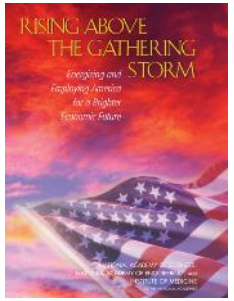
Advanced Research Projects Agency – Energy Introduction

US Department of Energy

ABOUT ARPA-E

History of ARPA-E

In 2007, The National Academies recommended Congress establish an Advanced Research Projects Agency within the U.S. Department of Energy to fund advanced energy R&D.



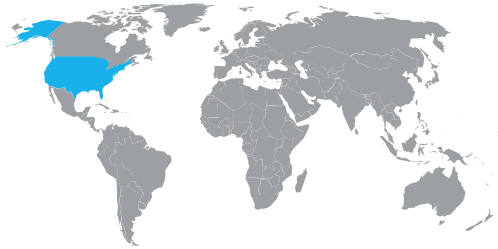
2007

Rising Above the Gathering Storm **Published** - warning policymakers that U.S. advantages in science and technology had begun to erode

America COMPETES Act **Signed** – authorizing the creation of ARPA-E

2009

American Recovery & Reinvestment Act **Signed** – Providing ARPA-E its first appropriations of $400 million, which funded ARPA-E's first projects



2022

1,415+ Awards
69+ Programs

Current Funding:
$470M
(FY23)

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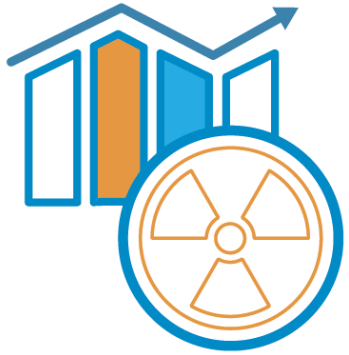
CHANGING WHAT'S POSSIBLE

ARPA-E Mission

REDUCE
imports

REDUCE
emissions

IMPROVE
efficiency



IMPROVE
radioactive waste management

IMPROVE
energy infrastructure resilience

ARPA-E Impact Indicators 2023

Since 2009
ARPA-E has provided
$3.58 billion
in R&D funding to
more than **1,500 projects**
+ 42 selected projects

212 projects
have attracted more than
$11.5 billion
in private-sector follow-on funding

149 companies
formed by
ARPA-E projects

27 exits
market valuations worth
$21.8 billion
from mergers, acquisitions, and IPOs

300 projects
have **partered with other government agencies**
for further development

6,797
peer-reviewed
journal articles
from ARPA-E
projects

1,039 patents
issued by
U.S. Patent and
Trademark Office

323 licenses
reported from
ARPA-E projects

As of July 2023

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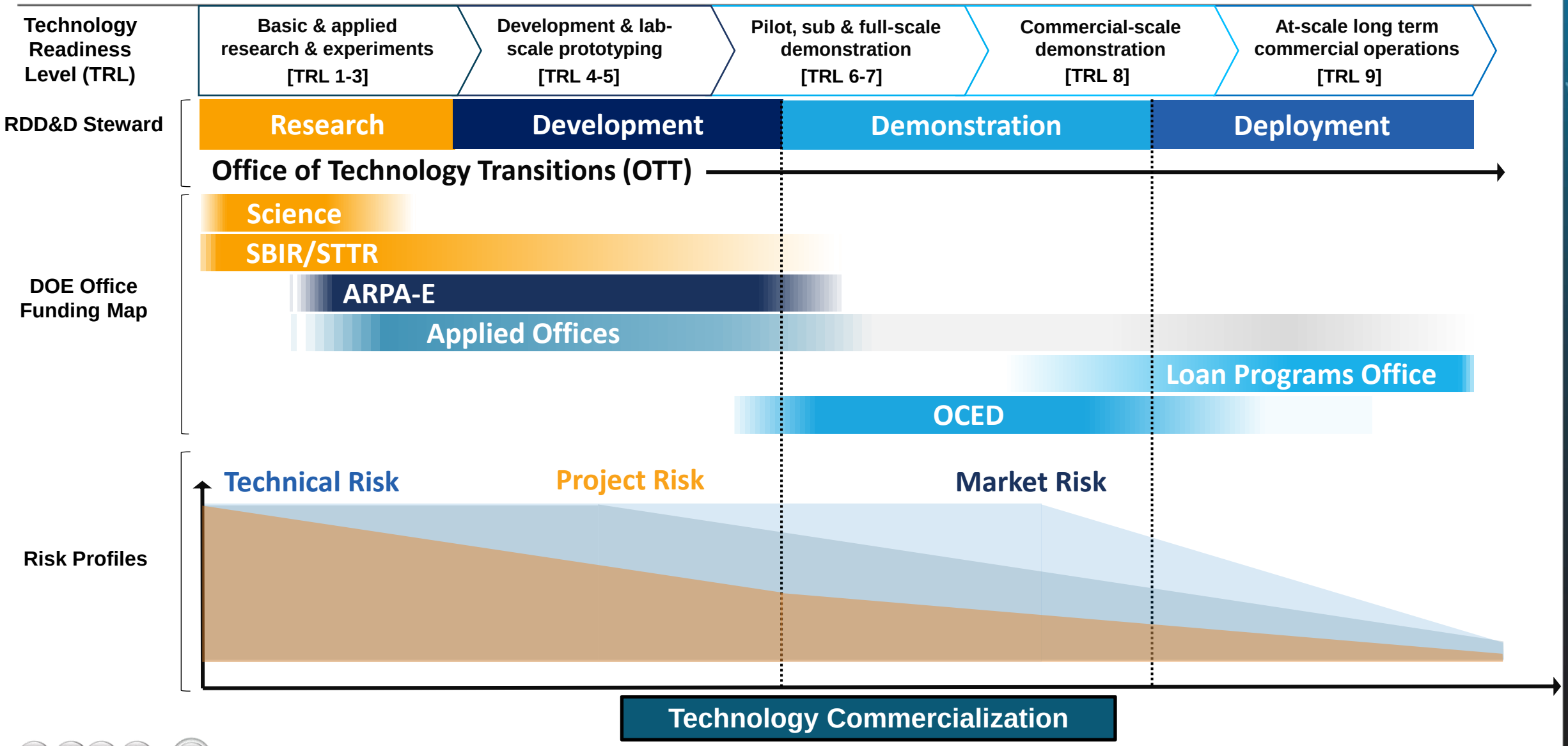
DOE Across Research, Development, Demonstration & Deployment (RDD&D) Continuum



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ARPA-E Industrial Decarbonization Programs

IPER Jan 30, 2024

Peter Debock and Jack Lewnard, ARPA-E Program Directors

FLECCS 1 Technology Teams Relevant for Industrial PCC

Flexible solvents, sorbents, membranes

RTI INTERNATIONAL

Susteon

LUNA

8 RIVERS
8 Rivers Capital, LLC

Envergex
Sparking Innovations

Flexibility via thermal or chemical storage

Colorado State University

SwRI
SOUTHWEST RESEARCH INSTITUTE

GE Research

Linde

Flexibility via DAC integration

Georgia Tech

Massachusetts Institute of Technology

University of Pittsburgh

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Susteon: sorbent with rotating packed bed

