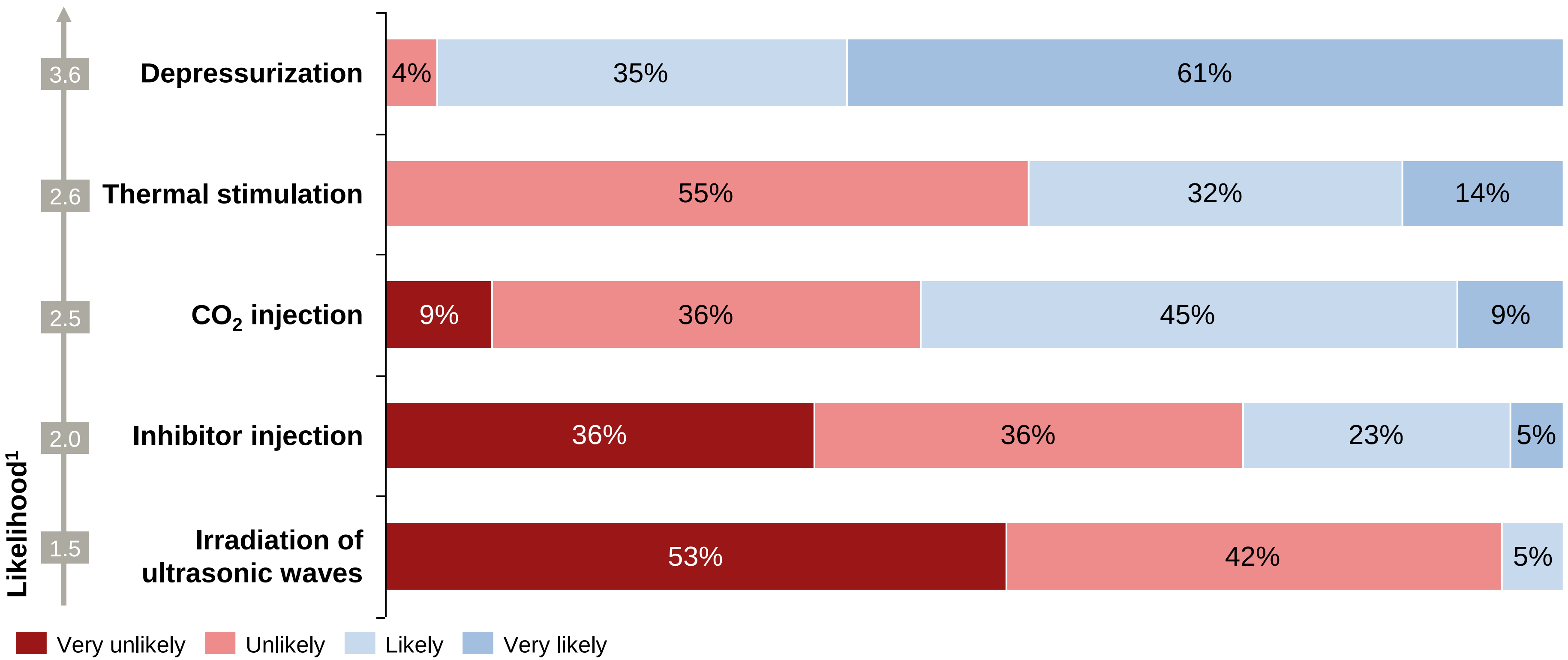
96% of respondents consider that depressurization is likely or very likely to be suitable for producing gas hydrates in sand-rich host sediments

Likelihood of success of various techniques for producing gas hydrates in sands

To what extent do you believe the following production techniques are suitable for producing from the accumulation type you identified in the previous questions as the most promising?



1. Likelihood was determined by calculating the average weighted sum of answers, with a score of 1 attributed to “Very unlikely”, 2 to “Unlikely”, 3 to “Likely” and 4 to “Very Likely”.

Source: A.T. Kearney Energy Transition Institute analysis

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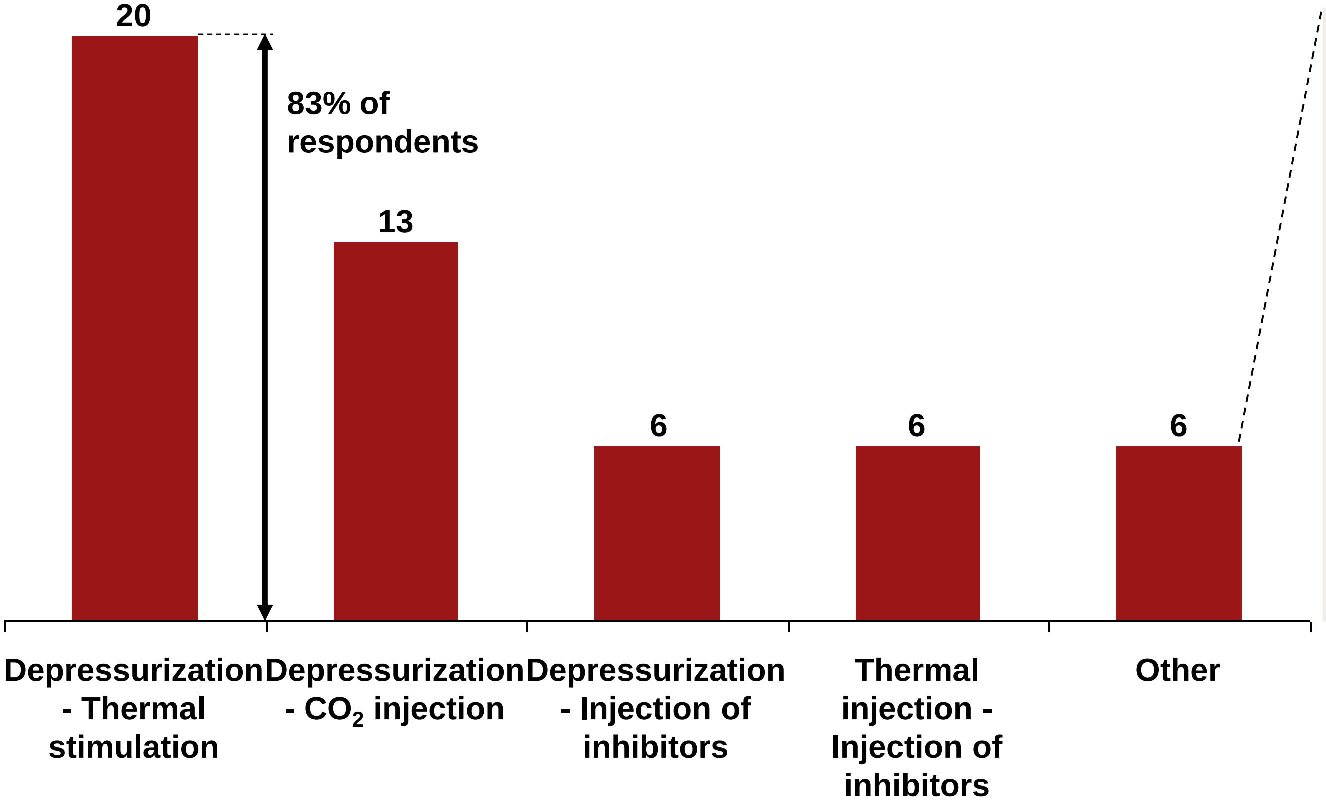
83% of respondents believe that combining depressurization and thermal stimulation could be promising for producing gas hydrates in sands

Combinations of production techniques

In your opinion, which combination(s) of production techniques may be promising in gas-hydrate production?



