Extremely Durable Concrete using Methane Decarbonization Nanofiber Co-products with Hydrogen

Advanced Conversion of Fossil/Waste Streams

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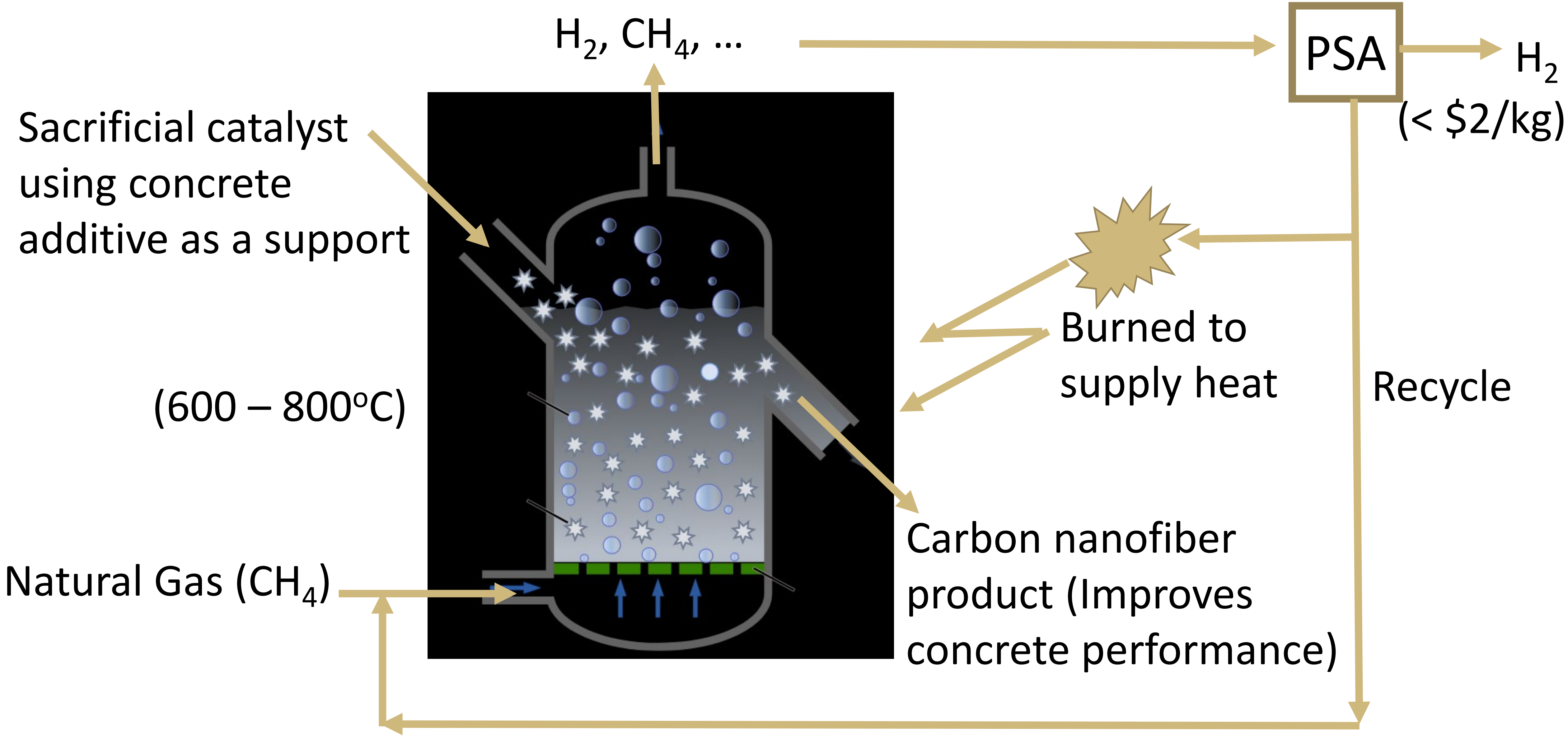
Additional Team Members:
- Civil Engineering (CU Boulder)
- Forge Nano (Thornton, CO)
- National Ready Mixed Concrete Assn. (Alexandria, VA)

