Development and Commercialization of Novel DOE/NETL Technologies Related to Gaseous Multi-Component Capture

A Technology Transfer Solicitation

A. SUMMARY

The U.S. Department of Energy's National Energy Technology Laboratory (NETL) is seeking partners to commercialize gaseous cleanup technologies through the licensing of U.S. Department of Energy (DOE)-owned patents and patent applications that are specifically identified in the following Topic Area discussions. In addition, NETL is also seeking collaborators to conduct research on these technologies with NETL scientists and engineers via Cooperative Research and Development Agreements (CRADAs). The licensing step can be an integral part of the CRADA. See NETL's CRADA webpage for scope of CRADA agreements. Significant benefits of the CRADA are:

- The Parties can negotiate intellectual property disposition, such as rights to patents, protection of information, and exclusive or non-exclusive licensing of inventions
- The private sector participant can take advantage of the government's unique analytical and unique laboratory capabilities
- The Parties have the opportunity to develop relationships that transcend the technology development and take them toward commercialization
- The Parties have the opportunity to leverage their own resources and research to achieve maximum benefit to technology development and commercialization.

Note that there will be no government funds available to directly fund proposers as part of this solicitation.

In this announcement, collaborations will be limited to Topic Areas 1, 2, and 3 and will be specifically related to patents and patent applications found within these Topic Areas. Topic Area 4 is limited to licensing opportunities only (no collaboration) of the indicated patents and patent applications.

Topic Area 1: Sorbents for the Removal of Carbon Dioxide from Gas Streams
Topic Area 2: Processes for the Removal of Carbon Dioxide from Flue Gas
Topic Area 3: Sorbents for the Removal of Pollutants from Gasification Process Streams
Topic Area 4: Techniques for the Removal and Measurement of Mercury from Flue Gas Streams

Proposals will only be entertained for these topic areas described in detail later in this announcement. Proposals that do not address any one of these topics will not be considered. Submitting to more than one Topic Area with a single proposal can be done if a bundling of multiple technologies from different topic areas occurs; otherwise, separate submissions in each individual topic area is preferred.

B. BACKGROUND

Coal-fired power plants will continue to be the dominant source of electricity generation through 2030 (Annual Energy Outlook 2008). The Energy Information Administration predicts that coal-fired electricity generation capacity will increase to nearly 450 GW by 2030. By that time, the annual amount of carbon dioxide (CO_2) produced by use of fossil fuels in the U.S. will have reached over 6 billion metric tons. Anthropogenic CO_2 emissions have increased since the industrial revolution, and high ambient CO_2 levels are thought to be linked to increasing global temperatures and changing weather patterns.

Carbon capture and sequestration is a viable method to reduce the emissions of the greenhouse gas, carbon dioxide, from large point sources such as fossil fired power plants. Because nearly one-third of the anthropogenic CO_2 emissions are produced by these facilities, conventional coal- and natural gas-burning power plants and advanced power generation plants, such as integrated gasification combined cycle (IGCC), present opportunities where carbon dioxide can be removed and then permanently stored. Although pulverized coal-fired-base steam cycles have been the predominant electric power generation technology for many years, it is projected that advanced power generation technologies (for example, gasification-based IGCC) will make in-roads in the power generation sector in the near future.

Capture of the carbon dioxide from point sources is the first and most costly critical step. New technologies for the separation and capture of carbon dioxide are being developed that can have significant impact on carbon sequestration. The U.S. Department of Energy's National Energy Technology Laboratory is conducting in-house research investigating novel techniques to separate and capture CO_2 from current or advanced power generation systems. The new techniques can have wide applications, but the research has focused on capture of carbon dioxide from flue gas (post-combustion streams from conventional fossil fuel-fired combustors) and from fuel gas (pre-combustion streams from advanced integrated gasification combined cycle plants (IGCC)).

Some of the techniques applied to post-combustion fall within the process category of chemical absorption or adsorption with solid sorbents. In addition to solid sorbent technology, various other post combustion carbon dioxide capture processes are being studied. Some involve solvent-based techniques to remove CO_2, such as conventional monoethanolamine scrubbing, or include novel sorbents, such as solvent-containing carbonic anhydrase.

