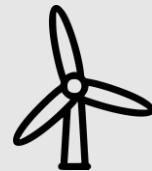




Decarbonizing the U.S. Energy Systems

Presentation to B.U. Advisory Committee on Socially Responsible Investing

*Prof. Peter Fox-Penner
Questrom School of Business
Director, Institute for Sustainable Energy
February 25, 2021*



Shoutout to the ISE Team for Their Help



Jacqueline Ashmore
Executive Director
Research Associate Professor,
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Professor, Earth & Environment



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Associate Director
Assistant Professor, Mechanical Engineering



Laura Hurley
Director
Marketing & Communications

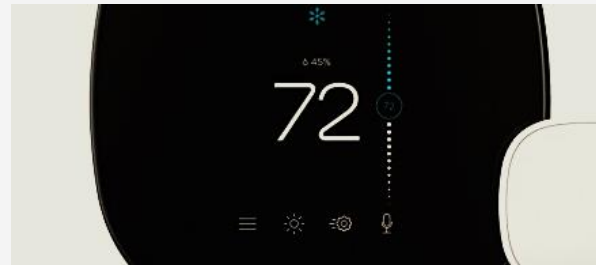


Grant Jones
College of Engineering
MS, Mechanical Engineering
Expected May 2022



Naseme Hallum
MET College
MS, Global Marketing Management
Expected May 2021

Energy & Climate Policy in Advanced Economies



**Maximize Energy
Efficiency**



**Electrify Transportation and Heat
or Use Clean Fuels**



**Convert Industrial Process
to Electricity or Clean Fuel**



Much Larger Grid
Meeting all Societal Goals:
**Affordable, Equitable,
Reliable, Financially
Viable**