- "Microbial-enhanced oil recovery and inhibitor injection"
- "Irradiation of ultrasonic waves from horizontal leg"
- "Harvesting hydrates from the seabed or from bubbling seeps"
- "Heat-producing radionuclides, beta radiation emitters"
- "Transportation of hydrates to point of thermal injection"
- "None of these can be done economically and safely"

Source: A.T. Kearney Energy Transition Institute analysis

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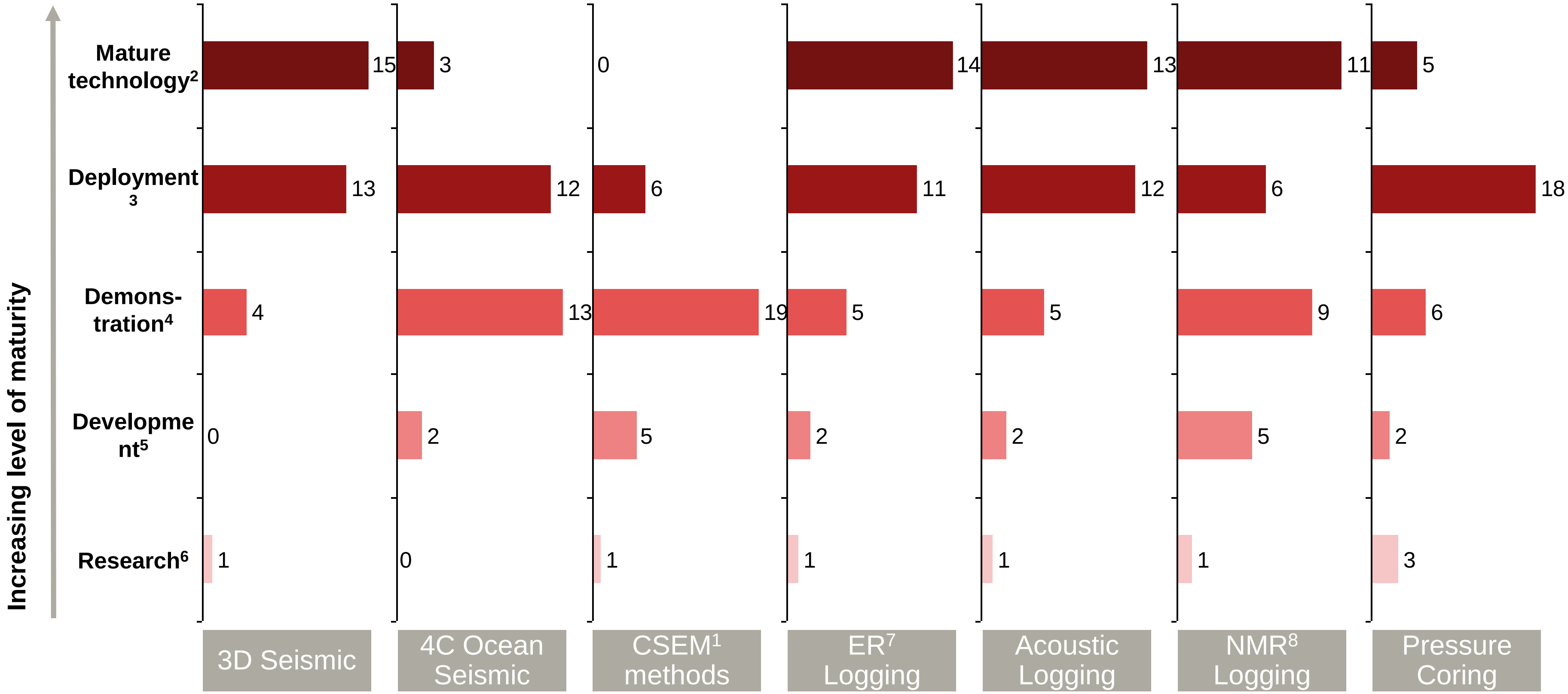
With the exception of CSEM[1], respondents classified gas-hydrate exploration technologies as mature or under deployment

Maturity of Exploration techniques

How would you rank the level of maturity of these technologies as applied in gas-hydrate exploration?



1. Controlled-source electro-magnetic; 2. Commercial-scale, widely deployed, with limited optimization potential; 3. Proved commercial-scale process, with optimization work in progress; 4. Pilot-scale; 5. Bench-scale; 6. Lab work/theoretical research; 7. Electrical Resistivity; 8. Nuclear Magnetic Resonance.

Source: A.T. Kearney Energy Transition Institute analysis

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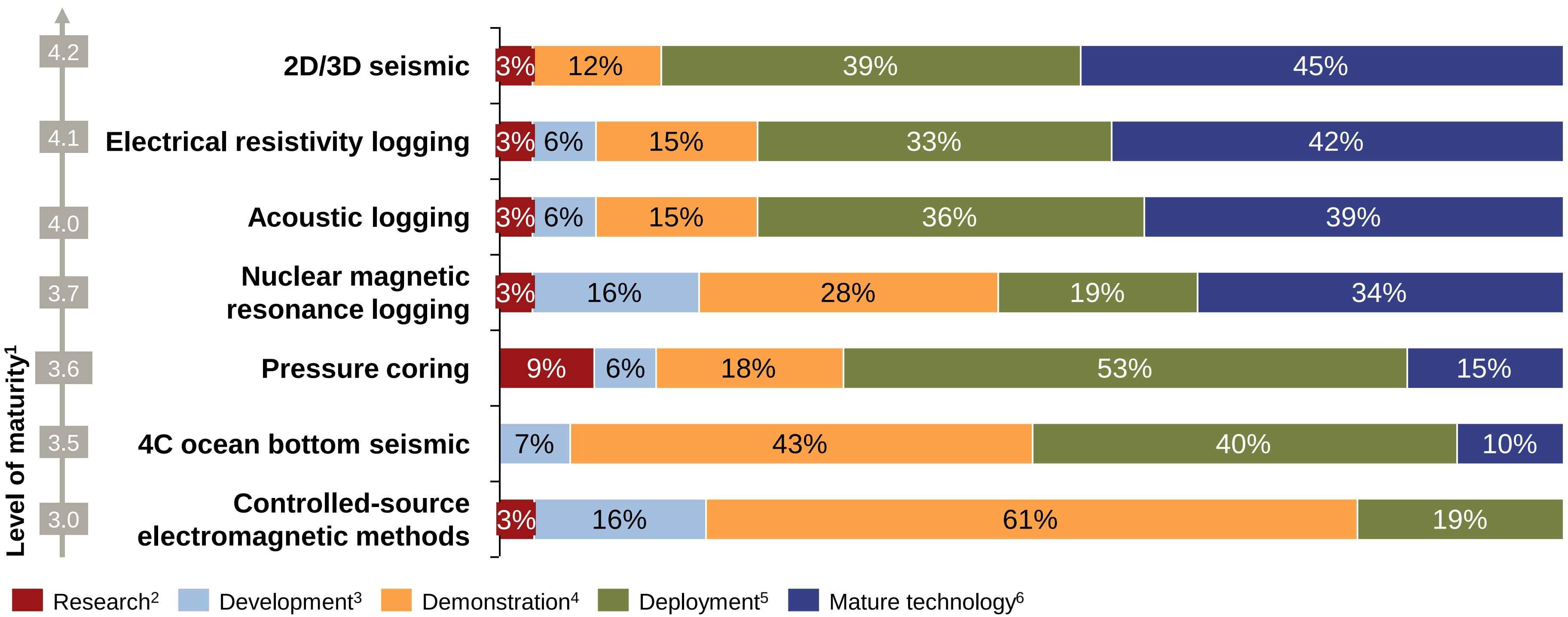
Respondents rank 2D/3D seismic technologies and electrical and acoustic logging as the most mature exploration technologies

Maturity of Exploration/assessment techniques

How would you rank the level of maturity of these technologies as applied in gas-hydrate exploration?