All post-combustion capture technologies, and pre-combustion technologies, within the context of the carbon sequestration scheme, must address program goals. The overall goal of NETL's CO_2 capture R&D effort is to develop fossil fuel conversion systems that achieve 90% CO_2 capture with 99% storage permanence at less than a 10% increase in the cost of electricity for pre-combustion capture (2007 Carbon Sequestration Roadmap) and less than a 35% increase in the cost of energy services for post- and oxy-combustion capture at new and existing pulverized coal–fired power plants (Fout et al., 2008).

In gasification schemes, including IGCC power plants, a fossil fuel is reacted with oxygen and steam in a gasifier to produce a fuel gas (synthesis gas or syngas) consisting mainly of carbon

monoxide and hydrogen. This mixture is then cleaned and burned to generate power in a gas turbine combined cycle. Assuming oxygen-blown gasification with coal (oxygen is used instead of air to eliminate the pressurization and processing of nitrogen), the main products of the gasification process are CO, H_2, CO_2, H_2O, H_2S, HCl, NH3, some gaseous hydrocarbons, and trace amounts of certain pollutants, including mercury. Synthesis gas cleanup includes particulate removal and acid gas scrubbing. It is preferred that gaseous components be captured at warm temperatures (300-700º F) rather than the cooler temperatures of traditional wet scrubbing techniques. The main advantage in cleaning the gas in an IGCC application at higher temperature is that the thermal plant efficiency will be as much as 2-3% greater as compared to the lower temperature acid gas cleaning scenario. The moisture content in this humid gas stream remains constant as compared to the cold gas cleanup case, and is then available for expansion and work generation when combusted (Newby, 2005). The areas of efficiency improvements are that the transfer of heat and latent heat to the more efficient gas turbine cycle are maximized; the capital and operating costs are lowered by reducing the duty on any heat exchangers; and the need for process waste water treatment facilities are eliminated (Mitchell, 1998). Additional research has been directed toward the removal of H_2S and HCl at elevated temperatures to reduce system corrosion.

When coal is burned or gasified, trace amounts of mercury are also produced. Although the EPA has relaxed the regulation of mercury, certain states will continue or propose to regulate it, and techniques are required to capture or monitor it. Activated carbon injection appears to be a popular technique in post-combustion applications. NETL has been studying and developing other techniques to remove mercury directly or to enhance its reactivity to facilitate its removal. Additionally, NETL is investigating low-cost, novel techniques to monitor mercury concentration in process gases.

C. SOLICITATION OBJECTIVE

The overall goal of this Technology Transfer Solicitation is to solicit proposals for the commercialization of NETL patents and patent applications related to certain gaseous cleanup technologies identified in the following Topic Areas. NETL is also agreeable to potential collaboration with outside entities to work with NETL researchers through Cooperative Research and Development Agreements (CRADA) as described on NETL's CRADA webpage. **CRADAs can only occur in Topic Areas 1, 2, and 3. Topic Area 4 is a licensing opportunity only.** A proposal must identify which of the following collaboration and commercialization scenarios it is applying for:

a) Exclusive or nonexclusive licensing as described on NETL's Patents and Licenses webpage.
b) A combination of a CRADA and a license.
c) A CRADA only.

Commercialization opportunities will occur within the following Topic Areas and will be specifically related to NETL patents and patent applications found within these Topic Areas.

D. AREAS OF INTEREST

Proposals are sought to develop, test and commercialize:

Topic Area 1: Regenerable Sorbents for the Removal of Carbon Dioxide from Gas Streams

a) CO_2 removal sorbents for post combustion gas streams (low temperature and low pressure) -- The use of solid, regenerable sorbents is a method to remove CO_2 from gas streams. Amine-enriched or other CO_2-philic sorbents have been investigated in flue gas streams at temperatures (40-60º C) similar to that found after lime/limestone desulfurization scrubbing. Two types of sorbents have been investigated by NETL researchers.

One type of CO_2 capture sorbent is prepared by the chemical treatment of high surface oxide materials and other substrates with various organic compounds. [Gray, U.S. Patent Nos. 6,547,854 and 7,288,136; Gray U.S. Patent Application Case Nos. S-108,132 and S-109,408;]. The immobilization or encapsulation of amine groups on or within the high surface area material significantly increases the needed contact area between CO_2 and amine.

