High-Throughput Methane Pyrolysis for Low-Cost, Emissions-Free Hydrogen

Dr. Brad Rupp, PARC

Cabot, Modular Chemical, Susteon, and Stony Brook University

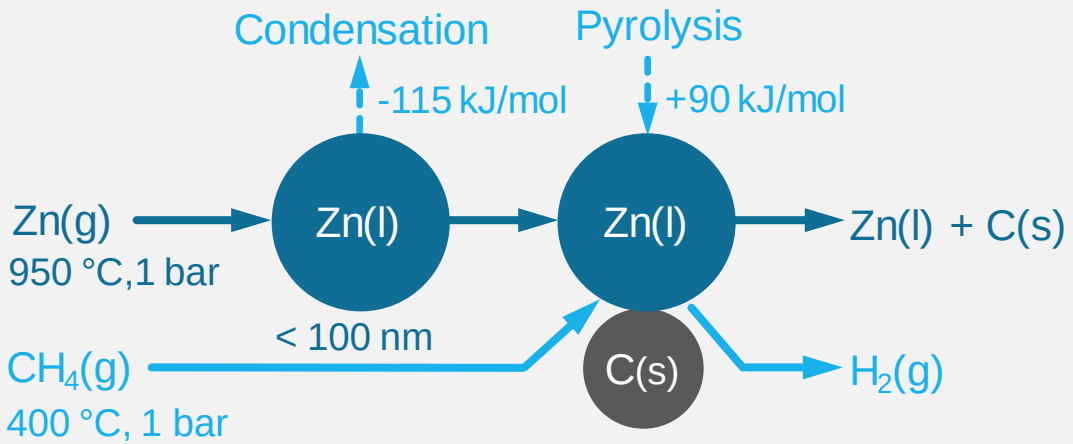
Project Vision

We aim to deliver low-cost, emission-free hydrogen using a novel condensing liquid metal catalyzed methane pyrolysis reactor that enables modest operating temperatures, high space velocities, and low capital costs

Total project cost:	$4.2M
Length	42 mo

The Concept and Project Objective

The Concept



Benefits

- High catalytic activity via high surface area
- Integration of vaporization and reaction heats
- Moderate reactor temperatures and pressures
- Simple, safe, and effective carbon-metal separation

The Objective

Final Project Prototype

- Bench-scale process producing 1 kg/d H_2
- Reactor space velocity > 1000 h^{-1}
- Single pass methane conversion > 90%
- Reactor temperature < 1000 °C
- Carbon separation efficiency > 99.99 wt% C
- Carbon market value > 100 $/tonne
- Plant (1000 kg/d H_2) economics < 3.0 $/kg H_2

