EESI
Environmental and Energy Study Institute

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Energy Earthshots: The Frontier of Climate Innovation

Thursday, February 01, 2024

About EESI

Non-partisan Educational Resources for Policymakers

A bipartisan Congressional caucus founded EESI in 1984 to provide non-partisan information on environmental, energy, and climate policies

Direct Assistance for Equitable and Inclusive Financing Program

In addition to a full portfolio of federal policy work, EESI provides direct assistance to utilities to develop “on-bill financing” programs

Commitment to Diversity, Equity, Inclusion, and Justice

We recognize that systemic barriers impede fair environmental, energy, and climate policies and limit the full participation of Black, Indigenous, people of color, and legacy and frontline communities in decision-making

Sustainable Solutions

Our mission is to advance science-based solutions for climate change, energy, and environmental challenges in order to achieve *our vision of a sustainable, resilient, and equitable world*.

Policymaker Education

Briefings and Webcasts

Live, in-person and online public briefings, archived webcasts, and written summaries

Climate Change Solutions

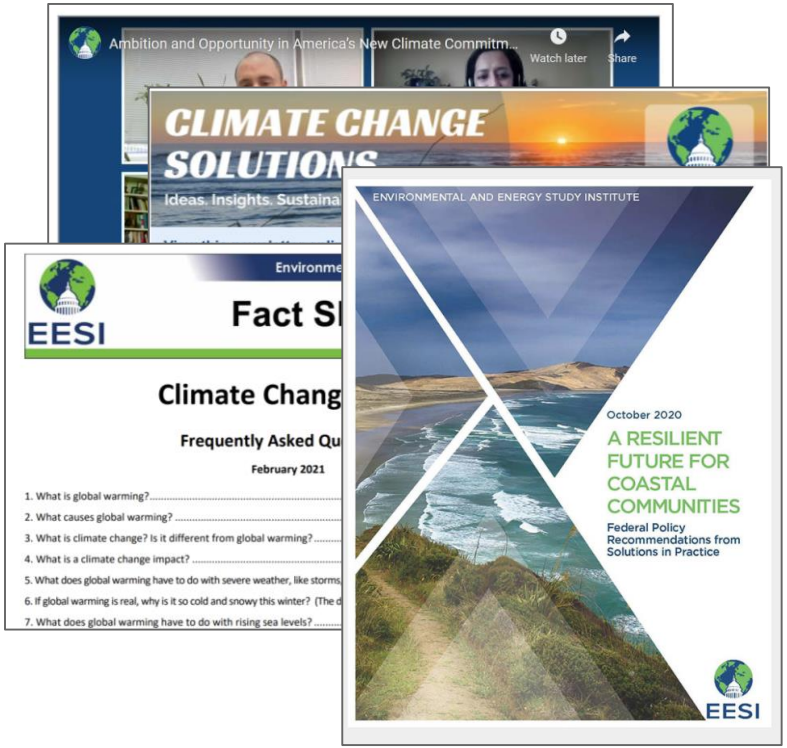
Bi-weekly newsletter with everything policymakers and concerned citizens need to know, including a legislation and hearings tracker

Fact Sheets and Issue Briefs

Timely, objective coverage of environmental, clean energy, and climate change topics

Social Media (@EESIOnline)

Active engagement on Twitter, Facebook, LinkedIn, and YouTube



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What did you think of the briefing?

Please take 2 minutes to let us know at:
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Thursday, February 01, 2024

ENERGY earthshots
U.S. DEPARTMENT OF ENERGY

ENERGY EARTHSHOTS: THE FRONTIER OF CLIMATE INNOVATION

Industrial Heat Shot™ &

Affordable Home Energy Shot

Dr. Carolyn Snyder, *Deputy Assistant Secretary for Buildings & Industry, Office of Energy Efficiency & Renewable Energy*

February 1, 2024

ENERGY earthshots
U.S. DEPARTMENT OF ENERGY

INDUSTRIAL HEAT SHOT

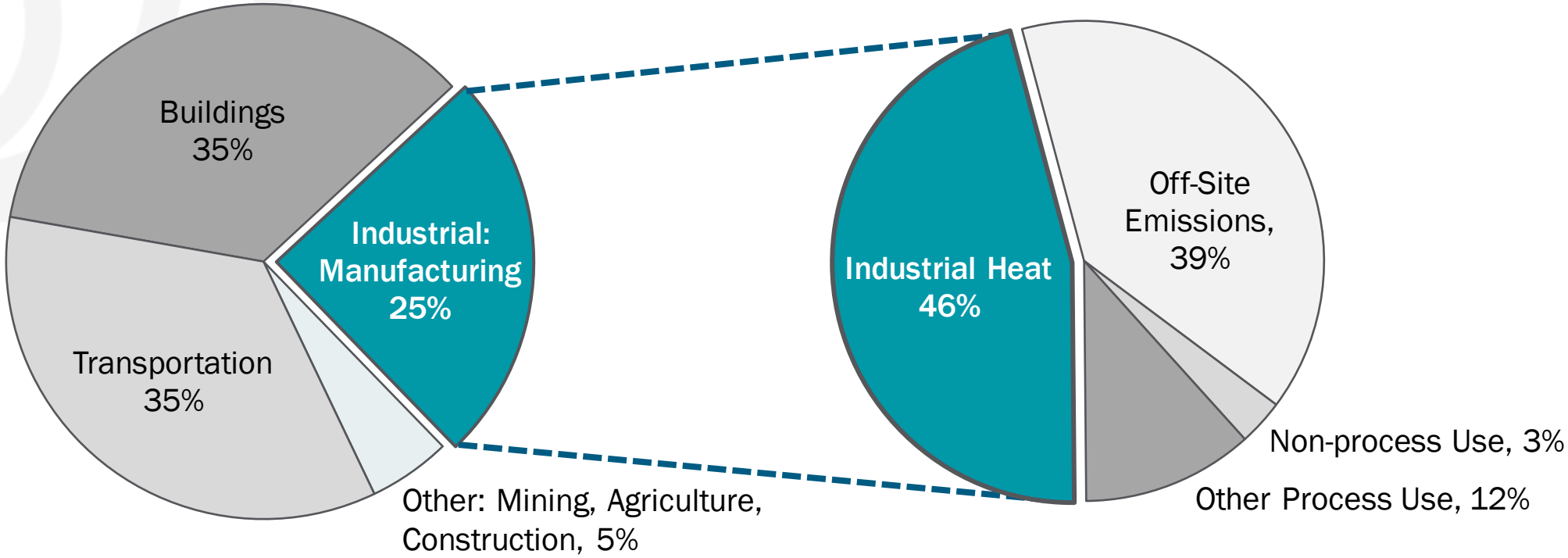
Develop cost competitive industrial heat decarbonization technologies…

…with at least **85%** **lower** GHG emissions…

…by **2035**

Why Industrial Heat?

U.S. Energy-Related Emissions:
~11% Attributable to Industrial Heat



2020 Energy-Related CO_2 Emissions by U.S. Economic Sector

2020 Estimated Industrial: Manufacturing Energy-Related CO_2 Emissions by Source

Sources: EIA Annual Energy Outlook (2021); AMO 2018 Manufacturing Energy and Carbon Footprints (2022)

Why Industrial Heat?

ENERGY earthshots U.S. DEPARTMENT OF ENERGY | Industrial Heat™

Industrial Heat is <u>Essential</u> and <u>Pervasive</u>:

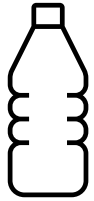
Every major industry subsector uses heat in <u>different ways</u> to make products…

drying
paper,
batteries

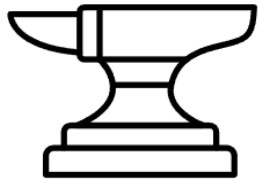
steam
pasteurized food

distillation
high purity
chemicals

melting
formed plastics,
semiconductors



smelting
iron, copper,
vehicle bodies



calcining
cement,
fuel cell catalysts

~300°C **Process Temperatures Needed** **>800°C**

Three Pathways

ENERGY earthshots U.S. DEPARTMENT OF ENERGY | Industrial Heat™

Goal: Reduce the amount of heat and/or emissions from heat to make cleaner products

Generate Heat from Clean Electricity

Reduce Emissions:
electrify equipment & use clean electricity, improve energy efficiency

Examples:
resistive heating, heat pumps, microwave heating, thermal storage, etc.

