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# CCS Ready Policy: Considerations and Recommended Practices for Policymakers

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# Preface

The Global CCS Institute engaged ICF International and its partners: Aurecon; Bradshaw Geoscience Consultants (BGC); Energy Research Centre of Netherlands (ECN); Ian Murray & Company (IMC); Howard Herzog; and Bill Senior to develop a proposed internationally recognized definition of Carbon Dioxide Capture and Storage Ready (CCS Ready) and provide *Considerations and Recommended Practices* for policymakers to develop and implement CCS Ready policy and programs. In the process of developing the definitions and *Considerations and Recommended Practices*, ICF solicited worldwide peer input through a series of international roundtable discussions. A second document entitled *Defining CCS Ready: An Approach to An International Definition* provides the basis for the definition. The final version of these *Considerations and Recommended Practices* will feed into a workshop to be held by the Global CCS Institute and the Carbon Sequestration Leadership Forum (CSLF) in 2010.

# Acknowledgements and Citations

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# Executive Summary

The capture and geological storage of carbon dioxide ($CO_2$) can play a critical role in reducing greenhouse gas (GHG) emissions from power plants and other industrial facilities. $CO_2$ capture, transport, and storage (CCS) allows electricity producers and energy-intensive industries in a GHG-constrained future to continue to use proven and affordable carbon-intensive fuels that have long-established extraction and delivery infrastructure in place.

Despite its acknowledged benefits, CCS today faces significant technical, legal, regulatory, environmental, public acceptance, and economic barriers to its widespread deployment. Addressing these barriers will take time. Meanwhile, new fossil-fuel power plants and industrial facilities continue to be designed and built worldwide. Unless these new plants are designed from the start with an eventual CCS system in mind, efforts to retrofit them at a later date could incur significant costs and time delays.

The desire to avoid those high retrofit costs and facilitate a smooth transition to CCS has led to a policy concept known as CCS Ready, in which carbon-emissions-intensive plants are encouraged or required to prepare for CCS during their design and planning phases so they are ready to retrofit CCS at a later date. Under a CCS Ready policy, developers of new plants and existing plants undergoing significant modifications will make arrangements for future $CO_2$ capture retrofit and plan for $CO_2$ transport and storage.

CCS Ready policy can also avert the future risk of "stranded assets," in which plants may be closed before the end of their planned period of operation if they are uneconomic to retrofit to CCS. It could also avoid "carbon lock-in," a situation in which plants continue to emit large amounts of $CO_2$ if mitigation through CCS is technically and economically infeasible due to equipment and site constraints. However, building a CCS Ready plant involves potentially significant risks associated with uncertainties about future regulations, the future cost of carbon, long-term $CO_2$ ownership liability, and the still-evolving development of capture technology. Implementing a CCS Ready policy could also distract attention and resources from other short-term mitigation options.

## Definition of a CCS Ready Plant

A well-reasoned definition can be used as the foundation for policymakers to develop the requirements for a CCS Ready plant. In order to help policymakers, the *Considerations and Recommended Practices* described in the main body of this document propose such a definition, reflecting the concept that a CCS Ready plant needs to be Capture Ready, Transport Ready, and Storage Ready. All three phases are interrelated and required for successful deployment of CCS.

The proposed definition for CCS Ready (presented in the text box below) reflects the key principles that 1) capture, transport, and storage are best addressed holistically in order to increase the feasibility of a smooth transition to retrofitting CCS; 2) a degree of flexibility (in terms of stringency) is advisable to allow jurisdictions to adapt the definition according to their own regional-specific issues; 3) the initial cost of building a CCS Ready plant is most easily justified when offset by the future cost savings for a CCS retrofit; and 4) identifying and addressing early the potential barriers for a future retrofit to the extent possible is good practice.

Based on the definition, the *Considerations and Recommended Practices* also identify the different components of a CCS Ready plant (e.g., plant design, equipment pre-investment, storage site selection, conflicting uses and rights for storage site and transport corridor). For each of these components, specific requirements for a CCS Ready plant are indicated at three levels of stringency.

## CCS Ready Policy Design

CCS Ready policy is most appropriate when drivers to adopt CCS exist or are expected soon. A well-designed CCS Ready policy will include criteria for characterising CCS Ready plants, along with a clear delineation of roles and responsibilities for implementing the policy.

An effective CCS Ready policy will be linked to the goals and provisions of a jurisdiction's existing or anticipated GHG policy. It will also take into account jurisdictional issues, such as sources and volumes of GHG emissions and local economics of CCS. A jurisdiction can also base its CCS Ready policy on an economic rationale, ensuring a reasonable chance that the policy will reduce total long-run costs for complying with future limits on GHG emissions.

Governments could require CCS Ready plants by law or regulation, or could encourage it through incentives such as grants, loan guarantees, government services-in-kind, and other measures. Potential mechanisms for implementing CCS Ready policy include mandates for plants to become CCS Ready, emissions standards that tighten over time, economic incentives for readiness, and voluntary education and certification programs. Working cooperatively with industry and professional organizations to determine the appropriate mechanisms and criteria for demonstrating CCS Ready plants will facilitate industry acceptance of a CCS Ready policy.

## CCS Ready Policy Implementation

Successful implementation of a CCS Ready policy requires that policymakers establish clear roles and responsibilities for all relevant regulatory authorities, such as environmental agencies, technical and economic regulatory bodies, geological agencies, and land use and zoning commissions. Integrating CCS Ready regulations with existing approval processes will reduce the likelihood of large new administrative burdens.

Regulators can help accelerate the adoption of CCS Ready policy by providing clear guidance and information to project developers, such as details on locations and characteristics of suitable storage sites and planned $CO_2$ pipeline locations. Government support for developing regional-scale geological prospectivity studies (if they do not already exist) would assist project developers in assessing the feasibility of their plant becoming Storage Ready.

Reporting and recordkeeping requirements will allow regulators to stay informed regarding the CCS Ready status of a plant, and provide them the opportunity to intervene when data suggest that a plant is no longer in compliance with CCS Ready requirements. If exemptions are appropriate in a jurisdiction, drawing them narrowly will avoid undercutting the goals of a jurisdiction's CCS Ready policy.

Outreach programs, including professional training for industry and government, can be used to communicate the value of a CCS Ready policy, thus reducing potential barriers and resulting time delays.

In conclusion, the *Considerations and Recommended Practices* provide guidance to policymakers on deciding whether a CCS Ready Policy is desirable and, if so, selecting different levels of requirements for a Capture Ready plant, a Storage Ready plant, and a Transport Ready plant based on their jurisdiction's characteristics and requirements. They also provide detailed guidelines for policymakers in developing CCS Ready policy, and for regulators in implementing such a policy.

## Proposed International Definition of CCS Ready

### Capture Ready Plant

A $CO_2$ Capture Ready plant satisfies all or some of the following criteria:

1) Sited such that transport and storage of captured volumes are technically feasible;
2) Technically capable of being retrofitted for $CO_2$ capture using one or more reasonable choices of technology at an acceptable economic cost;
3) Adequate space allowance has been made for the future addition of $CO_2$ capture-related equipment, retrofit construction, and delivery to a $CO_2$ pipeline or other transportation system;
4) All required environmental, safety, and other approvals have been identified;
5) Public awareness and engagement activities related to potential future capture facilities have been performed;
6) Sources for equipment, materials, and services for future plant retrofit and capture operations have been identified; and
7) Capture Readiness is maintained or improved over time as documented in reports and records.

### Transport Ready Plant

A $CO_2$ Transport Ready plant satisfies all or some of the following criteria:

1) Potential transport methods are technically capable of transporting captured $CO_2$ from the source(s) to geologic storage ready site(s) at an acceptable economic cost;
2) Transport routes are feasible, rights of way can be obtained, and any conflicting surface and subsurface land uses have been identified and/or resolved;
3) All required environmental, safety, and other approvals for transport have been identified;
4) Public awareness and engagement activities related to potential future transportation have been performed;
5) Sources for equipment, materials, and services for future transport operations have been identified; and
6) Transport Readiness is maintained or improved over time as documented in reports and records.

### Storage Ready Plant

A $CO_2$ Storage Ready plant satisfies all or some of the following criteria:

1) One or more storage sites have been identified that are technically capable of, and commercially accessible for, geological storage of full volumes of captured $CO_2$, at an acceptable economic cost;
2) Adequate capacity, injectivity, and storage integrity have been shown to exist at the storage site(s);
3) Any conflicting surface and subsurface land uses at the storage site(s) have been identified and/or resolved;
4) All required environmental, safety, and other approvals have been identified;
5) Public awareness and engagement activities related to potential future storage have been performed;
6) Sources for equipment, materials, and services for future injection and storage operations have been identified; and
7) Storage Readiness is maintained or improved over time as documented in reports and records.

Note: "Economically acceptable" means that, during the operating life of the plant, a reasonable probability exists that the plant can be retrofitted and operated with CCS at a total cost comparable to the GHG mitigation costs borne by other plants in the jurisdiction. The plant's total cost for capture, transport, and storage would include costs for planning, construction capital, and operating costs, including the time value of money.

"Technically feasible" or "technically capable" means that technologies exist that can be applied to capture, transport and store a significant portion of the $CO_2$ emitted from the plant, while substantially preserving the original functionality of the plant.

# 1. CCS Ready Policy

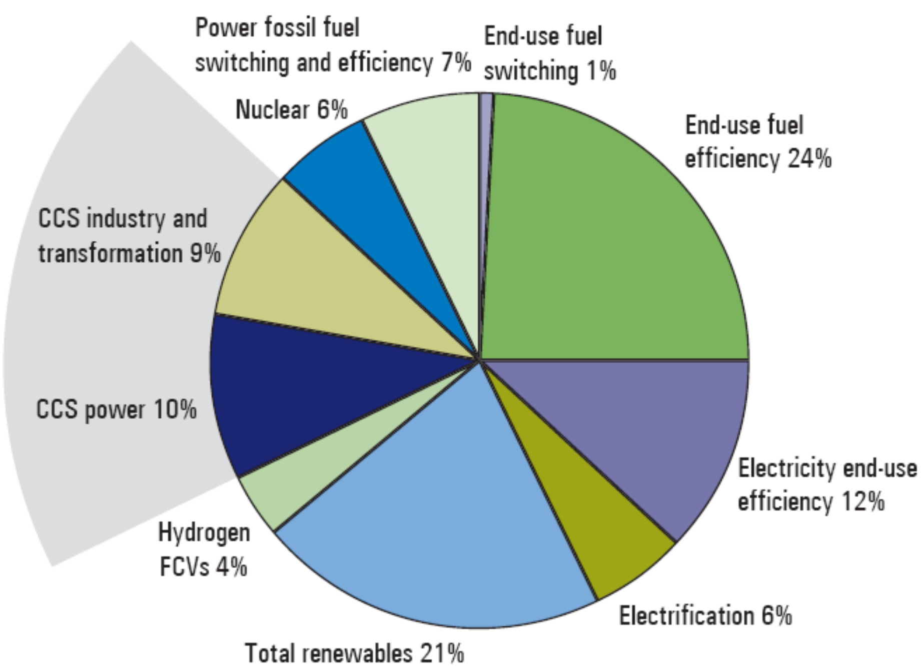
The aim of this report is to provide practical guidance to policymakers who are considering CCS Ready measures as part of their broader CCS development framework and GHG mitigation policy.

## What is CCS Ready?

CCS Ready is a collection of measures that can be undertaken by industry[1] in order to smoothly and efficiently transition to capturing, transporting, and storing $CO_2$ in the future, as barriers to CCS are progressively reduced. CCS is expected to be an important technology for reducing global GHG emissions. CCS Ready anticipates future CCS implementation, but usually does not lead to $CO_2$ emission reductions in the immediate term.

The International Energy Agency (IEA) calls for a 50% reduction in global GHG emissions by 2050,[2] with 19% of this reduction coming from CCS in the power, manufacturing industry, and fuel transformation sectors (see Exhibit 1-1). However, the deployment of CCS requires further demonstration at commercial scale to reduce technological and performance uncertainties; large investments given the high cost of deploying CCS; and time for design, permitting, construction, and start-up of CCS operations. As such, government

**Exhibit 1-1: Breakdown of Reductions for IEA BLUE Map 48 Gt $CO_2$ Reduction Scenario in 2050**




Source: IEA, 2008

[1] Some industry sectors are better placed to implement CCS, and in some instances are already implementing it; e.g., some unique sectors of the natural gas production industry.

[2] International Energy Agency (IEA). (2008). *Energy technology perspectives 2008: Scenarios and strategies to 2050.* Paris, France: Author.

and industry have been working together to resolve technical, legal, regulatory, and economic barriers to CCS. In the meantime, CCS Ready measures are being viewed as a way to plan for the future and provide potential cost savings, while CCS technology is being developed and more knowledge is gained on CCS cost and performance.

### Considerations for a CCS Ready Policy

The specific considerations for CCS Ready policy will vary across jurisdictions reflecting differences in, *inter alia*, the amount and type of GHG emissions, the amount and type of $CO_2$ sequestration opportunities, plans for and impacts on economic development, legislative processes, and ongoing and projected commitment to GHG emissions reductions from fossil fuels. The *Considerations and Recommended Practices* in this report can be used by policymakers to assess the applicability of CCS Ready in their jurisdiction, and design, develop, and implement a CCS Ready policy in consultation with industry and other stakeholders. Industry, in particular, will have to work with policymakers to deliver the expected outcomes of a CCS Ready policy and to analyse how such a policy will affect its operating environment. Outreach to other stakeholders to raise public awareness about the balance of benefits of a CCS Ready project in a community should help facilitate the success of such a project, both at the CCS Ready stage and at the CCS deployment stage.[3]

## 1.1 CCS Ready Definition

Governments, industry, and NGOs around the world have committed to an unprecedented global effort to demonstrate both individual elements of CCS and integrated CCS programs. In the coming years, this effort is expected to greatly reduce uncertainties about the potential role of CCS as a method for GHG mitigation.

During this period, in response to continued growth in global economic development and energy demands, new $CO_2$-emitting power plants and industrial facilities will be planned and built—possibly without making any provisions for potential future adoption of CCS. Thus, assuming CCS ultimately becomes a proven and applied $CO_2$ mitigation technique, the future choices for these facilities will include:

- Retrofit of capture technologies and connection to transport and storage systems;
- Closure, if $CO_2$ mitigation options are technically infeasible or too expensive; or
- Exemption from future CCS requirements with resulting carbon lock-in.

An alternative approach is to adopt upfront CCS Ready planning and plant design, and perhaps some incremental pre-investment, in order to reduce potential compliance costs and risks without fully committing to CCS before it has been widely commercially proven. But even when such a policy is chosen, the question remains: how much readiness is enough?

The definition of CCS Ready proposed in this report reflects the concept that a CCS Ready plant needs to be Capture Ready, Transport Ready, and Storage Ready, in recognition that all three components are interrelated and required and need to be integrated for successful deployment of CCS. The following definition of CCS Ready for a plant is proposed:

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[3] Further information on public outreach and coordination with industry can be referenced in US Department of Energy, National Energy Technology Laboratory (US DOE-NETL). (2009). *Public outreach and education for carbon storage projects.* (DOE/NETL-2009/1391).