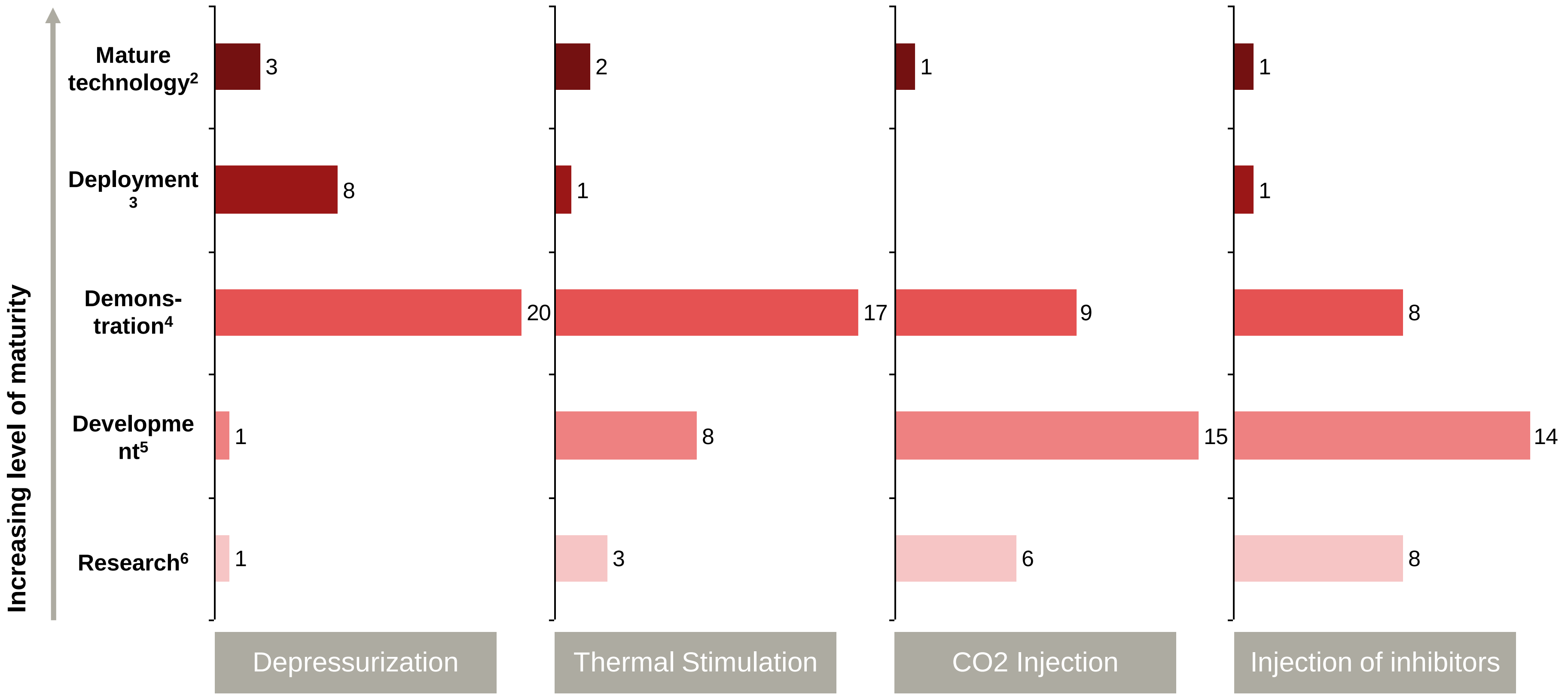


1. Maturity was determined by calculating the average weighted sum of answers, with a score of 1 attributed to "Research", 2 to "Development", 3 to "Demonstration", 4 to "Deployment" and 5 to "Mature technology"; 2. Lab work / theoretical research; 3. Bench-scale; 4. Pilot-scale; 5. Proved commercial-scale process, with optimization work in progress; 6. Commercial-scale, widely deployed, with limited optimization potential.
Source: A.T. Kearney Energy Transition Institute analysis

Most respondents consider gas-hydrate dissociation techniques to be under development or in the demonstration phase

Maturity of Production techniques

How would you rank the level of maturity of these technologies as applied in gas-hydrate production?



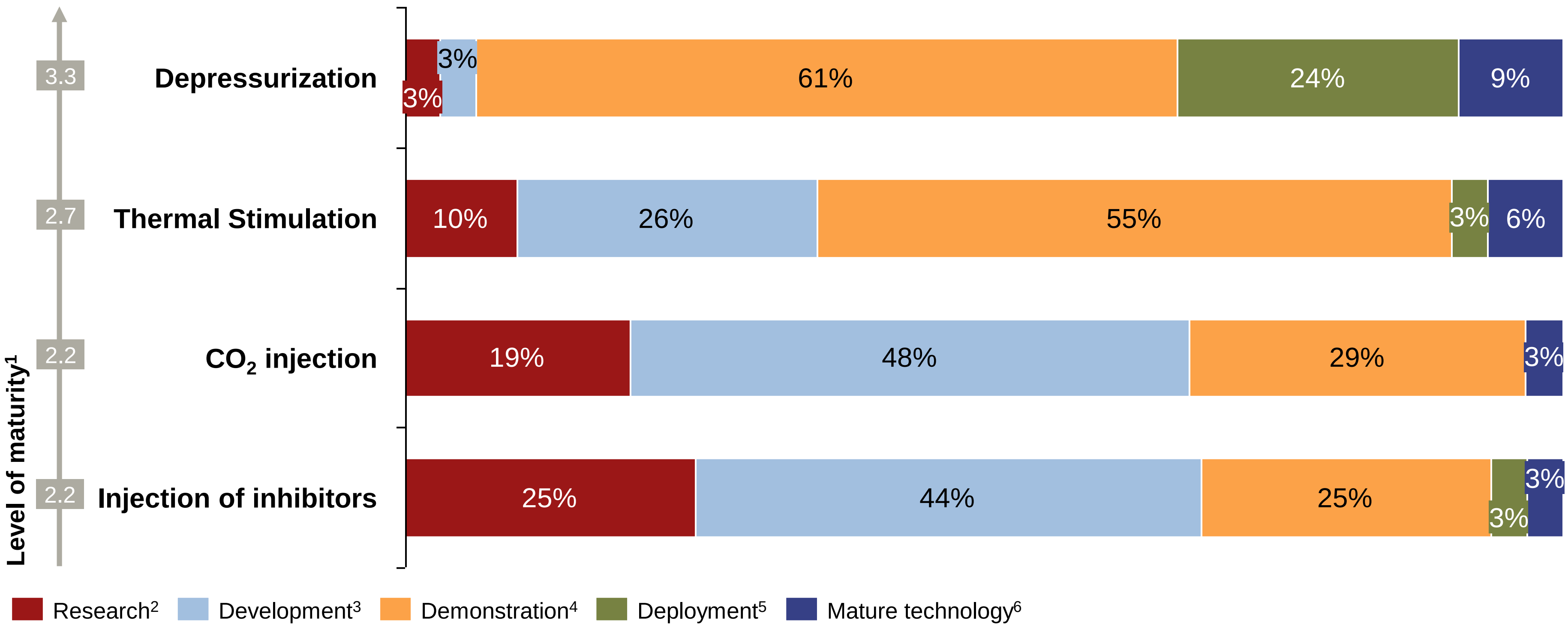
1. Commercial-scale, widely deployed, with limited optimization potential; 2. Proved commercial-scale process, with optimization work in progress; 3. Pilot-scale; 4. Bench-scale; 5. Lab work / theoretical research.

Source: A.T. Kearney Energy Transition Institute analysis

Depressurization is considered the most mature dissociation technique, followed by thermal stimulation

Maturity of Production techniques

How would you rank the level of maturity of these technologies as applied in gas-hydrate production?



