$1M+ Call for Proposals on Energy-Materials Nexus from Carbon Hub Collaborators

Launch: November 28, 2022

Proposals Due: 11:59 pm Central Time US, January 30, 2023

INTRODUCTION

The Carbon Hub is a grassroots, global community of scientists, engineers, product developers, business developers, and investigators, from academia, industry, and institutes focused on significantly impacting the Energy-Materials nexus to reduce global greenhouse gas emissions through well thought out improvements in materials manufacturing and utilization. Specifically, the goal is to bring online a substantial production of Value Added Carbon Solids (VACS) and their advanced material supply chains, with co-production of Clean Hydrogen (H_2). We see opportunities for novel materials designs that impact the displacement of high energy and CO_2 emissions intensive, existing commercial materials. Our starting point is utilizing methane and other light hydrocarbons, to produce materials that can be used at large scale (above 1 million tons/year) via efficient processes that, sooner than later, will co-produce hydrogen at sufficient level to impact the global energy grid. To advance on the Carbon Hub goals and Vision, we must re-think approaches, build diverse teams, and work intensively – together.

The Carbon Hub has established a competitive call for proposal process to fund projects in order to help advance its Vision. These one-year projects may, with demonstrated success, receive renewal funding or transition to multi-year funding (2-3 years). We understand all these projects involve risk, and some topics have not been studied well previously, which amplifies the importance of a systematic approach by a committed field of investigators to evaluate all viable options. Carbon Hub funding is intended to encourage Collaborators to move the needle, far and fast, and to build scientific understanding from underlying principles. We expect interdisciplinary advanced materials and energy research to be proposed that digs deeper and crosses boundaries between industry and academia – our problems do not recognize any boundaries we may traditionally work within.

What are VACS?

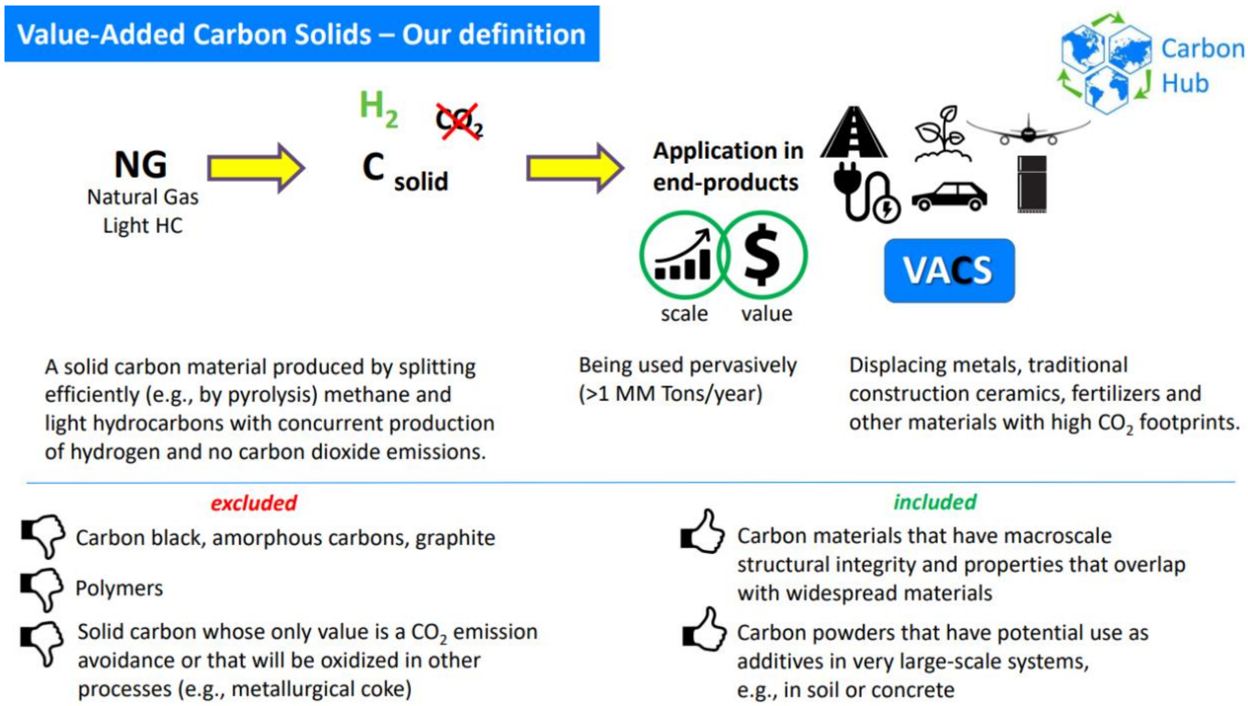
VACS are solid carbon materials produced by efficiently splitting (e.g., by pyrolysis) methane and light hydrocarbons with concurrent production of hydrogen and no carbon dioxide emissions. VACS will be used pervasively (above 1 million tons/year), displacing metals, traditional construction ceramics, fertilizers, and other materials with high carbon dioxide footprints.

