Carbon Hub Webinar - Call for Proposals Fall 2021

Carbon Hub




Topic #2: Improve Carbon nanotube (CNT) and VACS standardization and environmental impact understanding.






Carbon Hub Webinar – Agenda – Topic #5

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General	❑ Introduction Carbon Hub ❑ Mission and Vision	10 min
What are we trying to solve?	❑ Topic Introduction ❑ Expert deeper dive ❑ Key deliverables ❑ What is out of scope – What are we NOT looking for ❑ Budget and timeline	30 min
Q&A	❑ Please ask us questions	15 min
Next Steps	❑ In summary – How to submit your proposal ❑ Call for Proposal Process and timeline - Some Terms & Conditions	5 min

The Carbon and Material Challenge

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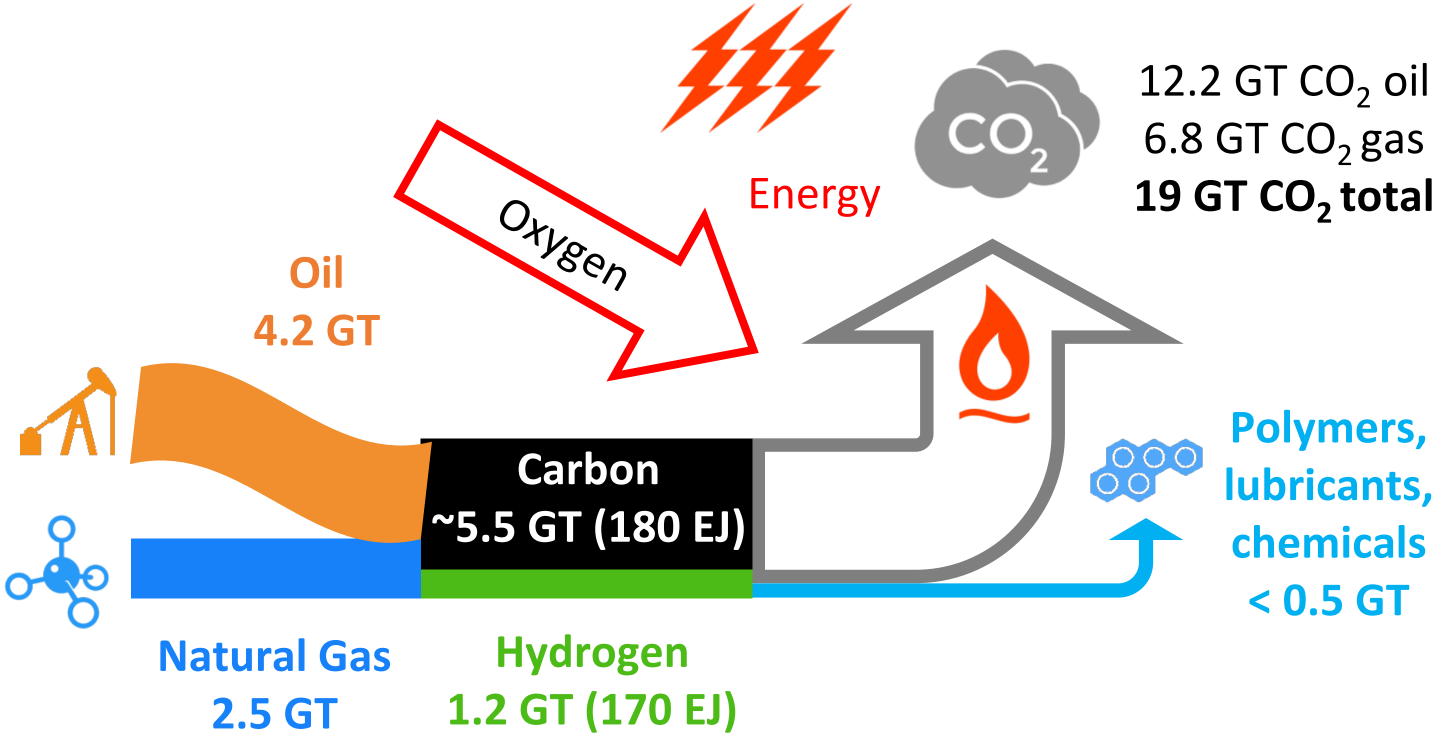
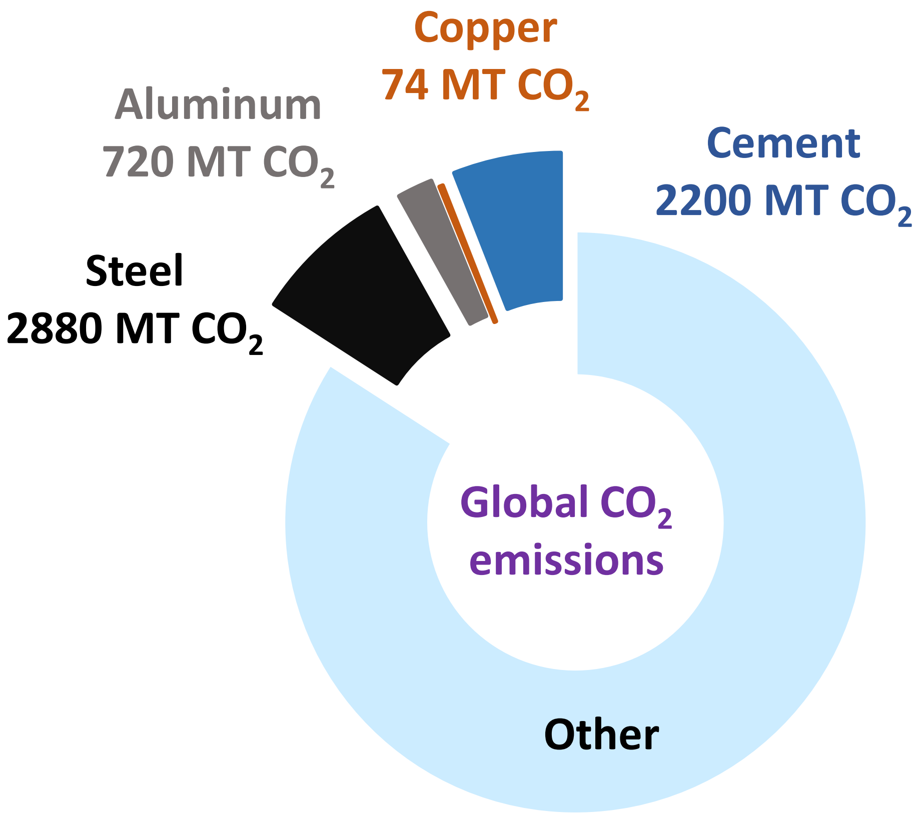
85% of world energy comes from carbon combustion



