APPENDIX B

CARBON CAPTURE AND STORAGE RETROFIT TECHNICAL APPENDIX

I. Carbon Capture Retrofit is Demonstrated

Integrated carbon capture systems are technically feasible and available in the power sector and in other industries.[1] Retrofitting existing sources with carbon capture is demonstrated and sequestration is feasible for most existing sources and can lead to substantial reductions in CO_2 emissions.

As early as 2001, the National Energy Technology Laboratory ("NETL") found that there are no major technical barriers to carbon capture retrofit.[2] Existing plants generally apply post-combustion capture technology because it can be retrofitted to the flue gas processing system at low cost, allowing the combustion process to remain substantially unchanged.[3] Post-combustion is an end-of-the-pipe pollution control and can be installed without significant modification to the plant.[4] Current post-combustion capture uses electricity from the plant to provide heat to regenerate the solvent and power CO_2 compression, which results in an "efficiency penalty."[5] However, a wide range of options exist for effective integration of CO_2 capture equipment with the steam cycles of existing coal and gas power plants, allowing electricity output penalties per ton of CO_2 captured to be achieved that are close to those for new build plants using the same

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[1] *See generally* Comment submitted by Clean Air Task Force (CATF), Technical Appendix, Doc. ID No. EPA-HQ-OAR-2013-0495-11005 (May 12, 2014) (describing describe the current status of integrated CCS projects on power plants, and in other industrial applications in the U.S. and around the world, and then describing the current status of projects employing each of the component technical elements of CCS – capture, compression, transportation, and injection –whether for EOR or sequestration in depleted oil and gas fields or deep saline geologic formations) (Appx. B, Ex. 1). *See also generally* Global CCS Institute, "Submission to The European Commission's Evaluation Process of the Directive on the Geological Storage of Carbon Dioxide," (Aug. 27, 2014) (providing an update on the status of CCS globally) (Appx. B, Ex. 2).

[2] C. Bozzuto *et al.*, DOE NETL, *Engineering feasibility and economics of CO2 capture on an existing coal-fired power plant* (2001) (Appx. B, Ex. 3).

[3] Chao Fu and Truls Gunderson, *Carbon Capture and Storage in the Power Industry: Challenges and Opportunities*, 16 ENERGY PROCEDIA 1806, 1808 (2012) (Appx. B, Ex. 4); *See also* Geoffrey P. Hammond and Jack Spargo, *The prospects for coal-fired power plants with carbon capture and storage: A UK perspective*, 86 ENERGY CONVERSION & MGMT. 476, 477 (2014) (Appx. B, Ex. 5).

[4] Mathieu Lucquiaud and Jon Gibbins, *Effective retrofitting of post-combustion capture to coal-fired power plants and insensitivity of CO_2 abatement costs to base plant efficiency*, 5 INT'L J. OF GREENHOUSE GAS CONTROL 427 (2011) (Appx. B, Ex. 6).

[5] *Id*.

capture technology.[6] One option is to add a gas turbine combined heat and power cycle or renewable energy backup instead of integrating the retrofit with steam extraction from the main power cycle.[7] It is expected that future solvent improvements will continue to reduce CCS efficiency penalties for retrofits, with those currently under development reducing penalties by 2.5 percent.[8] In fact, the net energy penalty for amine solvent capture decreased by 26 percent between 2005 and 2012.[9] And further reductions can be achieved through process reconfiguration and effective waste heat integration with the power plant.[10]

Existing plants can also use oxy-combustion technology by retrofitting the combustion system.[11] Oxy-combustion retrofit requires addition of an air separation unit, CO_2 scrubbing and compression to the conventional plant.[12] While post-combustion technology may be easier to retrofit, oxy-combustion results in a lower "reduction in power efficiency and…increment of investment for CO_2 capture."[13] A recent risk analysis for an oxyfuel combustion retrofit on a 560 MWe power plant found that the retrofit and operation "would only involve low magnitude risks and no critical risk at all."[14] The Callide CS Energy Project, a retrofit to a 30 MW coal unit in

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[6] Jon Gibbins *et al.*, *Techno-economic assessment of CO2 capture retrofit to existing power plants*, 4 ENERGY PROCEDIA 1835 (2011) (describing "six rules for effective thermodynamic integration of post-combustion capture and CO_2 compression."), *available at*: http://ac.els-cdn.com/S187661021100258X/1-s2.0-S187661021100258X-main.pdf?_tid=c67a4d7e-799d-11e4-8f62-00000aab0f26&acdnat=1417468107_278930d3136311068cd499f1fe9ced5b. *See also* Mathieu Lucquiaud and Jon Gibbins, *Steam cycle options for the retrofit of coal and gas power plants with post-combustion capture*, 4 ENERGY PROCEDIA 1812 (2011) (Appx. B, Ex. 7).

[7] *See generally* Mathieu Lucquiaud *et al.*, *Carbon capture retrofit options with the on-site addition of gas turbine combined heat and power cycle*, 37 ENERGY PROCEDIA 2369 (2013) (Appx. B, Ex. 8). IEAGHG, *Retrofitting CO2 Capture to Existing Power Plants*, at 21-22 (May 2011) (Appx. B, Ex. 9). Other options include fully integrated retrofit; boiler heat-matched retrofit; boiler heat and power matched retrofit; advanced coal boiler retrofit; gas turbine heat matched retrofit; and solar thermal systems.

[8] Desmond Dillon *et al.*, *A Summary of EPRI's Engineering and Economic Studies of Post Combustion Capture Retrofit Applied at Various North American Host Sites*, 37 ENERGY PROCEDIA 2349, 2357 (2013) (Appx. B, Ex. 10).

[9] Kristin Gerdes, DOE NETL, Powerpoint, "NETL Studies on the Economic Feasibility of CO2 Capture Retrofits for the U.S. Power Plant Fleet," (Jan. 9, 2014) (Appx. B, Ex. 11).

[10] Global CCS Institute, *The Global Status of CCS 2014*, Appendix A, at 109 (Nov. 2014), *available at*: http://decarboni.se/sites/default/files/publications/180923/global-status-ccs-2014.pdf [hereinafter *Global Status of CCS 2014*].

[11] *See* Chao Fu and Truls Gunderson, (Appx. B, Ex. 4) *supra* note 3 at 808. *See also* Geoffrey P. Hammond and Jack Spargo, (Appx. B, Ex. 5) *supra* note 3 at 477.

[12] Geoffrey P. Hammond and Jack Spargo, (Appx. B, Ex. 5) *supra* note 3 at 478.

[13] Chao Fu and Truls Gunderson, (Appx, B, Ex. 4) *supra* note 3 at 1809.

[14] Kati Kupila *et al.*, *Risk Analysis of FORTUM's 560MWe net Power Plant Retrofit to Oxyfuel Combustion*, 4 ENERGY PROCEDIA 1820, 1821 (2011) (Appx. B, Ex. 12).

