Testimony of
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Committee on Energy and Commerce
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“Factors Affecting the Commercial Feasibility of Carbon Capture and Sequestration Technologies for Coal-fired Power Stations”

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SUMMARY

The U.S. Environmental Protection Agency (EPA) has proposed carbon dioxide (CO_2) limits for coal-fired power stations that require carbon capture and sequestration (CCS) technology. EPA’s judgment that CCS technology is commercially proven is based on results from pilot-scale and demonstration tests, and experience with one commercial-scale unit located in the U.S. providing “co-production” of chemicals and power. In addition, EPA assumes storing CO_2 in depleted oil reservoirs – providing the benefit of enhanced oil recovery (EOR) – can be generalized nationwide.

In fact, meaningful experience is lacking with the three evolving CCS-related options: postcombustion control, precombustion control, and oxycombustion. These options have been tested at pilot plant and demonstration-scale, but no integrated processes operate dedicated to power generation. Although claims abound of experience, most are of limited relevance. For example, the CCS Institute in its *Global Status of CCS: 2013* notes twelve “large-scale” projects presently operate world-wide, but eleven address natural gas processing or chemical production, using equipment that is a fraction of the scale required for power generation.[1]

We need additional demonstration-plant experience so we can design large, commercial-scale units for almost any coal, at almost any domestic U.S. site. We need to “scale” results, which means applying what we learn at small units (those 100 MW or less) to the design of typical base load units of 500 MW or more. We also need to “generalize” results, which means applying what we learn with one type of fuel at one site, to fuels and sites nationally. Further, we must assure components

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[1] *The Global Status of CCS: 2013*, Global CCS Institute, Table A.3., page 162

that work as individual pieces at small-scale also will work in a system at large scale, while meeting a variable load.

There is no shortcut for acquiring this knowledge; demonstration and early commercial units must be financed, built, and tested for several years. At present only two test units are certain to operate in the U.S. by 2014. About six others are planned – including several in Europe, but financing for these six additional projects is not complete, leaving these projects at risk. One of the control options (precombustion) operates in the U.S. at commercial scale, but on one unique fuel, and in a chemical "co-production" mode with power.

CO_2 once captured must be safely sequestered or reused. Most of the proposed demonstrations or early commercial units plan to reuse CO_2 for EOR, which has a long history in the U.S. But assuming broad CCS application based on EOR restricts plant location and does not eliminate uncertainty. EOR sites are relatively limited. Absent EOR, the most prominent form of sequestration is within deep saline reservoirs. The capacity to store CO_2 in deep saline reservoirs is better distributed across the U.S. than for EOR, but still presents an uneven sink for CO_2 across all states.

Other challenges exist for both EOR and deep saline reservoirs. Characterization of subsurface formations is not complete. And both CO_2 fates require investment in infrastructure for pipeline delivery, and clarifying property right laws.

It is possible CCS can evolve to help mitigate CO_2 emissions, but that is dependent on the results of future demonstration tests, and field studies to clarify the uncertainties of EOR and sequestration. We do not know enough now to draw a conclusion. The work planned between now and 2020 must be completed, and supplanted by additional projects, to give CCS a chance of being commercially proven.

INTRODUCTION

Chairman Upton, Ranking member Waxman, and members of the Subcommittee, thank you for the opportunity to speak with you. Today I will present a brief overview of carbon capture and sequestration (CCS) and provide an example of the type of work being done to demonstrate these technologies. I will also present a timeline for major CCS demonstration projects - mostly in North America, but including several international efforts that may affect the commercial feasibility of CCS in the U.S.

Based on my experience in over 40 years of conducting research, demonstration, and testing of environmental controls for fossil fuels, I believe that we do not yet have sufficient experience by which to judge the commercial prospects of CCS. We will not have that experience until about 2020 – and that assumes that a sufficient number of demonstrations are actually funded, built, and provide us with data.

There does not appear to be a way to considerably shorten the time necessary to evaluate CCS processes under commercial conditions, without incurring significant risk. This risk would be manifested in terms of cost overruns to apply CCS and possibly compromise to reliability of a generating unit so equipped. I am not alone in this projection – it is generally consistent with the recent assessment of CCS issued by the Congressional Research Service.[2]

DESCRIPTION OF CARBON CAPTURE AND SEQUESTRATION METHODS

Carbon capture and sequestration, as the name implies, enables the capture of CO_2 and ultimate sequestration or storage - or where possible reuse for enhanced oil production. There is significant research and demonstration ongoing in this sector, which may eventually pay off to refine the technology. At present, there are three categories of CCS vying for near-term commercialization. These are:

<u>Postcombustion control</u>, which removes CO_2 from the products of fossil fuel combustion in conventional steam boilers. The process equipment is located following the conventional environmental control system, and typically employs a chemical reagent to capture CO_2.