Susteon

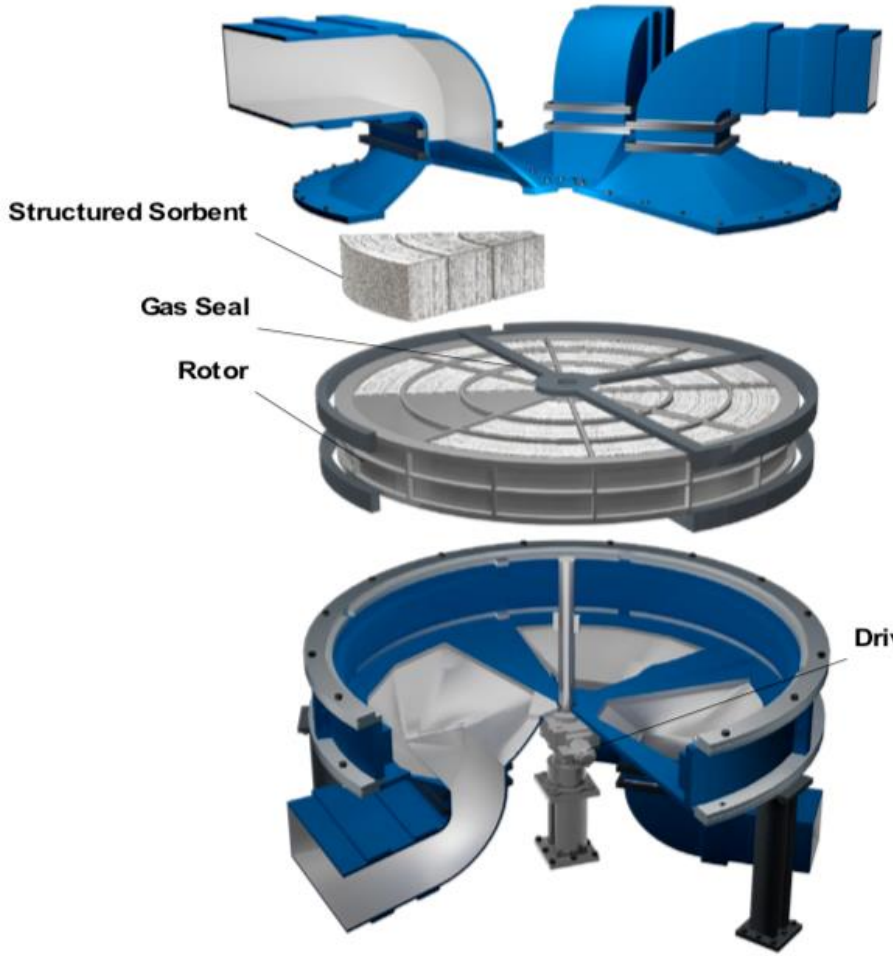
NATIONAL ENERGY TECHNOLOGY LABORATORY

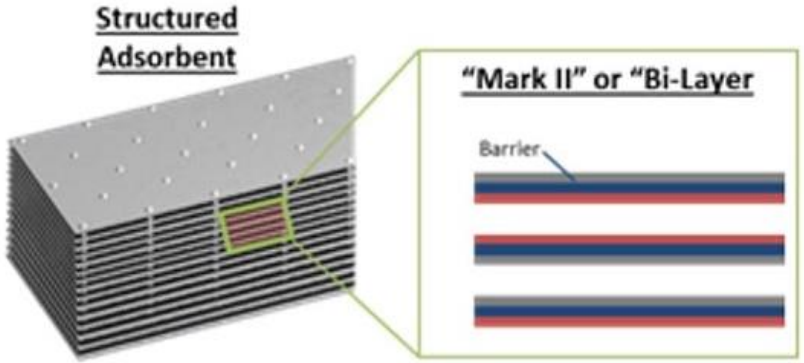
WestVirginiaUniversity.

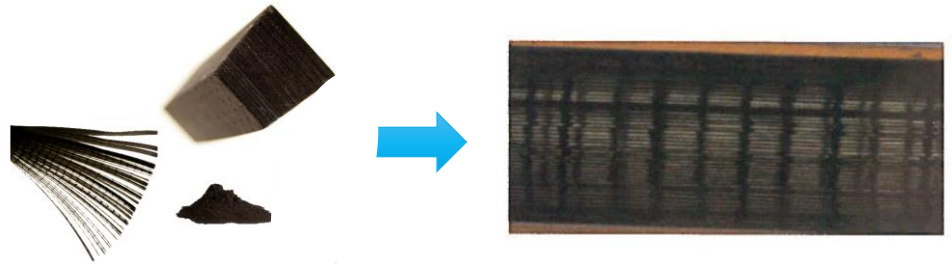
Svante

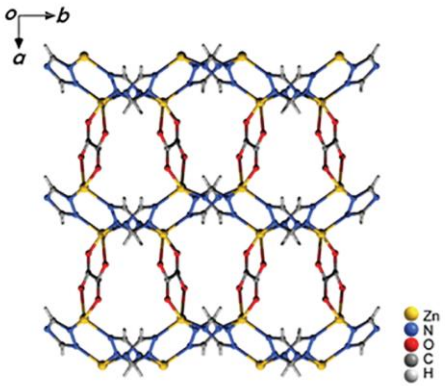
SoCalGas

LA DWP Los Angeles Department of Water & Power









Svante's (formerly Inventys) VeloxoTherm™ Technology (VTS), structured amine/MOF adsorbents for a rapid cycle temperature-swing adsorption and moisture-swing process

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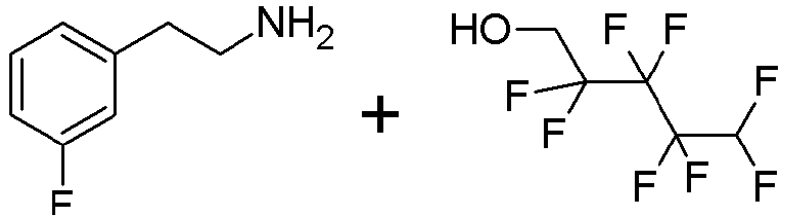
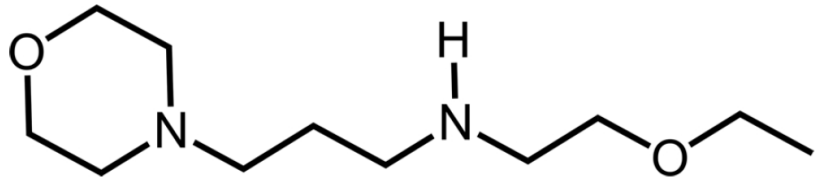
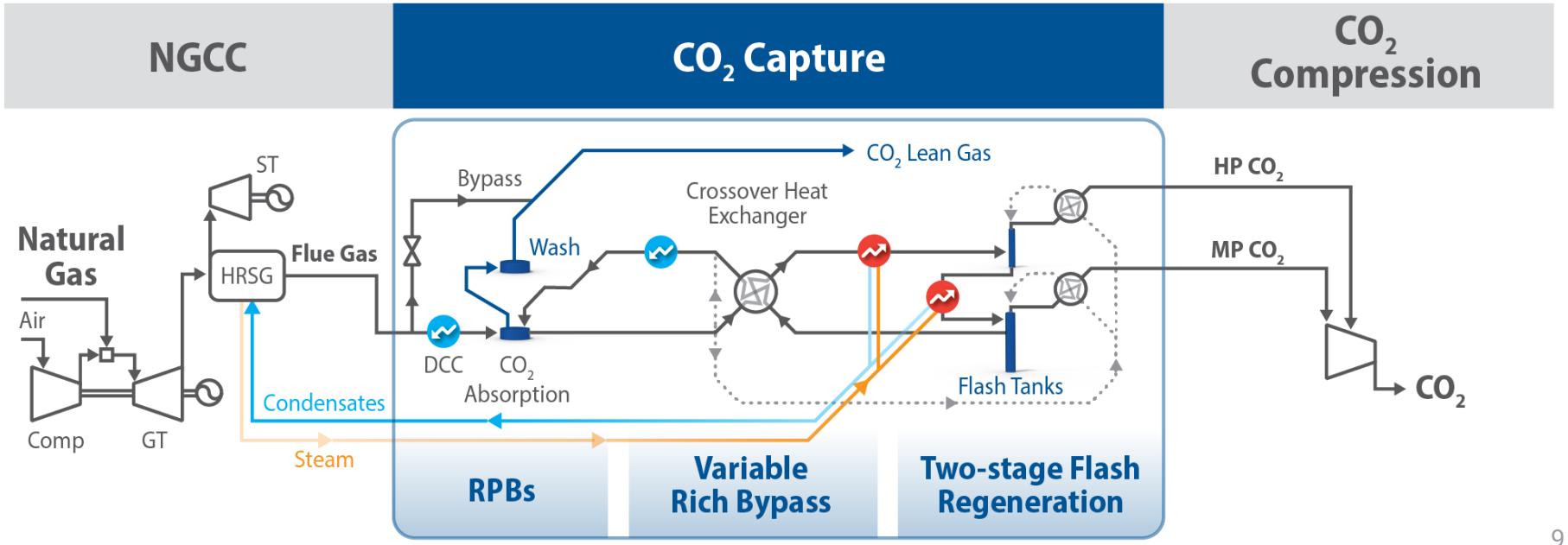
RTI: water-lean solvents with new unit ops



RTI's multi-component NAS (Non-Aqueous Solvents)- carbamate-forming amines



PNNL's single component binding organic liquid (CO_2BOL) solvents- EEMPA (*N*-(2-ethoxyethyl)-3-morpholinopropan-1-amine



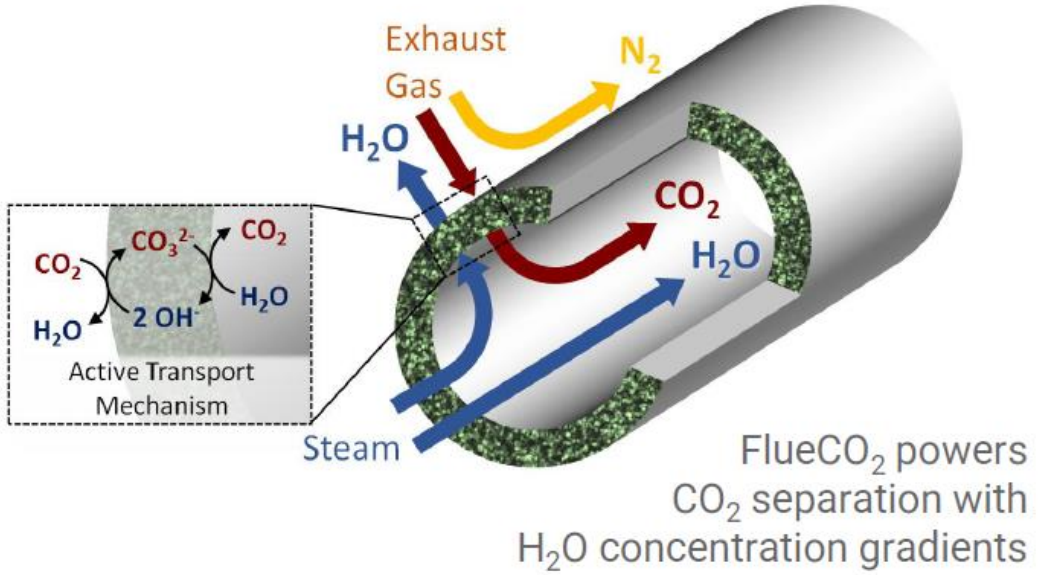
Luna: thermochemical membrane

- Dual-phase membrane technology for CO_2 capture that is integrated into the heat recovery steam generator (HRSG) of NGCC power plants
  - Reduces CAPEX and OPEX with simplified process control and heat integration