19 GT CO_2 / yr

“indicative numbers” 2017 data

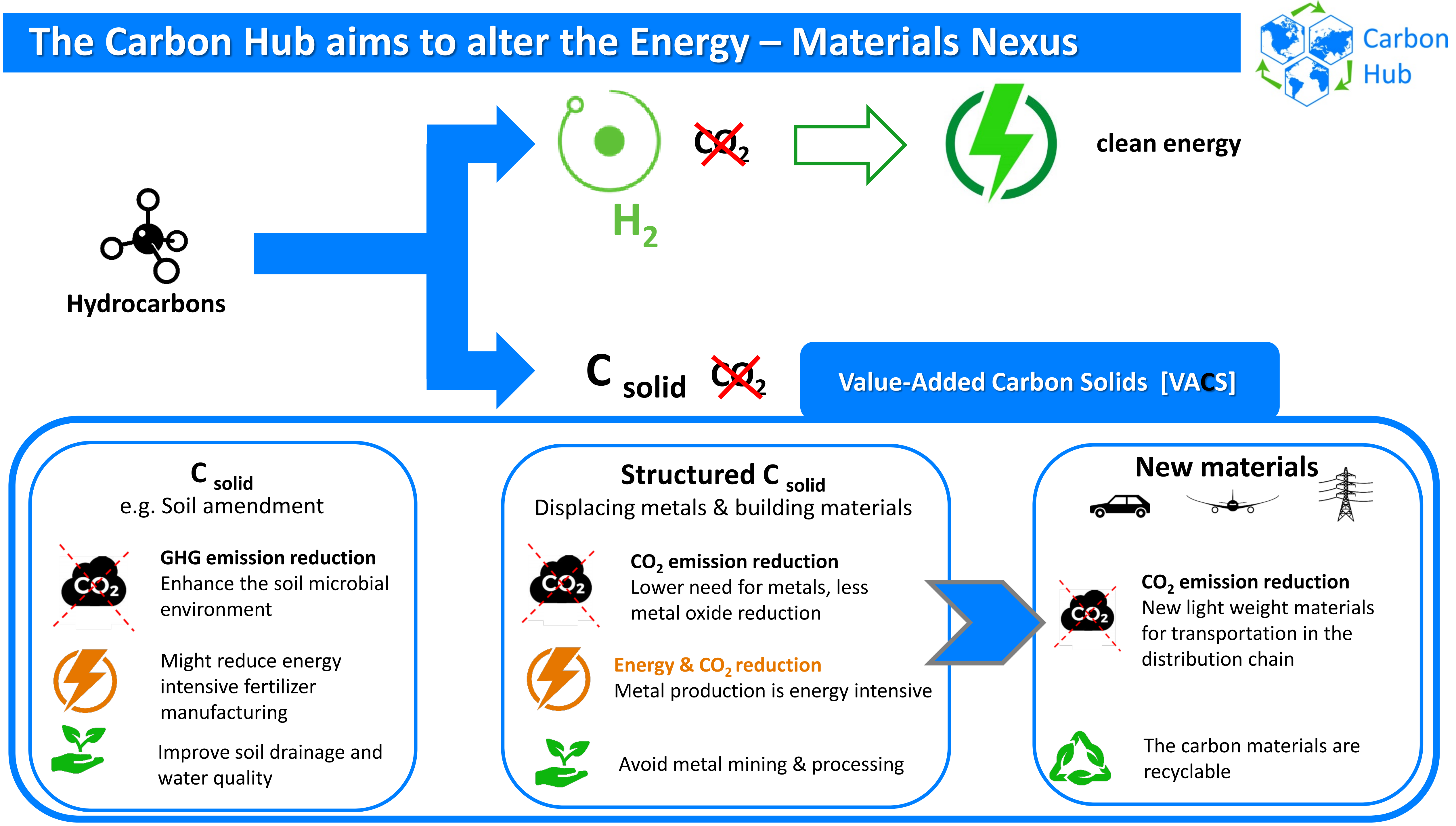
12% of world energy is used for production of steel , aluminum and copper



5.9 GT CO_2 / yr

“indicative numbers”

The Carbon Hub aims to alter the Energy – Materials Nexus



Value-Added Carbon Solids – Our definition

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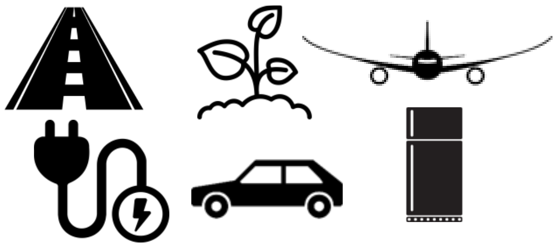
NG Natural Gas Light HC → **C solid** (H_2, ~~CO_2~~) → **Application in end-products**

scale value



VACS

A solid carbon material produced by splitting efficiently (e.g., by pyrolysis) methane and light hydrocarbons with concurrent production of hydrogen and no carbon dioxide emissions.