### Capture Ready Plant

A $CO_2$ Capture Ready plant satisfies all or some of the following criteria:

1) Sited such that transport and storage of captured volumes are technically feasible;
2) Technically capable of being retrofitted for $CO_2$ capture using one or more choices of technology at an acceptable economic cost;
3) Adequate space allowance has been made for the future addition of $CO_2$ capture-related equipment, retrofit construction, and delivery to a $CO_2$ pipeline or other transportation system;
4) All required environmental, safety, and other approvals have been identified;
5) Public awareness and engagement activities related to potential future capture facilities have been performed;
6) Sources for equipment, materials, and services for future plant retrofit and capture operations have been identified; and
7) Capture Readiness is maintained or improved over time as documented in reports and records.

### Transport Ready Plant

A $CO_2$ Transport Ready plant satisfies all or some of the following criteria:

1) Potential transport methods are technically capable of transporting captured $CO_2$ from the source(s) to geologic storage ready site(s) at an acceptable economic cost;
2) Transport routes are feasible, rights of way can be obtained, and any conflicting surface and subsurface land uses have been identified and/or resolved;
3) All required environmental, safety, and other approvals for transport have been identified;
4) Public awareness and engagement activities related to potential future transportation have been performed;
5) Sources for equipment, materials, and services for future transport operations have been identified; and
6) Transport Readiness is maintained or improved over time, as documented in reports and records.

### Storage Ready Plant

A $CO_2$ Storage Ready plant satisfies all or some of the following criteria:

1) One or more storage sites have been identified that are technically capable of, and commercially accessible for, geological storage of the full volumes of the captured $CO_2$, at an acceptable economic cost;
2) Adequate capacity, injectivity, and storage integrity have been shown to exist at the storage site(s);

3) Any conflicting surface and subsurface uses at the storage site(s) have been identified and/or resolved;
4) All required environmental, safety, and other approvals have been identified;
5) Public awareness and engagement activities related to potential future storage have been performed;
6) Sources for equipment, materials, and services for future injection and storage operations have been identified; and
7) Storage Readiness is maintained or improved over time as documented in reports and records.

Further discussion of the approach behind and reasoning for the above definition is provided in the report entitled *Defining CCS Ready: An Approach to An International Definition.*

## 1.2 Economic Case for CCS Ready Policy

A jurisdiction will decide whether a CCS Ready policy is appropriate and, if so, where, when and how to apply the policy. A major part of the decision-making process is likely to involve investigation of the economics of CCS as a GHG mitigation measure, and how a CCS Ready policy would affect the adoption of CCS and the overall cost of GHG mitigation. The investigation into the economics may be done both from the perspective of a developer deciding how a plant should be built and operated and from the perspective of the jurisdiction as a whole, taking into account all social costs and benefits—including externalities.

The developer's perspective is relevant because the policy will have to influence the behaviour of plant developers. From the point of view of a plant developer, the economic case for a CCS Ready plant is that the higher upfront costs relative to building a business-as-usual (BAU) plant are offset by the present value of (a) lower adaptation costs for the plant to later add CCS to mitigate GHG emissions, or (b) lower risks that the plant will face premature closure if future $CO_2$ mitigation requirements are technically infeasible or too expensive. In other words, by investing early in making a plant CCS Ready, the developer could experience a lower-cost GHG compliance option that can be (but does not have to be) exercised some time during the plant's operating life.

The society-wide economic perspective is similarly concerned with the plant's economics, as well as its ability to supply electricity and other products to society with the smallest feasible use of resources. However, the society-wide perspective adds other considerations such as the improvement of human capital (education and skills formation), job creation, human health, and the reduction of environmental degradation. Also the society-wide perspective is often longer-term and values future benefits more highly (i.e., has a lower discount rate) than does the perspective of a developer.

Any CCS Ready policy anticipates that CCS will be implemented sometime in the foreseeable future due to general GHG technology mandates, emissions performance standards, economic penalties, or economic incentives. The potential for cost savings from building low-cost CCS Ready plants, as opposed to BAU plants, is an important basis for CCS Ready policy in a jurisdiction. The cost savings from CCS Ready are most favourable when GHG mitigation comes reasonably soon, so that discounting of future savings is not too large.

However, large uncertainties about GHG policy, future cost of fuels/carbon, and cost and performance characteristics of CCS technologies can reduce the perceived economic value of CCS Ready investments from a developer's perspective. In addition, the "private" discount rate for cost of capital used by plant developers may be higher than the "social" discount rate that policymakers might attribute to GHG mitigation initiatives. Hence, industry might continue on a BAU path for determining plant production economics that may not be optimal from a broader social-cost perspective—thus, justifying some form of government-sponsored CCS Ready policy.

Therefore, a CCS Ready policy is most likely to be justified when plant developers:

- Do not perceive economic value in making facilities CCS Ready, because they do not appreciate or they underestimate the likelihood of future requirements for GHG reductions;
- Lack knowledge about CCS and how it can be applied as a GHG mitigation technology for their facilities;
- See much greater technology risks for CCS than those seen by policymakers;
- Believe that future GHG allowance prices will be too low to ever make CCS economic for projects being designed now;
- Hold the misperception that potential storage sites are geographically ubiquitous and simple to identify, rather than being unevenly distributed with complex characterisation processes like all other subsurface resources; or
- Do not adequately investigate the availability and feasibility of transport and storage options for the plant.

The specific form that a CCS Ready policy takes in any jurisdiction depends on which of these conditions hold. Outreach and education programs will help in informing developers about the schedule of upcoming GHG regulations and the applicability of CCS technologies to different types of facilities.

## 1.3 Mechanisms for CCS Ready Policy

Existing or possible future GHG mitigation policy and regulatory frameworks will shape any CCS Ready policy. In particular, the specific approaches in a jurisdiction for the development and deployment of CCS will affect the mechanisms by which a CCS Ready policy is implemented. There are three primary approaches for deploying CCS in a jurisdiction: a) a mandate for CCS, b) emission standards, and c) creation of economic incentives (e.g., tax or emissions trading scheme). A CCS Ready policy likewise could rely on mandates, standards, and incentives.

### Mandates

A mandate for CCS Ready could require new and/or modified plants to be CCS Ready as a condition for approving their construction. For example, the European Commission's Directive 2009/31/EC on geological storage of $CO_2$ requires that all new fossil-fired power plants of a specified size "have suitable space on the installation site for the equipment necessary to capture and compress $CO_2$ if suitable storage sites are available, and if $CO_2$ transport and retrofitting for $CO_2$ capture are technically and economically feasible."[4]

Mandates send clear signals to industry and guarantee implementation by a certain date, without involving government expenditure or revenue losses for economic incentives. However, a poorly designed mandate could result in increased cost of compliance and economic inefficiencies. Furthermore, imposition of a mandate, without development of the appropriate processes, policy, and mechanisms required to become CCS Ready, could lead to delays in decisions to invest in new infrastructure. Delays may come about if there is a high level of uncertainty due to unstable policy or financial environment, or lack of access to adequate technology or subsurface land tenure. In any case, the requirement to implement CCS Ready at each individual plant will increase costs to consumers; hence there is a political benefit in having minimal CCS Ready requirements.

## Emission Standards

Strict emission standards that limit $CO_2$ releases from major power plants and other industrial facilities can stimulate the uptake of CCS and make CCS Ready measures more desirable in a jurisdiction. For example, in the US state of California, new power plants are subject to a limit of 500 kg of $CO_2$ per MWh, which is roughly equivalent to emissions from an efficient gas-fired power plant.[5] This, in and of itself, would stimulate the uptake of CCS at new power plants that wish to use fuels that are more carbon intensive than natural gas. If such a standard were to become more stringent over time, the need to mitigate GHGs would increase. This would allow for project developers today to start becoming ready for a future with lower emissions. However, like mandates, emission standards can result in economic inefficiencies and higher compliance costs by limiting mitigation options and forcing CCS onto plants where it is very expensive.

## Economic Incentives

The adoption of CCS and CCS Ready can also be promoted indirectly through taxes on GHG emissions or an emissions cap-and-trade scheme, both of which put a price on $CO_2$ emissions (whether economy-wide or only on the supply side). As the cost of emissions increases over time, the incentives to decrease $CO_2$ emissions through CCS and other mitigation options increase. In other words, emitters will be aware of the point at which investing in abatement technologies provides savings over the cost of paying to emit, and will act accordingly under rational circumstances. Such an approach will also indirectly incentivise CCS Ready, as developers perceive economic value in building plants capable of retrofitting for CCS implementation in the future. The economic incentives will allow industry to make decisions on mitigation options based on the marginal control cost of each plant, and are thus economically efficient. However, imposing taxes is generally difficult politically, as consumers will directly perceive the higher costs. While emission trading provides industry with maximum economic and technology flexibility, it may lead to a shift toward low-carbon fuels with localized economic dislocations in the coal and related

[4] Paragraph 47, page L140/119 of European Parliament and the Council of the European Union. (2009). Directive 2009/31/EC of the European Parliament and of the Council of the European Union. *Official Journal of the European Union, 140*.

[5] Note that the California standard already requires 50% of emissions from coal fired power plants to be capture and stored. See: California Energy Commission (CEC). (2009). *SB 1368 emission performance standards.*

industries. Furthermore, if the price of an emission unit fails to equal the cost of abatement, the policy target of reducing GHG emissions may be missed.

CCS Ready policy can also be designed to make CCS Ready more attractive to industry by reducing costs or increasing economic benefits through initiatives such as monetary grants for CCS Ready facilities. A variant is to offer services-in-kind, through activities such as research into potential storage sites. A government loan guarantee, contingent on adopting CCS Ready, can also benefit proponents by reducing financing costs. Other common mechanisms for reducing costs include reduced taxes and tax postponements (e.g., accelerated depreciation). Such cost reduction options are particularly useful if CCS Ready is mandated (either through an explicit mandate or implicitly through emission standards).

Offering an explicit "credit" to developers incorporating CCS Ready within a cap-and-trade system may also be effective.[6] The "credit" may take the form of (1) a grant of tradeable emission allowances, or (2) somewhat relaxed emission standards for CCS Ready plants. For example, Environment Canada has described a regulatory framework in which certain sectors could postpone compliance with an emissions target based on a cleaner fuel standard if new plants in those sectors are built carbon-capture ready.[7] Such a linkage between CCS Ready and emissions limits allows the facility developer to weigh the additional costs of CCS Ready against the financial benefits of a less stringent emissions cap. The main disadvantage of relaxing emission limits as an incentive for CCS Ready is that they will increase near-term emissions and could promote policy scepticism from environmental groups. An economic analysis may be useful in order to determine how much increased emissions, if any, could be allowed in exchange for uptake of CCS Ready.

### Illustrative Examples of Other Mechanisms

CCS Ready Certification Programs. Policymakers can explore various ways of recognizing and rewarding plants that become CCS Ready. One possibility is award of a nationally recognized CCS Ready certificate, subject to periodic renewal. Such a certificate may be issued by regulators or accredited third party agencies. As CCS Ready becomes internationally recognized, exports of, for example, steel produced by certified CCS Ready mills could be marketed as "produced by a CCS-Ready plant."

Incorporation of CCS Ready in International Agreements and Treaties. CCS Ready may be included into international environmental and trade agreements and treaties. For example, CCS Ready could be included for support from the Clean Technology Fund of the World Bank, or from the upcoming Climate Fund that was discussed at the 15th Conference of Parties meeting at Copenhagen. Preferred support for trading of products from CCS Ready plants could also be an option, as long as it is consistent with World Trade Organization rules. The recognition of CCS Ready in such documents may lead to national benefits in relation to GHG commitments and credits, as well as in environmental aspects of import/export agreements.

International Requirements for Funding New Projects. International aid and financial institutions involved in financing new industrial projects periodically issue and update environmental requirements for eligible projects. The international recognition of CCS Ready may result in such institutions making CCS Ready a requirement, or future CCS implementation an objective for finance/lending. For developing countries, this prospect provides another potential reason for implementing CCS Ready policy and programs.

[6] For example, the EU has set aside 300 million allowances under the European Union Emissions Trading Scheme to help co-fund CCS demonstration plants and renewable energy projects. See: Directive 2003/87/EC of the European Parliament and of the Council of the European Union. *Official Journal of the European Union, 87*.

[7] Environment Canada. (2008). *Turning the corner: Regulatory framework for industrial greenhouse gas emissions*. (Publication no. En84-60/2008). Ottawa, Ontario, Canada: Author.

## 1.4 Applicability of CCS Ready Policy

A wide range of industrial production and CCS related infrastructure could become subject to CCS Ready requirements, and hence it is important for a CCS Ready policy to delineate the types of plants to which it applies. CCS Ready will likely be applied first to industries, plant types, and facility sizes with the most favourable retrofit economics. This would most likely include situations where CCS Ready measures can be deployed when planning new facilities, as well as when planning major changes to existing facilities. A CCS Ready policy would not likely apply to existing plants that are not undergoing major changes, as plant siting and space allocation decisions have already been made and cannot be undone. Any investment to make an existing plant CCS Ready would likely have the same cost if performed now or in the future, if and when the plant retrofits to CCS. Any CCS-related expenses incurred to make an existing plant CCS Ready would have to bear the time value of money (i.e., interest expenses) and would not be sufficiently offset by future savings stemming from better plant siting and design.

Technical feasibility, cost, and likelihood of eventual adoption of CCS are some of the key criteria to consider for defining the applicability of CCS Ready policy to new and significantly modified plants. Other considerations include:

- Type of production plants to include. New fossil fuel power plants typically have been considered prime candidates for CCS Ready, due to the large number of new plants likely to be constructed in the near future and the potential for large emissions reductions, particularly from coal-fired plants. New industrial facilities, especially those with high-purity $CO_2$ process gas streams and gasification/conversion processes, are also good candidates for CCS Ready.
- Whether to include existing plants undergoing significant modifications. The advantage of including plants undergoing significant modifications is that such modifications typically are supported by extended operating lives, and the additional burden of CCS Ready measures may be relatively inconsequential to the overall planned modification. As well, the number of CCS Ready plants will increase, thereby increasing the potential mitigation of future $CO_2$ emissions. However, in addressing existing plants, a consistent and enforceable definition of “significant modification” is needed.[8]
- Whether to include power or industrial capacity or product output. Generally, it is likely to be less cost-effective and economically attractive for small units to retrofit CCS than for large units, and threshold specifications may be required. The types of covered plants can be based on product capacity or output (e.g., MW, kWh, or metric tons of product per year). For example, the UK guidance note on Carbon Capture Readiness (CCR) applies to proposed power stations above 300 MW.[9]

[8] A jurisdiction may define significant modification in terms of changes to the plant’s product output capacity (e.g., modifications that increase a power plant’s production capacity by 20% or more), in terms of emissions (e.g., modifications that increase peak hour emissions of $CO_2$ by 20% of more) or by capital cost (e.g., modifications that cost 20% or more of the cost of a new plant of similar size and type). The threshold level (e.g., 20%) may need to be consistent with existing environmental or other regulations if the term “significant modification” is already used for other regulatory purposes. Also, the definition may need to take into account the cumulative impact of small changes (e.g., “A significant modification is a single modification or a series of modification conducted over 24 months which in aggregate increase peak hour emissions of $CO_2$ by 20% of more.”).