LUNA

NOOTER ERIKSEN

TRIMERIC



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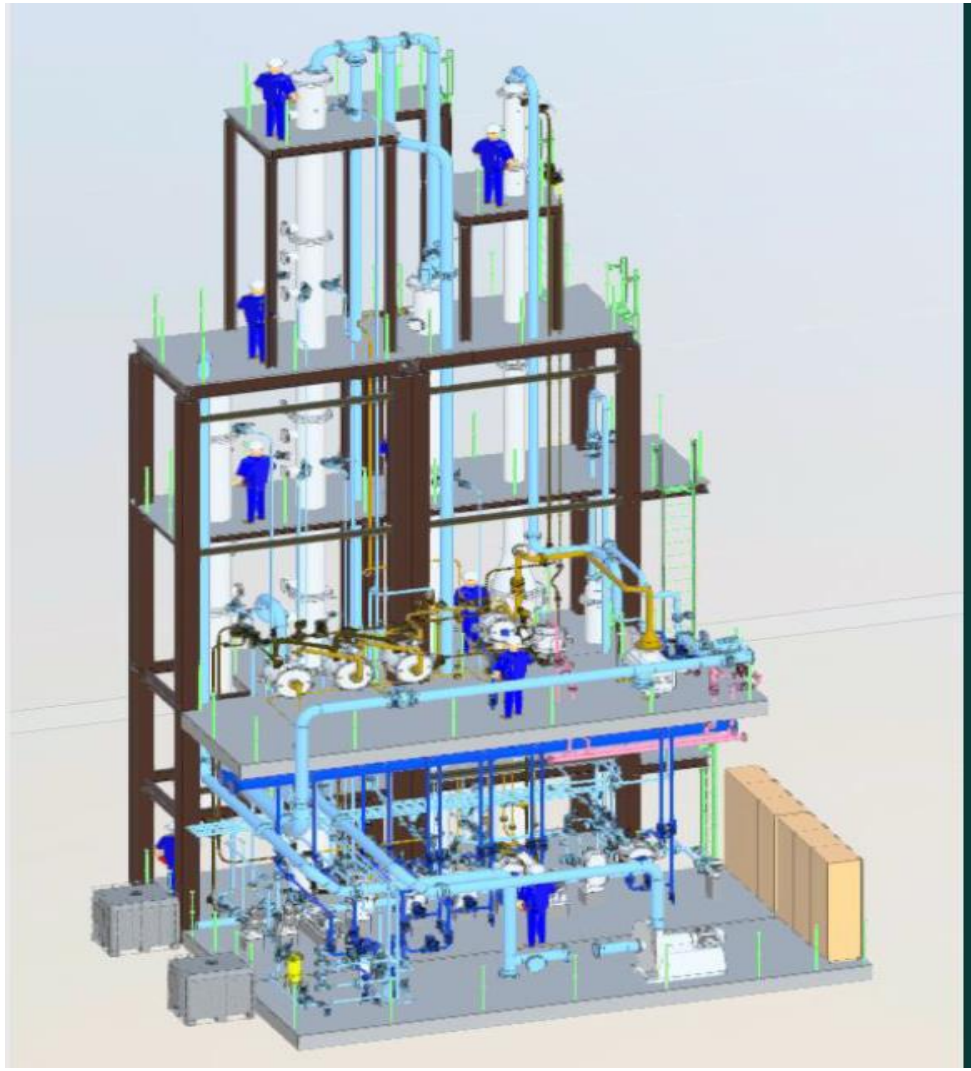
8 Rivers/KC8: K_2CO_3 Phase-change solvent



Cemtech Webinar

- **90 - 95% Capture rate**, low operating energy
- Solvent is **safe**, easy to use & not harmful to the environment
- Up to **50% less CAPEX** - Less equipment, smaller footprint and overall lower carbon footprint
- Up to **15% less OPEX** – direct to the bottom line.
- Designed for single train for **large emitters**
- **Retrofit** to exiting plant

KC8

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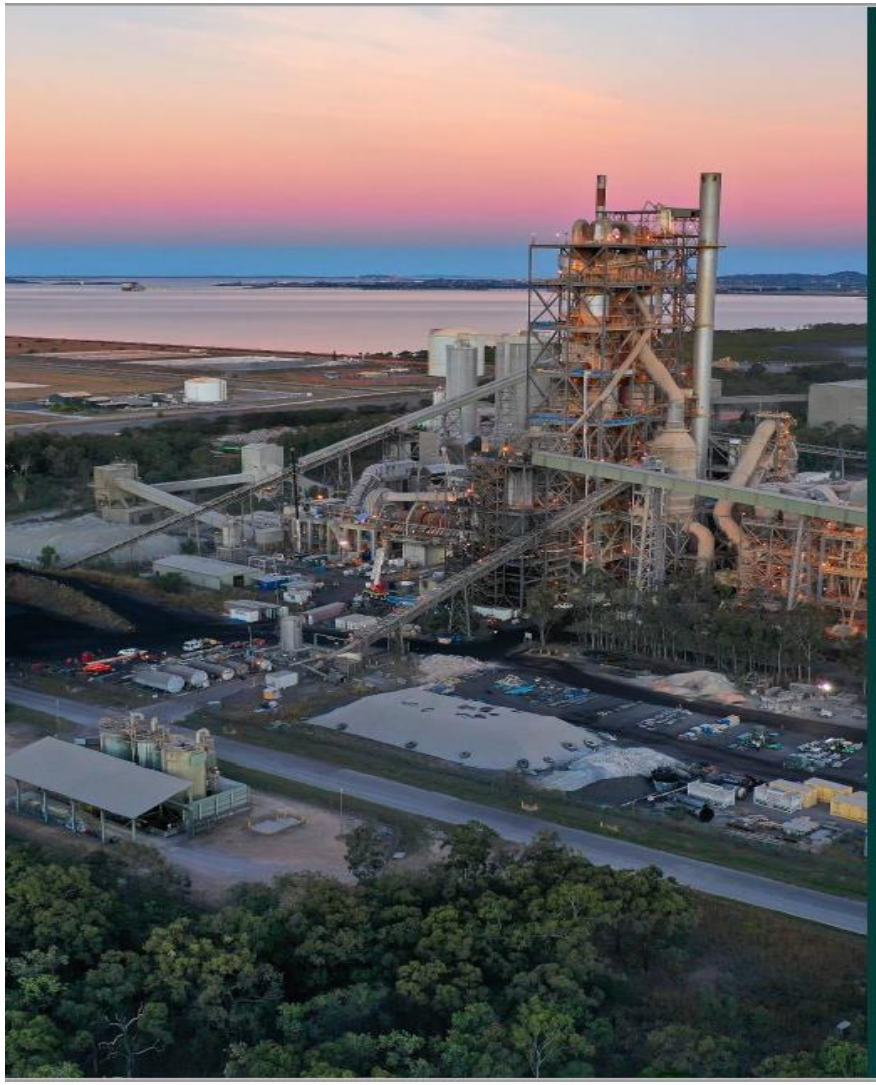
Cement Australia (Holcim/Hanson-Heildelberg JV) Project