Being used pervasively (>1 MM Tons/year)

Displacing metals, traditional construction ceramics, fertilizers and other materials with high CO_2 footprints.

excluded

- 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)

included

- Carbon materials that have 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

Examples of Value-Added Carbon Solids – Carbon Nanotubes (CNTs)

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Opportunities

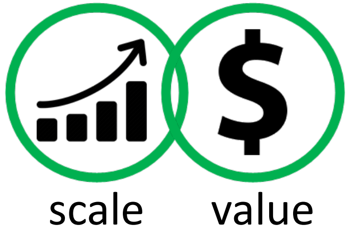
- ❑ CNTs can be synthesized in one process step from methane or light hydrocarbons
- ❑ CNTs can be converted into macroscopic materials;
- ❑ based on properties, a subclass of CNT macro-materials could replace metals or other construction material

Challenges

- ❑ CNT synthesis is still 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 must be developed

VACS

Application in end-products



Examples of Value-Added Carbon Solids – Soil Amendment

Carbon Hub

Opportunities

- forms of carbon (e.g., biochar) may improve the fertility and viability of soils while simultaneously reducing fertilizer usage and the agricultural carbon footprint.

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

VACS

Application in end-products

scale value

The Carbon Hub aims to alter the Energy – Materials Nexus

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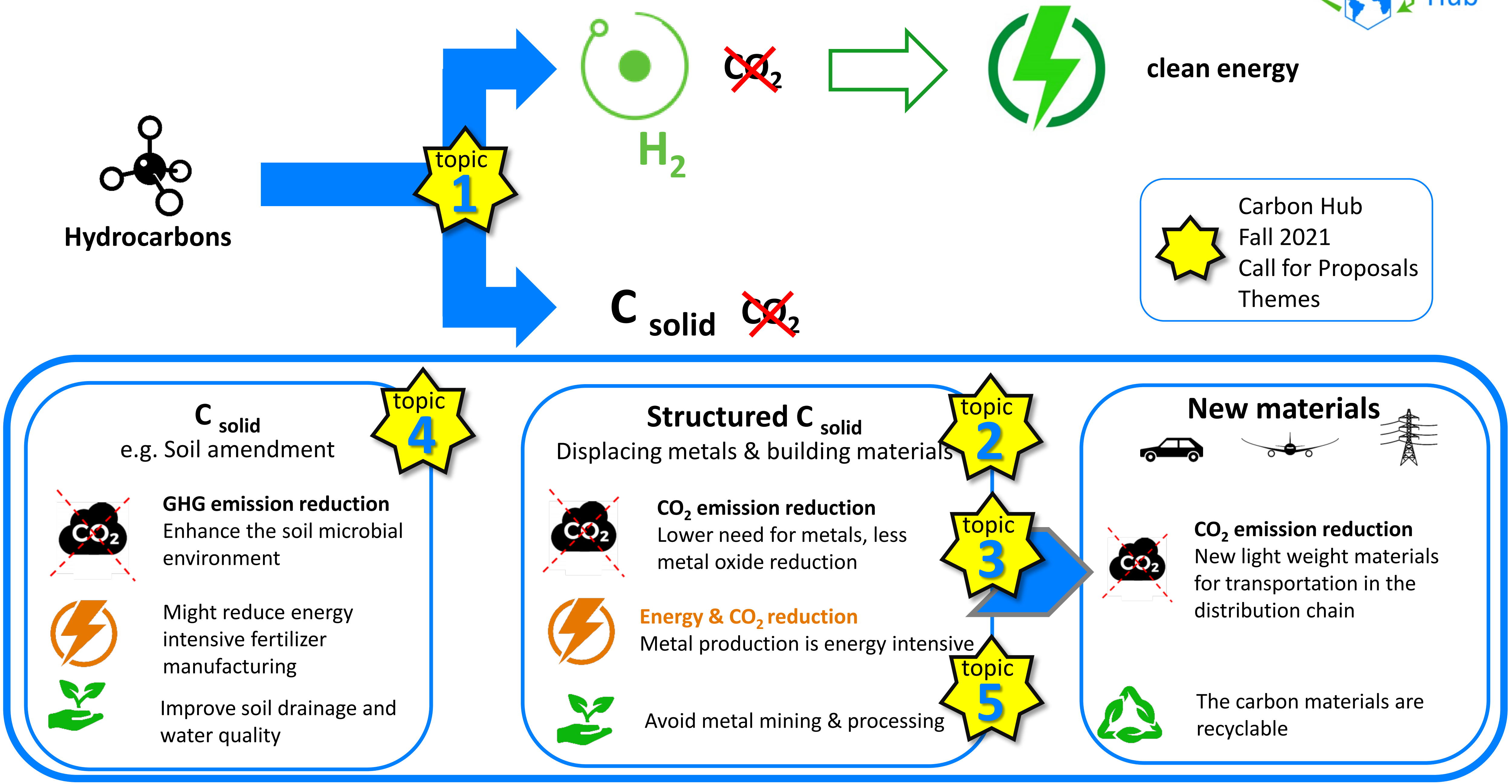

Carbon Hub Webinar - Agenda

Carbon Hub

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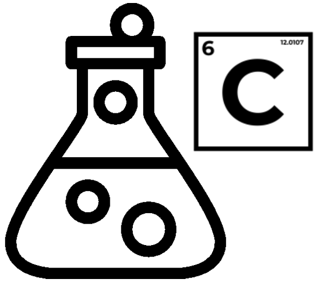
Overview Fall 2021 - Call for Proposal Topics

Carbon Hub

1

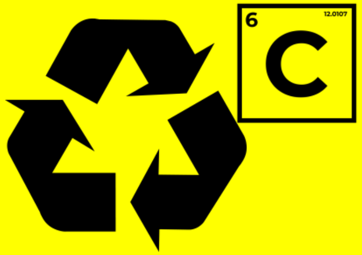
Improve understanding of the catalysis and reaction mechanism in (thermocatalytic) pyrolysis to efficiently convert methane to VACS.



