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ISSUEBRIEF

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ENERGY AND ENVIRONMENT PROGRAM

US Policy Shift to Carbon Capture, Utilization, and Storage Driven by Carbon Dioxide Enhanced Oil Recovery

Absent climate-change legislation, commercial drivers are necessary to advance carbon-management approaches for large-scale fossil fuel power plants and industrial facilities. Given this reality, the United States has shifted its policy focus from carbon capture and storage (CCS) technologies to one that emphasizes carbon capture, utilization, and storage (CCUS). Although there are many uses for carbon dioxide (CO_2) (e.g., food and beverage production, conversion into fuels, use as a chemical feedstock, or possible replacement for water as a hydraulic fracturing fluid), the primary utilization opportunity in the United States is enhanced oil recovery (EOR). Currently, CO_2-EOR offers the only significant price signal for carbon, and it provides the nation's most viable commercial CCUS pathway. The CO_2-EOR industry is positioned to create the largest market for CO_2 captured from power plants and industrial facilities (that would otherwise be vented into the atmosphere), increase domestic oil production, and help to revitalize the US economy.

This issue brief is one in a series the Atlantic Council is publishing on CCUS. It discusses the current market landscape for CO_2-EOR, highlights early commercial CCUS demonstration projects that are positioned to supply CO_2 for EOR, and addresses issues and methods to account for CO_2-EOR as carbon storage. It also provides an Appendix with background on advances in CCS and the shift in US policy from CCS to CCUS. Three additional Atlantic Council CCUS issue briefs include: the Business Case for Carbon Capture, Utilization, and Storage; Key US Policy Proposals to Advance Carbon Dioxide–Enhanced Oil Recovery and Carbon Capture, Utilization, and Storage; 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 and the Current Market Landscape

Typically, only a fraction of the original oil in place (OOIP) in an oil field can be produced, which is dependent on many factors, including: reservoir geology and oil characteristics; the market price of oil; technology; and the availability of adequate CO_2 supplies or other EOR injectates. When an oil reservoir is first produced (primary production), the natural pressure in the reservoir drives the oil, gas, and water in the rock to the surface. As reservoir pressure and output drop, secondary production using formation water

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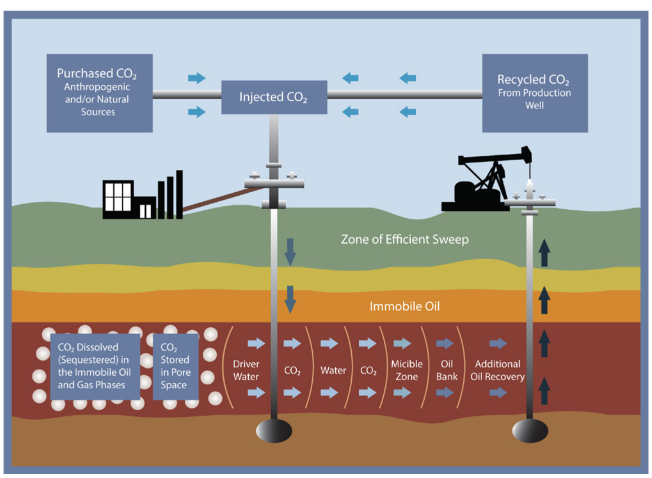
Key Discussion Points:

- CCUS is a business-driven path and a US policy to promote immediate and long-term CO_2 capture and storage via CO_2-EOR.
- The United States is the global leader in CO_2-EOR. Currently, CO_2-EOR contributes about 6 percent to US domestic oil production but has the potential to contribute 30 to 40 percent, and generate $6.8 trillion in revenue and economic activity.
- CO_2 supply is the limiting factor in CO_2-EOR expansion, and large volumes of CO_2 captured from power plants and industrial facilities (anthropogenic sources) are needed.
- CO_2 captured from anthropogenic sources costs roughly twice as much as natural CO_2 supplies. Policy action is needed to incentivize early movers and help close the "cost gap," or difference between the cost to capture and transport CO_2 and what EOR operators are willing to pay.
- A number of new policy proposals conclude that tax receipts and royalty revenues received by the government from oil produced from CO_2-EOR can more than pay for proposed CO_2 capture incentive programs.
- CO_2-EOR inherently provides CO_2 storage; however, in order to be considered CCUS, operators must demonstrate that the CO_2 is anthropogenic, and provide assurances through monitoring, verification, and accounting (MVA).
- Legal and regulatory uncertainty regarding MVA requirements for CCUS and long-term liability for carbon storage must be resolved.

(or sometimes natural gas) will push additional oil out of the rocks to producing wells. Tertiary production (or EOR) often takes place after a waterflood using various injectates (natural gas, steam, nitrogen, or CO_2) to further pressurize the reservoir and increase oil output. Primary and secondary production will generally yield about 30 to 40 percent of the reservoir's OOIP, and EOR can add another 5 to 20 percent of the OOIP to ultimate recovery, and extend the life of an oil field by thirty years.

Figure 1: Illustration of CO_2-EOR



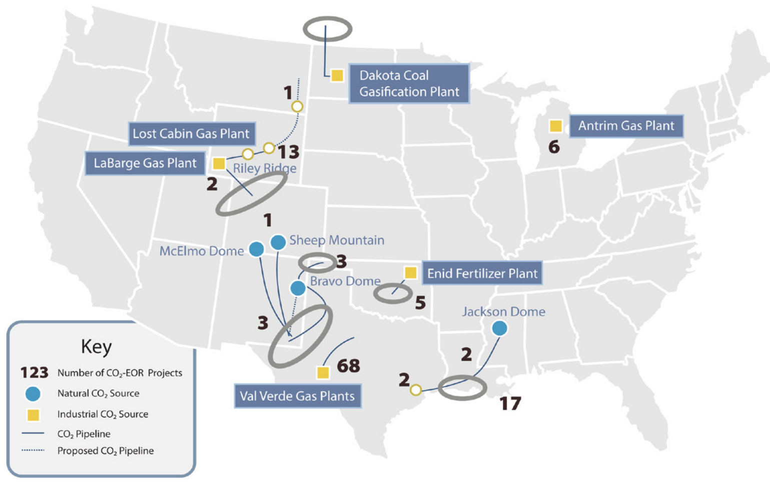
Injecting CO_2 into depleted oil fields can mobilize trapped oil and improve recovery. The CO_2 that is produced jointly with the oil is "recycled" (separated and injected back into the reservoir) in a closed-loop cycle. At the end of the project, essentially all of the purchased CO_2 is stored in the reservoir rocks.