JOINT INFRASTRUCTURE

Electrolysis

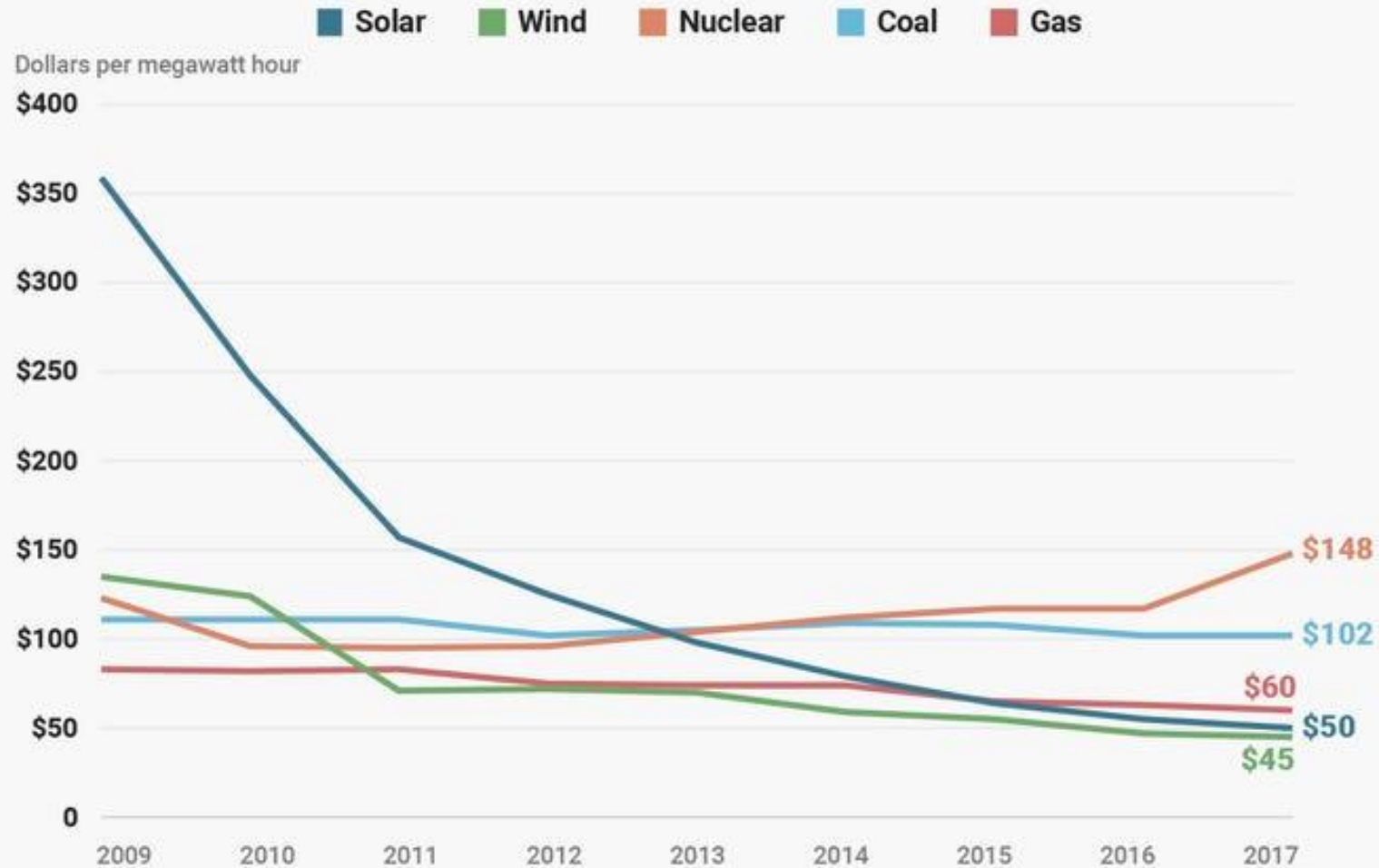
Clean Gen Fuels



**Clean Fuels, Including
Delivery Networks**

1. Carbon-Free Electricity Supply

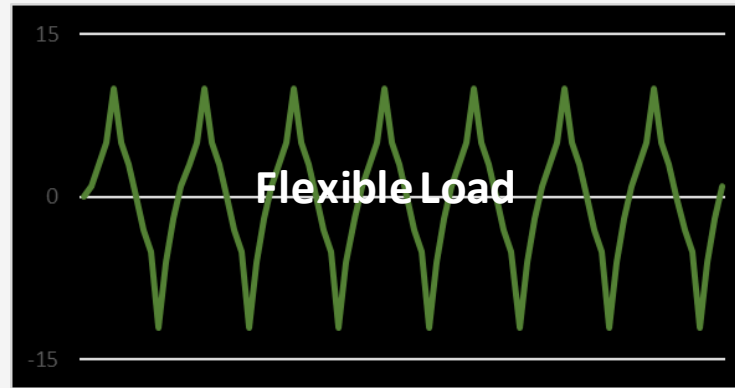
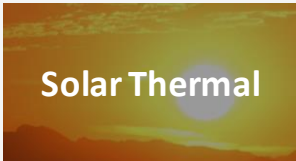
The average cost of energy in North America