Included in this category are:

- Carbon materials with macroscale structural integrity and properties that overlap with widespread materials;
- Carbon powders that have potential use as additives in very large-scale systems, e.g., in soil or concrete.

Not included in this category are:

- Carbon black, amorphous carbons, graphite;
- Polymers;
- Solid carbon whose only value is a CO_2 emission avoidance or that will be oxidized in other processes (e.g., metallurgical coke).



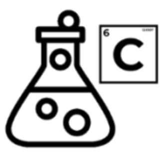
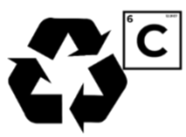
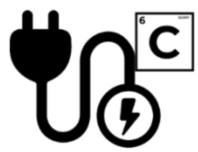
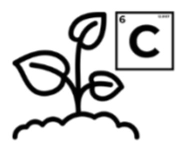
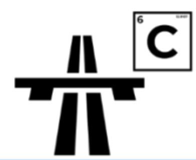
Example of VACS and challenges:

- Carbon Nanotubes (CNTs)
    - Opportunity: CNTs can be synthesized in one process step from methane or light hydrocarbons and can be converted into macroscopic materials; based on properties, a subclass of CNT macromaterials could replace metals or other construction material
    - Challenges: CNT synthesis is an early-stage, low-volume endeavor; synthesis efficiency is low and must be increased by orders of magnitude to attain competitiveness with incumbent materials; the knowledge base for increasing the efficiency and scale of CNT synthesis coupled with properties control must be developed
- Soil additives
    - Opportunity: forms of carbon (e.g., biochar) may improve the fertility and viability of soils while simultaneously reducing fertilizer usage;
    - Challenges: current carbon soil additives are too expensive for large-scale deployment and are not made from methane and light hydrocarbons; the knowledge base for efficiently synthesizing soil additives from methane and light hydrocarbons must be developed

<u>Mission Critical</u>: Proposed projects must have linkage to the Carbon Hub Vision. For the Carbon Hub to enable and accelerate the development and deployment of VACS and clean hydrogen, from methane or light hydrocarbons, each effort needs to attack problems, create knowledge, propose/interrogate policies, create product/process solutions, and build the collective knowledge of our community so that we will accelerate by a decade or more new pathways that are not currently on the energy transition maps. The challenges are immense, thus our formation of the Carbon Hub and the critical need that all efforts are focused.

Call for Proposals 2022

This call for proposals (CFP Fall 2022) is open to Carbon Hub Collaborators to submit new ideas, approaches, technology, and studies in the following topics:

Improve understanding of the catalysis and reaction mechanism in (thermocatalytic) pyrolysis to efficiently convert methane and light hydrocarbons to Value Added Carbon Solid (VACS)	**Improve carbon nanotube (CNT) and VACS standardization and environmental impact understanding**	**Demonstrate the value of a CNT fiber-based power cable prototype**	**Demonstrate and explain efficacy of a VACS as a soil amendment**	**Demonstrate the value of CNT or other VACS, from methane (thermocatalytic) pyrolysis, in structural applications, including non-critical ones**
				

VISION of the CARBON HUB

Every year, we extract over 4.2 GT of oil, 2.5 GT of natural gas, and 3.4 GT of coal. That's equivalent to 8.7 GT of carbon and 1.3 GT of hydrogen to sustain our global economies. Almost all of these resources are burned to generate energy, causing over 30 GT of CO_2 to enter the atmosphere which is unsustainable in light of climate change—the only significant exception is polymers, which fix 0.35 GT/yr of hydrocarbon resources (~3% of the total production) into valuable solid materials. At the same time, every year we use over 12% of the world energy production (over 60 EJ) on metals: most of this energy goes into mining, refining, and processing ~3 GT/yr of metal ores into usable metals, including 1.6 GT/yr of steel, 50 MT/yr of aluminum, and 20 MT/yr of copper. Unlike hydrocarbons (which are mined at high concentration and in reduced form), metals are mined at low concentration (typically ~ 50% for iron ore, 15% for aluminum ore, and less than 1% for copper ore) and in oxidized form. In addition to the well-known environmental impacts of mining metal ores, metals also have to be reduced using carbon, generating 3.7 GT of CO_2 emissions (equivalent to ~20% of the emissions caused by burning oil and gas). This situation triggers an immediate query: Why don't we make more effective use of the carbon contained in oil and gas in making materials? Surprisingly, however, we are not focusing on this "Energy-Materials" nexus.

