Deeper Decarbonization

Carbon Capture to achieve Net-Zero Emissions in the U.S.

EVOLVED ENERGY RESEARCH

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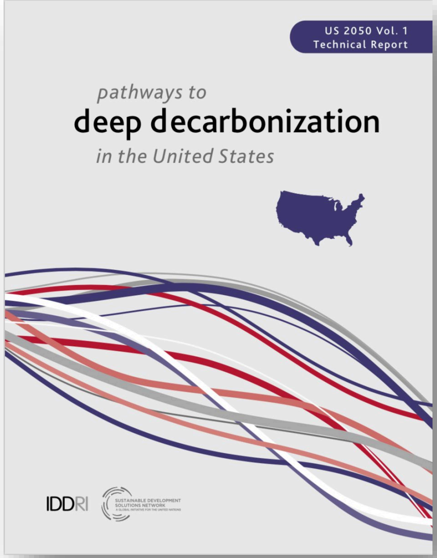
About Evolved Energy Research

- Energy consulting firm focused on addressing key energy sector challenges posed by energy system transformation
- Lead developers of EnergyPATHWAYS and RIO, two models used to investigate pathways to deep decarbonization
- We advise clients on issues of policy implementation and target-setting, infrastructure investments, R&D strategy, technology competitiveness, and asset valuation



Constraints:

- BAU population, GDP growth
- BAU energy services
- Commercial and near-commercial technology
- infrastructure inertia
- reliable electricity
- no early retirement
- no NETs
- Net FF CO_2 <120 Gt CO_2 to 2100

Figure 5. Stock-rollover Example in PATHWAYS: Light Duty Auto Sales and Stock by Model Year

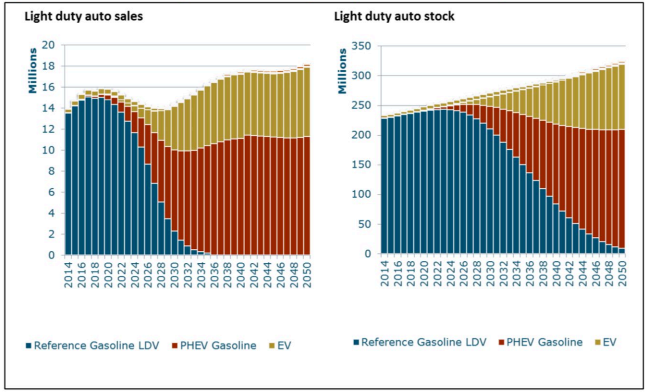
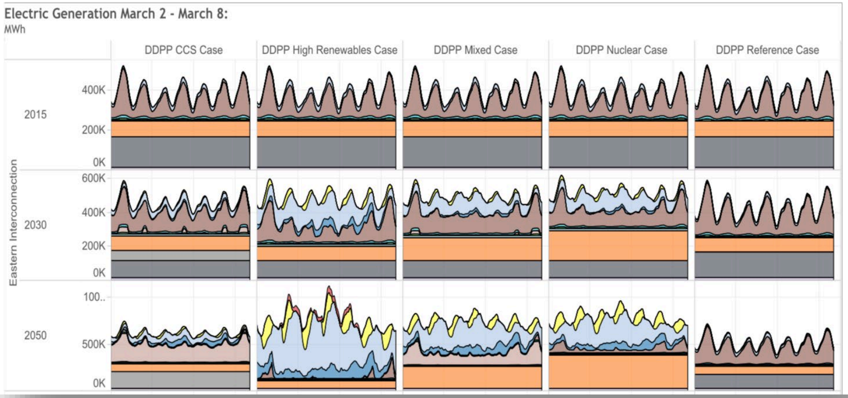