2

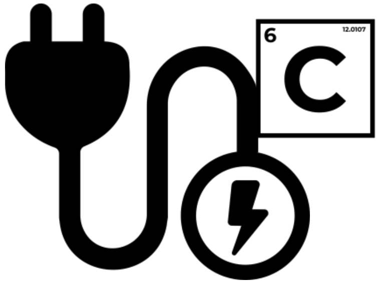
Improve Carbon nanotube [CNT] and VACS standardization and environmental impact understanding.

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



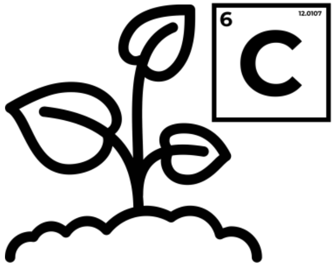
3

Demonstrate the value of a Carbon nanotube [CNT] fiber-based power cable prototype.



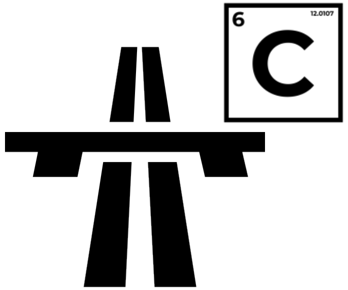
4

Demonstrate and explain efficacy of a VACS as a soil amendment.



5

Demonstrate the value of CNT or other VACS, in structural applications, including non-critical ones.



Key Topic #2 Areas:

Improve CNT and VACS standardization and environmental impact understanding

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

- 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 impact 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

Why LCA-TEA-Standardization for VACS?

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- We have a (small) opportunity to do this at the outset, versus post or FULLY in process of the ecosystem developing

- We can help influence appropriate policies to guide, grow this technology and related business space including proper Governments investment to help Academia/Institutes/Industries focus on the most pressing issues and identify others

- VACS, as a broad advanced carbon materials (nano/micro etc) set have significant potential to transform industries and create new ones – standards will be critical, metrology systems and taxonomy can help accelerate progress
    - The early CNT and graphene days . . . Never sure what you'd get or had
    - Proper studies were difficult to complete/believe/replicate – assigning performance to properties extremely challenging due to products variability, unknown nature, inability to measure key product characteristics
    - Can lead to inaccurate conclusions for Health/Safety/Environment, fitness for use in products/manufacturing

- The Carbon Hub is in a position to help organize this effort to establish industrially relevant standardization efforts and partner with international groups (ANSI, NIOSH, NIST, ISO, IEEE etc) to create frameworks

Example: Commercially Available CNT Product

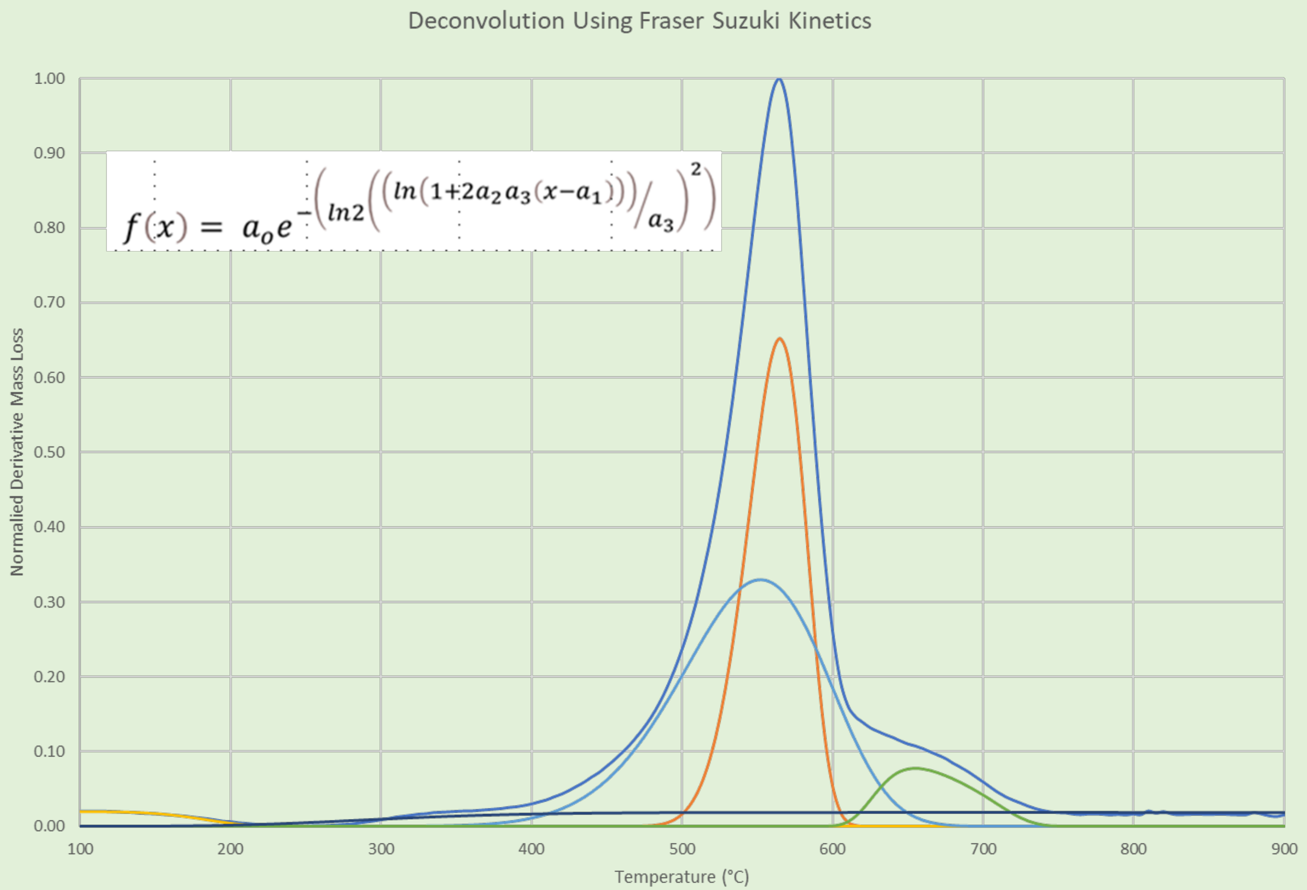
- Ongoing challenges with advanced Carbon nanomaterials and other VACS is product quality, composition