Integrate Clean Heat from Alternative Sources

Reduce Emissions:
switch to low-emissions heat sources

Examples:
solar thermal, nuclear, geothermal, hydrogen, some sustainable fuels

Innovative Low- or No-Heat Process Technologies

Reduce Emissions:
new chemistry and emerging biotechnology processes to reduce heat demand

Examples:
bio-based manufacturing, electrolysis, ultraviolet curing, advanced separations, etc.

Enabling technologies and systems: energy storage, materials, modeling, data analytics, etc.

All-Hands-on-Deck Effort

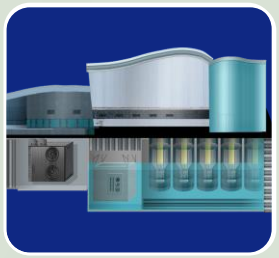
ENERGY earthshots U.S. DEPARTMENT OF ENERGY | Industrial Heat™

Office of Science

- Foundational R&D capabilities at the user facilities
- High performance computing for manufacturing

Industrial Efficiency and Decarbonization Office

RD&D in manufacturing processes, technologies, products, facilities, and supply chains



Nuclear Energy

RD&D to expand nuclear energy to industrial, transportation, and energy storage applications

Bioenergy Technologies Office

RD&D of processes using alternative feedstocks and low/no heat manufacturing options

Hydrogen and Fuel Cell Technologies Office

RD&D of clean hydrogen technologies for low-carbon feedstocks and fuels

Fossil Energy and Carbon Management

RD&D to convert captured carbon into products without the need for heat or using substantially less heat

Solar Energy Technologies Office

RD&D in concentrated solar thermal and thermal storage technologies

Office of Clean Energy Demonstrations

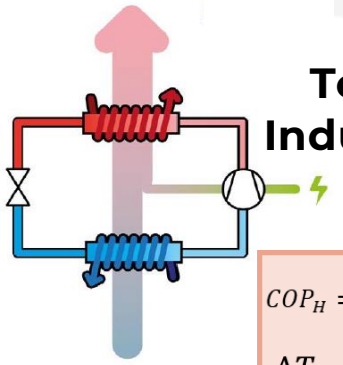
Industrial decarbonization demonstration projects

DOE National Laboratories RD&D

DOE is Driving Innovation

ENERGY earthshots U.S. DEPARTMENT OF ENERGY | Industrial Heat™

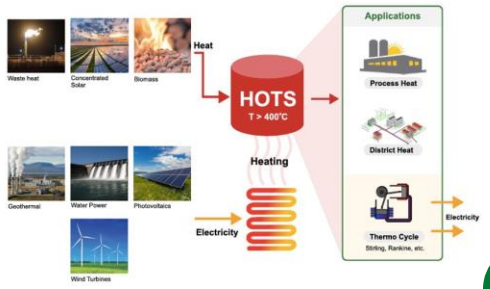
Industrial Efficiency and Decarbonization *(IEDO, June 2023)*
Announced awards for RD&D projects that advance industrial heat pumps, thermal storage, and other technologies to decarbonize thermal processes



Higher Temperature Industrial Heat Pumps

$$COP_H = \frac{heat\ output}{electric\ power\ input}$$

$$\Delta T_{Lift} = T_H - T_C$$



High Operating Temperature Storage

Electrified Processes for Industry without Carbon *(IEDO, May 2023)*
Announced selection of EPIXC to develop electrified industrial heating processes, supporting technologies, and a skilled workforce

ASU Arizona State University
EPIX ELECTRIFIED PROCESSES FOR INDUSTRY WITHOUT CARBON

EERCs & Science Foundations for Energy Earthshots *(SC, September 2023)*
$264 million awarded for Basic Research in Support of Energy Earthshots, including 2 Research Centers and 6 Science Foundations projects for IHS

OAK RIDGE National Laboratory
Argonne NATIONAL LABORATORY

DOE is Driving Innovation

ENERGY earthshots U.S. DEPARTMENT OF ENERGY | Industrial Heat™

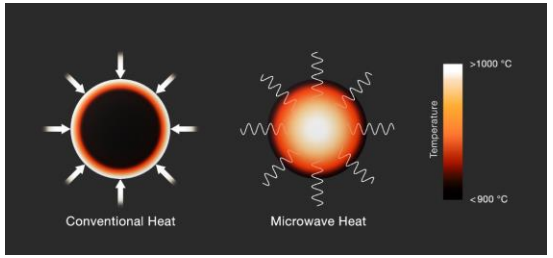
Hydrogen Hubs *(OCED, October 2023)*
$7 billion for seven Regional Clean Hydrogen Hubs to accelerate the deployment of low-cost, clean hydrogen for a broad range of end uses, including industrial heat

IEDO Multi-Topic FOA *(IEDO, January 2024)*
Announced awards for RD&D projects that advance electrification, heat pumps, low-/no-heat processes, hydrogen end-use, and thermal storage

Industrial Heat Shot Summit *(S4, October 2023)*
Convened DOE leaders, members of Congress, and climate champions to discuss the importance of decarbonizing industrial heat, EEJ, and potential technology pathways

IEDO FY24 FOAs *(IEDO, December 2023 and January 2024)*
Advancing technologies to decarbonize industrial heat, including cross-sector approaches and targeted investments in energy-intensive industries

Membrane separations



Electromagnetic heating

ENERGY earthshots U.S. DEPARTMENT OF ENERGY | Affordable Home Energy™

Affordable Home Energy Shot

The Energy Affordability Challenge

Energy earthshots U.S. Department of Energy | Affordable Home Energy™

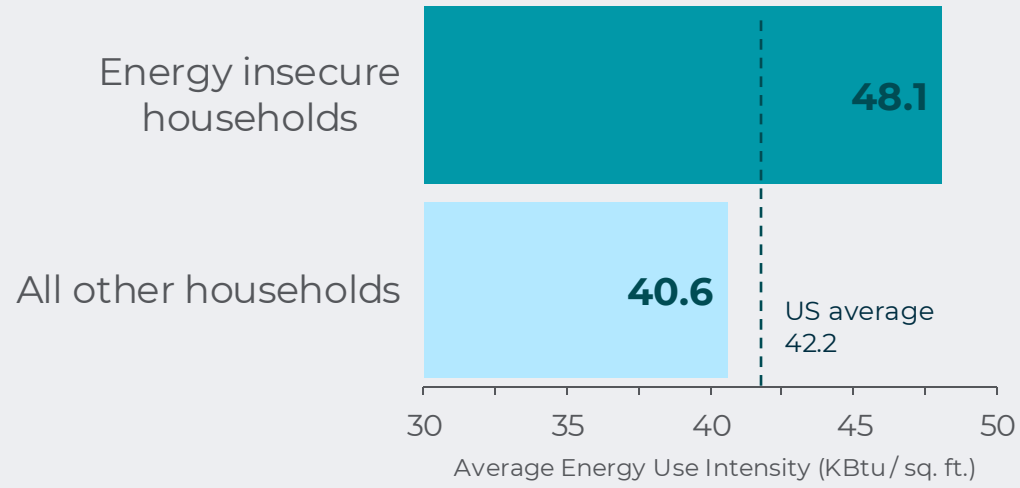
Our imperative is to deliver equitable solutions to households with the highest energy burdens.

High energy burdens
1 in 4 households face high energy burdens (>6% of income spent on energy).

Energy affordability challenges
1 in 5 households were unable to pay an energy bill in full in 2022.

Adverse pollution & health impacts
Black children are nearly **twice as likely** to have asthma compared to the national average.

Households that experience energy insecurity live in less efficient homes.