[9] Page 4 of U.K. Department of Energy and Climate Change (U.K. DECC). (2009). *Carbon capture readiness (CCR): A guidance note for Section 36 Electricity Act 1989 consent applications* (Publication no. URN 09D/810). London, UK: Author.

- Whether to include plants based on fuels or feedstocks. Although there is great interest in deploying CCS Ready for coal-based power plants, other power plants using different kinds of fuels (e.g., natural gas, petroleum coke, biomass, and mixtures of various fuels) and other industrial facilities could potentially be retrofit with CCS in the future and thus may be candidates for CCS Ready now or in the future.

## 1.5 Responsibility for Demonstrating Readiness

A successful implementation of CCS Ready policy requires the identification of an entity or entities that will be responsible for fulfilling CCS Ready obligations. For example, the EC Directive 2009/31/EC on geological storage of $CO_2$ places the responsibility on plant developers to make the required assessments.[10] These entities could also involve the participation of government, as CCS Ready activities would link with broader CCS policy. For example, governments may participate in the longer-term direction and planning of $CO_2$ storage sites and transportation networks, as well as their integration with industrial infrastructure. Governments may also wish to consider potentially financing and, possibly, taking an equity position in the development of larger $CO_2$ pipeline networks, in order to help alleviate early-phase development hurdles when pipeline utilization rates are low and uncertain. After the pipeline revenues increase and stabilize, the government equity position can be sold to private investors.

Regardless of how responsibility is allocated, there will remain a need to coordinate capture, transport, and storage readiness for eventual retrofit. This means, for example, that the timing, location, volumes, and chemical characteristics of the captured $CO_2$ must be compatible with the corresponding attributes of transportation systems and storage sites. If a jurisdiction puts the primary responsibility on a plant developer for demonstrating this integration as part of showing CCS Readiness, the regulatory body that receives the CCS Ready filing and determines its adequacy will be responsible for judging whether such integration has been properly demonstrated.

## 1.6 Gaps and Obstacles in Laws

The successful implementation of CCS requires the establishment of a legal and regulatory framework for all aspects of CCS, including capture, transportation, and storage. While CCS Ready activities need not wait for every element of CCS-related legal and regulatory structure to be in place, a comprehensive legal and regulatory framework for CCS activities will facilitate CCS Ready activities and reduce uncertainty in cost estimates for industry. For example, resolution of legal liability for $CO_2$ transportation and storage may help define suitable storage sites and transportation corridors, and will affect the CCS Ready and CCS retrofit cost estimates made by project developers. Given that CCS related legal and regulatory issues are complex and will take time to sort out, it may be very desirable that their resolution be simultaneously and vigorously pursued along with any CCS Ready policy.

## 1.7 Cost and Timeline of CCS Ready Policy

CCS Ready policy will impose costs on developers, and if poorly designed could delay the development of infrastructure. It is therefore important that a thorough assessment of

[10] Article 33 of European Parliament and the Council of the European Union. (2009). Directive 2009/31/EC of the European Parliament and of the Council of the European Union. *Official Journal of the European Union, 140*.

cost and timing implications of a proposed CCS Ready policy be conducted as part of policy development for any jurisdiction. Obtaining inputs from industry stakeholders in each jurisdiction is also important for assessing the level of investment that they are willing to make and costs that they are willing to bear. In addition, any future economic benefit from a CCS Ready policy needs to be balanced against industry's need to reduce costs in a shorter timeframe.

At a minimum, the costs of CCS Ready to, for example, a power plant developer are embedded in preparing additional documentation and reports, purchasing additional land for installing capture facilities, making design changes to the plant to accommodate future capture, and assessing storage sites and transportation routes. The costs and timeframe for getting the same plant to only Capture Ready status depend primarily on the level of pre-investment that a developer is willing to make (or is asked to make by regulators). For example, a 600 MW supercritical PC power plant expecting to use an amine-based post-combustion capture system could incur an additional cost of about 0.5% relative to the overall plant cost for the purchase of land and an incremental design, whereas the comparable cost increase of a more substantive initial oversizing of the boiler and associated components would be roughly 30%. Similarly, depending on the extent of pre-investment and design changes, a project developer would need an additional 0.5 to 1 work-year to become Capture Ready. This additional labour cost would, for example, amount to US$150,000-$300,000 in the United States.

The costs of Transport Ready requirements generally result from identifying, researching, and documenting potential transportation routes, and from assessing these routes for potential land use conflicts. The cost of these efforts is expected to be similar to or lower than Capture Ready costs. However, costs of Storage Ready requirements could be higher, depending largely on the amount of exploration that may be needed to identify and screen potential storage sites. The cost and time required depend on the availability of existing geological data in various jurisdictions and the types of storage option available. Due to available geologic data from petroleum exploration and production activities, these costs are expected to be much lower for storage options in oil and gas fields (including enhanced oil recovery) than for saline aquifer formation storage.

Based on experiences in Australia, the textbox below illustrates the expected work years, cost, and duration of performing geological assessments at different levels for saline aquifer storage options. For each stage, more detailed data are assembled and comprehensive studies performed. Each successive level will advance the knowledge and reduce the uncertainty regarding the technical viability of geological storage for a region or site. However, these assessments could take years, thereby delaying the time by which plants could become CCS Ready. Consequently, developing a plan and timeline for the necessary assessments to support CCS Ready is beneficial for formulating the requirements outlined in Chapter 2.

### Levels and Parameters for Storage Ready Activities, Based on Australian Saline Aquifer Experience

| | Country | Province (State) | Basin | Site (Initial) | Site (Exploration/ FEED) |
|---|---|---|---|---|---|
| Work Years[a] | 6 | 8 | 2 | 4 | 100s |
| Cost (AUD) | $1 Mill | $2 Mill | $1 Mill | $0.75 Mill | $50 - $100 Mill |
| Duration (yrs) | 2 | 1 | 0.5 | 1 | 5 |

[a] Work Years is the total number of years of work required for all staff to complete the assessment.
Source: Bradshaw Geoscience Consultants

The assessment work at the country level benefits from regional assessments previously completed for petroleum prospectivity that were adapted to geological storage assessments. If such assessments are not available at a country level, more work will be required to understand geological storage prospectivity. Assessments made at the basin level are usually the domain of government agencies and research organizations, but once site-specific studies are required, industry will focus on the detailed assessments that are necessary. At the basin and sub-basin levels, screening studies (Level 3 requirement, see Chapter 2) are required that consider the presence of suitable reservoir/seal pairs, potential trapping mechanisms, and migration pathways. In the transition from sub-basin to prospect studies, the work time and costs increase considerably as wells and seismic costs are incurred with a detailed focus on the reservoirs, seals, injectivity, containment, and migration pathways. For each specific geological storage site, the likely costs will be site-specific based on the complexity, characteristics, and pre-existing knowledge of the site being investigated.

# 2. Levels of CCS Ready Requirements

Exhibits 2-1, 2-3, and 2-7 provide examples of three different levels of requirements that could be set out for developers to make their projects CCS Ready. The exhibits are meant to illustrate the continuum of options that can be adopted in any jurisdiction, recognising that more lenient or stringent requirements might be appropriate in some cases.

This framework of options allows policymakers to choose different levels of requirements for each particular component of CCS (i.e., capture, transport, and storage). Jurisdictions that expect CCS to be an integral and near-term part of their GHG emissions reduction strategy could require developers to meet a higher level of requirements for being CCS Ready—thereby enhancing the likelihood of retrofitting to CCS quickly, despite the higher initial costs for becoming CCS Ready. Hence, more stringent CCS Ready levels will likely be imposed for jurisdictions with ambitious GHG emission targets, dependency on fossil fuel as an energy source, and/or high expectations of a large role for CCS in their general GHG policy. A more stringent CCS Ready level will also impose a higher cost to industry, and consequently to consumers. Furthermore, as national and international climate change and CCS policy, technology trajectories, and extent of CCS commercialization evolve over time, CCS Ready policy and requirements might eventually be replaced by policy and regulations that require the immediate deployment of full-scale CCS technologies in new and modified plants.

## 2.1 Advantages of Different Levels

The least stringent requirements for CCS Ready (Level 1 in the exhibits below) have the lowest costs and time expenditures for compliance by project developers. Such an approach may the best chance of avoiding delays in energy and industrial investments. The least stringent requirements also help avoid capture technology lock-in,[11] because developers do not have to invest in specific capture equipment. A low level of requirements for Capture Ready increases the flexibility in capture technology choice and timing for project developers.

However, a more stringent approach (i.e., Level 2 and 3 in exhibits below) brings other advantages to CCS Ready policy. For example:

- Technical uncertainty is reduced as more work is done upfront on designing the capture facility, selecting transport corridors, and exploring storage sites. This increases the assurance of technical feasibility for the eventual CCS deployment.
- Retrofitting CCS to the CCS Ready plants is more likely if "money forward" costs are reduced (i.e., expenditures for future capital investments at the time of retrofit). Down time for retrofitting the capture technology to the plant can also be reduced with upfront investment.
- Better estimates of retrofitting costs are obtained, thereby reducing cost uncertainties and providing a better basis for determining incentives, if any.

[11] Technology lock-in refers to the concept that a facility has been designed for or is "locked into" a specific $CO_2$ capture technology. There is a risk that the expected capture technology may never be adopted, because more efficient and less expensive CCS options may emerge or there can be significant progress in other non-CCS sectors. This may mean that some of the money spent on making the facility CCS Ready will be wasted, or that retrofitting to the expected technology would be expensive and/or inefficient.

- Given the geological uncertainties surrounding storage sites, additional geological information gathered through a more stringent CCS Ready policy would be useful for validation and public awareness of large-scale geological $CO_2$ storage.
- A higher level of requirements can be considered as part of a staged implementation of CCS, which can be advantageous in some jurisdictions.
- The CCS-related knowledge base would be increased among engineering and design firms, and, consequently, industries can also better plan and manage the development of future CCS-related products and services.
- Potential loss of required land for the $CO_2$ capture technology, transport corridor, and storage site is reduced, if uncertainty in needed space requirement estimates is reduced; the increased certainty and proper land-use planning will also help in reducing the potential for encroachment due to development.
- The additional upfront investment in CCS Ready will increase public awareness of CCS and may help assure the public of the safety, economic viability, and effectiveness of CCS projects.

## 2.2 Disadvantages of Different Levels

The low level of requirements for CCS Ready Level 1 runs the risk that the capture technology would be mischaracterised (e.g., the efficiency of the technology is significantly overestimated or the cost of the technology is underestimated) or problems related to the construction or operation of the capture technology would remain unidentified. Only during the retrofitting stage will any previously unknown deficiencies be identified, which could result in project delays or increased cost. The availability and suitability of storage sites could also be underestimated, and in some cases anticipated storage areas might not be confirmed by further assessment work.

On the other hand, moving to more stringent levels also has disadvantages, including:

- Increased project development costs and increased regulatory compliance burden.
- This additional regulatory burden could slow down projects.
- Regulators will also have increased administrative burden, which can result in increased expenses and a slower approval process, without additional resources.
- Increased investment in capture technology design and pre-investment in capture-related equipment can result in technology lock-in, and could potentially lead to wasted expenditure if better-performing advanced technologies (or alternative compliance mechanisms) are available in the future.
- Developers and technology providers asked to divulge confidential business information will insist on more cumbersome and non-public administrative processes to avoid the potential for such information being compromised.
- Requirements for detailed exploration of storage sites for higher levels of CCS Ready could necessitate additional enabling legislation and regulation, which could then create delays or roadblocks for plant approvals.

- Implementing high levels of CCS Ready for capture technology at a plant when storage sites in nearby sedimentary basins have not been adequately proven to be viable could result in a stranded capture plant, if ultimately the storage site is not viable.

## 2.3 Requirements for Capture Ready Plant

Exhibit 2-1 provides illustrative examples of the different graduated levels of requirements for defining Capture Ready Plants. Capture-specific components in this exhibit are discussed below, with components common to all three parts of CCS (capture, transport, storage) being discussed in a later section.

**Exhibit 2-1: Illustration of Graduated Levels of Requirements for a $CO_2$ Capture Ready Plant**

| | Component | CCS Ready Level 1 | CCS Ready Level 2 | CCS Ready Level 3 |
|---|---|---|---|---|
| $CO_2$ Capture Ready Plant | Plant site selection | Locate plant in a site where transportation to storage sites is potentially feasible. | | |
| | Technology Selection | Identify one or more potential capture technologies. | Identify preferred capture technologies. | Identify chosen capture technology. |
| | Design for Capture Facilities | Prepare a preliminary design for capture facilities and their integration into the plant. | Prepare technical feasibility study for capture facilities and their integration. | In additional to Level 2 requirement, prepare a Design Basis Memorandum (DBM) for capture facilities and their integration. |
| | Space Allowance | Allow sufficient space, as determined by design studies, for needed equipment and construction zone. | | |
| | Equipment Pre-investment | Make little or no equipment pre-investment. | Make modest level of equipment pre-investment. | Make high level of equipment pre-investment. |
| | Cost Estimate for Capture Facilities | Prepare preliminary economic analysis of capture facilities. | Prepare preliminary economic feasibility study based on technical feasibility study. | In addition to Level 2 requirement, prepare follow-on economic feasibility study based on technical information provided in DBM. |
| | Environmental, Safety, and Other Approvals for Capture Facilities | Identify all approvals that will need to be obtained for retrofitting capture facilities. | Conduct feasibility studies for obtaining all approvals for retrofitting. | Prepare key documents for obtaining all approvals. |
| | Public Awareness and Engagement Related to Capture Facilities | Notify public of eventual capture facilities retrofit via web site and other actions. | Seek public engagement in planning of capture facilities. | In addition to Level 2 requirement, encourage public engagement in approval process. |
| | Sources for Equipment, Materials, and Services for Capture Facilities | None. | Compile list of companies who can supply construction and operation services to capture facilities. | Contact companies and negotiate nonbinding letters of intent to bid on project. |
| | Ongoing Obligations | File periodic reports with regulators on status of capture ready. | | In addition to Level 2 requirement, respond to mandatory trigger mechanism to retrofit capture facilities. |

Source: ICF International

### 2.3.1 Plant Site Selection

A CCS Ready plant must be built where its normal business operations and future operations with CCS are both technically feasible. Considerations for siting could stem from requirements for capture facilities (e.g., finding a plant site with enough extra space for capture equipment),[12] storage facilities (e.g., finding a plant site near a suitable geological formation), or transportation facilities (e.g., finding a plant site that has access to a feasible transport corridor to a selected storage location). For example, the UK guidance note on CCR requires project developers to ensure that suitably located land is available for capture retrofit use and that a feasible "way out" exists from the capture site for a $CO_2$ pipeline.[13] Such considerations will likely increase construction costs for new plants and may reduce the number of acceptable sites.