- As a community, we have VERY limited ability to conclusively measure what materials we actually have

- This data shared in last year's webinar was investigated by a team at Rice Univ and found similar impurities/levels – even had non-CNT, non-amorphous carbon . . . . . Naphthalene in the 5 – 10 wt% level

- A Fraser Suzuki kinetics model elucidates the complex composition, which is originally deemed "high purity"

- This underscores the need for improved analytical and materials standardization for CNTs and other VACS materials to be developed

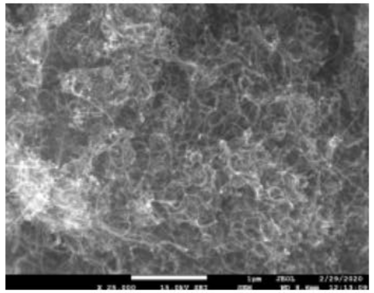


Courtesy Mark Banash, Neotericon

Cnano, SUSN (Cabot) Product Options – Good Enough?

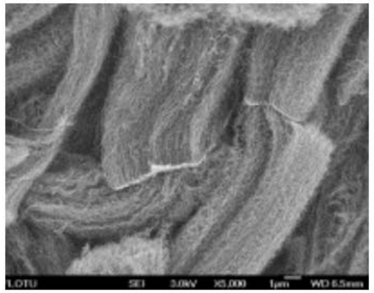
Cnano

Carbon nanotubes powder



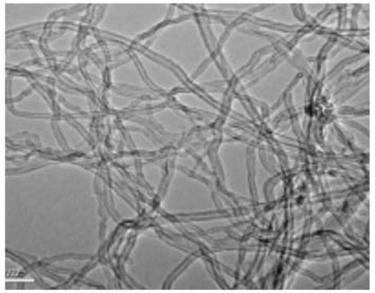
FT9000 series powder

CNT Average Diameter: 10-25nm
Purity: ≥95%, ≥98%, ≥99.9%
Length: 10um
Ash: ≤5%, ≤2%, ≤0.1%
Specific Surface Area (BET) : 110-250m²/g
Tap Density: 0.02-0.35g/cm³
Moisture Content: <1000 ppm



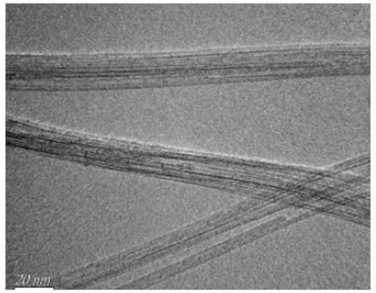
FT7000 series powder

CNT Average Diameter: 7-11nm
Purity: ≥90%, ≥98.5%, ≥99.9%
Length: 5-20um
Ash: ≤10%, ≤2%, ≤1.5%
Specific Surface Area (BET) : 200-300m²/g
Tap Density: 0.01-0.2g/cm³
Moisture Content: <1000 ppm



FT6000 series powder

CNT Average Diameter: 7-11nm
Purity: ≥95%, ≥98%, ≥99.9%
Length: 50-250um
Ash: ≤5%, ≤2%, ≤0.1%
Specific Surface Area (BET) : 250-350m²/g
Tap Density: 0.005-0.25g/cm³
Moisture Content: <1000 ppm



FT2000 series powder

CNT Average Diameter: 2-4nm
Purity: ≥80%
Length: ≥500um
Ash: ≤15%
Specific Surface Area (BET) : ≥450m²/g
Tap Density: ≤0.005g/cm³
Moisture Content: <1000 ppm

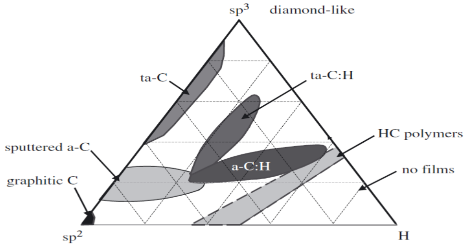


Figure 1. Ternary phase diagram of amorphous carbons. The three corners correspond to diamond, graphite and hydrocarbons, respectively.

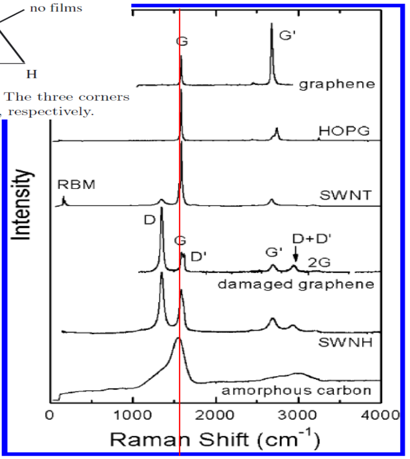
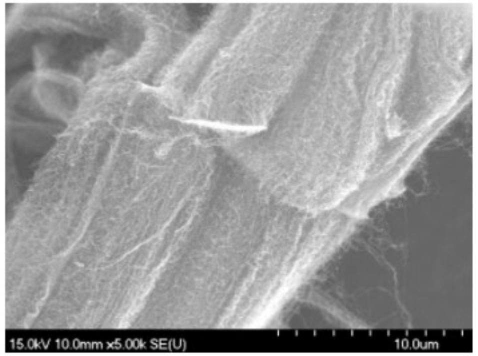


FIGURE 2. Raman spectra from different types of sp² nanocarbons. The graphene-related structures are labeled next to their respective spectra. The main features (RBM and disorder-induced D, D′ and D + D′ bands; first-order Raman-allowed G band; and second-order Raman overtones G′ (2iTO) and 2G) are labeled in some spectra, but the assignment applies to all of them. The detailed analysis of the frequency, line shape, and intensity for these features gives a great deal of information about each respective sp² carbon structure.

