



2018 THOUGHT LEADERSHIP

CCS STORAGE INDICATOR (CCS-SI)



GLOBAL CCS
INSTITUTE

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2018 REVIEW

The geological storage of carbon dioxide (CO₂) is the final stage of the carbon capture and storage (CCS) value chain. The availability of storage resources is the ultimate prerequisite for CCS.

The Global CCS Institute's (the Institute) CCS Storage Indicator (CCS-SI) tracks the development of storage resources for 80 countries. The CCS-SI examines a broad range of factors that are core to developing commercially-viable storage resources for CCS. These factors are assessed through criteria-based analysis, and include:

- Natural geological storage potential
- Maturity and confidence of storage resource assessments
- Experience in CO₂ storage projects and larger facilities.

The result is a score out of 100, with higher scores indicating a greater state of readiness of storage resources to support wide-scale deployment of CCS. The CCS-SI uses a defined methodology to undertake critical analysis of a nation's storage resource development, and record the progress in national, and global storage development.

The 2018 assessment has now expanded to review 80 countries. The 2018 scores show an overall improvement since the 2015 edition (Appendix 1). The addition of new countries and a general increase in scores shows that storage resource development has continued since 2015.

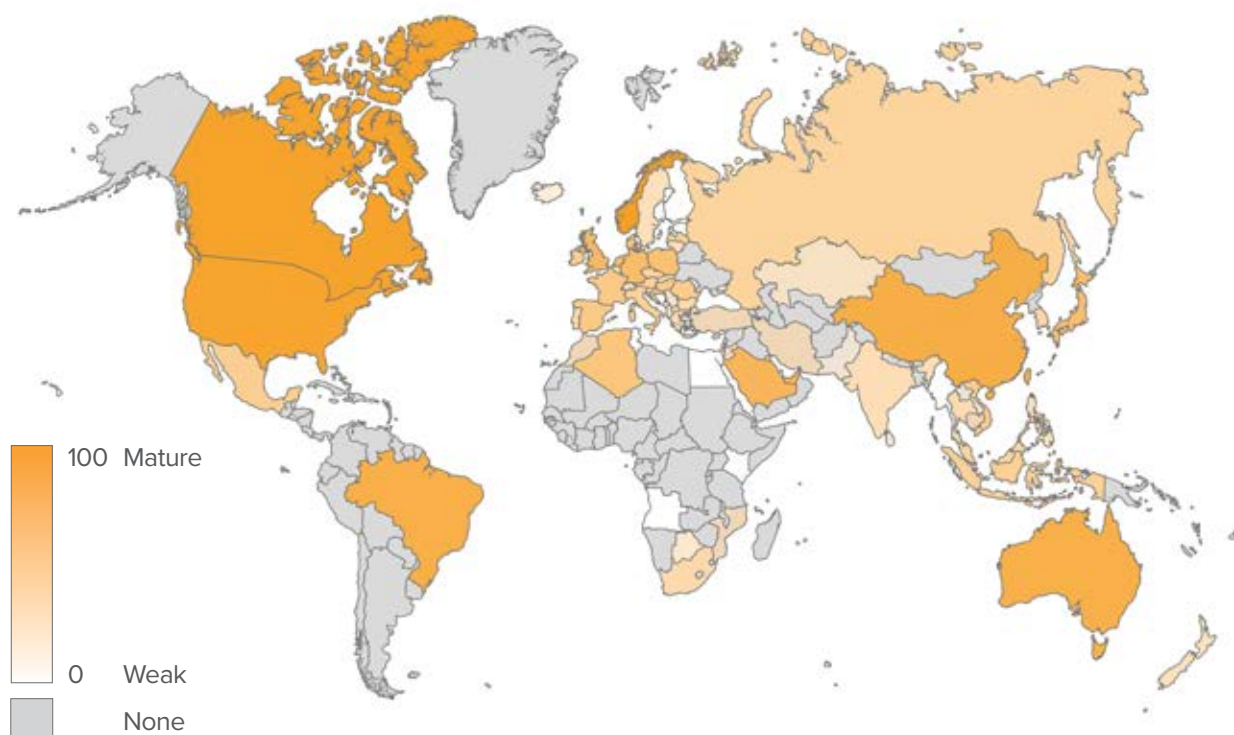
The improvement in scores can be mostly attributed to the ongoing refinement of existing storage resource assessments. Two areas of refinement include nations proceeding to:

1. Comprehensive basin, or site-scale 'desktop' assessments
2. Exploration and appraisal of prioritised sites.

It is clear from the 2018 review that there are ample global geological storage resources to enable CCS to play its full role in meeting emission reduction targets.



