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ISSUEBRIEF

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ENERGY AND ENVIRONMENT PROGRAM

The Business Case for Carbon Capture, Utilization and Storage

This issue brief is one in a series the Atlantic Council is publishing on carbon capture, utilization, and storage (CCUS), a business-driven path and US Department of Energy (DOE) policy to promote carbon dioxide (CO_2) capture and storage. It discusses the unique opportunity the country faces to capitalize on CO_2 enhanced oil recovery (CO_2-EOR) to reduce both foreign oil imports and domestic CO_2 emissions, and to generate significant economic activity. It also examines CCUS economic issues, including CO_2-capture costs, project risks, and emerging business models. Three additional Atlantic Council CCUS issue briefs include: *US Policy Shift to Carbon Capture, Utilization, and Storage Driven by Carbon Dioxide–Enhanced Oil Recovery; Key US Policy Proposals to Advance Carbon Dioxide–Enhanced Oil Recovery and Carbon Capture, Utilization, and Storage, and Deployment* and *Key Developments in Carbon Capture, Utilization, and Storage: A Fifteen-Year Look Back and What Lies Ahead.*

The **Energy and Environment Program** at the Atlantic Council explores the economic and political aspects of energy security and supply, as well as international environmental issues. Major shifts in policies, behavior, and expectations are increasingly required throughout the world to meet the challenges of maintaining secure and sustainable energy supplies and protecting the environment while maintaining economic competitiveness. The Energy and Environment Program facilitates international cooperation on developing strategies, policies, and regulations to address the energy security, environmental and economic challenges posed by increasing energy demands and climate change.

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CO_2- EOR as a National Strategy for CCUS

CCUS is a business-driven path and US DOE policy that will enable private investment to flow toward projects that contribute to reductions in US oil imports and CO_2 emissions, and provide an engine for economic growth and job creation. The primary CO_2 utilization opportunity is CO_2-EOR, a commercially mature technique that injects CO_2 into depleted reservoirs to produce incremental oil that would have otherwise been left in the ground after the use of conventional methods. Essentially all of the injected CO_2 (after some recycling) remains in the reservoir rocks upon closeout of the operation, thus providing the added benefit of CO_2 storage.

Crude oil production from CO_2-EOR has increased 40 percent over the last six years, and has tremendous potential for continued growth. In 2012, 123 CO_2-EOR projects in the United States will produce about 350,000 barrels of oil per day (6 percent of domestic oil production), using approximately 62 million metric tons (Mt) of CO_2 (see Figure 1) (Koottungal, 2012; Kuuskraa, 2012). A number of CO_2-EOR projects are approaching CO_2 utilization rates on

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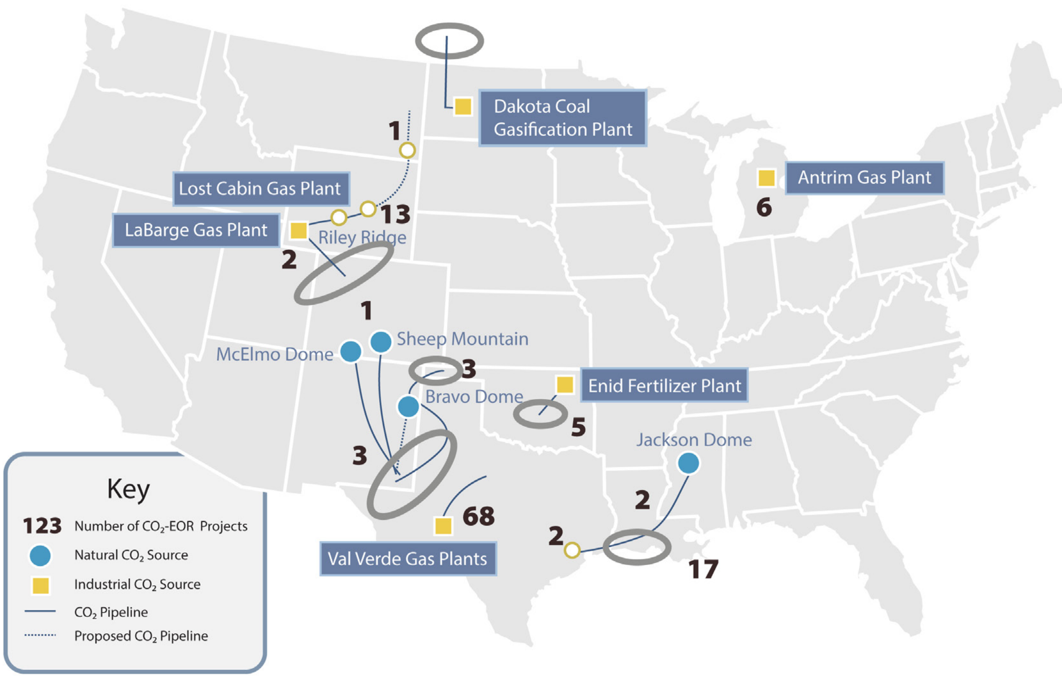
Figure 1: Current US CO_2-EOR Activity

Source: Adapted from Kuuskraa, 2012.