<u>Pre-combustion control</u>, which removes carbon after coal is gasified into hydrogen and carbon monoxide, and after the energy in the carbon monoxide is transferred into more hydrogen. CO_2 oxidized from the carbon monoxide is separated from the hydrogen, and the latter is used in gas turbines for power.

<u>Oxy-combustion</u>, which is based on first separating the oxygen from air, and combusting fossil fuel in the nearly pure oxygen environment.

Each option has equal prospects to be successfully commercialized – that is, offered for sale with meaningful guarantees for performance and reliability. This criterion for commercialization – that CCS not just is offered for sale but also that it be backed up by meaningful guarantees – is required for success. The recent Congressional Research Service report on CCS acknowledged the importance of this distinction.[3]

Carbon capture is the first step – and responsible for 90% of the estimated cost for removing and sequestering CO_2. But it is not the sole task at hand. Once captured, CO_2 must be re-used or sequestered, where it is intended to reside for perpetuity. A widely discussed form of CO_2 storage is sequestration in deep saline aquifers, while the primary form of CO_2 re-use is enhanced oil recovery (EOR). Both CO_2 fates may in time prove viable – EOR has been used for decades. However, questions arise as to how these sites are distributed in the U.S., and how long it takes to fully characterize the subsurface geology.

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[2] *Carbon Capture: A Technology Assessment*, prepared by the Congressional Research Service, October 21, 2013. Report 7-5700 R41325.

[3] Ibid. Page 24.

For example, sequestration may not be feasible where surface and subsurface property rights are not clear. Although early results from the eight Regional Carbon Sequestration Partnerships suggest deep saline aquifers can safely store CO_2, the integrity of sequestration over long periods of time must be proven. And, measurement and verification methods to evaluate site integrity must continue to be refined.

RESEARCH AND DEMONSTRATION ACTIVITIES

Research and demonstration tests are underway to explore how to commercialize CCS for broad industry application. As will be discussed, success with CCS at any one facility or unique site conditions, although informative, does not assure broad availability across the U.S. To broadly apply CO_2 capture we must learn how to do three things. These are (a) scaling results from pilot plants and early demonstration units to a commercial size unit, (b) generalizing CCS design beyond the specific coal and site condition for any one test or demonstration, and (c) assuring components work together seamlessly. These lessons are elaborated as follows.

<u>Scaling Design to Larger Capacities</u>. The task of "scaling" the design from pilot plant or demonstration equipment to a large commercial generating unit must be addressed. Experience at small pilot plant capacities that are equivalent to 20-100 MW is invaluable, but we must know how to extend these lessons to larger sizes.

The size of postcombustion CO_2 capture equipment is indicated by Exhibit 1, which presents the conceptual design of a proposed coal plant employing postcombustion control. Exhibit 1 shows three categories of equipment that comprise this plant. First, encircled in red is the steam generator and turbine that generate power. Second, next to the steam generator and turbine - encircled in green - are environmental controls to limit emissions of nitrogen oxides (NO_x), sulfur dioxide (SO_2), particulate matter, and other species that are addressed by the Mercury and Air Toxics program.

The CO_2 capture equipment is the third category - within the blue circles. As shown in Exhibit 1, equipment both for absorption of CO_2 and regeneration of a concentrated byproduct is required.

Exhibit 1 represents a conceptual design of a 750 MW plant that was proposed but not built. In the U.S., the sole experience with postcombustion control is with the 25 MW-equivalent pilot plant at Alabama Power Company's Barry Station – shown in Exhibit 2. The pilot absorber tower is designed as an "apple core" in a commercial reactor – with the resulting data used to scale the design by a factor of 20 to support a 500 MW unit.

Exhibit 1 represents a conceptual design for one approach – postcombustion CO_2 control – and does not reflect pre-combustion or oxycombustion methods. The latter two methods may differ from Exhibit 1 in the size of equipment and plant "footprint", but they are equally complex and share the need for step-by-step demonstration.

Generalizing Design for Broad Application. Any one test or demonstration site is characterized by coal composition and site conditions which cannot readily be generalized to other fuels or sites. Extending design lessons from demonstration equipment to different fuels and sites is necessary to provide CO_2 capture technology on a broad national basis.