Large up-front capital investment and a readily available and affordable CO_2 supply over a long-time horizon (twenty-plus years) is required in order to prepare a field for CO_2-EOR. Most CO_2-EOR floods are developed in stages to match the availability of CO_2 investment capital and field services (e.g., drilling and workover rigs, field workers, etc.). During CO_2-EOR operations, nearly pure (>99 percent) CO_2 is injected into the reservoir at high pressure (often with alternating injections of water), which interacts with oil and brine in the formation over time (months and years) to increase oil saturation and mobility. In a successful operation, the oil, brine, and CO_2 that enters production wells is pumped to the surface (see Figure 1).

The entire operation manages CO_2 in a closed-loop cycle. Upon initial CO_2 injection, approximately 40 to 50 percent of the CO_2 dissolves into the reservoir fluids and is trapped; any CO_2 that is produced with the oil is recycled (separated and reinjected into the reservoir). Because CO_2 is a valuable commodity in EOR operations, there is a financial incentive to use it efficiently. Typically, any CO_2 losses are very small,and essentially all of the purchased CO_2 is stored in the reservoir when operators close the oil field at pressure. Industry experience indicates that, depending on reservoir conditions and EOR techniques, for every 2.5 barrels of oil produced, CO_2-EOR will safely store 1 metric ton (Mt) of CO_2.

Figure 2: US CO_2-EOR Activity

Source: Adapted from Kuuskraa, 2012.



In 2012, US CO_2-EOR projects are expected to produce 350,000 barrels of oil per day, ~6 percent of domestic oil. CO_2 supply is the limiting factor for CO_2-EOR expansion. With a robust policy and "next generation" CO_2-EOR technology, CO_2-EOR could account for 30 to 40 percent of domestic oil production and generate approximately $6.8 trillion in revenues and economic activity. This would require 20 to 45 billion metric tons of CO_2, equal to the total US CO_2 production from fossil fuel electricity generation for ten to twenty years (ARI, 2011).

The United States is the global leader in CO_2-EOR, and the first commercial operations were launched in the early 1970s. There are currently 123 projects that are expected to provide about 350,000 barrels of oil per day (bbl) in 2012, or approximately 6 percent of US crude oil production (Koottungal, 2012) (see Figure 2). The Permian Basin of West Texas accounts for two-thirds of global CO_2-EOR production, but growth has been increasing in the Gulf Coast, Mid-Continent, and Rocky Mountain regions, largely because of new CO_2 supplies from natural gas processing plants.

In 2010, a total of 63 Mt of CO_2 was supplied to EOR operations. Most of the supply (~80 percent) came from naturally occurring CO_2 accumulations, followed by natural gas processing plants and some hydrocarbon conversion facilities (e.g., coal gasification) (DiPietro, et al, 2012). By 2020, approximately 14 Mt of additional CO_2 supply will become available from large-scale integrated CCUS projects in the US Department of Energy's (DOE) portfolio. In fact, many of these projects have CO_2 off-take agreements already in place to supply CO_2 to EOR operators (see Figure 6 in Appendix).

The United States has approximately 4,000 miles of CO_2 pipelines that can be expanded into a large-scale national network to link anthropogenic CO_2 sources with CO_2-EOR and large-scale saline reservoir storage (see Figure 3). The Interstate Oil and Gas Compact Commission (IOGCC) and the Southern States Energy Board (SSEB) convened a Pipeline Transportation Task Force to assess the development of a national CO_2 pipeline infrastructure for EOR and sequestration, which built on the IOGCC's model state legislation for geologic storage (IOGCC, 2008; 2010). The task force emphasized that once planning, markets, rights-of-way, and contractual terms are established, CO_2 pipelines can be rapidly constructed and states can take action to facilitate these efforts (IOGCC, 2011).

Some states (Wyoming, Illinois, and the Gulf Coast states) are investigating comprehensive CO_2 pipeline networks as a part of broader energy strategies linked to economic development, and Wyoming currently offers best practices on CO_2 pipeline preplanning. While Wyoming's plan (under development with the governor's office, industry, environmental stakeholders, and members of the public) does not seek to build new pipelines, it essentially preapproves potential routes for future pipelines to carry CO_2 from natural and anthropogenic sources. This action will significantly shorten permitting time and expedite oil production, thus accelerating state royalty revenues from CO_2-EOR operations, which are a large part of the

Wyoming economy. (In 2011, the state collected approximately $144 million in various taxes and royalties from CO_2-EOR [MacKay, 2012; Cook, 2012].)

As noted, US oil production from CO_2-EOR operations has increased steadily over the last forty years, and currently accounts for 6 percent of domestic production (see Figure 4). About half of the oil reservoirs in the contiguous United States are amenable to CO_2-EOR, and recent analysis estimates that CO_2-EOR—with affordable CO_2 supplies and "next generation" CO_2-EOR technology—could account for 30 to 40 percent of domestic oil production (ARI, 2011) (see Table 1).