Figure 1: 2018 Storage Indicator Heat Map



Twelve leading nations driving storage resource development

Twelve nations have mature, or near-mature, storage resources to enable wide-scale CCS (Figure 1). These highest scoring 12 nations are leaders in storage. Located around the world, they include:

- Norway
- Canada
- United States
- China
- Australia
- Brazil
- United Arab Emirates
- Saudi Arabia
- United Kingdom
- Netherlands
- Germany
- Japan

Collectively these nations have hundreds of billions of tonnes of storage resources available, and the opportunity to achieve deep reductions in emissions through the application of CCS.

To support the deployment of CCS, nations require the following from the perspective of geological storage resource development.

1. A domestic portfolio of commercially viable storage sites. Norway, the United States and the United Kingdom have programs in place to build their storage portfolio. Japan is also now undertaking an offshore storage appraisal programme.
2. Investment in CO₂ storage project deployment. Projects should ideally assess the feasibility of large-scale injection rates (million tonne per annum or greater) and be well located for future large-scale CCS facilities. The United States is a clear leader, having completed publicly-funded CO₂ storage drilling programmes for future CCS Facilities.

Storage resources are not a barrier to meeting global targets

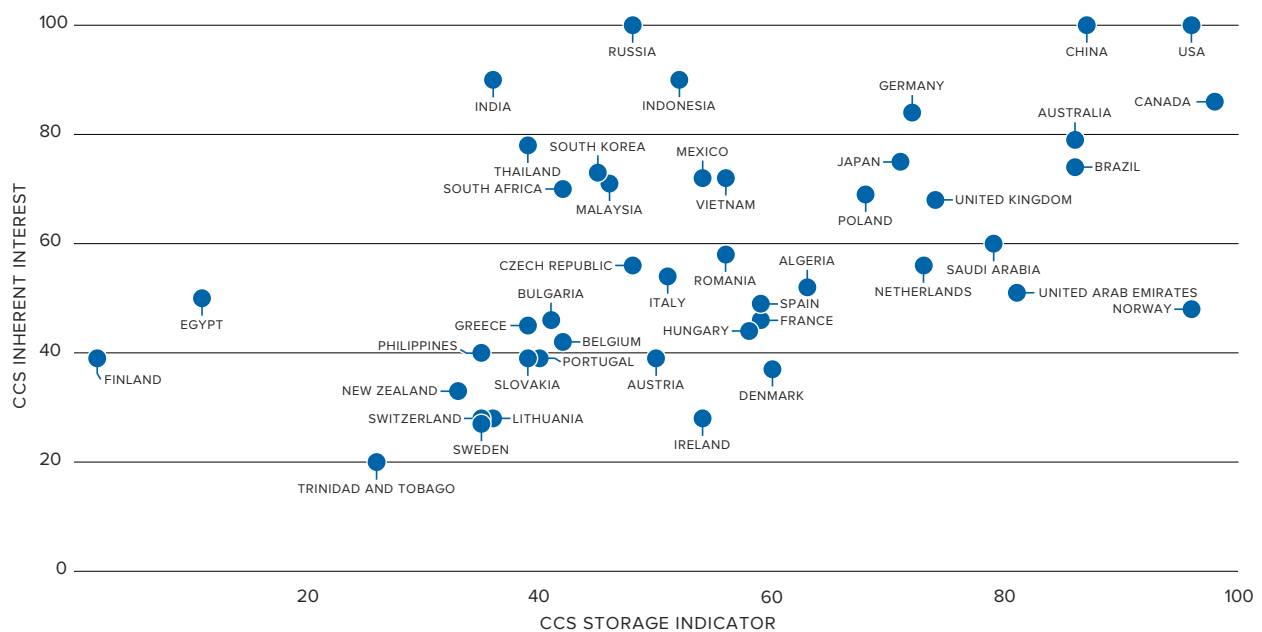
The vast majority of nations with high emissions have mature or near-mature storage resources. The Inherent CCS Interest Indicator (CCS-CI) intrinsically reflects emission-intensity and shows a nation's dependence on CCS to decarbonise.

A clear trend in the 2018 results is that those nations with high CCS-CI scores also have high storage indicator scores (both greater than 70) (Figure 2). Collectively these nations are responsible for over half of the world's emissions.

This trend has two implications for meeting global emission reduction targets:

1. Appraisal and development of prospective storage sites could be accelerated, developing commercially-viable storage sites, ready for CCS deployment.
2. The availability of storage resources is not a barrier for CCS to meet emission reduction targets.

Figure 2: Comparing 2018 CCS Storage Indicator results and the 2018 Inherent CCS Interest Scores for key countries



Immediate action needed in high opportunity nations

The 2018 results show that there is significant opportunity around the world to further develop storage resources. Moderately scoring European nations are high opportunity nations. The moderate score of those nations is due to their identification and broad assessments of storage prospects. The current focus for the European countries should now shift to appraising these prospects to identify commercially viable storage sites.

The second high-opportunity group of nations are those that have high CCS-CI scores but contrasting low CCS-SI scores, namely India, Indonesia, and Russia. These countries have high emissions and fossil fuel dependency, but lack mature storage resources. The development of CCS in these nations is critical as they are dependent on CCS to:

- Meet their emission reduction targets
- Protect current and future high emitting industries.