Figure 18 Example Week Electric Generation by Case, Year, and Interconnection

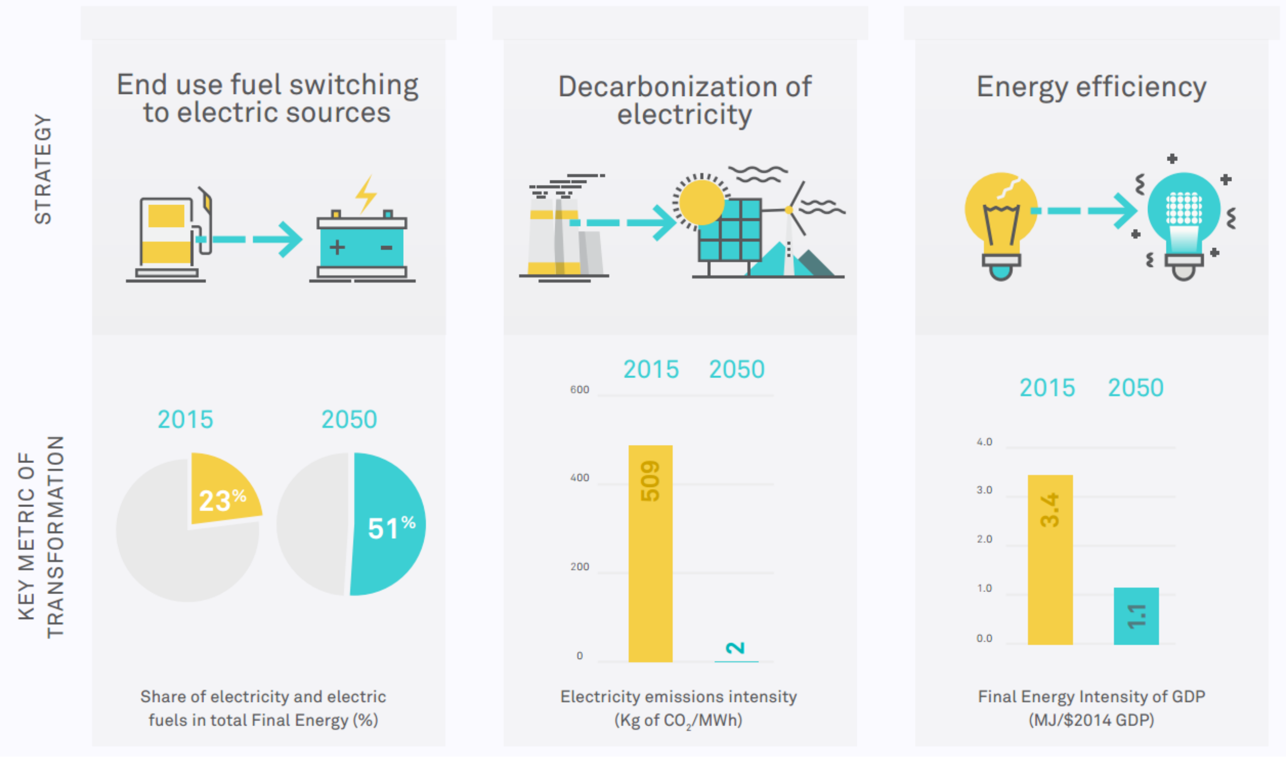


Three pillars of deep decarbonization (for 80% by 2050)

United States

2050 U.S. Benchmarks

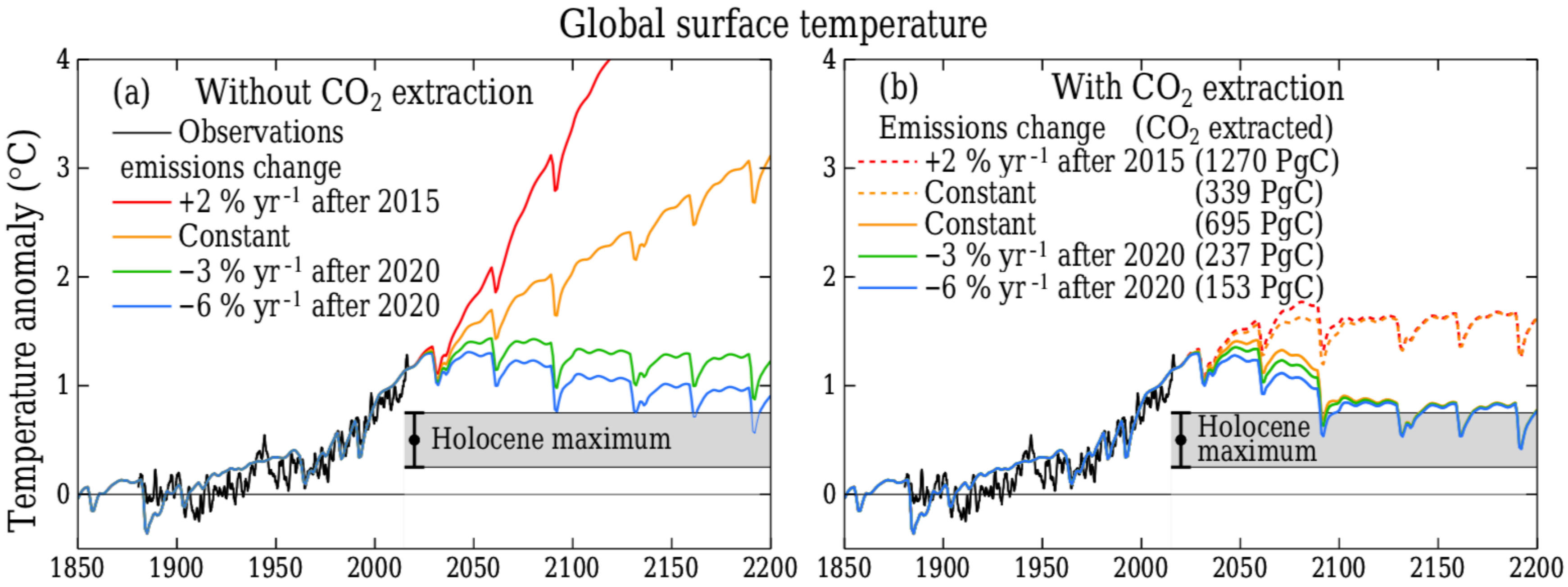
- 2x increase in the share of energy from electricity or electrically derived fuels
- ~99% decrease in the emissions intensity of electricity generation
- 3x drop in energy use per unit GDP