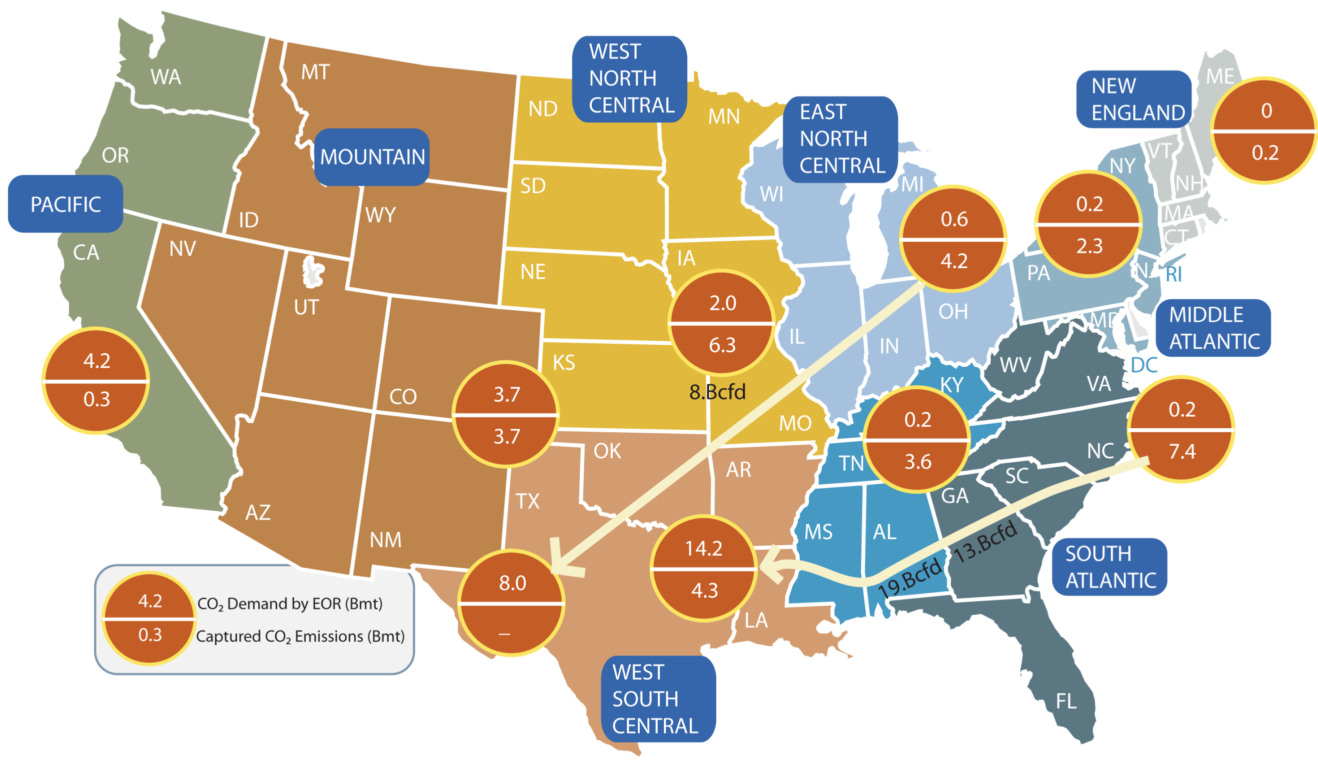
An emerging CO_2-EOR opportunity and potential game-changer is the Residual Oil Zones (ROZs) of Texas and Wyoming, which could add billions of barrels of additional capacity to US oil reserves. Under certain geologic and hydrodynamic conditions, the ROZ exists beneath the oil-bearing transition zone and the oil-water contact of a reservoir. ROZs naturally have high water content and are similar to reservoirs that have undergone secondary production with water flooding. This condition makes ROZs ideal for CO_2-EOR. Further assessments are needed to better quantify the scale of the ROZ resource, but current estimates range from 33 billion barrels of oil to over 100 billion. These CO_2-EOR opportunities require substantial volumes of anthropogenic CO_2 supplies, estimated between 25 to 45 billion metric tons. This amount is equal to the total US CO_2 production from fossil fuel electricity generation for ten to twenty years (ARI, 2011).

Issues and Methods to Integrate and Account for CO_2-EOR and Carbon Storage

CO_2-EOR operates as a closed-loop system and provides for CO_2 storage as an inherent part of operations. However, in order for CO_2-EOR to be considered CCUS with permanent storage, operators must demonstrate that the CO_2 used in the operation is from anthropogenic sources, and provide assurances through MVA methods that the CO_2 remains permanently stored. The regulatory pathway is not entirely clear at the federal level; however, some states (e.g., Texas) have paved the way for CCUS by providing a clear legal path to store CO_2 via CO_2-EOR (Miller, 2011).

Figure 3: Linking CO_2 Supplies with CO_2-EOR Demand

Source: Advanced Resources International, Inc., 2011.



A large-scale national CO_2 pipeline network is needed to link CO_2 emissions sources in the Ohio River Valley and Southeast to CO_2-EOR opportunities in the Mid-Continent and Texas oil fields and ROZ "fairways."

Table 1: Impact of "Next Generation" CO_2-EOR Technology on Economically Feasible* Oil Recovery

Source: Advanced Resources International, Inc., 2011

Resource Area	"State-of-the Art" Technology	"Next Generation" Technology	Impact of Advances in Technology
	(BBbls)	(BBbls)	(BBbls)
More Effiicient Recovery from "Lower 48" Oil Fields	24	60	36
Alaska/Offshore	3	7	4
Residual Oil Zone (Below Oil Fields)	-	13	13
Residual Oil Zone "Fairways" (Preliminary)	-	20	20
TOTAL	**27**	**100**	**73**

** At $85 per barrel oil price and $40 per metric ton, CO_2 market price with 20 percent rate of return (before tax).*

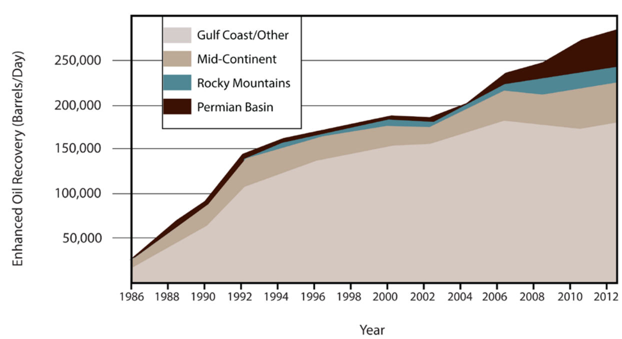
CO_2 injection permits are issued through the US Environmental Protection Agency's (EPA) Underground Injection Control Program (UIC), which is administered by regional EPA offices unless a state applies for primacy. There are three types of permits for CO_2 injection wells: Class VI (geologic storage), Class II (EOR), and Class V (experimental). These permits are complimented by EPA's Mandatory Greenhouse Gas Accounting Rule: Subpart RR (geologic storage) and Subpart UU (EOR). Class VI geologic storage wells are required to create a site-specific plan to monitor, report, and verify the amount of CO_2 stored using a mass balance approach, which could be subject to a fifty-year post-closure monitoring period (US EPA, 2010). Class II EOR projects have more limited reporting requirements (e.g. basic information on the amount and source of CO_2 injected). There are three regulatory pathways for CO_2 EOR to account for CO_2 storage: 1) remain Class II and report under Subpart UU; 2) remain Class II and "opt-in" to Subpart RR (geologic storage), and 3) transition from Class II to Class VI under Subpart RR.

The Subpart RR reporting requirements are more stringent and costly than Subpart UU, and may cause a barrier to entry. For example, the EPA estimates that basic EOR reporting under Subpart UU will cost $4,000 per year, versus $320,000 per year for the more-involved Subpart RR reporting for geologic sequestration (US EPA, 2011). Given the additional burden and cost (as required under Subpart RR) that a dedicated MVA program places on the operator, most CO_2-EOR operators are still assessing the impacts of opting in. Many states and operators are also exploring possible approaches to remain within the regulatory framework already established for EOR operations that could enable them to receive carbon storage credit.

Given the additional cost associated with dedicated MVA programs, only a few CO_2-EOR projects have included them via research-oriented activity supported by public-private sector funding. The most prominent example is the Weyburn project in Saskatchewan, Canada, but there are also a number of smaller-scale carbon storage validation projects at CO_2-EOR fields in the United States (e.g., Bell Creek Integrated CO_2-EOR and Storage Project, SECARB's Cranfield Early Test Project, West Pearl Queen Field, Loudon Field, etc.).