CO_2 supply is the limiting factor in the expansion of CO_2-EOR. While West Texas is currently home to most of the nation's CO_2-EOR activity, there are a number of regional clusters at different levels of market readiness. States are playing key roles to enable pipeline development and capitalize on CO_2-EOR and long-term storage opportunities.

par with the amount of CO_2 produced by a 500-megawatt (MW) pulverized coal-fired power plant (3 to 4 Mt per year). Most of the current CO_2 supply (~80%) is delivered from naturally occurring CO_2 deposits via CO_2 pipelines; however, these sources, and the pipeline network, are constrained (DiPietro, et al., 2012). Any significant growth in CO_2-EOR will need to tap CO_2 captured from anthropogenic (man-made) sources—power plants, industrial, or polygeneration facilities—supported by a build-out of the country's existing CO_2 pipeline network (currently more than 4,000 miles).

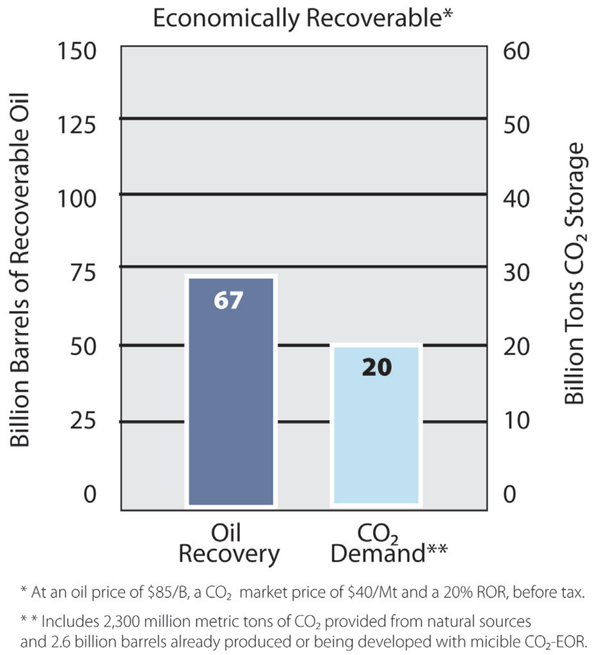
Assessments of CO_2-EOR potential conducted by Advanced Resources International, Inc. (ARI) on behalf of the DOE indicate that about half of the large US oil fields are amenable to CO_2-EOR. Approximately 67 billion barrels of oil are economically recoverable, which would create demand for 20 billion tons of CO_2 that would ultimately be stored (see Figure 2) (ARI, 2011). Each oil field and CO_2 flood is different, and the amount and rate of CO_2 utilization varies; however, a typical reservoir will store about 0.25 metric tons of CO_2 for every barrel of oil produced. After refining, a barrel of oil contains about 0.30 metric tons of CO_2; therefore, using today's technology, CO_2-EOR stores about 80 percent of the CO_2 content of a barrel of oil. With advanced CO_2-EOR designs and "next generation" technology, CO_2 storage can be optimized, and it becomes possible to store over 100 percent of the CO_2 content in the produced oil.

New research and field experiments have also identified the feasibility of using CO_2-EOR in partially oil-saturated structures known as the Residual Oil Zone (ROZ), which could expand CO_2 utilization, oil recovery, and CO_2 storage by orders of magnitude (Melzer, 2006). The DOE is supporting further analysis to better determine the scale of the opportunity; however, initial estimates indicate that CO_2-EOR in the ROZ could yield another 33 billion barrels of oil (for a total of at least 100 billion barrels) (ARI, 2011).

There is no single CO_2-EOR market in the United States; rather, there are a number of regional clusters at different

Figure 2: Domestic Oil Supplies and CO_2 Demand (Storage) Volumes from "Next Generation" CO_2-EOR Technology

Source: ARI, 2011.