Cemtech Webinar

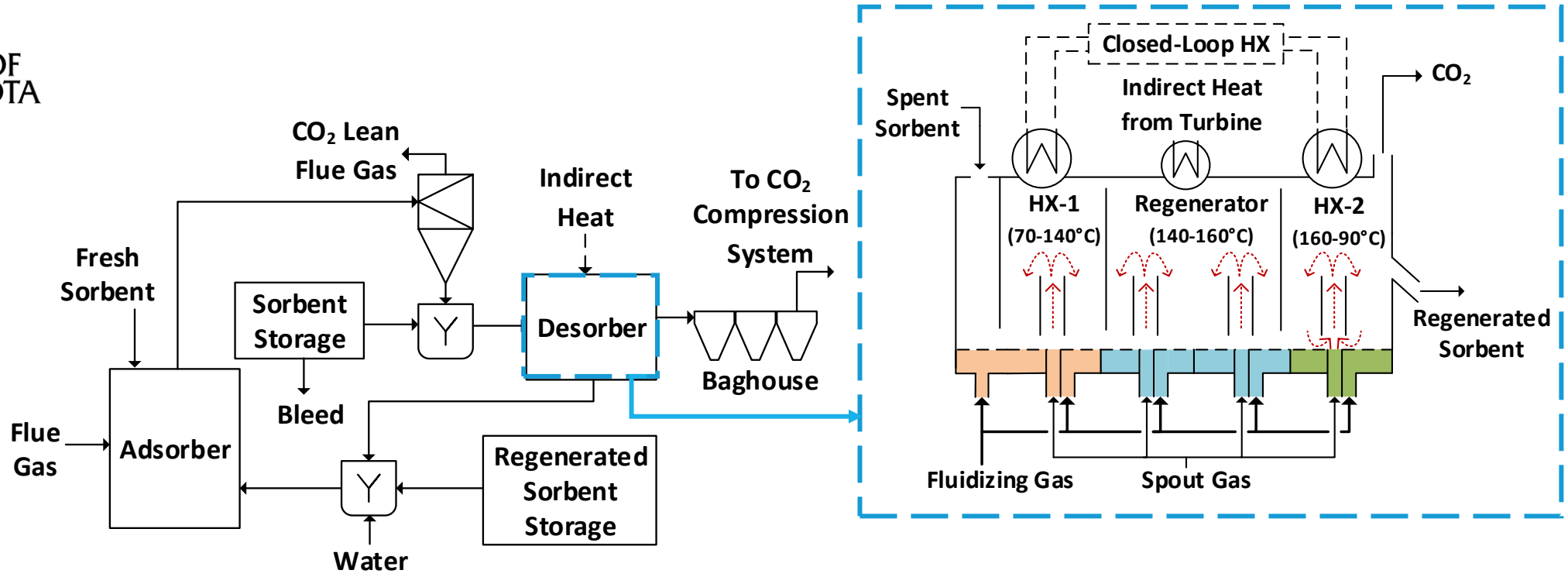
PACER Project - Gladstone

- Potassium carbonate Absorption for Clinker Emissions Reduction – PACER
- $12 MAUD demonstration project
- 15-20 TPD CO2 from direct flue gas stream
- Location - Gladstone, Queensland
- 95% CO2 capture rate.
- Demonstrate near ZERO emissions from conventional coal fired clinker process.
- Installed by August 2024.

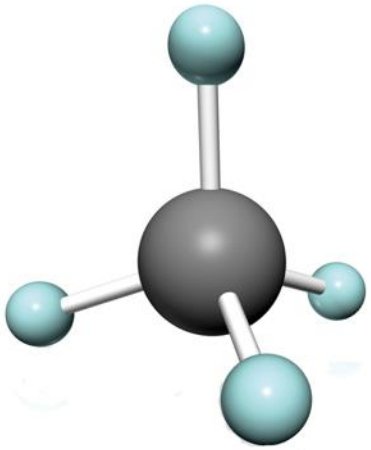
LETA CEMENT AUSTRALIA KC8

Envergex: novel, undersized regenerator w/ storage

- Load-following CCS technology with regenerable hydrated sorbent (alkali carbonate) for CO2 capture with sorbent storage that allows flexibility and lower CAPEX and OPEX



Methane Pyrolysis – Opportunity for Two Products



750 - 1200°C

Gaseous hydrogen

+

Solid carbon

CH_4 ⟶ $2\ H_2$ + $C\ (s)$

¼ of the weight, but ½ of the energy

Hydrogen for Industrial Decarbonization

Technology	Electrolysis	SMR/ATR with CCS	Methane Pyrolysis
Feeds	Electricity and water	Natural gas	Natural gas and NGLs
Products	H_2 and O2	H_2 and CO_2	H_2 and solid carbon
Advantages	Linearly scalable; suitable for small scale and on-site H_2 Maturing technology Good option with low-cost renewable electricity O_2 sales theoretically can reduce H_2 cost	0.6 scaling rule; preferably large scale H_2 Commercial technology Good option with low-cost natural gas Electricity sales can reduce H_2 costs	Expected economy of scale; may be suitable for on-site and large scale H_2 Multiple technologies Good option with low-cost natural gas and NGLs Carbon sales can reduce H_2 cost
Disadvantages	70-80% electricity efficiency (50-55 kWhr/kg H_2)	Need CO_2 pipeline/CCS and most likely need H_2 pipeline	Earlier stage technology Market for carbon?

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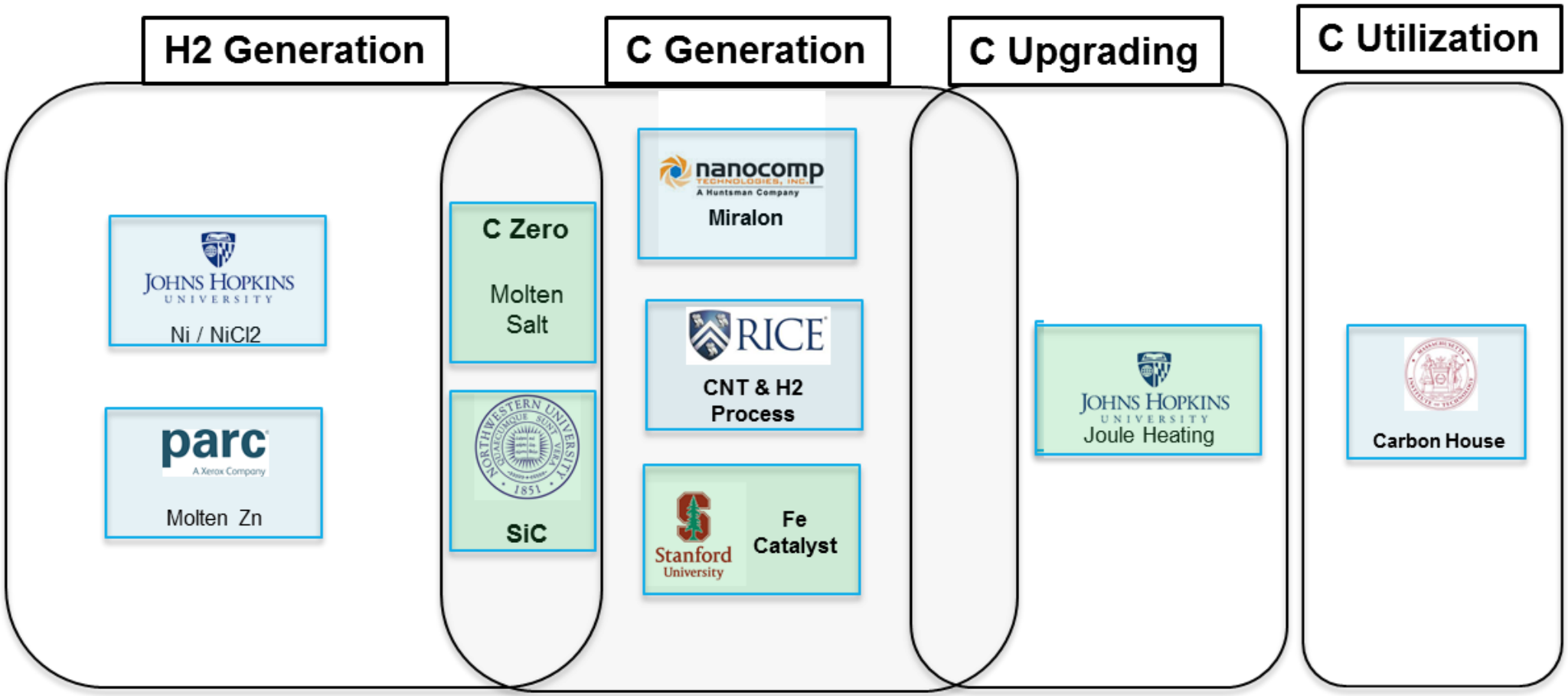
Methane Pyrolysis Cohort.. 2018 OPEN & 2019 FOA



[2022 Methane Pyrolysis Cohort Annual Meeting | arpa-e.energy.gov]

TINA 2019

OPEN 2018

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Monolith Pyrolysis Project *(not ARPA-E)*