Figure 4: Domestic Oil Production from CO_2-EOR

Sources: Advanced Resources International, Inc. and Koottungal, 2012.



The Permian Basin remains the dominant area for CO_2-EOR; however, limits on CO_2 have constrained growth. Increased CO_2 supplies from gas processing plants have driven Rocky Mountain and Gulf Coast expansion. Oil production growth from CO_2-EOR will largely depend on technology advances and US policies to address the higher costs of CO_2 capture and transport.

“Next Generation” CO_2-EOR Technology: Priority Elements

Since CO_2-EOR was first introduced in the early 1970s, there has been an evolution in the technology design and implementation that has resulted in steady improvements in oil-recovery efficiencies (currently 33 percent). These best practices enable significant oil recovery, but “next generation” CO_2-EOR technology could offer significantly more recovery with efficiencies over 60 percent (ARI, 2011). Seven priority topics for “next generation” CO_2-EOR technology include:

1) advanced reservoir characterization (to map residual oil and reservoir heterogeneity);
2) horizontal and “smart” well technology;
3) CO_2 mobility control agents;
4) increased volumes of efficiently targeted CO_2;
5) miscibility pressure-reduction agents;
6) near-miscible CO_2-EOR technology; and
7) advanced reservoir surveillance (feedback, diagnostics, and control) technology.

Various greenhouse-gas accounting frameworks have also developed quantification methodologies using international best practices for CCS to document emissions reductions that can be eligible for carbon offset credits (e.g., Clean Development Mechanism and European Union Emissions Trading Scheme). A new certification framework for CCS projects was also recently launched (DNV, 2012). In the United States, the Center for Climate and Energy Solutions (the successor to the Pew Center on Global Climate Change) issued A Greenhouse Gas Accounting Framework for Carbon Capture and Storage Projects to guide CCS project developers and advance policies that reward qualified CCS investments (McCormick, 2012). At the state level, California is also investigating the inclusion of CCS in California’s climate law, AB 32, which would enable CCS to quality for carbon offset credits (California CCS Review Panel, 2010).

As noted previously, approximately 1 metric ton of CO_2 is stored for every 2.5 barrels of oil produced. As CO_2-EOR expands in the United States, greater volumes of anthropogenic CO_2 will be needed, resulting in permanent sequestration of CO_2 that would have otherwise been emitted to the atmosphere. Some groups have raised concerns that once the oil produced from CO_2-EOR is consumed, it will contribute to anthropogenic CO_2 emissions. A number of studies have investigated the overall life cycle emissions associated with CO_2-EOR and CCUS under different scenarios. Conclusions can vary widely depending on where the boundary of the analysis is drawn, how these values compare with other petroleum or alternative fuel sources, and whether those sources were produced domestically or imported. Some studies conclude that CO_2-EOR results in net carbon emissions when you account for the carbon in the oil produced (Jaramillo, 2009). Others conclude that the barrel of domestic oil produced from CO_2-EOR will displace either a barrel of oil produced through traditional methods, or an imported barrel, both with larger carbon footprints. Some studies also consider the benefits—both in terms of emissions savings and cost—of leveraging the CO_2-EOR pipeline infrastructure that is incremental to existing oil-field developments for large-scale geologic carbon storage.

While discussions continue on where the boundary for greenhouse-gas accounting should be drawn, CO_2-EOR will utilize CO_2 that would have otherwise been emitted into the atmosphere, and advance the only commercial pathway for CCUS. The extent to which CO_2-EOR will be leveraged for wide-scale CCUS deployment depends largely on how the CO_2-EOR market develops, and on what type of policy actions will be taken to incentivize CO_2 capture, an issue addressed in the Atlantic Council issue brief, Key US Policy Proposals to Advance Carbon Dioxide–Enhanced Oil Recovery and Carbon Capture, Utilization, and Storage.

Appendix: CCS Advances and US Policy Shift to CCUS

In the 1980s, a few dozen scientists, mainly from the United States and Japan, began to investigate CCS, also known as carbon sequestration, as an important technology solution in a portfolio of power-generation options (e.g., renewables, nuclear, efficiency) to mitigate global climate change. If implemented cost-effectively and safely, CCS can enable the United States to maintain its diversified portfolio of electricity-generation options—critical to reducing financial and security risks, improving reliability and environmental performance, and minimizing price volatility—and to address CO_2 emissions from large industrial sources.

Table 2: CCUS Best Practices Manuals

Source: US DOE, NETL

Best Practices Manual	Version 1 (Phase II)	Version 2 (Phase III)	Final Guidelines (Post Injection)
Monitoring, Verification and Accounting	2009/2012	2016	2020
Public Outreach	2009	2016	2020
Site Characterization	2010	2016	2020
Geologic Storage Formation Classification	2010	2016	2020
Simulation and Risk Assessment	2010	2016	2020
Carbon Storage Systems and Well Management Activities	2011	2016	2020
Terrestrial	2010	**2016 - Post MVA Phase III**	

The US DOE's National Energy Technology Laboratory (NETL) has issued a series of CCUS best practices manuals to share lessons learned through DOE research and the experiences of NETL's regional partnerships in conducting CCS field tests. The manuals are available on NETL's CCUS Reference Shelf (www.netl.doe.gov/technologies/carbon_seq/refshelf/refshelf.html).