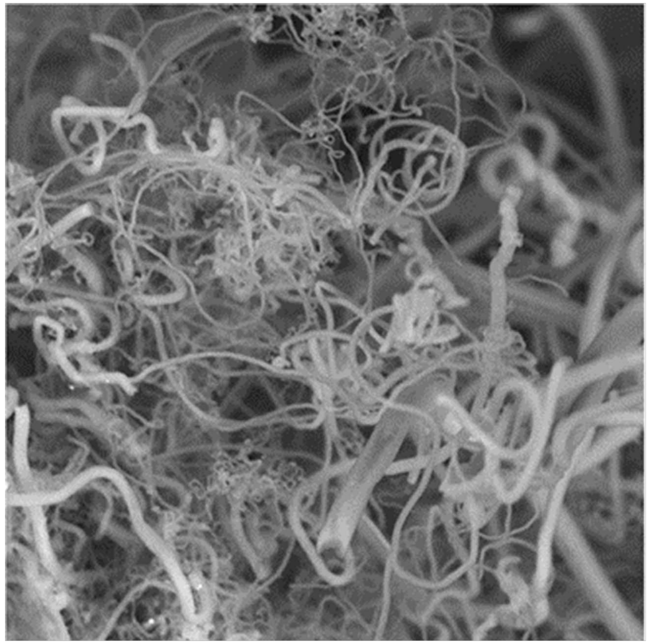
Chemical Vapor Deposition Process



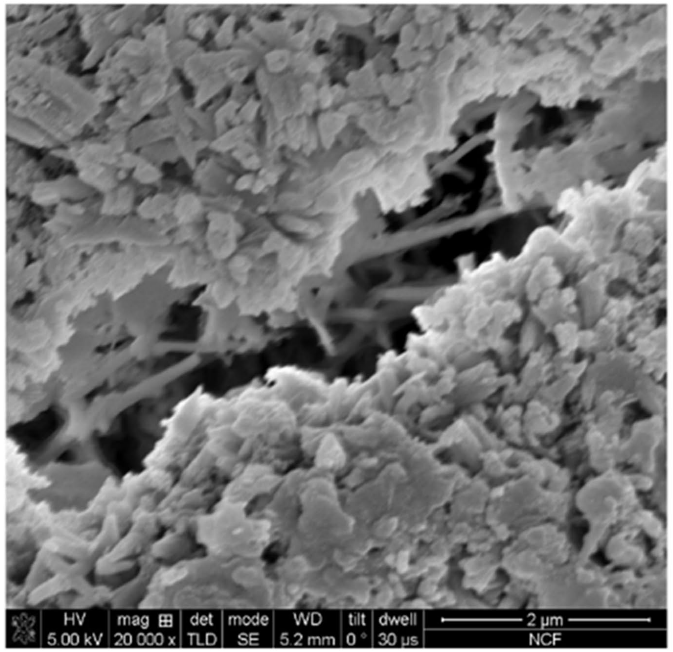
T2M and Technology Impact

T2M: 1) US Market for Ready Mixed Concrete ~ 275M m^3/yr; 2) 7.8M mt CNF/yr (3 wt% loading); 3) 2.6M mt H_2/yr

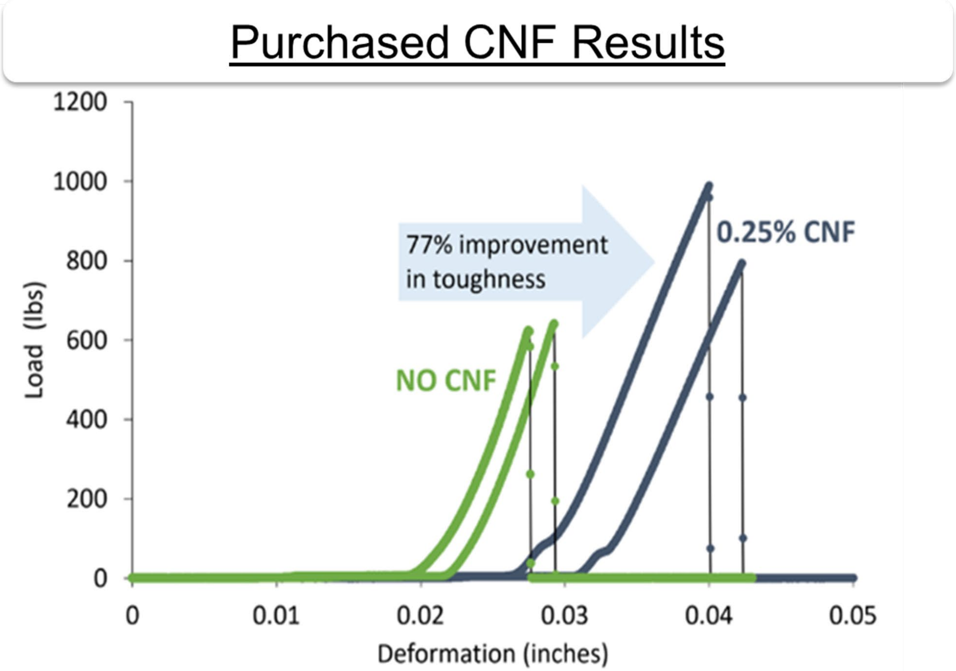
Impact: 1) Improved concrete – reduced cracking, improved lifetime; 2) can replace up to 25% of the U.S. H_2 production



CNF SEM



University of Colorado (unpublished)
SEM image showing CSH bridging mechanism of CNFs