Australia, is the largest oxyfuel combustion demonstration on a power plant in the world.[15] Existing plants cannot utilize pre-combustion capture.[16]

The Electric Power Research Institute ("EPRI") recently performed detailed economic and engineering studies to determine the feasibility of retrofitting five existing, North American, pulverized coal ("PC") and/or circulating fluidized-bed ("CFB") plants with post-combustion capture and found that all sites were technically capable of 90 percent retrofit.[17] Another recent study commissioned by the IEAGHG concluded, "a general rejection of retrofitting on grounds such as age or lower efficiency of existing plants is not justified."[18]

The issues associated with CCS retrofit are generally site-specific and depend on the characteristics of the plant and the capture technology installed. The most important of them are access to suitable CO_2 storage and space on-site[19] for additional equipment associated with capture."[20] But even though most existing plants were not originally designed to operate with CCS "they can achieve performance with capture close to a plant built with capture from the outset independently of the initial plant steam conditions and efficiency with appropriate steam turbine retrofits."[21]

CCS retrofits costs are reasonable especially in light of the extensive emission reductions achievable and the fact that without CCS, existing power plants will be forced to retire prematurely in order to avoid the most dangerous climate change, resulting in significant stranded assets.[22] Retrofitting plants is a lower-cost option to reduce CO_2 emissions than replacing the plant with an entirely new plant.[23] A CCS retrofit can result in a levelized cost of electricity almost $50 less than a new build with CCS.[24]

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[15] Global CCS Institute, "The Callide Oxyfuel Project," (Feb. 13, 2013), *available at*: http://www.globalccsinstitute.com/insights/authors/dennisvanpuyvelde/2013/02/13/callide-oxyfuel-project.

[16] Umberto Desideri and Marco Antonelli, *A simplified method for the evaluation of the performance of coal fired power plant with carbon capture*, 64 APPLIED THERMAL ENG'G 263-64 (2014) (Appx. B, Ex. 13).

[17] Desmond Dillon *et al*., (Appx. B, Ex. 10) *supra* note 8 at 2357.

[18] Jon Gibbins *et al*., *supra* note 6 at 1836.

[19] Jia Li *et al*., *An assessment of the potential for retrofitting existing coal-fired power plants in China*, 4 ENERGY PROCEDIA 1805, 1811 (2011) (Appx. B, Ex. 14). For most plants, however "there is the potential to have at least partial retrofit, which means retrofitting only some of the generating units rather than the whole power plant."

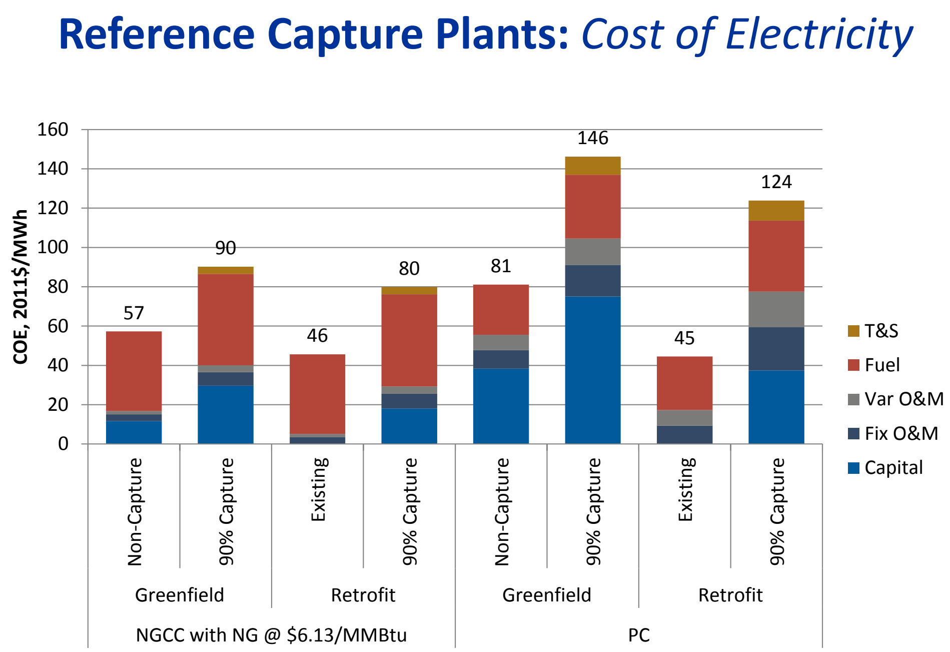
[20] Jon Gibbins *et al*., *supra* note 6 at 1838.

[21] Mathieu Lucquiaud and Jon Gibbins, (Appx. B, Ex. 7) *supra* note 6 at 1819.

[22] Nils Johnson *et al*., *Stranded on a low-carbon planet: Implications of climate policy for the phase-out of coal-based power plants*, __ TECH. FORECASTING & SOC. CHANGE ___ (2014) (Article in press) (Appx. B, Ex. 15).

[23] IEA, Technology Roadmap: Carbon Capture and Storage, at 29 (2013); *See also generally* Desmond Dillon *et al*., (App. Ex. 10) *supra* note 8 at 2349.

[24] Desmond Dillon *et al*., (Appx. B, Ex. 10) *supra* note 8 at 2356 (assuming that the retrofitted plant is paid off and will continue to operate for 30 more years).



Kristin Gerdes, DOE NETL, Powerpoint, "NETL Studies on the Economic Feasibility of CO2 Capture Retrofits for the U.S. Power Plant Fleet," (Jan. 9, 2014) (App. Ex. 11).

The lower capital cost of retrofit on an existing plant over a new build can offset any additional costs associated with reduced efficiency and additional capture cost.[25] Existing plants can take advantage of existing infrastructure, grid connections, water supplies, coal and gas delivery facilities and environmental permits.[26] It was originally thought that the existing plant efficiency would have a dramatic effect on CCS costs,[27] however recent studies have found,"[p]rovided that effective capture system integration can be achieved…abatement costs …is independent of the initial plant efficiency."[28] U.S. DOE currently estimates that capture costs for the nth coal combustion and gasification plant is \$60/ton of CO_2 with a goal of \$40/ton of CO_2 by 2025 and further reductions thereafter.[29]

Partial CCS retrofit meets the definition of best system of emission reduction because it is achievable and adequately demonstrated "to serve the interests of pollution control without becoming exorbitantly costly in an economic or environmental way."[30]

II. Most Existing Power Plants Have Sufficient Space to Add Carbon Capture

[25] Jon Gibbins *et al.*, *supra* note 6 at 1836.

[26] IEAGHG (Appx. B, Ex. 9) *supra* note 7 at ii.

[27] *Id*. at x.

[28] Mathieu Lucquiaud and Jon Gibbins, (Appx. B, Ex. 6) *supra* note 4 at 427.

[29] Global Status of CCS 2014 at 106.

[30] *Essex Chem. Corp. v. Ruckelshaus,* 486 F.2d 427, 433 (D.C. Cir. 1973).