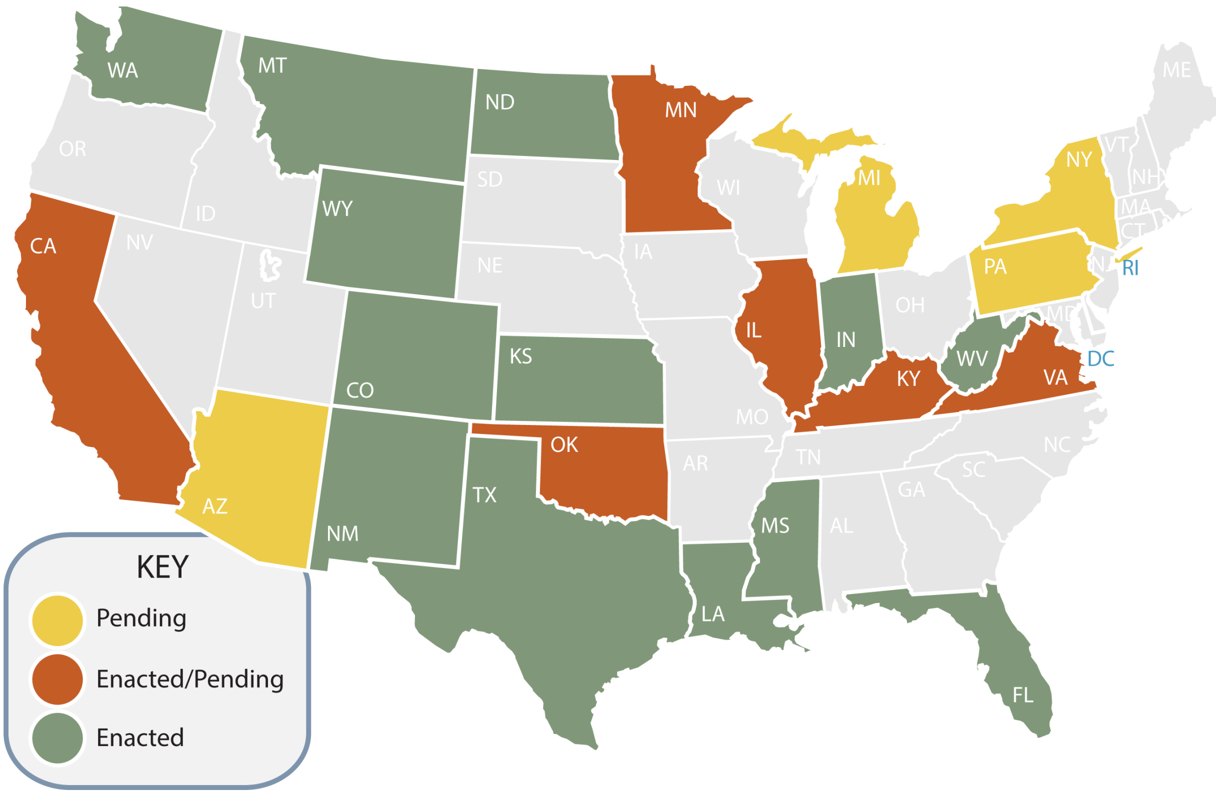
CCS involves three main stages: 1) capture of CO_2 emissions from fossil fuel power plants or large industrial facilities, and compression into a dense liquid; 2) transport generally via a CO_2 pipeline; and 3) injection into porous rock formations deep below the surface (3,000 to 20,000 feet), where it will flow through the reservoir rock and remain trapped over time. With careful site selection, monitoring, and regulation, CO_2 storage can be a safe and cost-effective means to mitigate CO_2 emissions (IPCC, 2005). Much of the confidence among the international scientific community to support this conclusion comes from natural analogs (e.g., oil and gas reservoirs, natural CO_2 deposits) and industrial experience with natural gas storage, acid gas disposal, and CO_2-EOR. In addition, twenty-five years of cumulative performance with actual commercial CCS projects (Sleipner, Snohvit, In Salah, and Weyburn) include robust CO_2-monitoring programs to ensure safe and permanent storage (GCCSI, 2012)

All CCS technology components have been commercially available for forty-plus years, but their integration for large-scale carbon management has been under development only in the last fifteen years. During this time, measured progress has been made on all fronts (technical, legal and regulatory, public engagement, etc.), but the high cost of CCS (especially CO_2 capture, which is roughly 70 percent of total CCS costs)—although on par with other low-carbon electricity options—is one of its most significant commercial barriers. Furthermore, the critical issue of who will accept long-term liability for carbon storage, and under what mechanism, must still be resolved.

Based on an assessment of key research needs, the US DOE launched its Carbon Sequestration Program in 1998 (Herzog, 1993; Herzog, 1997). In the early years of the program, DOE's research and development (R&D) portfolio spanned the range of scientific and technical issues across the CCS chain with the aim to reduce costs, improve efficiency, and enhance storage safety (DOE, 1999). Over the past decade, DOE has built on its core R&D program with a focus on infrastructure development for regionally specific implementation approaches (e.g., Regional Carbon Sequestration Partnerships, geologic characterization, and small- and large-scale storage field tests) (DOE, 2011). Through DOE's Clean Coal Power Initiative, an emphasis has also been placed on large-scale integrated demonstration projects. Key findings from all of these activities have built further confidence in the technology, and can be accessed in DOE's best practices manuals, critical guides for project development and implementation (see Table 2).

Figure 5: State CCS Incentives and Regulation

Source: SSEB, 2011



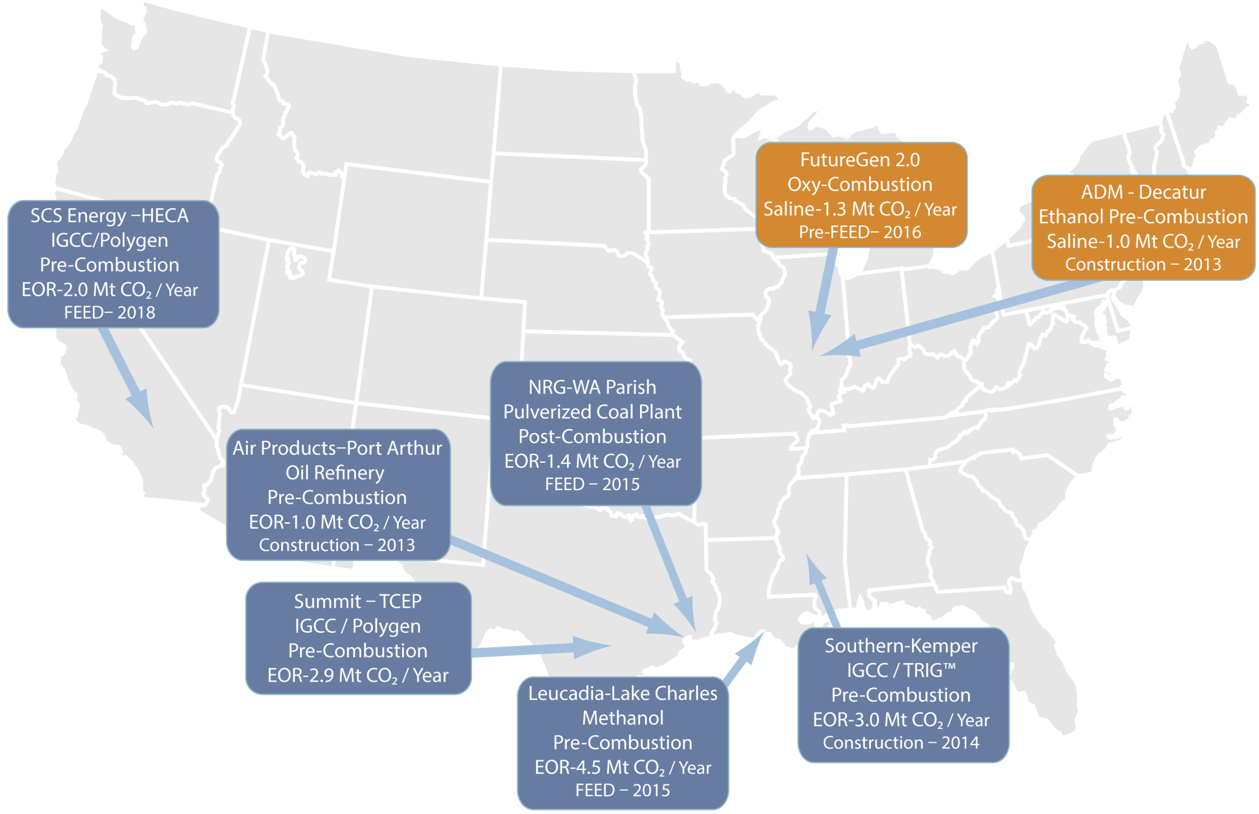
Twenty-three US states have incentives or regulations for CCS in place. While most individual pieces of legislation do not address all the CCS issues comprehensively, they provide a patchwork that covers the issues and helps to inform developments in other states.