The Team

parc
A Xerox Company

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Carbon Separation

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Project Advisor

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Project Advisor

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Process Modeling

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Process Dev

CABOT

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Carbon & Modeling

Toivo Kodas
Carbon Markets

modular CHEMICAL

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Tech Dev & T2M

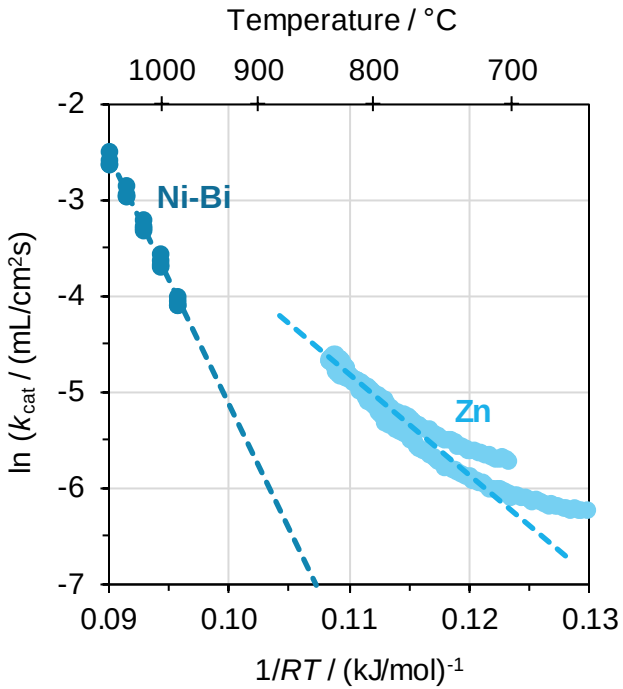
Stony Brook University

Matt Eisaman
Carbon & TEA

Key Results and Updates

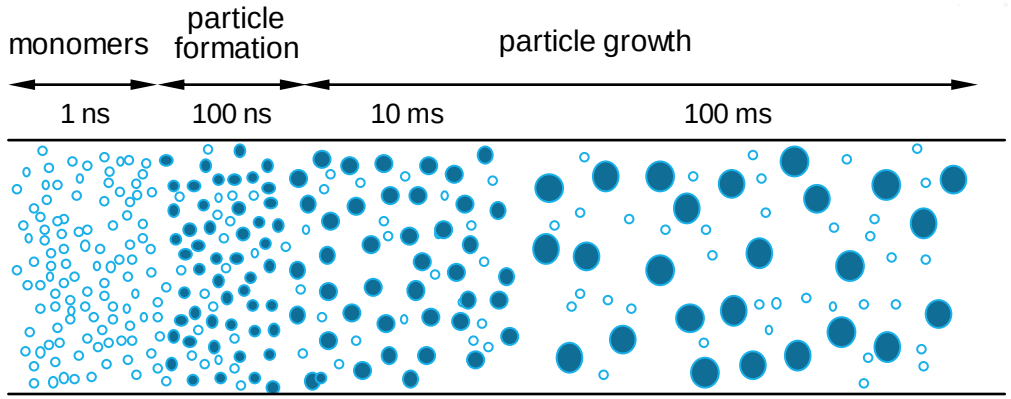
Catalyst Activity Measurement

Catalytic Activity Measurement Setup



- Catalytic activity of liquid Zn and Ni-Bi measured
- Ni-Bi results in good agreement with Upham (2017)
- Zinc catalytic activity, k_{cat}= 0.052exp(-58,000/*RT*)

Particle Growth & Reactor Modeling



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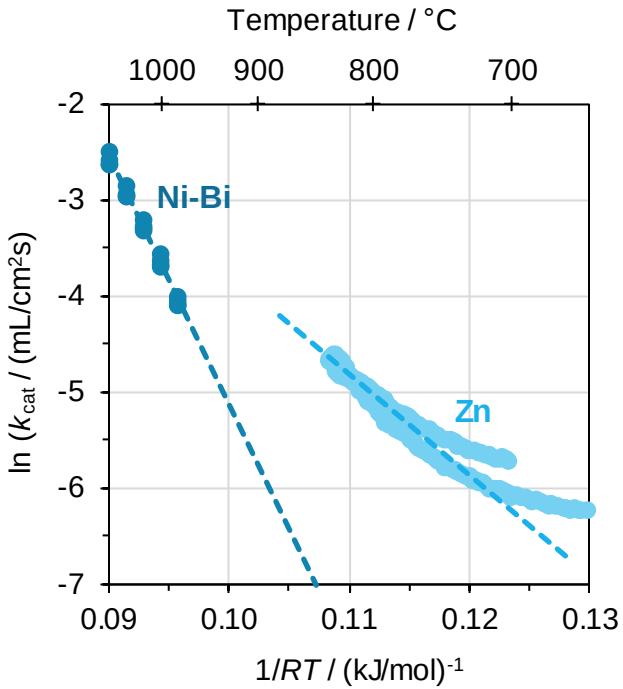