University of Colorado (unpublished)
Improved mechanical properties with addition of CNF

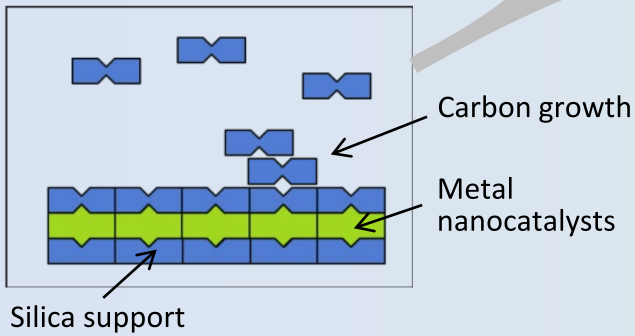
Research Plan

1 Methane Decarbonization Nanofiber Co-production

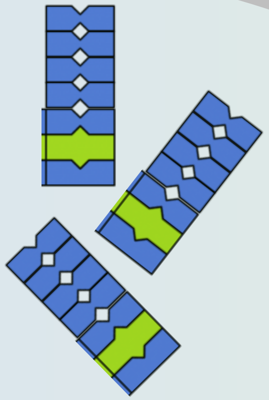
H_2

2 Carbon Nanofiber Co-product Cement Design

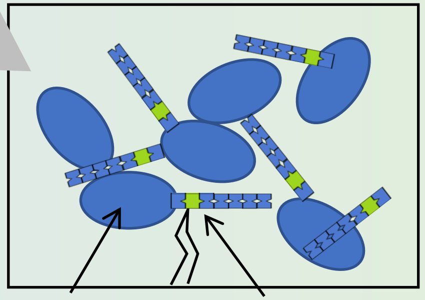
Low cost ALD



Addresses uncontrolled carbon deposition during H_2 production from methane.



Carbon Nanofibers



Addresses need for extremely durable concrete.

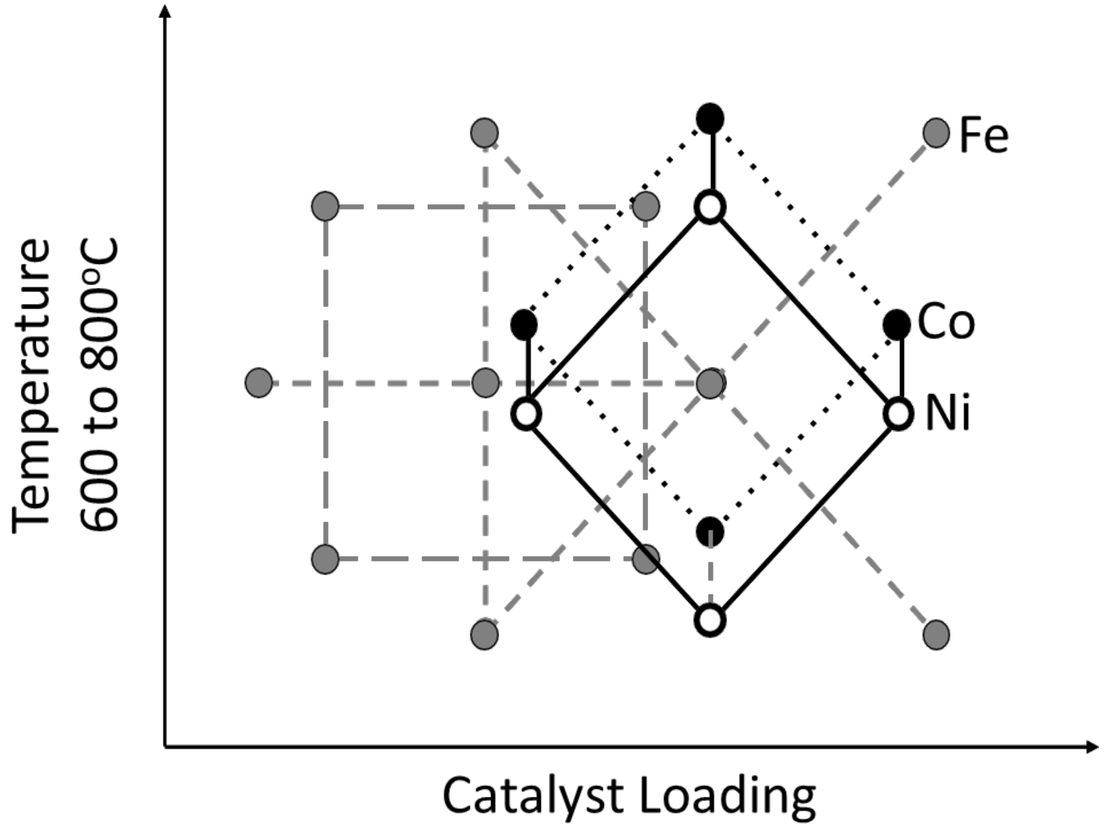
3 Hydrogen and Concrete Market Transformation