Significant volumes of anthropogenic CO_2 are needed to support CO_2-EOR expansion. The amount of CO_2 stored is a function of technology and economics; however, a typical reservoir using today's technology will store about 80 percent of the CO_2 content of a barrel of oil. With "next generation" technology, it is possible to store over 100 percent.

levels of market readiness. As shown in Figure 1, current operations are generally limited to three corridors: the Permian Basin of West Texas and New Mexico (about 61 percent of all CO_2-EOR activity); the Rocky Mountain states (~12 percent); and Mississippi and Louisiana (~14 percent). There are a number of areas throughout the country with significant potential, which can be broken down into three primary market segments: 1) regions with active CO_2-EOR operations where infrastructure has been bought and paid for; 2) areas with nominal pipeline infrastructure in which CO_2-EOR opportunities are within striking distance (50 to 100 miles) from existing pipelines; and 3) regions with CO_2-EOR potential and candidate CO_2 sources but lacking pipeline networks. New CO_2 sources will drive broad-based EOR growth both in volume and in new locations across the United States; however, technology advancements and a robust CO_2-EOR policy are critical to optimize both CO_2-EOR and carbon storage.

Using "next generation" technology, the CO_2-EOR industry, over the next thirty years, could develop a market greater than $1 trillion for CO_2 captured from fossil fuel power plants and industrial facilities, create 2.5 million jobs, reduce imported oil by 30 to 40 percent, and generate domestic economic activity equal to $6.8 trillion (see Table 1) (ARI, 2011). Additionally, approximately 25 billion metric tons of anthropogenic CO_2—that would have otherwise been vented into the atmosphere—could be permanently stored. While these estimates are subject to certain assumptions and some uncertainty, the potential for CO_2-EOR in the current market environment is significant. Furthermore, in the absence of carbon pricing mechanisms, CO_2-EOR presents the only major commercial pathway, and offers a viable national strategy for CCUS.

Table 1: Distribution of Revenues from "Next Generation" CO_2-EOR

Source: ARI, 2011.

Revenue Recipient	Value Chain Function	Revenues	
		Per Barrel ($)	TOTAL ($ billion)
Power/Industrial Companies	Sale of Captured CO_2 Emissions	$14.10	$1,130
Federal/State Treasuries	Royalities/Severance/Income Taxes	$19.80	$1,580
US Economy	Services, Materials and Sales	$26.50	$2,120
Other	Private Royalties	$7.70	$620
Oil Industry	Return of/on Capital	$16.90	$1,350
	Total	**$85.00**	**$6,800**

With a robust CO_2-EOR Policy and "next generation" technology, the CO_2-EOR industry is poised to reduce foreign oil imports by 30 to 40 percent, and generate overall domestic revenues and economic activity equal to $6.8 trillion

Emerging CO_2 Supplies

The key to expanding US CO_2-EOR and carbon storage is the ability to drive costs down throughout the CCUS chain in order to meet CO_2-EOR business case economics. CO_2-capture costs are expected to account for roughly 70 percent of total costs (assuming 85 to 95 percent CO_2 capture), with transportation and storage at 20 percent and 10 percent respectively. Figure 3 provides a cost curve for various anthropogenic CO_2 sources, many of which are in reasonable proximity to CO_2-EOR fields (Dooley, 2010). CO_2 from ammonia production and natural gas processing offer some of the lowest costs, but volumes are limited. Conversely, coal-fired power plants offer the greatest volume of CO_2, but the cost of capture is on the high end of the cost curve.