- $1B from DOE Loan Program Office for 10X expansion of Hallam NE site

- $300MM raise led by TPG Rise Capital and Decarbonization Partners

“Carbon” for Industrial Decarbonization

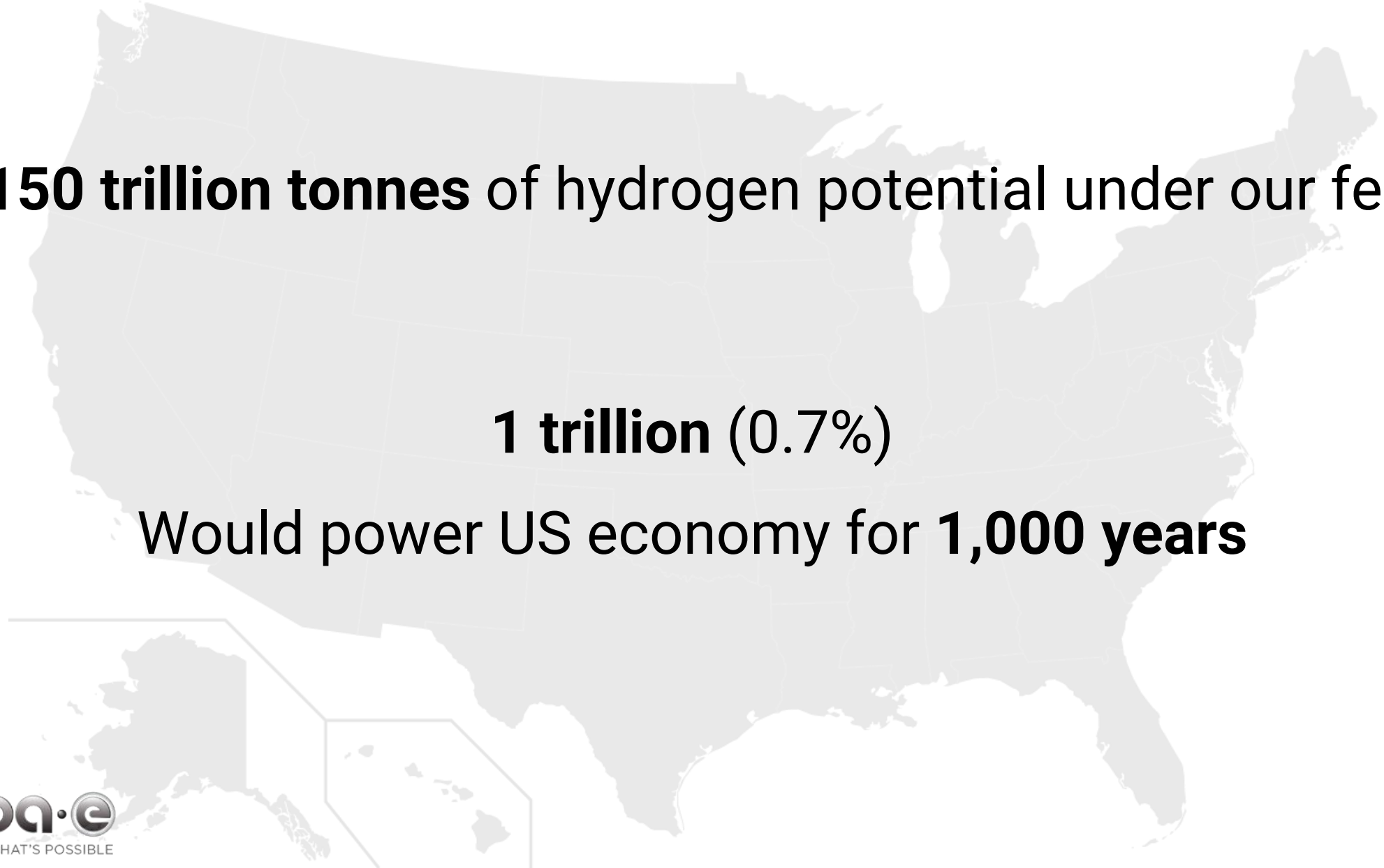
- Carbon from methane pyrolysis displaces higher LCA materials
  - Carbon solids added to cement
  - Carbon fibers replace steel, aluminum, and copper

- CO_2 “sequestration” into ash/tailings for cement SCM

- CO_2 “sequestration” into ash/tailings for cement SCM

GEOLOGIC HYDROGEN ($GEOH_2$) PROGRAM MOTIVATION AND TARGETS

The Opportunity is MASSIVE



150 trillion tonnes of hydrogen potential under our feet

1 trillion (0.7%)

Would power US economy for **1,000 years**

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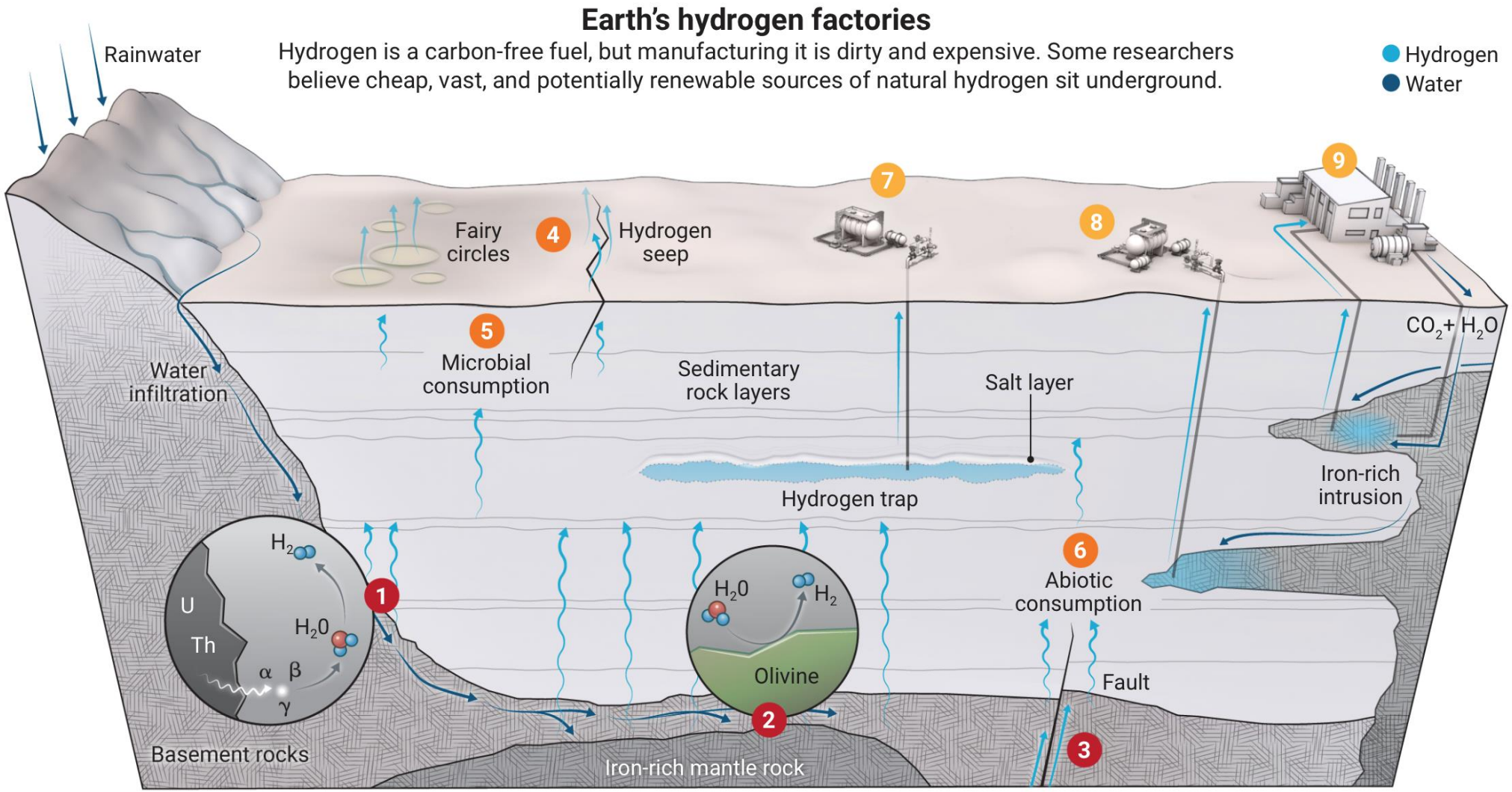
Reminder: Where does the H_2 come from?



Sources
E. Hand, *Science* **379**, 630–636, (https://doi.org/10.1126/science.adh1477) (Feb. 2023).

