Energy Earthshots and the National Laboratories

Peter Green, Deputy Laboratory Director for Science and Technology and Chief Research Officer

National Renewable Energy Laboratory

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Photo from iStock-627281636

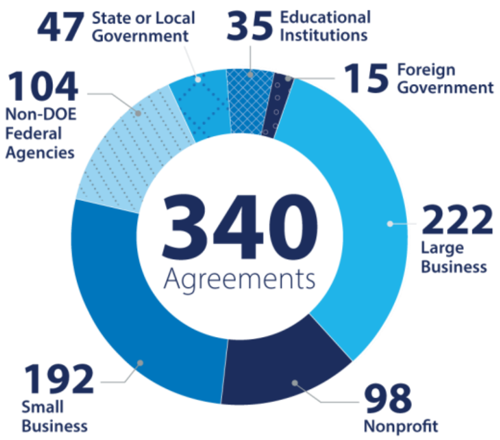
Coast to Coast

The **17** National Laboratories have served as the leading institutions for scientific innovation in the United States for more than seventy years.

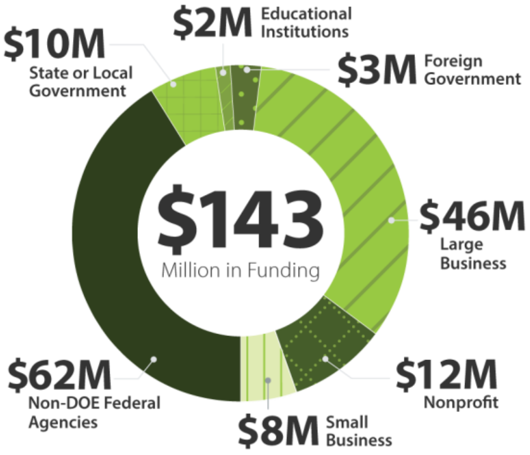
NREL at a Glance

- **3,700 Workforce** (as of 9/2023)
- **1,200 Publications annually**
  - Technical Reports
  - Archival peer reviewed
- **World-class research expertise in:**
  - Renewable Energy
  - Sustainable Transportation & Fuels
  - Buildings and Industry
  - Energy Systems Integration
- **Over 1000 Active Partnerships**
  - Industry
  - Academia
  - Government
- **4 Campuses** operate as living laboratories

More Than 1,000 Active Partnerships in FY 2023



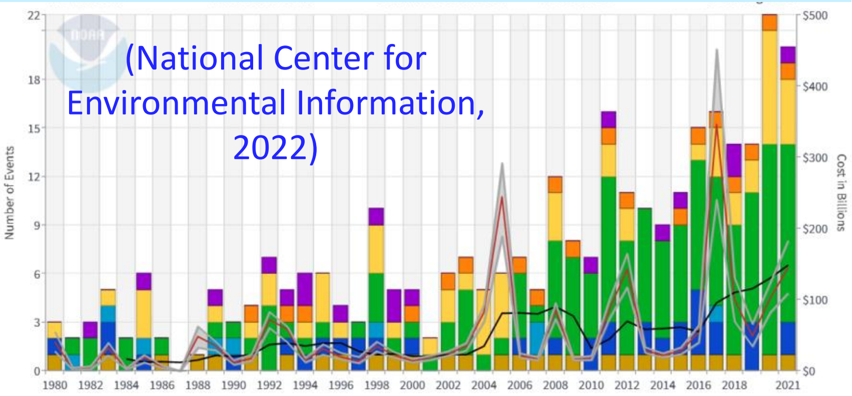
Agreements by Business Type



Funding by Business Type

Global Challenges Necessitate Earthshots

Billion-dollar disaster events in the U.S.