- Target co-production scaling challenges & cement utilization scaling

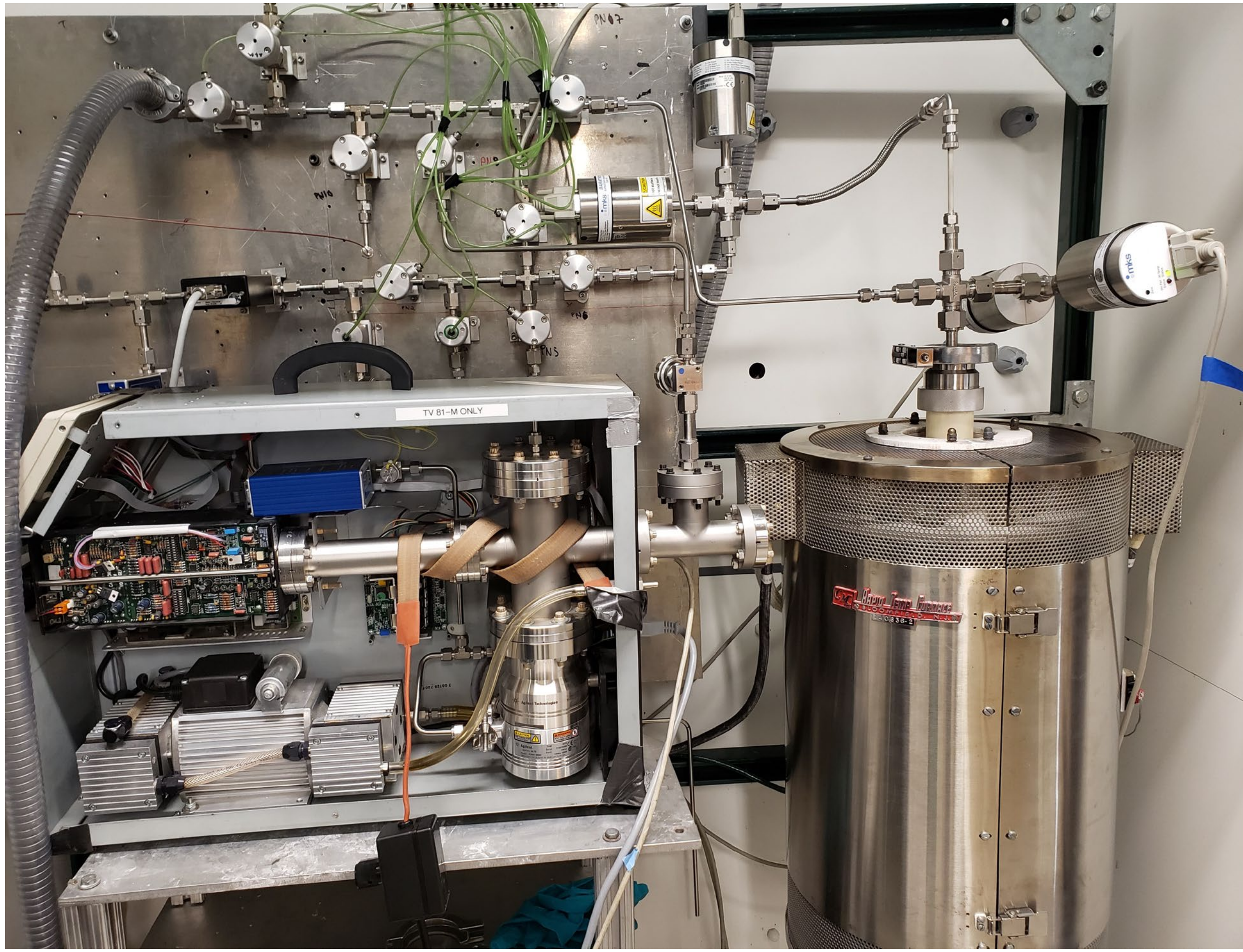
- H2A analysis
- Join ACI nanotechnology committee
- Obtain industry standard cements to build on