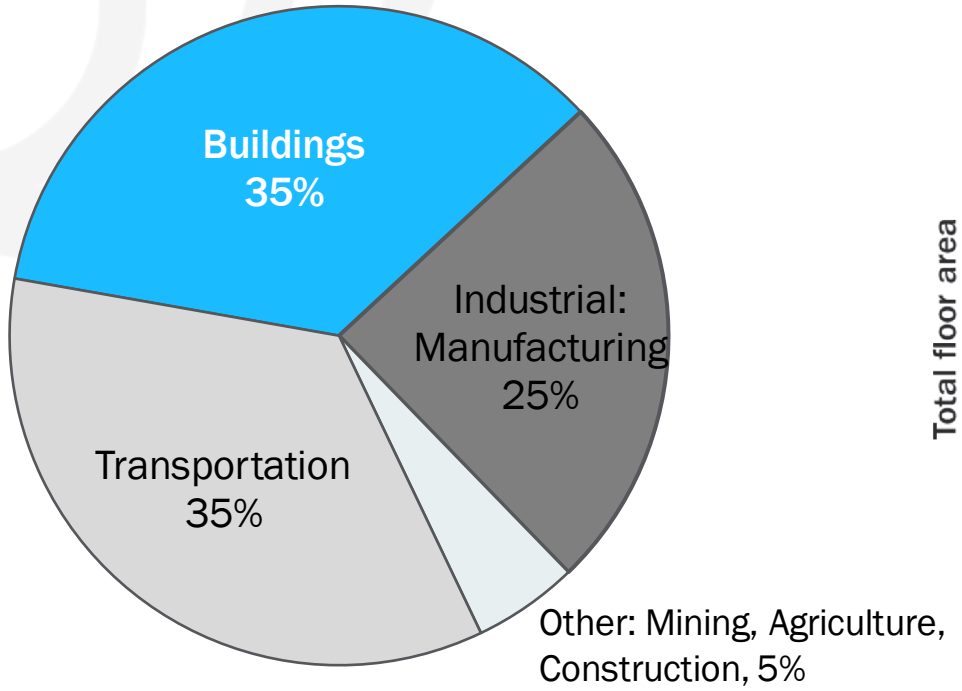


Source: US Energy Information Administration, 2020 Residential Energy Consumption survey

Building Decarbonization Must Be Accelerated

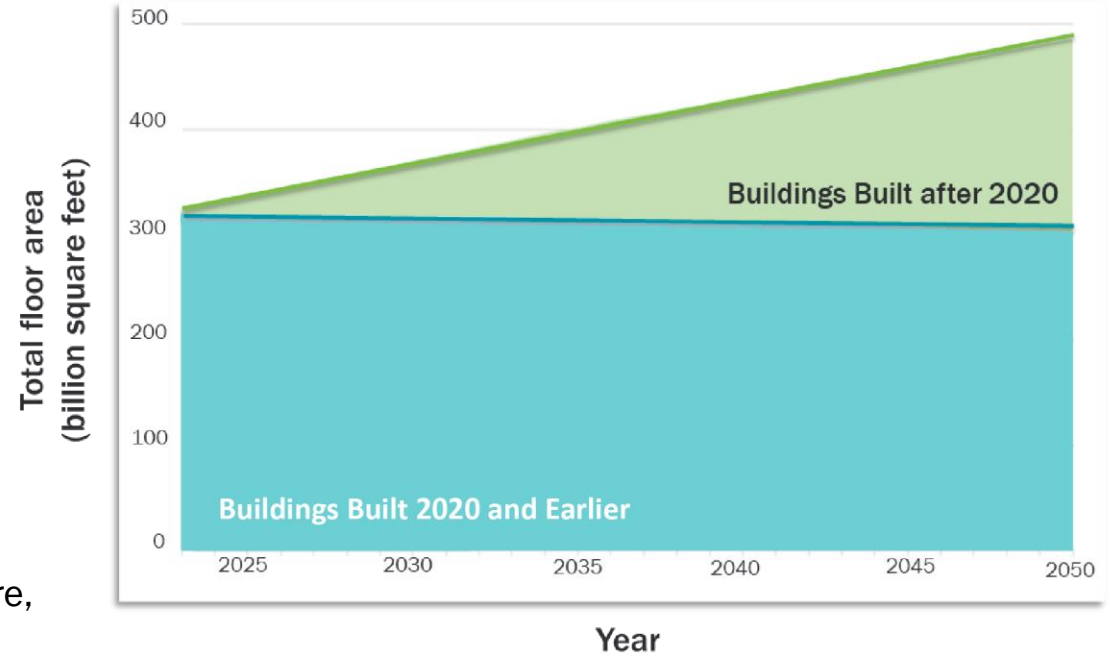
ENERGY earthshots U.S. DEPARTMENT OF ENERGY | Affordable Home Energy™

Buildings are a **leading emitter of GHGs** in the United States



2020 Energy-Related CO_2 Emissions by U.S. Economic Sector

Retrofits are key: The majority of buildings that will exist in 2050 have already been built today



Source: ACEEE calculations based on data in EIA AEO 2023; LBNL Building Performance Standards Overview graphics

Lead Target

ENERGY earthshots U.S. DEPARTMENT OF ENERGY | Affordable Home Energy™

Reduce by 50%+ the cost of retrofit packages needed to decarbonize affordable housing while lowering energy bills by 20% within a decade.

50% lower upfront cost

20% lower energy bills

Within a decade

Three Technology Areas Unlock Cost Savings and Energy Performance

ENERGY earthshots U.S. DEPARTMENT OF ENERGY | Affordable Home Energy™

Integrated designs will deliver whole-home solutions

Building Envelope*

Improved livability and comfort make for more resilient homes

- Advanced leakage detection
- Low-impact retrofit techniques
- Panelized exterior insulation

Efficient Electrification*

Smaller, compact equipment and streamlined systems enable affordable and adaptable installations

- Lower-voltage equipment
- Plug-and-play HP designs
- Integrated ventilation packages

Smart Controls*

Flexible energy loads transform homes into energy resources

- Grid-interactive technologies
- Smart electric panels
- Shared circuit control between loads

*Listed technologies are examples of what could be achieved in each area and are not representative of every solution possibility

Example: Funding in Action

ENERGY earthshots U.S. DEPARTMENT OF ENERGY | Affordable Home Energy™

The Buildings Upgrade (Buildings UP) Prize

Provides more than $22 million in cash prizes and technical assistance to support the transformation of existing U.S. buildings into more energy-efficient and clean energy-ready homes, commercial spaces, and communities.

45 Phase 1 winners across the U.S. include:

- **Fairbanks, AK –** A program increasing access to affordable energy upgrades for low-income housing & nonprofits in Alaska on the frontline of climate change.
- **Evanston, IL -** Renovating affordable housing for climate resiliency, with focus on Black and Latin(x) neighborhoods.

Duluth, MN

Partner with Us!

ENERGY earthshots U.S. DEPARTMENT OF ENERGY | Affordable Home Energy™

Connect us with your constituents, so together we can create solutions that are meeting stakeholders where they are to innovate and advance the market.

Ways that we can work together –

- **Stakeholder Events**: can we partner with you to have them in your district?
- **Creation of a Roadmap**: we need the input of your constituents
- **Introduce Us to Constituents**: we need the hear from your constituents for their input that can inform future funding opportunities such as FOAs, prizes, etc.

Contact: Jenah.Zweig@hq.doe.gov

Achieving the DOE Long Duration StorageShot

Nidhi Thakar, VP of Policy and Regulatory

Form energy

Energy Storage
For A Better World

Rising to the challenge of climate change with a team that will deliver

LED BY ENERGY STORAGE VETERANS

Decades of cumulative experience in energy storage

- 100’s of MW of storage deployed

OUR INVESTORS: LONG-TERM AND IMPACT-FOCUSED

$820M+ in venture capital from top investors including: Breakthrough Energy Ventures (BEV), TPG’s Climate Rise Fund, Coatue Management, GIC, NGP Energy Technology Partners III, ArcelorMittal, Temasek, Energy Impact Partners, Prelude Ventures, MIT’s The Engine, Capricorn Investment Group, Eni Next, Macquarie Capital, Canada Pension Plan Investment Board, and other long-term, impact oriented investors