Developing storage resources is a prerequisite for wide-scale CCS deployment

CCS is a critical technology to meet international climate agreements. The emission reduction scenarios of the IPCC and IEA rely on the wide-scale, global deployment of thousands of CCS projects. For global CCS deployment, each country needs to know where, and how much, CO₂ can be stored. Each nation needs to characterise, explore and appraise a national portfolio of accessible, commercially-viable storage sites ready for CCS Facilities. Only through individual national initiatives will the global deployment of CCS happen.

1.0 INTRODUCTION



Knowledge of the world's geological CO₂ storage resources is continually being improved. There are now sufficient storage resources defined to enable the wide-scale deployment of carbon capture and storage (CCS) to meet global climate change reduction targets.

Defining storage resources can take decades and, much like the geology of a storage site, the development pathway is unique to that country. The Institute continues to assess the development of national storage resources through the CCS Storage Indicator (CCS-SI).

The 2018 CCS-SI builds upon the assessment methodology developed in 2015 and now encompasses a review of 80 countries. The 2018 assessment once again seeks to:

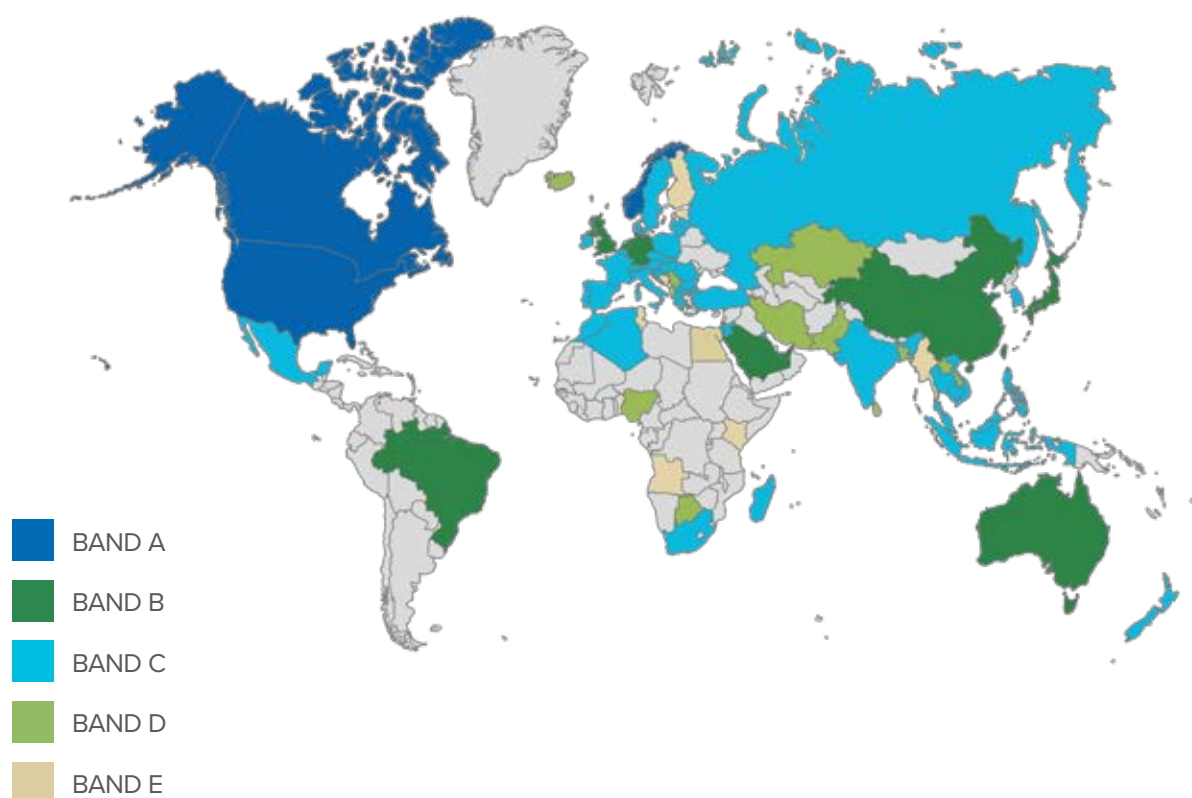
- Determine global progress in the development and maturation of storage resources for CCS.
- Highlight nations that are prepared for the wide-scale deployment of CCS when considering only the technical components of the geological storage of CO₂ (geology, subsurface knowledge, research and operator experience as examples) while excluding non-technical issues such as regulations or policy.
- Document a nation's storage resource development in a systematic and easily-replicated method.
- Track and compare the progress of storage resource development, as well as identify enablers and barriers for individual nations.