350 ppm Pathways for the United States

- It is technically possible to transition the U.S. off of fossil fuels at a pace consistent with 350 ppm trajectories
- Placing the U.S. energy system on a pathway to 350 ppm is affordable and would increase the total cost of the energy system in the U.S. by only 2-3% of GDP
- Delay is exceedingly costly as a strategy when examining cumulative emissions targets. At current pace, we will exceed our mid-century emissions budget by 2030.
- There are multiple scenarios that achieve this scale and pace of reductions

350 ppm global trajectories



Hansen et al. 2017. *Earth System Dynamics*

Mitigation targets and net CO_2 emissions

2^oC

$\downarrow$

1.5^oC

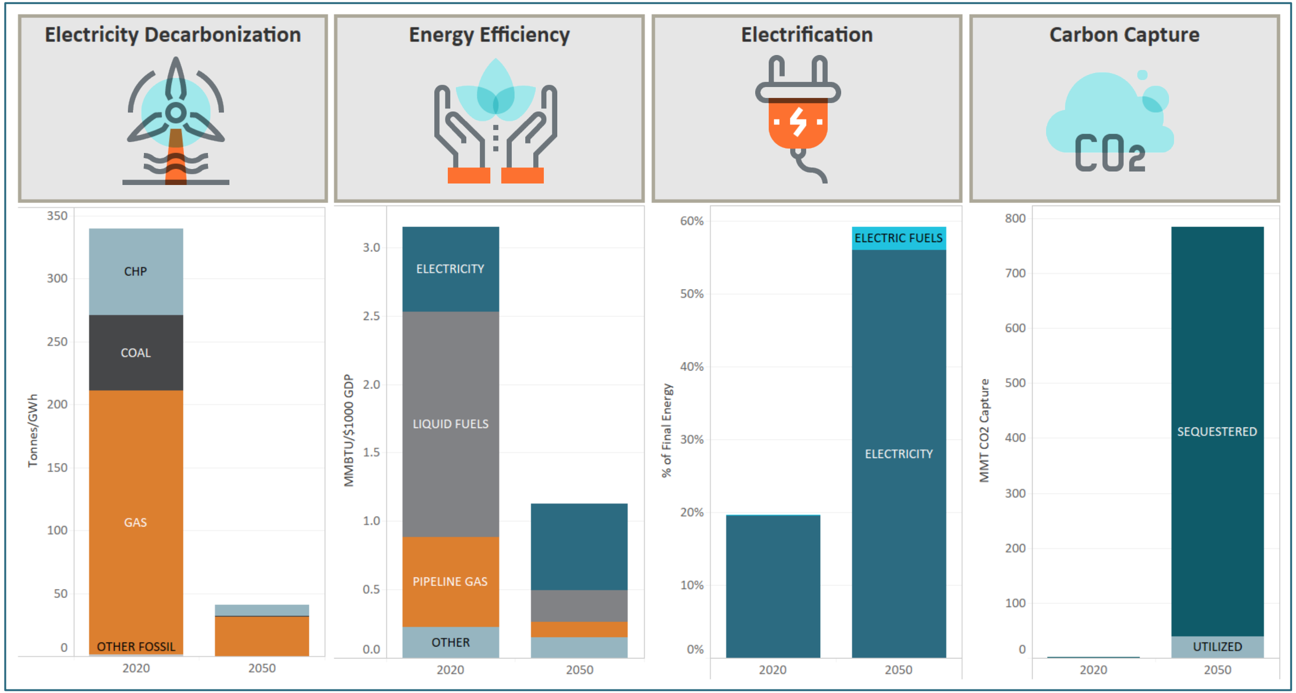
$\downarrow$

350 ppm

$\downarrow$ CO_2 emissions

$\uparrow$ CO_2 removal

Four Pillars



- 350 PPM analysis reinforces necessity of three pillars defined in previous 80x50 analyses
- 350 PPM also requires the employment of CO2 capture strategies in heavy industry, biorefining as well as the deployment of direct air capture facilities