- Review technical developments annually with Forge Nano and NMRCA consultants

Research Reactor System Operational

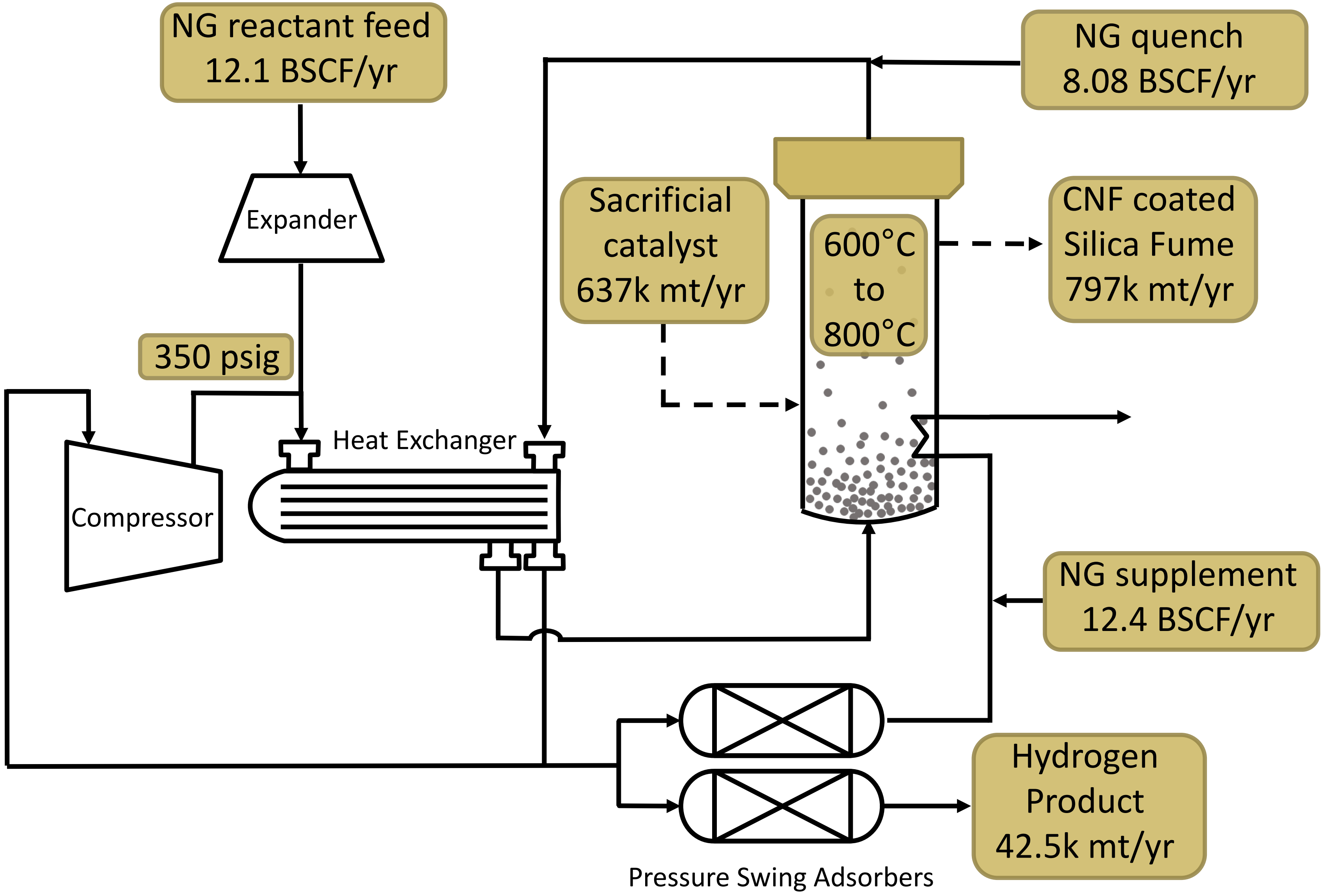


- Reaction kinetics
- Carbon growth kinetics, …



CVD Reactor System

Preliminary Technoeconomic Analysis



Parameters

Hydrogen cost: $2.00/kg
NG cost: $3.00/KSCF
IRR: 10%
Lifetime: 15 years
Estimated TIC: $2B-4B
Cost of Capital: 8.5%

Results

CNF coated silica, price range:
$2.00 - $4.00 per kg
Pure CNF, price range:
$10.00 - $20.00 per kg
Pure CNF, current technology:
$286.60 per kg[1]

Acknowledgements

- Weimer Research Group – Department of Chemical & Biological Engineering
- Hubler Research Group – Department of Civil, Environmental, and Architectural Engineering
- Andy Broerman – Forge Nano
- Colin Lobo – National Ready Mixed Concrete Association

University of Colorado
Boulder

Hydrogen Energy Earthshot Summit

Advanced Conversion of Fossil/Waste-Streams

Eric McFarland

Hydrogen Energy is, has been, always will be, all about low-cost production of Hydrogen !

Chemical production converts feedstocks to products in a process.