The CCS-SI is further complemented by the Institute's three broader indicators which consider inherent CCS interest, law and regulation and policy. These indicators track the progress of CCS deployment and collectively form the CCS Readiness Index (CCS-RI). The Index was developed to consolidate a range of specific datasets and enables a holistic assessment of a country's CCS activity and progress worldwide.

2.0 DETAILED REGIONAL REVIEW

The 2018 CCS-SI Indicator is a measure of the ability of a nation's geological storage resources to support wide-scale CCS deployment. The Indicator also groups nations using a qualitative evaluation. Using the Institute's expertise, and a country's total score, the Indicator places nations into broad bands; 'Band A', ready for wide-scale deployment, through to 'Band E', limited storage development to date (Figure 3) (see methodology for Band definitions).

Figure 3: CCS Storage Indicator country ranking



2.1 Global review

Canada, Norway and the United States have a Band A rank, demonstrating they are the only countries with sufficiently developed geological storage resources to support the wide-scale deployment of CCS. All three have extensive operator experience in the deployment and storage of CO₂, both at commercial CCS facilities and smaller storage projects. Band A nations have a comprehensive understanding of their storage resource potential through mature storage assessments — completing site-specific studies across many of their storage basins. These nations continue to set the standard for storage assessments and storage project operation.

There are nine Band B countries including:

- Australia
- Brazil
- China
- Germany
- Japan
- Netherlands
- Saudi Arabia
- United Arab Emirates
- United Kingdom

Band B countries exceed most criteria, however typically fall short in criteria focused on operating a commercial-scale CCS facility. The exceptions are Brazil, China, Saudi Arabia and the United Arab Emirates. These four nations have not completed detailed domestic storage assessments with lower scores in those criteria, but have completed assessments of specific sites. Band B nations all have sufficient, extensive storage resources currently being developed.

Collectively, Band A and B nations have vast, multi-billion tonne storage potential. In most nations, an extensive oil and gas industry is indicative of suitable geology for storage: permeable reservoirs and overlying caprocks.

The most significant increase has been the number of countries within Band C. In 2018, there are 42 Band C countries compared to 31 in 2015. These countries typically do not have any experience in CO₂ storage deployment. Their moderate score is due to the continued drive to develop their national storage resources. To date, most of these nations have not completed comprehensive assessments or site-specific studies.

2.2 Europe, Middle East and Africa (EMEA)

EUROPE, UNITED KINGDOM AND SCANDINAVIA

Europe continues to drive storage development in the EMEA region and overall, the European Member States are the most improved. The 2015 European-wide assessment (CO₂Stop) has been surpassed by the identification of individual storage formations across Europe. Many of the 27 participating nations are currently completing storage resource assessments of those formations.

The European assessment ensured a firm Band C ranking for most countries. Advancing to higher scores will only happen through:

- CO₂ storage deployment, at pilot or larger scale
- Creating a series of well-defined storage sites with robust resource estimates.

Norway is the highest rank at Band A. This nation is actively assessing their substantial storage resources within a portfolio of storage sites. Norway has two operating CCS Facilities, Snøhvit and Sleipner, with another in the advanced planning phase.

The United Kingdom has also developed a portfolio of storage sites. Within the portfolio is over 70 billion tonnes of CO₂ storage resources. However, the United Kingdom is yet to deploy a CO₂ storage project at any scale, resulting in its Band B rank.

Norway and the United Kingdom have vast storage potential, as evidenced by their mature oil and gas industries. In addition, both countries demonstrate a comprehensive understanding of this storage potential.

Other Band B nations include Germany and the Netherlands. Both nations have experience in deployment, in the Ketzin (Germany) and K-12B (Netherlands), however, they lack a comprehensive appraisal of sites.

AFRICA

The overall score of African nations is improving. New assessments, and a refinement of existing assessments, add to their scores. Algeria aside, a major factor in African CO₂ storage development is a lack of knowledge of its storage potential, with limited oil and gas exploration and production.

Angola, Morocco, and Mozambique have been added to the African region's evaluation in 2018. The highest ranked Band C African nations are (in order):

1. Algeria
2. South Africa
3. Morocco
4. Mozambique

The rest of the countries in this region have lower scores with the majority falling into Band D and E. On deployment, there are plans for a pilot project in South Africa. Also, learnings from the In-Salah CCS facility in Algeria continue to be distributed throughout the international CCS community.