Economist, March 2018

Emissions from Sectors: EPA (2021)

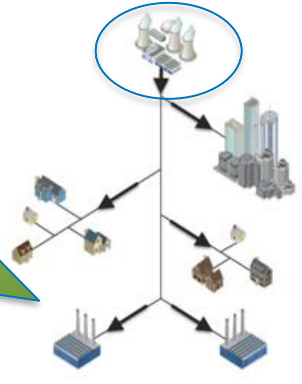
Transportation (29%); *Electricity* (25%)
Industry (23%); *Buildings* (13%)

Need for a future energy system to enable entirely new ways -low energy, low carbon -to produce chemicals, materials, fuels

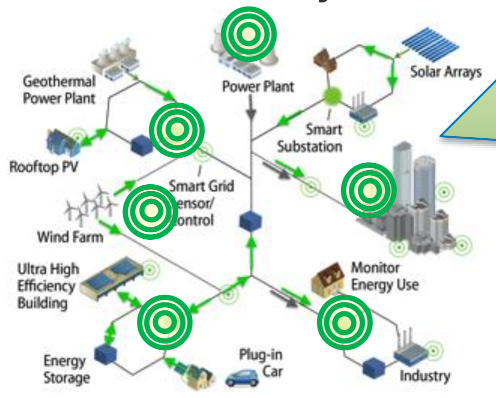
Evolution of the Conventional Power Grid Toward a Future Low-Carbon Energy System

- Generation follows demand
- Large-central station plants generation
- Central control

Power System of the Past



Future Power Systems

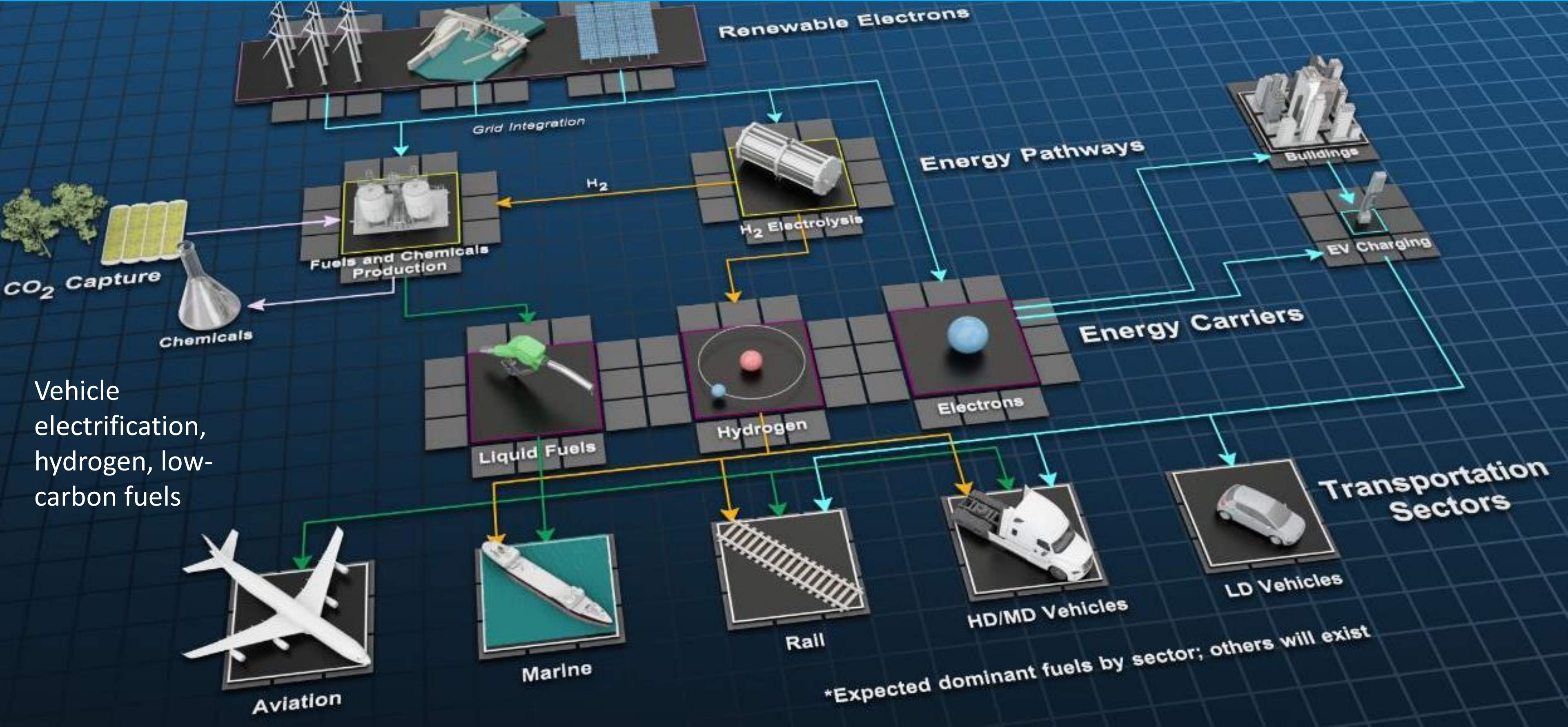


- More measurements and data
- More variable generation
- More distributed resources