1. Maturity was determined by calculating the average weighted sum of answers, with a score of 1 attributed to "Research", 2 to "Development", 3 to "Demonstration", 4 to "Deployment and 5 to "Mature technology"; 2. Lab work / theoretical research; 3. Bench-scale; 4. Pilot-scale; 5. Proved commercial-scale process, with optimization work in progress;
6. Commercial-scale, widely deployed, with limited optimization potential.
Source: A.T. Kearney Energy Transition Institute analysis

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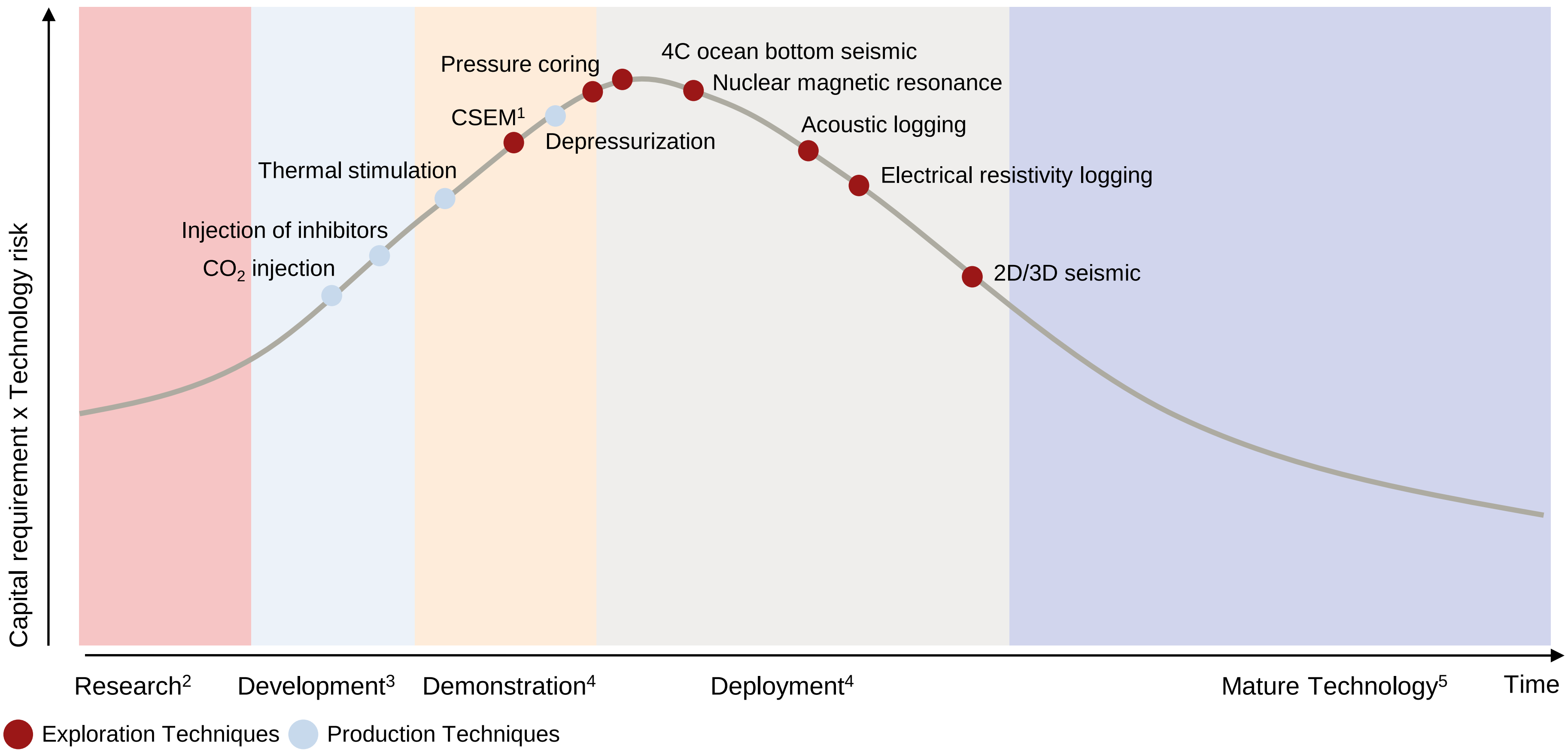
Gas-hydrate exploration technologies are mostly in the deployment phase, whereas production technologies tend to be in the development/demonstration stages

Maturity curve[1]



1. Controlled-source electromagnetic methods; 2. Lab work / theoretical research; 3. Bench-scale; 4. Pilot-scale; 5. Proved commercial-scale process, with optimization work in progress; 6. Commercial-scale, widely deployed, with limited optimization potential.
Source: A.T. Kearney Energy Transition Institute analysis

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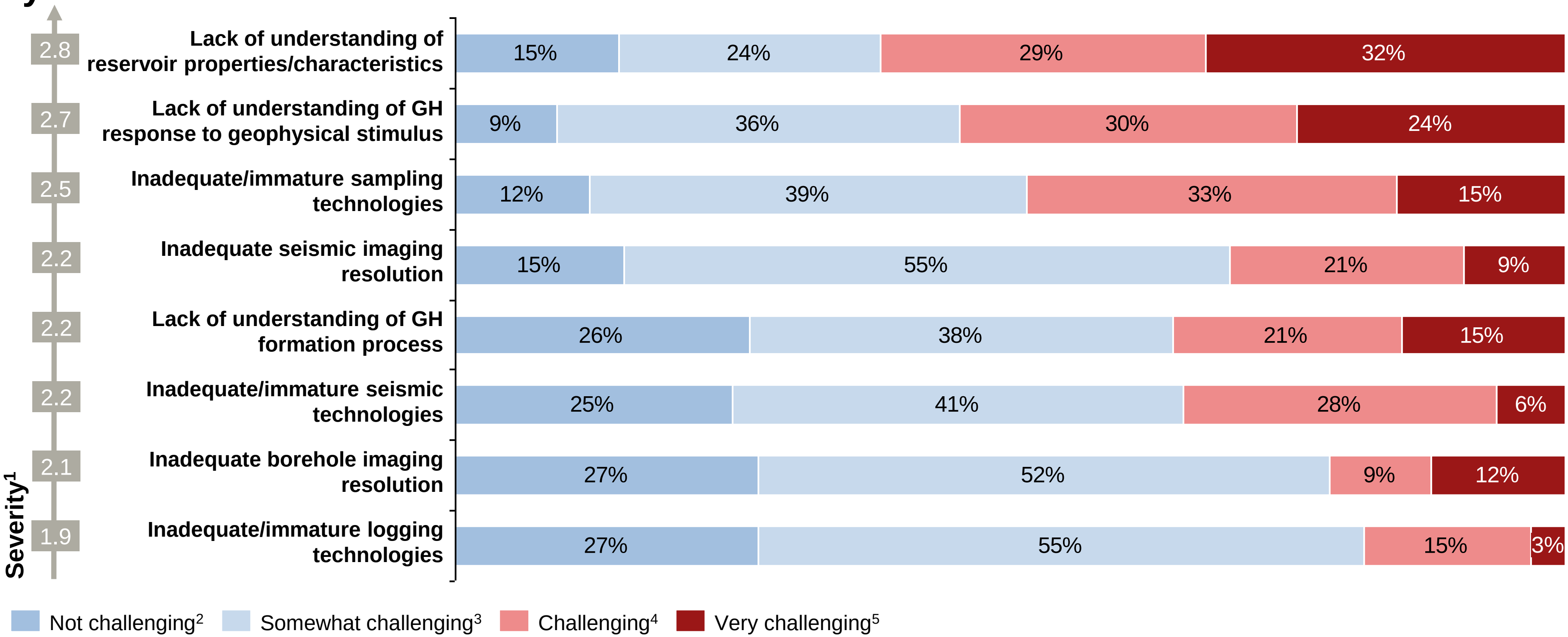
The biggest challenges in exploration are the lack of understanding of reservoir properties and of how gas hydrates respond to geophysical stimulus

Severity of exploration challenges

How would you grade the following challenges associated with exploration for gas hydrates?