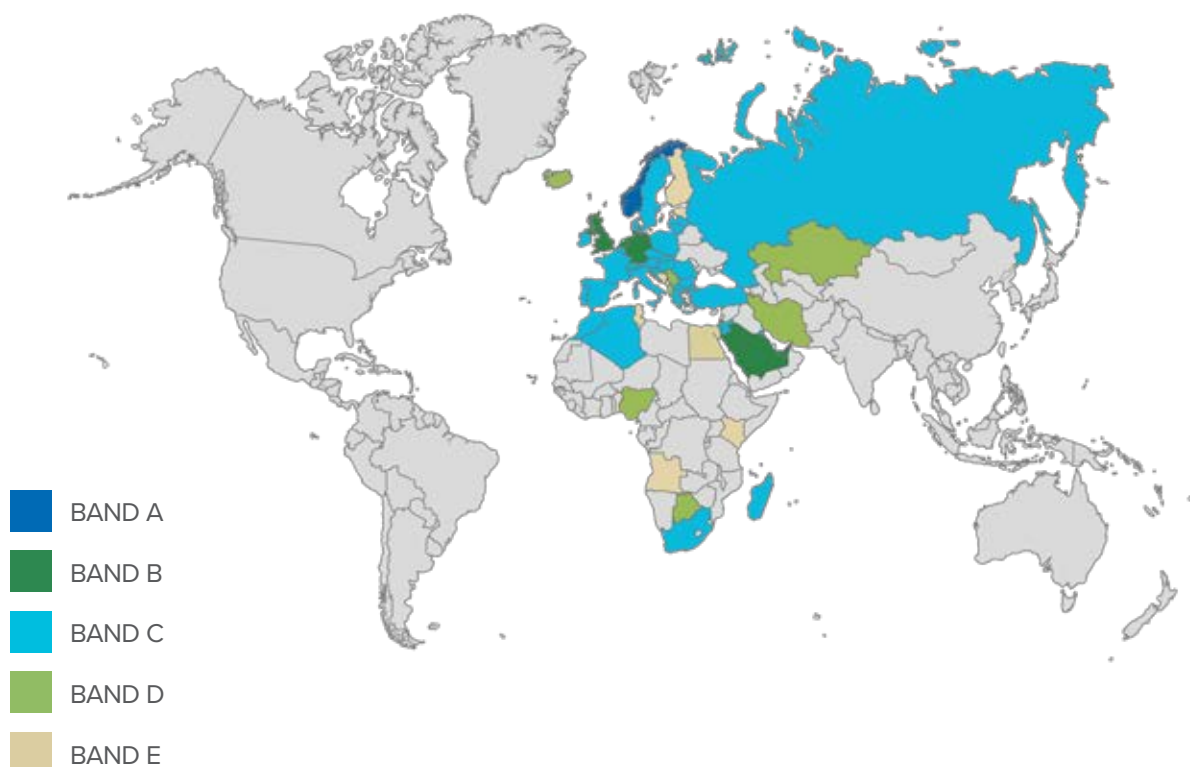
MIDDLE EAST

In the Middle East, Saudi Arabia and the United Arab Emirates receive a Band B ranking. Even though these nations have not published local storage assessments, their high rank is due to:

- Operational storage projects (at all scales) including the Abu Dhabi CCS and Uthmaniyah CCS facilities
- Their vast storage potential (according to multi-national storage assessments completed for both nations).

Finally, three countries in the Middle East have recently published their first storage resource assessments and have been added to the storage indicator. These countries are Iran, Israel and Kuwait.

Figure 4: EMEA CCS Storage Indicator country ranking



2.3 Americas

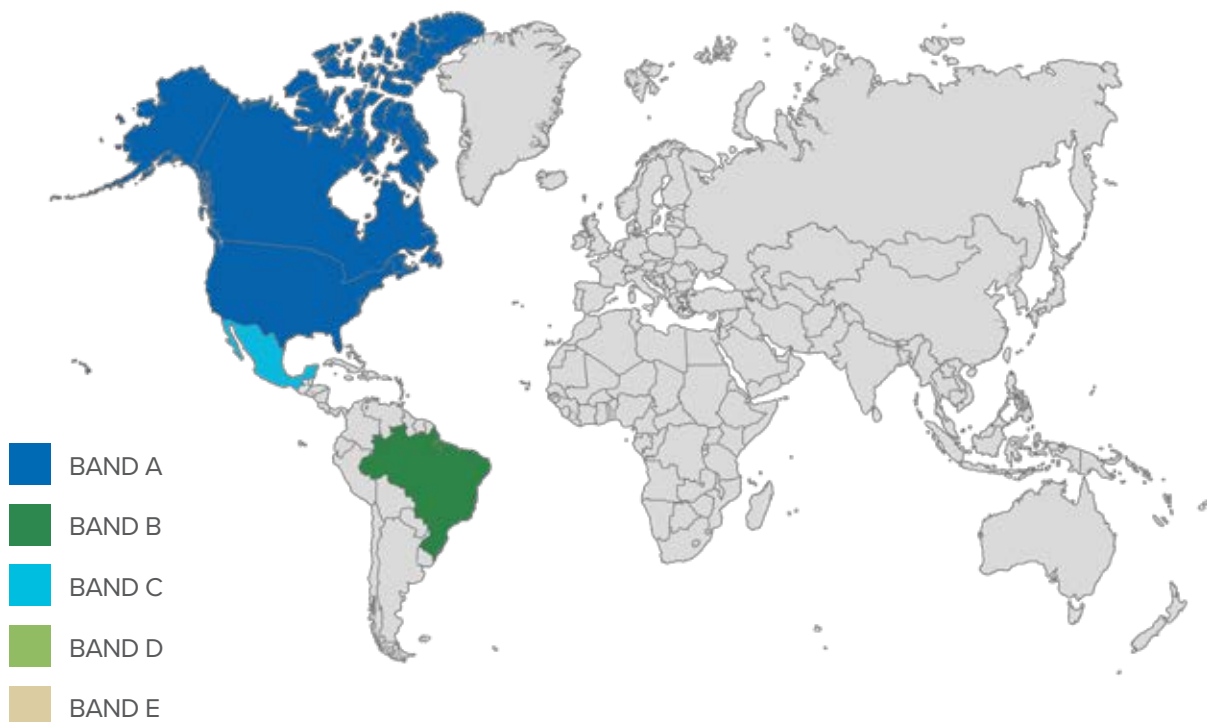
There are no additional countries for the Americas region in the 2018 assessment. The United States and Canada maintain a Band A rank, continuing their CCS leadership role. Both nations have progressed their storage assessments, and are exploring new basins. In the United States, for example, groups are now assessing offshore storage potential.