Source: Lazard levelized cost of energy analysis

BUSINESS INSIDER

Supply Side of a Carbon-Free Big Grid



Big Grid Challenges Are Large



**Accelerated RD&D for storage
and dispatchable generation**



**Public Funding+Market Reforms
to Finance Transition
+CES or equivalent**

Build at ~8x-5x Current Pace



**Improved Transmission and
Infrastructure Planning,
incl. integrated DG**

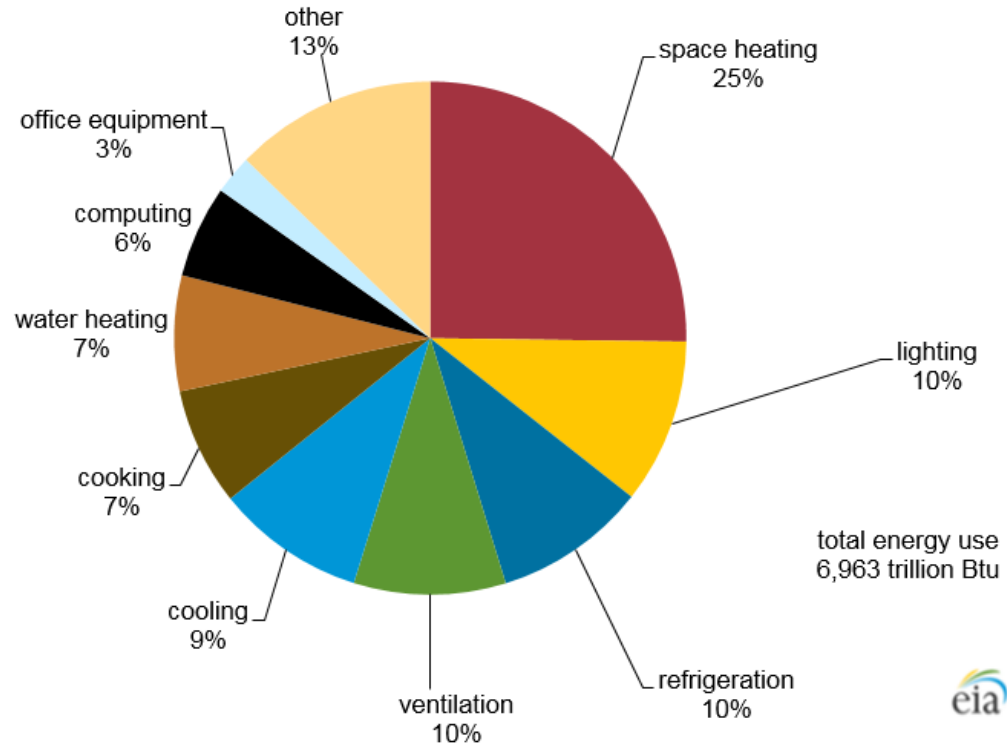


Cybersecurity and Resilience

2. Changing Electricity Use

Decarbonizing Building Energy Use

Commercial Buildings Energy Use