However, the full scale of the problem is gargantuan. On the supply side, fixing all the carbon present in fossil oil and natural gas would generate ~5 GT/yr of solid carbon and ~1.3 GT of H_2, eliminating 18.3 GT/yr of CO_2 emissions and yielding ~180 EJ of clean H_2 energy. 160 EJ of energy would be stored in the solid carbon (note that the sum of these two energies is slightly higher than the yearly energy supply from oil & gas, ~310 EJ/yr, because ~5% of fossil hydrocarbons are used to make polymers and smaller amounts are used for chemicals, lubricants, etc). Eliminating the production of primary metals[2] would reduce energy consumption by ~65 EJ/yr and CO_2 emissions by ~4 GT/yr. We are not suggesting that metals could be completely supplanted by VACS; yet, we are showing the magnitude of the opportunity. Now, with a rapidly shifting energy ecosystem, the need for the opportunity is pressing. Further, we do not want to repeat the missteps of the coal energy supply chain and generate new legacy problems. We must be smarter and design a new Energy-Material nexus from the beginning, with all factors considered and useful applications for the VACS.

Polymers alone cannot replace metals because of insufficient strength and low electrical/thermal conductivity. Carbon fibers (CF) possess the right properties, but their energy intensive, subtractive manufacturing process results in large energy and CO_2 footprints (and associated cost). Carbon black is a mature product space with 12-15 MT/yr commercial utilization, and has no known path to 100MT/yr markets. As a solution, we propose to convert methane (HC) into VACS (i.e. CNTs) with concurrent production of Clean Hydrogen (H_2), and the VACS to be integrated into existing and new supply chains to positively impact global energy consumption and greenhouse gas emissions. Several key questions need to be answered: how to upscale these processes, the processes' energy and CO_2 footprints at scale, and projected costs (financial, energy, environmental) and performance of commercialized products.

The Carbon Hub aims to simultaneously address three technological needs that all significantly influence our global energy production and use:

(1) fixation of the carbon present in methane and light hydrocarbons into a VACS (e.g. CNTs), with concurrent production of Clean H_2 to reduce CO_2 emissions while generating clean energy;
(2) replacement of major primary metals (copper, aluminum, and steel); to reduce energy consumption and CO_2 footprint associated with the mining and processing of primary metals;
(3) utilization of VACS by substituting for existing materials in commercial applications (metals with lighter CNT-polymer composites, soil amendments); when used in structural applications, lightweight VACS products will increase fuel efficiency (cars, airplanes, ships etc.) and reduce energy consumption and associated CO_2 emissions.

Additionally, we anticipate that scientists, engineers, and entrepreneurs will identify additional routes to utilize VACS to displace other CO_2 emissions - **we welcome such additional pathways**.

Additional Resources:
Please review the following video presentations for additional insight and background. All videos are located on the Carbon Hub YouTube channel here.

- **The Carbon Hub**, by Matteo Pasquali, Rice University, from the Carbon Hub kickoff, which outlines the Carbon Hub vision and mission.
- **The Growing Importance of Hydrogen in our Energy System**, by Bryan Pivovar, National Renewable Energy Laboratory, from the Carbon Hub kickoff, which outlines the scale of hydrogen as a global energy component.
- **Innovative R&D Partnerships to Drive the Energy Transition**, by Ajay Mehta, Shell New Energies Research and Technology from the Carbon Hub kickoff, which discusses the scale and needs of this energy transition.
- **Turning Methane into Low-Carbon Hydrogen and Useful Carbon Products**, by Marc von Keitz, US ARPA-E, from the Carbon Hub kickoff, which discusses challenges and ongoing efforts to convert methane to useful carbon products.
- **2020 and 2021 Carbon Hub Webinars** are available on the CFP webpage.

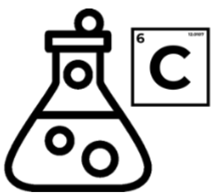
CFP SCOPE

The proposed research may involve the broad range of disciplines involved in advanced materials and energy—from science and technology to economics and policy—individually or in combination. In the topics below, you will find specific questions to help develop your ideas and research proposals. An inter-disciplinary team of scientists, engineers, business professionals, generated these questions and policy experts during the Technical Workshop held on Feb 14, 2020 as part of the Carbon Hub kick-off events.

As this is the Carbon Hub's 2nd year funding cycle, we recommend that you review the 2020 projects that were funded, so as not to propose projects with significant overlap. However, if you have compelling data and information, which the Carbon Hub proposal reviewers can consider, in that instance we are open to new proposals that may have some overlap with existing awardees. We invite you to read about the 2020 Carbon Hub funded projects here.