Continued deployment of research, site appraisal, and CCS facilities embody progress in the United States and Canada. In 2003, the United States Department of Energy established the National Technology Energy Laboratories Regional Carbon Sequestration Partnerships. These industry, government, and research partnerships are a pioneering model for the development of storage sites. The Partnership's first phase was site characterisation. The programme has now progressed to multiple storage sites.

Several storage projects exceeding one million tonnes have been born out of the initiative including the world's first bio-energy CCS project, Illinois Industrial Carbon Capture and Storage.

Elsewhere in the Americas, Brazil has not advanced on existing studies, but continues to operate the Petrobras Santos Basin Pre-Salt Oil Field CCS Facility. Mexico has also not progressed their storage characterisation. The 2018 CCS-SI review found that Mexico and Brazil's national assessments were less detailed than initially assessed. Subsequently, these countries' overall score has decreased. Both nations maintain their rank: Band C for Mexico and Band B for Brazil. Both nations need to further develop their storage resources through to site selection.

Figure 5: Americas CCS Storage Indicator country ranking



2.4 Asia-Pacific

China has improved its score and maintains its high ranking (Band B), through:

- Refining national and basin assessments to proceed to identify individual sites for injection
- Developing storage sites through modelling and techno-economic assessments
- Jilin CCS facility moving into operation
- Construction of one full chain CCS facility (Yanchang Integrated CCS)
- Significant experience in storage operations, especially around CO₂EOR with well over 25 projects.

Japan moved up to Band B with:

- The Tomakomai Project moving to operational status
- The Mikawa Post Combustion Capture Demonstration Plant under construction
- Ongoing development of its storage resources through continuing the exploration and appraisal of offshore storage sites.

Australia maintains its Band B rank. The development of Australia's storage resources has stalled when compared to other countries such as China, Europe and USA. Also, no new projects have been announced or entered construction/operation since the last assessment. Australia should refine early basin-scale assessments and appraise storage sites across the nation, with emphasis on strategic, high-emission centres.

All ASEAN nations are now analysed. The addition

of Brunei, Cambodia, Laos, Myanmar and Singapore join other ASEAN nations from the 2015 evaluation: Indonesia, Malaysia, Philippines, Thailand and Vietnam. Firstly, the 2015 ASEAN nation's scores have improved overall when compared to previous results.

Also, each nation (with the exception on Singapore) has completed domestic assessments, with each nation identifying large (multi-billion tonne) storage potential. Their completed assessments, although variable in detail and largely broad evaluations, still indicate vast resources when compared to their national emissions.

Singapore has not identified any storage potential within its national borders, and is unlikely to do so. Singapore is ranked as having no storage potential in the 2018 assessment.

Finally, focusing on CO₂ storage projects, Indonesia is in the advanced planning phase of a pilot project. Malaysia is also actively identifying offshore CCS opportunities.

Figure 6: Asia-Pacific CCS Storage Indicator country ranking



3.0 INHERENT CCS INTEREST 2018

The regional observations of the 2018 Storage Indicator results are reinforced when considering the 2018 results of the Inherent CCS Indicator (CCS-CI). The CCS-CI uses a range of data on fossil fuel production and demand to determine a relative measure of a nation's economic dependence upon fossil fuels. The reliance of fossil fuels is calculated by analysing the coal, oil and gas consumption and production within a country, or as an export.

The positive correlation between the two indicators has promising results (Figure 2). High scoring nations in the CCS-CI are actively developing their storage resources yielding high CCS-SI scores. The high scoring nations are therefore actively addressing their reliance on fossil fuels through CCS.