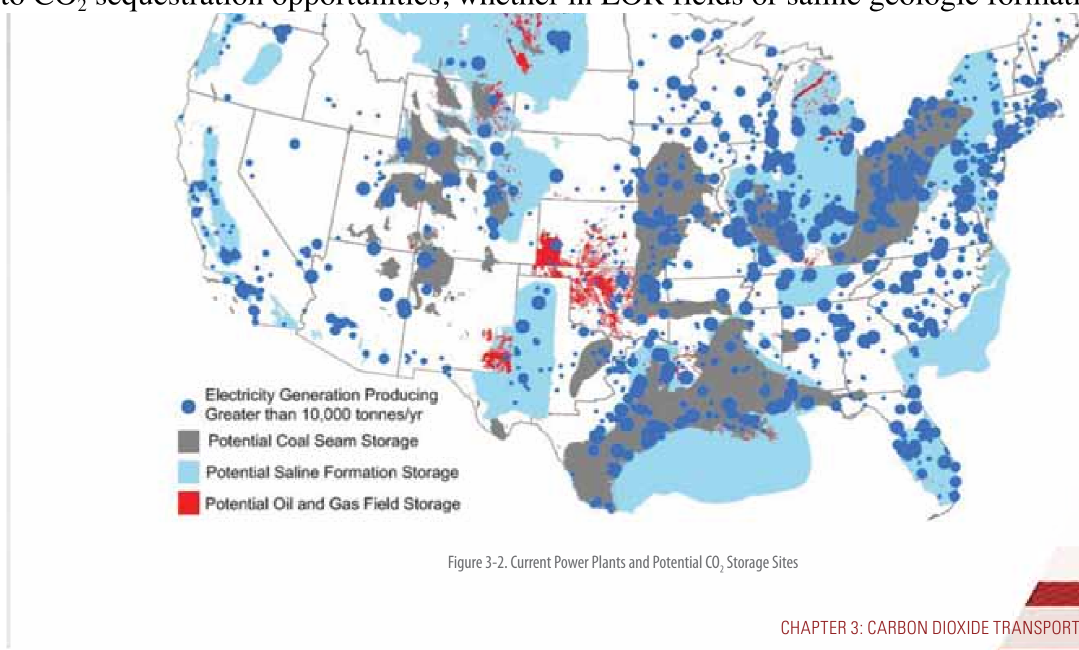
Equipment

Some commentators have identified the generalized problem of inadequate space for capture equipment at existing plants as a potential limiting factor for CCS. However, as will be described below, research shows that for most existing sources, partial CCS retrofit is technically feasible and available.

A 2010 NETL study evaluated the feasibility of adding retrofitted capture at existing power plant sites using aerial and satellite images of the power plant site.[31] No sites were considered totally infeasible for retrofit.[32] And, for most plants, "there is the potential to have at least partial retrofit, which means retrofitting only some of the generating units rather than the whole power plant."[33] Further, different capture technology options, especially oxyfuel, may require less space and increase partial CCS retrofit potential.[34]

III. Carbon Storage Capacity is Widely Available

As the map below depicts, the majority of U.S. coal-fired power plants are located in regions with potential storage options. While carbon storage is technically available and feasible for all power plants, a potential limit to installing CCS at some plants may be cost-effective access to CO_2 sequestration opportunities, whether in EOR fields or saline geologic formations.



DOE/NETL, *Carbon Dioxide and Storage RD&D Roadmap*, at 45 (Dec. 2010) (App. Ex. 28).

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[31] IEAGHG, (Appx. B, Ex. 9) *supra* note 7 at 84, 86.

[32] *Id*.

[33] Jia Li *et al*., (Appx. B Ex. 14) *supra* note 19 at 1811.

[34] IEAGHG, (Appx. B, Ex. 9) *supra* note 7 at 84, 86.

The CO_2 injection technology that is the basis for CO_2 is mature and has a long history. Experimental CO_2 injections began half a century ago in the Mead Strawn Field in 1964 and commercial scale CO_2 flooding began in 1972 at the SACROC Field, both in Texas.[35] Today 136 sites are actively injecting CO_2 underground for EOR.[36] EOR is an important sequestration technology because CO_2 is stored in the process of producing oil via a variety of trapping mechanisms. Because CO_2 is recycled, virtually all of the CO_2 initially injected remains stored in the field. Moreover, CO_2 is a valuable commodity, and in some areas, in short supply, and provides a revenue stream back to capture sources that can offset the cost of capture. For example, in the Permian Basin Eastern New Mexico, Utah and Wyoming, the value of CO_2 is approximately $40 per metric tonne.[37] [38] [39] "Next generation" CO_2-EOR technology including reservoir surveillance and process control is emerging that will allow greater volumes of CO_2 to be stored in depleted oil fields.[40] These technologies are also being applied to revive oil fields as well as new injection sites such as residual oil zones ("ROZ") that may exist below existing fields or in areas without a main oil pay zones increasing the demand for CO_2-.[41]

In 2010, NETL performed a study that looked at 388 large, efficient, coal plants and found that 84 percent of them were within 25 miles of storage, 97 percent were within 100 miles of storage – 322 of the 323 GW examined were within 150 miles of storage.[42] NETL found that "both transport and storage requirements for retrofits at a significant number of sites have a good

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[35] Bruce Hill, *et al.*, *Geologic carbon storage through enhanced oil recovery*, 37 ENERGY PROCEDIA 6808, 6811 (2013), *available at*: http://www.elsevier.com/__data/assets/pdf_file/0019/206191/Geologic-carbon-storage.pdf.

[36] Kuuskraa and Wallace, *CO_2-EOR Set for Growth as New CO_2 Supplies Emerge*, OIL & GAS J. (Apr. 7, 2014) (Appx. B, Ex. 16).

[37] Michael L. Godec, Advanced Resources International, Powerpoint, *From CO_2-EOR to CCS:* "*Prospects and Challenges of Combining CO_2-EOR with Storage*," IEA-OPEC CO_2-EOR Kuwait Workshop (Feb. 2012), *available at*: http://www.iea.org/media/workshops/2012/ieaopec/Godec.pdf.

[38] Benjamin R. Cook, *The Economic Contributions of CO2 Enhanced Oil Recovery in Wyoming's Economy* (June 2012) *available at*: http://www.uwyo.edu/cee/_files/docs/cook-benjamin-economic-contribution-co2-eor.pdf.

[39] Klaas van't Veld and Owen R. Phillips, *Pegging Input Prices in Long Term Contracts: CO_2 Purchase Agreements in Enhanced Oil Recovery* (July 2009) *available at*: http://www.uwyo.edu/owenphillips/papers/co2pegging071509.pdf.

[40] Vello A. Kuuskraa *et al.*, *The synergistic pursuit of advances in MMV technologies for CO_2 – Enhanced Recovery and CO_2 storage*, 37 ENERGY PROCEDIA 4099 (2013) (discussing "five case studies of using MMV technology and smart wells to monitor and manage CO_2 storage and CO_2-EOR operation"), *available at*: http://ac.els-cdn.com/S1876610213005547/1-s2.0-S1876610213005547-main.pdf?_tid=7492b150-798d-11e4-8fef-00000aab0f27&acdnat=1417461098_42b46a768c22b83643134ffbad4615f8.

[41] Vello A. Kuuskraa *et al.*, *CO_2 utilization from "next generation: CO_2 enhanced oil recovery technology*, 37 Energy Procedia 6854 (2013), *available at*: http://www.elsevier.com/__data/assets/pdf_file/0006/179214/CO2-Utilization-from-Next-Generation-CO2-Enhanced-Oil.pdf.

[42] IEAGHG, (Appx. B, Ex. 9) *supra* note 7 at 84-85 (citing Christopher Nichols, NETL, *Coal-Fired Power Plants in the United States: Examinations of the Costs of Retrofitting with CO2 Capture Technologies, Revision 3* (Jan. 4, 2011)).

chance of being met."[43] A 2009 study modeled possible build-out scenarios for CO_2 pipelines and concluded: "the need to increase the size of the existing dedicated CO_2 pipeline system should not be seen as a major obstacle for the commercial deployment of CCS technologies in the United States."[44] There are about 4,000 miles of onshore CO_2 pipeline in the U.S.[45] and infrastructure continues to expand with market demand for even further buildout.[46] In total, this system carries approximately 68 Mtpa of naturally mined and anthropogenic CO_2 throughput,[47] and continues to grow to meet demand.[48]

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[43] *Id*. at 84.

[44] JJ Dooley *et al*., *Comparing Existing Pipeline Networks with the Potential Scale of Future U.S. CO_2 Pipeline Networks*, 1 ENERGY PROCEDIA 1595 (2009), *available at*: http://ac.els-cdn.com/S1876610209002100/1-s2.0-S1876610209002100-main.pdf?_tid=68c9643a-798e-11e4-ab93-00000aacb362&acdnat=1417461507_82ec94a603dee8e29cf213349b3f313b.