If you are uncertain, do not hesitate to contact us.

<u>TOPIC #1</u>: **Improve understanding of the catalysis and reaction mechanism in (thermocatalytic) pyrolysis to efficiently convert methane and light hydrocarbons to VACS.**



We seek breakthrough understanding to unlock high yields and selectivity for the production of VACS materials using thermocatalytic pyrolysis, with an emphasis on methane.

The relationship between catalyst, reaction conditions and resultant synthesized carbon material properties, in particular CNTs, is still poorly understood for thermocatalytic pyrolysis of methane and light hydrocarbons. This results in low feedstock conversion, low catalyst utilization values (typically below 2% for CNTs), and a poor control over carbon material properties (dimensions) and performance.

This gap in understanding of the catalysis/reaction mechanism and inability to improve hydrocarbon conversion processes leads to poor process efficiencies, high material costs, and market adoption hurdles due to limited and inconsistent material availability at a competitive price. For example, this is a long-standing problem in the area of CNTs, where high-quality CNTs are produced with low-efficiency processes. Therefore, this area needs new thinking and approaches. For other VACS, the morphology development and control of the produced solid carbon is not understood, which will impede successful application and commercial adoption. Thus, we welcome fundamental studies on how to control solid carbon morphology development in catalyzed processes while achieving acceptable efficiencies.

This call for proposal is aiming to stimulate technical breakthroughs and an improved fundamental understanding based on scientific principles. Key research questions to consider:

- Do we need to tear apart the existing hypothesis for synthetic pathways and start fresh?
- How can we probe the reaction mechanism better (in-situ)? Can we measure short-lived species and determine their effect on the reactions? Can we make transparent (or partially transparent) reactors?
- How do we identify and exploit the barriers to efficiency? What fundamental knowledge must be generated to support the reaction and reactor design?
- How do we design/manufacture the correct catalyst (diameter, composition, durability) to selectively control product morphology and achieve high conversions of feedstock?
- Can we improve product performance and selectivity with additives to the workhorse Fe catalyst? Alternatively, are there improved catalyst compositions that can be used? Can we use cheaper catalysts? What is deactivating the catalyst?
- What roles can improved Reaction Engineering and Novel Reactor concepts play in improving efficiency? Can we increase reaction density?

- Can we improve the models for kinetic calculations of growth?
- Can we use data science & standardized databases?
- Can we couple experiments and modeling to accelerate progress?

<u>Additional Resources:</u>

The following video presentations provide additional insight and background. All videos can be viewed on the Carbon Hub YouTube channel here.

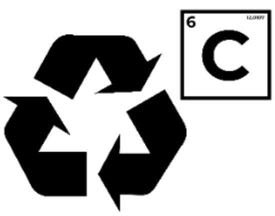
- **Carbon Nanotube Materials: Hope and Challenges** by Adam Boies, Cambridge University, from the Carbon Hub kickoff, which outlines the challenges in efficient CNT synthesis.
- **Carbon Materials from Natural Gas Pyrolysis: Exploring Options in a Decarbonized World** by Leonardo Spanu, Shell International Exploration and Production Inc., from the Carbon Hub kickoff, which outlines options and challenges for CO_2-free hydrogen and carbon markets.

TOPIC #1 OUT OF SCOPE: we are NOT looking for:

- Any work related to carbon black or metallurgical coke
- Projects not linked to the Carbon Hub vision
- Studies previously completed

<u>TOPIC #2</u>: **Improve CNT and VACS standardization and environmental impact understanding.**

- **CNT material standardization (terminology, testing)**
- **LCA and End-of-Life use mapped for CNT or other VACS**



We need to drastically improve the understanding of health, safety and environmental (HS&E) impacts of CNT and Life Cycle impacts of CNT and other VACS. We must improve how material properties of CNT/VACS are described and determined, and study how VACS influences supply and value chains. In particular, we are interested in how CO_2 *(& other emissions) and energy footprints are changed when using VACS materials.*

For VACS to be successfully adopted at wide commercial scale, it is essential to understand thoroughly their health, safety, and environmental impacts and lifecycle consequences. In addition, it is critical to have consistent and meaningful material property standards and measurement methods.

Three decades after their discovery, there is still an ambiguous understanding of CNT HS&E, and few literature studies showing life cycle and end-of life use opportunities. Material properties of CNTs or other VACS materials are not standardized, tested, and do not have a consistent taxonomy.

Topic #2 seeks to determine gaps and identify opportunities to develop a common language, measurement and testing protocols that will allow positioning these important material classes for large-scale applications introduction.