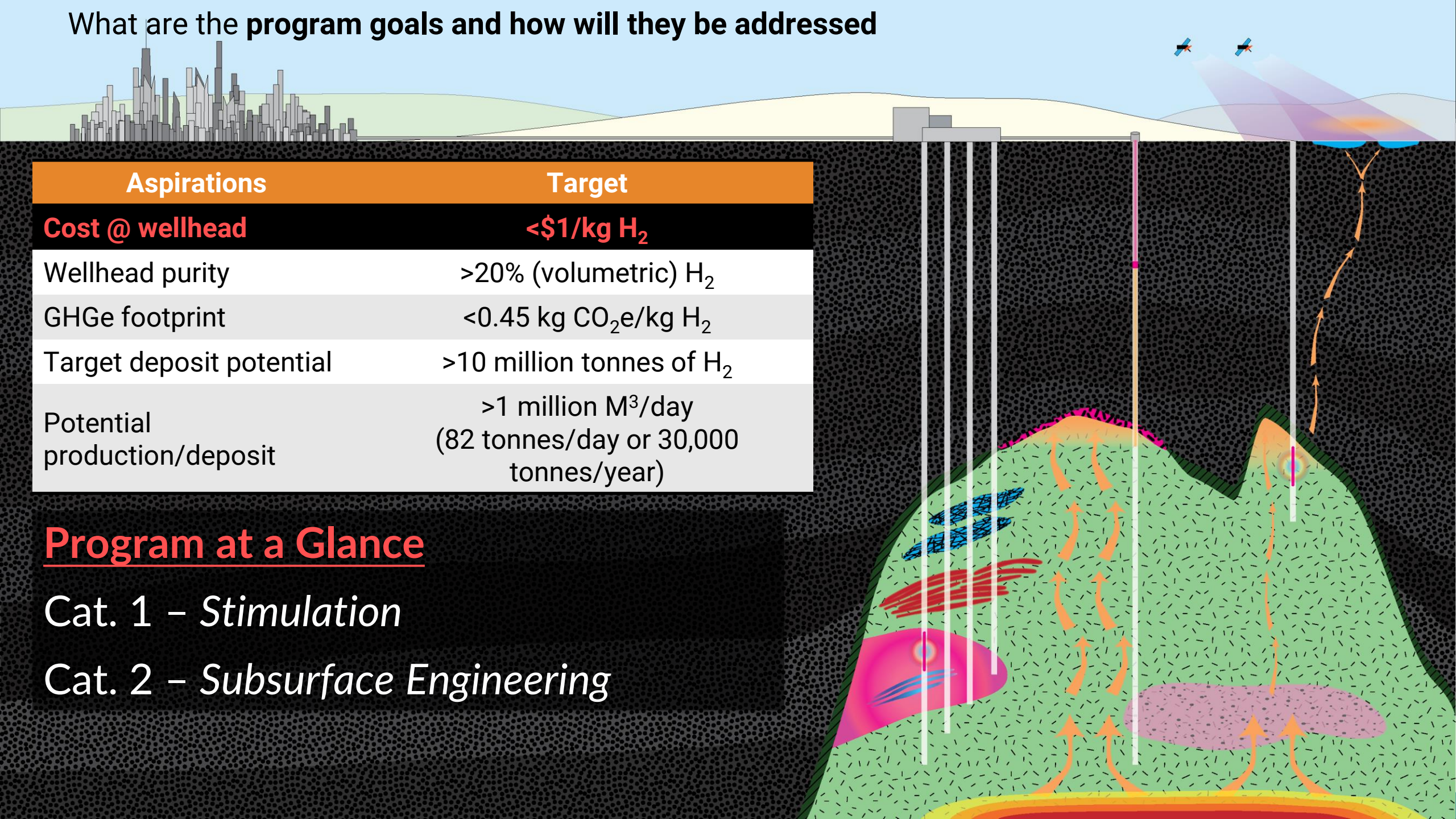
What are the **program goals and how will they be addressed**

Aspirations	Target
Cost @ wellhead	**<$1/kg H_2**
Wellhead purity	>20% (volumetric) H_2
GHGe footprint	<0.45 kg CO_2e/kg H_2
Target deposit potential	>10 million tonnes of H_2
Potential production/deposit	>1 million M^3/day (82 tonnes/day or 30,000 tonnes/year)

Program at a Glance

Cat. 1 – *Stimulation*

Cat. 2 – *Subsurface Engineering*



Renewables to Liquids (RtL)

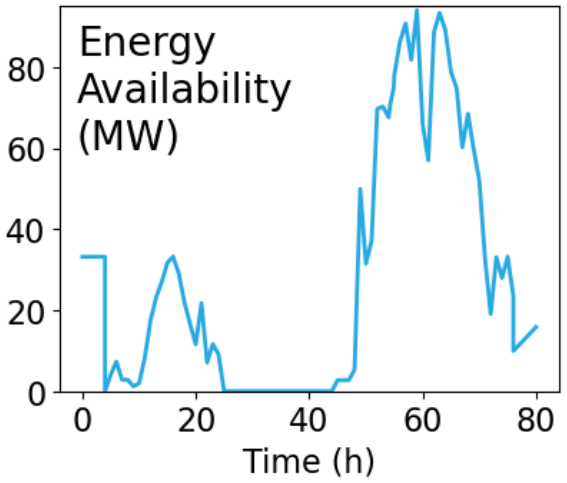
A Distributed Energy Production Model for Infrastructure Compatible Liquid Fuels

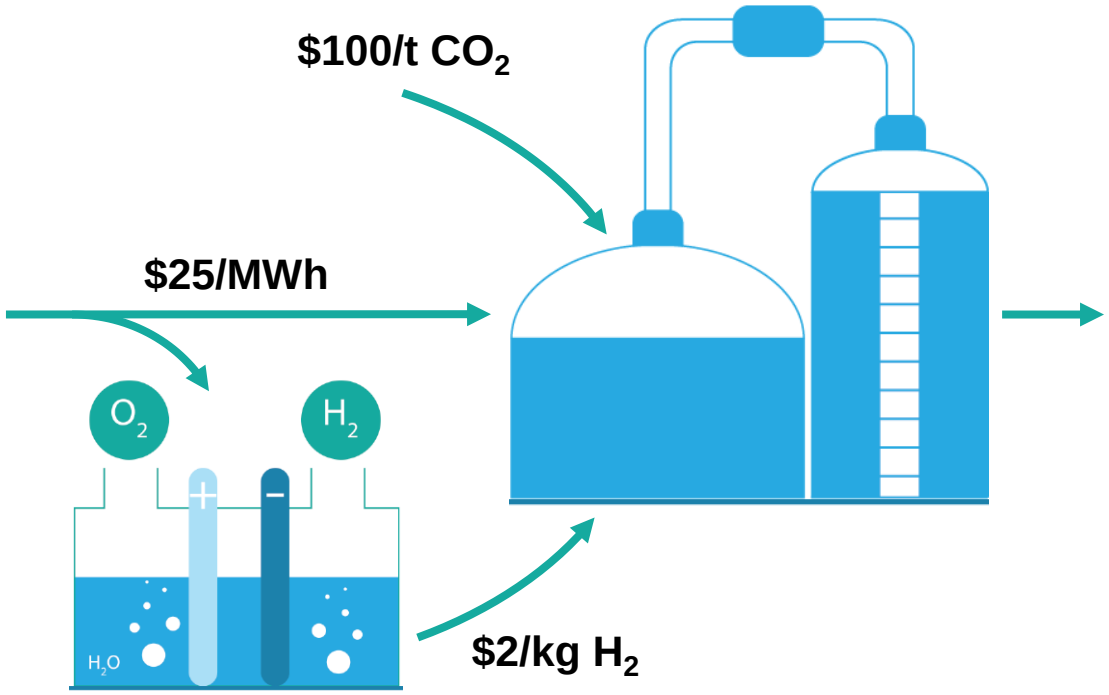
James Seaba
Program Director ARPA-E
james.seaba@hq.doe.gov

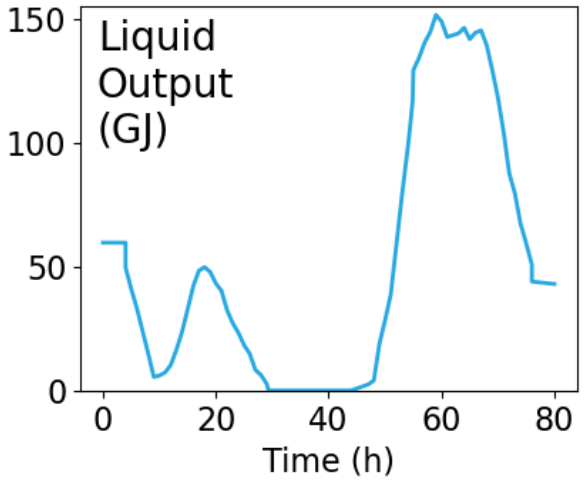
GREENWELLS Program

Grid-free
Renewable
Energy
Enabling
New
Ways to
Economical
Liquids and
Long-term
Storage
(GREENWELLS)

Intermittent Power-to-Fuel







Fuel Type	Price target
C1: Methanol	$600/Ton
C2: Ethanol	$2.50/gal
C3s - on: Propane, …	$40/MMBTU
Diesel	$5/gal
Jet	$5/gal

ELECTRIFIED THERMAL SOLUTIONS

Electrifiedthermal.com

Decarbonizing Industry with Electrified Heat

ELECTRIFIED THERMAL

Joule Hive™ thermal battery turns zero-carbon electricity into 24/7 industrial heat.