Source: U.S. Energy Information Administration, 2012 Commercial Buildings Energy Consumption Survey.

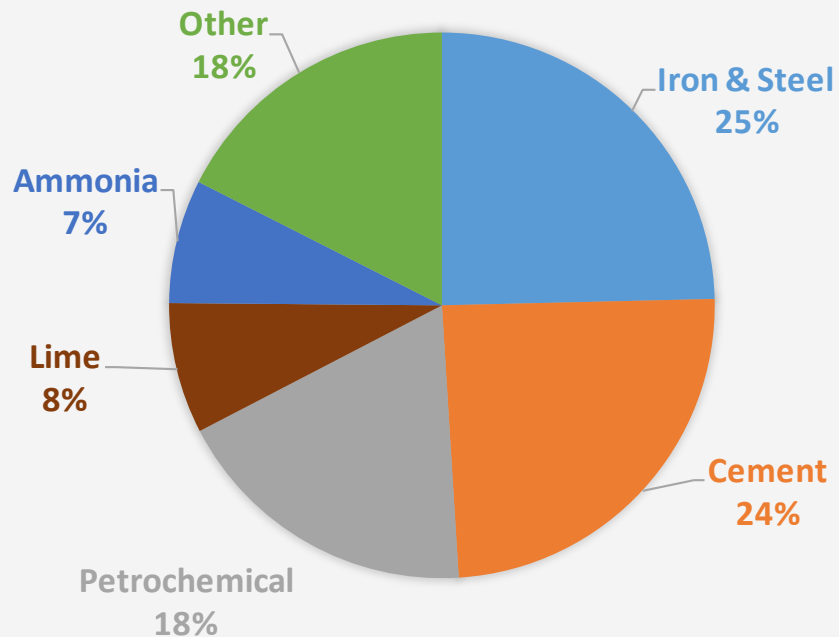
- Electrify Heat in 130mm buildings via Heat Pumps
 - Air Source
 - Ground Source (geothermal)
 - District Heating
- Clean non-electric heat from renewable gas, green hydrogen

Challenges:

- Policies to promote new & retrofits
- Financing is critical: ~\$10Tn

Decarbonizing Industrial Energy Use

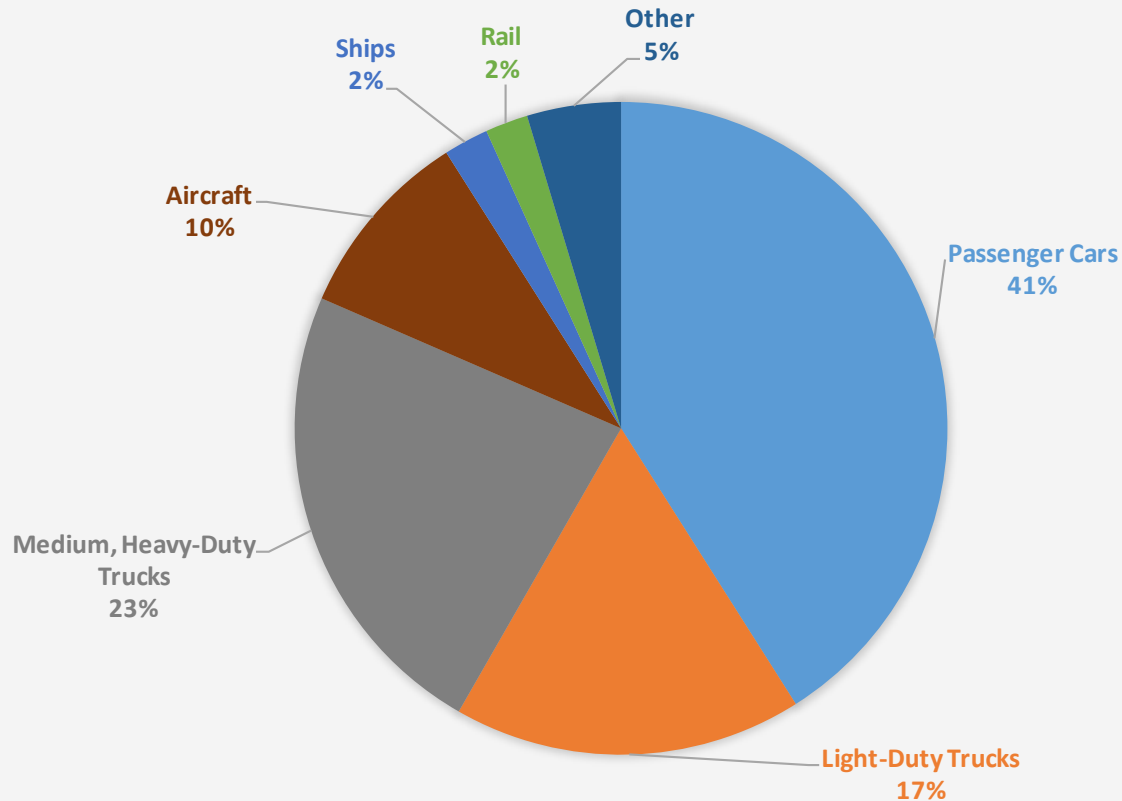
EMISSIONS FROM INDUSTRIAL PROCESSES & PRODUCTION