A second type of CO_2 sorbent is prepared by incorporating polar liquids containing amines in clay substrates [Siriwardane, U.S Patent No. 6,908,497]. Even though the clays have low external surface areas, clays have the ability to retain a large amount of polar liquids, such as water and amines, between their unit layers because the unit layers can expand in the presence of polar liquids, allowing the polar molecules to reside in them. The low heat capacity of the clay and the low cost of the materials contribute to the low regeneration energy required.

Thus the increase in contact area and less energy consumption during the regeneration step, as compared to conventional MEA scrubbing, potentially improves the efficiency of the process. The regeneration step is crucial for these types of sorbents and either pressure swing and/or temperature swing can be effectively utilized.

b) CO_2 removal sorbents from pre-combustion gas streams (moderate temperature and high pressure) -- In addition to the post-combustion sorbents described above, pre-combustion regenerable sorbents have also been investigated [Siriwardane, U.S. Patent No. 7,314,847]. The proposed usage of these would be in reducing atmospheres such as those found in gasification systems. Additionally, the sorbents would be used at elevated temperatures (200-300º C) to encompass the advantage of better plant thermal efficiency as compared to cooler gas cleanup techniques. The sorbents can be regenerated at high pressure at 375º C.

Topic Area 2: Processes for the Removal of Carbon Dioxide from Flue Gas

Various CO_2 capture/separation techniques, other than the regenerable sorbents in Topic Area 1, are being investigated by NETL and have culminated in intellectual property. Although regenerable sorbents can be used to continuously process vast quantities of CO_2 emitted from power generation sources, there may be an application for a throwaway sorbent that can be used as a niche technology. Such a process can use a waste material as the disposable sorbent [Soong, U.S. Patent Application Case No. S-105,754].

In the event that a dry regenerable sorbent is used to remove carbon dioxide from flue gas, various reactor schemes can be identified. The choice of the reactors will certainly depend on the sorbent, including the physical, thermodynamic, and kinetic properties. Stationary reactors such as packed beds have the advantage of no movement of the sorbent and thus no sorbent attrition. However, in temperature swing applications, heating and cooling of the reactor vessel itself along with the charge of sorbent may be energetically prohibitive. Transport reactors offer the advantage of continuous movement of sorbent between the absorption and regeneration steps although attrition may be a factor. A cross flow moving bed reactor [Pennline, U.S. Patent 6,387,337] offers the advantage of low pressure drop and excellent contacting of the gas with the sorbent.

Wet scrubbing of flue gas to remove CO_2 has been conducted by the conventional process of monoethanolamine (MEA) scrubbing. However, there have been certain novel techniques that can improve the scrubbing efficiency over the benchmark MEA process. One scrubbing method involves the use of carbonic anhydrase as an enzyme to remove CO_2 in the absorption step. A key to the success of the CO_2 scrubbing is in the buffering of the solution. However, the cost of the carbonic anhydrase can be prohibitive. Inventors [Soong, U.S. Patent Application Case No. S-108,423] at NETL have developed a bio-chemical technique to improve the production of the carbonic anhydrase and thus make the overall process less costly. The excellent CO_2 capture performance of the wet scrubbing solution will be maintained.

Electrochemical techniques to separate CO_2 from flue gas obtained by fossil fuel combustion can produce a stream rich in CO_2 but also oxygen. Oxy-firing of a carbonaceous fuel will produce a stream of carbon dioxide and steam that can be further processed to obtain pure CO_2 for storage. However, due to material limits within the combustor, recycle of CO_2 and/or moisture is required in an oxy-fired combustor. If the CO_2/O_2 ratios of the stream that emanate from the electrochemical separation device are within the proper range, this stream could be used as the feed to another oxy-fired combustor. [Pennline, U.S. Patent Application Case No. S-110,250]. Thus, the product from this ancillary combustion unit will be a stream of pure CO_2 once the moisture has been condensed.