- The grid is undergoing changes, addressing current and future consumer needs, increased use of renewable generation, decarbonization, improved resilience

- The Grid Modernization Initiative (GMI): U.S. Department of Energy (DOE) and the National labs, with industry, work collaboratively to achieve the grid of the future.

NREL Decarbonization Strategy: Transportation



Vehicle electrification, hydrogen, low-carbon fuels

Earthshots Enable a Future Low Carbon Economy - 2050 Net Zero

- **Decarbonize power generation**

  ***Wind and solar**, with geothermal, hydro, nuclear (fossil)*

- Floating offshore wind
- Geothermal

- **GRID: Autonomous control of the grid**
  - Electrification
  - Distributed energy resources (energy storage, generation-primarily renewables, smart homes, devices, EV charging)

- Long-duration storage

- **Decarbonize transportation, buildings**
  - Grid interactive buildings/communities
  - Transportation –electrification, low carbon fuels
  - Decarbonize industrial processes

- Affordable home energy
- Industrial heat

- **Low-carbon fuels and processes**
  - Hydrogen infrastructure
  - Biomass conversion to chemicals, materials, fuels
  - Carbon capture, storage, utilization:
    - CO_2 conversion to chemicals, materials, **fuels**

- Clean fuels and products
- Carbon-negative
- HYDROGEN

Earthshots: DOE, National Labs, Academia, and Industry Collaboration

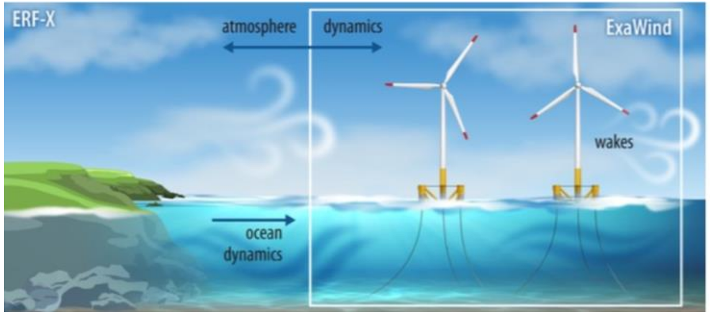
Future energy system scenarios, market and policy, sustainability and techno-economic analytics were exploited to develop each Energy Earthshot.