- Can focus first on big five: steel, cement, chemicals, lime, ammonia
- Massive R&D -- new technologies, processes, and materials (\$30 Bn)
- Policies that promote decarbonization for all industry – carbon tax insufficient
- “Buy green” incentives seem useful
- Industries need public-private collaboratives
- Pre-commercial public funding important

Decarbonizing Transportation

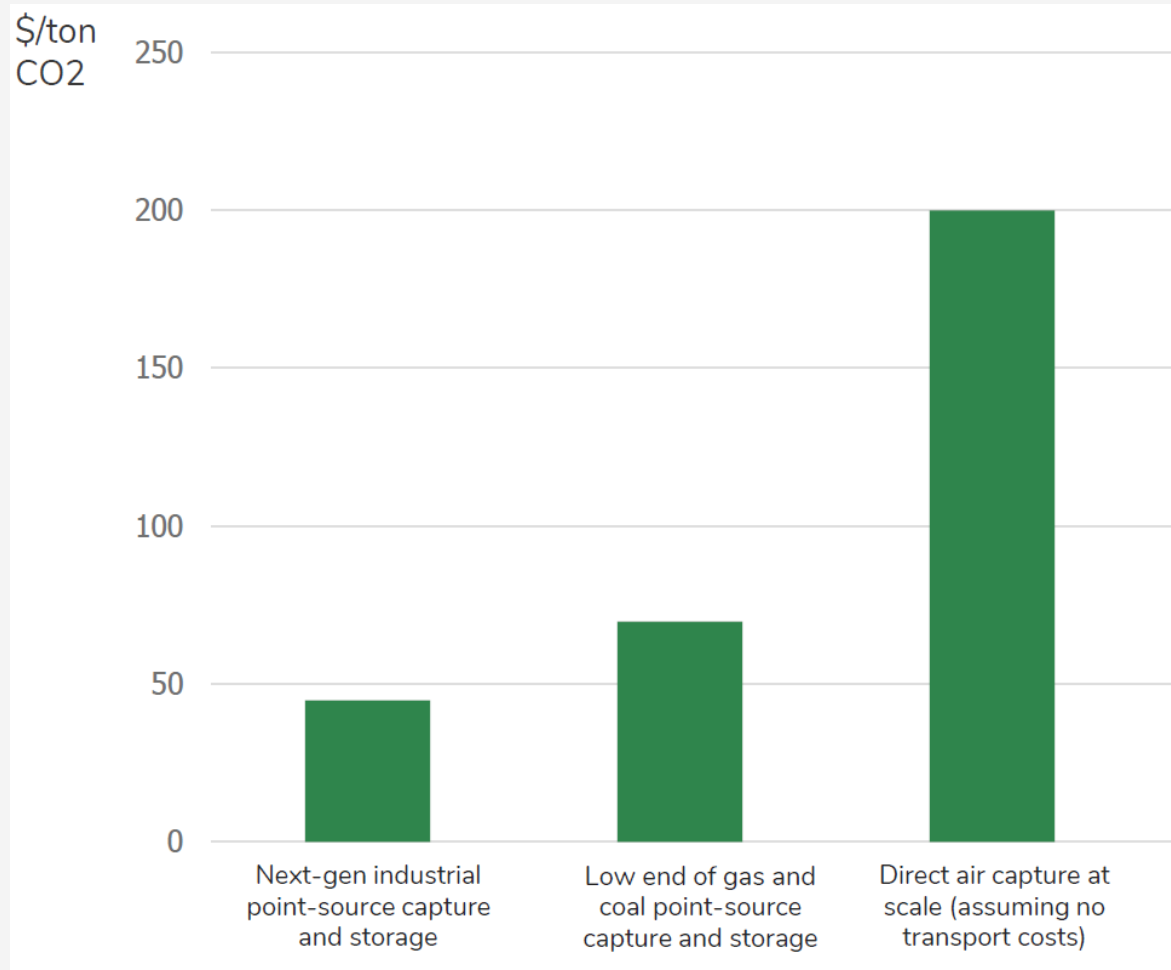
TRANSPORTATION EMISSIONS



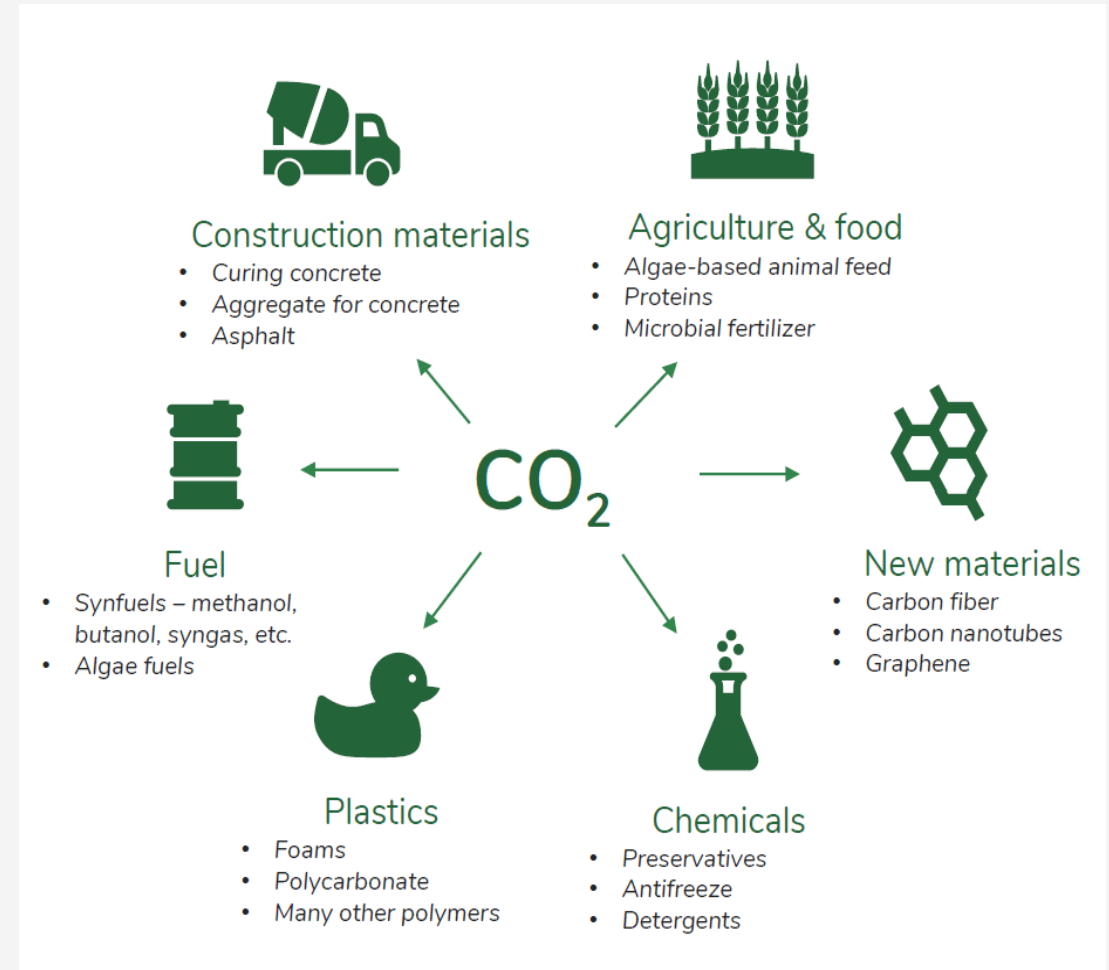
- Passenger car transition to EV and FCVs underway – need public and private infrastructure
- All other forms of transport need R&D, incentives, and requirements:
 - Airlines and trucking: electricity, H₂, biofuels
 - Railroads: electricity likely
 - Ships: electricity, H₂, ammonia