The Challenge

The electrical grid needs to fundamentally transform to meet today's challenges

Extreme weather events have become more frequent and disruptive

Power supply is becoming tighter

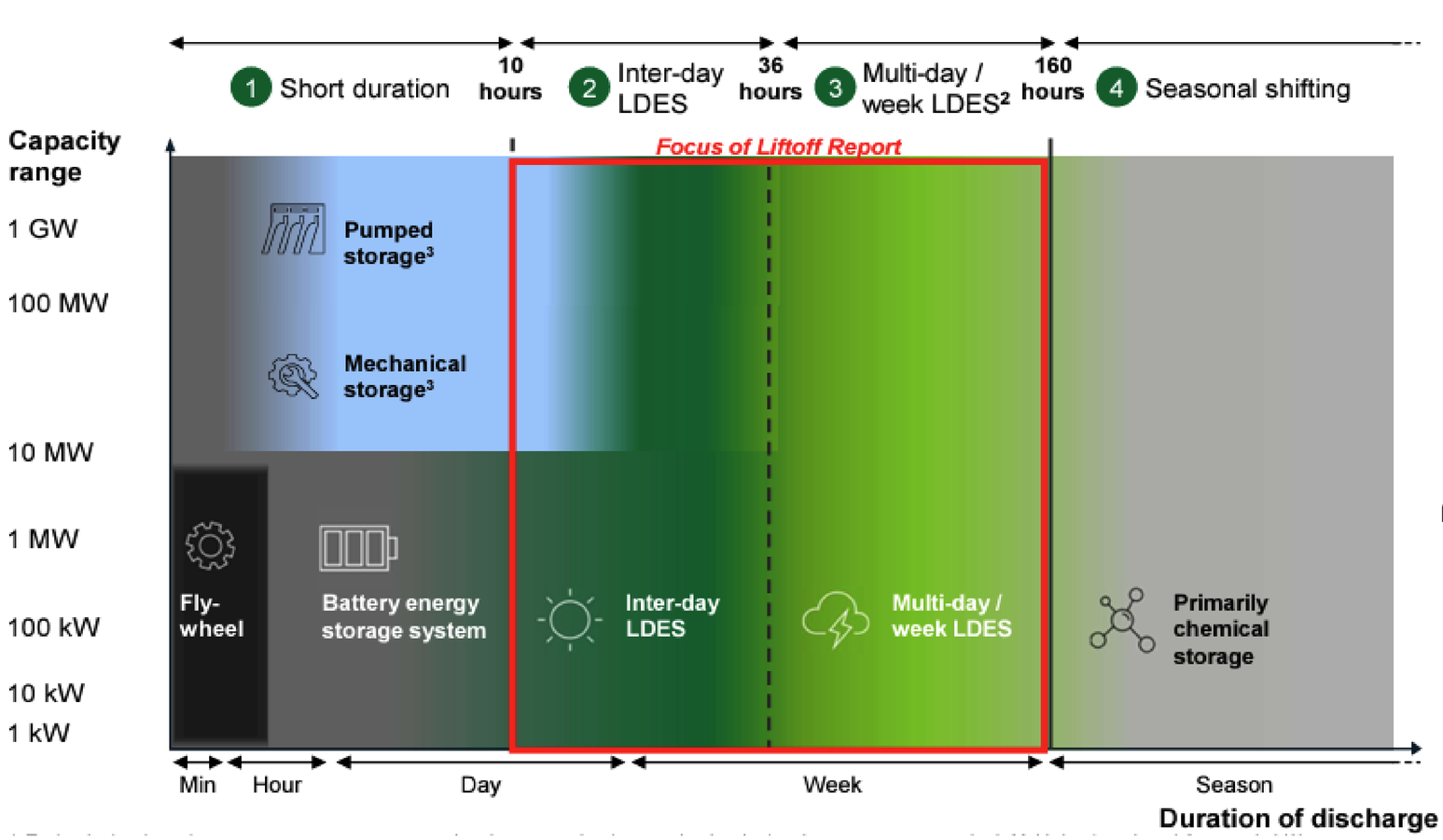
Intermittent resources need firming up

Transmission congestion and interconnection queues are increasing

DOE’s Long Duration Storage Shot is a Dedicated Effort to Drive Down Cost of LDES, in partnership with industry

Long Duration Energy Storage is the Key

LDES moves beyond today's li-ion technology to inter-day and multi-day storage



Codifying the technology

0-10 hours — 1 **Short duration:** Durations up to 10 hours

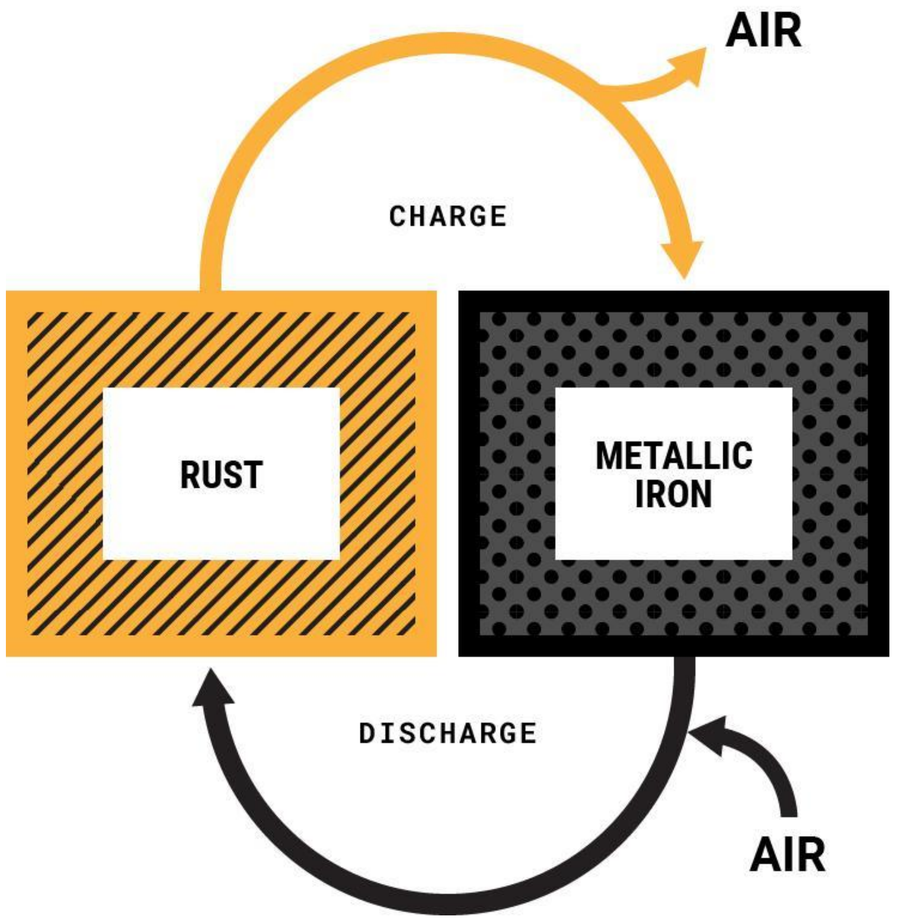
10-36 hours² — 2 **Inter-day LDES:** Sometimes called "diurnal"

36-160 hours¹ — 3 **Multi-day / week LDES:** Commonly called "seasonal"

160+ hours — 4 **Seasonal shifting:** Generally included in "seasonal", but distinct in that this does function as a conventional, storable fuel

Rechargeable iron-air is the best technology for multi-day storage

Form's 100-Hour Reversible Rust Battery



COST

Lowest cost rechargeable battery chemistry.
Less than 1/10th the cost of lithium-ion batteries

SAFETY

Non-flammable aqueous electrolyte. No risk of thermal runaway.

SCALE

Uses materials available at the global scale needed for a zero carbon economy. High recyclability.