- For additives, applications may be able to tolerate a lower quality of material, impurities levels
- For Li-ion Battery tech, it is can absorb a higher cost point and a 10% “hidden” carbon impurity may not be a factor, now
- What is not known, is impacting the final product performance…..



GCNTs5

Ash content: ≤0.8%
Resistivity: ≤1200 μΩ·m
Specific surface area: 230～350 m²/g
Pipe diameter: 5-10 nm
model: GCNTs5

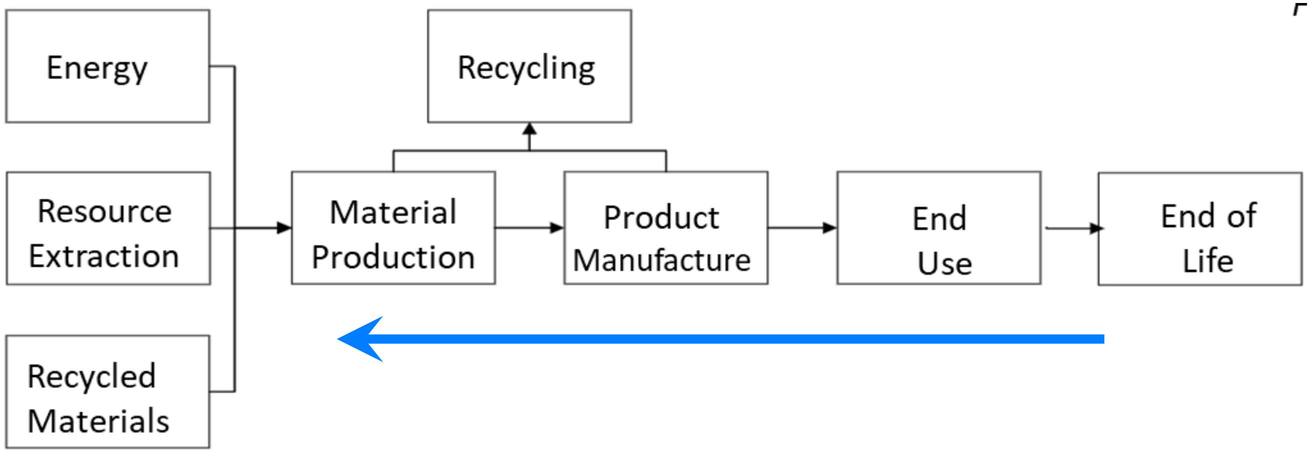
SUSN 三顺纳米

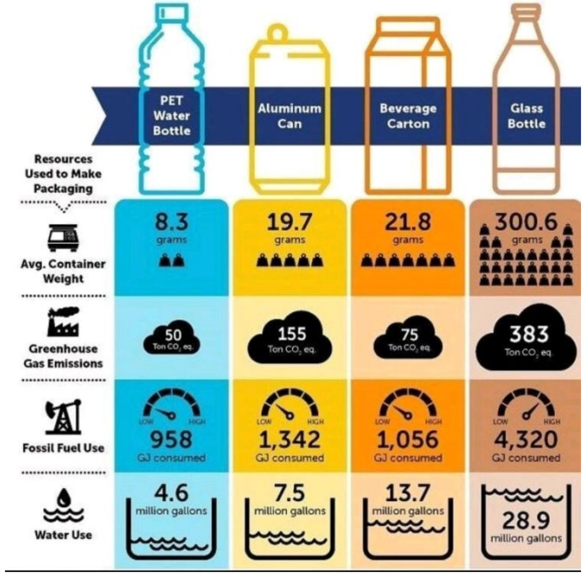
Fig 1 - Phil. Trans. R. Soc. Lond. A (2004) 362, 2477–2512

Carbon Nanomaterials

- High thermal conductivity
- High electrical conductivity
- 6X elongation to failure versus carbon fiber
- Very high tensile strength
- Highly flexible
- Low thermal expansion coefficient
- 50 to 100X cost reduction over last decade
  - Pricing comparable to high-end specialty additives

Comparative LCA-TEA to set efficiency and cost targets





- Normally, this analysis is run forward based on process and material energy, cost, and environmental impact
- Comparative studies often more impactful
  - e.g., which water container has the least CO2/energy/environmental impact?
- VACS properties, cost, and uses are rapidly evolving (Topics 3, 4, 5)
- VACS production processes are becoming more efficient (Topic 1)
- VACS production processes co-produce hydrogen (unique among material production processes)
- Interest in “backward” analyses
  - At what level of properties/efficiencies do VACS achieve attractive LC impact vs. incumbents?
  - At what level of properties/cost do VACS have attractive TCO vs. incumbents?
- Requires significant engagement with teams working on topics 1, 3, 4, and 5 (do not need to be co-PIs and/or receive funding)

Example: Electrical Conductors for Grid Cables

$$\frac{R}{L} = \frac{\Delta V}{IL}$$

$$\frac{R}{L} = r = \frac{1}{\sigma A} = \frac{\rho}{\sigma}\frac{1}{m} = \frac{\rho\gamma}{\sigma}\frac{1}{C} = \frac{\rho e}{\sigma}\frac{1}{E} = \frac{\rho f}{\sigma}\frac{1}{F}$$

R	cable resistance
L	cable length
σ	electrical conductivity
ρ	density
γ	unit cost ($/kg)
e	embodied energy
f	CO_2 footprint of the material
A	cross-sectional area of cable
m	linear mass of cable (kg/m)
C	linear cost of cable ($/m)
E	linear production energy of cable (MJ/m)
F	linear CO_2 footprint of cable (kg CO_2/kg)