Throughout the United States, considerable momentum for large-scale deployment has been built at the local, state, and federal levels, largely through engagement with a wide range of over 400 stakeholders in DOE's Regional Carbon Sequestration Partnerships. Currently, 19 states have passed CCS-related legislation that addresses various implementation issues, ranging from streamlined permitting processes and establishment of roles for various state agencies to clarifying property rights (e.g., pore space ownership, mineral rights, eminent domain, storage-site unitization); long-term liability provisions; MVA guidelines; financial responsibility; incentives; and so forth. Another four states have CCS bills pending (SSEB, 2011) (see Figure 5). Many states have adopted model guidelines for CCS and CO_2 infrastructure development issued by a special task force of the IOGCC. These guidelines were largely based on existing legal and regulatory frameworks governing EOR, or gas-recovery operations (IOGCC,

The Weyburn Project in Saskatchewan, Canada, is the world's largest commercial CO_2-EOR and CCUS project. It features an extensive risk assessment and MVA program, developed and implemented by an international consortium of public and private researchers. Since 2000, the Weyburn project has stored approximately 19 Mt of anthropogenic CO_2 sourced from Dakota Gasification Company's lignite-fired Great Plains Synfuels Plant in North Dakota, under a purchase agreement valued at around $30 million per year. The CO_2 is delivered via a 205-mile pipeline to oil-field operators Cenovus (formerly EnCana Corp.) and Apache. The companies currently inject about 2.4 Mt of CO_2 per year into the Weyburn and adjacent Midale fields to support EOR operations. CO_2-EOR has increased oil production in Cenovus's Weyburn field from 16,000 to 28,000 barrels a day, and from 2,300 to 5,800 barrels a day in Apache's Midale field. MVA researchers have determined that CO_2 has been safely stored in the reservoir without any leakage to the surface. The field has an estimated storage capacity of ~55 Mt of CO_2, and it is estimated that over 30 Mt will be permanently stored over the life of the project (Whittaker, 2010).

Figure 6: Large-Scale CCUS Projects in the US DOE Portfolio

Source: Adapted from the US DOE



All of the large-scale CCUS projects in the US DOE's portfolio were competitive bid with significant industry cost-share. Generally, each project has four phases: preliminary engineering and design; feed; construction; and operation. Most of the projects are associated with CO_2-EOR operations; many have secured off-take agreements for their CO_2. Kemper, ADM, and air products are under construction and are expected to commence commercial operations in 2013-2014. Summit is expected to reach financial close by the end of 2012.

2005; IOGCC, 2008; IOGCC, 2010; IOGCC, 2011). In 2010, the CCSReg project developed model federal legislation for CO_2-EOR and carbon storage (CCSReg, 2010). The National Enhanced Oil Recovery Initiative (NEORI), a broad coalition of environmental and labor representatives and industry and state officials, has also highlighted model state incentive policies to help realize CO_2-EOR's energy security and economic and environmental benefits, which is discussed further in the Atlantic Council issue brief, *Key US Policy Proposals to Advance Carbon Dioxide–Enhanced Oil Recovery and Carbon, Capture, Utilization, and Storage* (NEORI, 2012).

As discussed previously, at the federal level, the US EPA finalized two closely linked rules in 2010, designed to support and facilitate commercial-scale CCS deployment. The first establishes a new well classification specifically for geologic sequestration (Class VI) under its UIC Program through the Safe Drinking Water Act (EPA, 2010). The second rule finalizes the requirements for CCS (and CO_2-EOR) under the mandatory greenhouse-gas reporting rule (Subparts RR and UU of 40 CFR, Part 98) to enable the EPA to quantify the amount of CO_2 stored underground, along with any surface CO_2 emissions from injecting facilities.

In parallel with state and federal regulatory framework activities, the American Recovery and Reinvestment Act (ARRA) provided an infusion of funds to support large-scale CCS demonstration projects. In FY 2008, the DOE received $3.4 billion in ARRA funding for industrial and commercial-scale CCS projects, and an additional $2.3 billion in annual appropriations. DOE's portfolio of competitively awarded, large-scale CCS projects is supported by $10 billion in total investment ($3.1 billion in federal dollars and $6.9 billion from industry) (see Figure 6). These projects will

Table 3: Projected Distribution of Revenues from "Next Generation" CO_2-EOR*

Source: ARI, Inc, 2011

Revenue Recipient	Value Chain Function	Revenues Per Barrel ($)	Revenues TOTAL ($ 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**

** Assuming 80 billion barrels of oil recovery; oil prices of $85 per barrel and CO_2 sales price of $40/metric ton*

CO_2-EOR can generate tremendous economic and energy security benefits for the nation while decreasing man-made CO_2 emissions. A number of new policy proposals conclude that tax receipts and royalty payments received by the government for domestic oil produced from CO_2-EOR can more than pay for proposed CO_2-capture incentive programs.

demonstrate various CO_2-capture approaches (pre-combustion, post-combustion, and oxy-fuel) on different types of power plant and industrial applications, and most are linked to CO_2-EOR.

While government cost-share support to help cover the incremental cost of CCUS in these "first-mover" commercial projects is critical, funding alone is insufficient to stimulate wide-scale deployment; further policy action is needed to create markets, reduce risk, and attract private capital. In 2009, the 111th Congress took action on two bills (H.R. 2454 and S. 1733) that would have authorized a national cap-and-trade system to limit greenhouse-gas emissions and incentivize deployment of low-carbon technologies, including CCS. In a historic vote, the House of Representatives passed H.R. 2454 (Waxman-Markey's American Clean Energy and Security Act of 2009), but S. 1733 (Clean Energy Jobs and American Power Act) was defeated in the Senate, and neither bill was enacted. Political conditions changed with the 2010 midterm elections, and climate-change legislation—which seemed all but certain the previous year—has become highly unlikely in the near term. The legislative landscape on climate change further remained supportive of low-carbon energy, and an increasing emphasis has been placed on its benefits to the US economy and national security over climate-change mitigation (Dawson, 2010). Furthermore, climate-change adaptation and CO_2 utilization have also been elevated in the national discussion.