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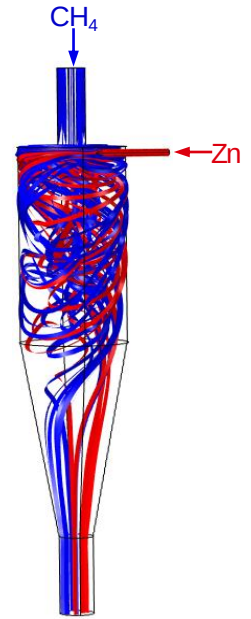
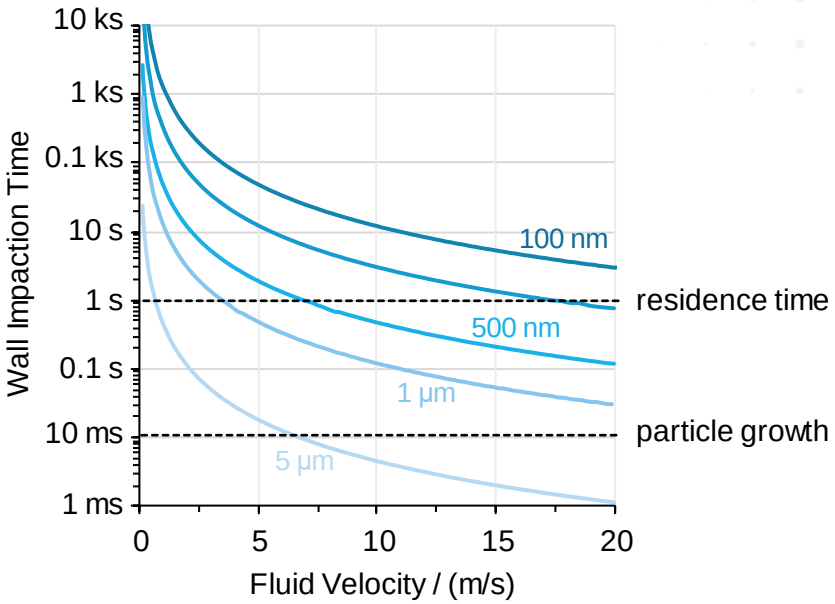


Hot Wall Cyclone Reactor

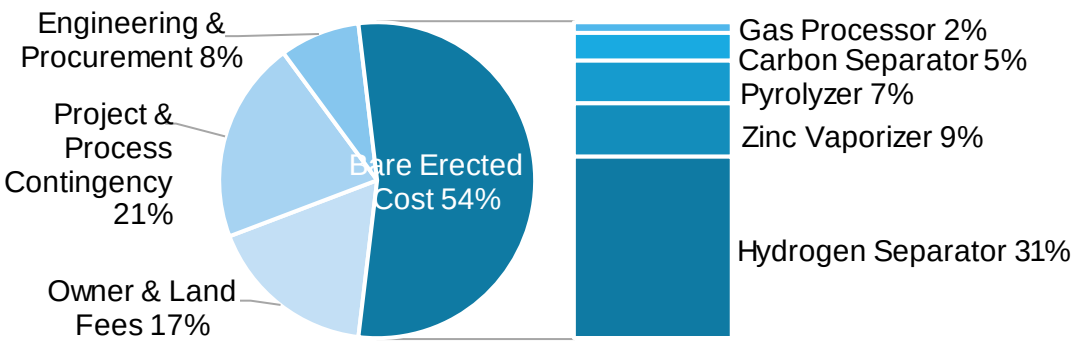


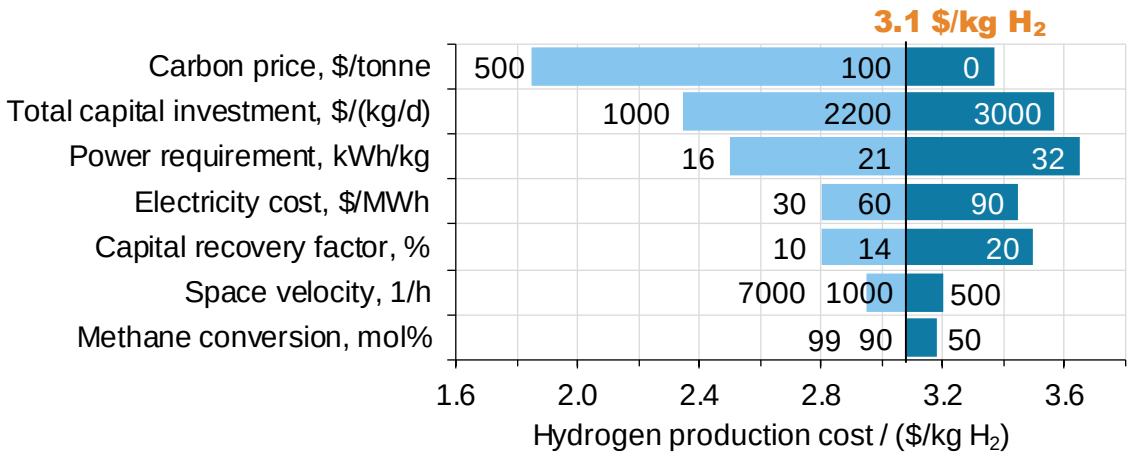
- Particles must stay < 100 nm for 1 s residence time
- Hot wall cyclone concept impaction times too long
- Proprietary new reactor design – promising solution