[45] Global Status of CCS 2014 at 117.

[46] Kevin Bliss, *et al., A Policy, Legal, and Regulatory Evaluation of the Feasibility of a National Pipeline Infrastructure for the Transport and Storage of Carbon Dioxide*, (Sept. 10, 2010) *available at*: http://www.secarbon.org/files/pipeline-study.pdf; *See also* Advanced Resources International, *U.S. Oil production potential from accelerated deployment of carbon capture and storage,* at 2 (2010) *available at*: http://www.adv-res.com/pdf/v4ARI%20CCS-CO2-EOR%20whitepaper%20FINAL%204-2-10.pdf. EPA estimates in 2013 that there are 3,600 miles of pipeline and also notes that 95% of the top 500 largest CO_2 point sources are within 50 miles of a possible geologic sequestration site. 79 Fed. Reg. at 1472 (*citing* JJ Dooley et al., *Carbon Dioxide Capture and Geologic Storage: A Key Component of a Global Energy Technology Strategy to Address Climate Change*, Joint Global Change Research Institute (2006)); *accord* Jordan K Eccles, Lincoln Pratson, *A 'carbonshed' assessment of small- vs. large-scale CCS deployment*, 113 APPLIED ENERGY 352, 357 (2014) (Appx. B, Ex. 17) (noting that "the large, low cost carbonsheds for Mt. Simon and Frio [geologic sequestration formations] also coincidentally contain the majority of existing coal-fired power plants….").

[47] Global Status of CCS 2014 at 117.

[48] *See e.g*. Denbury Resources Denbury Resources, "CO2 Sources and Pipelines – Gulf Coast Region," http://www.denbury.com/operations/gulf-coast-region/co2-sources-and-pipelines/default.aspx. Construction of Denbury's 325-mile Green Pipeline was completed in mid-December 2010; Denbury, "CO2 Sources and Pipelines – Rocky Mountain Region," http://www.denbury.com/operations/rocky-mountain-region/co2-sources-and-pipelines/default.aspx. Denbury also completed construction of 232 miles of the Greencore CO_2 pipeline in the Rocky Mountain region in late 2012; "Carbon dioxide injection starts in Oklahoma's Burbank oil field," OIL & GAS J. (July 8, 2013) (Appx. B, Ex. 18). In 2013, Chaparral Energy began operation of a 68-mile CO_2 pipeline connecting the Coffeyville fertilizer plant to Burbank, Oklahoma to enable the use of the anthropogenic CO_2 for EOR.

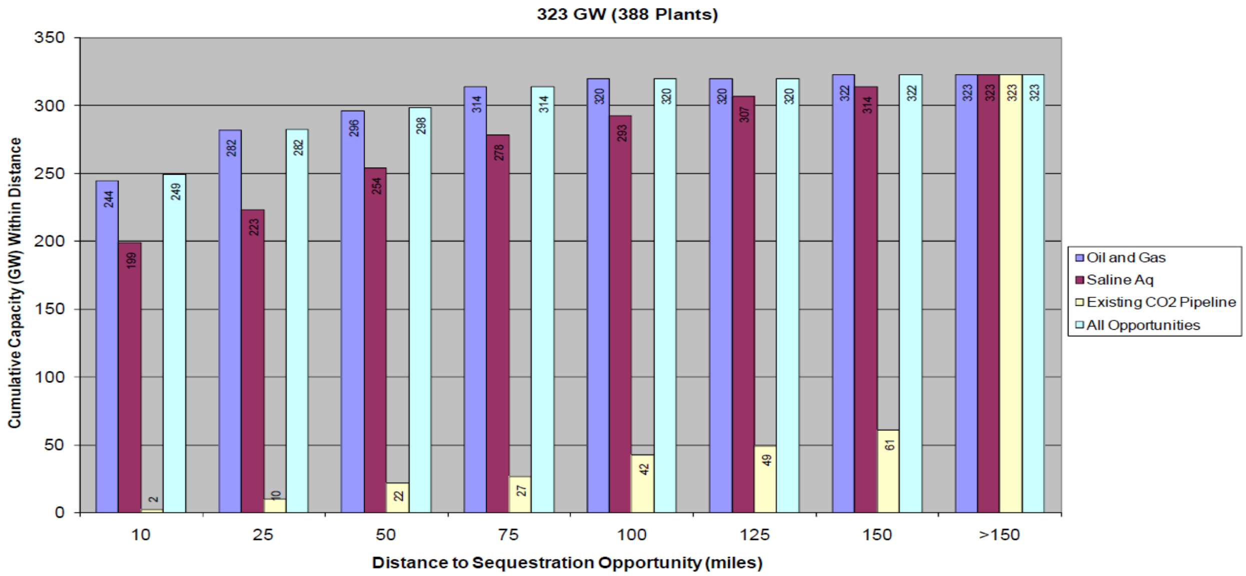

Figure 6.4 Distance to prospective storage locations for operating US coal plants
(100 miles = 160 km)

IEAGHG, *Retrofitting CO2 Capture to Existing Power Plants*, at 84-85 (May 2011) (citing Christopher Nichols, NETL, *Coal-Fired Power Plants in the United States: Examinations of the Costs of Retrofitting with CO2 Capture Technologies, Revision 3* (Jan. 4, 2011)).

In its 2013 National Assessment of Geologic Carbon Dioxide Storage Resources, the U.S. Geological Survey assessed the technically accessible geologic carbon storage resources in 36 sedimentary basins in the onshore and beneath state waters of the United States.[49] The assessment only inventoried geologic formations below 3,000 feet with adequate porosity and permeability to accept commercial volumes of CO_2.[50] The assessment estimates that there are approximately 3,000 Gt of subsurface storage capacity.[51] This represents more than 500 times the 2011 annual 5.5 Gt of energy-related CO_2 emissions in the U.S. today. In addition, DOE estimates that 500 to 7,500 Gt of CO_2 could be sequestered in all U.S. offshore formations on the outer continental shelf.[52]

The analysis suggests storage potential in nearly all regions of the U.S.[53] Capacity and transportation and injection infrastructure currently available in EOR fields in the parts of the

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[49] *See* USGS, *National Assessment of Geologic Carbon Dioxide Storage Resources* (Sept. 24, 2013) *available at*: http://pubs.usgs.gov/ds/774/

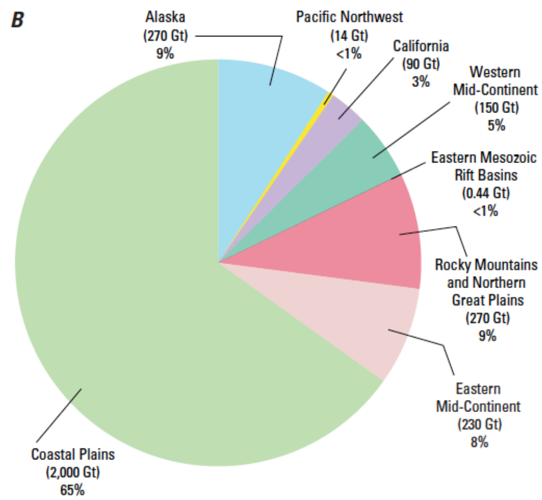
[50] *Id.*

[51] *Id.*

[52] DOE, *The United States Carbon Utilization and Storage Atlas* (2012), 4th Edition, *available at*: http://www.netl.doe.gov/File%20Library/Research/Coal/carbon-storage/atlasiv/Atlas-IV-2012.pdf.