In some jurisdictions, the government or another appropriate authority could coordinate $CO_2$ transportation and storage planning and development. In such a case, that authority could also assist project developers in identifying suitable site options for CCS Ready plants.

### 2.3.2 Technology Selection, Design for Capture Facilities, and Space Allowance

A Capture Ready plant needs to be designed in such a way that the future retrofit is technically feasible, with acceptable economic costs. The technical feasibility depends on the specific capture technology type (e.g., post-combustion, pre-combustion, oxy fuel) and the existing equipment and processes in the subject power plant and industrial facility. For each of the technology types, there are existing capture technologies and potentially new technologies that could be commercialized in the future. For example, the current technology for post-combustion capture is based on amine solvents, whereas future technologies could use chilled ammonia or other solvents that are currently under development.

As part of the different levels of Capture Ready requirements, project developers could be asked to either 1) identify one or more potential capture technologies, 2) identify preferred capture technologies, or 3) choose a specific capture technology. The first alternative provides developers with maximum flexibility in selecting an advanced technology choice in the future. However, it could also result in inefficient or more costly designs for the eventual retrofit as provisions must be made for many alternatives, only one of which is likely to be implemented. Alternatively, the requirement to choose a particular technology immediately could help the developer to design the plant more optimally for the retrofit, although it runs the risk of technology lock-in or added costs if another technology is ultimately selected.

Several options exist to demonstrate that the design of the plant is amenable to future retrofit. These options include requiring a preliminary design, a technical feasibility study, or a design basis memorandum (DBM), related to commissioning a front end engineering and design (FEED) study. The preliminary design is part of CCS Ready Level 1 (see Exhibit 2-1), and could include:

[12] Generally, land availability for capture facilities has little impact on site selection. See: Ghose, S. (2008). *Impact of carbon management on plant site selection.* Presentation at the West Coast Regional Carbon Sequestration Partnership (WESTCARB) Annual Business Meeting, October 1, 2008, Anchorage, AK.

[13] Paragraph 44, page 18 of U.K. Department of Energy and Climate Change (U.K. DECC). (2009). *Carbon capture readiness (CCR): A guidance note for Section 36 Electricity Act 1989 consent applications* (Publication no. URN 09D/810). London, UK: Author.

- Description and preliminary layout plan of Capture Ready plant design, indicating areas where the plant differs from BAU, and the ways in which the layout will assist retrofit.
- Assessment of additional space needed for retrofitting the plant using currently available technology. At a minimum, this assessment should include needed space estimates for:
  - The capture plant and associated equipment;
  - Waste handling and processing from the capture plant;
  - Additional equipment for flue gas cleanup needed for the capture plant;
  - Additional boiler and heat exchanger units, if needed;
  - Additional cooling water units, if needed;
  - Equipment for integrating the capture plant with the existing plant;
  - Staging of construction activities; and
  - $CO_2$ compressors and dehydration units, and connections with the $CO_2$ pipeline.
- Technical options for partial capture, if allowed as an intermediate step before a full capture retrofit.[14]

For a Level 2 Capture Ready requirement, a technical feasibility study could be required that includes all of the elements of the preliminary design with additional technical details. This could include, at a minimum:

- A detailed technical description of specific design changes relative to a BAU plant, including preliminary mass and energy balance statements and mass and energy balance flow sheets for the capture retrofit;
- Preliminary blueprints for layout of both the Capture Ready plant and of the capture retrofit using a more limited set of preferred technologies;
- An initial list of equipment required for capture retrofit;
- Preliminary resource analysis for preferred capture technologies, such as water consumption, raw materials (e.g., amine) consumption, and heat and power consumption;
- Preliminary analysis of the technical performance of the retrofitted plant (including, for example, overall plant efficiency, estimated $CO_2$ capture efficiency, loss in output, etc.);
- Discussion of potential advanced capture technologies and their compatibility with the proposed plant; and
- More detailed planning, including of the construction process itself, for the capture retrofit.

At Level 3, the requirement could extend the technical feasibility study to a DBM—a document that is used to initiate the FEED process. Such a requirement may be appropriate when CCS is expected to become mandatory in the near future, hence the requirements could help reduce the lead time and money forward costs. A CCS Ready policy could be set up to ask the developer to provide the technical feasibility study during the initial plant

[14] For example, policymakers could indicate that developers comply with capture from 40-50% of flue streams at the initial stage, with an option to increase the capture percentage to close to 100% of flue streams at later stage.

approval process, and the DBM as part of a periodic reporting update once retrofit to CCS is triggered by regulation or becomes economically viable. Elements of the DBM could include:

- Detailed technical description of specific design parameters for the chosen $CO_2$ capture technology, including mass and energy balance statements, and mass and energy flow diagrams and process flow diagrams for the capture retrofit;
- Piping and instrumentation diagrams;
- Detailed equipment lists, equipment sizing, and arrangement drawings (blueprints) for layout and design of both the proposed Capture Ready plant and the capture retrofit using chosen $CO_2$ capture technology;
- Identification of items on the equipment list that would be installed immediately, as well as those that would be added later once the retrofit decision is made; and
- Detailed planning, including potential plan and logistics for construction and start up for the chosen capture technology.

The primary advantage in requesting developers to conduct more detailed technical studies is the reduction in technical and cost uncertainties. It increases the assurance that capture retrofits to plants are indeed realistic and feasible. The increasing amount of technical studies will also serve to build capture-related knowledge and capacity among engineering and design firms, reducing lead times for retrofitting. On the other hand, disadvantages include increased project development costs and time,[15] potential for wasted investment if a different technology is chosen for retrofit, increased potential for proprietary data being compromised, and additional burden on regulators to assess the more detailed technical information.

One important result of the technical design requirement is the determination of the space required for capture retrofit. This will vary based on choice of capture technology, type of plant, and kind of feedstock used. For example, industrial plants typically have densely packed facilities and equipment, and are often co-located with other plants; these attributes make it challenging to ensure adequate available space. As one moves from a preliminary assessment to the DBM, the degree of accuracy in the estimates of required space will increase.

### 2.3.3 Equipment Pre-Investment

As part of the higher level of requirements for being CCS Ready, developers could be requested to "pre-install" a limited amount of capture related equipment, in order to enhance the economic viability of the future retrofit. For example, a recent study by the US National Energy Technology Laboratory (NETL) suggested a Capture Ready design that increases the size of the steam boiler so that there is no loss in electric output capacity (MWe) when the plant is retrofitted for $CO_2$ capture.[16] The Capture Ready design requires subsystems (coal handling, boiler, ducting, steam turbine generator, cooling flue gas cleanup, feedwater, and other balance of plant systems) to be upsized to accommodate both the increase in steam flow as well as flue gas. Investing in such extra capacity could help reduce

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[15] For example, the Electric Power Research Institute estimated that a FEED study for an oxy-coal $CO_2$ capture facility would cost $5.7 million to prepare and require 18 months to complete. Electric Power Research Institute (EPRI). (2008). *Oxy-coal/$CO_2$ capture and storage front-end engineering design.*

[16] For more details, see: US Department of Energy, National Energy Technology Laboratory (US DOE-NETL). (2008). *$CO_2$ capture ready coal power plants* (DOE/NETL Publication no. 2007/1301).

lifecycle economic costs to the project developer in some circumstances. Exhibit 2-2 provides an illustrative list of the key types of plant equipment for which pre-investment in extra capacity may be beneficial.

**Exhibit 2-2: Keys Types of Equipment for Consideration of Pre-investment**

| | |
|---|---|
| ▪ Coal handling | ▪ Additional flue gas cleanup |
| ▪ Boiler | ▪ Feed water |
| ▪ Ducting | ▪ Wastewater treatment |
| ▪ Steam turbine generator | ▪ Other balance of plant systems |

Source: NETL, 2008

Extensive pre-investment in additional equipment (relative to a BAU plant) may lock the Capture Ready plant into a particular capture technology, rendering it relatively more expensive to adopt more effective advanced capture technologies should they become available in the future. Hence, a high level of equipment investment is likely to be appropriate only when CCS deployment is imminent. An advantage of this approach is that equipment pre-investment would help accelerate the knowledge build-up in engineering firms, reduce the lead time for retrofitting, and make the adoption of capture facilities more likely by reducing money forward costs.

## 2.4 Requirements for Transport Ready

In order to demonstrate that a plant is ready for $CO_2$ transportation, developers will be required to identify a particular transport method (or combination of methods), select a transport corridor, and develop designs and cost estimates for transportation systems. $CO_2$ transportation requires knowledge of the plant location, as well as the location of the potential storage sites. Hence, the information provided for a Transport Ready plant needs to be consistent with the information provided on how the plant is Capture and Storage Ready. Exhibit 2-3 provides the different graduated levels of requirements for defining Transport Ready Plants.

There are two main methods for large scale $CO_2$ transport: pipelines and shipping.[17] In some cases, developers may choose to use a combination of pipelines and shipping. Requiring the developer to identify and select the transport method(s) sets the stage for evaluating the other components for a $CO_2$ Transport Ready plant.

As a minimum level of requirement, feasible corridors for pipeline routes, including the potential necessity to traverse waterways, roads, other pipelines or the shoreline, and/or feasible ports for shipping, including any restrictions on navigation, should be documented. Developers should also identify any conflicting land use activity, as well as feasibility of land access for pipelines or additional port infrastructure, including construction activities. This information can be used to assess whether a feasible transport plan is possible for linking the future capture plant with a storage site.

For example, the UK CCR guidance note requires the suitable siting of $CO_2$ transport pipelines as part of the planning process of large combustion plants. It recommends that developers identify an initial route for the pipeline within a 1km corridor for the first 10km

[17] Although road transportation using trucks is another option, it is unlikely to be used for transporting large volumes of $CO_2$.

of pipeline from the large combustion plant, and thereafter identify a 10km corridor to the point(s) on the coast where the pipeline is expected to go offshore or be transported by ships.[18] Where necessary, the UK requires the operator to mitigate the negative impact of a pipeline on protected nature areas and Sites of Special Scientific Interest (SSSI).

**Exhibit 2-3: Illustration of Graduated Levels of Requirements for a $CO_2$ Transport Ready Plant**

| | Component | CCS Ready Level 1 | CCS Ready Level 2 | CCS Ready Level 3 |
|---|---|---|---|---|
| $CO_2$ Transport Ready Plant | Transport Method | Identify and select one or more potential transport method(s). | | |
| | $CO_2$ Transport Corridor Selection | Identify one or more feasible pipeline and/or shipping routes. | Obtain contractual options to rights of way. | Obtain rights of way to assess the pipeline corridor or shipping route. |
| | Conflicting Uses and Rights | Identify any conflicting land use activity, as well as feasibility of land/port access. | | Resolve any issues with conflicting surface and sub-surface uses, and land/port access. |
| | Design of Transport Facilities | Prepare preliminary design options for feasible transport method(s). | Prepare technical feasibility study for the transport method(s) including coordination of pipeline corridor use and/or shipping routes with other capture plants. | In addition to Level 2 requirement, prepare a Design Basis Memorandum (DBM) for the chosen transport method(s). |
| | Cost Estimate for Transport Facilities | Prepare preliminary economic analysis for transport facilities, and estimate the cost of transportation for the capture plant. | Conduct preliminary economic feasibility study, based on technical feasibility study, including cost of transportation for the capture plant. | In addition to Level 2 requirement, prepare follow-on economic feasibility study based on technical information provided in DBM. |
| | Environmental, Safety, and Other Approvals for Transport Facilities | Identify all approvals that will need to be obtained for transporting $CO_2$. | Conduct feasibility studies for obtaining all approvals for transportation facilities. | Prepare key documents for obtaining all approvals for transportation facilities. |
| | Public Awareness and Engagement Related to $CO_2$ Transport | Notify public of chosen transport method(s) and corridor(s) via web site and other actions. | Seek public engagement in transportation planning. | In addition to Level 2 requirement, encourage public engagement in transportation approval process. |
| | Sources for Equipment, Materials, and Services for Transport Facilities | None | Compile list of companies who can supply equipment, materials and services needed for construction and operation of $CO_2$ transportation. | Contact companies and negotiate nonbinding letters of intent to bid on project. |
| | Ongoing Obligations | File periodic reports with regulators on status of transport ready. | | In addition to Level 2 requirement, respond to mandatory trigger mechanism to develop transport facilities. |

Source: ICF International

A higher level of requirement could require developers to obtain contractual options for specific transport corridors. For the Level 3 requirement, obtaining rights of way to the pipeline corridor or ports could be required. Resolving any issues regarding conflicting uses and access to land or ports could also be a Level 3 requirement. Depending on the jurisdiction, regulators or other authorities could assist in resolving conflicting issues on behalf of the developer.

[18] Paragraph 61, page 23 of U.K. Department of Energy and Climate Change (U.K. DECC). (2009). *Carbon capture readiness (CCR): A guidance note for Section 36 Electricity Act 1989 consent applications* (Publication no. URN 09D/810). London, UK: Author.

Greater information on the transport corridor will help reduce cost uncertainties and the cost of future retrofit. Knowledge about transport corridor locations will help to reduce any potential future land use conflict and prevent encroachment due to other development. However, this action will add to upfront development costs, as the more stringent levels will require more research—including investigation of the location of the storage site and connecting transport corridor.

In addition to transport corridor selection, an assessment of the technical feasibility of constructing transport facilities could be required. At Level 1, a preliminary design option for transport facilities could be required, including:

- Routing maps and geographic information system (GIS) files;
- Potential barriers in building the pipeline or shipping network along the chosen corridor; and
- Feasibility for altering routes if barriers emerge.

For a higher level of requirement, a technical feasibility study could be required. This study could include:

- Sizing of pipelines to match the expected $CO_2$ volumes, or planning for tankers and port infrastructure (in case of shipping);
- Location and size of pumping stations and receipt and delivery points and any interconnects on pipeline; and
- Detailed planning for how the tankers will be obtained/commissioned and port infrastructure developed for shipping if required.

For Level 3 requirements, a DBM, as part of activities related to commissioning a FEED study for pipelines and/or shipping, could be required. At this level, developers could be required to coordinate with appropriate agencies on the need for development of larger pipeline networks. In some jurisdictions, a governmental authority may be tasked with developing pipeline networks,[19] and developers could work with such an authority to access or support the development of large scale pipeline networks and hubs.

While obtaining greater detail on transportation facility design will reduce money forward cost and accelerate CCS deployment, it does increase upfront project development costs. Stringent requirements for transport system design require the precise location of the capture plant and the storage site, and thus require coordination with Storage Ready provisions.

## 2.5 Requirements for Storage Ready Plant

Geological storage of $CO_2$ is at an early stage of implementation and practical development. It is based largely on well-established petroleum geology and reservoir engineering practices, and uses oilfield technology developed over the last 100 years. There is a limited amount of practical experience in identifying, characterizing, and injecting $CO_2$ for the purpose of geological storage in underground formations from pilot, demonstration, and a small number

[19] In general, it might not be technically efficient or cost-efficient to have project developers design and construct pipelines or port facilities only for their projects. Hence, designing a national $CO_2$ pipeline network could be considered an inherently governmental function.

of commercial projects. Hence, practices and regulations for geological storage will likely evolve as large-scale $CO_2$ injection projects proceed, and the resulting improved knowledge may need to be incorporated into Storage Ready policy and procedures through time.