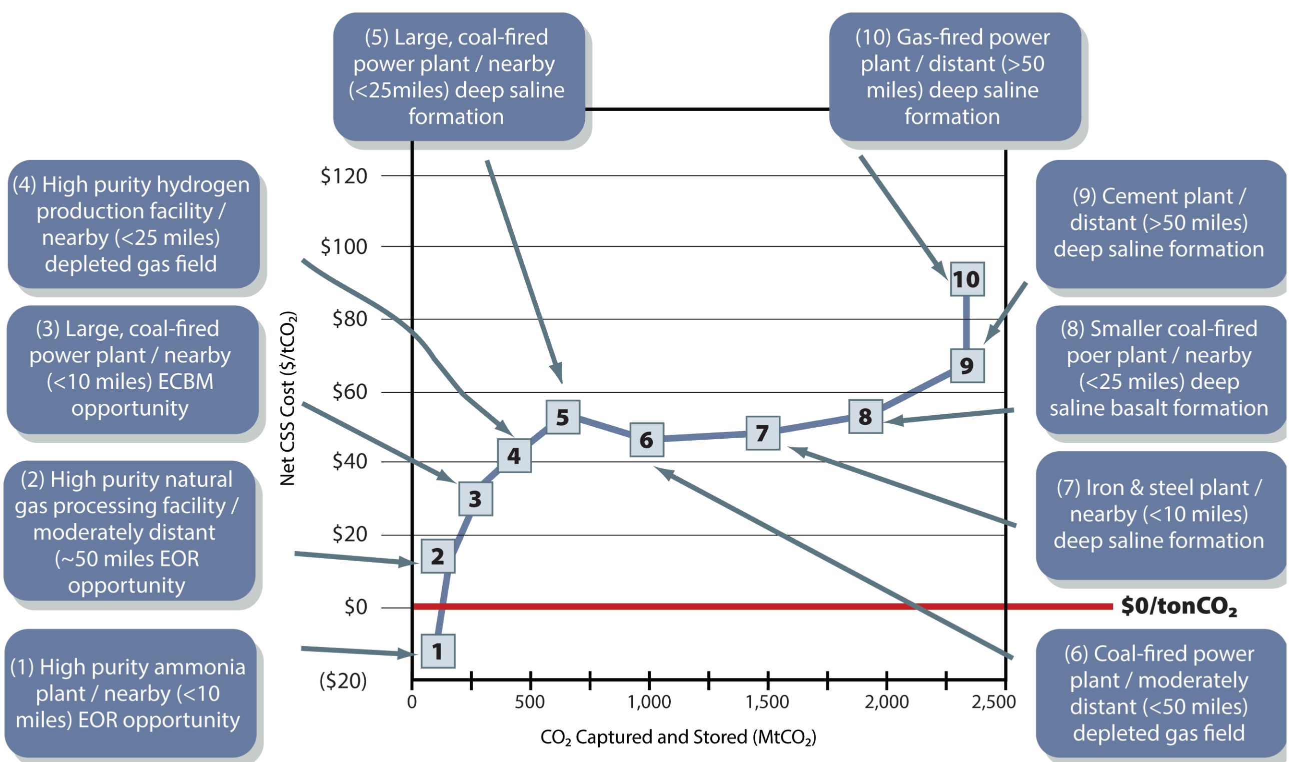
The price CO_2-EOR operators pay for CO_2 varies by region and is negotiated on a project-by-project basis. Routinely, the CO_2 price is indexed to the price of West Texas Intermediate (WTI) crude oil. As a rule of thumb, CO_2-EOR operators are accustomed to paying about 2 percent of the WTI oil price for CO_2 compressed and delivered to the oil field (or 38 percent of the oil price on a CO_2 per ton basis). For example, with crude oil priced at $100, this equates to $2 per thousand cubic feet (Mcf), or about $38 per metric ton of CO_2 (to convert 1 Mcf of CO_2 to metric tons, divide the Mcf by approximately 19.2).

In order to capture CO_2, it must first be separated from other gases in the flue stream, purified, and compressed for pipeline transport. (CO_2 specifications for EOR vary, but CO_2 purity of 95 percent or more is typically required.) Most large emission sources (e.g., fossil fuel power plants) have CO_2 concentrations of less than 15 percent, which makes CO_2 capture from these dilute streams both energy- and capital-intensive. A number of industrial and fuel production processes result in CO_2 as a by-product, and concentrations can range between 30 to 95 percent. Removal of CO_2 from these gas streams is more straightforward and less costly than CO_2 captured from power plant flue gas because of smaller volumes, lower temperatures, higher pressures, and fewer impurities.

Commercial CO_2 capture is currently being used in a number of industrial applications worldwide, with more

Figure 3: Net Cost of Employing CCUS within the United States—Current Sources and Technology

Source: Dooley, 2010.



There are a number of lower-cost anthropogenic CO_2 capture opportunities within reasonable proximity of EOR fields; however, the most abundant sources (e.g., coal-fired power plants) have much higher capture costs than what EOR operators are accustomed to paying for CO_2.

than twenty-five years of cumulative experience with ongoing integrated CCS projects that include CO_2 monitoring for permanent storage (e.g., Sleipner and Snøhvit in Norway; Weyburn in Canada; and In Salah in Algeria) (GCCSI, 2011). However, CO_2 capture for power plant applications has been slower to develop. In June 2011, Southern Company began operating the world's first CO_2-capture demonstration on a post-combustion coal-fired power plant. The 25 MW unit at Plant Barry in Alabama uses a commercially proven, proprietary solvent from Mitsubishi Heavy Industries to capture approximately 500 metric tons of CO_2 per day (~150,000 metric tons per year). In September 2012, the integrated operation commenced. The captured CO_2 is transported via a twelve-mile pipeline to the Citronelle Dome, where it is injected into a deep saline formation under a storage test project managed by the DOE's Southeast Regional Carbon Sequestration Partnership (SECARB).