Additionally, what policy changes may be necessary, as supported by a data-driven analysis using an LCA and/or TEA study, to incentivize adopting VACS in broad applications? Proposals of interest include those that investigate VACS full lifecycle via estimation of costs and volumes of CO_2 removed/avoided and energy utilization avoided to better understand environmental and energy trade-offs of different VACS-based material solutions integrated into applications at large scales, e.g. VACS used as a soil amendment and the quantified cascade of impacts on greenhouse gas emissions vs. a traditional combustion use of natural gas/methane.

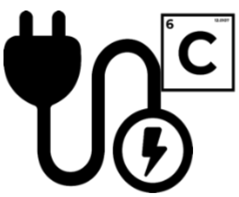
Areas of interest include:

- New or improved analytical techniques to better identify different solid carbon products within the same sample, e.g. intended product vs. secondary or unwanted products, with emphasis on accuracy, quantification, portability and speed.
- Improved material standards and material descriptions studies or analyses of how CNTs and other VACS might influence product chains/systems upon introduction.
- Analysis of how multifunctional VACS properties may result in improved costs of ownership, e.g., are there unique manufacturing savings or simplifications? Is it possible to improve system designs?
- LCA and TEA studies that estimate energy utilization, energy savings, CO_2 emissions impacts, e.g. when using VACS in soil amendments, concrete additives, vehicle (terrestrial or aerospace) parts composites, etc.

TOPIC #2 OUT OF SCOPE: we are NOT looking for:

- Studies that only evaluate scenarios where a produced solid carbon is disposed, e.g. via burial.
- Toxicity studies

***<u>TOPIC #3</u>*:** **Demonstrate the value of a CNT fiber-based power cable prototype.**



We seek fundamental and applied advances towards the development and testing of a prototype CNT fiber-based power cable meeting commercial AC or DC power transmission requirements.

Over the last 15 years, CNT fiber technology has advanced significantly demonstrating tensile strengths (4 GPa), electrical conductivity (11 MS/m) and thermal conductivity (600 W/m K) comparable or better than existing commercially used materials. Still, published data on integration of these fibers into electrical conductor systems has been limited. Moreover, despite improved understanding of the mechanics and transport properties at the level of an individual CNT, the understanding of transport at the macroscale is still limited. As an example, it is still unknown (1) whether the electrical conductivity of state-of-the-art CNT fibers is limited by losses within CNTs or at their junctions and (2) what is the upper conductivity limit that can be realized in a macroscale CNT conductor, as a function of CNT helicity and number of walls. At the systems level, there is little to no understanding of the relative importance of advantages in strength, thermal conductivity, density, stiffness, and resistance to interfacial heat transport vs. disadvantages in electrical conductivity, and how these factors may change depending on operating temperature and environment (e.g., overhead vs. buried vs. undersea tethered as in umbilical cables). Thus, we seek fundamental understanding as well as applied experiments that will further the successful prototyping of CNT fiber in a cable conductor power line application (including overhead power lines). The expectation is that the conductor performances are evaluated in comparison with existing material and cable solutions to find a suitable mix of performances, which are competitive in specific power distribution/supply applications. Understanding the bare CNT fiber thermal performance in relation to current carrying capacity, tension-temperature-sag characteristics, and steady state heat balance are areas of interest.

When considering distribution and transmission power lines, the technical community has developed accurate models and design rules for all copper, all aluminum, and composites of aluminum with steel power line performance characteristics. Given the vastly different properties CNT fibers have compared to Cu and Al, it is imperative to develop appropriate models for CNT fiber stranded conductors. For example, the metal components of transmission lines are presently modeled as monolithic structures, which influences estimation of radial heat and electrical transport, convective heat transport with the environment, mechanical behavior under load, and temperature-dependence of transport and mechanical properties. However, CNT fibers are ensembles of hierarchical structures, which may behave very differently than monolithic cylinders, and may depend on the CNT wire architecture. Therefore, we must develop foundational understanding and data for CNT fiber based systems to allow accurate comparison to existing technologies. This requires improved understanding both at the level of individual CNT fiber properties and, even more so, at the level of stranded bundles to prototype wire structures.