DURABILITY

Iron electrode durability proven through decades of life and 1000's of cycles

What makes up a Form Energy system

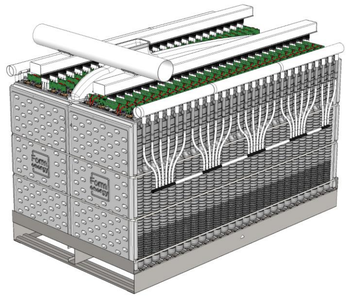
Modular design enables easy scaling to GWh systems

Cell

Electrodes + Electrolyte

Smallest **Electrochemical** Functional Unit

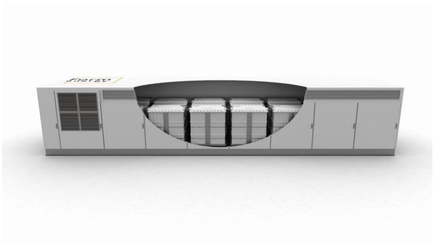
Battery Module



~50 **Cells**

Smallest Building Block of **DC** Power

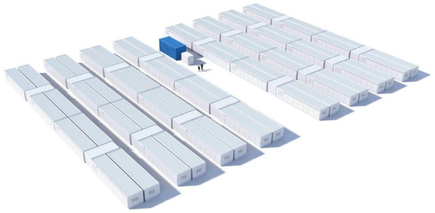
Enclosure



~5 **Modules**

Product Building Block with **integrated module auxiliary systems**

Power Block



~3.5 MW / 350 MWh

<2 acres

~50 - 100 **Enclosures**

Smallest independent system and **AC Power** building block

System

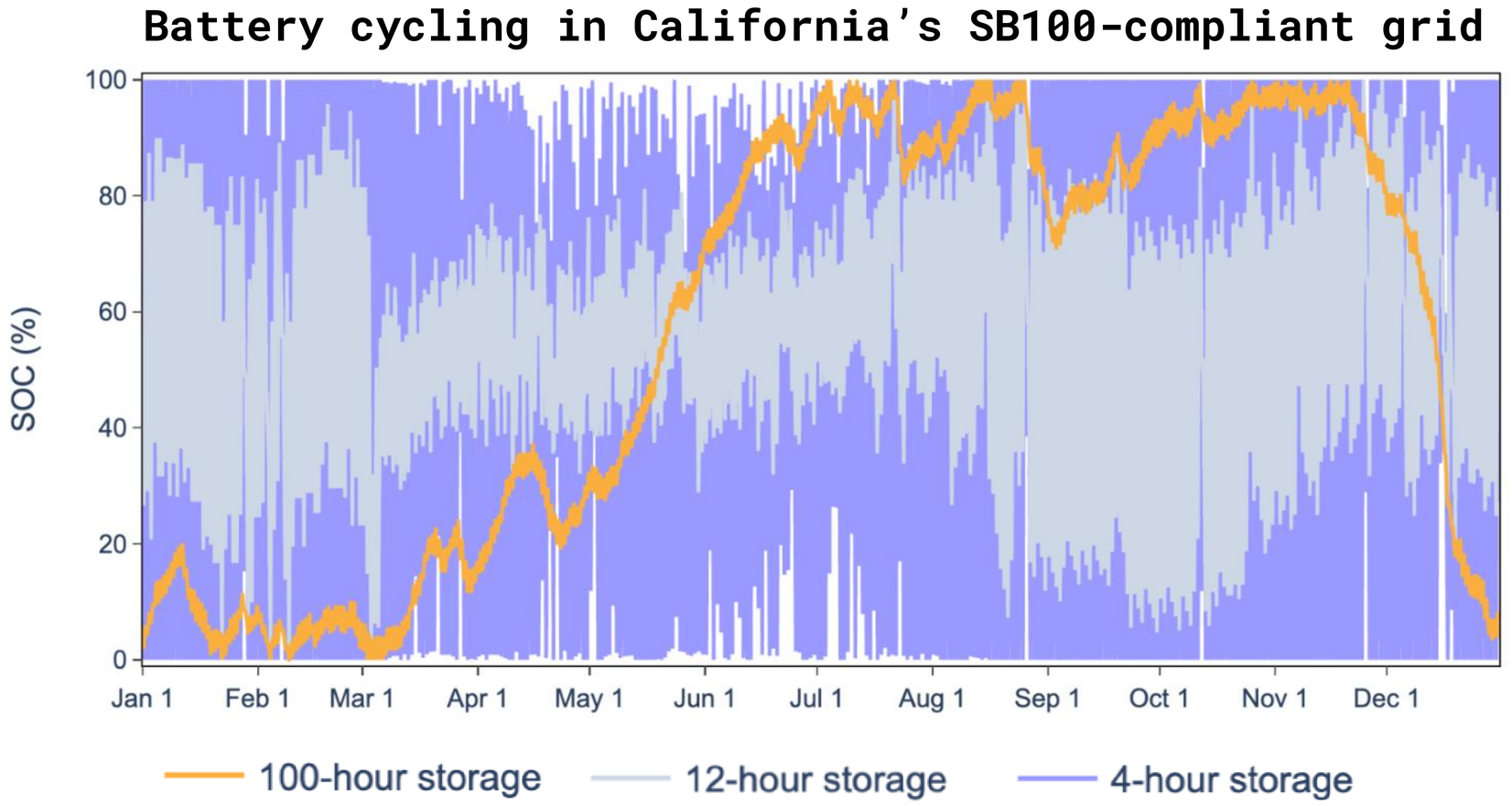
10 MW / 1000 MWh

5+ acres

10s - 100s of **Power Blocks**

Commercial Intent System

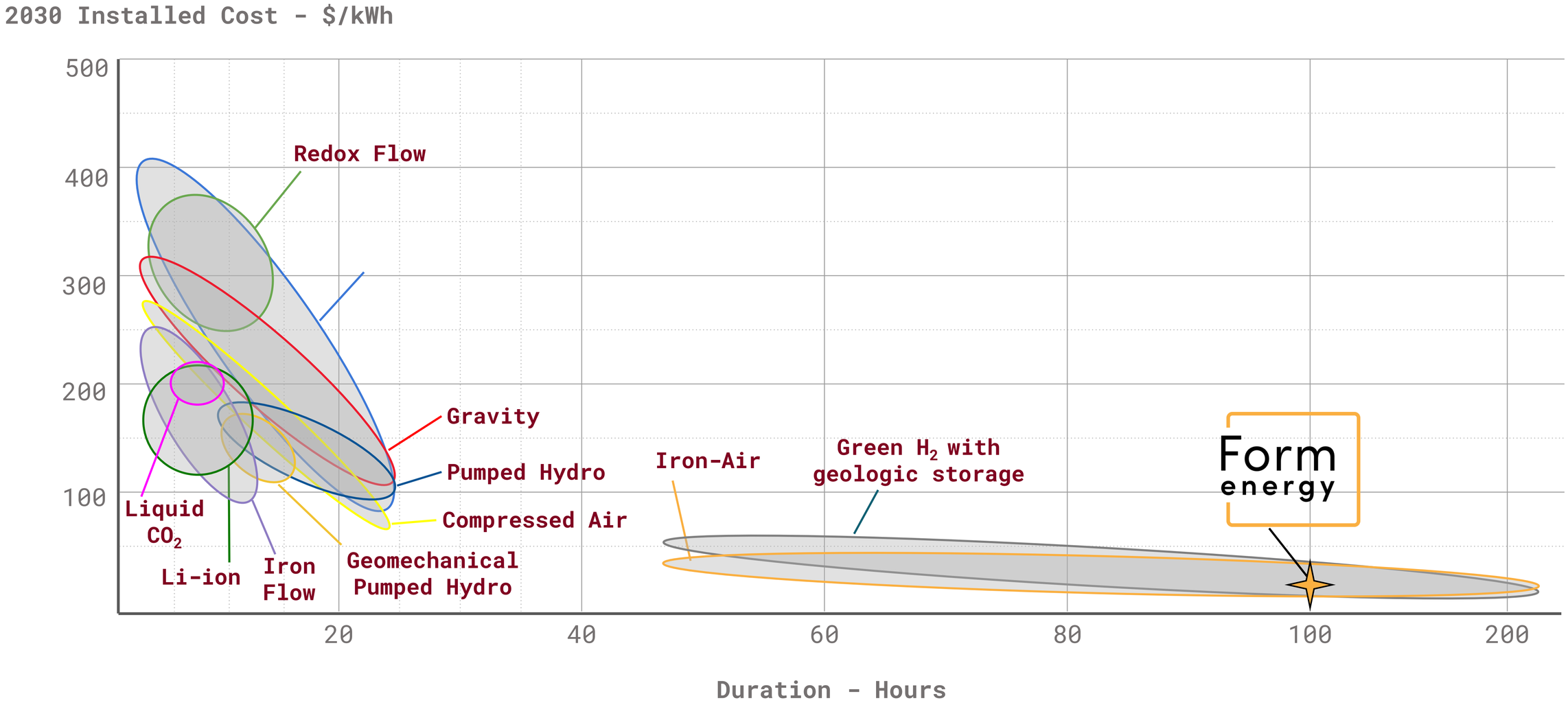
Multi-day storage, mid-duration storage, and lithium ion batteries provide different grid functions



Short- and medium-duration storage provide daily balancing for meeting ramps and hitting peaks.