All three CO_2-capture approaches (pre-combustion, post-combustion, and oxy-fuel) will be demonstrated on a large scale at different base plants (three industrial and five power or polygeneration plants) under a US DOE and industry cost-shared program (see Table 2). The capture technologies selected are considered first-generation, and are commercially proven, but have not been operated at this scale in an integrated CCUS system. In parallel, a number of second-generation or potentially "breakthrough" capture technologies (e.g., novel solvents, sorbents, membranes, etc.) are in the research and development (R&D) or pilot stage, and will be ready for larger-scale testing in the 2017–18 time frame. The current portfolio of projects will inform the true costs of capture and improve system integration; however, with sustained R&D, it is more likely that second-generation CO_2-capture technology will realize substantial cost and performance breakthroughs.

As indicated in Table 2, all of the projects in the US DOE portfolio except for two will sell captured CO_2 for EOR, and a number already have off-take agreements in place with CO_2-EOR operators. (A CO_2 off-take agreement is a step short of a firm contractual commitment for a company to take the CO_2, but it is a key element before a project enters the financing phase.) The sale of CO_2 as a commodity helps to offset the high costs of capture, but it is still insufficient to close the "cost gap" (difference between the cost to capture and transport CO_2 and what EOR operators are willing to pay), and each project still requires a mix of different incentives (e.g., DOE grants, investment or tax credits, production tax credits, accelerated depreciation, loan guarantees, etc).

The total US DOE commitment to the large-scale portfolio (awarded via a competitive bid process) is about $3 billion, and if all the projects go forward, the private-sector contribution will be approximately $10 billion. (The private-public cost-share split ranges between 50:50 and 80:20.) Because these projects are "first-of-a-kind," they carry greater risk (technical, regulatory, financial), and government funding serves as critical early-stage, high-risk capital that otherwise would be extremely difficult to secure in private markets.

Generally, each project has four phases: preliminary engineering and design; front-end engineering and design (FEED); construction; and operation. This approach allows the project sponsors and the DOE to review the status of each phase before proceeding to a subsequent phase, in which the funding requirement is likely to be much higher than the prior phase (these projects follow the typical project management "S" curve of cumulative costs over time). It is anticipated that the majority of the DOE project portfolio will complete financial close and move into construction by 2013. (Financial close requires that all project and financing agreements are signed, and all conditions in them are met to enable funds—debt, equity, and grants—to flow to the project.)

FEED is complete on the three industrial projects (Port Arthur, Lake Charles, and Decatur), as well as the Texas Clean Energy Project (TCEP), Kemper, and WA Parish. Also, FEED is currently under way on FutureGen 2.0 and HECA. Three projects (Kemper, Decatur, and Port Arthur) are currently under construction, and are expected to commence commercial operations in 2013–14. The TCEP is expected to reach financial close by the end of 2012 (see text box), and NRG is in the process of obtaining vendor-fixed firm quotes before it presents the project to its board for approval. It is expected that by 2015–17, a great deal of data will be generated from the operation of these projects (e.g., capital and operating costs, emissions performance, systems integration, etc.), which will significantly improve understanding of actual operations, performance, and costs.

Table 2: Large-Scale CCUS and CCS Demonstrations in the US DOE Portfolio

Project	Company	Location	Facility / Size	Feedstock	Capture Approach / Technology	Capture Efficiency (%)	CO_2 Supply Mt/year	CO_2 Offtake	Status On-line Date	Cost
Port Arthur	Air Products	Port Arthur, TX	Oil Refinery	N/A	Pre-combustion Steam Methane Reformers	75	1.0	Denbury & Valero	Construction 2013 - start	$431 million - Total $284 million - DOE
Kemper	Mississippi Power	Liberty, MS	IGCC/TRIG 582 MW	Coal	Pre-combustion Selexol	67	3.0	Denbury & Treetop Midstream Services	Construction 2014 - start	$2.8 billion - Total $270 million - DOE
HECA	SCS Energy	Elk Hills, CA	IGCC Polygen 300 MW	Petcoke	TBD	90	3.1	Occidental	FEED 2018 - start	$4.0 billion - Total $408 Million - DOE
WA Parish	NRG Energy - Petra Nova	Sugarland, TX	Post Combusion 240 MW	Coal	Post-combustion Flour Econamine FG Plus	90	1.4	Joint Venture Petra Nova-Hilcorp	FEED 2015 - start	$339 million - Total $167 million - DOE
Lake Charles	Leucadia Energy	Lake Charles, LA	Co-generation Chemicals (Methanol)	Petcoke	Pre-combusion - Rectisol	90	4.5	Denbury	FEED 2016 - start	$2.4 billion - Total $261 million - DOE
Texas Clean Energy Project (TCEP)	Summit Power Group	Penwell, TX	IGCC Polygen 400 MW	Coal	Pre-combustion Linde Rectisol	90	2.5	Whiting Petroleum	Financing 2015 - start	$2.5 billion - Total $450 million - DOE
FutureGen 2.0	FutureGen Alliance	Meredosia, IL	Oxy-Fuel 200 MW	Coal	Cryogenic separation	90	1.3	N/A Saline	FEED 2016 - start	$1.3 billion - Total $1.0 billion - DOE
Decatur	ADM	Decatur, IL	Ethanol	Corn	Pre-combustion	90	1.0	N/A Saline	Construction 2013 - start	$208 million - Total $141 million - DOE