1. Severity was determined by calculating the average weighted sum of answers, with a score of 1 attributed to “Not challenging”, 2 to “Somewhat challenging”, 3 to “Challenging” and 4 to “Very challenging”; 2. Ranked 1 by survey respondents; 3. Ranked 2 by survey respondents; 4. Ranked 3 by survey respondents; 5. Ranked 4 by survey respondents.
Source: A.T. Kearney Energy Transition Institute analysis

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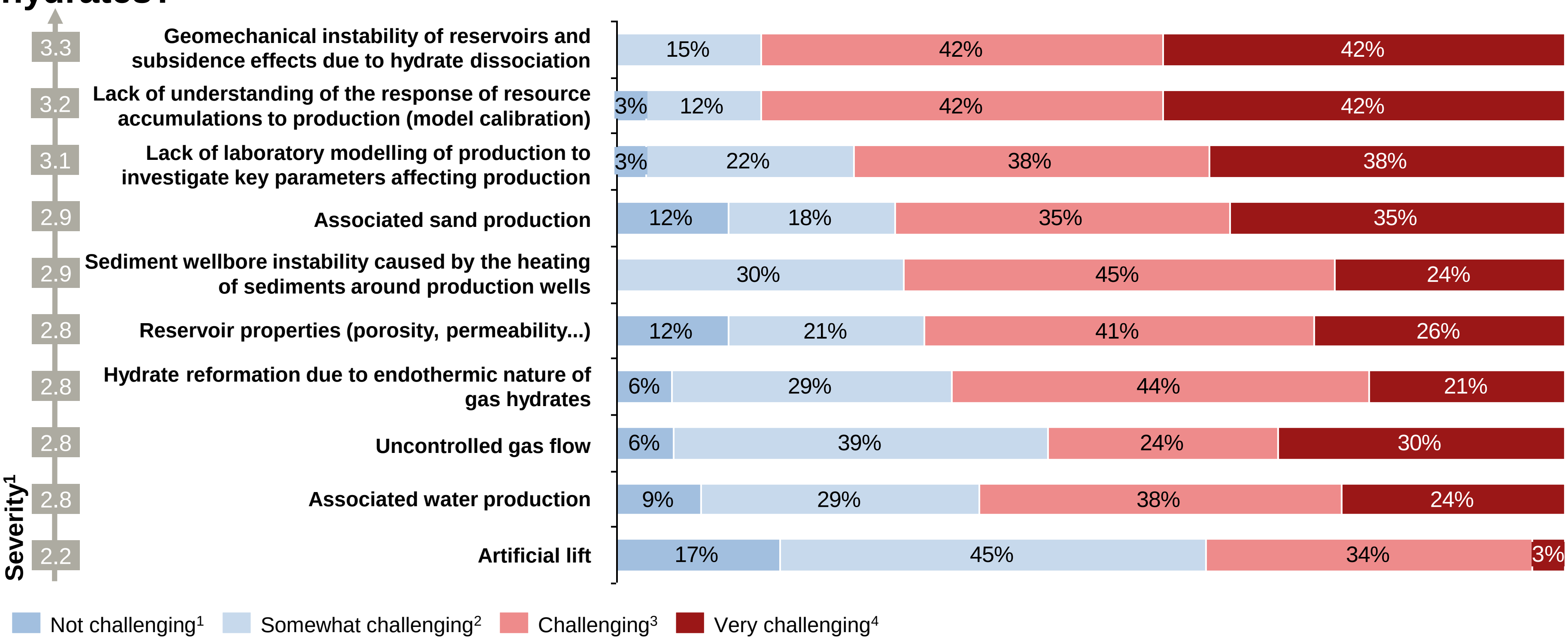
Respondents rank the most significant challenges in production as the geo- mechanical instability of reservoirs and subsidence caused by hydrate dissociation

Severity of production challenges

How would you grade the following challenges associated with the production of gas hydrates?



1. Severity was determined by calculating the average weighted sum of answers, with a score of 1 attributed to "Not challenging", 2 to "Somewhat challenging", 3 to "Challenging" and 4 to "Very challenging"; 2. Ranked 1 by survey respondents; 3. Ranked 2 by survey respondents; 4. Ranked 3 by survey respondents; 5. Ranked 4 by survey respondents.
Source: A.T. Kearney Energy Transition Institute analysis

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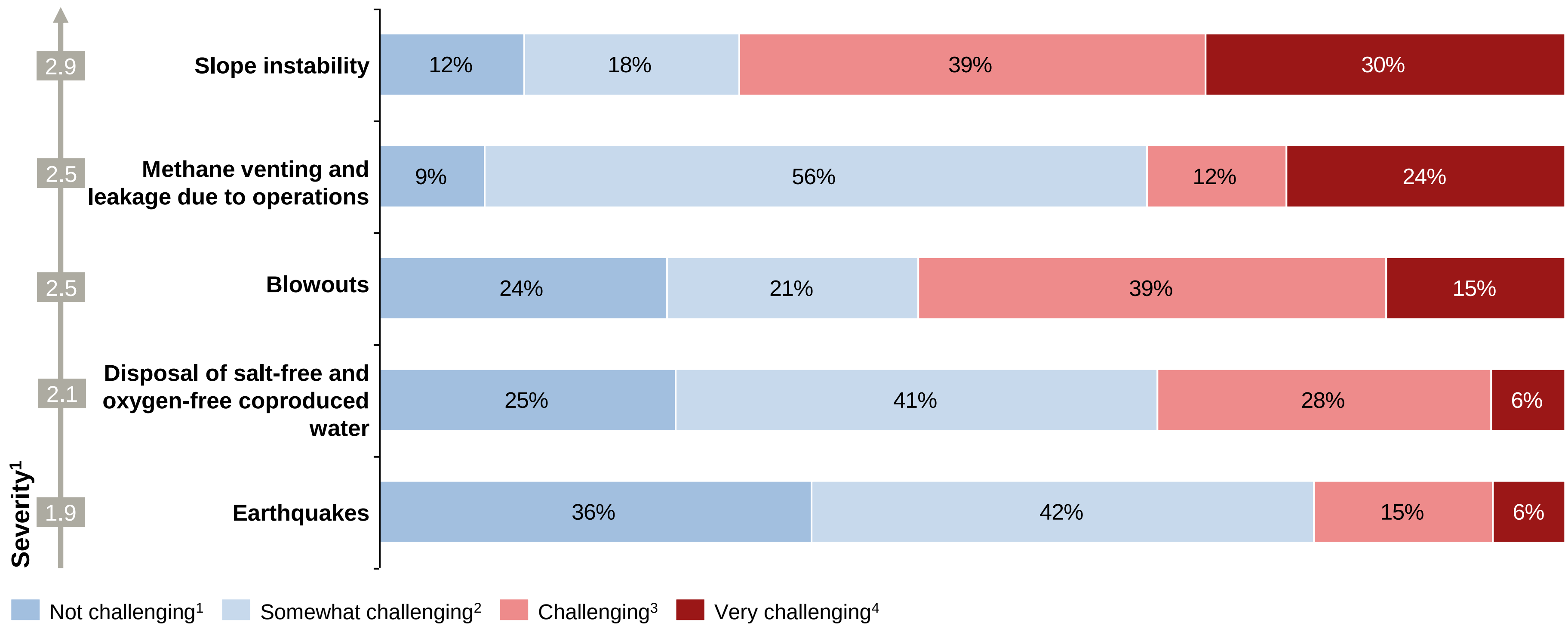
Slope instability and earthquakes are considered the most and least challenging environmental hazards in upstream gas-hydrate operations

Severity of environmental hazards associated with upstream operations

What do you see as the main environmental challenges likely to result from gas-hydrate production?



1. Severity was determined by calculating the average weighted sum of answers, with a score of 1 attributed to “Not challenging”, 2 to “Somewhat challenging”, 3 to “Challenging” and 4 to “Very challenging”; 2. Ranked 1 by survey respondents; 3. Ranked 2 by survey respondents; 4. Ranked 3 by survey respondents; 5. Ranked 4 by survey respondents.
Source: A.T. Kearney Energy Transition Institute analysis