The Technology

Hot

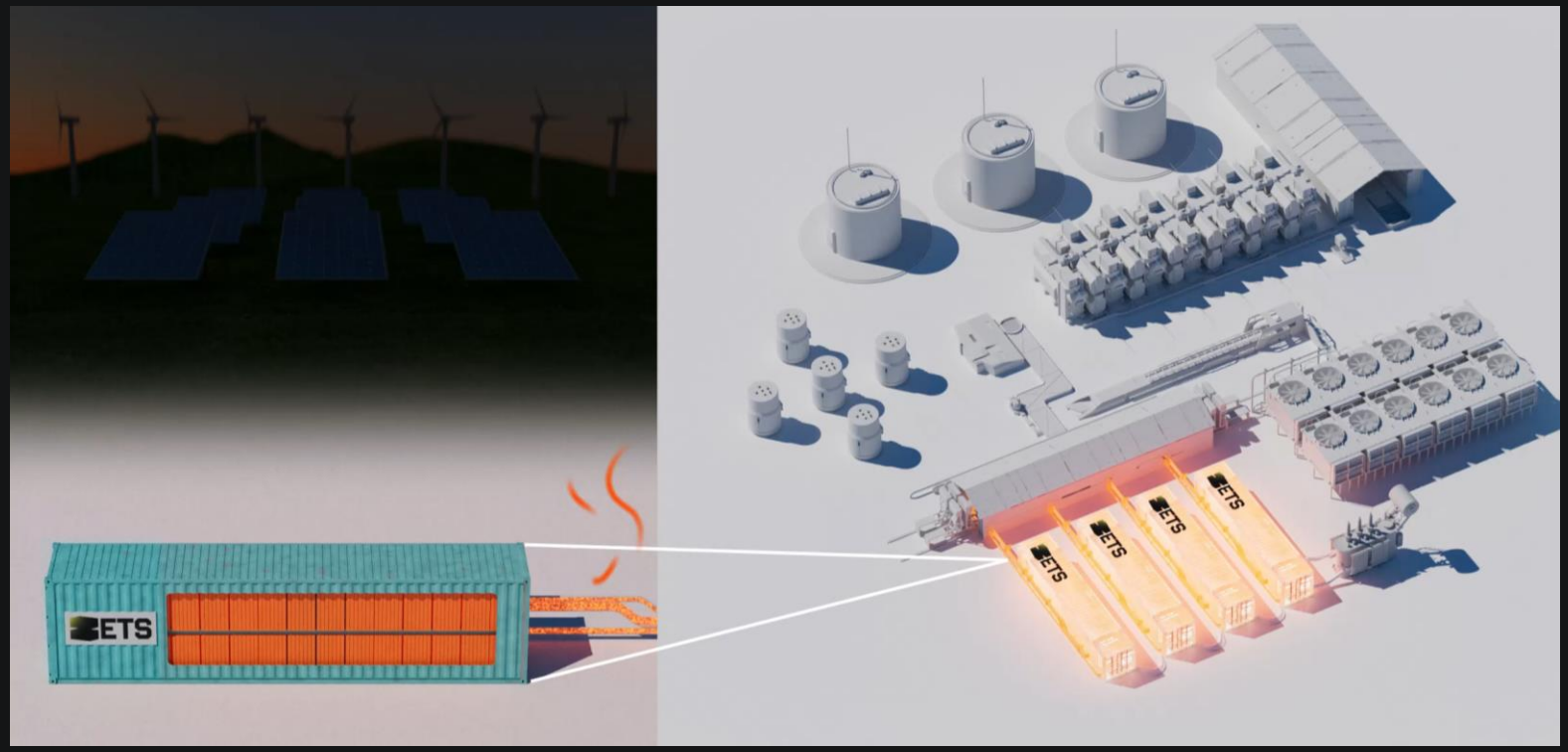
1,800°C (3,270°F) deliverable temperatures

Affordable

3x cheaper than green hydrogen

Retrofittable

Plugs into existing processes



ELECTRIFIED THERMAL

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electrifiedthermal.com

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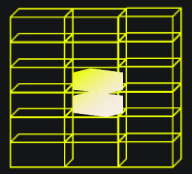
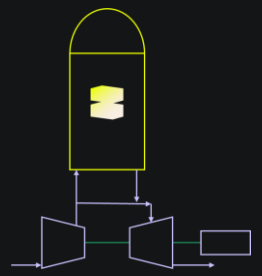
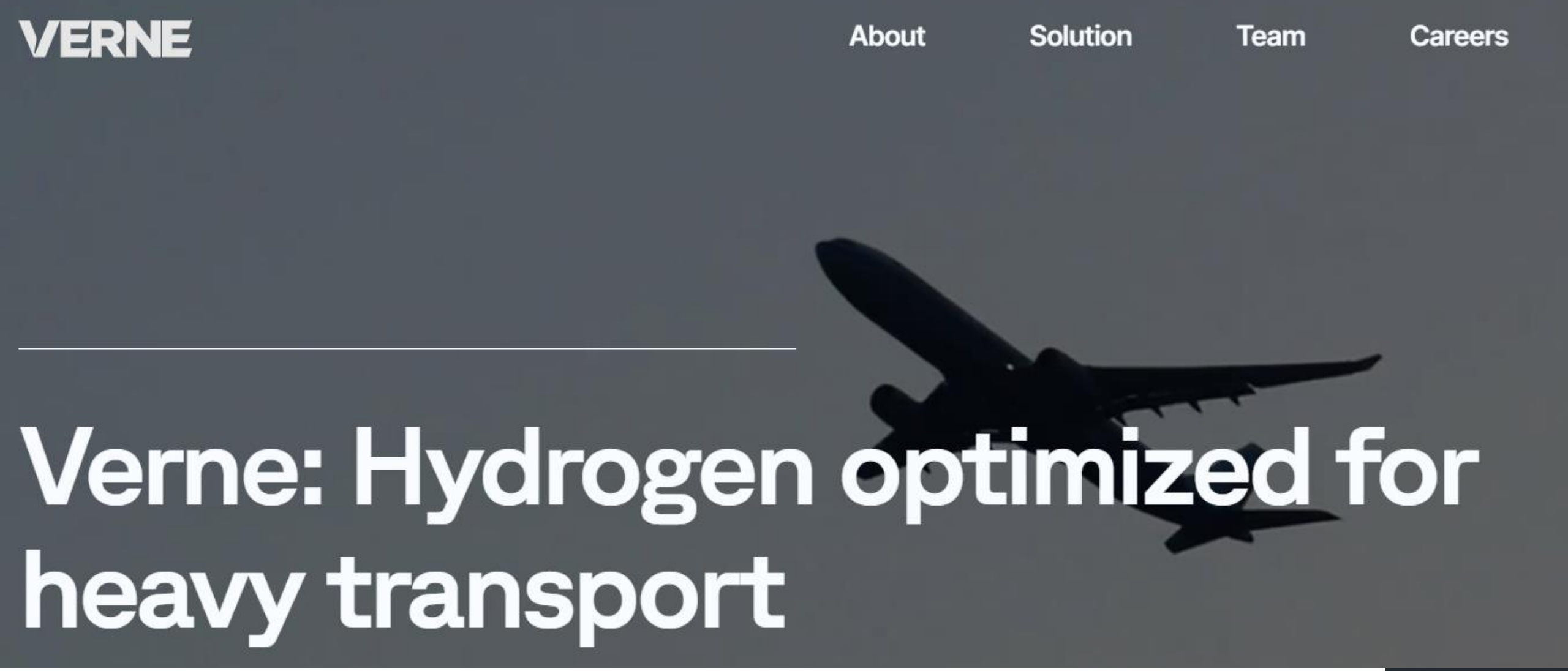
Technology Suite to Support Industry

