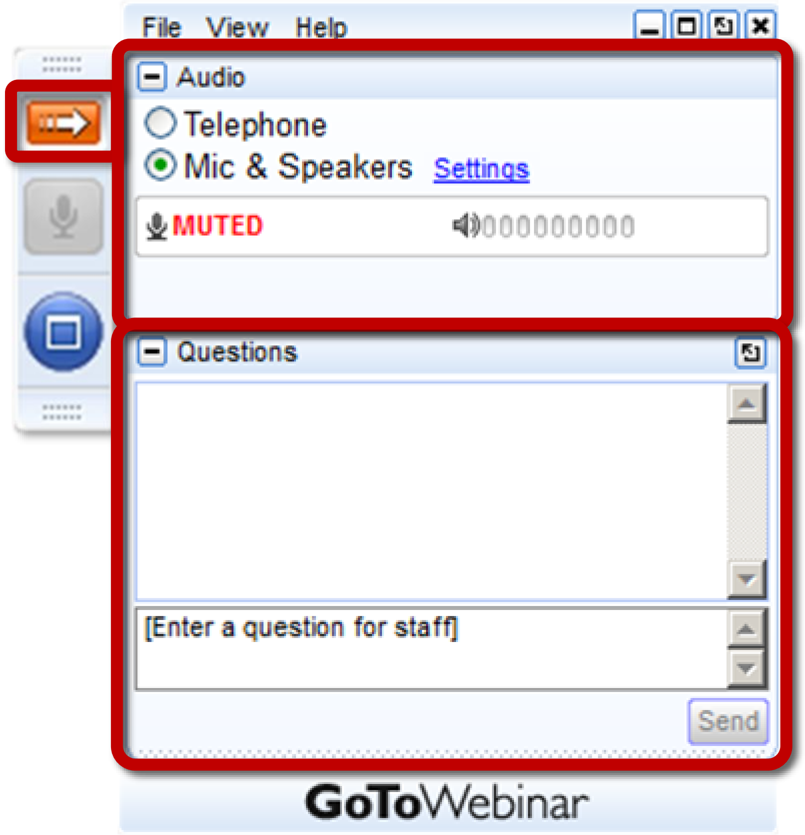
Net-Zero America

February 23, 2021

Webinar Logistics



Join audio:

- Choose Mic & Speakers to use VoIP
- Choose Telephone and dial using the information provided

Use the orange arrow to open and close your control panel

Submit questions and comments via the Questions panel

This webinar is being recorded. We will email you a webinar recording within 48 hours. This webinar will be posted on CESA's website at www.cesa.org/webinars

Clean Energy States Alliance

STATE OF CALIFORNIA ENERGY COMMISSION

CONNECTICUT GREEN BANK

DEPARTMENT OF ENERGY & ENVIRONMENT

Energy Trust of Oregon

IPA ILLINOIS POWER AGENCY

GOVERNOR'S Energy Office

Maryland Energy Administration

MASSACHUSETTS CLEAN ENERGY CENTER

EGLE MICHIGAN DEPARTMENT OF ENVIRONMENT, GREAT LAKES, AND ENERGY

mn COMMERCE DEPARTMENT

BPU New Jersey's cleanenergy program njcleanenergy.com

NEW MEXICO emnrd Energy, Minerals and Natural Resources Department

NEW YORK STATE OF OPPORTUNITY. NYSERDA

STATE OF RHODE ISLAND OFFICE OF ENERGY RESOURCES

SMUD Powering forward. Together.

VERMONT CLEAN ENERGY DEVELOPMENT FUND PUBLIC SERVICE DEPARTMENT

DMME Virginia Department of Mines Minerals and Energy

OEI Wisconsin Office of Energy Innovation

STATE OF WASHINGTON Department of Commerce Innovation is in our nature.

CONNECTICUT ENERGY ENVIRONMENT

ILLINOIS COMMERCE COMMISSION ICC

INCLUSIVE PROSPERITY CAPITAL

DOER Massachusetts Department of Energy Resources

MassDEP

NREL NATIONAL RENEWABLE ENERGY LABORATORY

COMMISSIONER STEPHANIE GARCIA RICHARD NEW MEXICO STATE LAND OFFICE

OPC-DC Office of the People's Counsel ADVOCACY | EDUCATION | PROTECTION

OREGON DEPARTMENT OF ENERGY

PRAIRIE ISLAND INDIAN COMMUNITY IN THE STATE OF MINNESOTA

RHODE ISLAND COMMERCE CORPORATION

Smart Electric Power Alliance

www.cesa.org

Webinar Speakers

- **Eric Larson**, Senior Research Engineer, Andlinger Center for Energy and the Environment, Princeton University
- **Jesse Jenkins**, Assistant Professor, Mechanical and Aerospace Engineering Department and Andlinger Center for Energy and the Environment, Princeton University
- **Warren Leon**, Executive Director, Clean Energy States Alliance (moderator)