ENERGY earthshots U.S. DEPARTMENT OF ENERGY | Floating Offshore Wind™

>70% Reduction | 2035

~ 1 TW of wind installed in the US by 2035

ENERGY earthshots U.S. DEPARTMENT OF ENERGY | Hydrogen

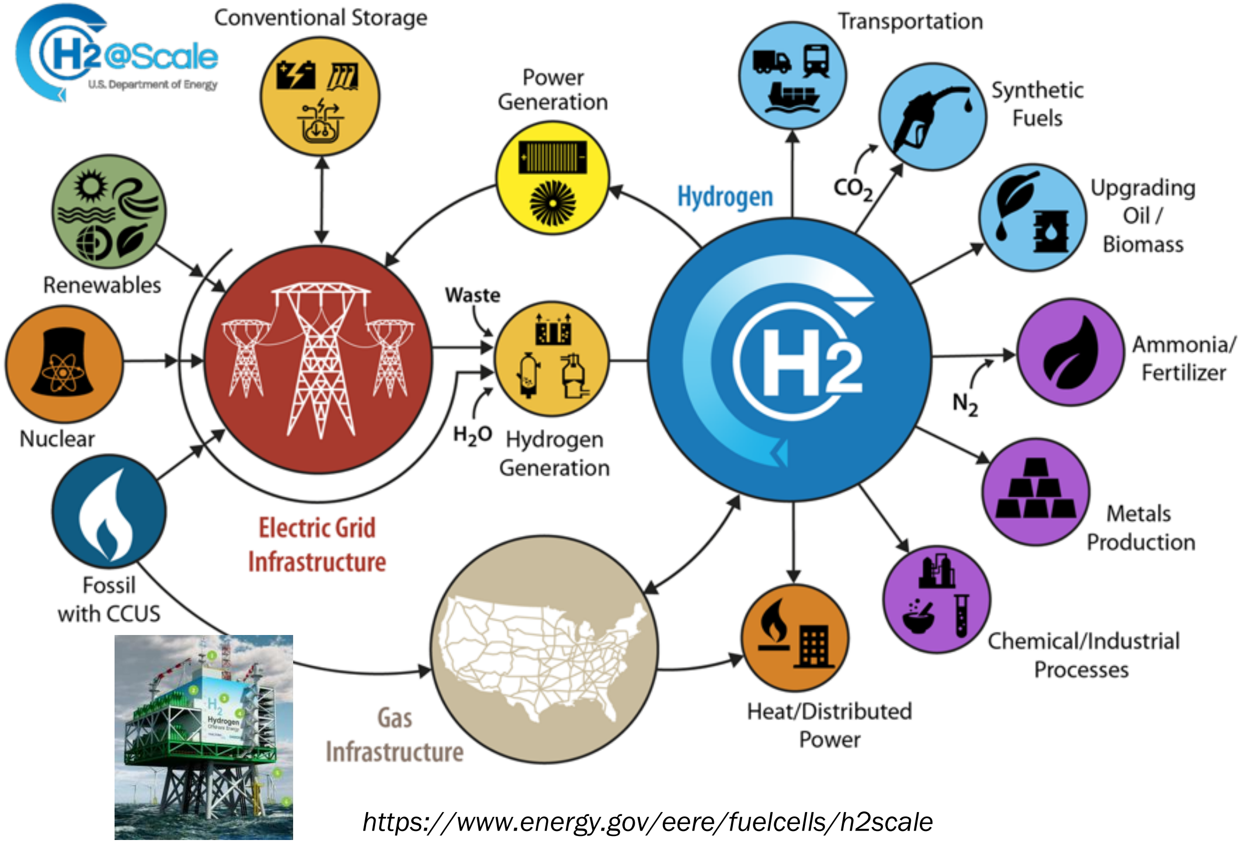


ENERGY earthshots U.S. DEPARTMENT OF ENERGY | Clean Fuels & Products™

NREL Transforming ENERGY | BERKELEY LAB Bringing Science Solutions to the World

Sandia National Laboratories | OAK RIDGE National Laboratory

Net-zero targets → U.S. needs ~100 million metric tons of H_2 per year by 2050



https://www.energy.gov/eere/fuelcells/h2scale

Hydrogen: grid, transportation, industry, buildings, agriculture

- Interconversion of electrical and chemical energy
- Grid integration
- Fuel, feedstocks, chemicals/materials
- CO_2 capture, conversion,

Hydrogen Earthshot (1 1 1)

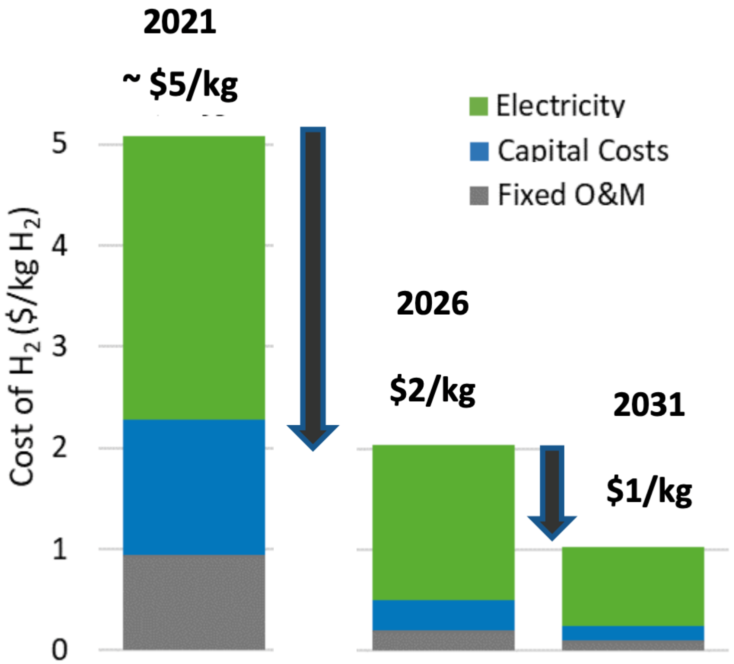
Context: Hydrogen Shot: "1 1 1"