The TCEP and HECA projects are both "polygeneration" facilities, meaning they are designed to coproduce electricity, fertilizer, sulfuric acid, and supercritical CO_2 for EOR. The polygeneration approach (versus standard power generation) is attractive in some markets where electricity is deregulated, or where it is a lower-value product compared to fuels or chemicals. While HECA is still in the FEED stage, the TCEP is expected to reach financial close by the end of 2012. The $2.4 billion, 400 MW integrated gasification combined cycle (IGCC) polygeneration plant includes a number of design features to reduce risk and make the project more attractive for financing in private capital markets:

1) No experimental technology: All technology components are proven and warranted (integration of fully warranted components is the only new project feature).
2) Three major revenue streams (CO2, electricity, and urea) were secured under long-term contracts to add revenue stability and reduce commodity risk.
3) The plant is a reference plant design that offers the ability for replication and improvement elsewhere.

While these design features have significantly reduced project risk, any first-of-its-kind plant carries greater risk and higher costs than conventional plants, which makes public support so critical. Summit's ability to secure federal and state incentives, coupled with design features to attract private capital, are key to enabling the technology deployment that will ultimately help drive down costs and risks.

CCUS Costs

It is common to hear that CCUS is expensive, but it's important to consider—expensive compared to what? All low-carbon technologies (CCUS, renewables, nuclear) for electricity generation are more expensive than conventional options (post-combustion coal or natural gas combined cycle plants), and on a cost-of-electricity basis, a number of studies have concluded that CCS is cost-competitive with other low-carbon options (Alstom, 2011 ; NETL, 2010).

Capture technologies (the most expensive component of CCUS) are in different stages of development, and a number of studies show a wide range of costs for capture at power plants and industrial facilities (see Table 3) (IPCC, 2005). Furthermore, no commercial-scale plants have reached the operational stage for power plants, polygeneration, or many industrial applications; therefore, true costs are not yet known. As noted, over this decade, experience from the first-of-a-kind, large-scale CCUS demonstrations in the DOE's portfolio, coupled with sustained R&D on second-generation (potentially breakthrough) technologies, should help drive down costs. In the meantime, policies to incentivize early movers and help close the cost gap are needed.
Once large-scale CCUS projects become operational in the United States, data will be available in the 2015–17 time frame to better understand actual costs. In the meantime, cost studies have a wide range of estimates.

A number of policy proposals to address the cost gap and accelerate CCUS deployment have been developed, and are highlighted in the Atlantic Council issue brief, Key US Policy Proposals to Advance Carbon Dioxide–Enhanced Oil Recovery and Carbon Capture, Utilization, and Storage. A key recommendation by the National Enhanced Oil Recovery Initiative (NEORI), a diverse coalition of public and private leaders convened by the Great Plains Institute

Table 3: Range of CO_2-Capture Costs for Several Types of Industrial Processes (2007$/ton CO_2)

Source: IPCC, 2005, based on Metz, adjusted to 2007 cost basis.

Industrial Process	Capture Cost Range
Fossil Fuel Power Plants	$20-$95 /t CO_2 net captured
Hydrogen and Ammonia Production, or a Natural Gas Process Plant	$5-$70 /t CO2 net captured
Other Industrial Processes	$30-$145 /t CO2 net captured

Once large scale CCUS projects become operation in the United States, data will be available in the 2015-17 time frame to better understand actual costs. In the meantime, cost studies have a wide range of estimates