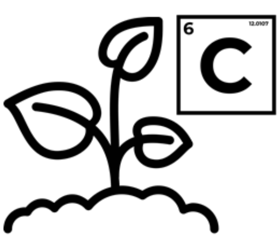
Areas of interest include:

- Low-voltage power conductors, DC and AC
- Medium to high voltage power transmission and distribution conductor cables
- Fundamental understanding of transport in CNT fibers and fiber assemblies, including effects of impurities, defects, alignment, CNT aspect ratio and polydispersity, doping, contact resistance
- Determination of fundamental limits to transport in CNT conductors as a function of size and scale
- DC and AC motor conductors including novel motor architectures using CNT fiber conductors
- Electrical applications that could lead to early, low-volume introductions, e.g., speaker cables, antennas, signal data transmission, electrical connections in solar panels, replacement of steel in long-span applications, dual strength/conductivity opportunities in elevator cables, shielding applications
- Development of plug-and-play demos
- Applications that can benefit from anisotropic conductivity of CNT conductors
- Applications that can benefit from CNT conductor behavior in extreme environments
- Effect of aging, temperature, environmental conditions on CNT conductor performance, including doping

TOPIC #3 OUT OF SCOPE – We are NOT looking for

- Prototype studies based on instrumentation, control, data cables
- Studies that seek to improve CNT fiber properties empirically, without relating properties to the application performance, or without understanding the dependence of properties on fundamental CNT parameters

TOPIC #4: **Demonstrate and explain efficacy of a VACS as a soil amendment.**



We seek new ideas for developing VACS as a soil amendment, both at the level of synthesis as well as utilization efficacy.

Healthy and productive soils generally have high soil organic carbon contents. Amendment of soils to improve soil health and thus agricultural yields via better physical, chemical and biological properties using solid carbon has long been sought. Controlled hydrocarbon pyrolysis has the potential to produce significant quantities of solid carbon materials, which can influence large-scale soil health improvements with cost structures useful in agricultural and arable land development. Agricultural engineering, including engineering advanced materials to be used as soil amendments provides a significant opportunity for MT quantities of VACS materials that would be co-produced with Clean H_2 at scales relevant to energy production. A VACS material, if applied in amounts similar to biochar, could demand 2 to 10 metric tons/hectare at depths of 10 - 20 cm, only, clearly presenting a substantial value chain if the efficacy can be demonstrated.

The current commercial incumbent technology for soil amendment technology, biochar, provides useful guidelines on areas to study and potentially significant material properties to design and measure. There are two aspects: (1) How much more effective could biochar be if its material properties and macro-assemblies could be controlled better? and (2) Could an effective soil amendment carbon be produced via methane or light hydrocarbon splitting, at an efficiency and cost that would lead to large-scale utilization?

Improved carbon soil amendments may provide opportunities to change fertilizer utilization with significant benefits such as:

- Reduce overall emissions through decreasing fertilizer needs;
- Greenhouse gas reductions via N_2O elimination;
- Avoiding problematic emissions of NO and ammonia, important precursors of particulate matter and other air pollutants;
- Reduce fertilizer run-off contributions to eutrophication, including acute and long-term ecosystems changes;
- Reduce energy consumption for extremely energy intensive fertilizer manufacturing.

In order to explore these opportunities, it is essential to understand the fundamental relationships between different properties of the synthesized solid carbon and the soil ecosystem chosen to study. The particle properties (morphology, dimensions, charges, adsorption of key ionic species, hierarchical structure) will influence how VACS integrate into soil ecosystems, potentially improving soil health, landscape, and ecological impacts. We need to understand the value of control over microstructure and resultant macro-assembly of solid carbon to selectively improve microbial communities, soil water filtration, soil mechanical properties or crop yields. In contrast to the largely uncontrolled material design of biochars, there exists an opportunity to engineer a VACS material learning from the biochar and organic carbon foundational work. This engineered VACS material would be synthesized using efficient processes and have a path to scale and cost structures to achieve wide applicability.

Some additional questions and areas of interest are:

- How would VACS soil amendments affect:
  - Crop yield and quality
  - Carbon uptake by soils
  - Water retention by soils
  - Soil microbiome
  - N_2O emissions
  - NO, NH_3, NONO emissions
  - Run-off and leaching
  - Fertilizer application needs
  - Repetitive addition needs
- How does VACS performance depend on local effects, such as soil type, climate, precipitation patterns, etc?
  - How should VACS be tailored to the soil and climate where they are deployed?

- How does VACS performance compare with a selected biochar?
- Understand the VACS net carbon balance, nitrogen cycle and resultant greenhouse gas emissions
- Are VACS best used as powders, or other macrostructures (foams, fibers, structures)
- What is the full-scale LCA of VACS as a function of their production and performance?
- Are there VACS attributes that would make them toxic as soil additives?
- Collaborative studies between VACS producers and testers are encouraged

Additional Resources:

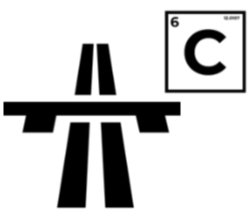
The following video presentation provides additional insight and background. All videos can be viewed on the Carbon Hub YouTube channel here.