The Only Hydrogen Feedstocks

- Fossil hydrocarbons (~ \$0.6-1.2/kg H_2)
- Biomass (~ \$0.5-2.5/kg H_2)
- Water (~ \$0/kg H_2)

Process Capital (\$0.1/kg H_2 /\$1M/kta) →

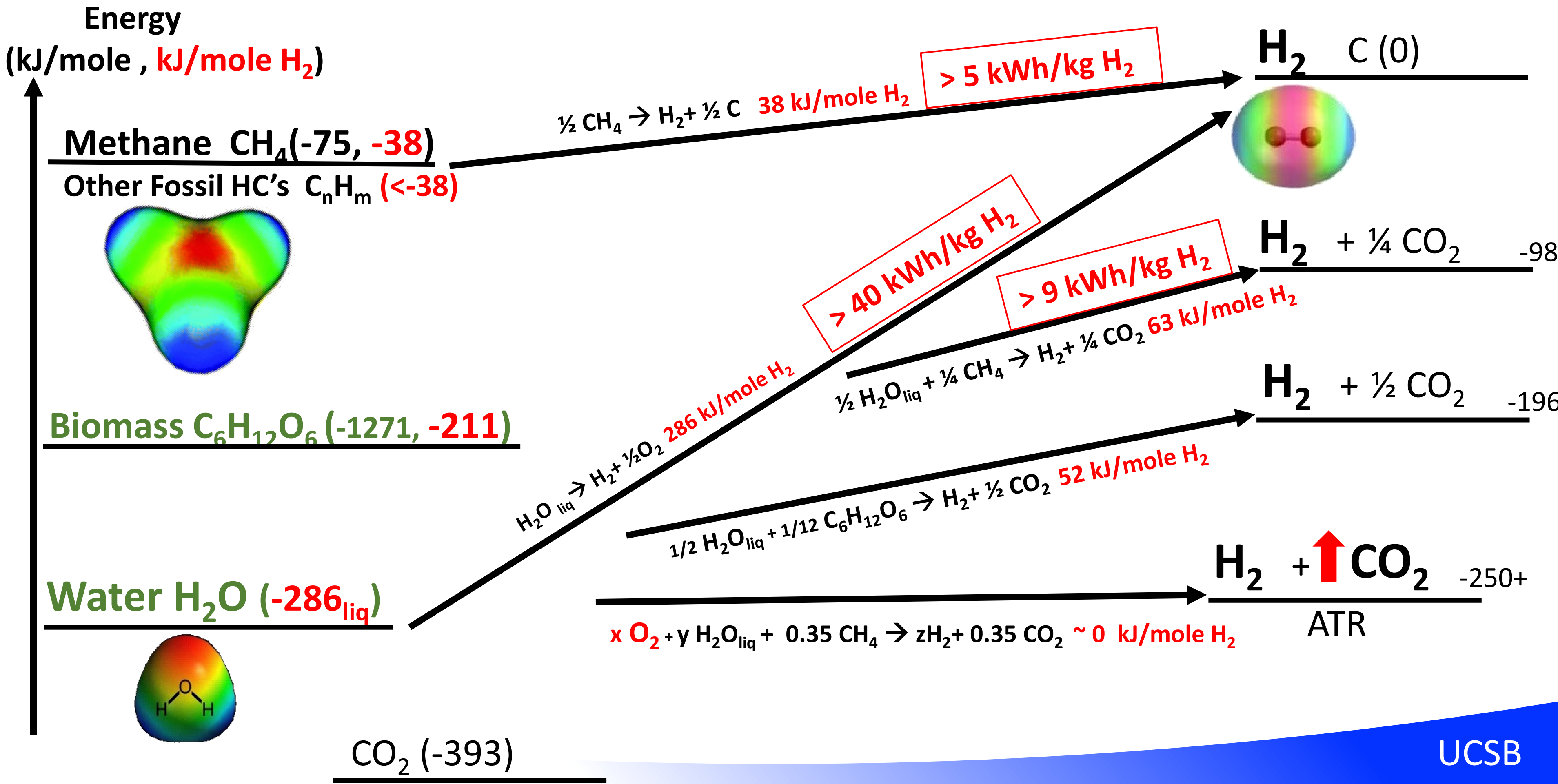
Energy (\$3-15/GJ = \$0.01- \$0.05/kWh)

Products

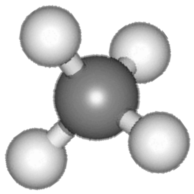
- H_2
- O_2
- C
- CO_2 (~ \$0 - 0.2/kg)

The lowest cost source of, CO_2-free, H_2 can be from methane

Nature has already determined the possible feedstocks and thermodynamics for H_2



Prediction: Methane will be the Most Important Molecule for the Next Century



The US consumes ~ 30 Tcf per year of natural gas
The US has over 2500 Tcf of technically recoverable natural gas reserves with ~ 500 Tcf of proven reserves.

Fugitive emissions from natural gas production can and must be reduced to less than 0.5% of production. Tax It!