Multi-day storage provides intra-day, multi-day, and seasonal energy balancing, supplying reliability needs unmet by short- and medium-duration storage.

Form's iron-air battery is the only technology targeting multi-day duration without geographic constraints



Form Factory 1: Commercial-Scale Manufacturing

Transforming Weirton Steel Land for Battery Manufacturing in West Virginia

- **Total Local Investment:** $760 million
- **Construction Start:** Early 2023
- **Production Start:** Late 2024
- **Jobs:** Minimum of 750 full-time jobs

Location Benefits

- Close to our existing pilot manufacturing facility in PA
- Strong natural infrastructure
- Local manufacturing know-how

Factory Function

- Semi-to-fully automated cell, module, & enclosure assembly
- Ability to scale production in modular blocks

Over 5 GWh of Commercial Engagements

First-of-its-kind **1.5 MW /150 MWh** MDS project in Cambridge, Minnesota to come online in 2024

Two 10 MW / 1,000 MWh MDS systems; one in Becker, MN and one in Pueblo, CO. Both expected to come online as early as 2025

5 MW / 500 MWh MDS system in collaboration with the California Energy Commission in Mendocino County; online by 2025

10 MW / 1000 MWh MDS system in New York to come online as early as 2025

15 MW / 1500 MWh MDS system in Georgia to come online as early as 2026

5 MW / 500 MWh MDS system in Virginia to come online as early as 2026

NREL
Transforming ENERGY

Energy Earthshots and the National Laboratories

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

February 1, 2024

Photo from iStock-627281636

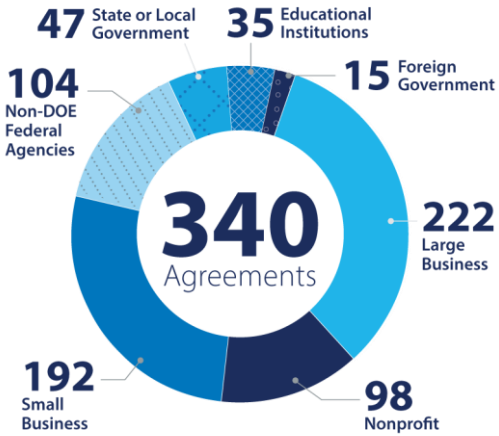
Coast to Coast

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

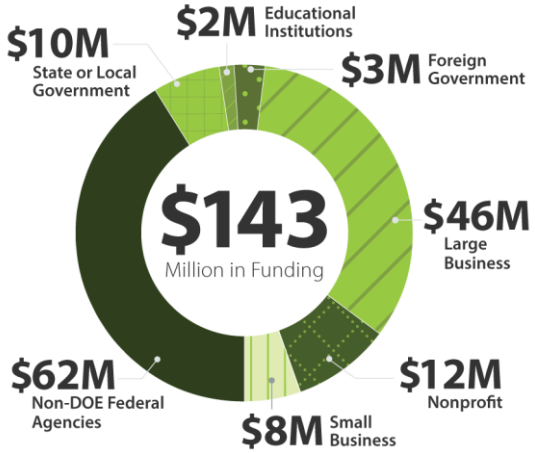
NREL at a Glance

- **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



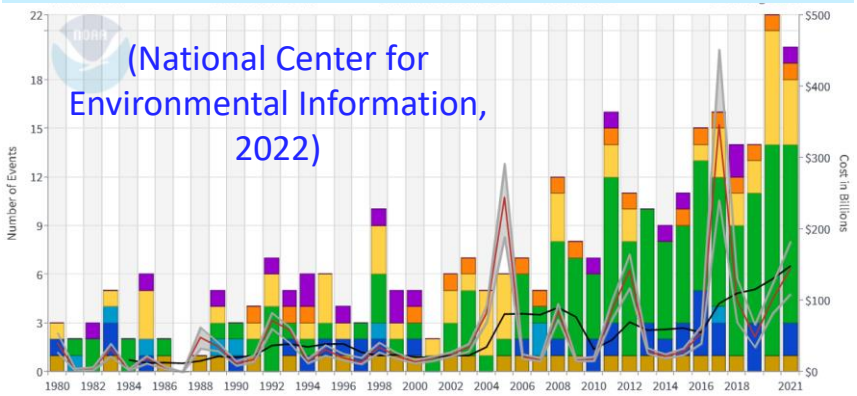
Agreements by Business Type

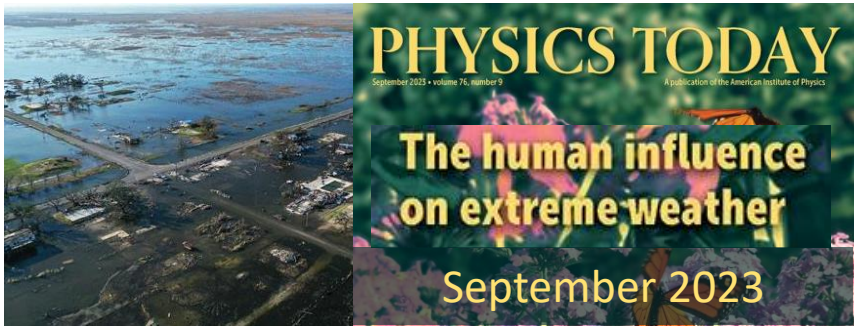


Funding by Business Type

Global Challenges Necessitate Earthshots

Billion-dollar disaster events in the U.S.





Economist, March 2018

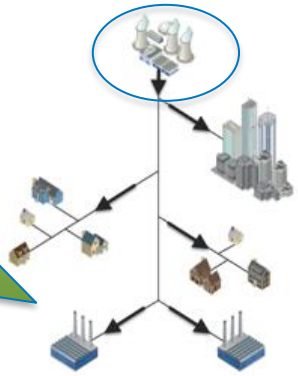
Emissions from Sectors: EPA (2021)
Transportation (29%); *Electricity* (25%)
Industry (23%); *Buildings* (13%)

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

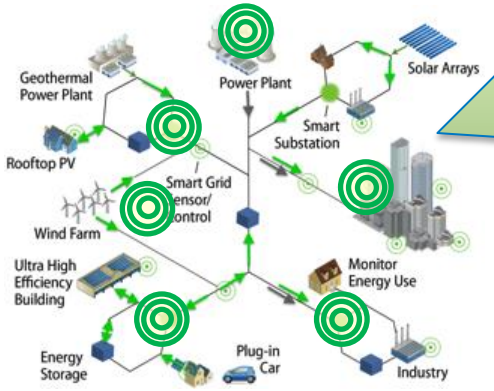
Evolution of the Conventional Power Grid Toward a Future Low-Carbon Energy System