3. Clean Fuel Supplies

Carbon Capture, Sequestration, and Use



Source: Center for Climate and Energy Solutions report, (2019), McKinsey(2020); Energy Impact Partners



CO₂ Pipeline Network

2050 totals: 21,000 km trunk lines + 85,000 km spur lines
(equivalent to ~22% of US natural gas transmission pipeline total)



E+ scenario

929 million tCO₂/y

106,000 km pipelines

Capital in service: \$170B

CO₂ point source type

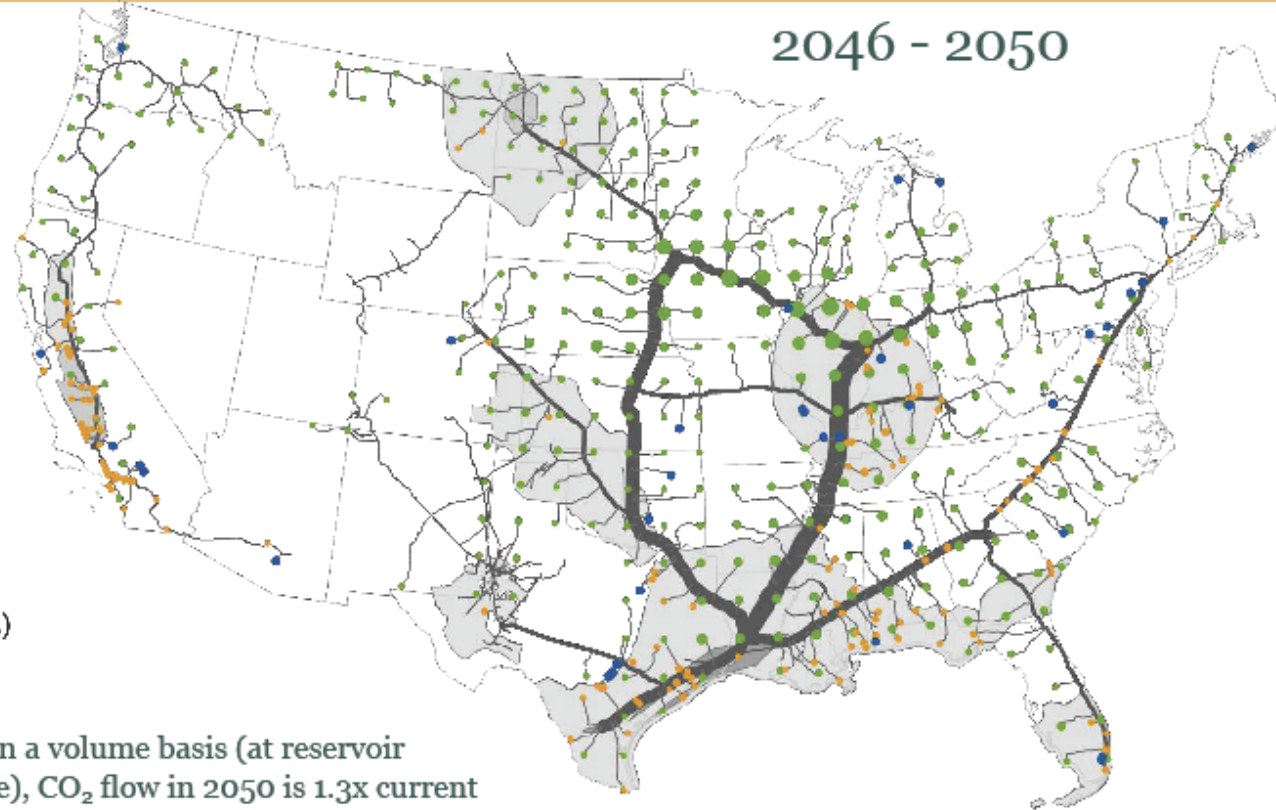
- CO₂ point sources
- BFGCS - power and fuels
- Cement w/ CCS
- Natural gas power CCS oxyfuel

CO₂ captured (MTPA)

- 0.0006449
- 7.9144
- 15.8282
- 23.7419

Trunk lines (capacity in MTPA)

- 5
- 166.667
- 328.333
- 490



Note: On a volume basis (at reservoir pressure), CO₂ flow in 2050 is 1.3x current U.S. oil production and 1/4 of current oil + gas production.