Topic Area 3: Sorbents for the Removal of Pollutants from Gasification Process Streams

During gasification and particular to IGCC processes, various minor components are produced that must be removed before the fuel gas (syngas) can be further processed. As stated before, it has been the research direction within the gasification program to remove these contaminants typically at elevated temperatures in order to enhance the thermal efficiency of the IGCC process as compared to low temperature wet scrubbing to remove these compounds.

A regenerable, solid sorbent [Siriwardane, U.S. Patent Application Case No. S-110,897] has been developed that can absorb hydrogen chloride and hydrogen sulfide at high temperatures and at high pressure conditions. The HCl and H_2S capture sorbent was originally developed for impurity removal from coal gasification gas streams. The sorbent consists of manganese oxide. Multi-cycle bench-scale flow reactor tests and multi-cycle thermo gravimetric analysis tests have shown the sorption ability of the sorbent with either hydrogen chloride or hydrogen sulfide. Test

results also showed that the sorbent can remove HCl and H_2S simultaneously at temperatures from 315 to 450º C. The most interesting characteristic of the sorbent is the regenerability with oxygen starting at 500º C. Currently there are no sorbents available for HCl removal or for simultaneous removal of both HCl and H_2S that are regenerable between 315-450º C.

Topic Area 4: Techniques for the Removal and Measurement of Mercury from Flue Gas Streams

Although the federal regulations for mercury (Hg) have recently been limited, future regulations may be promulgated and certain states have instituted criteria pertaining to Hg control. Although activated carbon injection is a popular technique for controlling Hg from flue gas, some coal-fired power generation facilities have flue gas desulfurization (FGD) units that can remove mercury without the installation of activated carbon scrubbers. However, the FGD is often not efficient in capturing the mercury. NETL has developed two techniques to enhance the removal of the Hg [Granite, U.S. Patent 6,576,092] and U.S. Patent Application Case No. S-105,871]. In one technique, elemental mercury that can be present in significant quantities when certain coals, i.e. lignite, are burned can be photochemically oxidized, thus significantly enhancing the mercury's ability to be scrubbed in the downstream wet or dry FGD unit.

The technique uses irradiation of the mercury at a wavelength that is near its excitation potential, developing new classes of catalysts for enhancing the removal of heavy metal contaminants, especially mercury (Hg) from effluent gases were developed. Both of these classes of catalysts are also excellent absorbers of HCl and Cl_2, which are present in effluent gases. This adsorption of oxidizing agents aids in the oxidation of the heavy metal contaminants into forms that are more readily captured. The catalysts remove mercury by oxidizing the Hg into mercury (II) moieties. For one class of catalysts, the active component is selected from the group consisting of iridium (Ir) and iridium-platinum (Ir/Pt) alloys. The Ir and Ir/Pt alloy catalysts are especially corrosion resistant. For the other class of catalyst, the active component is partially combusted coal whose ash constituency plays a role in the oxidation.

Lastly, a great deal of effort has gone into the development of detectors for mercury. There are certain drawbacks on numerous exotic analytical techniques for the continuous detection of mercury within a flue gas. A recent advancement [Granite, U.S. Patent Application S-104,279] describes a new simplistic method for semi-continuous detection of heavy metals and metalloids including mercury in gaseous streams. The method entails mass measurement of heavy metal oxides and metalloid oxides with a surface acoustic wave (SAW) sensor having an uncoated substrate. An array of low-cost SAW sensors can be used where each sensor is for the semi-continuous emission monitoring of a particular heavy metal or metalloid.

E. TECHNOLOGY TRANSFER INSTRUMENTS

a) Licensing: NETL envisions the licensing of patents and patent applications to non-federal participants. Proposals for licensing the patents and patent applications shall include a business plan (see example outline) and an application for exclusive and nonexclusive licensing.

b) CRADAs: NETL also envisions potential collaborative arrangements involving a CRADA that includes a patent licensing agreement (exclusive or non-exclusive). CRADAs are collaborative technology transfer agreements between the Federal government and the private sector where participants work together on a mutually beneficial project. Each partner in the CRADA applies whatever resources are agreed to, such as personnel, equipment, or facilities. While participant dollars may be used to fund all or portions of the government's effort, the government cannot provide Federal funds directly to support the private sector participant. **CRADAs can only occur in Topic Areas 1, 2, and 3.**

c) NETL Facilities and Capabilities: The facilities, labs and capabilities that NETL brings to this collaboration through a CRADA are described in the document "ORD Capabilities Related to Gaseous Multi-Component Capture."

d) Patents: All patents and patent applications related to this solicitation are available on the technology transfer solicitation web page under the Patents section.