For example, coal composition – particularly inorganic material - can affect process chemistry. Success with a specific coal like lignite does not guarantee success for other widely used coals, such as eastern bituminous coals or coals from the Powder River Basin. Further, the content of chlorides and fluorides in coal is important as this affects corrosion, and the materials-of-construction necessary to resist corrosion. Other fuel factors such as volatility – the ease with which solid particles gasify when exposed to heat – is also important, particularly for the pre-combustion method.

Site characteristics, such as ambient temperature and humidity, and access to water for process equipment and cooling towers are features important to CCS performance.

In summary, generalizing equipment design for each of postcombustion, precombustion, and oxycombustion CO_2 control methods will require experience with at least the three "ranks" of coal used in the U.S., as well as various sites.

"Seamless" Operation of Components . A third precondition to any broad deployment of carbon capture is making sure the individual components work together in a seamless or integrated manner. Some observers note individual CCS components have been used successfully at small sizes in singular applications – equating this experience with demonstrated integrated design. However, CO_2 control processes must respond with the rest of the plant to meet a variable – and at times unpredictable – load, particularly in today's competitive power markets.

Satisfying variable load requires not a collection of components but an integrated system. This task is as important as design of any individual component. In fact, the Global CCS Institute, in its recently released *Global Status of CCS: 2013*, note that "....the key technical challenge for widespread CCS deployment is the integration of component technologies into successful large-scale demonstration projects in *new* (emphasis added) applications such as power generation ....".[4] Further, the International Energy Agency, in its *Technology Roadmap for Carbon Capture and Storage: 2013* states that "....although the individual component technologies required for capture, transport, and storage are generally well understood........the

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[4] *The Global Status of CCS: 2013*, Global CCS Institute, page 10.

largest challenge for CCS deployment is the integration of component technologies into large-scale demonstration projects".[5]

These lessons can only be learned with large-scale demonstration projects. For example, Sask Power's Boundary Dam Unit 3 - equipped with a postcombustion CO_2 control and scheduled to start-up in early 2014 – employs 125 separate subsystems. Mississippi Power's Kemper County unit – equipped with pre-combustion CO_2 capture designed for lignite coal- and also scheduled to startup in 2014 – employs an equally large number of subsystems never operated as one integrated design to exclusively serve power generation.

In summary, the need to scale, generalize, and integrate the operation of CO_2 capture processes requires large-scale demonstration.

TIMELINE FOR TESTING AND DEMONSTRATION INSTALLATION

Reviewing the timeline for pilot plant, demonstration, and early commercial application is instructive in understanding the state of commercial development.

Exhibit 3 depicts a timeline for pilot, demonstration, and early commercial tests that could affect CCS feasibility in the U.S. The start date is shown for each activity on the horizontal axis, and the size of the unit in terms of the equivalent generating capacity is shown on the vertical axis. Projects represented by symbols that are "closed" are operating or under construction, while "open" symbols reflect projects planned but not yet financed. Most of these test facilities are located in North America, but several are at facilities in Europe. Exhibit 3 shows for each test the date when the unit begins operation. This date - although noteworthy – is not the most important. Rather, progress is actually determined most by when results are available to deduce design principles. The date when design rules can be derived from experimental data is typically 2-3 years subsequent to the unit start date.

Exhibit 3 shows that with the exception of the Dakota Gasification Facility, operating experience on large units does not accrue until about 2017-2018. In 2014 Sask Power's 110 MW Boundary Dam Unit 3 begins operating with postcombustion control, and Mississippi Powers' Kemper County with pre-combustion control. These units, being first-of-a-kind, may not produce useful data in the first months of operation. It is possible 6-12 months may be required to "shake down" the process equipment, eliminate operating "bugs", and begin to accrue data.

The duration of tests cited in Exhibit 3 varies significantly. Several small postcombustion processes that capture CO_2 for use on-site (e.g. not requiring transport for sequestration or reuse) have operated for 10 years (Warrior Run, Shady Point, Searles Valley Minerals). Two small (10-30 MW-equivalent)

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[5] *Technology Roadmap: Carbon Capture and Storage: 2013 Edition*, The International Energy Agency, 2013. See page 5.

oxycombustion pilot plants (Calide, Lacq) operated for 2 years, while the Vattenfall oxycombustion pilot plant will operate for a decade to derive adequate experience.