This positive correlation between the Indicators means that the largest CO₂ emitting countries also have mature or maturing storage resources. For example, the United States and Canada's readiness for deployment is matched by their high dependency on CCS to decarbonise. Both nations score very high in the CCS-CI (USA scoring maximum of 100), and their high CCS-SI scores also indicate their early recognition of CCS to reduce emissions. Adding Australia, Brazil, China, and Japan (top high emitting nations), countries responsible for the majority of the world's emissions have storage resources to enable the wide-scale deployment of CCS.

The CCS-CI also identifies nations that are high scoring (and dependent on CCS to decarbonise) but have not developed their storage resources. These nations with contrasting low CCS-SI scores, but high CCS-CI scores include India, Indonesia, Germany and Russia.

Russia has the maximum CCS-CI of 100. The maximum score is due to their high share of coal, oil and gas consumption and production. Russia has only completed limited and specific storage assessments (oil and gas fields, CO₂ enhanced recovery) and small CO₂ pilots (for enhanced oil recovery). Those assessments have identified significant storage potential (10's gigatonnes) across Russia. Therefore, there is a clear opportunity to expand those initial assessments. The assessments need to be comprehensive and nation-wide.

Germany, despite their Band B ranking, has stalled their storage resource development. German's high CCS-CI score reflects a high reliance on CCS to decarbonise, especially with regards to industrial emissions. The European nation has completed several national and basin-scale assessments over the past decade, which have now stalled at the national level. Germany now needs to restart the development and appraisal of storage sites in their prospective basins. The first major initiative should be a demonstration storage project.

For India and Indonesia, the paths to mature storage resources are different. Each nation does need to complete comprehensive national assessments to identify prospective storage sites. For Indonesia, comprehensive storage assessments on two basins identified significant storage potential (gigatonnes). Hence, more basins need to be reviewed in across Indonesia. The storage potential in India is poorly defined with only a very broad assessment completed. A comprehensive national study on Indian storage basins is needed.

4.0 METHODOLOGY

The Institute sought to standardise a method to critically analyse and evaluate storage resource development around the world through the CCS-SI. The first edition was published by the Institute in 2015. The 2018 CCS-SI now reviews 80 countries and seeks to:

- Determine global progress in the development and maturation of storage resources for CCS
- Highlight nations that are prepared for the wide-scale deployment of CCS:
 - Considering only technical components CO₂ storage
 - Excluding non-technical experiences such as regulations or policy.
- Document a nation's storage resource development in a systematic and easily-replicated method
- Track and compare the progress, identifying enablers and barriers for individual nations.

The methodology retains the criteria-based system and allocates individual countries' quantitative scores based on their individual storage resource development. Four overarching primary criteria provide the basis for the CCS-SI assessment (Table 1). A series of sub-criteria sit beneath these overarching primary criteria.

Table 1: CCS-SI assessment

| | |
|---|--|
| 1 | CO ₂ storage potential of a nation within its national borders. |
| 2 | The extent of CO ₂ storage resource development towards identifying storage capacity within suitable sites for CCS. |
| 3 | The number of storage (including monitoring) operations and experience within the country. |
| 4 | Proactive development of storage resources by national bodies (including academia) including working with the broader international CCS community. |

Each nation is assessed against these criteria using the following steps:

1. First screening criterion is if a country has significant storage potential.
2. Each country is assessed against each criterion from A to E; high to low.
3. Graded criteria are converted to a numerical score and weighting applied. The weighting is based on the criteria's importance, as determined by the authors, in consultation with the broader storage community.
4. A qualitative evaluation of the final score is the final step. Each nation is grouped across five categories from Band A through to Band E, highest to lowest respectively.

The five broadly-defined bands have been used to categorise the storage resource development, or “storage readiness” for individual countries with the following definitions:

- **BAND A:** highest scoring nations considered ready for the wide-scale deployment of storage projects. These nations have:
 - sufficient storage resource potential to meet emission reduction goals for CCS in that country
 - mature storage resources with a portfolio of contingent storage resources individual sites
 - extensive experience in pilot and large-scale injection projects directly for CCS Facilities.
- **BAND B:** Well-advanced countries which offer the potential for wide-scale CCS deployment. These nations have:
 - mature storage resources, but contingent resources are often limited to key basins, or not at all reached
 - experience in storage operations specifically for CCS deployment; in places, demonstration or have large-scale CCS facilities are active.

- **BAND C:** Countries with limited readiness for the wide-scale deployment of CCS. Most of the storage potential are considered only prospective resources. Storage project experience is typically limited to smaller-scale operations or associated with CO₂Enhanced Oil Recovery (CO₂EOR).
- **BAND D:** Storage resources within these countries are mostly uncharacterised, albeit only as a broad assessment of prospective basins. Very isolated experience in storage operations, typically part of CO₂EOR operations.
- **BAND E:** No storage characterisation in these nations, and countries have a limited understanding of storage potential.