F. PROPOSAL PREPARATION INSTRUCTIONS

The project proposal narrative must not exceed 25 pages, including cover page, table of contents, charts, graphs, maps, photographs, and other pictorial presentations, when printed using standard 8.5" by 11" paper with 1 inch margins (top, bottom, left, and right). Any necessary forms, applications, or agreements, will not count toward the page limit. EVALUATORS WILL REVIEW ONLY THE NUMBER OF PAGES SPECIFIED ABOVE. The font must not be smaller than 12 point. Do not include any Internet addresses (URLs) that provide information necessary to review the application.

For the project proposal narrative, proposers shall provide the following information in the following format:

1.0. Background, Introduction, and Justification

2.0. Technology Selection

- Identification of Specific Topic Area under which the proposal falls
- Identification of the specific patents and or patent applications related to the Topic Area
- Specific collaboration and commercialization scenario being proposed

3.0. Proposal Description

A narrative organized into sections according to the following outline, depending on the scenario chosen, as illustrated below:

Scenario 1: Proposals for licensing patents and patent applications(s)

3.1. a plan for developing and commercializing the patent/patent application(s)

3.2. proposed company capabilities relevant to the chosen topic area

3.3. commercialization experience, success and demonstrated commitment
3.4. license application, including a commercialization and marketing plan, and the proposed royalty structure for licensing of the patent/patent application(s)

Scenario 2: Proposals for collaborating via a CRADA and licensing
3.1. a plan for conducting collaborative research
3.2. a plan for developing and commercializing the patent/patent application
3.3. proposed company capabilities relevant to the chosen topic area
3.4. research, development and demonstration (RD&D) experience
3.5. commercialization experience, success and demonstrated commitment
3.6. proposed CRADA scope of work, including the amount of cost sharing offered for the CRADA (higher amounts of cash-in would be given more consideration)
3.7. license application, including a commercialization and marketing plan, and the proposed royalty structure for licensing of the patent/patent application(s)

Scenario 3: Proposals for collaborating via a CRADA only
3.1. a plan for conducting collaborative research
3.2. a plan for developing and commercializing the patent/patent application
3.3. proposed company capabilities relevant to the chosen topic area
3.4. research, development and demonstration (RD&D) experience
3.5. proposed CRADA scope of work, including the amount of cost sharing offered for the CRADA (higher amounts of cash-in would be given more consideration)

G. PROPOSAL EVALUATION CRITERIA

NETL will conduct a review of all proposals based on the applicant's ability to effectively develop and commercialize the technology, taking into consideration factors such as:

- experience in conducting research in the chosen topic area
- experience, capabilities, and facilities relevant to the chosen topic area
- experience and success in commercializing new technologies
- amount of cost sharing offered for the CRADA
- proposed royalty structure for licensing of the patent/patent application
- demonstrated commitment to the deployment and commercialization of the technology

H. ELIGIBLE APPLICANTS

All types of entities are eligible to apply, except other federal agencies, Federally Funded Research and Development Center (FFRDC) Contractors and nonprofit organizations described in section 501(c)(4) and 501(c)(3) of the Internal Revenue Code of 1986 that engaged in lobbying after December 31, 1995. At least one member of the proposing team must be an entity capable of commercializing the technology. See information on related federal regulations in 37 CFR Part 404.

I. SUBMISSION

Questions regarding this solicitation and completed proposals are to be submitted via email to this address: Newlon@netl.doe.gov

Proposal due date is March 16, 2009 by the end of the day. NETL is open to the possibility of multiple selections being made, contingent on its availability of resources to conduct the collaboration activities.

J. ADMINISTRATIVE CONTACT

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K. REFERENCES

All reference documents may be viewed on the technology transfer solicitation web page under the Reading Room section.