[53] New England could access storage in the Midwest by pipeline, or in the offshore outer continental shelf along Georges Bank as was suggested by an abandoned CCS project that would have stored its CO_2 in the Mississauga Formation 70 miles off of the coast of New Jersey.

Rocky Mountains, Midwest, Southeast United States and parts of California provide a model for expansion. Where formations that have capacity for CO_2 do not exist, research suggests that the expansion and build-out of today's 4,000-mile CO_2 pipeline network is feasible and would reach much of the rest of the U.S. Offshore areas are under investigation.



USGS, *National Assessment of Geologic Carbon Storage Resources – Summary*, at 2 (2013) *available at*: http://pubs.usgs.gov/fs/2013/3020/pdf/FS2013-3020.pdf.

CO_2 Capacity in Depleted Oil Fields: Depleted oil fields, some with existing transportation and injection infrastructure in place for CO_2 flooding, can provide available storage during the scale up of CCS projects or beyond for many states. The figure below shows that as of 2014, there are 136 CO_2-EOR projects with approximately 13,000 CO_2 injection wells injecting over 73 million tons of CO_2 annually.[54] And demand for anthropogenic CO_2 is climbing to the support *doubling* of EOR production and CO_2 utilization by 2020.[55] Advanced Resources Inc. ("ARI") has estimated that next-generation EOR combined with currently limited estimates of ROZ production could produce a demand for approximately 33 Gt of CO_2 .[56] [57] [58] [59] This suggests

[54] J. Meyer, API Background Report: *Summary of Carbon Dioxide Enhanced Oil Recovery (CO2-EOR) Injection Well Technology*, *available at*: http://api.org/environment-health-and-safety/environmental-performance/~/media/D68DE1954B8E4905A961572B3D7A967A.ashx.

[55] Kuuskraa and Wallace, *CO_2-EOR Set for Growth as New CO_2 Supplies Emerge*, OIL & GAS J. (Apr. 7, 2014) (Appx. B, Ex. 19).

[56] Vello Kuuskraa, Powerpoint, *Using the economic value of CO2 EOR to accelerate the deployment of CO_2 capture, utilization and storage* (CCUS) (Apr. 25-26 2012) (Appx. B, Ex. 20).

[57] Tip Meckel, *et al*., *Offshore CCS in the Northern Gulf of Mexico and South Atlantic*, Poster, Regional Carbon Sequestration Partnership Meeting Pittsburgh (Sept. 2011) (Appx. B, Ex. 21).

[58] Tip Meckel and Ramon Trevino, Gulf Coast Carbon Center, Powerpoint, *Gulf of Mexico Miocene CO2 Site Characterization Mega Transect* (2011) *available at*: http://www.netl.doe.gov/publications/proceedings/11/carbon_storage/tuesday/11_1115_Meckel_DOE_Review_mtg_offshore_compress.pdf.

EOR-ROZ could store approximately twelve years of U.S. EGU system CO_2 (at 2.2 Gt/y). Currently there is an estimated 2 to 3 Gt of naturally occurring CO_2 available to meet this demand. The remaining future demand must be made up by captured sources.

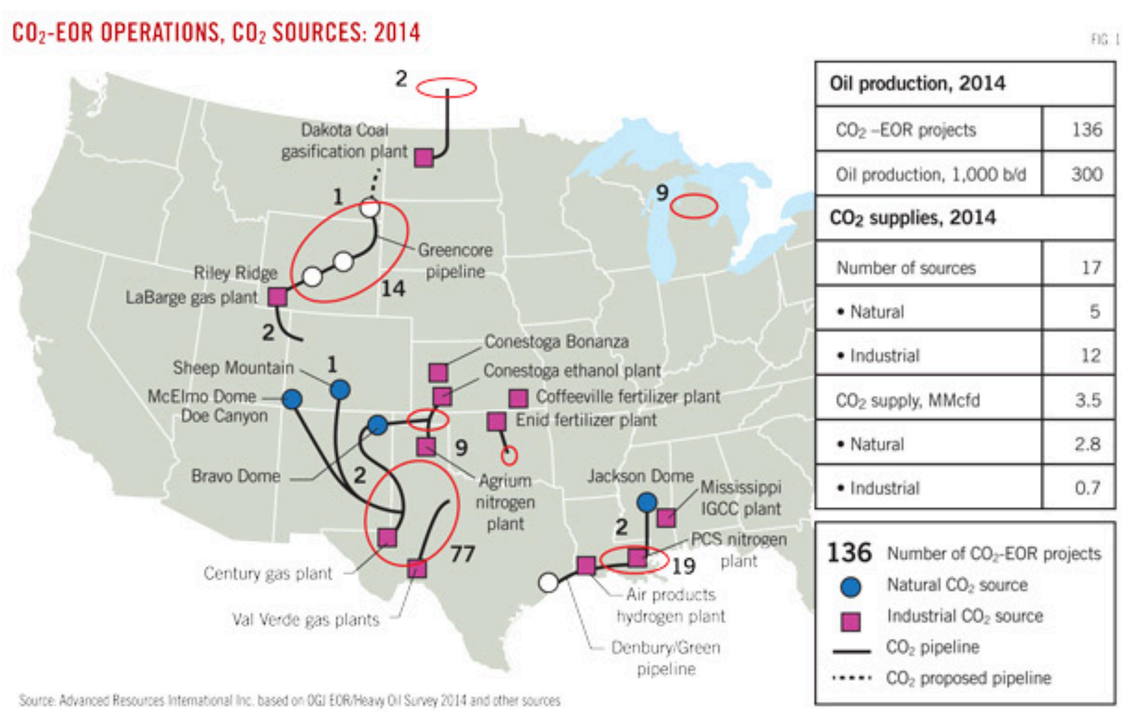
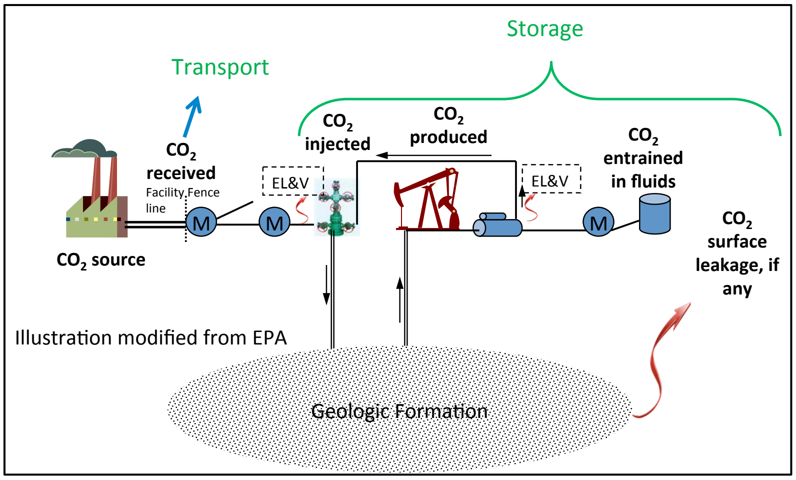


Fig. 1 provides the state-by-state locations for the 136 currently active CO_2-EOR projects. Much of the activity is in West Texas with 77 projects, followed by Mississippi (19 projects), and Wyoming (14 projects).

Fig. 1 also shows the location of existing CO_2 supply sources. While much of the CO_2 is from natural CO_2 fields, industrial sources in growing numbers also provide CO_2 to the EOR industry. A robust infrastructure of CO_2 pipelines, totaling more than 3,000 miles, links CO_2 supply areas with oil fields.