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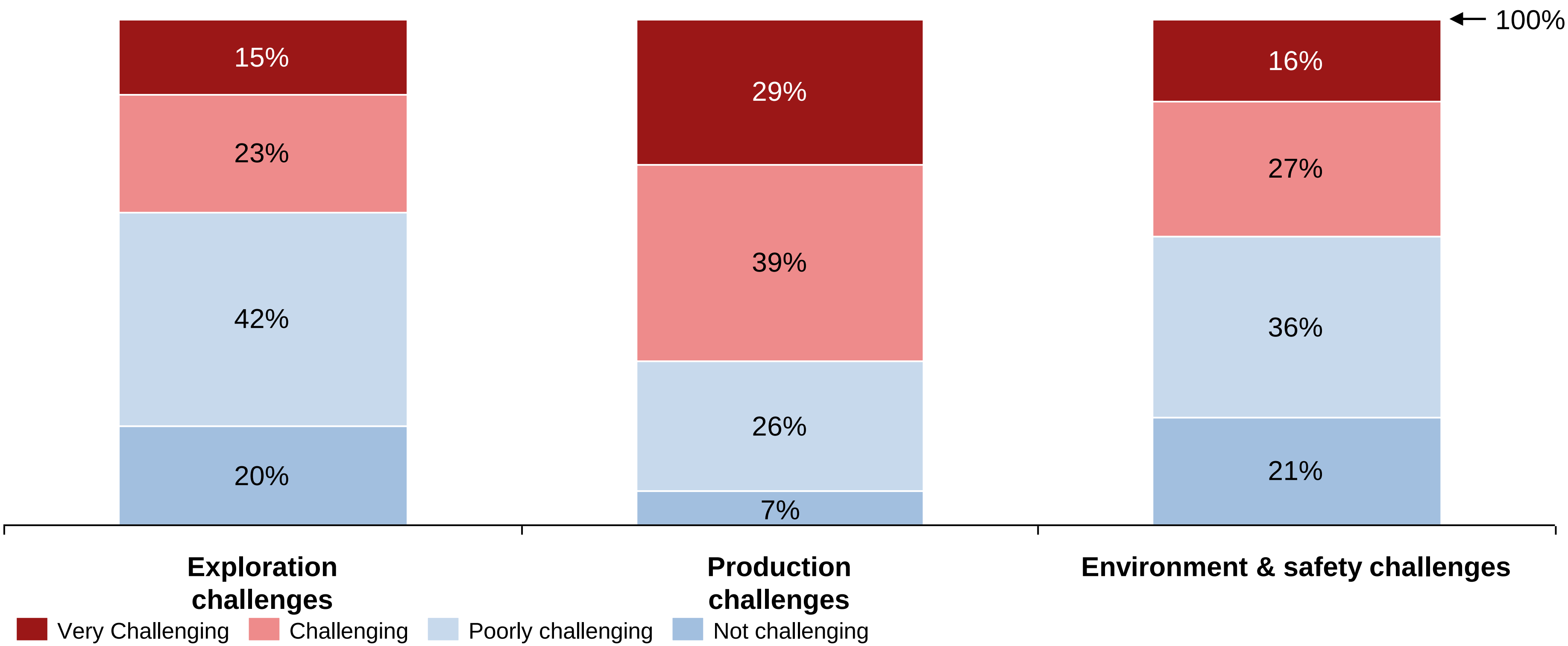
Overall, gas-hydrate production-related challenges appear to be more severe than those associated with exploration and the environment

Comparative severity of exploration, production and environmental challenges

Number of responses on a 100% basis

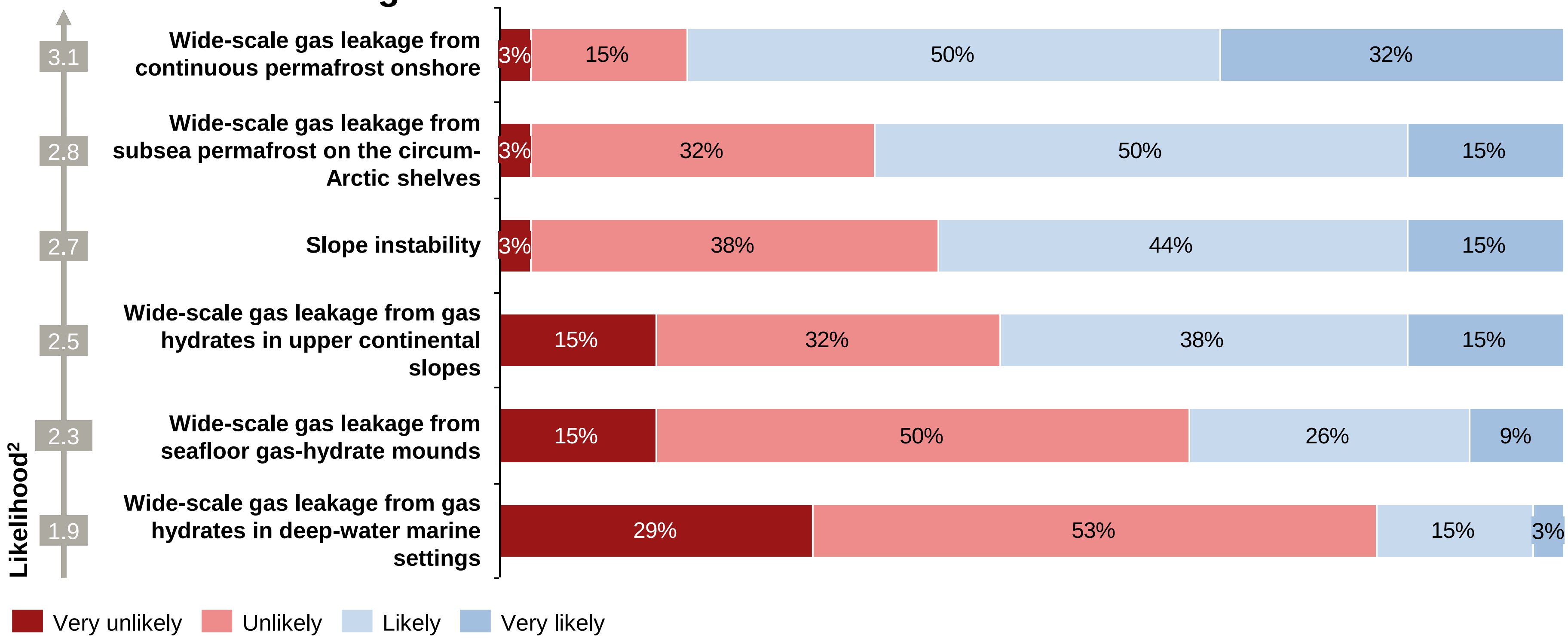


Source: A.T. Kearney Energy Transition Institute analysis

Methane leakages from onshore permafrost and from deep-water marine settings are considered the most and least likely environmental hazards respectively

Likelihood of potential natural[1] environmental hazards

How would you evaluate the likelihood of gas-hydrate (GH) dissociation occurring as a result of climate change?



1. Natural environmental challenges are defined as those occurring as a result of climate change; 2. Likelihood was determined by calculating the average weighted sum of answers, with a score of 1 attributed to "Very unlikely", 2 to "Unlikely", 3 to "Likely" and 4 to "Very Likely".
Source: A.T. Kearney Energy Transition Institute analysis

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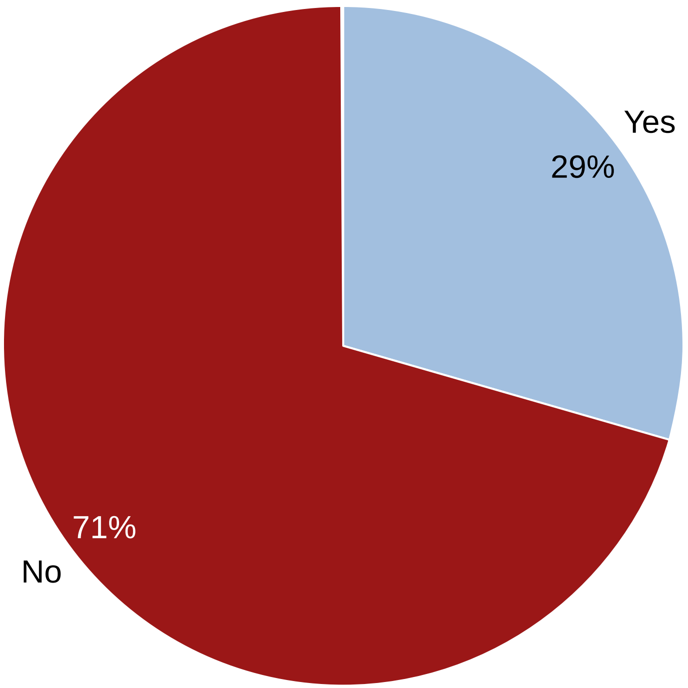
71% of respondents consider that producing gas hydrates cannot be a solution for mitigating the climatic impact of natural gas-hydrate dissociation

Production of gas hydrates as a climate-change mitigation strategy

Do you believe that producing gas hydrates can be a solution for mitigating the climatic impact of natural dissociation?