Key Results and Updates

Pure Hydrogen Plant Economics

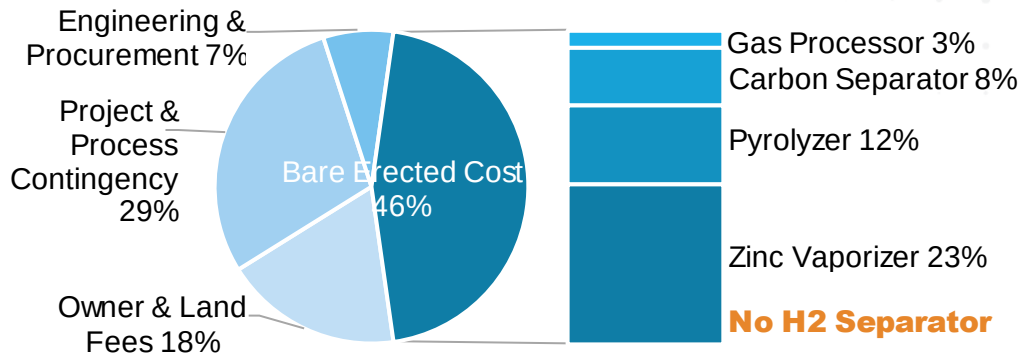
Total Capital Investment: $3.3M, Basis: 1500 kg/d H_2 **(99.999% H_2)**