- electrical conductivity σ is the right metric if we are limited by area
- specific conductivity (σ/ρ) is the right metric if we are limited by weight
- $\sigma/(\rho\gamma)$ is the right metric if we are cost-limited
- $\sigma/(\rho f)$ is the right metric to minimize CO_2 emissions
- this is just the conductor
  - some conductors may afford advantages in insulation, longer life, etc.
- there are other application-specific considerations (installation, cost, etc)
- mixed metrics are possible
  - assign a price to CO2 and use it to recalculate γ
  - can (and should) use additional climate metrics, e.g., deforestation, loss of habitat, etc.,
- note: there is already significant attention to similar metrics for battery materials
  - different considerations for grid vs. vehicles

Example: target process efficiencies for VACS (CNTC)

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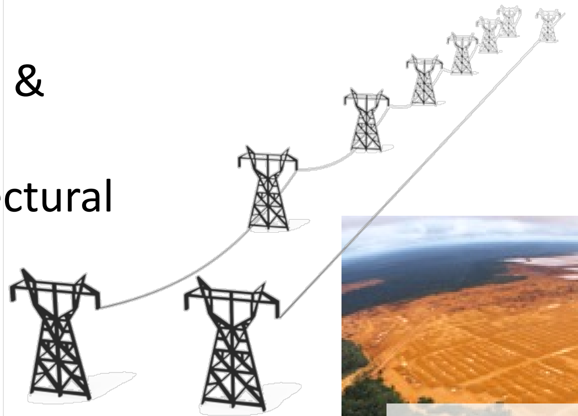
efficiency

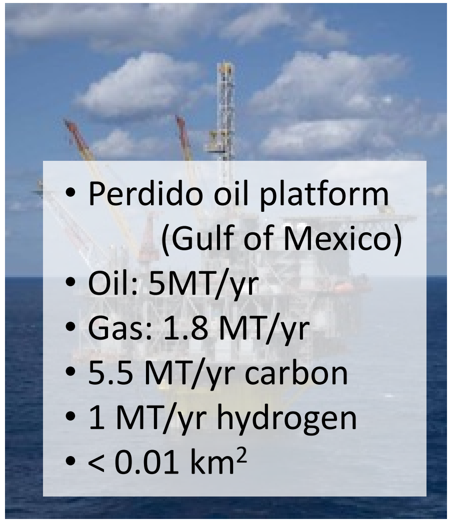
Material	□	□	□	□/□□	□	□	□	□/(□□)	□/(□□)	□/(□□)
	MS/m		kg/m³	kS m²/kg	$/kg	MJ/kg	kg CO_2/kg	S m²/$	S m²/MJ	S m²/kgCO_2
Copper (IACS)	58	10%	9000	6.4	7	59	3.7	921	109	1742
Aluminum	36	55%	2700	13.3	2.5	210	12	5333	63	1111
Silver	62	N/A	10500	5.9	900	1500	100	7	4	59
CNTC 2021	11	1%	1800	6.1		625	33		10	185
CNTC 2025	22	5%	1800	12.2		125	3.9		98	3111
CNTC 2030	44	10%	1800	24.4		63	0.3		391	82130
CNTC 2035	55	20%	1800	30.6		31	-1.5		978	NEG
CNTC 2040	60	25%	1800	33.3		25	-1.9		1333	NEG

- Very simplistic example
- Does not include mining & extractive impacts
- Does not include architectural advantages
  (e.g., spacing of grid towers)
- Yet, provides efficiency and performance goals



Bauxite mining and deforestation in Brazil

- Escondida Cu mine (Chile)
- 1.1 MT/yr production
- Tailing pond: ~ 20 km²
- Main pit: ~6 km²
- Whole site: > 200 km²



- Perdido oil platform (Gulf of Mexico)
- Oil: 5MT/yr
- Gas: 1.8 MT/yr
- 5.5 MT/yr carbon
- 1 MT/yr hydrogen
- < 0.01 km²

Project Examples

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- Nanotaxonomy – Using existing nanostandards as a base and existing manufacturing methods to identify compounds that could be present, create a working nanotaxonomy to parse industrially/commercially relevant nanomaterials, including levels of impurities (e.g., residual metals, non-nanocarbon).

- Property maps – Using current intended applications for CNT/VACS, identify rationalized list of their physical and chemical properties expected to be related to the needed performance of the applications (e.g., surface area, surface chemical groups present).

- Metrology – Based on the nanotaxonomy and the property map, survey the existing analytical methods to identify which methods are relevant and where there are gaps. Propose and test new or modified methods to fill the gaps.

- LCA/TEA - 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 – compare/contrast with an incumbent technology

LET’S TALK – What else?

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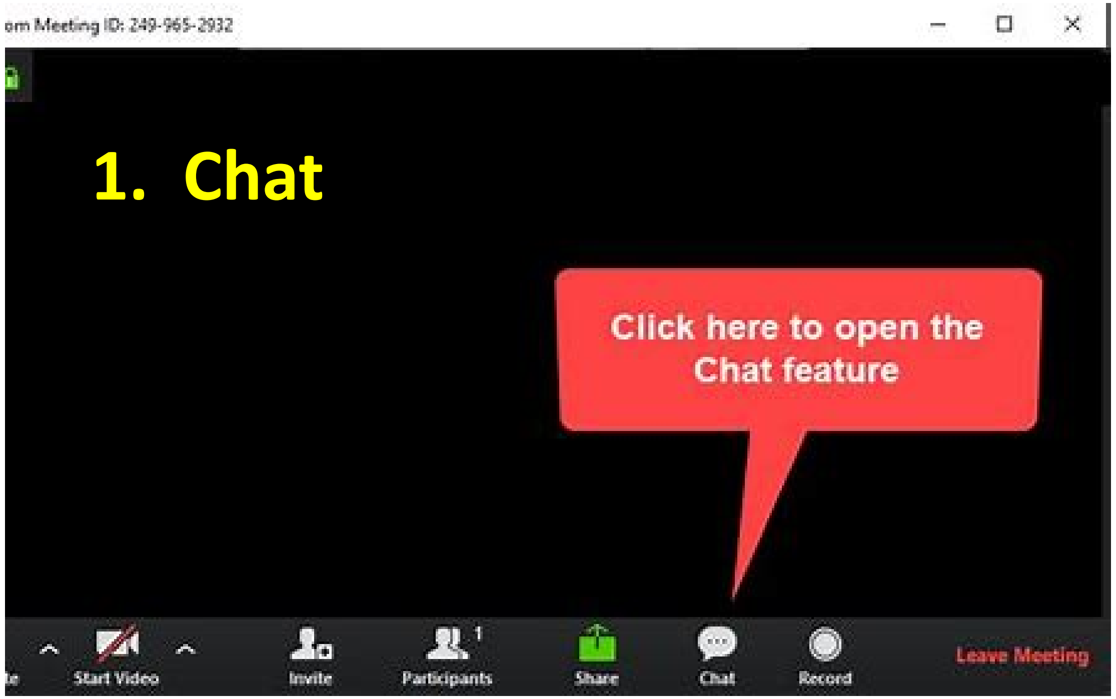
Q&A – Please ask us any questions you might have