Within this shifting landscape on climate change, energy, and the economy, the US "shale gas revolution" has fundamentally changed domestic energy markets, and has been a leading story for both its benefits to the economy and concerns over production methods (hydraulic fracturing). Between 2005 and 2010, domestic shale gas production grew 45 percent per year, and now constitutes 24 percent of overall US gas production (up from 4 percent in 2005) (US EIA, 2012). In May 2012, the domestic price of natural gas dipped below $2 per thousand cubic feet (tcf), too low for producers to break even, but attractive to manufacturers, utilities, and the chemical sector, looking for cheaper supplies of fuel and feedstock. In 2011, the price of natural gas averaged $3.95 per mcf, providing the nation with $103 billion in savings, which is expected to be even greater in 2012. Hundreds of thousands of jobs have been created, and billions of dollars of lease payments and royalties to landowners and cash-strapped states have been made. As long as production rates are maintained and industry addresses environmental concerns, the benefits from the technology and production are expected to exceed $100 billion per year in the coming decades (Ames, et al., 2012). However, this dramatic shale gas development has fundamentally impacted the relative competitiveness of all low-carbon technologies, including CCS, raising important questions on what type of policy actions are needed to help maintain the country's diversified energy portfolio. (While fuel switching from coal to natural gas will provide near-term emissions reductions, in the face of climate concerns, CCS will still be required for natural gas applications.)

It is within the context of this new political and economic reality that the United States has capitalized on the fifteen-year advances and momentum for CCS and shifted its policy emphasis to CCUS. In July 2011, during a hearing before the Senate Energy and Natural Resources Committee to consider his nomination as DOE's Assistant Secretary for Fossil Energy, Charles McConnell fielded a number of questions on how CCS could move forward in the absence of climate-change legislation or a price on carbon. Mr. McConnell articulated DOE's new strategy to advance CCUS, with CO_2-EOR as a key to increasing domestic oil production while storing CO_2 in an economically viable manner. He also emphasized the need for continued R&D in DOE's core Carbon Sequestration Program, and the development of "next generation" CO_2-EOR technologies that will be critical to improving EOR efficiency, ensuring effective MVA of stored carbon, and driving down CO_2-capture costs (ENR, 2011).

This CCUS policy shift was supported by a foundational report prepared by Advanced Resources International, Inc. (ARI), Improving Domestic Energy Security and Lowering CO_2 Emissions with "Next Generation" CO_2-Enhanced Oil Recovery (ARI, 2011). The study assessed technically and economically feasible CO_2-EOR and carbon-storage potential throughout the United States, using "state of the art" and "next generation" technology. (This work built on previous analyses of best practices in the reports, CO_2-EOR Technology in Storing CO_2 with Enhanced Oil Recovery and a series of Ten Basin-Oriented Reports [ARI, 2008; ARI, 2006]).

ARI estimates that the CO_2-EOR industry could create a market greater than $1 trillion for CO_2 captured from fossil fuel power plants and industrial facilities. When used with "next generation" technology, the CO_2-EOR sector, over the course of thirty years, could create 2.5 million jobs, reduce imported oil by 30 to 40 percent, and generate domestic economic activity equal to $6.8 trillion (ARI, 2011) (see Table 3). Additionally, ~25 billion Mt of anthropogenic CO_2—that would have otherwise been vented to the atmosphere—could be permanently stored (ARI, 2011). While these estimates are subject to certain assumptions and some uncertainty, the potential for CO_2-EOR in the current market environment is significant, and in the absence of carbon-pricing mechanisms, presents the only major commercial pathway for CCUS.

References:

Advanced Resources International, Inc. (ARI). Ten Basin-Oriented Reports. Prepared for the US Department of Energy (2006), www.fe.doe.gov/programs/oilgas/eor/Ten_Basin-Oriented_CO2-EOR_Assessments.html.

Advanced Resources International, Inc. (ARI). Storing CO_2 with Enhanced Oil Recovery. Prepared for the US Department of Energy DOE/NETL-402/1312/02-07-08 (February 7, 2008), www.netl.doe.gov/energy-analyses/pubs/StoringCO2NexGenEOR10.pdf

Advanced Resources International, Inc. (ARI). U.S. Oil Production Potential from Accelerated Deployment of Carbon Capture and Storage. (March 2010), www.adv-res.com/pdf/v4ARI%20CCS-CO2-EOR%20whitepaper%20FINAL%204-2-10.pdf.

Advanced Resources International, Inc. (ARI). Storing CO_2 and Producing Domestic Crude Oil with Next Generation CO_2-EOR Technology: An Update. Prepared for the U.S. Department of Energy, DOE/NETL-2010/1417 (April 30, 2010), www.netl.doe.gov/energy-analyses/pubs/StoringCO2NexGenEOR10.pdf.

Advanced Resources International, Inc. (ARI). Improving Domestic Energy Security and Lowering CO_2 Emissions with "Next Generation" CO2-Enhanced Oil Recovery (2011), www.netl.doe.gov/energy-analyses/pubs/storing%20co2%20w%20eor_final.pdf.

Ames, R., A. Corridore, J. N. Epross, E. Hirs, P. MacAvoy, and R. Tavelli. The Arithmetic of Shale Gas. Yale School of Management (June 2012), http://papers.ssrn.com/sol3/papers.cfm?abstract_id=2085027.

California Carbon Capture and Storage Review Panel. Findings and Recommendations by the California Carbon Capture and Storage Review Panel (December 2010), www.climatechange.ca.gov/carbon_capture_review_panel/documents/2011-0114_CSS_Panel_Recommendations.pdf

CCSReg. Model CCS Legislation. (October 2011), http://www.ccsreg.org/pdf/CCS%20Legislation%20October%202011.pdf

Cook, B. The Economic Contribution of CO_2-EOR in Wyoming's Economy. University of Wyoming, Department of Economics and Finance, Enhanced Oil Recovery Institute (June 2012), www.uwyo.edu/cee/_files/docs/cook-benjamin-economic-contribution-co2-eor.pdf.

Dawson, B. Massaging the Climate Message: New Political Conditions Bring Shifting Strategies. Yale Forum on Climate Change & the Media (2010), www.yaleclimatemediaforum.org/2010/05/massaging-the-climate-message/.