There are three major geologic options for storing $CO_2$:[20]

- $CO_2$ Storage with Enhanced Oil and Gas Recovery (EOR or EGR) offers potential where suitable oil and gas fields are present and a suitable commercial framework exists, with benefits from additional production and revenues. EOR is already commercial deployed in onshore settings; EGR is at the demonstration stage.
- Depleted Oil and Gas Fields are a potential option in major oil- and gas-bearing regions, but availability, suitability of the specific fields, and well integrity risks are key issues. Use of depleted fields for $CO_2$ storage is considered low risk overall, although still at the demonstration stage worldwide.
- Saline Reservoir Formations are more widespread with large potential capacities, but geological and scientific understanding and data are relatively more limited than for other options associated with oil and gas fields. The option is a being demonstrated in several locations around the world.

In defining requirements for Storage Ready plants, the three key technical parameters for evaluation are:

- Capacity: whether sufficient storage volume is available, or can be engineered to be available;
- Integrity: the confidence level about leakage risk and storage security at the site, related to the injection site and surrounding area; and
- Injectivity: whether suitable reservoir properties allow sustained injection at industrial supply rates into the geological formations.

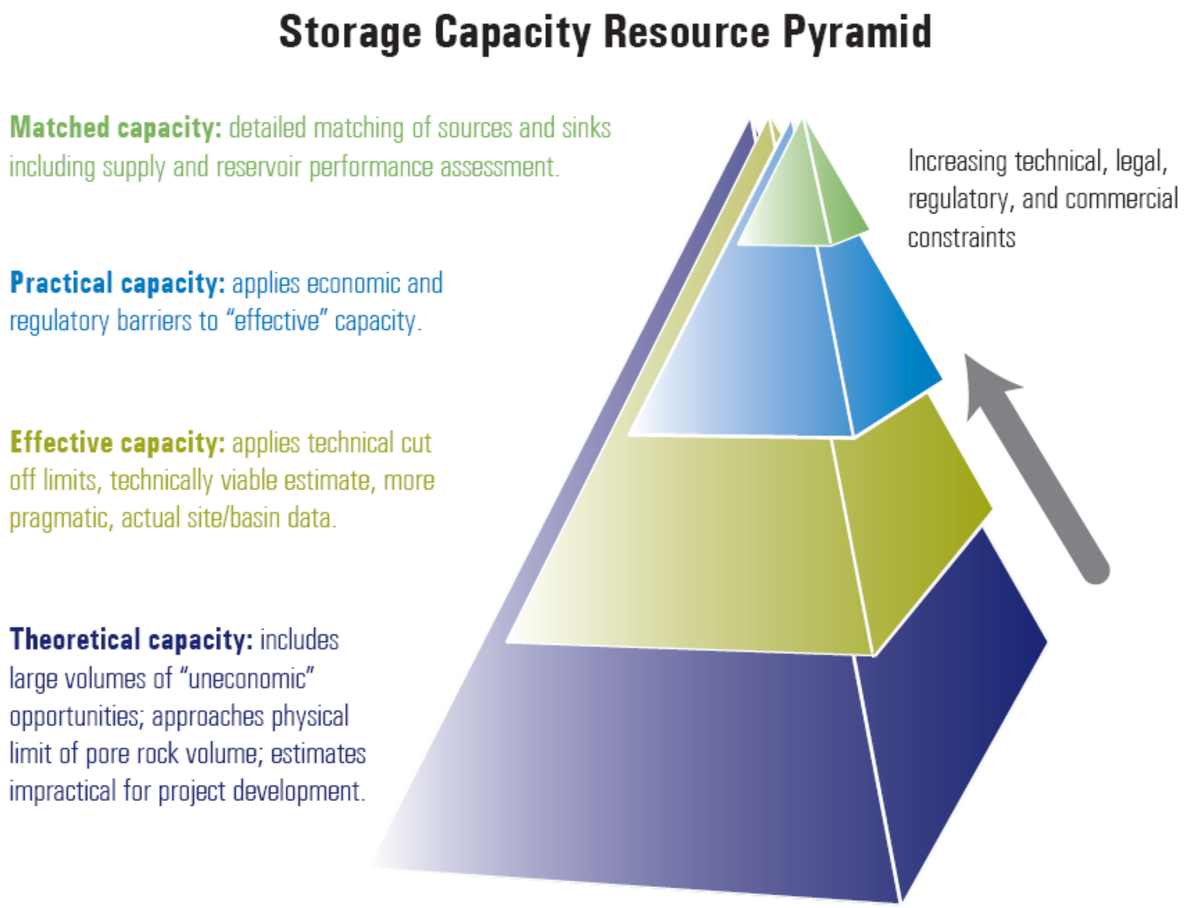
There are also additional non-geological assessment criteria for specific sites, including engineering criteria relating to facilities and wells for oil and gas fields (including EOR/EGR), non-technical criteria such as availability, impact on other resources, and economic criteria (e.g., storage costs).

Storage capacity of a site is especially important, as developers are required to determine whether they would have to consider additional sites to store the full volumes of the captured $CO_2$ over the future operating lifespan. Storage capacity estimates can be categorized into "theoretical," "effective," "practical," and "matched" (see Exhibit 2-4). Each successive category produces a subset of sites associated with the preceding larger category. As indicated by the Exhibit, the uncertainty of capacity estimates is likely to be reduced with increased knowledge on technical, legal, commercial, and regulatory constraints. Developers should use qualifying terms (shown in Exhibit 2-4) with any numerical capacity estimates provided to regulators, to clearly indicate the level of certainty, assessment and validation, and stage of geological storage project development.

[20] Confidence levels would be higher for storage options related to oil and gas fields, provided data are available and in the public domain.

In order to begin the development of the site for storage, the capacity estimates will have to progress up the resource pyramid definitions.

**Exhibit 2-4: Description of the Terminology for Geological Storage Capacity**




Source: Bradshaw Geoscience Consultants

Storage integrity is also an essential prerequisite, and consideration of any potential storage site to ensure that geological storage will be a safe and effective mitigation option. This requires assessment of storage trapping conditions and potential leakage risk through geological and man-made pathways such as pre-existing wells. Risk assessment is likely to be required throughout the life cycle of the storage site, beginning with preliminary assessment at the early stage, with a more rigorous process during site characterisation, and ongoing updates through to closure. The risk assessment, which must be fully integrated with and based on the geological evaluation, should be used to manage risks at different stage through site exploration, assessment, design of the injection scheme, monitoring, verification, and remediation. Specific risk assessment requirements are included in the regulatory framework for geological storage in many regions, along with requirements for Site Characterisation, modelling, and monitoring.

Storage Ready requirements in some jurisdictions could differ for each of these geologic settings, as the technical risks and available data can differ in each case. Some important differences are summarized in Exhibit 2-5. In all cases, obtaining a detailed understanding of the geological environment of a specific site is important, since geology and geological attributes of the subsurface are highly variable among different countries, regions, and even among sites within any region.

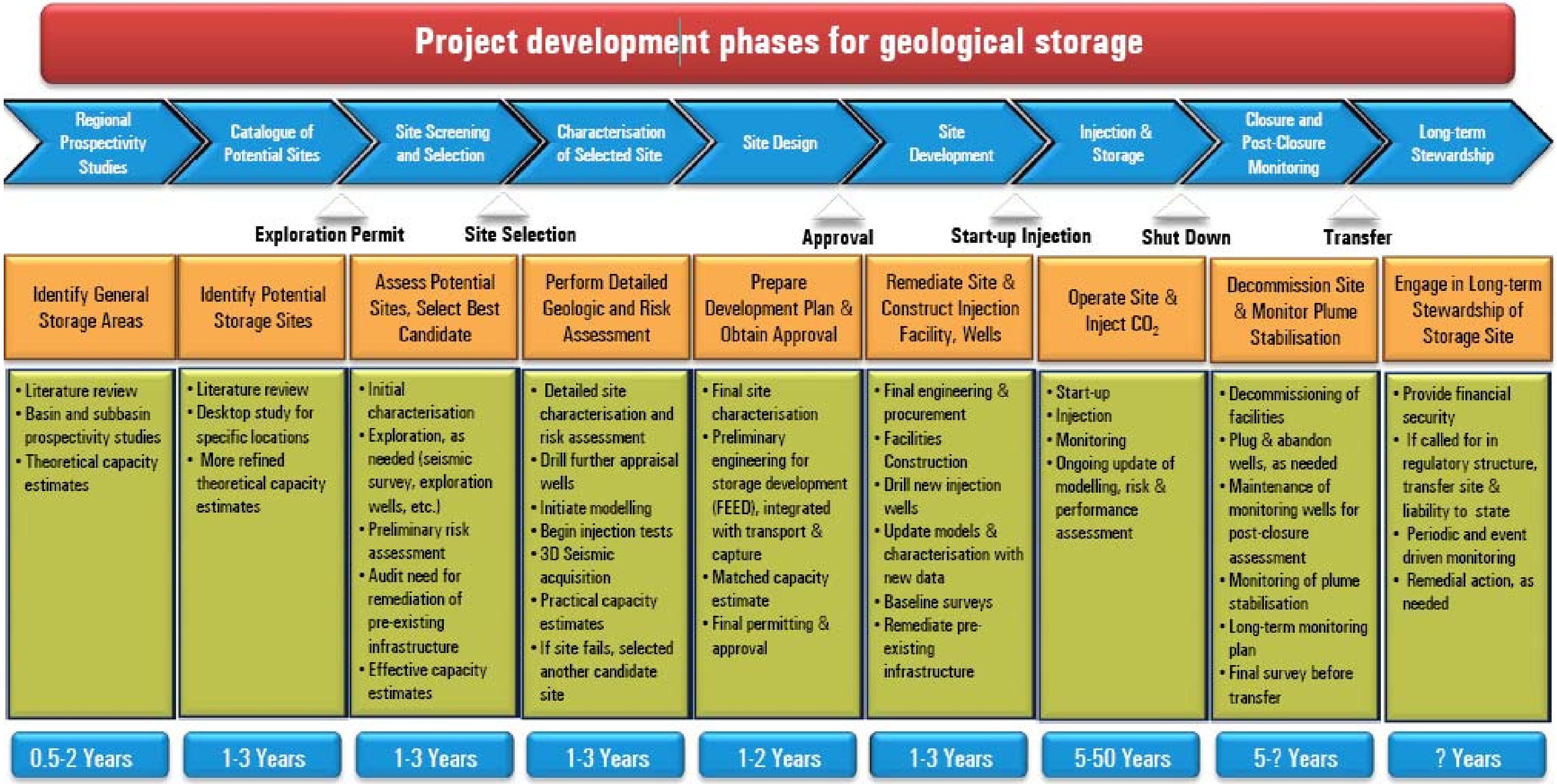
Exhibit 2-6 shows the entire chain of activities required for geological storage of $CO_2$, including activities leading up to full-scale injection, closure, and long-term stewardship of the site after closure. Exhibit 2-6 is intended to assist understanding of the overall process for geological storage, while Storage Ready polices and regulations are being developed. It also shows that specialized entities (either private or public) are needed to develop storage sites and provide storage services. Project developers will need to hire or enter into an agreement with these entities to prepare the required studies and materials for a Storage Ready plant.

Exhibit 2-7 shows illustrative examples of three graduated levels of requirements for defining Storage Ready plants. As indicated in Exhibit 2-6, the first four phases encompass the Storage Ready requirements shown in Exhibit 2-7.

**Exhibit 2-5: Considerations for Different Geological Options for $CO_2$ Storage**

| Favourable | Unfavourable |
|---|---|
| EOR or EGR in Existing Oil and Gas Fields | |
| ▪ Geologic integrity demonstrated by ability to hold oil and gas for millions of years.<br>▪ Have high certainty about the geological characteristics, thus, making geological analysis and site characterization relatively straightforward. | ▪ The potential for leakage through pre-existing wells and facilities will need to be assessed, and may need to be remediated prior to commencing injection.<br>▪ EOR/EGR viability is field-specific. Offshore EOR viability and economics are unproven; EGR technology is at the demonstration stage. |
| Inactive (Abandoned) Oil and Gas Fields | |
| ▪ Geologic integrity demonstrated by ability to contain oil and gas for millions of years.<br>▪ Moderate to high certainty about the geological characteristics and capacity, provided knowledge and data are not lost when fields are abandoned.<br>▪ Potential site-specific opportunities for re-use of facilities, infrastructure, and wells. | ▪ The potential for leakage through pre-existing wells and facilities will need to be assessed, and may need to be remediated prior to commencing injection.<br>▪ Facilities and wells may not be suitable for conversion to $CO_2$ storage, depending on their age and physical integrity.<br>▪ Potential exists for extensive "lost" corporate knowledge and data which may result in the storage integrity being affected by the lack of detailed documentation associated with the engineering, operation, and characteristics of the field. |
| Saline Reservoirs | |
| ▪ Widespread, with potentially large capacities.<br>▪ Present both within and outside oil and gas regions<br>▪ With significantly fewer well penetrations than other options, the risk of leakage through any pre-existing wells will be substantially less. | ▪ The geological characteristics proximal to the proposed storage site will be less certain than for oil and gas fields due to a lesser amount of well and seismic data.<br>▪ More primary data will need to be acquired to reach the equivalent high levels of technical certainty compared with oil and gas fields.<br>▪ No fluid flow data about reservoir performance will exist. Hence, significant testing of the reservoir will likely be required to estimate the long-term performance characteristics prior to final commitment to develop the site. |

**Exhibit 2-6: Phases of Geological Storage of $CO_2$**




Note: Orange boxes refer to "Project Developer Goals"; Green boxes refer to "Developer Activities

Source: Senior CCS Solutions and Bradshaw Geoscience Consultants

## Exhibit 2-7: Illustration of Graduated Levels of Requirements for a $CO_2$ Storage Ready Plant

| | Component | CCS Ready Level 1 | CCS Ready Level 2 | CCS Ready Level 3 |
|---|---|---|---|---|
| $CO_2$ Storage Ready Plant | Storage Site Selection | Estimate total amount of $CO_2$ to be captured and stored for all years of CCS operation of the plant, and identify one or more feasible storage sites expected to accommodate the captured $CO_2$. | In addition to Level 1 requirement, obtain contractual options to one or more appropriate storage sites. | In addition to Level 2 requirement, obtain rights to one or more appropriate storage sites. |
| | Verifying Injectivity, Capacity, and Integrity of Storage Site | Review existing regional prospectivity studies and show that the required capacity is theoretically available; conduct preliminary assessment of storage integrity and risks; and submit an overall plan for site assessment. | In addition to Level 1 requirement, conduct desktop study of injectivity, capacity, and integrity of storage location(s), and show that "effective" capacity is available. | In addition to Level 2 requirement, conduct geological exploration to screen and select specific site(s) for more detailed characterization of aquifers, or detailed assessment of oil/gas options; estimate "practical" capacity and conduct initial modeling of long-term reservoir behavior; and prepare Detailed Storage Integrity Risk Assessment. |
| | Design of Storage Facility | Prepare preliminary design for storage facility. | Prepare technical feasibility study for storage facility, including preliminary monitoring and verification plan. | In additional to Level 2 requirement, prepare a Design Basis Memorandum (DBM) for storage site facility, including monitoring and verification plan. |
| | Conflicting Uses and Rights | Identify any conflicting surface and subsurface uses, as well as feasibility of access to site(s). | | Resolve any issues with conflicting surface and sub-surface uses, and site access. |
| | Cost Estimate for Storage Facility | Prepare preliminary economic analysis for storage facility including capital and operation and maintenance costs, and estimate the cost of storage for the capture plant. | Conduct preliminary economic feasibility study based on technical feasibility study, including the cost of storage for the capture plant. | In addition to Level 2 requirement, prepare follow-on economic feasibility study based on technical information provided in DBM. |
| | Environmental, Safety, and Other Approvals for Storage Site | Identify all approvals that will need to be obtained for storage site. | Conduct feasibility studies for obtaining all approvals for storage site. | Prepare key documents for obtaining all approvals for storage site. |
| | Public Awareness and Engagement Related to $CO_2$ Storage Site | Notify public of eventual storage site via web site and other actions. | Seek public engagement in storage site planning. | In addition to Level 2 requirement, encourage public engagement in storage site approval process. |
| | Sources for Equipment, Materials, and Services for Storage Site | None. | Compile list of companies who can supply equipment, materials and services needed for construction and operation of storage site. | Contact companies and negotiate nonbinding letters of intent to bid on project. |
| | Ongoing Obligations | File periodic reports with regulators on status of storage ready. | | In addition to Level 2 requirement, respond to mandatory trigger mechanism to develop storage site for injection. |

Source: ICF International

An important consideration is the time that it could take project developers or associated entities to complete the various phases. While the actual time required will vary based on the availability of information and the geological complexity of the site, it is clear that the aspects related to storage site(s) identification, screening, selection, and detailed characterization could take significant time, particularly for saline aquifer options.