Kuuskraa and Wallace, *CO_2-EOR Set for Growth as New CO_2 Supplies Emerge*, OIL & GAS J. (Apr. 7, 2014).

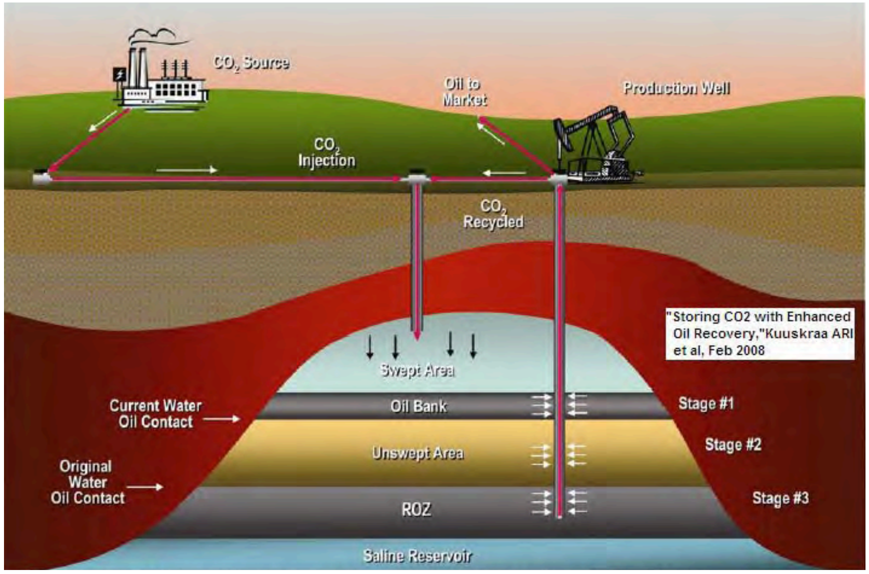
[59] Louise S. Durham, *Texas Miocene Targeted Offshore CO2 Repository Potential Studied*, AAGP EXPLORER, Sept. 2010 at 22, 42, *available at*: http://archives.aapg.org/explorer/2010/09sep/09explorer10.pdf.



Mark de Figueiredo, Powerpoint, *EPA's Greenhouse Gas Reporting Program: Geologic Sequestration and Injection of Carbon Dioxide* (Nov. 15, 2011). The graphic above illustrates how CO_2 that is received at a project site is a recycled and subsequently accounted for in EPA's greenhouse gas accounting scheme (Subpart RR). During the progressive injection and reinjection of CO_2 nearly all of the CO_2 is stored in geologic formations. Very little is lost to the atmosphere. Recently released filed life carbon balance data from the Kinder Morgan SACROC project suggest that 93 percent of the purchased CO_2 that was injected for EOR was stored (taking into account stationary and mobile emissions associated with the project.)[60]

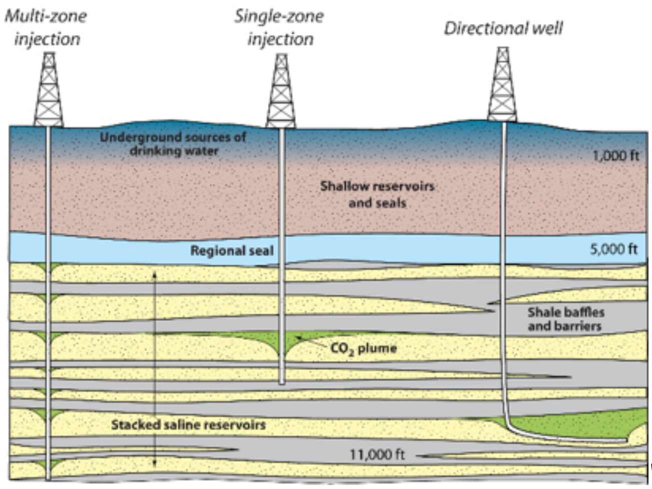
CO_2 Capacity in Residual Oil Zones: ROZs are naturally water-flooded formations below the oil water contact in oil fields (see illustration below). They are formed when meteoric water flushes out the primary oil deposit over geologic time leaving only residual oil behind. That residual oil can be substantial - in some cases as large as the primary deposit (*e.g*. Hess Seminole Field, TX) - but it can only be produced using tertiary EOR methods since water flooding will not be effective. Because oil is soluble in CO_2 at pressure, ROZs represent another frontier for CO_2-EOR oil production while at the same time promising capacities for large volumes of CO_2 to be stored. Significant ROZs have been discovered in Texas (and produced) and Wyoming and are being investigated elsewhere.

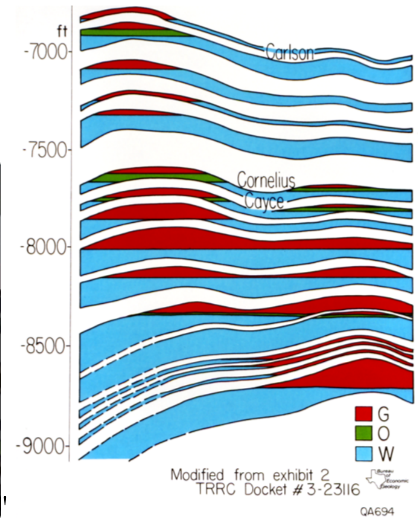
[60] *See* Charles E. Fox, Kinder Morgan CO_2 Company, LP, Powerpoint, *CO_2 EOR Carbon Balance* (2013) *available at*: http://www.co2conference.net/wp-content/uploads/2013/05/Fox-KM-Presentation-SACROC.pdf.



Vello A. Kuuskraa *et al.*, *CO_2 Utilization from "Next Generation" CO_2 Enhanced Oil Recovery Technology*, 37 ENERGY PROCEDIA 6854, 6862 (2013).

CO_2 Capacity in Stacked Storage: Another potential storage opportunity, potentially at a lower cost, takes advantage of existing infrastructure for EOR to store CO_2 in associated saline formations, "stacked storage." Thick sedimentary sequences commonly are characterized by repeating layers of interbedded sand and mud. Stacked storage takes advantage of these repeating sequences in the geologic section to build storage capacity vertically (see illustrations below). Utilizing multiple layers for storage is advantageous because instead of creating a large plume, CO_2 volumes can be managed - along with formation pressures - by spreading out the CO_2 vertically in the geologic section. Stacked storage, used in combination with EOR, allows storage of commercial volumes of CO_2 by the same existing facilities that are used to produce tertiary oil by EOR. EOR combined with stacked storage therefore takes advantage of existing pipeline transportation and injection infrastructure and could allow EOR operators to transition from oil production once the field is depleted, to storage with incidental EOR. As a result, there is a potential for large commercial volumes to be stored not only in oil fields but also in the formations associated with oil fields at a lesser capital cost.