Methane leverages Nature's no-cost processing,

CH_4 is the Lowest Cost Source of H_2

UCSB

Today, H_2 is produced at low-cost by reforming of fossil hydrocarbons

$$\text{Feedstocks } (\text{-CH}_n + H_2O) \xrightarrow[\text{Energy}]{\text{Process}} \text{Products } (H_2) + \text{Byproducts } (CO_2)$$

$$COP\left(\frac{\$}{kg}\right) = \text{Fixed Costs}\left(Cap\left(\frac{\$}{kg}\right)\right) + \text{Variable Feed Costs}\left(VFC\left(\frac{\$}{kg}\right)\right) + \text{Variable Energy Costs}\left(VEC\left(\frac{\$}{kg}\right)\right) + \text{Variable Byproduct Costs}\left(VBC\left(\frac{\$}{kg}\right)\right)$$

From public domain contracts and information we know a great deal about SMR

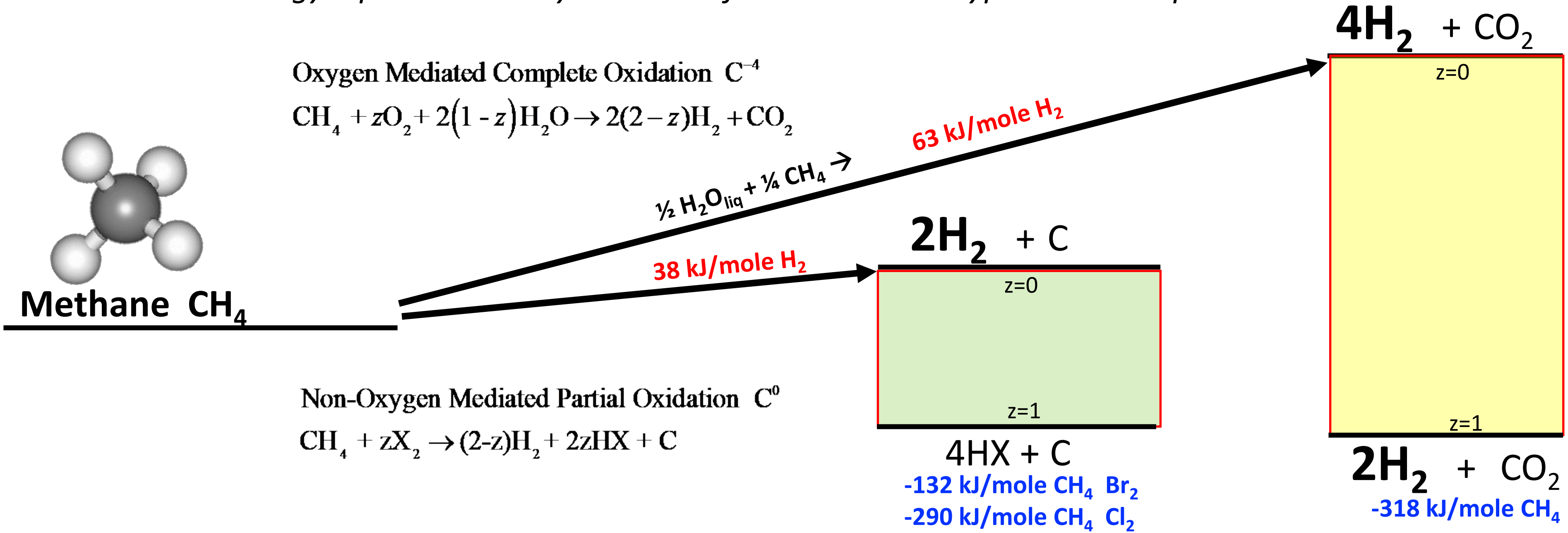
$$COP\left(\frac{\$}{kg\ H_2}\right)_{SMR} \approx 0.11\left(\frac{\$}{kg}\right)_{\$1M/kta} + 0.33\left(\frac{\$}{kg}\right)_{\$0.15/kg} + 0.23\left(\frac{\$}{kg}\right)_{\$3/GJ,noCO_2} + 0/0.55\left(\frac{\$}{kg}\right)_{\$0-0.1/kgCO_2} \approx 0.7\left(\frac{\$}{kg}\right) / +0.5\left(\frac{\$}{kg}\right)_{100/ton}$$

Without a significant price on CO_2 it is unlikely any process can beat SMR/ATR where half the hydrogen comes from low-cost water and most of the energy is from low-cost methane.

Decomposition processes for methane and other hydrocarbons may compete with SMR/ATR + CCS when the costs of CO_2 emissions exceed the cost of the additional feed and processing required for the same hydrogen production.