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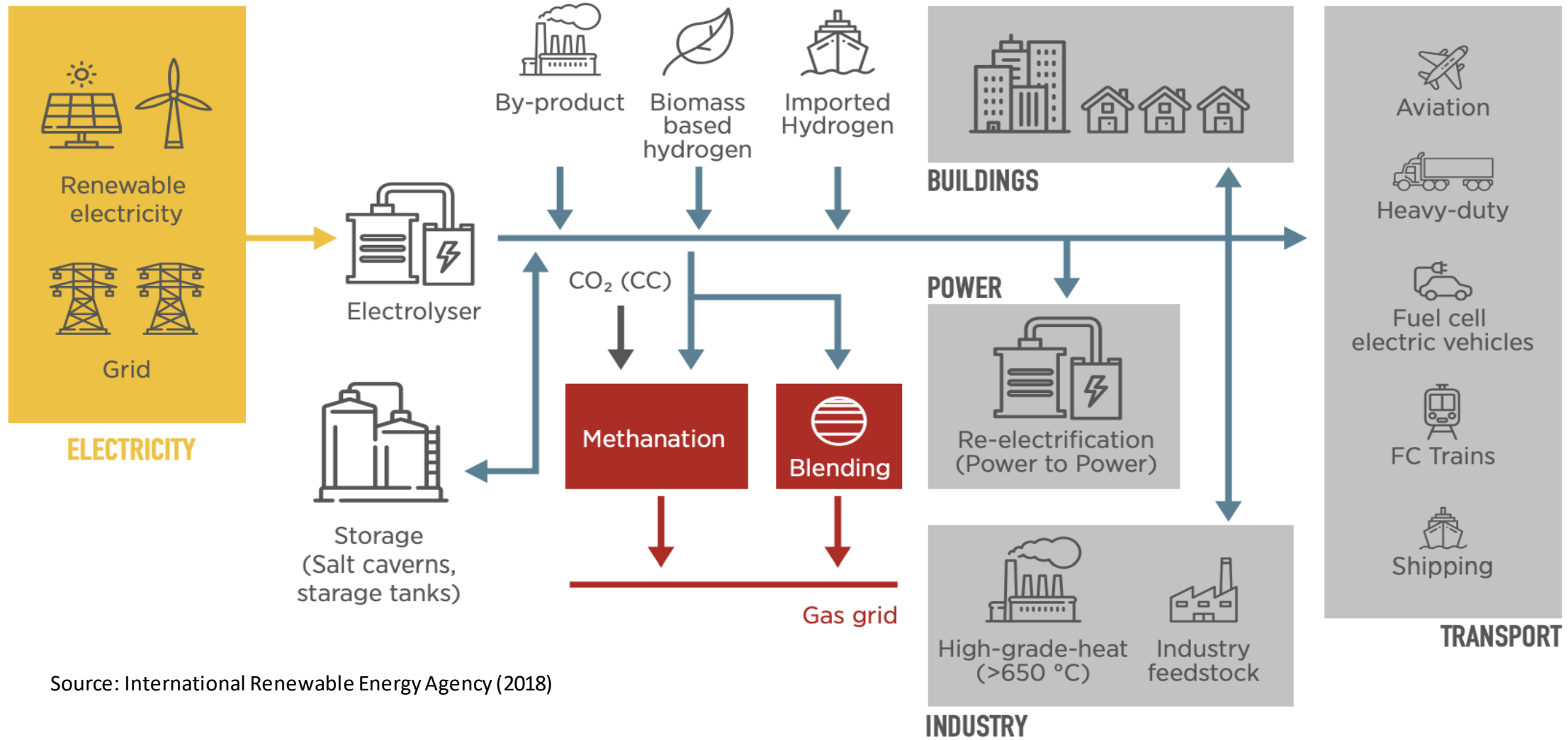
[The Net-Zero America Project](#)