Experience with integrated commercial CCS projects is limited to Sleipner, Snøhvit, In Salah (CO2 capture from natural gas processing), and Weyburn (CO2 capture from industrial coal gasification and synthetic fuels production for use in CO2-EOR). As detailed in Table 2, a number of large-scale, integrated CCUS commercial demonstrations for power plant and industrial applications are under development or construction in the United States, but none are operational, and the true costs of these first-of-a-kind projects are not yet known. Over the past five years, roughly fifty CCS studies worldwide have attempted to address the cost issue, but there are significant differences in underlying costing methods (as well as key assumptions) that contribute to the confusion about the wide range of costs, and misunderstanding among various audiences (Rubin, 2012). Some cost differences can be attributed to CO2-capture system design, but the major source of variability is in the reference plant to which the capture technology is applied. CCS is also site-specific, and no single set of assumptions applies to all situations or all parts of the world; therefore, it is difficult to accurately compare cost estimates among studies, and a range of costs is generally given. A recent effort led by the International Energy Agency (IEA) is working to establish more-consistent costing methodologies and reporting across organizations that should reduce uncertainty and variability, and help to ensure that data is more clearly understood (IEA, 2011). Actual operating experience will also help to reduce uncertainty.

and Center for Climate and Energy Solutions (formerly the Pew Center on Global Climate Change), is a federal tax credit. Based on projected revenues set out in a previous table (see Table 1), NEORI suggests the tax credit would more than pay for itself (NEORI, 2012). Similar revenue-neutral policy proposals or recommendations to advance CO_2-EOR with CCUS have been put forward by the Coal Utilization Research Council, the National Coal Council, the US Carbon Sequestration Council, Texas Clean Coal Foundation, and others.

CCUS Risks

High CCUS capital costs are a key issue, but a project developer's ability to reach financial close is driven not only by costs, but also by how risks are negotiated over a long project lifetime (thirty to forty years). Financing is negotiated for a return given an evaluated risk level; equity can accommodate more risk, while debt seeks less risk. Critical risks generally fall in three major areas: 1) technical and operating risks (e.g., system integration, performance, and capital equipment; 2) policy or political and regulatory risks, particularly long-term liability related to storage; and 3) market and financial risks (e.g., fuel costs, interest rates, and, in the case of CCUS with CO_2-EOR, oil price and CO_2 price and availability). Table 4 details some of the key CCUS project risks for North America, Europe, and Asia (CSLF, 2009).

Any projects with CCUS will need to navigate the range of risk issues presented in Table 4, before advancing to financial close. Key risks will vary by project and region, but a government role at this early stage is essential, and governments can use different mechanisms to address them.

Some risks are common across regions. For example, high capital costs will be similar because equipment vendors are drawn from a global vendor base. Also, at this juncture, incentives to offset higher project costs and risks are generally inadequate worldwide. Differences across regions are significant as well. One of the largest issues for the United States is the lack of federal clarity on long-term liability for carbon storage. For example, in the case of CO_2-EOR, operators are driven to recover more oil using CO_2, and these projects (depending on the market price of oil) are generally financed quite easily by private investors on the balance sheet, or by issuing debt. If the oil field will also be used as a CO_2 storage site to secure credit for carbon storage, the operator will be required to implement a more-rigorous and more-costly CO_2 monitoring, verification, and accounting (MVA) program to verify permanent storage. Furthermore, the issue of long-term liability for stored carbon has not yet been resolved at the federal level, which poses a significant risk to operators. At this stage, the financing scheme for CCUS with CO_2-EOR, therefore, is considerably more complicated than a straightforward CO_2-EOR project.

CCUS Business Models

There is no clear-cut business model for CCUS, but any business model that emerges must address the full range of project risks and align them with rewards in order to make projects bankable. As noted, in the early stages of these first-of-a-kind projects, a government role is essential to cover high-risk early capital, and address key policy and

Table 4: Overview of Key Risks with CCS Projects (Europe, North America, Asia)

Source: Adapted from CSLF, 2010.

Risk Type	Business Case Risk Reduction	EU	N. Am	Asia
Technology	Capital costs (plus energy penealty / parasitic load) high relative to competing baseload	High	High	High
Policy	Electricity rate regulation fails to offer dispatch preference or incentives	High	High	High
Market / Financial	Credit financing constraints result in difficult terms (more equity, short debt tenor)	High	High	Med
Policy	Uncertain regulation on CO_2 emissions results in low economic value for CCS	Low	High	High
Market / Financial	Natural gas prices remain lower making CCS on coal less competitive	Med	High	Med
Policy	Incentives (grants, allowances, tax credits, etc) inadequiate for additional costs and risks	Med	Med	High
Market / Financial	Carbon price (or lack of) volatility hinders financing	Med	High	Low
Policy	Water use regulations threaten coal plant operations with CCS (shutdowns)	Med	Med	Med
Policy	Lack of clarity about liability for long-term stewardship of carbon storage hinders financing	Low	High	Low
Market / Financial	Long-term demand growth fails to justify investment in baseload power generation	High	Low	Low
Technology	Technical performance problems lead to excessive repairs and downtime	Med	Med	Low
Policy	Older coal units are allowed to run longer posing competitive challenges	Low	Med	Low
Market / Financial	Imported coal prices rise to see more volatility raising costs	Med	Low	Low
Technology	Transport of CO_2 proves too costly or logistically difficult	Med	Low	Low
Policy	Lack of public recognition of acceptance of CCS value hinders permitting	Med	Low	Low
Technology	Injection and storage encounters operating problems triggering higher costs	Med	Low	Low
Market / Financial	Interest rates rise threatening financing terms and costs	Low	Low	Low

