Nano4EARTH Roundtable Discussion Summary: Capture, Storage, and Use of Greenhouse Gases

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Overview

The National Nanotechnology Initiative (NNI) launched the National Nanotechnology Challenge on climate change (Nano4EARTH) to convene and mobilize the broad nanotechnology community to accelerate solutions for climate change. The NNI, with support from the National Nanotechnology Coordination Office (NNCO), has organized a series of roundtable discussions on particularly promising areas that could have near-term impacts (four years or less) on climate change. These promising areas were identified at the Nano4EARTH kick-off workshop. Among them was *capture, storage, and use of greenhouse gases (GHGs),* which was the focus of the third roundtable discussion.

To achieve net-zero goals, the International Energy Agency predicts that 1.2 Gt of CO_2 per year needs to be captured by 2050[1], but current facilities and projects are not on track to achieve that goal. With this in mind, NNCO assembled 12 subject-matter experts from different sectors, including academia, national laboratories, small and large businesses, and technology development and finance, to discuss and identify the most pressing near-term needs, opportunities, and challenges to expand the capture, storage, and use of GHGs. The agenda and list of invited participants for the roundtable can be found here.

Greenhouse Gas (GHG) Capture, Storage, and Use

While the technical challenge of capturing CO_2 tends to draw the most attention, other GHGs are also important (e.g., methane), and all captured GHGs must be stored or used to achieve long-term climate goals. Strategies identified at the roundtable for **GHG capture** include direct air capture, point-source capture (e.g., flue gases), soil-carbon capture, and ocean capture. Nanotechnology can contribute directly to these efforts in the near term through advanced solvent processes, the development of non-amine sorbents, non-thermal regeneration of solvents/sorbents, advanced nanofilters and nanomembranes, alternative structural materials, and monolithic or amine-appended metal-organic frameworks.

GHG storage opportunities that were discussed range from geological storage to brine dissolution to portable/small-footprint storage. For this discussion, the storage options that were considered need to keep GHGs stored for at least 100 years. Relatedly, **GHG use** options that involve nanotechnology – which offer some economic return on what would otherwise only reflect a cost – included mineralization or transformation into building materials (e.g., concrete, cement, solid carbon nanostructures); luxury items (e.g., cosmetics, jewelry); and liquid fuels (e.g., biogas, jet fuel, syngas). In addition, nanotechnology can enable novel sensing and monitoring strategies that contribute to GHG accounting and verification.

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[1] https://www.iea.org/energy-system/carbon-capture-utilisation-and-storage

The levers to advance innovation in GHG capture, storage, and use are diverse. Value-added products create opportunities to harness market forces, potentially focusing on low volumes with high price points for initial markets. Voluntary markets – such as those created when large companies commit to GHG reductions or offsets, create important economic incentives for pilot projects. Government agencies can also position themselves as “first customers” (e.g., the U.S. Department of Energy’s 2023 Carbon Dioxide Removal Purchase Pilot Prize of $35 million). More broadly, government incentives – such as the 2022 Inflation Reduction Act’s update of the 45Q tax credit for CO_2 that is captured and permanently stored in geological formations – encouraged R&D and scaling-up deployment. Most of these technologies are relatively young, and participants expect failures on the way to mature technologies and established markets. The challenges and opportunities for nanotechnology-enabled solutions that were discussed are summarized in Table 1.

Table 1. Challenges and Opportunities for Nanotechnology-Enabled GHG Solutions

Challenges Identified	**Opportunities Discussed**
Fundamental scientific understanding to enable innovation	● Kinetics for CO_2 capture ● GHG storage properties of liquids and polymers ● Thermal properties and hydrophobic surfaces ● Oxidize methane from atmosphere ● Removal of CNTs from electrodes where they are grown ● NOx and SOx scrubber efficiency before vs. after CO_2 removal ● Interface with the Materials Genome Initiative and other efforts to do high throughput characterization of materials
Scaling up operations from the laboratory to the industrial scale	● Novel thermal management strategies and materials (lab scale experimentation does not always predict industrial scale energy and thermal requirements) ● Alternative earth-abundant materials (iridium and platinum are too rare to expand production significantly)
Stability of materials to avoid costs of frequent replacement	● Materials resilient to impurities ● Regenerative materials ● Extended life of solvents
Diverse capture targets and environments of application	● Form factors (membranes, fibers, interfacial support) that can adapt to different capture targets (CO_2, methane, hydrogen) ● Specificity of materials to work in different environments (e.g., geographies)
Reducing power requirements	● Energy recovery (e.g., with thermoelectrics) and reuse ● Energy harvesting and storage ● Alternative heat sources (e.g., microwave)
Monitoring and reporting	● Advanced sensors

GHG capture and storage	● Detection of unintended emissions, including hydrogen that can reduce the availability of OH for methane oxidation

Other technical challenges surround GHG capture, storage, and use, and should be considered regardless of the role of nanotechnology. For example, life-cycle analysis – with new standards – will be required to measure the net GHG storage for processes that require energy, manufactured materials, land, and water; generate emissions of GHGs and other pollutants; and involve eventual disposal of materials.

As a second example, design strategies that rely on modularity are attractive for scaling up production but may miss important economies of scale or face other hurdles related to materials' costs. Much might be learned from other industries that have increased their scales of production (e.g., aluminum). More generally, challenges related to moving toward deployment require early-stage testing in realistic environments and enhanced linkages between laboratories and industries.

Challenges also arise from the societal realm. Supply chain risks threaten the sustainability of processes that rely on imported materials or offshore manufacturing. Similarly, the domestic workforce may lack technical training and skills, although there are opportunities for connections to community college training programs and important overlaps with the oil and gas industry workforce. In fact, GHG operations may offer communities non-cyclical, sustainable, and well-paid jobs without advanced educational requirements.

Yet, this place-based reality also raises environmental justice concerns for these same communities. Opportunities include stakeholder and community engagement, co-managing sensor deployment to build trust, and monitoring and reporting emissions. On the positive side, distributing systems across the landscape to capture GHGs and use them in fuels could reduce the need for pipeline infrastructure and could enhance national security.

Nanotechnology's competitive advantages of selectivity and precision create specific opportunities to dramatically increase performance and reduce the associated costs of GHG capture, storage, and use. Mindful of the rising threat of climate change in an uncertain policy landscape, roundtable participants emphasized the importance of getting GHG capture and storage to work, rather than only aiming for the "perfect" technology.