High Meadows
Environmental
Institute

Carbon
Mitigation
Initiative

Hydrogen is Versatile, But Must Get Cheaper and Needs Infrastructure



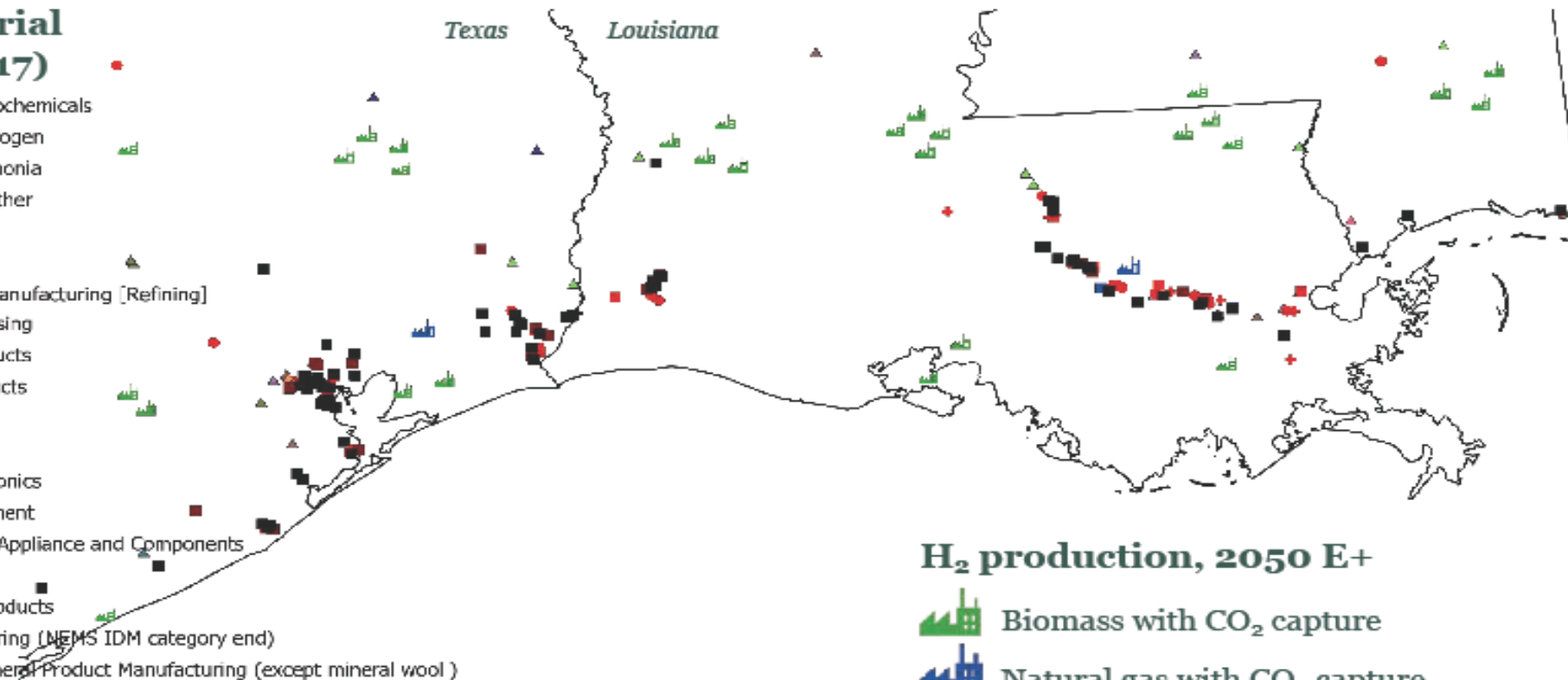
Source: International Renewable Energy Agency (2018)

Notional view of H₂ production and use on the Gulf Coast, 2050



Large industrial facilities (2017)

- Bulk Chemicals - petrochemicals
- Bulk Chemicals - Hydrogen
- Bulk Chemicals - Ammonia
- Bulk Chemicals - All other
- Cement and Lime
- Iron and Steel
- + Petroleum Products Manufacturing [Refining]
- ▲ Food products/processing
- ▲ Paper and Allied Products
- ▲ Glass and Glass Products
- ▲ Fabricated Metals
- ▲ Machinery
- ▲ Computers and Electronics
- ▲ Transportation Equipment
- ▲ Electrical Equipment, Appliance and Components
- ▲ Wood Products
- ▲ Plastic and Rubber Products
- ▲ Balance of Manufacturing (NEMS IDM category end)
- ▲ Other Nonmetallic Mineral Product Manufacturing (except mineral wool)



H₂ production, 2050 E+

- Biomass with CO₂ capture
- Natural gas with CO₂ capture

We Can Do This, But It's Not Easy



Rosie the Riveter

- Projections show a net zero energy system achievable by 2050
 - Electric prices and reliability ~ same(!)
 - ~2x+ the size of current grid
 - 500,000 to 1,000,000 net new jobs
 - Large health and env. justice benefits
- The challenges are **technical, policy, and fiscal commitment**
 - ~2x to ~3x increase in federal R&D – storage, clean fuels, industrial processes
 - Planning and policies to 2x grid and build H2/RNG/CCS infrastructure
 - \$100s of Bn in public funds – unlocking \$Tns private capital



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CONFLICT OF INTEREST DISCLOSURE

Dr. Fox-Penner holds equity in Energy Impact Partners, a utility-backed energy investment and innovation firm, EOSE, and consults for Energy Impact Partners and The Brattle Group on energy technologies. Dr. Fox-Penner also conducts research in areas of interest similar to the business interests of Energy Impact Partners and The Brattle Group. The terms of this arrangement have been reviewed by Boston University in accordance with its financial conflicts of interest in research policies.