- **Amending Soil with Carbon-Rich Materials**, by Caroline Masiello, Rice University, from the Carbon Hub kickoff, which discusses how solid carbon affects soils.

TOPIC #4 OUT OF SCOPE – We are NOT looking for

- Projects that seek to sequester a solid carbon with no additional, functional value.
- Carbon materials that do not meet the definition of VACS.
- Solid carbon materials that will NOT add additional value to soil or the health and productivity of the eco-system.
- Solid carbon materials NOT made from methane or light hydrocarbons.

TOPIC #5: **Demonstrate the value of CNT or other VACS, from methane (thermocatalytic) pyrolysis, in structural applications, including non-critical ones.**



We seek new ideas and Proof of Concept testing to identify and demonstrate a viable and economically compelling application for CNTs or other VACS materials in structural application with high annual volume opportunities.

To accelerate the deployment of VACS, we must investigate and develop viable product lines that will lead to large volumes of solid carbon utilization. These solid carbon applications must have commercial benefits, positively impact global environmental emissions, and energy utilization. Structural uses can be divided roughly into critical, where a component is bearing the load of the structure, and non-critical, where a component is serving other functions. Structural applications have the potential to use VACS's functionalities to improve mechanical, thermal and/or electrical properties for structures in transportation, construction, housing, and infrastructure (roads, levees, etc.). Carbon fibers have shown some progress in this space (automotive); CNT fibers, mats, powders, and composites have collective properties exceeding the performance of carbon fibers and present design and product opportunities not previously possible. Additionally, CNT fibers and mats have the potential for much simpler manufacturing processes and cost structures, which would allow access to a broader portfolio of applications. Ideas and proof of concepts could address the gradual introduction of high-value VACS starting from high-end applications (e.g., CNT fibers and tapes), or opportunities for rapid large-scale deployment (e.g., additives in concrete, road surfacing, levees, roofs, etc.) of lower-end VACS whose efficient production is already proven at the laboratory or pilot scale.

Questions and areas of interest are:

- Demonstrate and explain the science underlying viable, structural applications for a VACS
- Select a prototype system to demonstrate performance using VACS properties to improve product design, manufacturing processes, installation ease, or total cost of ownership over the life of the structure
- Luxury items where VACS can push boundaries of performance and esthetics
- Demonstrate proof of concept for novel applications such as concrete or asphalt additives
    - Can VACS improve performance, e.g., impact damage, durability, service life?
    - What is the economic value of improved performance in these low-cost systems?
- Investigate how a CNT fiber surface modification scheme influences load transfer, and mechanical properties under application conditions
- Can VACS be used to build chemical reactors?
- Comprehensive comparison of interface modification techniques
- Effect of creep on CNT fibers
- Applications that utilize simultaneously two or more properties of CNT fibers, e.g., mechanica/electrical, or mechanical/thermal, etc.
- Scalable composite fabrication techniques that leverage CNT fiber properties
- Novel CNT/thermoplastic composites for automotive/structural applications.

Additional Resources:

The following video presentation provides additional insight and background. All videos can be viewed on the Carbon Hub YouTube channel here.

- **The Introduction of New Materials in the Construction Industry**, by Gianni Royer-Carfagni, University of Parma, from the Carbon Hub kickoff, which outlines further potential structural applications of VACS materials.

TOPIC #5 OUT OF SCOPE – What are we NOT looking for

- Applications with low potential volumes/demand

PROPOSAL TEMPLATE, REVIEW, AND AWARD PROCESS

Proposal Submission

Full proposals (format and submission instructions described below) should be submitted to carbonhub@rice.edu by 11:59pm Central US time on **January 30, 2023.**

For Rice PIs – do not enter your proposal into Cayuse. As the administrative unit for the awards, the Carbon Hub will manage all Cayuse activity.

Proposal Checklist for Review Consideration:

Proposal applications are deemed compliant, and will be accepted for review if:

- The applicant, Principal Investigator, is an Academic Collaborator with the Carbon Hub;
- The full application complies with the content and form requirements of the CFP (listed below);
- The applicant entered all required information and successfully submitted all required documents by the deadline stated in the Call for Proposal.

An email receipt will be sent to confirm that the applicant's proposal was received by the deadline.