Source: A.T. Kearney Energy Transition Institute analysis

3. Outlook

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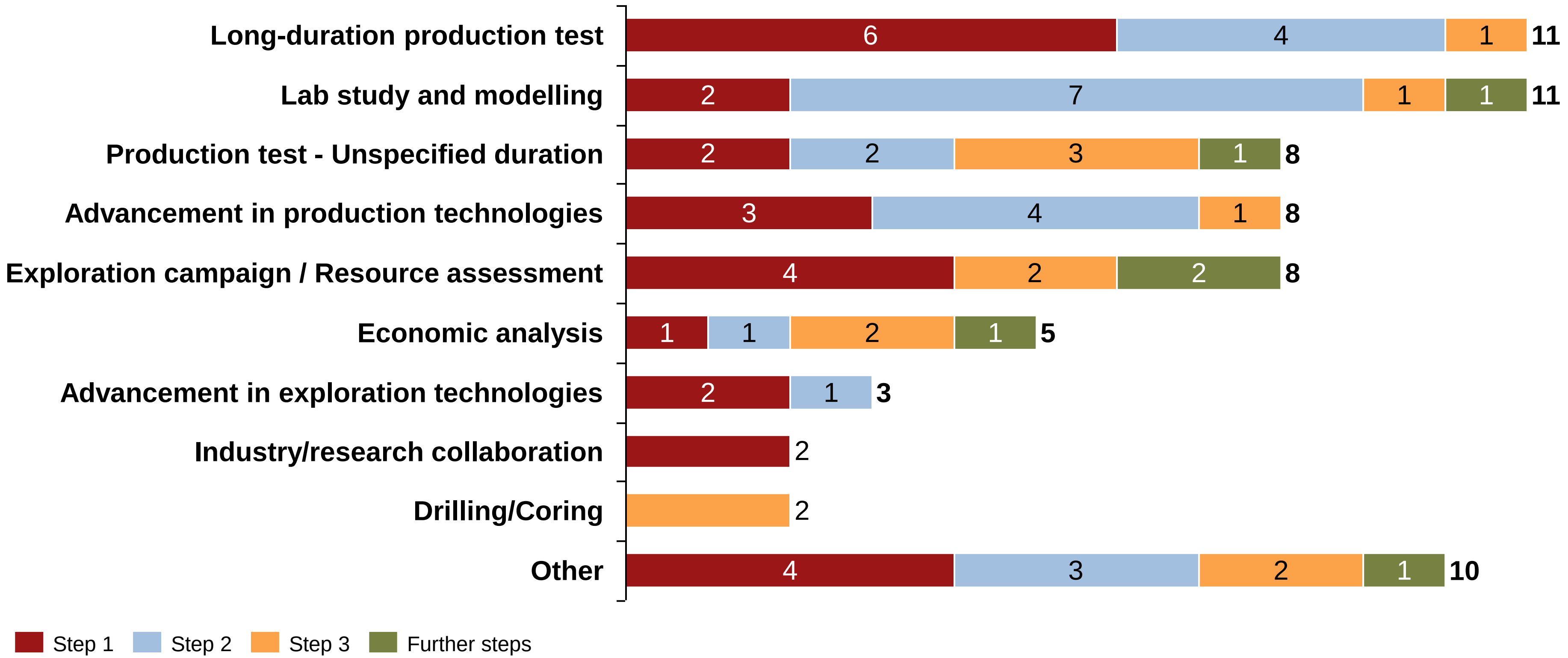
Long-duration production test was ranked as the most important pre-requisite for enabling the development of gas hydrates

Steps required for enabling gas-hydrate development – All steps

What do you see as the principal steps required to enable the development of gas hydrates?



Source: A.T. Kearney Energy Transition Institute analysis

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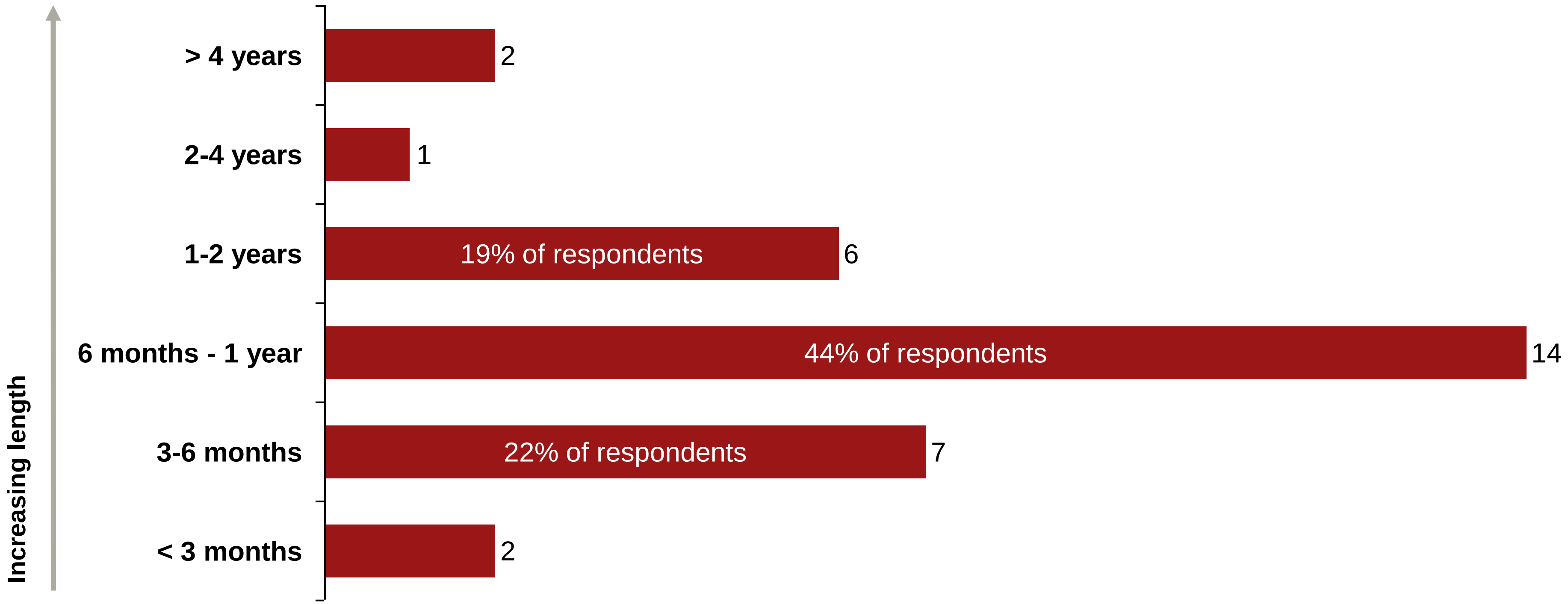
In order to yield useful results, a long-duration production test should last between 6 months and 1 year, according to 44% of respondents

Required length of long-duration test

How long should a long-duration production test last in order to assess the viability of gas-hydrate recovery?