Carbon Capture and Removal Categories

Category	Description	Negative Emissions When CO2 Sequestered	Zero Emissions When CO2 Sequestered
Natural Sequestration	Sequestration of additional CO2 in enhanced land sinks (i.e. soil, forests, etc.)	☑	
Direct Air Capture	Technical removal of CO2 from the ambient air	☑	
Bioenergy Carbon Capture	Point source capture of CO2 from facilities using bioenergy	☑	
Fossil Carbon Capture	Point source capture of CO2 from facilities using fossil energy		☑

CO2 Source and Sinks in Low-Carbon Economy

Heavy Industry
Iron & Steel; Cement; Petrochemicals; Refineries

Biorefining
Ethanol; FT Liquids

Hydrogen Production
Steam reforming; Autothermal reforming; BECCS

Direct Air Capture

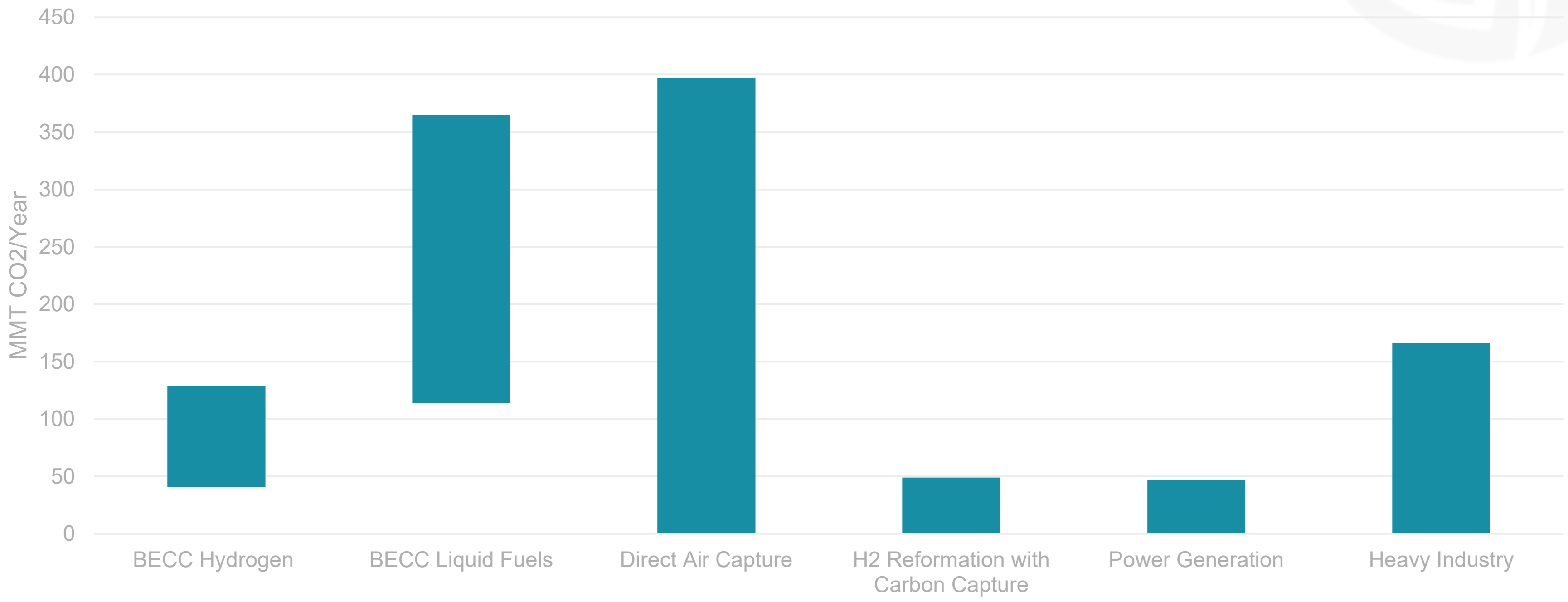
Electricity Generation
Post-combustion capture; Allam cycle