Exhibit 3 suggests commercial design data may start to be available around 2017 and 2018 – but results will be limited in scale and scope. There are no large postcombustion CO_2 demonstrations planned for any of the three U.S. coal ranks (lignite, eastern bituminous, subbituminous); only the 25 MW Plant Barry pilot plant provides data. Experience with oxycombustion control will emerge from the Department of Energy (DOE) sponsored FutureGen project by about 2019. Although several helpful projects are planned, the financing for them is not complete (e.g. open symbols).

In summary, Exhibit 3 shows that by 2020 a limited number of demonstrations will be available from which to derive design rules.

CO_2 REUSE OR SEQUESTRATION

Equally important to the capture of CO_2 is the ultimate fate of the CO_2 – where to put it once removed from the gas stream. The reuse of CO_2 for EOR is one possible long-term fate. CO_2 has been used to increase production of oil or gas in partially depleted reservoirs for decades. However, the ability for EOR to broadly supply CO_2 sinks for coal-fired generation across the entirety of the U.S. is not apparent – the largest sites are concentrated in a limited number of states. The pipeline network to deliver CO_2 from around the U.S. to these sites must be expanded. The technical challenges to expanding the pipeline network can be overcome, but it may be harder to address several non-technical issues, including property rights, right-of-way, and the conflicting laws and rules of multi-state jurisdictions.

The alternative to EOR – sequestration in deep saline reservoirs – also offers potential to store CO_2. The DOE estimates significant capacity to store CO_2 in deep saline reservoirs, and reports deep saline "sinks" for CO_2 are more uniformly distributed than sites for enhanced oil recovery. Similar to EOR, there are important non-technical issues, mostly related to property rights.

Three aspects of property rights are important: (1) acquisition of pore space for storage over a broad area; (2) right-of-way to construct transport pipelines; and (3) access to the surface for monitoring.

Subsurface lands with the desired pore space can be privately owned, and CO_2 injection can impact owners in multiple states. Historically, the laws governing access to oil and gas fields from multiple owners – addressing compulsory unitization and eminent domain - may be inadequate for CO_2 injection.

CO_2 repositories must be extensive and due to their size could infringe on existing minerals, water, and private property rights (both surface and subsurface). Repositories located across state lines will introduce jurisdictional questions –

particularly if CO_2 plumes migrate. CO_2-derived liabilities are not fully defined and there is little basis for resolving disputes. Further complicating the issue of how to address long-term CO_2 fate is the time frame for monitoring and responsibility for sequestration, which extends well beyond that typical for oil/gas experience.

In summary, the potential to permanently isolate CO_2 by EOR or sequestration exists, but uncertainties remain. Candidate sites for sequestration or EOR must be extensively studied to assess their feasibility – the International Energy Agency estimates 5 to 10 years to qualify a saline reservoir as adequate.[6] The DOE National Energy Technology Laboratory (NETL) Regional Partnerships address these questions through eight large-scale field studies, but all have operated for a relatively short period of time.[7] Similar to the CO_2 capture step, completing these and additional field studies is needed.

CCS: WHEN PROVEN?

Several organizations describe demonstration and commercialization goals for CCS for 2020. That these organizations publicly define a commercialization goal for 2020 is significant – it implies CCS at present is not commercially proven, and that a series of steps are required to be so proven. Whether or not CCS will be successfully demonstrated by 2020 remains to be seen – but three of the following "roadmaps" imply it is not demonstrated at present.

Specifically, the International Energy Agency (IEA) in its recently released *Technology Roadmap: Carbon Capture and Storage – 2013 Edition* recommended for 2020 that "....the capture of CO_2 is successfully demonstrated in at least 30 projects across many sectors....'.[8] The document also presents an Action 2, which advises governments to "develop national laws and regulations as well as provisions for multilateral finance that effectively require new-build, base-load, fossil-fuel power generation capacity to be CCS-ready".[9] The provision that new-build plants be CCS-ready is in contrast to requiring that new-build plants be equipped with CCS.

The U.S Department of Energy's National Energy Technology Laboratory's most recent *Carbon Dioxide Capture and Storage RD&D Roadmap* identified a DOE goal of "......having an advanced CCS technology portfolio ready by 2020 for large-scale demonstration that provides for the safe, cost-effective carbon management that will meet our Nation's goals for reducing GHG emissions".[10] The Roadmap further

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[6] Ibid. Page 17.

[7] *The United States 2012 Carbon Utilization and Storage Atlas*, Department of Energy, page 8.