A shift from descriptive rankings of 2015 (highest to lowest) to Bands “A to E” is the only change from the 2015 CCS-SI methodology. The use of Bands unites the rank categorisation of countries across the four indicators and the CCS readiness index.

SUPPORTING INDICATORS










The CCS-SI is complemented by the Institute’s three other indicators which consider inherent CCS interest, law and regulation and policy. These indicators track the progress of CCS deployment and collectively form the CCS Readiness Index (CCS-RI). The Index was developed to consolidate the indicators and enables a holistic evaluation of a country’s CCS activity and progress worldwide.

5.0 APPENDICES



















BAND A

| COUNTRY In alphabetical order | TOTAL SCORE Out of a possible 100 | MOVEMENT From 2015 assessment score |
|--|--------------------------------------|--|
|  Canada | 98 | - |
|  Norway | 96 | - |
|  USA | 96 | - |





















BAND B

| COUNTRY In alphabetical order | TOTAL SCORE Out of a possible 100 | MOVEMENT From 2015 assessment score |
|--|--------------------------------------|--|
|  Australia | 86 | - |
|  Brazil | 86 | ▼ |
|  China | 87 | ▲ |
|  Germany | 72 | - |
|  Japan | 71 | ▲ |
|  Netherlands | 73 | ▼ |
|  Saudi Arabia | 79 | ▲ |
|  United Arab Emirates | 81 | ▲ |
|  United Kingdom | 74 | ▲ |

BAND C

| COUNTRY In alphabetical order | TOTAL SCORE Out of a possible 100 | MOVEMENT From 2015 assessment score |
|--|--------------------------------------|--|
|  Algeria | 63 | ▲ |
|  Austria | 50 | ▲ |
|  Belgium | 42 | ▲ |
|  Bulgaria | 41 | ▲ |
|  Cambodia | 37 | New |
|  Croatia | 53 | ▲ |
|  Czech Republic | 48 | ▲ |
|  Denmark | 60 | ▲ |
|  France | 59 | ▼ |
|  Greece | 39 | ▲ |
|  Hungary | 58 | ▲ |
|  India | 36 | ▼ |
|  Indonesia | 52 | ▲ |
|  Ireland | 54 | ▲ |
|  Israel | 53 | New |
|  Italy | 51 | ▼ |
|  Jordan | 35 | ▲ |
|  Kuwait | 47 | New |

BAND C - CONTINUED

| COUNTRY In alphabetical order | TOTAL SCORE Out of a possible 100 | MOVEMENT From 2015 assessment score |
|--|--------------------------------------|--|
|  Latvia | 54 | ▲ |
|  Lithuania | 36 | ▲ |
|  Macedonia | 39 | ▲ |
|  Malaysia | 46 | ▲ |
|  Mexico | 54 | ▼ |
|  Morocco | 38 | ▲ |
|  Mozambique | 35 | New |
|  New Zealand | 33 | ▼ |
|  Philippines | 35 | ▲ |
|  Poland | 68 | ▲ |
|  Portugal | 40 | ▲ |
|  Romania | 56 | ▲ |
|  Russia | 48 | ▲ |
|  Slovakia | 39 | ▲ |
|  Slovenia | 39 | ▲ |
|  South Africa | 42 | ▼ |
|  South Korea | 45 | ▼ |
|  Spain | 59 | ▲ |
|  Sweden | 35 | ▼ |
|  Switzerland | 35 | ▲ |
|  Thailand | 39 | ▲ |
|  Turkey | 38 | ▼ |
|  Vietnam | 56 | ▲ |

BAND D

| COUNTRY In alphabetical order | TOTAL SCORE Out of a possible 100 | MOVEMENT From 2015 assessment score |
|--|--------------------------------------|--|
|  Albania | 18 | ▲ |
|  Bangladesh | 24 | New |
|  Botswana | 26 | ▲ |
|  Brunei | 24 | New |
|  Iceland | 19 | New |
|  Iran | 29 | New |
|  Kazakhstan | 29 | ▲ |
|  Laos | 18 | New |
|  Nigeria | 22 | New |
|  Pakistan | 24 | ▼ |
|  Serbia | 23 | ▲ |
|  Sri Lanka | 19 | New |
|  Trinidad/ Tobago | 26 | ▲ |

BAND E

| COUNTRY In alphabetical order | TOTAL SCORE Out of a possible 100 | MOVEMENT From 2015 assessment score |
|--|---|--|
|  Angola | 12 | ▲ |
|  Bosnia and Herzegovina | 13 | - |
|  Egypt | 11 | ▼ |
|  Kenya | 12 | - |
|  Myanmar | 13 | New |
|  Tunisia | 15 | - |
|  Andorra | No storage potential or highly unlikely | |
|  Estonia | No storage potential or highly unlikely | |
|  Finland | No storage potential or highly unlikely | |
|  Kosovo | No storage potential or highly unlikely | |
|  Luxembourg | No storage potential or highly unlikely | |
|  Singapore | No storage potential or highly unlikely | |

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