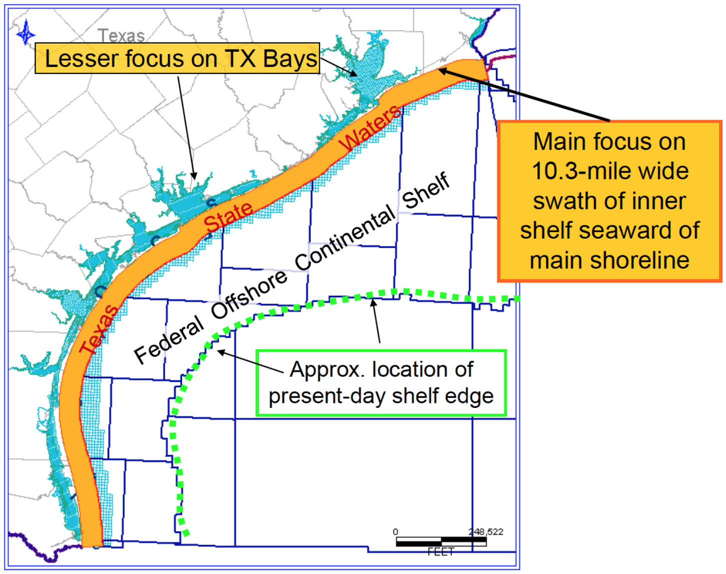
Illustrations above-- Left: J.C. Pashin *et al.*, *Southeastern Regional Carbon Sequestration Partnership (SECARB) Phase III: Final Report* prepared for Advanced Resources International, at 57 (2008) (illustration of stacked saline storage). Right: Susan Hovorka, TX BEG modified from Noel Tyler and William A. Ambros, *Facies architecture and production characteristics of strand plain reservoirs in North Markham – North Bay City Field, Frio Formation, Texas*, 70 AAPG BULL. 809-829 (July 1986) (illustration of layered oil, gas and saline formations (and intervening caprock in white) at the SECARB Frio project, Texas that could be accessed in stacked storage).

Offshore CO_2 Capacity: The Gulf Coast Carbon Center ("GCCS") at the University of Texas, Austin has recently mapped and is in the process of estimating the magnitude of the large storage volumes in offshore sites with a capacity to store 30 Mt or more CO_2 within 10 miles of shore in the Gulf of Mexico (see map below). The "Megatransect Project" has documented capacity for billions, if not trillions of tons of CO_2 in geologic formations below the Gulf of Mexico.[61] [62] [63] Combined with existing pipelines and future potential for pipelines from the Midwest, the Gulf Coast could potentially be a hub for CO_2 storage.

[61] Tip Meckel, *et al.*, *supra* note 57 (Appx. B, Ex. 21).

[62] Meckel and Trevino, *supra* note 58.

[63] Durham, *supra* note 59.



Tip Meckel and Ramon Trevino, Gulf Coast Carbon Center, Powerpoint, *Gulf of Mexico Miocene CO2 Site Characterization Mega Transect* (2011).

Existing EGUs are within a reasonable distance of cost-effective CO_2-EOR opportunities. Further, In addition to storage capacity available in depleted oil fields, next-generation CO_2-EOR technology is unlocking storage capacity in ROZs, stacked storage and offshore formations.

IV. Power Generation Retrofit Projects

CCS retrofit is available for existing affected sources with access to storage, as demonstrated by a number of commercial-scale demonstration retrofits,[64] as well a recent full-scale integrated retrofit at existing coal-fired power plant units. Further, many CCS retrofits to existing power plants are currently under development.

a. Boundary Dam Integrated Carbon Capture and Sequestration Demonstration Project

On October 2, 2014, Boundary Dam commenced operation and became the first full-scale coal-fired power plant CCS retrofit.[65] The SaskPower project added post-combustion, absorption chemical solvent-based capture to a recently refurbished, 110 MW EGU (Unit 3 at Boundary

[64] *See e.g*. Plant Barry, MIT, "Plant Barry Fact Sheet: Carbon Dioxide Capture and Storage Project," https://sequestration.mit.edu/tools/projects/plant_barry.html; Mountaineer, MIT, "AEP Mountaineer Fact Sheet: Carbon Dioxide Capture and Storage Project, https://sequestration.mit.edu/tools/projects/aep_alstom_mountaineer.html.

[65] Maria Gallucci, *World's First Full-Scale Carbon Capture and Storage Project to Launch at Canada's Boundary Dam Plant*, INT'L BUS. TIMES, Oct. 1, 2014, *available at*: http://www.ibtimes.com/worlds-first-full-scale-carbon-capture-storage-project-launch-canadas-boundary-dam-plant-1697926.

Dam Power Station).[66] Unit 3 was originally built in 1969 and was scheduled for retirement in 2013.[67] SaskPower received approval from the Saskatchewan Government to build the project in April 2011.[68] The project will capture 90 percent of the CO_2 from the Unit or approximately 1 million Mtpa (MMtpa).[69] CO_2 from the project will be will be transported via a 60-mile pipeline, and both contained as a result of EOR activity (supplementing the existing CO_2 supply to the Weyburn–Midale oil fields, captured and delivered from the Great Plains Synfuels plant, a coal gasification facility in North Dakota), and some will also be sequestered in a nearby deep saline formation as part of the Saskatchewan Aquistore project.[70] U.S. DOE estimates that the energy penalty for CO_2 capture is 24 to 42 percent more fuel input per MWh, however, Boundary Dam is only expected to use an extra 21 percent.[71] Costs of the project were offset by CO_2 sales and utilizing existing infrastructure.[72] The project include numerous cost-saving engineering innovations such as using a single system for SO_2 removal and CO_2 separation, amine columns made of concrete instead of stainless steel, and prefabrication and modular design.[73] Saskpower expects that learnings from the Boundary Dam project will result in a 20 percent electrical cost reduction and a thirty percent capital cost reduction.[74]

b. FutureGen 2.0 Project

FutureGen 2.0 is a 168 MWe project, which will involve repowering the 200 MWe Unit 4 at Ameren's power plant in Meredosia, Illinois, with oxy-combustion technology.[75] 1.1 MMtpa of CO_2 will be captured and transported by pipeline to Morgan County, Illinois for sequestration in

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[66] Global CCS Institute, "Boundary Dam Integrated Carbon Capture and Sequestration Demonstration Project," http://www.globalccsinstitute.com/project/boundary-dam-integrated-carbon-capture-and-sequestration-demonstration-project.

[67] *Id*.

[68] On September 12, 2012, Canada's Minister for the Environment published final CO_2 performance standards applicable to both new coal-fired EGUs and to coal-fired units that have reached the end of their useful lives. *Reduction of Carbon Dioxide Emissions from Coal-fired Generation of Electricity Regulations,* SOR/2012-167 §§ 3(1), 2 (definitions of "old unit" and "useful life"), 146 C. Gaz. II, 19 (Sept. 12, 2012).

[69] Global CCS Institute, *The Global Status of CCS 2013*, Appendix A, at 12 (Feb. 2014), *available at*: http://www.globalccsinstitute.com/publications/global-status-ccs-february-2014 [hereinafter *Global Status of CCS 2014 App*].

[70] Global CCS Institute, *supra* note 66.

[71] Global Status of CCS 2014 at 103.

[72] Mike Monea, President, Carbon Capture and Storage Initiatives, SaskPower, Powerpoint, "Sharing the Learning," (2013) (Appx. B, Ex. 22).

[73] *Global Status of CCS 2014* at 103.

[74] *Id*.