[8] *Technology Roadmap: Carbon Capture and Storage: 2013 Edition*, The International Energy Agency, 2013. See page 23.

[9] Ibid. See page 28.

[10] *DOE/NETL Carbon Dioxide Capture and Storage RD&D Roadmap*, December 2010, page 3; also Figure 1-10 timeline on page 12.

calls out completing by 2020 “full-scale demonstrations of advanced oxy-combustion and post-combustion CO_2 capture technologies”.[11]

In April of 2012 the UK Ministry for Energy and Climate Change issued a *CCS Roadmap*, which stated “Our aim is to enable industry to take investment decisions to build CCS equipped fossil power plant in the early 2020s.[12] This document further describes a CCS Commercialization Programme, which states an objective of “.....reducing the cost of CCS so that it can be deployed in the early 2020s”. [13]

CONCLUSION

CCS technology could eventually be a viable option to limit CO_2 emissions from coal-fired power stations. At present, the technology is not commercially proven to allow broad application in the U.S.

For CO_2 capture, additional demonstrations are necessary to enable design of large commercial systems that can be provided with meaningful guarantees. The work to date has contributed to a basic understanding of the processes, but is inadequate to formulate a reliable design for large units.

Sequestering CO_2 for extended periods of time is uncertain. Barriers must be addressed prior to broad application. Subsurface geology must be mapped. Uncertainties in property rights in many states must be clarified. And, the long-term fate of injected CO_2 – to be safely sequestered – must be verified, along with monitoring techniques. Significant investment in pipeline infrastructure will be required. There may be fewer uncertainties with EOR, but these sinks for CO_2 are not broadly distributed. Both pipeline infrastructure and the geologic mapping of depleted fields must be expanded.

Without additional demonstrations and field tests, significant risk for failure exists. These risks will be manifested in terms of higher costs, a compromise to reliability, or both.

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[11] Ibid. Page 12, Table 1-1.

[12] *CCS Roadmap: Supporting Deployment of Carbon Capture and Storage in the UK*, April 2012, page 5.

[13] Ibid, page 26.

EXHIBIT 1

Conceptual Design of Coal-Fired Power Plant Equipped with Postcombustion Carbon Capture (Source: Tenaska Trailblazer)