$1 for 1 kg in 1 decade for clean hydrogen

Energy Earthshots U.S. Department of Energy | Hydrogen

Launched June 7, 2021
Summit Aug 31-Sept 1, 2021

Example: Cost of Clean H_2 from Electrolysis



Electrolysis: One of several pathways to reach goals

- Reduce electricity cost from >$50/MWh to
  - $30/MWh (2025)
  - $20/MWh (2030)
- Reduce capital cost >80%
- Reduce operating & maintenance cost >90%

Bipartisan Infrastructure Law – $9.5B H2 Highlights

- **$8B** for at least 6-10 regional clean H2 Hubs
- **$1B** for electrolysis (and related H2) RD&D
- **$0.5B** for clean H2 technology mfg. & recycling R&D
- Aligns with H2 Shot priorities by directing work to reduce cost of clean H2 to $2/kg by 2026
- National H2 Strategy & Roadmap

Inflation Reduction Act

- Up to **$3/kg H2** Production Tax Credit for producing clean hydrogen (<0.45 kg CO2eq/kg H2)

2020 Baseline: PEM low volume capital cost ~$1,500/kW, electricity at $50/MWh. Need less than $300/kW by 2025, less than $150/kW by 2030 (at scale)

(Adapted from multiple briefing slides from Sunita Satyapal, DOE's HFTO)

National Laboratory Collaboration is Critical for Success

Hydrogen Production

H2NEW — Hydrogen from Next-generation Electrolyzers of Water — U.S. DEPARTMENT OF ENERGY

NREL Transforming ENERGY
Idaho National Laboratory
Argonne NATIONAL LABORATORY
BERKELEY LAB Bringing Science Solutions to the World
Lawrence Livermore National Laboratory
Los Alamos NATIONAL LABORATORY EST. 1943
NATIONAL ENERGY TECHNOLOGY LABORATORY
OAK RIDGE National Laboratory
Pacific Northwest NATIONAL LABORATORY

Hydrogen Storage

HyMARC — Hydrogen Materials Advanced Research Consortium

Sandia National Laboratories
NREL Transforming ENERGY
Pacific Northwest NATIONAL LABORATORY
Lawrence Livermore National Laboratory
BERKELEY LAB Bringing Science Solutions to the World

Hydrogen Production

HydroGEN Advanced Water Splitting Materials

NREL Transforming ENERGY
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Idaho National Laboratory

Fuel Cells

M2FCT MILLION MILE FUEL CELL TRUCK — U.S. DEPARTMENT OF ENERGY

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ENERGY **earthshots** U.S. DEPARTMENT OF ENERGY | Clean Fuels & Products™

Mobilize Renewable Carbon Resources	Carbon-Efficient Conversion
Expand and Develop New Feedstocks: Develop and utilize new technologies to maximize carbon incorporation and retention to generate low-cost, low-emissions biomass, waste, and CO_2 feedstocks at scale	**New Conversion Paradigm:** Develop technologies to maximize conversion of resources into fuels and chemicals utilizing clean power, clean hydrogen, clean heat, and optimized reactor systems
Examples: Forest residues, agricultural wastes, municipal solid waste, recycled materials, energy crops, algae, CO_2	**Examples:** Biomass gasification to SAF, solar fuels, power to liquids, catalytic conversion of CO_2