Det Norske Veritas (DNV). Geological Storage of Carbon Dioxide: Recommended Practice DNV-RP-J203 (April 2012).

Det Norske Veritas (DNV). Qualification Management for Geological Storage of CO_2: DNV Service Specification DNV-DSS-402 (June 2012).

DiPietro, P., J., P. Balash, M. Wallace. A Note on Sources of CO_2 Supply for Enhanced-Oil-Recovery Operations. Society of Petroleum Engineering, Economics & Management (April 2012).

Energy and Natural Resources (ENR) Committee, US Senate. Full Committee Hearing to Consider the Nominations of Charles McConnell, to be an Assistant Secretary of Energy (Fossil Energy) and Rebecca Wodder, to be Assistant Secretary for Fish and Wildlife and Parks (Hearing Room SD-366) (July 28, 2011), www.energy.senate.gov/public/index.cfm/hearings-and-business-meetings?ID=4e72417e-949b-83a6-8d95-7dabf9f4c012.

Global CCS Institute (GCCSI). Global Status of CCS Update: June 2012 (June 2012), www.globalccsinstitute.com/publications/global-status-ccs-update-june-2012.

Havorka, S. EOR as Sequestration – Geoscience Perspective: White Paper for Symposium on Role of EOR in Accelerating Deployment of CCS. (2010), http://web.mit.edu/mitei/docs/reports/eor-css/hovorka.pdf.

Herzog, H., E. Drake, J. Tester, and R. Rosenthal. A Research Needs Assessment for the Capture, Utilization, and Disposal of Carbon Dioxide from Fossil Fuel–Fired Power Plants. DOE/ER-30194, US Department of Energy, Washington, DC (1993).

Herzog, H., E. Drake, and E. Adams. CO_2 Capture, Reuse, and Storage Technologies for Mitigating Global Climate Change: A White Paper Final Report. DOE No. DE-AF22-

96PC01257, US Department of Energy, Washington, DC / Massachusetts Institute of Technology, Cambridge, MA (1997).
Intergovernmental Panel on Climate Change (IPCC). IPCC Special Report on Carbon Dioxide Capture and Storage. Cambridge University Press (2005).

Interstate Oil and Gas Compact Commission (IOGCC). Carbon Capture and Storage: A Regulatory Framework for States (2005).

Interstate Oil and Gas Compact Commission (IOGCC). CO_2 Storage: A Legal and Regulatory Guide for States (2008).

Interstate Oil and Gas Compact Commission (IOGCC). A Review of State and Provincial Action to Create a Legal and Regulatory Infrastructure for Storage of Carbon Dioxide in Geologic Structures, IOGCC CCGS Task Force (2010).

Interstate Oil and Gas Compact Commission (IOGCC). A Policy, Legal and Regulatory Evaluation of the Feasibility of a National Pipeline Infrastructure for Transport and Storage of Carbon Dioxide (2011).

Jaramillo, P., W. Griffin, S. McCoy. "Life Cycle Inventory of CO_2 in an Enhanced Oil Recovery System," Environmental Science & Technology 43, 8027-8032 (2009).

Jessen, K., L. Sam-Olibale, A. Kovscek, F. Orr. Increasing CO_2 Storage in Oil Recovery. Department of Petroleum Engineering, Stanford University (2005).

Koottungal, Leena, "Special Report: 2012 Worldwide EOR Survey," Oil and Gas Journal (April 2, 2012).

Kuuskraa, V. CO_2-EOR Can Accelerate the Deployment of CO_2-Capture, Utilization and Storage (CCUS). Presentation for the Atlantic Council of the United States (July 26, 2012).

MacKay, R. Governor Looks to Support CO_2 Pipeline Network. Office of Governor Matt Mead, Cheyenne, Wyoming (2012), www.CO2governor.wy.gov/media/pressReleases/Pages/GovernorLookstoSupportCO2.aspx.

McCormick, M. A Greenhouse Gas Accounting Framework for Carbon Capture and Storage Projects. Center for Climate and Energy Solutions (February 2012), http://www.c2es.org/docUploads/CCS-framework.pdf.

Melzer, L. S. Carbon Dioxide Enhanced Oil Recovery (CO_2-EOR): Factors Involved in Adding Carbon Capture, Utilization and Storage (CCUS) to Enhanced Oil Recovery (2012), www.neori.org/NEORI_Report.pdf.

Miller, C. Carbon Capture and Sequestration in Texas: Navigating the Legal Challenges Related to Pore Space Ownership. Texas Journal of Oil, Gas, and Energy Law (2011), http://tjogel.org/wp-content/uploads/2012/05/Chris_final.pdf .

Moore, M. How Far Can CO_2 Enhanced Oil Recovery Drive Carbon Capture, Utilization and Storage? Presentation to the Atlantic Council of the United States. (July 26, 2012).

National Enhanced Oil Recovery Initiative (NEORI). Carbon Dioxide Enhanced Oil Recovery: A Critical Domestic Energy, Economic and Environmental Opportunity. (February 2012), http://www.neori.org/NEORI_Report.pdf.

Southern States Energy Board (SSEB). Carbon Capture and Sequestration Legislation in the United States of America (2011), http://www.sseb.org/files/ccs-legislation-full-version.pdf.

US Department of Energy (DOE) National Energy Technology Laboratory (NETL). Carbon Dioxide–Enhanced Oil Recovery: Untapped Domestic Energy Supply and Long-Term Carbon Storage Solution (2010).

US Department of Energy (DOE) National Energy Technology Laboratory (NETL). Carbon Sequestration Program: Technology Program Plan (2011).

US Department of Energy (DOE), Office of Fossil Energy and Office of Science. Carbon Sequestration Research and Development (1999).

US Energy Information Agency (EIA). Annual Energy Outlook 2012 (2012).

US Environmental Protection Agency (EPA). Final Rule for Federal Requirements Under the Underground Injection

Control Program for Carbon Dioxide Geologic Sequestration Wells (2010).

US Environmental Protection Agency (EPA). Frequently Asked Questions for Geologic Sequestration and Injection of Carbon Dioxide: Subparts RR and UU, Greenhouse Gas Reporting Program (November 2011), www.epa.gov/climatechange/emissions/downloads11/documents/Subpart-RR-UU-faq.pdf.

Whittaker, S. IEA GHG Weyburn-Midale CO_2 Storage & Monitoring Project. Presentation at the Regional Carbon Sequestration Partnerships Annual Review (October 5, 2010), www.netl.doe.gov/publications/proceedings/10/rcsp/presentations/Tues%20am/Karen%20Cohen/Whittaker.%20WMP_Regional%20Partnership.pdf.

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