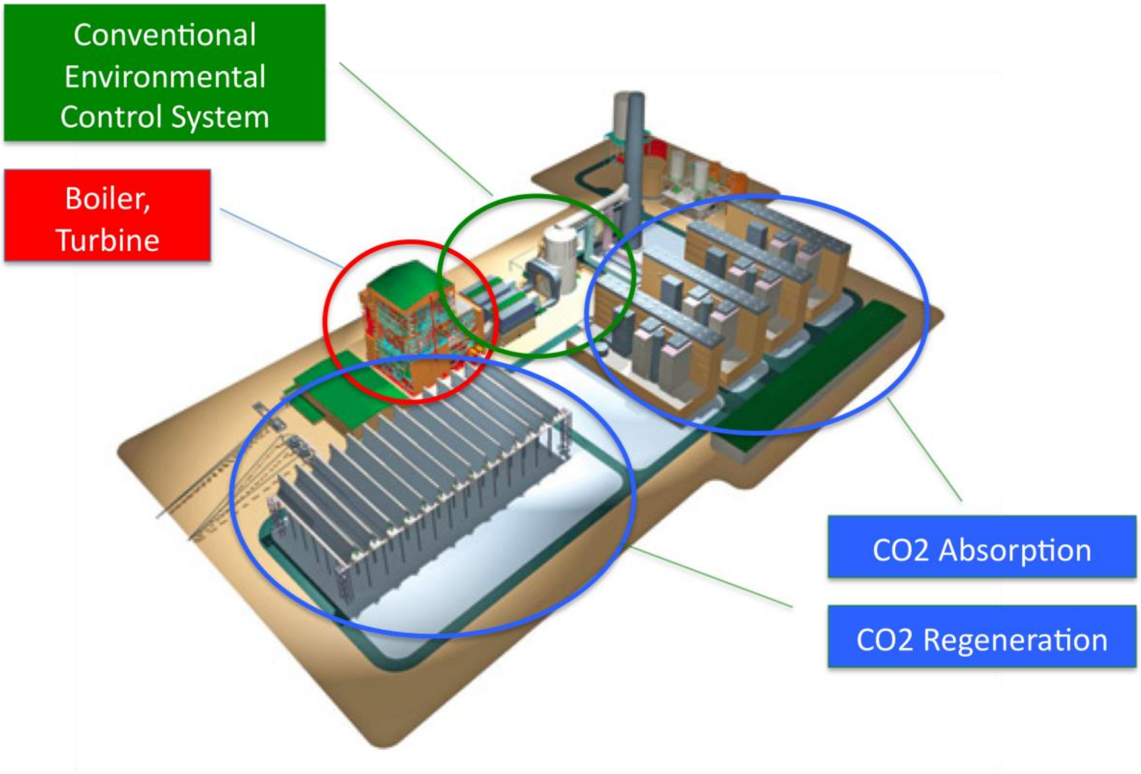

EXHIBIT 2

25 MW-Equivalent Postcombustion CO_2 Pilot Plant at Alabama Power Plant Barry (2012+)

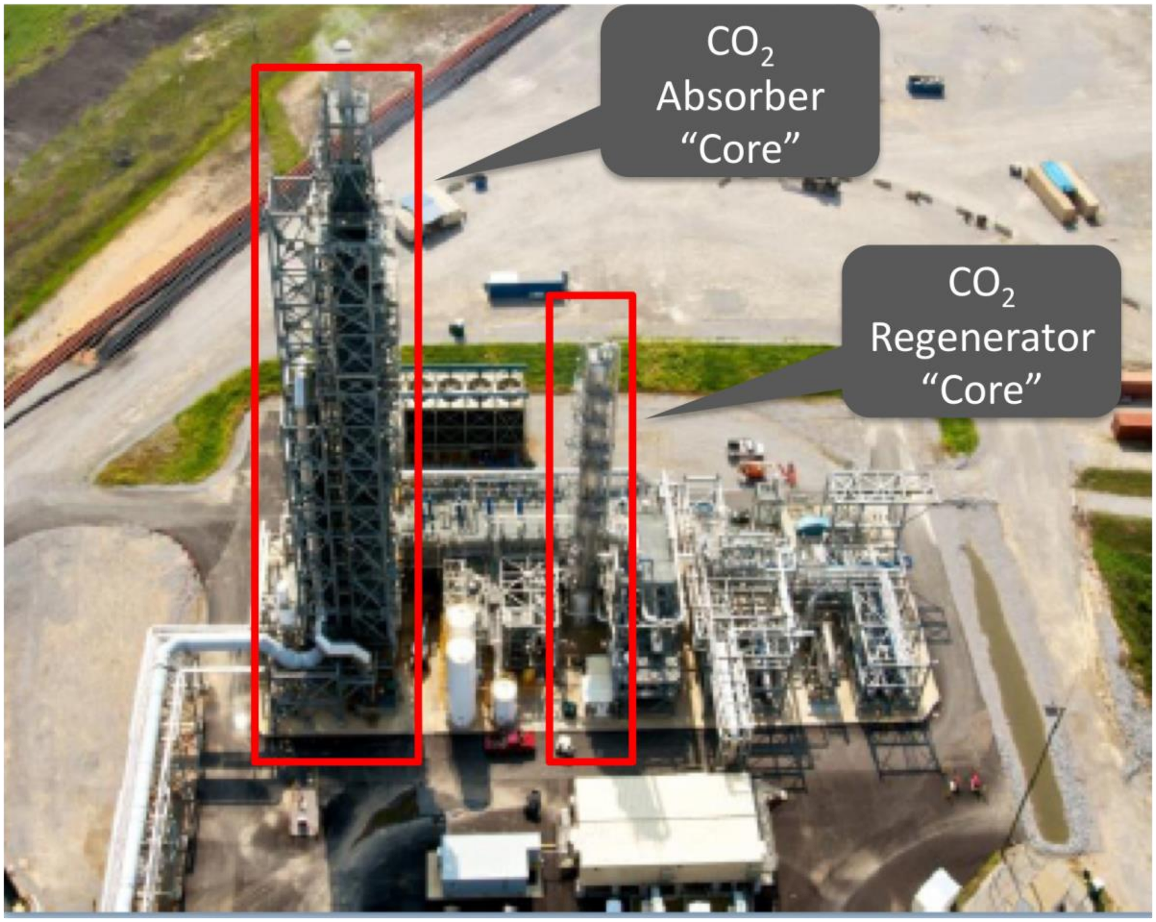

EXHIBIT 3

CCS PILOT PLANT AND DEMONSTRATION TIMELINE

Operating/Construction: Solid Symbols *Planned*: Open Symbols