In order to ensure that project developers are cognizant of the level of work needed, they can be required to submit an overall plan for the particular site(s) they intend to work with, including the expected duration for each phase. Such a plan would assist industries that have no or little or no exposure to subsurface processes acknowledge and understand the subtleties, uncertainties, and complexities of the geological environment. The industries that don't traditionally deal with the deep subsurface will have to become acquainted with:

- The extent of the work and planning required;
- The technology that has to be deployed;
- Levels of uncertainty and risk involved;
- Complexity of the decision processes; and
- The cost of finding and developing a site.

These industries will likely have a steeper learning curve and need to engage and work with entities with appropriate geological expertise. A CCS Ready policy itself could serve to promote the necessary coordination and knowledge sharing that would bring various industries to a similar appreciation of geological knowledge level required for CCS Ready.

Given the extent of geological knowledge and activity required to ensure that a storage site is ready for injection, jurisdictions may want to consider supporting the preparation of such studies and to designate an appropriate governmental authority to get sites prepared for storage. For example, the European Commission Directive 2009/31/EC on geological storage of $CO_2$ states that Member States should retain the right to determine the areas within their territory from which storage sites may be selected, and should undertake an assessment of available storage capacity within their territory.[21]

### 2.5.1 Storage Site Selection

To ensure that sufficient storage capacity is available, the total quantity of $CO_2$ that a project is expected to capture annually and over its lifetime should be estimated as part of the requirement to select appropriate storage sites. At the initial stage, it is important that developers identify multiple storage options for storing the full captured volume, given the inherent geological uncertainty in storage sites and the potential for unexpected complications due to lack of sufficient geological data.

Once the potential storage site(s) are screened and a particular storage site(s) can be chosen, developers could be required to obtain contractual options to the site(s). At a higher level, developers could be required to obtain the right to use the storage site(s) for injection in the future.

While obtaining options or rights to a storage site will result in increased project development costs, such requirements reduce the lead time and the cost of future retrofit, and increase the feasibility for storing the plant's $CO_2$. The uncertainty in cost estimates is also reduced, as developers know which storage sites they have access to. It would also assist in reducing the transport method choices and selecting appropriate transport corridor(s).

[21] Paragraph 22, page L140/116 of European Parliament and the Council of the European Union. (2009). Directive 2009/31/EC of the European Parliament and of the Council of the European Union. *Official Journal of the European Union, 140*.

### 2.5.2 Verifying Capacity, Injectivity, and Integrity of Storage Site

Exhibit 2-7 provides an illustrative example of the degree to which capacity, injectivity,[22] and integrity of a storage site need to be assessed by project developers to qualify as being Storage Ready. Existing publicly available discussions on generic storage option types, as well as generalized criteria and methodologies, are unlikely to be sufficient for assessing the capacity, integrity, and injectivity of a specific storage site (see discussion below and in the Technical Basis Report for more details). Therefore, better assessments—both using desktop analysis of existing data, as well as complex geotechnical studies, including potentially drilling and seismic surveys—are required to "prove up" a geological storage site.

A minimum consideration requires a review of regional prospectivity studies, if they exist, to provide indications of capacity, injectivity, and integrity of the proposed site(s). The term "prospectivity" refers to a qualitative assessment of the likelihood that a suitable storage location is present in a given area based on the available information and geology.[23] Prospectivity studies are developed by examining data (if possible), examining existing knowledge, applying established conceptual models, and, ideally, generating new conceptual models or applying an analogue from a neighbouring basin or some other geologically similar setting. The concept of prospectivity is often used when it is too complex or technically impossible (due to lack of available data) to assign numerical estimates to the extent of a resource. By nature, prospectivity will become substantiated over time with the availability of new information.

If regional prospectivity studies and atlases for specific geological areas exist for a particular jurisdiction, developers should use this information to provide estimates of *theoretical* capacity (see Exhibit 2-4) in the site(s). If such prospectivity studies and atlases do not exist, funding such publicly available studies is a critical first step for developers to commence site assessments. For example, the EU CCS Directive calls for its member states to undertake an assessment of storage capacity within their territory, and organize an exchange of information and best practices.[24]

> **Status of Prospectivity Studies**
>
> Currently, in many areas, assessments have been completed at a country or regional level to map storage prospectivity. These assessments have involved various levels of data quality, coverage, and public availability. Each and every region in the world will require updating of its assessments in the future, either at more intensive scale in some regions, with new data from exploration efforts, or using improved knowledge and methodology as the science of geological storage evolves. Prospectivity studies can be used to undertake source-sink matching to ensure that potential storage sites chosen by plant developers are in the optimal geological areas to be Storage Ready.

Level 2 Storage Ready requirements include conducting desktop-based geotechnical analyses of capacity, injectivity, and integrity using any existing prospectivity studies and all other available geological data. The studies may extrapolate from nearby regions or use analogue examples where data are scarce. Confidence levels will be higher for storage sites in oil and

[22] Injectivity of the site must be sufficiently proved for Storage Ready, and the pressure regime and fluid flow characteristics of the storage site must be reasonably understood.

[23] "Prospectivity" was defined for geological storage in Intergovernmental Panel on Climate Change (IPCC). (2005). *IPCC Special Report on Carbon Dioxide Capture and Storage* (Chapter 2, pg. 94). New York, NY: Cambridge University Press.

[24] Paragraph 22, page L140/116 of European Parliament and the Council of the European Union. (2009). Directive 2009/31/EC of the European Parliament and of the Council of the European Union. *Official Journal of the European Union, 140*.

gas fields, provided data are available and in the public domain. To facilitate the feasibility assessment of $CO_2$ storage, key results of the detailed desktop studies include:

- More detailed estimates for *effective* storage capacity (see Exhibit 2-4) and injectivity, including a confidence level for the estimates;
- Identification of the existence of potential reservoir and seal pairs in the chosen site;
- Identification of the location and status of drainage cells, migration pathways, and trapping mechanisms for the specific area being considered;
- Initiating modelling of long term behaviour of the reservoir under $CO_2$ injection and storage; and
- Preliminary assessment of storage site integrity and leakage risk.

These studies will build upon any existing prospectivity study and require the collection of all easily available geotechnical data and knowledge for a basin or province where geological storage is being considered. It is possible that developers, at this stage, would have enough geological data to prepare for site screening and selection, and in some cases (depending on data availability) choose a specific geological site for storage.

For a more stringent level, developers can screen the set of storage site choices through a process of additional geological characterization and more detailed and systematic risk assessment, and select one or more specific storage site(s), as appropriate. The site screening process could require additional geological exploration through seismic surveys, exploration wells, etc. To meet the Level 3 requirements, developers may need to obtain a permit or license for exploration, and such permits or licences need to be made available.[25] The additional information should be used to conduct more detailed simulation modelling to provide better estimates of injectivity and capacity. In addition, developers could apply regulatory and economic constraints to the "effective" capacity estimates to obtain an estimate of the "practical" capacity of the chosen site(s) (see Exhibit 2-4). A systematic risk assessment entails an analysis of all equipment, systems, geologic features and human operations associated with the storage site to identify how they might fail to perform as desired so as to cause leaks, damage property, endanger human health or damage the environment. The assessment also identifies ways in which these risks could be managed and what mitigation steps and corrective actions could be performed if and when a failure occurs.

Activities beyond this stage would imply the actual deployment of geological storage, and therefore would not be part of Storage Ready. With increasingly stringent requirements for Storage Ready plants, the geological uncertainty about the capacity, injectivity, and integrity of storage sites are reduced to low levels, and developers can be assured that the chosen site(s) are indeed potentially capable of safe injection and storage in the subsurface for the life of the storage project.

[25] For example, the EU CCS Directive suggests that wherever exploration is needed to generate additional data required for site selection, Member States should subject such exploration to a permit requirement. See: Paragraph 23, page L140/116 of European Parliament and the Council of the European Union. (2009). Directive 2009/31/EC of the European Parliament and of the Council of the European Union. *Official Journal of the European Union, 140*.

The potentially extensive duration and increased cost for establishing a knowledge base for geological storage prospectivity and for fully qualifying sites suitable for $CO_2$ storage could result in a long process of certifying plants as Storage Ready. Hence, some jurisdictions may be inclined to choose lower thresholds (i.e., Level 1 or Level 2, as shown in Exhibit 2-7) if Storage Ready status is to be attainable rapidly, or if the need to deploy CCS is in the very long term. Alternatively, certainty about whether a potential site is capable of large-scale $CO_2$ storage is critical for the success of CCS as well as to facilitate the required stages of financial investment at the various levels of Capture Ready. It is therefore important that jurisdictions balance the needs of industry along with the time and cost for reducing geological uncertainties. This process is well established in the US and other countries when permitting oil, gas, and industrial waste disposal wells. In addition, given that geological attributes of the subsurface are highly variable and their characterization requires specialized expertise, consideration may be required to either select a regulatory agency with sufficient geological expertise or involve third-party reviewers to supplement the capabilities of the regulators in assessing geological information submitted to the regulatory authority.

### 2.5.3 Storage Facility Design

Similar to requirements for designing capture facilities, several options exist to demonstrate the technical feasibility of constructing the storage facility. These options include requiring a preliminary design, technical feasibility study, or a DBM, related to commissioning a FEED study.

The preliminary design is part of CCS Ready Level 1 (see Exhibit 2-7) and could include a description and layout plan of storage facilities, including injection requirements, and preliminary well plans and outline monitoring schemes. For a Level 2 requirement, a technical feasibility study could be required that includes all of the elements of the preliminary design, but with more technical details. For example, the Technical Feasibility Study could include:

- Detailed technical description of storage facilities needed for the injection phase, including integration of the storage equipment with the transport pipeline;
- Technical feasibility for storage facilities, pumping, and injection equipment, including estimates of injection rates, well numbers, and well layout,
- Preliminary design for monitoring plans; and
- More detailed planning for construction of the storage facilities and drilling programmes.

At the Level 3 stage, the requirement could extend the technical feasibility study to a DBM, as part of FEED-related activities. The DBM could document:

- Detailed characterization of the selected site(s), including early modelling of the injection horizon(s) and overburden;
- More detailed systematic Risk Assessment, with mitigation and remediation options;
- Audit of pre-existing infrastructure and remediation of the infrastructure, if necessary; and
- Detailed monitoring and verification plan (including baseline surveys).

The advantages and disadvantages of requiring more stringent requirements for the storage facility design are similar to those discussed above for the requirements for the design of capture facilities. With more detailed technical studies, technical and cost uncertainties are reduced, and regulators can be assured to a greater degree that storage in a specific site is realistic and feasible. There will also be a build-up of knowledge among geology/geophysics, engineering, and drilling firms. However, more detailed design requirements will increase costs to industry and the potential for proprietary data being compromised.

### 2.5.4 Competing Uses and Rights

In many jurisdictions, access to subsurface and surface areas on and near a particular storage site may be required for a variety of uses. If the storage site is located in a populated area, there can be a large number of conflicts between $CO_2$ storage and the other users. There may also be issues related to land access for storage facilities, particularly for onshore storage sites. Competition for access to the subsurface rights can occur when industries extracting coal, oil, or gas need to explore or extract resources in the same location as the storage site, or for alternative uses such as gas storage. $CO_2$ storage and migration could also potentially affect the geology and operation of neighbouring oil and gas fields—both positively and negatively. Hence, identifying any potential conflicts with both surface and subsurface users at an early stage is critical. A more stringent requirement could also require that developers resolve potential conflicts. Depending on the jurisdiction, an appropriate authority can also play a mediating role in resolving conflicts.

## 2.6 Requirements for Components Common to All Parts of CCS Ready

The above sections focused on consideration of components for the three elements of CCS Ready. This section discusses common components for CCS Ready:

- Cost estimates and economic analysis;
- Environmental, safety, and other approvals;
- Public awareness and engagement related to potential future capture, transport, and storage;
- Sources for equipment, materials, and services; and
- Ongoing obligations.

### 2.6.1 Cost Estimates and Economic Analyses for New Plants

The developer of a new or significantly modified plant may be asked to study the cost of CCS Ready and CCS retrofit at that plant, and the economic feasibility of such a retrofit in the future. The economic analyses would encompass capture, transport, and storage. An assessment of costs for a CCS Ready plant as well as the costs for retrofitting is important in: (a) assessing whether the CCS retrofit can be done at an "acceptable economic cost"; (b) determining eligibility for government incentives such as monetary grants, tax reductions, tax eliminations, tax postponements, and tax credits; (c) encouraging plant developers to fully understand the economics of CCS; and (d) facilitating a voluntary due diligence review on the part of the developer comparing the life-cycle costs of the plant versus other production or conservation options.

Overall GHG policy, relevant laws and regulations, and international obligations will influence the economic value of carbon mitigation and whether CCS will be found to be at an "acceptable economic cost" as proposed in the definition for CCS Ready. Under the UK CCR guidance rules, approval is dependent on the developer demonstrating reasonable scenarios under which operational CCS would be economically feasible.[26]

### Acceptable Economic Cost

All definitions of $CO_2$ Capture Ready, $CO_2$ Transport Ready, and $CO_2$ Storage Ready contain the term "economically acceptable," which refers to whether the integrated plant's cost is acceptable under the expected economic conditions within a jurisdiction. The plant's total cost for capture, transport, and storage would include costs for planning, construction capital, and operating costs, including the time value of money.