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

Power System of the Past



Future Power Systems

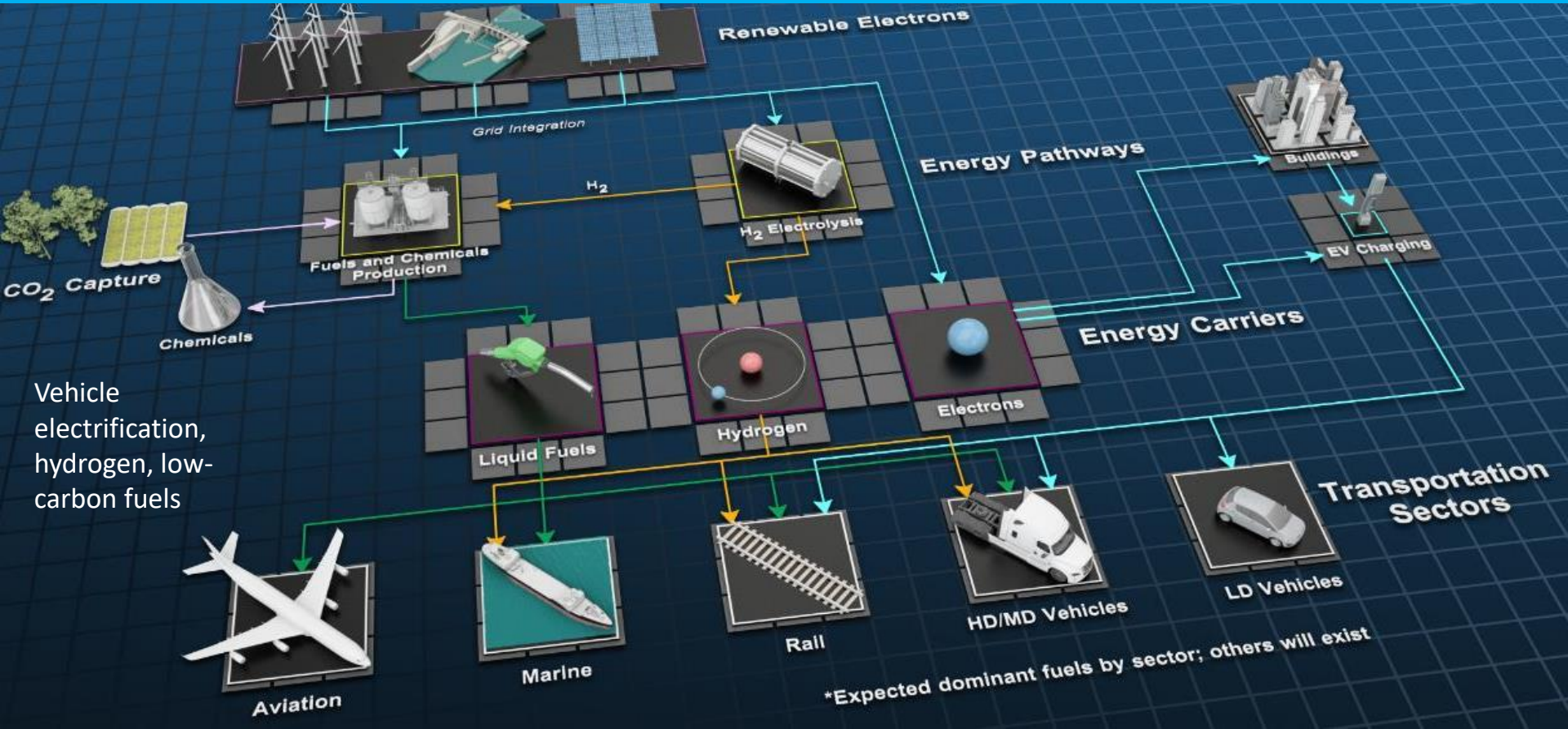


- More measurements and data
- More variable generation
- More distributed resources

- 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

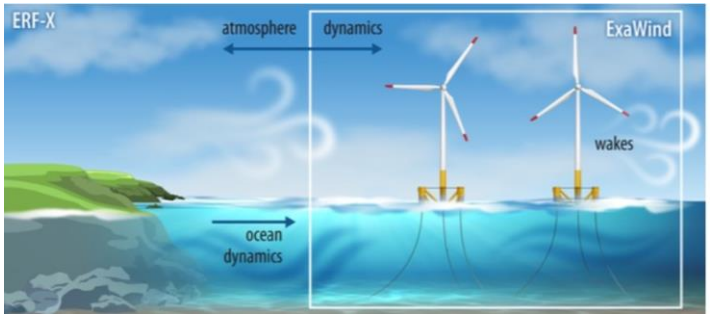
Future energy system scenarios, market and policy, sustainability and techno-economic analytics were exploited to develop each Energy Earthshot.

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

>70% Reduction

2035

~ 1 TW of wind installed in the US by 2035

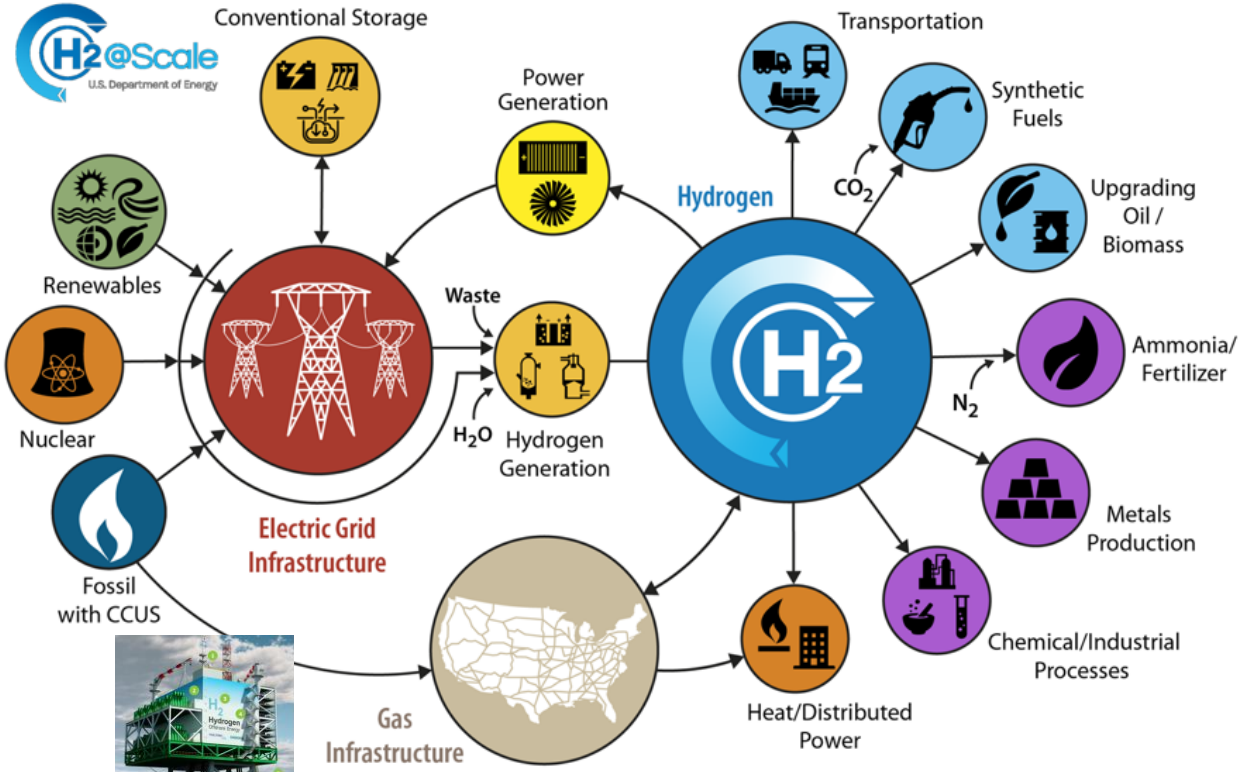


ENERGY earthshots U.S. DEPARTMENT OF ENERGY | Hydrogen

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

NREL | 8

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)

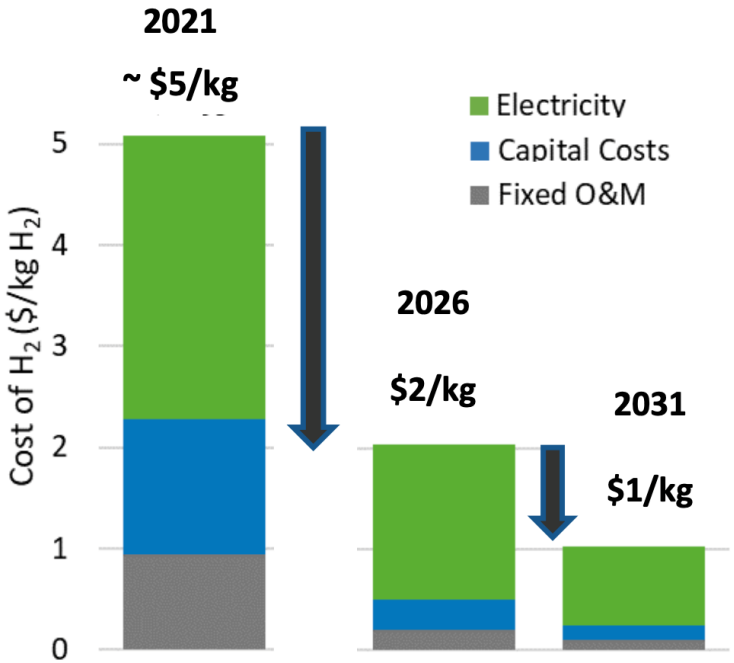
Context: Hydrogen Shot: "1 1 1"