Proposal Format and Template
12 point, single-spaced, and 1 inch margins
Fonts: Calibri, Times, Times New Roman, Helvetica
Submit proposal as a PDF. Do not include the budget table in the proposal pdf. Submit the budget as a separate Excel document

CURRENT PROPOSAL SECTION	SECTION CONTENTS	**PAGE LIMITATIONS**
Executive Summary	Research Team a) Name of Principal Investigator(s) b) Affiliation – institute c) Address, city, country Contact details: email and phone Topic # and Proposal Title Abstract	1
Innovation, Impact, and Linkage to Carbon Hub Vision	**How are you addressing the Topic Challenge?** Provide a concise description of why the proposed research will further the Carbon Hub Vision.	1
Proposed Work	**What techniques & knowledge will you use?** Provide a concise description of the equipment, technology and knowledge you will be using. **Why is this an effective way to address the challenge?** Provide a concise description why your approach is an effective and innovative way to create new insights and value. **What are the key deliverables?**	4
Team Organization and Capabilities	**What is the team to address this challenge?** Concise description of research team actively working on proposed effort: names, project roles. **Why should we fund your team?** **What is the team's expertise and capabilities?** Concise description of key expertise and capabilities as related to the project approach.	1
Budget (Excel spreadsheet)	Breakdown by categories, including any cost share. Include a ½ to 1-page long budget justification highlighting the different needs (# students, # post docs, summer salary, etc.). Do not include the budget table in the proposal pdf. Submit it as a separate Excel spreadsheet.	1

	Budget template for non-Rice PIs is provided on the CFP page. Rice PIs must contact us at carbonhub@rice.edu for the internal budget document.	
References cited	Includes both literature references and references to earlier work by the proposing team.	2
Personnel Qualifications Summaries	NSF-style preferred	2 pages per person
Risks and Other Insights	What are the key risks in your approach? How are you managing the risks? What else might be important?	1

Proposal Review

The objective of the review process is to identify the best projects that further the goals of this CFP Fall 2022 and the Carbon Hub Vision. The Carbon Technical Council will evaluate the proposals with expertise related to the areas of research and technology development; however, no CTC member will review a proposal if they are involved in the proposed projects. The Carbon Hub may request input from any qualified individual or organization in order to ensure the highest quality proposals are selected.

NOTE: Only **non-confidential information** can be included in submitted proposals.

Review criteria for full applications:

Impact of the technology, solutions or insights	20%
Proposed approach to address the challenge	35%
Soundness of plan and execution approach vs. required budget	20%
Qualifications, experience, and capabilities of team	25%

Please effectively answer the sections in the proposal format template and the following criteria.

Potential impact of the technology, solutions, or insights: [20%]

1. How are you addressing the challenge?
2. What specific techniques and knowledge will you use?

Proposed approach to address the challenge: [35%]

3. Why would this be an effective way to address the challenge?
4. How is this an innovative way to address the challenge vs current state of the art?
5. What preliminary data and/or background information supports the approach?
6. Does this approach link to the Vision of the Carbon Hub?

Soundness of plan and execution approach vs required budget: [20%]

7. What is the budget you need and how will you use the funds?
8. What are the key deliverables (this can be knowledge)?
9. How do you ensure to deliver on time?

Qualifications, experience, and capabilities of the team: [25%]

10. What is the track record of the investigators, individually and as a team?
11. What equipment, facilities, and resources are available to succeed?

Awards

The Carbon Hub will notify award recipients in early 2023.

The Carbon Hub expects to make over $1.3M available for new awards in the Fall 2022 funding cycle. The Carbon Hub anticipates granting 4 – 7 awards across the five topic areas in the Fall 2022 cycle. Individual awards will vary between $50,000 and $250,000.

The period of performance for projects will be from 12 – 18 months, depending on the topic chosen and type of proposal. For PIs who are not at Rice University, funding will start upon successful negotiation of a subcontract between Rice University and their home organization. Rice University PIs will be required to sign an acknowledgement letter that states the expectations for the awarded project. The Carbon Hub expects to start funding agreements in early 2023, or as soon as negotiations are complete. It is in all of our interests to start as soon as possible.

Eligibility for Carbon Hub CFP Fall 2022 Grant Funding

The primary Principal Investigator (PI) must be a Carbon Hub Academic Collaborator (https://carbonhub.rice.edu/collaborators). If you are interested in becoming a Collaborator, please send a request for information to carbonhub@rice.edu.

Project Reporting

We require PIs of funded projects to participate in the Carbon Hub annual workshop. PIs will also be required to prepare progress reports at each 6 month interval. Thus, for a 1-year project, it will be a 6-month and final (12 month) report.

Project PIs and students will be expected to participate in technical review sessions, workshops in related areas, and other activities that report on the research being performed. In addition, PIs will be expected to respond to information requests from the Carbon Hub regarding any publications, patents, follow-on funding, and other progress-related project funding after the end of the funded period.

Contacts

For technical issues or questions about topic areas, please contact: Dr. Matteo Pasquali. (mp@rice.edu).
Please use Subject: Carbon Hub CFP Fall 2022.

For questions associated with proposal submissions contact: carbonhub@rice.edu.