As an example, "economically acceptable" could be defined to mean that the total costs of CCS are within the range of X $/t$CO_2$e GHG mitigation costs expected to be undertaken by any economic sector in the jurisdiction sometime over the operating life of the CCS Ready plant. Alternatively, "economically acceptable" could be defined to mean that the total cost of a plant's products with CCS is acceptable to and can be absorbed by the marketplace, for example X$/kWh.

If a plant subject to CCS Ready requirements cannot show CCS at an economically acceptable cost, a jurisdiction may choose to require modification of location or design, or prohibit the plant's construction.

The level of requirements for such economic analysis can vary greatly and is linked to the level of technical analysis performed as part of the CCS Ready requirements. For example, a preliminary economic analysis (Level 1) will depend on the preliminary design developed for the capture, transport, and storage facilities. Similarly, a more detailed economic and cost analysis (Level 2) can be performed using information from technical feasibility studies. For Level 3, a follow-on economic analysis could be required based on detailed technical information and equipment lists provided in design basis memoranda.

The economic analyses will depend on specific economic drivers (e.g., tax rates, discount rates, tax incentives, other government incentives related to GHG policy, as well as emissions standards and mandates) and plant-specific data on capital, operating, and maintenance costs of the CCS system as well as impacts that the CCS system may have on pre-CCS plant production. Preliminary economic analysis (Level 1) could include:

- Capital cost estimates for constructing capture, transport, and storage facilities;
- Preliminary estimates for operating costs using current available capture technology;
- Preliminary estimates of the cost of transporting and storing[27] $CO_2$ for the capture plant (i.e., for power plants, estimates of costs in $/MWh for transport and storage could be required); and
- Comparison of the total cost of deploying CCS with the expected future economic value of carbon mitigation.

A more detailed economic feasibility study could include:

- Better estimates of capital and operating cost for capture and compression based on the technical details provided in the technical feasibility study (e.g., blueprints; equipment list;

[26] Paragraphs 64-65, page 24 of U.K. Department of Energy and Climate Change (U.K. DECC). (2009). *Carbon capture readiness (CCR): A guidance note for Section 36 Electricity Act 1989 consent applications* (Publication no. URN 09D/810). London, UK: Author.

[27] The cost of storage would also include cost estimates for monitoring and verification.

resource analysis for consumption of water, materials, and heat and power; performance analysis; construction process; etc.);

- Cost estimates for anticipated pre-investment of equipment;
- Cost estimates of required geological studies needed for exploration, characterization, and development of a storage site;
- Better estimates of the cost of transporting and storing $CO_2$, using information from the technical feasibility study; and
- An analysis of various scenarios (e.g., price of an emission unit) in which CCS retrofits for the plant are economically feasible.

The more stringent requirement (Level 3) could include a follow-on economic feasibility study based on technical information provided in the DBM.

In general, the developer would be required to provide available, non-proprietary cost data related to retrofitting the CCS plant, and if necessary could request for submitted data to be treated as confidential.

The degree of accuracy in the cost estimate, as well as the cost for preparing the economic analyses, increases with each successive level of CCS Ready requirements. Improving the accuracy of the cost estimates will provide greater information to regulators on whether CCS retrofits are ultimately economic to deploy. The downside of requiring more detailed cost analyses is that the project developer will incur additional upfront costs and that the data developed in the economic analysis will become unreliable over time as market conditions and prices for equipment, labour, and material change, or if CCS-related technologies evolve.

### 2.6.2 Environmental, Safety, and Other Approvals

One of the requirements for CCS Ready may be to have the project developer look forward into the future when retrofit may take place and to anticipate what environmental and other approvals will be needed at that time. This would be required so that the plans and designs for all CCS Ready facilities take into account those future approvals and thus avoid features that make obtaining those approvals very difficult. Therefore, the CCS Ready requirement of environmental, safety, and other approvals covers the following three levels:

- Identifying all approvals that will need to be obtained for retrofitting capture facilities;
- Conducting feasibility studies for obtaining all approvals for retrofitting; and
- Preparing key documents for obtaining all approvals.

As mentioned previously, technology may change during attainment of CCS Ready status and future retrofit. As a result, the required approvals, results of feasibility studies, and key documents may change throughout the planning process for eventual CCS. Exhibit 2-8 illustrates the types of approvals and permits that may be required for retrofit and operation of CCS. Seeking the approval or the issuance of permits for eventual CCS is not required for CCS Ready; however, at a minimum, the types of approvals and permits required for eventual retrofit should be identified.

Identifying the permits and approvals required for eventual CCS provides industry with an initial assessment of the extent of the approvals needed for CCS retrofit and the required time for obtaining such future approvals (e.g., obtaining permits to proceed with eventual CCS may take over a year). The feasibility studies for obtaining approvals indicate the likelihood and extent of the potential barriers that may prevent the plant from retrofitting to CCS. Under Level 3, the availability of the key documents for obtaining the approvals will expedite the process from CCS Ready to implementation of CCS. While the increasing requirements result in increases in costs to the developer for having the plant become CCS Ready, they also reduce the plant's financial risk in investing in processes that may not ultimately be approved.

**Exhibit 2-8: Aspects of CCS That May be Subject to Environmental and Safety Reviews**

| $CO_2$ Capture Plant | |
|---|---|
| ▪ Air<br>‣ Changes to emissions of local air pollutants (e.g. $NO_X$, $SO_X$) or toxic/hazardous air pollutants (e.g. mercury, lead) due to installation of exhaust gas cleanup (electronic precipitator, flue gas desulphurization system) or other modifications<br>‣ Potential air emissions from leaking of solvents<br>▪ Water<br>‣ Changes to effluent discharge due to $CO_2$ capture (e.g. potential introduction of monoethanolamine or other solvents)<br>‣ Liability or remediation provisions that might apply to accidental releases of chemicals or the $CO_2$ stream to land or water | ▪ Water (cont.)<br>‣ Availability of additional water to accommodate plant modifications<br>▪ Safety and storage<br>‣ Storing of monoethanolamine or other chemicals for capture<br>‣ Permits needed if the $CO_2$ stream is classified as a solid or hazardous waste<br>‣ Emergency planning or right to know laws triggered by potential storage of solvents or compressed $CO_2$ stream<br>‣ Equipment and system design<br>‣ Operational performance |
| **$CO_2$ Transport Corridor** | |
| ▪ Approving rights of way for pipelines<br>▪ Construction, maintenance, and operation<br>▪ Special permits for pipelines through populated or protected areas | ▪ Emergency planning, right to know, and cleanup laws governing pipeline leaks<br>▪ Classification of $CO_2$ stream and implications for permits/regulations<br>▪ Pipeline integrity (material corrosion, hydrate formation, propagating fractures) |
| **$CO_2$ Storage Site** | |
| ▪ Suitability of location<br>‣ Existence and integrity of cap/seal<br>‣ Leakage Risk (including potential impacts)<br>‣ Potential impacts to underground sources of drinking water<br>‣ Potential impacts to hydrocarbons<br>‣ Geologic stability of location (e.g. low seismic activity)<br>▪ Operation and monitoring<br>‣ Wellhead pressure, well integrity tests<br>‣ Reservoir pressure monitoring | ▪ Operation and monitoring (cont.)<br>‣ Air sampling and analysis<br>‣ Underground water sampling, formation fluid sampling<br>‣ Flow metering<br>‣ Seismic monitoring<br>▪ Mitigation planning<br>‣ Injection well failures<br>‣ Unintended migration of $CO_2$ plume outside of injection zone<br>▪ Siting, construction, operation and monitoring, and closure<br>▪ Emergency planning or right to know laws |

## 2.6.3 Public Awareness and Engagement

Experience to date indicates that lack of community awareness and lack of eventual acceptance of industrial development, transport, and storage activities located near significant populations or in pristine areas could delay or restrict project deployment. Including some form of public awareness and engagement as part of CCS Ready requirements will foster early government and industry cooperation in providing the public with information on the technical matters related to CCS and how CCS will play a significant and safe role in overall GHG mitigation. This approach may increase support for CCS among the public. The alternative of not engaging the public early risks a backlash that can seriously delay or eliminate the prospect of realizing a CCS or even a CCS Ready project.

The several gradations of public awareness and engagement include:

- Notifying the public of eventual CCS retrofit projects via web site and other actions during the early planning phase of the power or industrial plant;
- Actively seeking public participation in the power or industrial plant planning process through public/community meetings, information sessions, and through engagement with the environmental NGO community; or
- Encouraging public engagement in the regulatory approval processes for environmental clearances and CCS Ready certification, if applicable.

Key criteria to evaluate the most appropriate level of public awareness and engagement for CCS Ready within a jurisdiction include:

- Degree to which projects will be located in pristine, ecologically/historically sensitive, or populated areas;
- Historical acceptance or resistance to new technologies or industrial practices and projects;
- Overall public awareness of CCS Ready or CCS practices, technologies, and risks;
- Degree to which land rights need to be leased or obtained (e.g., for surface equipment, rights of way for $CO_2$ pipelines) and the amount of lands that would be affected;
- Level of commitment of the local/general community to low emissions outcomes for energy use, and their awareness of the potential environmental benefits of a reduction in $CO_2$ emissions globally;
- Effect of project(s) on electricity prices faced by ratepayers; and
- Expected public benefits of future CCS project(s), such as employment opportunities and other positive economic impacts to a community.

Examples of specific public engagement activities that can be undertaken to meet CCS Ready requirements include the following:

- Conducting outreach to potentially affected communities to provide information about CCS Ready and CCS technologies, their risks, and which laws or requirements are in place to minimize risks to human health or the environment;
- Engaging the community early in the project (i.e. during the planning stage), and maintaining engagement throughout the project lifetime,
- Providing access to information about CCS Ready projects and eventual CCS projects in local languages;
- Explanation in basic terms the concept of CCS, so there is full transparency of the procedures to be taken;

- Communicating to the local community the benefits of future CCS projects, such as job creation, stimulus to the local economy, and decreases in local air pollution;
- Contacting landowners to assess potential for buying or leasing land; and
- Providing local communities several opportunities to raise concerns, and addressing those concerns in a timely manner.

The timing, types, and extent of the public engagement activities depend on the level of engagement that is considered appropriate. Public awareness and engagement increase as the number of activities and the associated developer's costs for engagement increase. However, such increases in the level of awareness may also ultimately create a barrier to eventual CCS deployment. Nonetheless, gauging the level of acceptance by the public during the power or industrial plant design phase will help in identifying the extent of any potential public outcry that could ultimately stall an eventual CCS retrofit. A disadvantage of limiting requirements to Level I (i.e., only notifying the public and, hence, the public is not provided an opportunity for engagement) is an increased likelihood of backlash that could otherwise have been managed had an opportunity for engagement been provided.

### 2.6.4 Sources for Equipment, Materials, and Services

A CCS retrofit or new build will require a range of equipment and activities by different manufacturers and contractors. Provisions in CCS Ready may include requirements that a developer identify sources (i.e., companies or organizations) that can provide such equipment and services. Identification of sources for equipment, materials, and services more fully demonstrates the technical feasibility of the CCS plan[28] and minimizes delays in obtaining such equipment and services at the time of retrofit. The identified sources could build and operate the facilities and provide "full services" for transport or storage to the plant operator or help the plant developer design, build, and operate CCS-related facilities to be owned by the developer. Requirements to identify potential business partners and relationships may be most needed where plans include the intent to use new or unique technologies or contract for operational services from entities that are not owned by the project developer.

The levels for documenting sources for equipment, materials, and services include:

- No requirements;
- Compile a list of companies that can supply construction and operation services to capture facilities, supply equipment, materials and/or services needed for construction and operation of $CO_2$ transportation and storage; and
- Contact companies and negotiate nonbinding letters of intent to bid on project.

The increased level of detail and contact with companies will reduce the risk of construction delays once CCS is undertaken, and reduce the risk of plants being planned with capture technology but no feasible options for $CO_2$ transport and storage. The increased levels of requirements will increase the developer's upfront costs and time for meeting the requirements for CCS Ready.

[28] The CCS plan is as defined by the technology selection, design for capture facilities, transport corridor selection, design of transport facilities, storage site selection, and design of storage facility.

### 2.6.5 Ongoing Obligations

Even if a plant is deemed to be CCS Ready prior to its construction, ongoing annual statements can be used to confirm the level of preparedness and potential for CCS retrofit and higher levels of CCS Ready status. For example, the updates could document that space is being preserved at the plant and that access to land for transportation rights of way and storage sites is still available. Potential options include:

- File periodic reports with regulators on the status of Capture, Transport, and Storage Ready (see Exhibit 2-9); or
- In addition to filing periodic reports, respond to mandatory trigger mechanism to begin retrofitting capture facilities.

Level 3 CCS Ready would be implemented if the general GHG policy includes a mandatory trigger for actual implementation of CCS. A trigger mechanism could be based on date (i.e., to implement CCS after a certain date) or on certain circumstances (e.g., to implement CCS based upon a specific CCS commercialization threshold—for example, if more than five large-scale CCS demonstrations have been completed in a jurisdiction, then all future projects need to deploy CCS).

Filing periodic reports (e.g., annual reports) helps to ensure that the plant remains CCS Ready, in particular in situations where the plant changes ownership or the organizational structure of the plant's owner changes. Although the developer incurs a cost to file periodic reports, reporting can be advantageous to the developer as it will need to periodically revisit whether implementation of its CCS Ready plan is still feasible. This type of periodic review will also reduce the risk that investments are wasted (e.g., ensuring that suppliers of commercial $CO_2$ transport are still in business).

**Exhibit 2-9: Illustrative Sample of Potential Reporting Requirements for Ongoing Obligations**

| CO2Capture Ready Plant | |
|---|---|
| ▪ Confirmation that transport to storage areas is still potentially feasible<br>▪ Confirmation that capture technology is still applicable to plant (i.e., no major modifications have been made to plant such that previously identified capture technologies are no longer applicable) | ▪ Confirmation that sufficient space is still available for needed equipment and construction zone |
| **$CO_2$ Transport Ready Plant** | |
| ▪ Confirmation that potential feasible transport method is still applicable<br>▪ Confirmation that pipeline or other shipping route is still feasible and status of contractual options | ▪ Changes to conflicting land use activities<br>▪ Changes to transport design, if any |
| **$CO_2$ Storage Ready Plant** | |
| ▪ Changes to estimates of $CO_2$ to be captured and stored, if any<br>▪ Status of contractual options to one or more appropriate storage sites<br>▪ Changes to applicable regional prospectivity, injectivity, capacity, or integrity studies, if applicable | ▪ Changes to storage design, if any<br>▪ Changes to conflicting surface and subsurface uses, if any |
| **Common Components** | |
| ▪ Revisions to cost estimates based on design modifications, if any<br>▪ Confirmation that identified needed approvals for eventual CCS have not changed, and if they have changed, identified revised needed approvals | ▪ Status of public awareness and engagement<br>▪ Changes in status of sources for equipment, materials, and sources |

# 3. Implementing CCS Ready Policy

Implementing CCS Ready policy will include establishing a regulatory regime (including assigning regulatory responsibilities, and writing and approving regulations) and deciding whether and when compliance exemptions are warranted. A regulatory approval process may also be needed for verifying compliance with CCS Ready requirements. Other processes include reporting and recordkeeping, and provisions for public outreach and communications programs such as professional training for industry and government officials.