Geologic Sequestration

Utilization

Scale of Carbon Capture

Range of Capture Volumes from forthcoming U.S. analyses

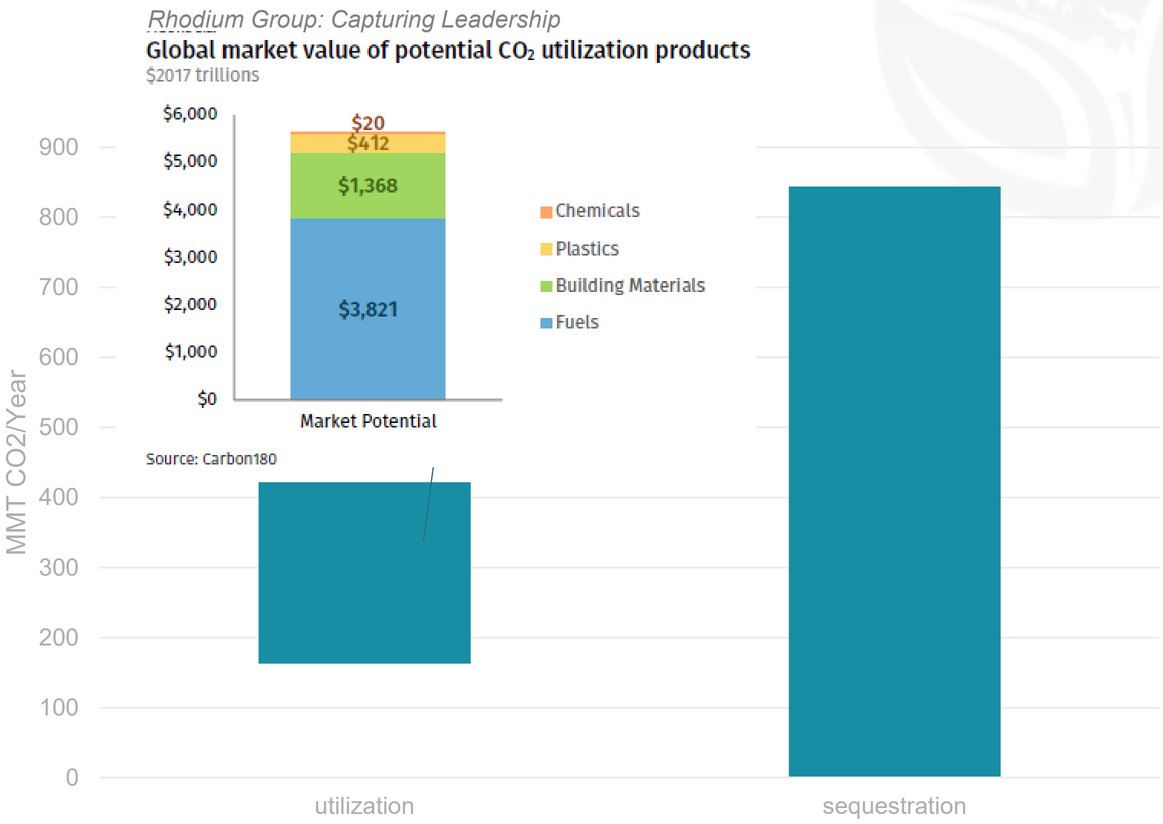


Carbon Capture Competitive Landscape

Application	Competitors
Hydrogen Production	Electrolysis
Biorefining	On-road electrification; electricity derived fuels
Heavy Industry	Process electrification; hydrogen
Electricity Generation	Renewables; batteries; fuel substitution in conventional gas power plants
Direct Air Capture	All decarbonization strategies including land-based sequestration

Utilization and/or Storage

- Competition between use and sequestration dictated by emissions targets, cost of fossil alternatives, and projected sequestration availability and cost.



Deep Decarbonization vs. Deeper Decarbonization

- Principal activities to go from deep (80% reductions) to net-zero targets is in the area of carbon capture for both sequestration and utilization purposes
- Need near-term technology development, deployment, and policy support to insure that these are available at scale when we need them
- Initial perceptions of carbon capture focused on their cost-effectiveness compared to renewables in power generation. Their importance to achievement of these net-zero targets, deployed in applications across the economy, is not well understood or appreciated

Open Questions

- Available sequestration injection potential
- Public acceptance of CO2 pipelines
- Technology demonstration timelines
- Emissions accounting
- Utilization vs. sequestration breakdown

THANK YOU

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