CO_2 >85% net reduction vs. fossil-based sources

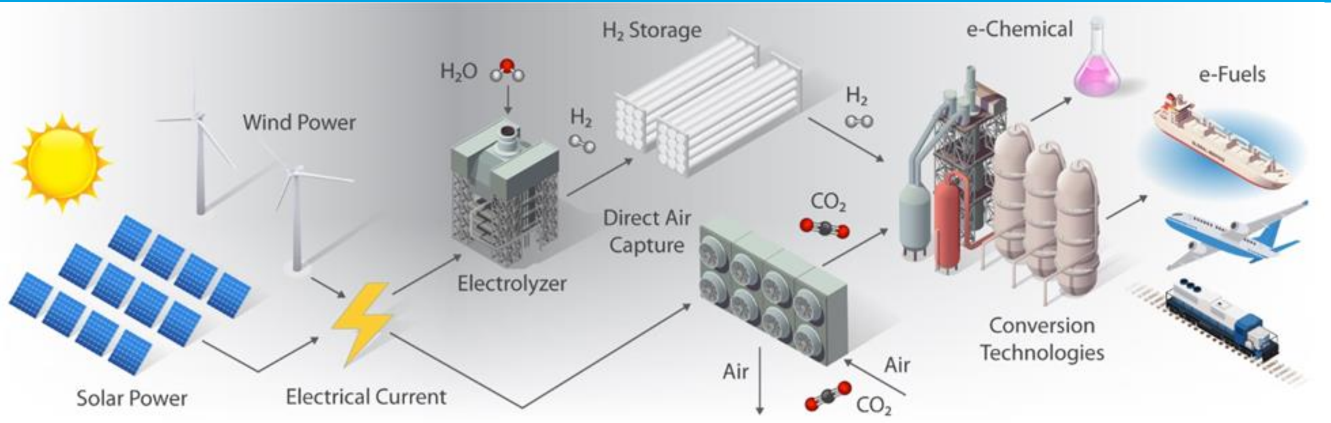
2035

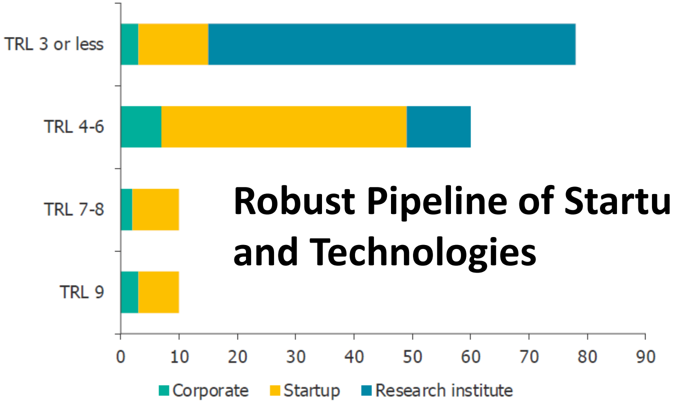
2050 Resource Supply | **2050 Projected Hydrocarbon Demand**

1,050 million metric tons (MMT) biomass and waste + 450 MMT CO_2 ...can be converted into... >400 MMT* fuels and chemicals

*This Energy Earthshot assumes that 50% of marine, rail, off-road, hydrocarbon chemicals and 100% of aviation demand will be met by hydrocarbon fuels in 2050.

