ARPA-E
CHANGING WHAT'S POSSIBLE

IMPACCT Program Overview

B.1. BACKGROUND

Coal-fired power plants currently generate approximately 50% of the electricity in the United States. According to the DOE Energy Information Agency (EIA) 2009 Annual Energy Outlook, demand for electricity in the U.S. is projected to increase between 16% (low growth case) to 36% (high growth case) by 2030[1]. The contribution of coal to the U.S. generation mix in 2030 is projected to decrease to a slightly lower, yet significant level of 47%. In the absence of carbon capture and sequestration (CCS) options, the projected increase in U.S. CO_2 emissions to 6.4 billion metric tons in 2030 could have serious consequences for the Earth's ecosystem.

For the past decade, organizations within DOE, primarily the Office of Fossil Energy (FE) and National Energy Technology Laboratory (NETL), have promoted research in the capture, transport, storage, and monitoring of CO_2. While significant technological advances have been accomplished during that time, numerous challenges related to the cost and energy required for CCS remain. The current state-of-the-art technology, monoethanolamine (MEA), requires heating to approximately 100-120^{o}C using power plant steam to regenerate the solvent. This requirement places a parasitic power demand of 22-30% of the power plant output, and a projected increase in Cost of Electricity (COE) of 81% for a supercritical pulverized coal plant[2]. Current DOE post-combustion research targets, as defined in a recent FOA issued by NETL, are 90% CO_2 removal with no more than a 35% increase in COE[3].

B.2. OBJECTIVES

ARPA-E seeks to complement existing DOE research efforts in the field of CCS. ARPA-E's objective is to fund high risk, high reward research efforts that, if successful, will have a transformational impact on dramatically lowering the energy and cost penalties associated with carbon capture. This FOA is focused on developing materials and processes for CO_2 capture that can be applied both to new plants and retrofitted to existing coal-fired power plants. ARPA-E seeks to reduce the parasitic power load and corresponding COE increase, described above, substantially below that of the baseline MEA process. To this end, ARPA-E seeks innovative proposals in the following Areas of Interest:

Area of Interest One: Enabling Materials for CO_2 Capture

Area of Interest Two: CO_2 Capture Processes

A description of technical requirements for applications submitted under each Area of Interest is provided below. If an applicant wishes to apply under multiple Areas of Interest, a separate and complete application will be required for each Area of Interest submittal, with no need for application reviewers to refer to another application.

It is anticipated that some applicants may wish to submit proposals that incorporate elements of more than one Area of Interest (an example of which might be a proposal to combine research on catalysts and integration into membrane modules). Such submissions are allowed, and applicants should consider submitting such applications to the Area of Interest where the greatest amount of ARPA-E funding would be devoted.

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[1] Annual Energy Outlook 2009, Report #: DOE/EIA-0383 (2009)
[2] "Cost and Performance Baseline for Fossil Energy Plants", NETL, http://www.netl.doe.gov/energy-analyses/baseline_studies.html (2007)
[3] National Energy Technology Laboratory, "Bench-Scale and Slipstream Development and Testing of Post-Combustion Carbon Dioxide Capture and Separation Technology for Application to Existing Coal-Fired Power Plants", Funding Opportunity Number: DE-FOA0000131

Multidisciplinary approaches to research and teaming are strongly encouraged.

B.3. AREAS OF INTEREST

Area of Interest 1: Enabling Materials for CO_2 Capture

Promising carbon capture technologies are often hindered by materials that lack the demanding properties required for effective capture of CO_2. Since "materials" is a broad term, this Area of Interest is further divided into two sub-areas to define more precisely the innovations sought by ARPA-E:

Area of Interest 1A: Catalysts

Capture technologies are often limited by slow rates of reaction as a result of the lack of catalysts that are inexpensive, effective, and stable in flue gas. This applies to capture methods such as solvents, sorbents, and membranes, but also to natural weathering reactions that capture CO_2 and provide the additional benefit of permanent sequestration. Where appropriate, the use of computational models in conjunction with a development effort could serve as a synergistic aspect of an experimental research program. Desired topics sought in this Area of Interest include, but are not limited to:

- Low cost, widely-available catalysts that enable solvents, sorbents, or membrane systems that exhibit superior thermodynamic properties compared to MEA, but are currently impractical due to slow kinetics
- Biological and/or chemical promotion of weathering reactions that greatly accelerate natural weathering of materials such as silicates

Area of Interest 1B: Robust Materials

Novel technologies that demonstrate promise in a laboratory setting often fail quickly when transitioned to actual flue gas. ARPA-E seeks advanced materials that can survive the high temperatures and multiple caustic contaminants associated with flue gas. Where appropriate, the use of computational models in conjunction with a development effort could serve as a synergistic aspect of an experimental research program. Desired topics sought in this Area of Interest include, but are not limited to:

Low cost, widely-available materials for carbon capture that are robust at appropriate temperatures and resistant to degradation caused by contaminants in actual flue gas

- Materials that enable alternative chemistries for CO_2 reactions (for example, alternatives to bicarbonate or carbamate reactions) that demonstrate promise for lower energy requirements for capture and regeneration. Chemistries that result in carbon in forms other than CO_2 could also be considered

In the Concept Paper phase, applicants to Areas of Interest 1A and 1B must quantitatively describe the status and current performance of the proposed catalysts or robust materials, as well as the expected performance improvements that would be enabled as a result of a successful program. Applicants should state why the proposed catalysts or robust materials show promise, the plan to validate this promise with specific metrics and goals, and what the major risks and pathways to overcome these risks would be. While the length of the concept paper prohibits extensive narrative, a summary of expected integration challenges and potential negative side-effects of the technology should be described to support the project.