1. Chat

2. Raise your hand and we will invite you to speak

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Next Steps – How to submit

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carbonhub.rice.edu/CFPCollaborators

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Accelerating the Energy Transition Through Green Hydrocarbons

Menu

Carbon Hub - Call For Proposals 2021

On this page, you will find the Call for Proposals details that are restricted to our Collaborators only.

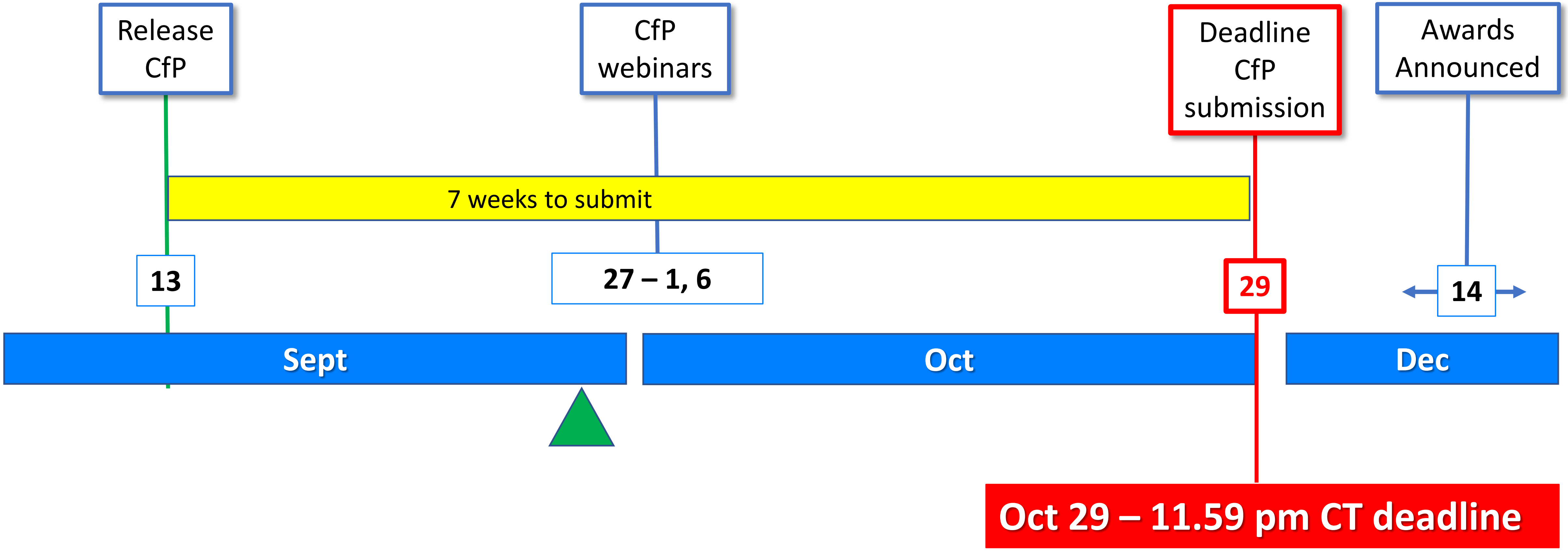
You may download the full Call for Proposals guidelines and instructions document in PDF form here.

**UPDATE: The Budget guidelines are attached here and the referenced spreadsheet can also be found here.

Please note, all Rice Collaborators should contact us directly at carbonhub@rice.edu to obtain the internal Budget template. That template cannot be shared with external Collaborators.

Oct 29 – 11.59 pm CT deadline

Call for Proposal Timeline



A Summary of the aspects we'd like you to address in your proposal (1/2)

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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

A Summary of the aspects we'd like you to address in your proposal (2/2)

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CURRENT PROPOSAL SECTION	SECTION CONTENTS	PAGE LIMITATIONS
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	Breakdown by categories, including any cost share. (budget template will be provided by September 30, 2020)	1
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

Some of the Terms & Conditions

- ❑ **The primary Principal Investigator (PI) must be a Carbon Hub Academic Collaborator** (https://carbonhub.rice.edu/collaborators) to be eligible to submit a proposal
- ❑ If you are not currently a Collaborator, please inquire at **carbonhub@rice.edu**

- ❑ **Fall 2021 : $1.5+ million budgeted for new and continuing awards**
- ❑ Anticipates granting 4 - 7 awards across the 5 Topic areas
- ❑ **Individual awards may vary between $50,000 and $250,000**
- ❑ For PIs who are not at Rice University, funding will start upon successful negotiation of a subcontract between Rice University and their home institution
- ❑ Funding agreements are expected to launch in Feb 2022, or once negotiations are complete

Results can be published – THEY ARE NOT CONFIDENTIAL
Results will be shared with Carbon Hub members

Further details on the Carbon Hub website and in the Call for Proposal documents

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