CO_2 Utilization to Fuels and Chemicals





Robust Pipeline of Startups and Technologies

Market value of CO_2 Utilization Products in 2017

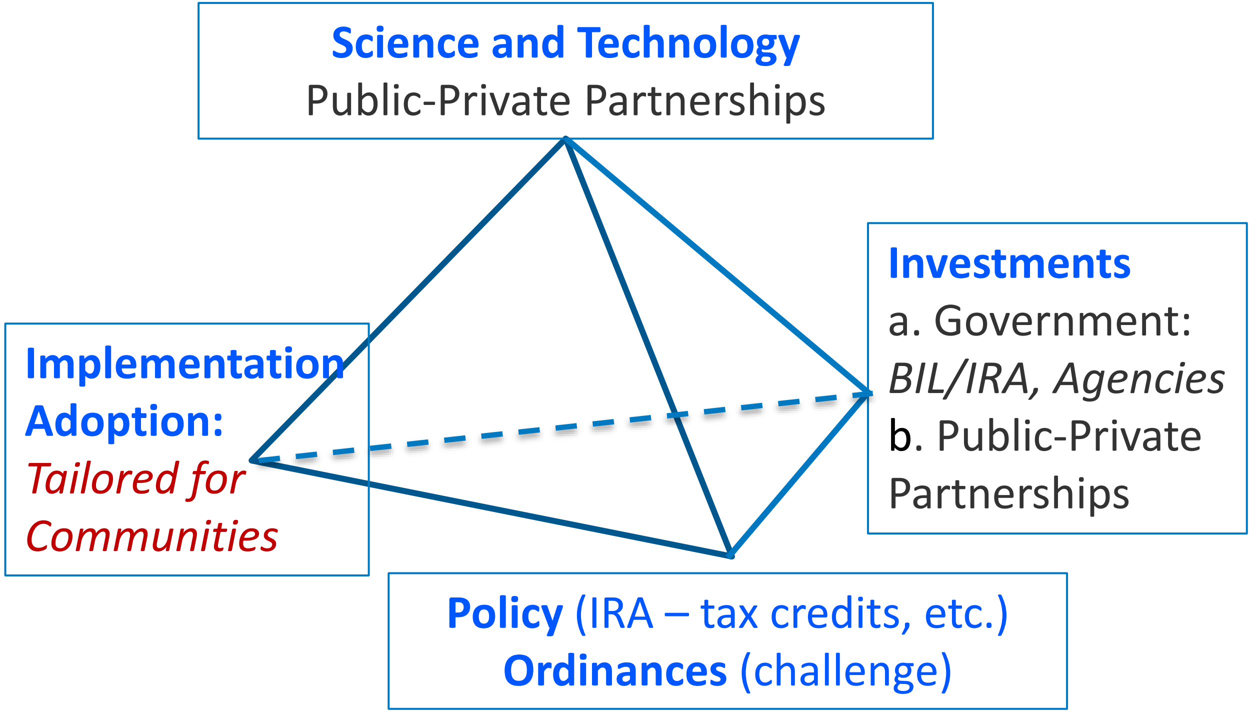
a. Fuels	$3.82 Trillion
b. Building materials	$1.37 Trillion
c. Plastics	$0.41 Trillion

Jacobson and Lucas, Carbon 180, 2018

Global CO_2 Initiative, *Implementing CO_2 Capture and Utilization at Scale and Speed,* May 2022

FINAL REMARKS

- Achieving each Earthshot requires a highly orchestrated team of researchers, with complimentary expertise
- Science and Technology Advances alone are not sufficient to achieve Net Zero Emissions



NREL
Transforming ENERGY

Thank you

Emerging Approach: Reactive Capture of CO_2

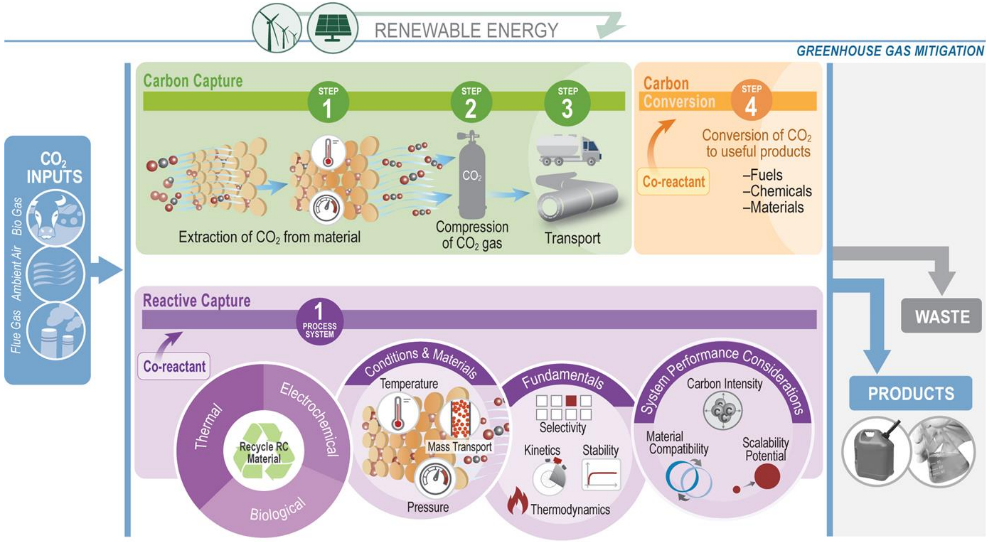
Reactive Capture Definition: The coupled process of capturing CO_2 from a mixed gas stream and converting it into a valuable product *without* going through a purified CO_2 intermediate

Can Include:

- Integration of CO_2 separation and conversion in one step
- Integration of separation and conversion in one unit
- Process intensification

Product Targets:

Form a valuable product, or mixture of products, in a more reduced state than CO_2



M. Freyman, et al., *Joule* 7 (2023) 631-651.