In the Full Application phase, applicants to Areas of Interest 1A and 1B should quantitatively describe the status and current performance of the proposed catalysts or robust materials, as well as the expected performance improvements that would be enabled as a result of a successful program. Metrics that quantify the catalyst or robust material performance shall be identified, and the applicants shall propose current values and target final values for those metrics relative to competing technologies and with supporting rationale. For Full Applications that include research on catalysts, membranes, solvents, or sorbents, required metrics are defined in Table 1 below.

Area of Interest 2: CO_2 Capture Processes

As described above, the amine solvent process is the current state-of-the-art capture technology. While this process has been continuously and incrementally improved as a result of decades of development, a 22-30% parasitic power load is required for capture and compression of CO_2[4]. The objective of this Area of Interest is to enable CO_2 capture processes that will dramatically reduce current parasitic power requirements. Use of modeling to extrapolate to scaled system implementations is an important element to demonstrate feasibility of proposed approaches. Desired topics sought in this Area of Interest include, but are not limited to:

- Capture techniques that utilize novel pathways in thermodynamic phase diagrams for CO_2 capture and release, potentially including supercritical phase transitions
- Novel forms of capture and regeneration that may utilize other thermodynamic inputs beyond temperature or pressure to effectively facilitate CO_2 capture and release
- Ultrathin membrane fabrication with high permeance and selectivity
- Large-area membrane modules with improved gas flow, membrane packing density, and resistance to flue gas contaminants

In the Concept Paper phase for this Area of Interest, applicants must quantitatively describe the status and current performance of the proposed process relative to the standard amine process, as well as the expected performance improvements that would be enabled as a result of a successful program. Applicants should state why the proposed process shows promise, the plan to validate this promise with specific metrics and goals, and what the major risks and pathways to overcome these risks would be. While the length of the concept paper prohibits extensive narrative, a summary of the energy requirements, expected integration issues, and potential negative side-effects of the technology should be described to support the project.

In the Full Application phase for this Area of Interest, applicants should quantitatively describe the status and current performance of the proposed process relative to the standard amine capture process, as well as the expected performance improvements that would be enabled as a result of a successful program. Metrics that quantify the process performance shall be identified, and the applicants shall propose current values and target final values for those metrics relative to competing technologies and with supporting rationale. For Full Applications that include research on catalysts, membranes, solvents, or sorbents, required metrics are defined in Table 1 below. Included in the analysis shall be a discussion of the work required for CO_2 capture in units of kJ/mole CO_2 removed, including a statement as to whether or not compression work was included in that value. A Life cycle analysis (LCA) , detailed mass and energy balances, and reaction rates expected are required to compare this technology to baseline references. If supporting systems-level modeling efforts are proposed, Full Applications shall identify whether the models are new, or based on existing models. Proposals shall state whether the models developed will be publicly-available at the conclusion of the program.

General Requirements

In addition to the requirements defined for Areas of Interest 1 and 2 above, ALL Full Applications are to include the following:

- Estimation of the parasitic power load required from the plant to operate the proposed technology, and the corresponding increase in COE. The assumptions comprising these values shall be clearly stated.
- Estimation of the cost per ton of CO_2 avoided. The assumptions comprising this estimate shall be clearly stated.
- Description of the stability of the material and/or process under operational temperatures and other flue gas species, including, but not limited to: particulates, SOx, NOx, and water vapor.
- Description of how the material and/or process would be integrated with an existing coal-fired power plant.
- Inclusion of preliminary LCA to provide an early assessment of the feasibility of using the proposed materials and/or processes at large scales (500 MWe). Emphasis shall be placed on the assumptions that comprise the LCA, rather than the final numerical results.

[4] G.T. Rochelle, "Amine Scrubbing for CO_2 Capture," Science 325, 1652-54 (2009).

For both Areas of Interest 1 and 2, it was stated above that metrics must be proposed to quantify the potential of the proposed technology relative to state of the art. In Table 1, common capture technologies are listed, as well as metrics that are required for any Full Applications that contain these technologies (even if proposed as a component of a larger system):

Table 1: Common technologies and required metrics

Technology	Required Metrics
Catalysts	• Turnover frequency • Loading (g/L)
Membranes	• Permeance (GPU) • Selectivity (CO_2 over N_2)
Solvents	• Capacity (g/L) • Regeneration temperature (^oC)
Sorbents	• Capacity (wt%) • Surface area (m^2/g) • Regeneration temperature (^oC)

It is anticipated that research programs will consist of one or more phases that total between 24-36 months, and must include at least annual intermediate Go/No-Go decision points. In both the Concept Paper and Full Application phases, applications must clearly indicate the Area of Interest that the application addresses. Applications that include incremental improvements to existing technologies, require large quantities of exotic elements, or propose trial-and-error experimental plans will not be considered for selection.

For both technical areas, ARPA-E will consider "Proof-of-Concept" programs for early investigation and exploration of highly novel ideas. In these proposals, respondents must provide a strong rationale for research in this area based on initial experimental results or relevant work in an associated field. These awards will be at the lower end of the funding and period of performance range, typically $500,000 to $1 million over a period of 24 months. Successful programs may obtain follow-on funding for further development where warranted.

ARPA-E anticipates making 3-10 awards in each area of interest, including Proof-of-Concept projects, but final awards are dependent on solicitations received.