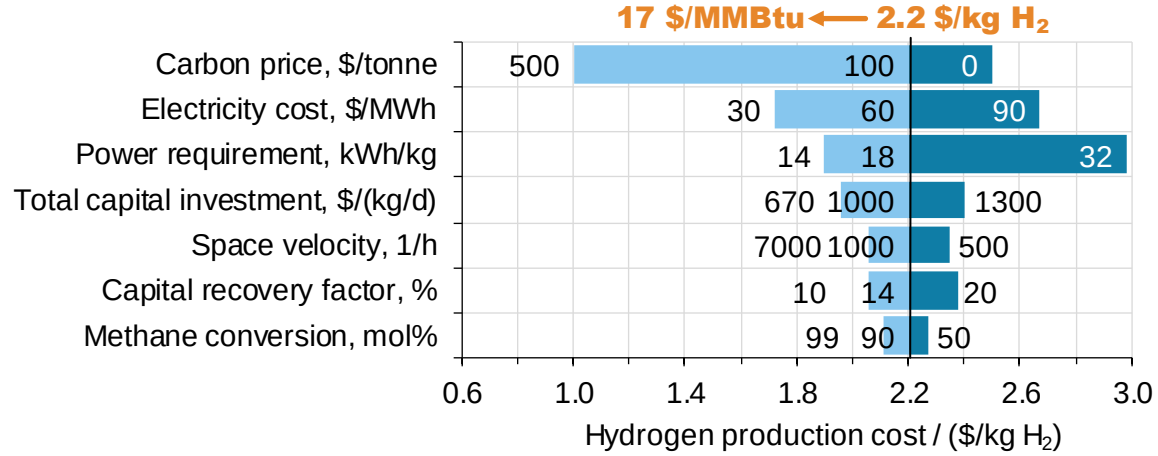




Crude Hydrogen Plant Economics

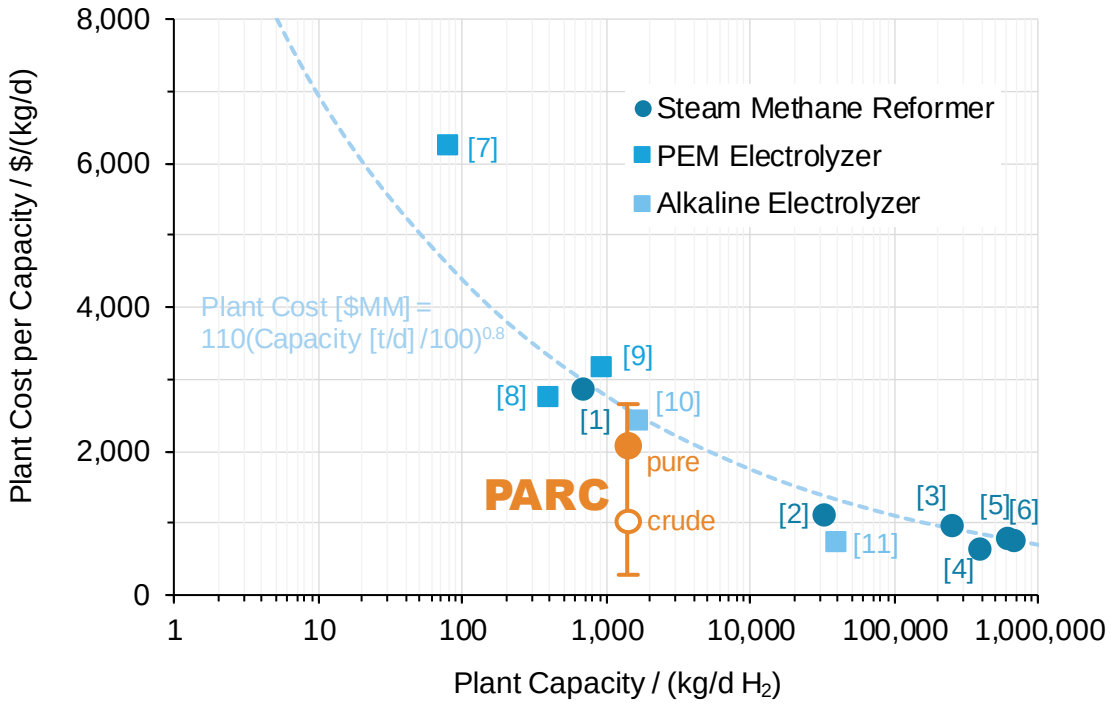
Total Capital Investment: $1.5M, Basis: 1500 kg/d H_2 **(94% H2)**