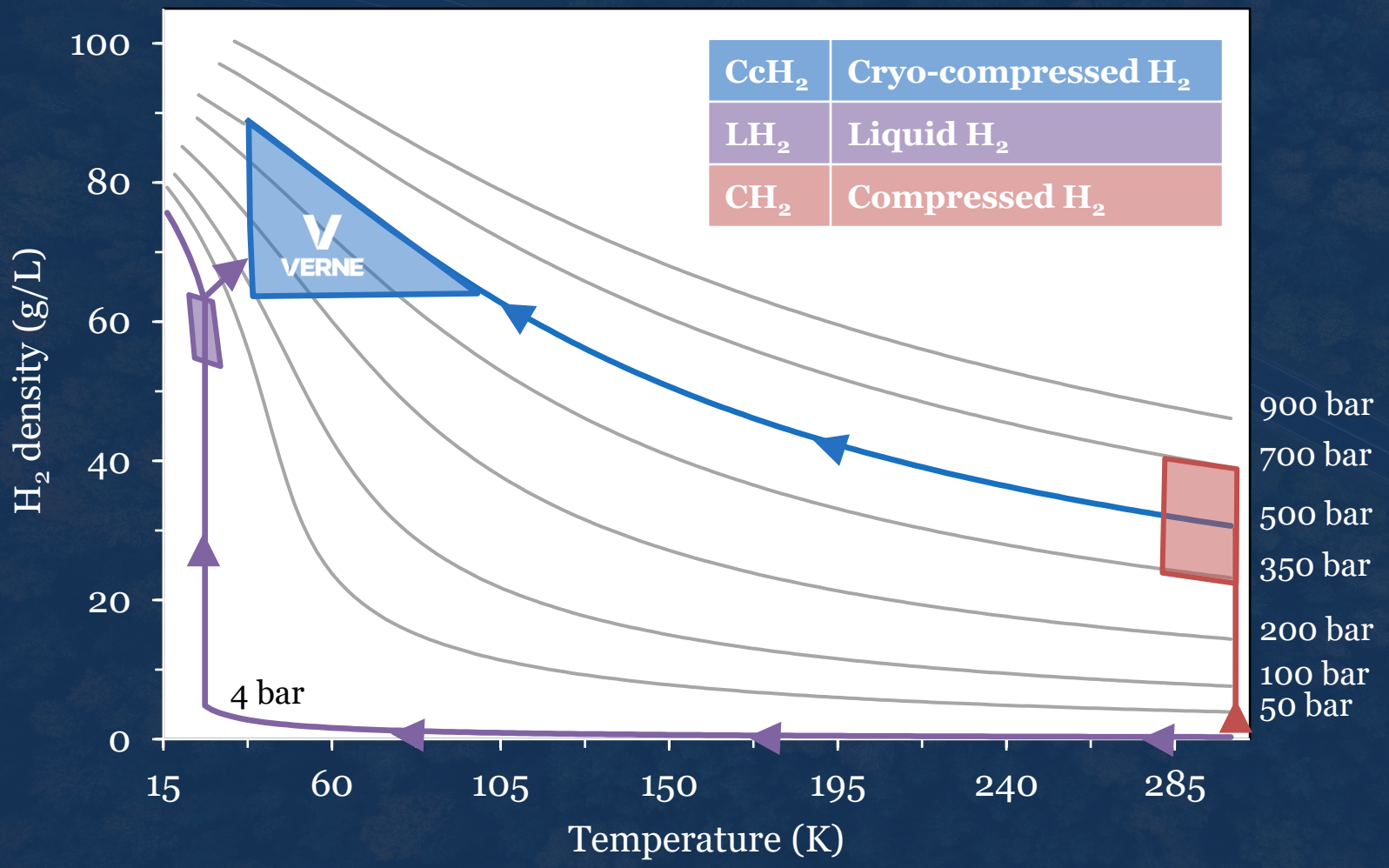




Product	Capacity Specs (Charge, Store, Discharge)	Application	Customer Industries
JHTB Box	5MW_e, 25MWh, 5MW_{th}	Small scale steam generation, drying, etc.	❑ Specialty Chemicals ❑ Hazardous Waste Incineration ❑ Minerals ❑ Metals ❑ Food
JHTB Tower	200MW_e, 1,000MWh, 200MW_{th}	Large scale high heat furnace, kiln, oven.	❑ Basic Chemicals ❑ Cement ❑ Steel ❑ Large District Heating
JH Hot Walls	TBD MW_e, 0 MWh, TBD MW_{th}	Furnaces and kilns built of "E-brick" walls, floors and ceilings.	❑ Basic Chemicals ❑ Glass ❑ Cement ❑ Steel
JHTB + Power Turbine	200MW_e, 1,000MWh, 200W_{th}	Energy Storage to Power Generation, combined heat and power.	❑ Electric Utilities ❑ IPPs ❑ Municipal Campus ❑ Industrial Campus


VERNE
About
Solution
Team
Careers
Verne: Hydrogen optimized for heavy transport

Cryo-compression is the highest-density hydrogen state, accessible from two densification paths

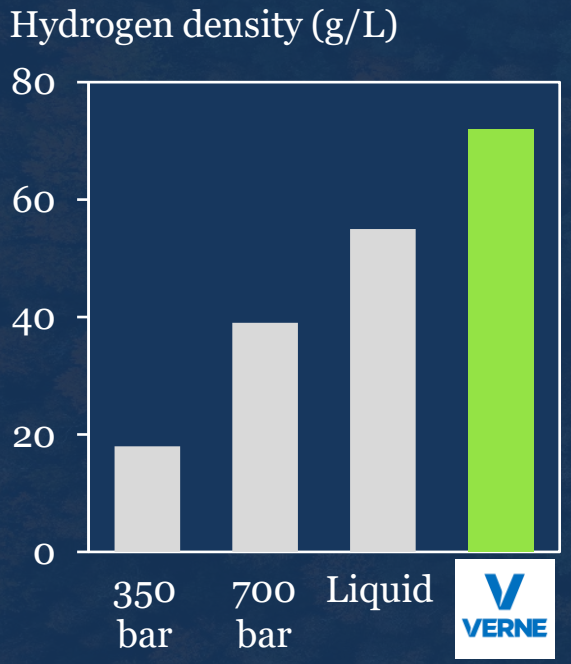


1. **Higher than LH_2 density**
2. **Accessible from LH_2 or GH_2 source:**
   - From liquid hydrogen, using a cryo-pump (purple path)
   - From gaseous hydrogen, compressing and cooling a gas using Verne's cryo-compressor (blue path)

Cryo-compressed hydrogen achieves maximum density while avoiding high costs of liquefaction

Hydrogen storage systems

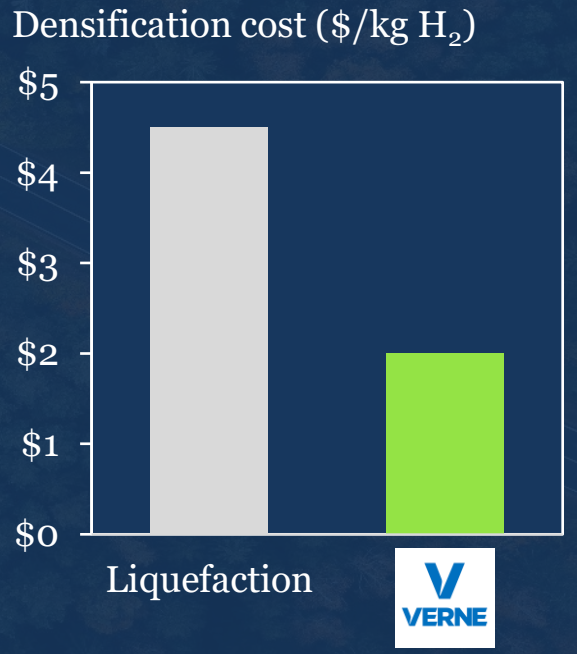
Insulated hydrogen storage tanks



Verne's 120 kg hydrogen storage system

Verne cryo-cooler

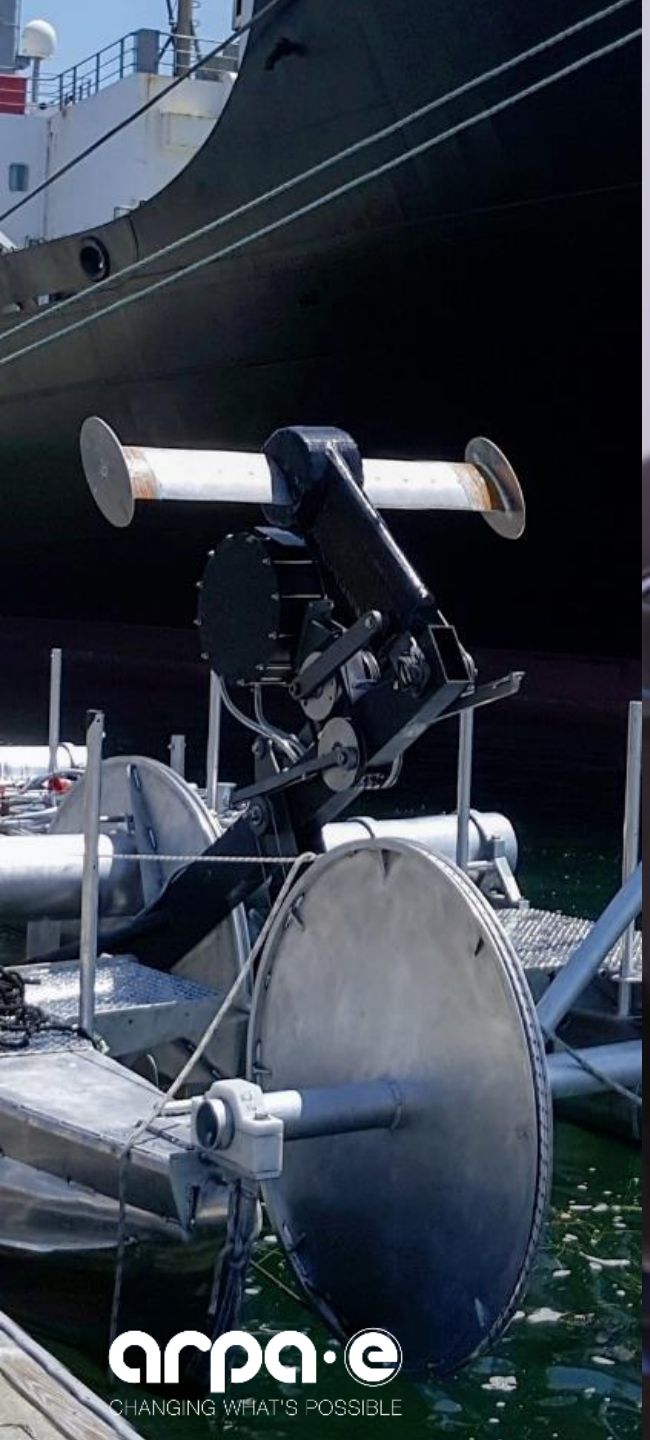
Compress and cool hydrogen to increase density



Verne's cryo-cooler

Store hydrogen at the highest density

Reach high density at half the cost



OPEN Programs

support new technologies across the full spectrum of energy applications

OPEN 2009

41 projects

$176 million investment

10 technical areas

OPEN 2012

66 projects

$130 million investment

11 technical areas

OPEN 2015

41 projects

$125 million investment

10 technical areas

OPEN 2018

77 projects

$199 million investment

13 technical areas

OPEN 2021

68 projects

$175 million investment

13 technical areas

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