[75] *Global Status of CCS 2014 App* at 12; Global CCS Institute, "FutureGen 2.0" http://www.globalccsinstitute.com/project/futuregen-20-project; MIT, "FutureGen Fact Sheet" https://sequestration.mit.edu/tools/projects/futuregen.html.

a deep saline formation up to a total of 24 metric tons (Mt) over twenty years.[76] The U.S. Department of Energy ("DOE") has stated that the plant's new boiler, air separation unit, CO_2 purification and compression unit will deliver 90 percent CO_2 capture and eliminate most SO_x, NO_x, mercury and particulate emissions.[77] The project will be one of the world's largest applications of oxy-combustion technology.[78] In January 2014 DOE issued its Record of Decision to provide financial assistance to the project.[79] In February 2014, FutureGen received permission from Illinois regulators for a 30-mile underground pipeline that would carry the CO_2 to an injection and saline sequestration site in northeast Morgan County, Illinois.[80] On April 14, 2014, FutureGen signed an agreement with seventeen local unions to support the construction of the project.[81] On August 29, 2014, EPA issued the first Class VI underground injection well permits to FutureGen for geologic sequestration of CO_2 captured at the plant.[82] Operation is expected to commence in 2017.[83]

c. Petra Nova Carbon Capture Project (also known as NRG Energy Parish CCS Project)

NRG Energy plans to retrofit CO_2 capture equipment on Unit 8, a 250 MWe slipstream, at its W.A. Parish coal-fired power plant southwest of Houston, Texas.[84] It will utilize post-combustion technology developed jointly by Mitsubishi Heavy Industries, Ltd. and Kansai Electric Power Co. to capture approximately 1.5 MMtpa of CO_2 or 90 percent of the CO_2 from the flue-gas slipstream.[85] The CO_2 will be transported by an 82-mile long pipeline to the Hilcorp

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[76] *Id*.

[77] U.S. DOE, "Secretary Chu Announces FutureGen 2.0," (Aug. 5, 2010) *available at*: http://energy.gov/fe/articles/secretary-chu-announces-futuregen-20.

[78] Global CCS Institute, "Hydrogen Energy California Project (HECA)" http://www.globalccsinstitute.com/project/hydrogen-energy-california-project-heca.

[79] 79 Fed. Reg. 3,577 (Jan. 22, 2014).

[80] Tim Landis, "Regulators Approve FutureGen 2.0 Pipeline," THE STATE JOURNAL REGISTER, Feb. 24, 2014, *available at*: http://www.sj-r.com/article/20140224/News/140229610.

[81] FutureGen Alliance, Blog, "Labor Agreement Supports FutureGen's Highly Skilled Workforce," Apr. 14, 2014,

[82] Michael Bologna, *EPA Grants First Underground Injection Permits to FutureGen for Illinois Project*, BNA BLOOMBERG NEWS, Sept. 4, 2014, http://www.bna.com/epa-grants-first-n17179894408/.

[83] *Global Status of CCS 2014* at 12; Global CCS Institute, "FutureGen 2.0" http://www.globalccsinstitute.com/project/futuregen-20-project; MIT, "FutureGen Fact Sheet" https://sequestration.mit.edu/tools/projects/futuregen.html.

[84] Global CCS Institute, *The Global Status of CCS 2013*, at 29, 38, 166 (2013) *available at*: http://www.globalccsinstitute.com/publications/global-status-ccs-2013 [herineafter *Global Status of CCS 2013*]; *Global Status of CCS 2014* at 6; Global CCS Institute, "Petra Nova Carbon Capture Project (formerly NRG Energy Parish CCS Project," http://www.globalccsinstitute.com/project/nrg-energy-parish-ccs-project; MIT, "W.A. Parish Petra Nova Fact Sheet," https://sequestration.mit.edu/tools/projects/wa_parish.html.

[85] 79 Fed. Reg. 30,901, 30,903 (May 23, 2014).

West Ranch Oil Field in Jackson County Texas where it will be used for EOR.[86] The project already has a contract with DOE to sequester 400,000 Mtpa of CO_2.[87] The project is expected to be operational in 2016.[88] The W.A. Parish project includes a number of innovative technical advances. Specifically, the project's proposed use of amine technology specifically designed to capture CO_2 from low-pressure coal plant flue gas streams that have been scrubbed of virtually all ash, sulfur and nitrogen.[89] The primary amine solvent ingredient used in the process is readily available worldwide and inexpensive.[90] The solvents have relatively low energy consumption properties and, in addition, the industry is developing more advanced solvents for even better performance.[91] Existing and future solvents can also be deployed in this project for testing with coal-fired flue gas.[92] Innovations in process equipment performance planned for this project, such as absorber intercooling and lean solution vapor compression have the potential to reduce the energy requirements of these systems by as much as 20 percent.[93] Additionally, efficiency improvements in the supporting balance of plant processes such as process steam generation and CO_2 compression will also reduce energy requirements.[94] These advances are anticipated to lower carbon capture costs and increase system flexibility and efficiency.[95] A new 80 MW natural gas-fired turbine is currently under construction on the site to provide the auxiliary electricity and steam necessary for the capture equipment.[96] On May 23, 2014, DOE announced its decision "to provide NRG with $167 million in cost-shared funding for its proposed project through a cooperative agreement under DOE's [Clean Coal Powering Initiative] program."[97] On July 3, 2014, NRG, through its wholly owned subsidiary, Petra Nova Holdings LLC, formed a

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[86] *Global Status of CCS of 2013* at 29, 38, 166; *Global Status of CCS 2014* at 6; Global CCS Institute, "NRG Energy Parish CCS Project," http://www.globalccsinstitute.com/project/nrg-energy-parish-ccs-project; MIT, "W.A. Parish Fact Sheet," https://sequestration.mit.edu/tools/projects/wa_parish.html.

[87] *Id*.

[88] *Id*.

[89] Petra Nova, "WA Parish CO2 Capture Project Fact Sheet," https://www.nrg.com/documents/business/pla-2014-petranova-waparish-factsheet.pdf.

[90] *Id*.

[91] *Id*.

[92] *Id*.

[93] *Id*.

[94] *Id*.

[95] *Id*.

[96] 78 Fed. Reg. 30,901, 30,903 (May 23, 2014).

[97] *Id*.

50/50 joint venture with JX Nippon, to build and operate the project.[98] The project is under construction and expected to be complete by the end of 2016.[99]

d. Peterhead CCS Project

Shell U.K Limited plan to retrofit a 385 MW slipstream at its existing Peterhead gas-fired power station with a CO_2 post-combustion capture system, which will capture around 1 MMtpa of CO_2.[100] The CO_2 would be sequestered approximately 160 miles offshore in the depleted Goldeneye gas reservoir.[101] The project entered into a front-end engineering design ("FEED") contract with the UK Government in February 2014.[102] A final investment decision is expected in 2015 with the project to become operational in 2018.[103]

e. Rotterdam Opslag en Afvang Demonstratieproject ("ROAD")

The ROAD Project is a proposed retrofit of a 250 MW post-combustion capture unit on a newly constructed 1,070 MW coal- and biomass-fired power plant.[104] The project would capture approximately 1.1 MMtpa of CO_2 and transport it via a 16-mile long pipeline for long-term sequestration in offshore, depleted oil and gas reserves at a depth of nearly 1,000 feet under the seabed.[105] Construction of the power plant has commenced and the demonstration phase is expected to begin in 2017.[106]

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[98] NRG, News Release, NRG Energy, Inc. Reports Second Quarter Results; Completed First NRG Yield Drop Down and Announces Formation of NRG Home and NRG Renew, (2014) http://phx.corporate-ir.net/phoenix.zhtml?c=121544&p=irol-newsArticle&ID=1956450.

[99] *Id*.

[100] Global CCS Institute, "Peterhead CCS Project," http://www.globalccsinstitute.com/project/peterhead-ccs-project.

[101] *Id*.

[102] *Id*.

[103] *Id*.

[104] Global CCS Institute, "Rotterdam Opslag en Afvang Demonstratieproject (ROAD)," http://www.globalccsinstitute.com/project/rotterdam-opslag-en-afvang-demonstratieproject-road; MIT, "ROAD (Maasvlakte) Fact Sheet," https://sequestration.mit.edu/tools/projects/maasvlkte.html.

[105] *Id*.

[106] *Id*.