Source: A.T. Kearney Energy Transition Institute analysis

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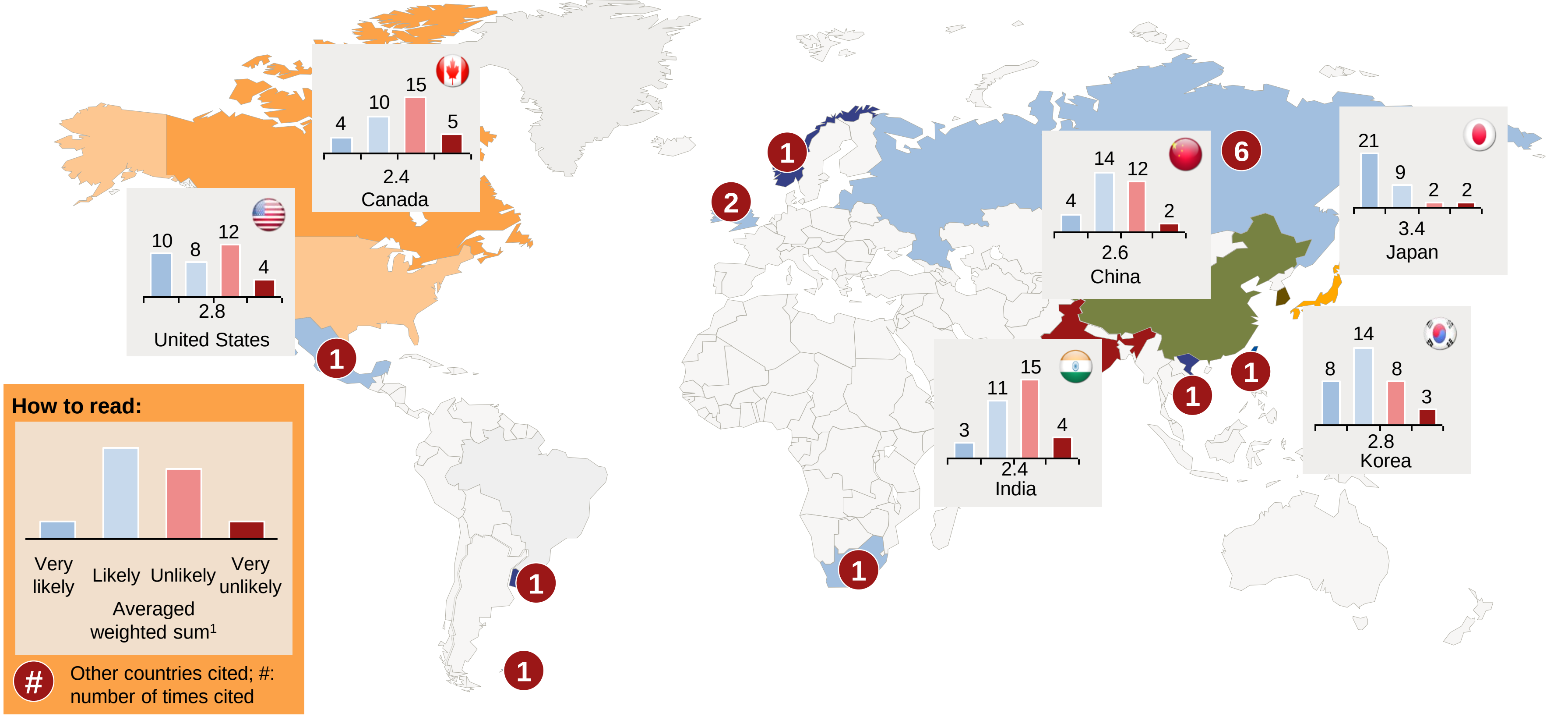
Japan is the only country where gas hydrates are very likely to be recovered on a commercial scale in the near-term, according to respondents

Promising Countries

Are you confident that gas hydrates will be recovered within the next 20 years at a commercial scale in these countries?



Note: Europe and Scandinavia were also each cited once but these responses have not been included on this map, because these are regions and not countries.; 1. Average weighted sum of answers, with a score of 1 attributed to “Very unlikely”, 2 to “Unlikely”, 3 to “Likely” and 4 to “Very Likely”.

Source: A.T. Kearney Energy Transition Institute analysis

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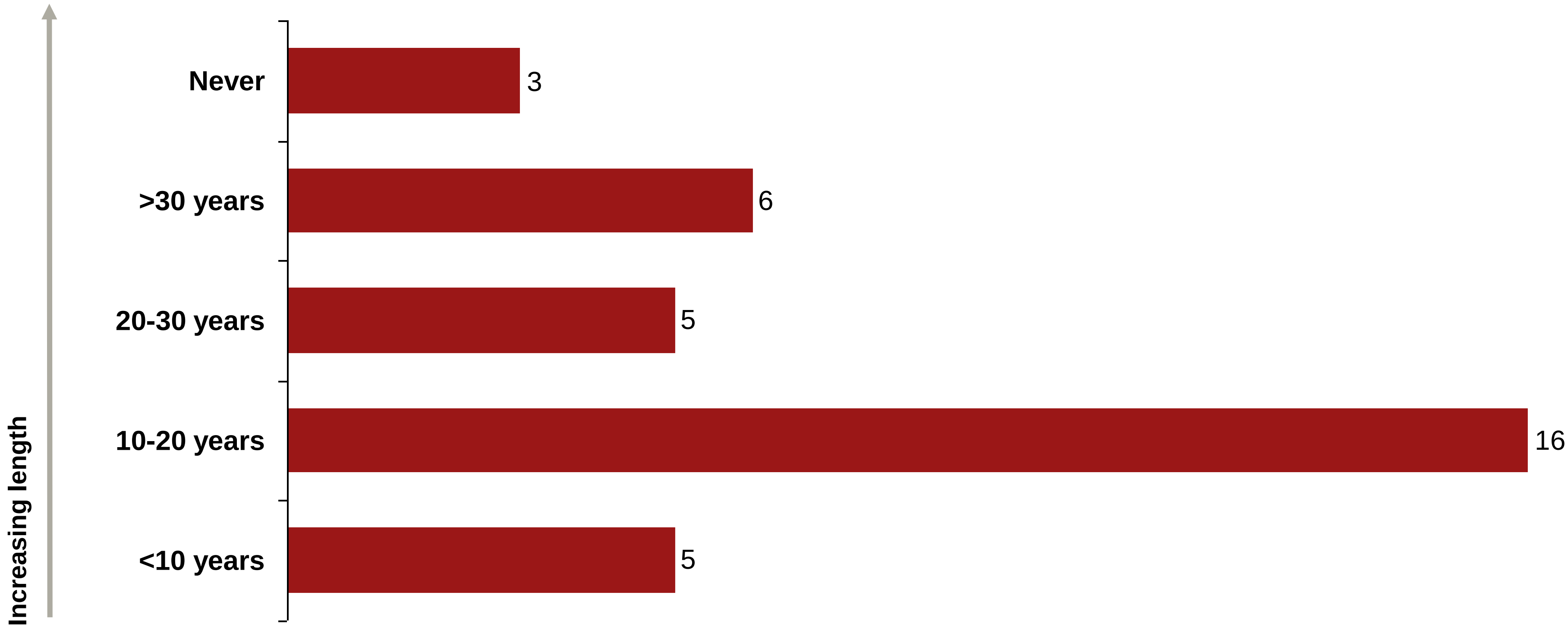
70% of respondents believe that gas hydrates will be produced economically within the next 20 years

Timeframe in which recovery may become economic

Over what timeframe do you think gas hydrates will be produced economically?



Source: A.T. Kearney Energy Transition Institute analysis

Appendix

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Picture credits

Slide 5: Close-up of methane hydrates observed at a depth of 1,055 meters, near a point at which bubble plumes had been detected in pre-existing sonar data; observed in the U.S. North Atlantic Margin by National Oceanic and Atmospheric Administration (NOAA) during the Okeanos Explorer Program; courtesy of NOAA

Slide 10: Aerial photo of the temporary ice pad built in Alaska (U.S) for the ConocoPhillips Ignik Sikumi production test, using CO_2-CH_4 exchange methodology, and, in the background, permanent operating gravel pads within the Prudhoe Bay Unit; courtesy of ConocoPhillips

Slide 26: Japanese deep-sea scientific drilling vessel Chikyu, built for the Integrated Ocean Drilling Program, used during Nankai Trough production test in 2014 and operated by Japan Agency for Marine-Earth Science and Technology (JAMSTEC); courtesy of JOGMEC

Slide 31: View of a test-well for collecting gas hydrates in Mallik, in the Mackenzie Delta-Beaufort Sea in Northern Canada; courtesy of the U.S. Geological Survey (USGS)

The A.T. Kearney Energy Transition Institute is a nonprofit organization. It provides leading insights on global trends in energy transition, technologies, and strategic implications for private sector businesses and public sector institutions. The Institute is dedicated to combining objective technological insights with economical perspectives to define the consequences and opportunities for decision makers in a rapidly changing energy landscape. The independence of the Institute fosters unbiased primary insights and the ability to co-create new ideas with interested sponsors and relevant stakeholders.

For further information about the A.T. Kearney Energy Transition Institute and possible ways of collaboration, please visit www.energy-transition-institute.com, or contact us at contact@energy-transition-institute.com.