Advanced Conversion Processes for CO_2-free H_2 from Fossil Resources

energy input reduced by addition of z oxidants but byproducts are produced



Earthshot Challenges

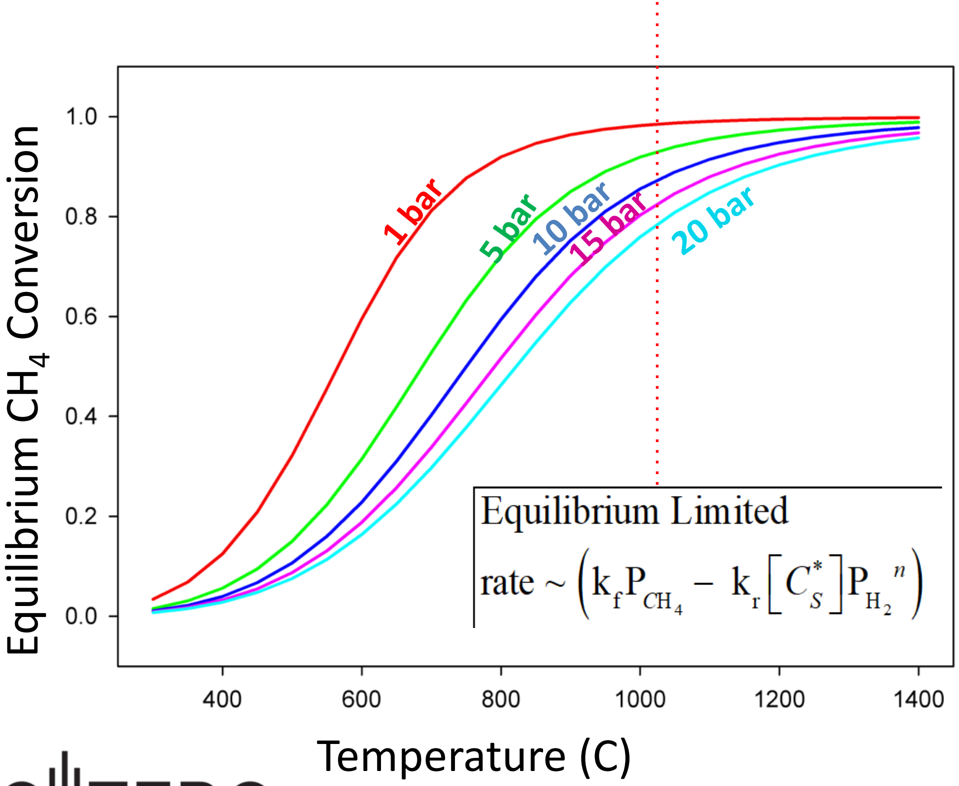
Reactor Designs for C management
High T, corrosion resistant materials
C valorization/utilization
HX valorization/utilization

Low-Cost CCS

C||ZERO Decarbonizing Natural Gas

UCSB

CZero is commercializing direct thermocatalytic methane decomposition utilizing high temperature liquid media $CH_4 \rightarrow 2H_2 + C$



Innovations:

- → High rates of heat transfer at high T ~ 1MW/m^3
- → Thermocatalytic melts ~ rates > 1 mole/m^3-s
- → Reactor design with high thermal efficiency and heat integration
- → Efficient carbon removal and processing.
- → Competitive without value from C

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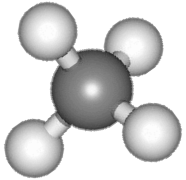
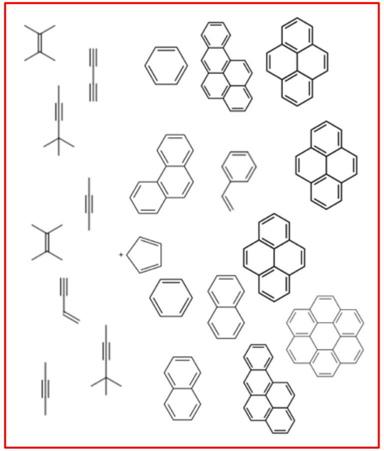
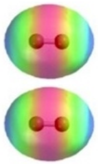
Reaction Pathway Determines Carbon Product Form (Value)

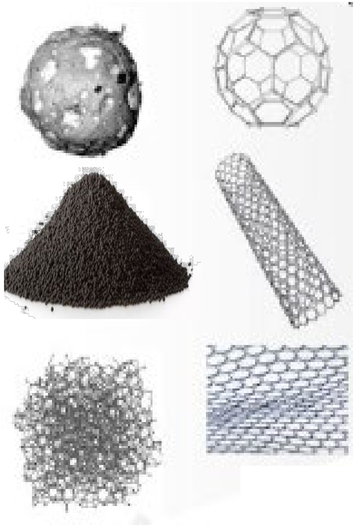




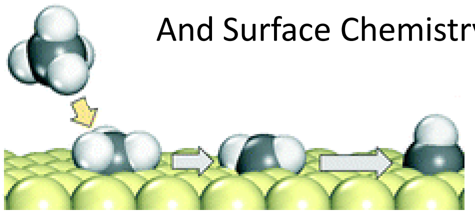
C-H Bond Activation
Gas Phase Small Molecule Chemistry



Suspended Solid Particle
Nucleation + Growth



C-H Bond Activation
And Surface Chemistry



Surface Structured
Carbon Growth

QUESTIONS?