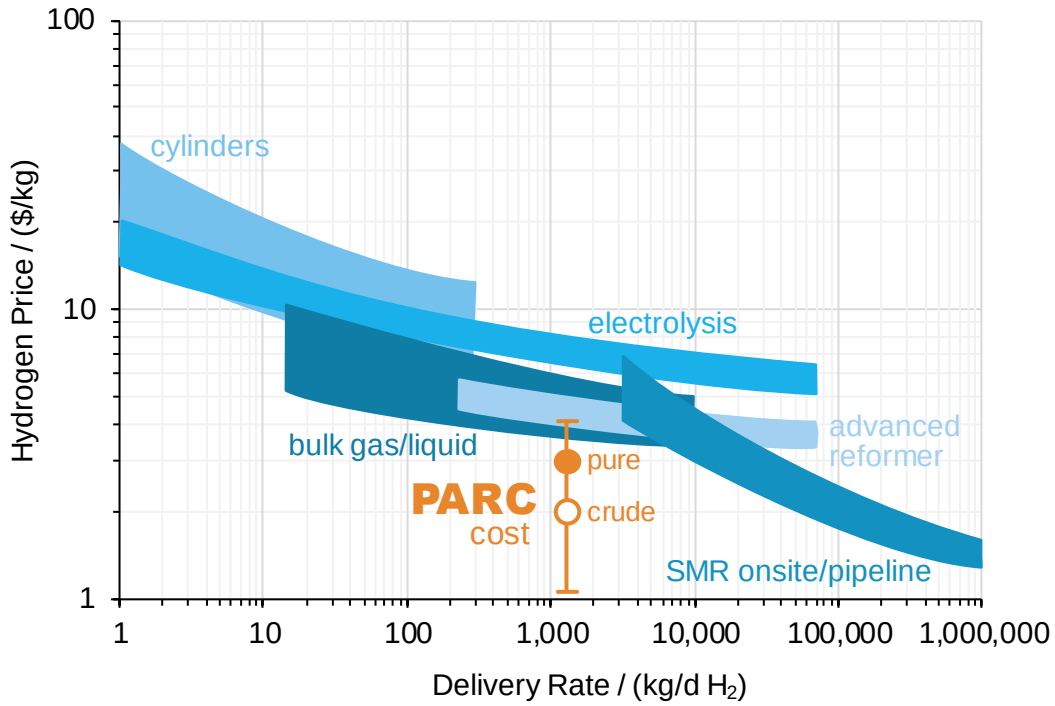
Key Results and Updates

Hydrogen Plant Cost versus Scale



Sources: [1] Linde, 2020 - private communications; [2] Linde, 2014 - www.leamericas.com/en/news_and_media/press_releases/linde_and_nynas.html ; [3] Air Liquide, 2008 - www.greencarcongress.com/2008/06/air-liquide-add.html ; [4] Linde, 2019 - www.opportunitylouisiana.com/led-news/news-releases/news/2019/04/02/linde-announces-construction-of-new-$250-million-world-scale-hydrogen-plant-in-st.-james-parish ; [5] Air Products, 2020 - www.airproducts.com/company/news-center/2020/01/0108-air-products-to-build-its-largest-smr-to-supply-gulf-coast-ammonia ; [6] Air Products, 2020 - chemweek.com/CW/Document/110146/Air-Products-to-acquire-five-hydrogen-plants-from-refiner-PBF-for-%24530-million ; [7,8] NREL, 2019 - www.nrel.gov/docs/fy19osti/72740.pdf ; [9] NEL, 2019 - www.greencarcongress.com/2019/02/20190226-nel.html [10] NEL, 2019 - www.greencarcongress.com/2019/08/20190831-nel.html; [11] NEL, 2020 - deepresource.wordpress.com/2020/06/05/nel-hydrogen-announces-350-kw-electrolyser/

Hydrogen Price versus Scale



Source:: Adapted from Esprit Associates, Global Hydrogen, August 2014.

Challenges and Partnerships

What have been the biggest challenges?

- Progressing experimental work in face of COVID-19 uncertainty (8 months of shutdowns to date)
- Developing a reactor design that limits droplet coagulation
- Demonstrating compelling economics without carbon valorization

How have we reduced project risk?

- Demonstrated that liquid zinc has catalytic activity for methane pyrolysis
- Developed proprietary reactor design that should limit droplet coagulation
- Created economic model that estimates a 3.1 $/kg pure and 2.2 $/kg crude H_2 production cost at 1500 kg/d

What partnerships or collaborations do we seek?

- None at this time

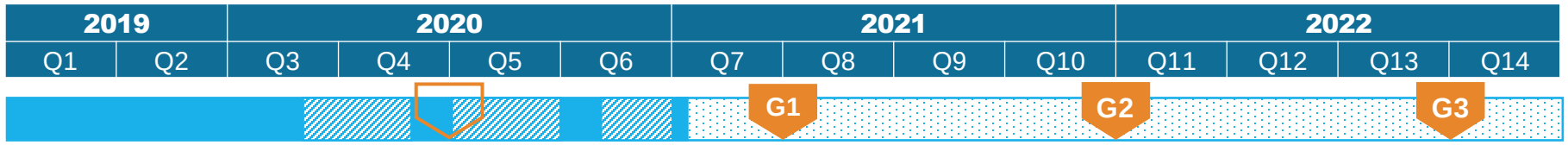
T2M

What is our final goal?

- Demonstrate bench-scale process with 2-year payback potential
- Technoeconomics suggest the need for a high-value market for carbon (graphite?)

Where are we now?

- G1: Proof of Concept—catalyst & carbon separate validation (delayed due to COVID-19)
- G2: Feasibility—bench reactor demo, carbon characterization, biz case
- G3: Preliminary Design—integrated bench process, pilot-scale design



What do we need?

- Help identifying graphite market product requirements and supply chain
- Connections to oil refineries to gauge interest in CO_2-free H_2 + graphite process

Advisory Board

Raghubir Gupta
Co-founder & President
Susteon Inc.

Greg Flemming
Investment Director
Air Liquide Ventures

Ron Kent
Adv Tech Dev Manager
Sempra Utilities

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Imperative Science Ventures

Toivo Kodas
Executive Director
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THANK YOU!

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