## 3.1 Setting up Regulatory Processes

Implementation of CCS Ready policy will require the establishment of several elements, starting with the designation of a regulatory body with administrative responsibilities. If the chosen CCS Ready policy is a mandatory CCS Ready requirement to show readiness before construction can commence, the lead regulatory body can be an agency that already is responsible to review and approve the construction of power and industrial plants. This approach would allow CCS Ready regulations to be integrated with existing approval processes, thus reducing the likelihood of large new administrative burdens. If the CCS Ready policy depends on economic incentives, the lead agency might be a tax authority or an economic regulator. If the CCS Ready policy consists entirely of voluntary programs and educational initiatives, the lead organization might be an educational or research agency that could work cooperatively with industry associations and other professional organizations. Alternatively, a separate agency that specializes in CCS could be created.

The chosen regulatory body needs to have several kinds of technical expertise. For example, assessing Capture Ready plants requires that regulators be familiar with plant design, know how to assess blueprints, and be able to assess whether the space allotted for capture facilities is sufficient. The need for geological expertise is particularly critical for regulators in developing the guidelines and regulations for a Storage Ready plant, as well as for geological storage in general. Regulators would need to ensure that the guidelines and regulations are consistent with practices of geological agencies and/or oil and gas licensing authorities within their jurisdictions. Development of a $CO_2$ transportation network could require governmental support (for planning and possibly for financing), and regulators may have to play an important role in developing a national or regional $CO_2$ transportation network, perhaps controlling issues of competition for pipeline capacity and disputes over third-party access.

The lead regulatory body would also have to coordinate CCS Ready regulations with other appropriate agencies. Depending on the jurisdiction, the siting and approval of new power plants may involve several regulatory bodies, such as environmental agencies, economic regulatory boards, oil and gas licensing, and land use and zoning commissions. These regulatory bodies could operate at the national, state/province, or local levels.

Another element of the regulatory process is developing specific CCS Ready regulations or guidance describing the criteria and processes for either demonstrating compliance or seeking an exemption from CCS Ready requirements. This process will differ across jurisdictions, with each jurisdiction following its own internal rules for developing regulations or guidance, including performing any necessary technical or cost-benefit analyses and soliciting public comments.

In some cases, a jurisdiction may choose to exempt certain plants from CCS Ready compliance. For example, in areas where storage of $CO_2$ is not feasible because of geologic restrictions, it may be appropriate to grant project developers an exemption to being CCS Ready. Keeping the goal of the overall GHG policy in mind, the granting of exemptions could be contingent on a developer demonstrating an alternative strategy to reduce GHG emissions.

## 3.2 Verifying Compliance

Assuring compliance is a necessary and important part of policy implementation. Methods for verifying compliance at CCS Ready plants may include the following:

- A jurisdiction may verify CCS Ready compliance for new plants at the design stage, after the plant has been built, and during plant operations;
- For existing plants that plan significant modifications and comply with CCS Ready requirements, a jurisdiction may review the modification designs, the "as modified" plants, and the operating plants; and
- Developers of plants may be asked to maintain records for defined time periods and report periodically on their CCS Ready status.

Exhibit 3-1 illustrates these options, which include verifying compliance for new plants prior to construction ("design" phase), after construction or modification ("as built") but before operations, and once the plant is operational ("operating"), and periodically thereafter. The compliance mechanisms used need not be the same at these different points in time, and may vary depending on the chosen requirements for CCS Ready.

**Exhibit 3-1: CCS Ready Compliance Verification**

| | Design | As Built | Operating |
|---|---|---|---|
| $CO_2$ Generating Plant | ✓ | ✓ | ✓ |
| $CO_2$ Transport Facility | ✓ | N/A | N/A |
| $CO_2$ Storage Facility | ✓ | N/A | N/A |

A potentially efficient approach could be to assess plant designs and modifications (e.g., to obtain the needed space) during a pre-construction permitting, approval, or siting process. In this way, the plans or designs for new or modified plants may be compared with CCS Ready requirements prior to construction or retrofit. Documentation can take the form of detailed architectural drawings for the plants to be built or modified. The drawings will help the regulator evaluate compliance of the design with CCS Ready requirements.

A related option is for a qualified independent third party, working for the regulatory agency, to certify the plans as CCS Ready. For example, a certified engineer's report may be used to demonstrate compliance with CCS ready requirements. The cost of such third-party review might be borne by the plant developer, even though the work is supervised by the regulatory agency.

Review of the "as built" plant for compliance with CCS Ready requirements may be valuable, as it is not uncommon for "as built" plants to deviate from original plans and designs. A review after construction or modification of the plant (and before operations) allows for confirmation of compliance with CCS Ready requirements. As noted above, the regulator may choose to rely on an engineering report for the "as built" plant or may perform a site inspection. It may also be desirable for regulators to confirm CCS Ready compliance again after the plant has begun commercial operations to ensure that any operation-related issues are addressed.

Periodic documentation and updates on the CCS Ready status of the plant will demonstrate ongoing compliance with CCS Ready requirements. Therefore, it will be beneficial for developers and operators of CCS Ready plants to report appropriate information (e.g., sampling, testing, photographs, reports, and other evidence) on a periodic basis to inform the regulator in advance of any changes to the plant's operations that have implications for CCS Ready.

The highest level of CCS Ready assurance will arise from requiring both periodic and event-based reporting. This level of reporting ensures that, in addition to regular periodic communication, the regulator is also notified when a need for re-evaluation of the plant's CCS Ready status occurs (e.g., the operation of the plant will change in some significant fashion or the anticipated storage site is found to be inappropriate). By receiving such information, the regulator is able to stay informed regarding the CCS Ready status of a facility and can intervene should a report indicate that the operator is no longer in compliance with CCS Ready requirements.

## 3.3 CCS Ready Policy Outreach and Communication with Stakeholders

Even after a CCS Ready policy has been determined, continued outreach and discussions with industry and other stakeholders remain valuable. Stakeholders include host country governments, industries, investors, NGOs, research institutions, local communities, the general public and international organizations. Outreach and consultation activity with stakeholders will differ from earlier identified mechanisms, and could focus on explaining the CCS Ready policy and promoting it as an element of sound long-term business planning. The audience for this outreach and communication may be much larger than the group of stakeholders involved in the initial development of the CCS Ready policy. This broader audience may include all stakeholders interested in the siting and nature of the facilities subject to the CCS Ready policy, including transportation and storage. Outreach is especially important for a relatively new technology such as CCS. Improving the understanding of a CCS Ready policy will assist in gaining the confidence of regulators, educators, industries, investors, and the general public in CCS as a desirable mitigation option.

Training and capacity building are important elements of outreach and communication. Key audiences for training include government regulators responsible for implementing CCS Ready and industry professionals who are responsible for complying with CCS Ready policy.

Key outreach to regulators and other stakeholders includes responses to several questions:

- How do CCS and CCS Ready fit into decisions in energy and industrial planning and GHG mitigation?
- What are the barriers for CCS deployment?

- What are the requirements for CCS Ready? What actions, studies, tests, or documentation are required to demonstrate that a plant is CCS Ready? When might CCS eventually be adopted?
- What are the options for being CCS Ready? How will being CCS Ready affect plant performance? What technologies will enable a plant to be CCS Ready?
- How much extra will designing a plant to be CCS Ready cost? Will financial incentives be available for project financing?
- What will CCS on a particular plant do to product prices in the marketplace? What will CCS on multiple plants do to product prices? What will be the effect on product prices if ultimate CCS targets for the jurisdiction are achieved?
- What are the activities required to show that a plant has met CCS Ready requirements?

Outreach to developers and operators of power plants and industrial facilities on CCS requirements and other information will assist them in making investment decisions about whether and where to build, what type of plant to construct or modify, and what future GHG mitigation options will be. Examples of information needs include:

- CCS Ready design options;
- Financing available for CCS Ready plants;
- Value in making a plant CCS Ready, compared with investing in an alternative technology or investing elsewhere;
- Qualifications to seek among engineering firms to build capture plants, transport $CO_2$, and conduct storage site characterization; and
- Advances or changes in CCS technologies, resources, costs, financial incentives, or laws that affect future investment decisions.

With a nascent technology like CCS, project developers may not even be aware of the services available from various operators in the market, including manufacturers, retailers, industry, utilities, service and product providers, small businesses, and contractors. Thus, there is a need to gather and disseminate information the services these market actors provide and the regions in which they operate.

Encouraging the sharing of knowledge is critical to breaking down institutional and knowledge barriers among industries. In particular, industries that have no or little exposure to subsurface processes would benefit from understanding the subtleties, uncertainties, and complexities of the geological environment.

# 4. Summary of Considerations and Recommended Practices

In designing and implementing a CCS Ready policy, policymakers and regulators play different but equally important roles. In general, policymakers will develop the general CCS Ready policy to reach specific desired outcomes. Typically, regulators will focus on implementing the CCS Ready policy by writing and administering regulations. The considerations and recommended practices for policymakers and regulators presented in this report are summarized below.

## 4.1 Considerations and Recommended Practices for Policymakers in Developing CCS Ready Policy

### Integration of CCS Ready with Other GHG Policy

- A well-designed CCS Ready policy will be linked to the goals and provisions of a jurisdiction's existing or potential GHG policy, which may promote CCS through technology mandates, emissions performance standards, financial penalties, or economic incentives.
- A CCS Ready policy is most appropriate when drivers toward CCS exist or are expected soon. However, a CCS Ready policy may also be called for in jurisdictions that wish to create and preserve the option for future low-cost CCS retrofits, if and when a general GHG policy is adopted.
- The details of a CCS Ready policy can vary among jurisdiction, depending on the status and provisions of broader GHG policies, sources and volumes of GHG emissions, level of required GHG emissions reductions, and the economics of CCS and other available GHG mitigation options.

### Evaluation of Economic Case for CCS Ready

- The economic case for CCS Ready is that the higher upfront costs (which can be minor) are offset by lower adaptation costs for the plant to later add CCS to mitigate GHG emissions. In other words, by investing early in making a plant CCS Ready, the developer would experience a lower-cost CCS retrofit that can be (but does not have to be) implemented sometime during the plant's operating life.
- A CCS Ready policy is intended to facilitate a rapid and lower-cost transition to CCS by industries and types of plants that have a reasonable chance of retrofitting to CCS.
- Basing a CCS Ready policy (including the subject industries and types of plants) on an economic rationale ensures a reasonable chance that the policy will reduce total long-run costs (including the time value of money) of complying with the jurisdiction's general GHG policy.

### Mechanisms for CCS Ready Policies and Roles and Responsibilities

- Potential mechanisms for implementing a CCS Ready policy include mandates to become CCS Ready, emissions standards that tighten over time, economic incentives for readiness, and voluntary education and certification programs. When oriented toward a jurisdiction's broader GHG policy, the mechanisms' effectiveness is enhanced.

- Working cooperatively with industry and professional organizations to determine the appropriate criteria for demonstrating CCS Ready will facilitate industry acceptance of a CCS Ready policy.

### Defining Requirements for CCS Ready

- A well-designed CCS Ready policy will have a three-part definition including $CO_2$ Capture Ready Plant, Transport Ready Plant, and Storage Ready Plant.
- Various jurisdiction-specific analyses—such as evaluating the advantages and disadvantages of different levels of CCS Ready requirements—will assist a jurisdiction in determining appropriate levels of stringency for the CCS Ready policy.
- Clear delineation of roles and responsibilities for implementing a CCS Ready policy will allow coordination between government and industry, as well as among multiple government regulatory agencies.
- Key criteria for defining Capture Ready include plant siting, evaluation of capture technologies, plant design and necessary space allowance, and any required equipment pre-investment for future capture facilities.
- Being ready for CCS makes plant siting more complex as capture, transportation, and storage of $CO_2$ must be considered holistically to determine the optimal location.
- Key criteria for defining Transport Ready include evaluations of transport method(s), assessment of transport corridors, and preparation of transport facility designs and cost estimates.
- Key criteria for defining Storage Ready include evaluations of siting; injectivity, capacity, and integrity of a storage site; design of storage facilities; and assessment of competing uses of the surface and subsurface areas at the site.
- Criteria common to Capture, Transport, and Storage Ready definitions include preparation of cost and economic analyses; assessment of needed future environmental, safety, and other approvals; initiatives for public awareness or engagement; assessment of sources for material, equipment, and services that will be needed for CCS; and periodic reporting obligations.

## 4.2 Considerations and Recommended Practices for Regulators in Implementing CCS Ready Policy

### Regulatory Processes

- Implementation of a CCS Ready policy requires that roles and responsibilities be made clear for regulatory agencies such as environmental agencies, economic regulatory bodies, and land use and zoning commissions.
- CCS Ready implementing regulations developed with stakeholder input are more likely to be successful.
- Adoption of CCS Ready will be accelerated by government-provided guidance and information to project developers to aid site selection and facilities planning, including locations and characteristics of suitable storage sites and planned $CO_2$ pipeline locations.

- Developing a common understanding of the amount of work and associated timeframes required for screening and selection of CCS Ready storage sites will assist regulators and developers in establishing feasible requirements and ultimately meeting compliance requirements.
- Government support for developing regional scale prospectivity studies (if they do not already exist) should speed up the identification of suitable sites and facilitate the coordination among CCS Ready plants and storage sites in siting CCS Ready facilities.

## Verifying Compliance

- Methods to verify and ensure compliance with CCS Ready regulations need not be onerous.
- Any CCS Ready compliance exemptions should be narrowly drawn to avoid undercutting the goals of a jurisdiction's CCS Ready policy.

## Outreach and Communication

- Government, industry, and interested NGOs can design and implement outreach programs communicating the value of a CCS Ready policy in order to reduce potential barriers and resulting time delays.

# Appendix A: Acronyms

| | |
|---|---|
| BAU | Business as Usual |
| CCR | Carbon Capture Readiness |
| CCS | Carbon Dioxide Capture and Storage |
| CCS Ready | Carbon Dioxide Capture and Storage Ready |
| $CO_2$ | Carbon Dioxide |
| CSLF | Carbon Sequestration Leadership Forum |
| DBM | Design Basis Memorandum |
| EGR | Enhanced Gas Recovery |
| EOR | Enhanced Oil Recovery |
| FEED | Front End Engineering and Design |
| GHG | Greenhouse Gas |
| GIS | Geographic Information System |
| IEA | International Energy Agency |
| kWh | Kilowatt Hour |
| MW | Megawatt |
| MWe | Megawatt Electrical |
| MWh | Megawatt Hour |
| NETL | National Energy Technology Laboratory |
| NGO | Non-Governmental Organization |
| $NO_X$ | Nitrogen Oxide |
| $SO_X$ | Sulphur Oxide |
| SSSI | Sites of Special Scientific Interest |
| US DOE | US Department of Energy |

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