$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

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Mobilize Renewable Carbon Resources

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

Examples:
Forest residues, agricultural wastes, municipal solid waste, recycled materials, energy crops, algae, CO_2

Carbon-Efficient Conversion

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:
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

1,050 million metric tons (MMT) biomass and waste

+ CO_2 450 MMT CO_2

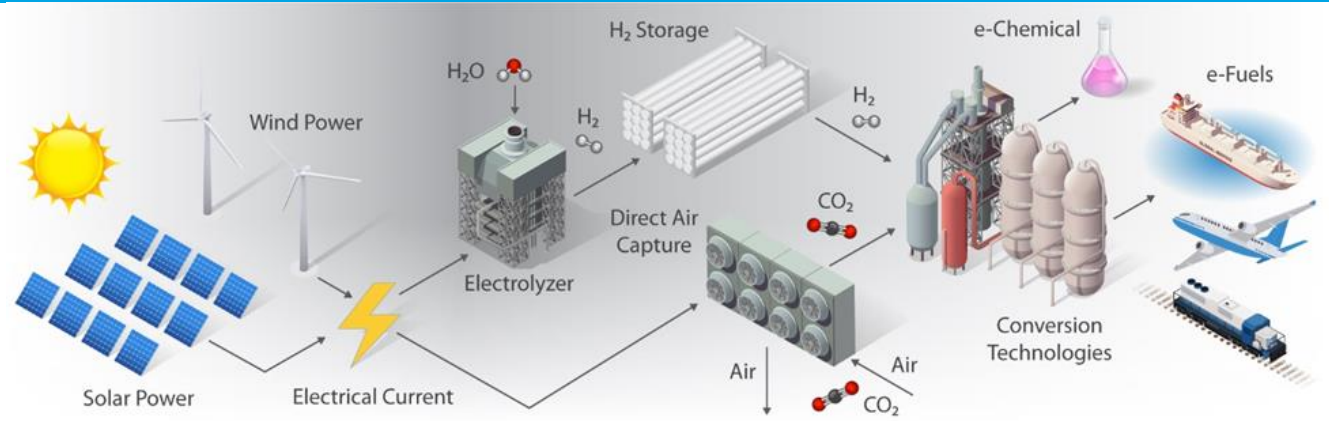
→ ...can be converted into... →

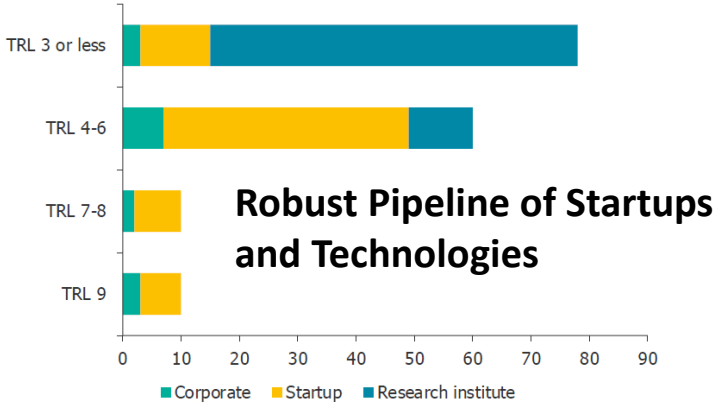
2050 Projected Hydrocarbon Demand

+ >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

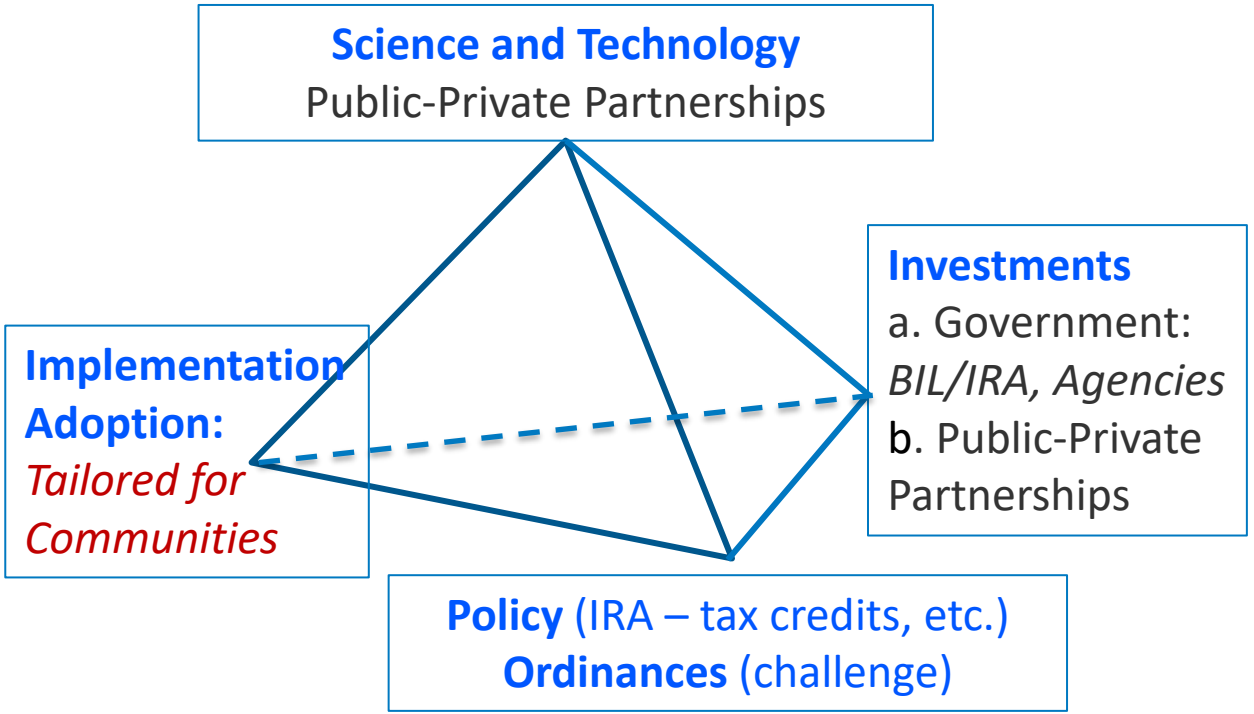
a. Fuels	$3.82 Trillion
b. Building materials	$1.37 Trillion
c. Plastics	$0.41 Trillion

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

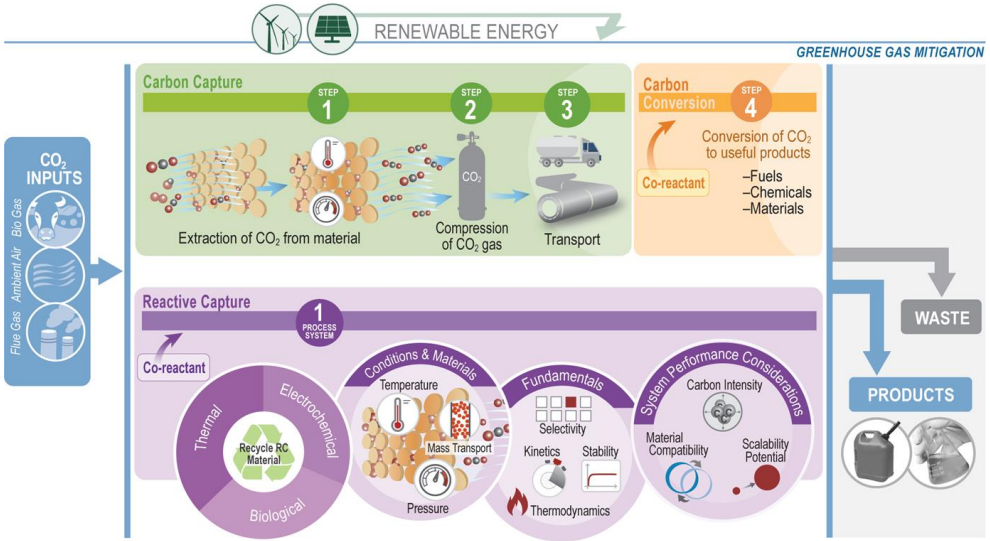
Reactive Capture Definition: The coupled process of capturing CO_2 from a mixed gas stream and converting it into a valuable product *without* going through a purified CO_2 intermediate

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.