Commercial deployment of power or energy projects with CCS or CCUS must fully address a range of technical, regulatory, and market risks in order to complete financing. The Carbon Sequestration Leadership Forum (CSLF) Financing Task Force and the CCS Alliance have worked with industry executives, government officials and non-governmental organizations to map critical business risks in different regions. This effort has advanced the development of regulatory or policy options to systematically address key risks.

regulatory risks to enable private capital to flow. Yet, the CCUS chain is fairly disjointed, and risks and rewards are not yet aligned. For example, CO_2 capture is essentially an added cost (with some offset for the sale of CO_2), which enables financial value further down the chain (e.g., revenues from the sale of oil from CO_2-EOR). Projects are also very complicated, lengthy, and expensive, with human resource constraints associated with a limited pool of skilled workers. Finally, CCUS requires integration of different industries and independent operating businesses (e.g., power generation, chemical processing, CO_2 pipeline transport, oil and gas, geological storage). Each industry and company has its own business culture, acceptable levels of risk and returns, and sources of capital, yet CCUS strategic alliances and new business models are needed.

The selection of a CCUS business model will be based on many factors, including: type of CO_2-emitting facility (electric power, polygeneration, industrial, new build, or retrofit); power market (regulated, unregulated); CO_2 demand and market price; distance to CO_2-EOR or storage site; CO_2 pipeline and transport infrastructure requirements; and internal engineering, design, and construction capabilities.

There are three emerging business models for utilities (and other CO_2 emitters) developing CCUS projects: self-build and operate; pay-to-take (or "pay at the gate"); and joint venture (Esposito, et al., 2011). In the self-build model, operations are vertically integrated, and utilities use internal engineering, technical, and commercial talent to link and operate each element of the CCUS chain. In the pay-to-take model, a utility will contract with a third party that has strong technical capabilities (e.g., engineering, geology) to take responsibility for the CO_2 after it is captured. For a fee, the third party will assess opportunities for EOR or storage in another type of geologic reservoir, and arrange for CO_2 transport.

Examples of companies that offer this type of service include Advanced Resources International, Inc., Schlumberger Carbon Services, C12 Energy, and Blue Strategies. Finally, a joint-venture model stresses a partnership between the utility and external EOR operators or geologic storage consultants. While the utility would likely be responsible for CO_2 capture, the transport and storage effort would be managed jointly, with a more-equitable division of risks and revenues. An example of the joint-venture model is associated with the WA Parish project (see Table 2) between NRG's Petra Nova and Hilcorp Energy, an independent oil and gas exploration and production company that owns and operates numerous fields in the Gulf Coast suitable for CO_2-EOR (NRG, 2011).

Conclusion

A number of elements are moving into place to support the business case for CCUS deployment:

- The oil price outlook remains strong, and significant CO_2-EOR potential is limited by the availability of large volumes of affordable CO_2 supply.
- A number of anthropogenic CO_2 sources are coming online that are linked to first-mover CCUS projects under the DOE portfolio.
- Experience from the large-scale CCUS projects in the DOE portfolio, coupled with R&D on second-generation CO_2 capture technologies, could result in cost and performance breakthroughs.
- New CO_2-EOR technologies to improve oil-recovery efficiencies are under development, and new strategic CCUS alliances that integrate nontraditional partnerships are emerging.

However, CO_2-capture costs must be driven to business-case economics, and the cost gap between the market price for CO_2 and the price CO_2-EOR operators are willing to pay must be closed. The extent to which CO_2-EOR will be leveraged for wide-scale CCUS deployment depends largely on how the CO_2-EOR market and "next generation" technology develops, and what type of policy actions will be taken to incentivize CO_2 capture from anthropogenic sources, an issue highlighted in the Atlantic Council issue brief, Key US Policy Proposals to Advance Carbon Dioxide–Enhanced Oil Recovery and Carbon Capture, Utilization, and Storage.

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