andlinger center
for energy+the environment

CleanEnergy
States Alliance

Clean Energy States Alliance webinar
23 February 2021

PRINCETON UNIVERSITY

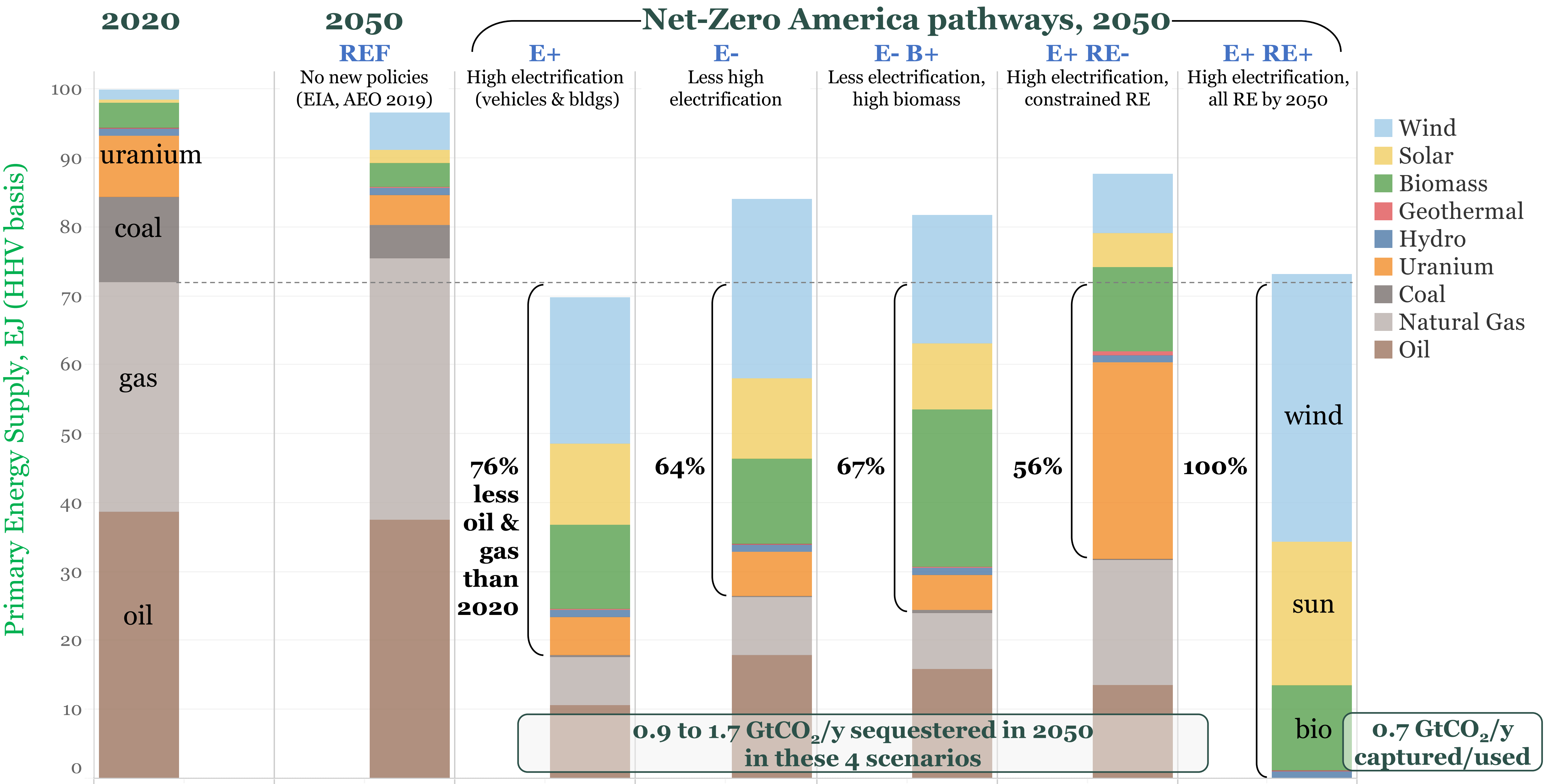
NET-ZERO AMERICA

POTENTIAL PATHWAYS, INFRASTRUCTURE, AND IMPACTS

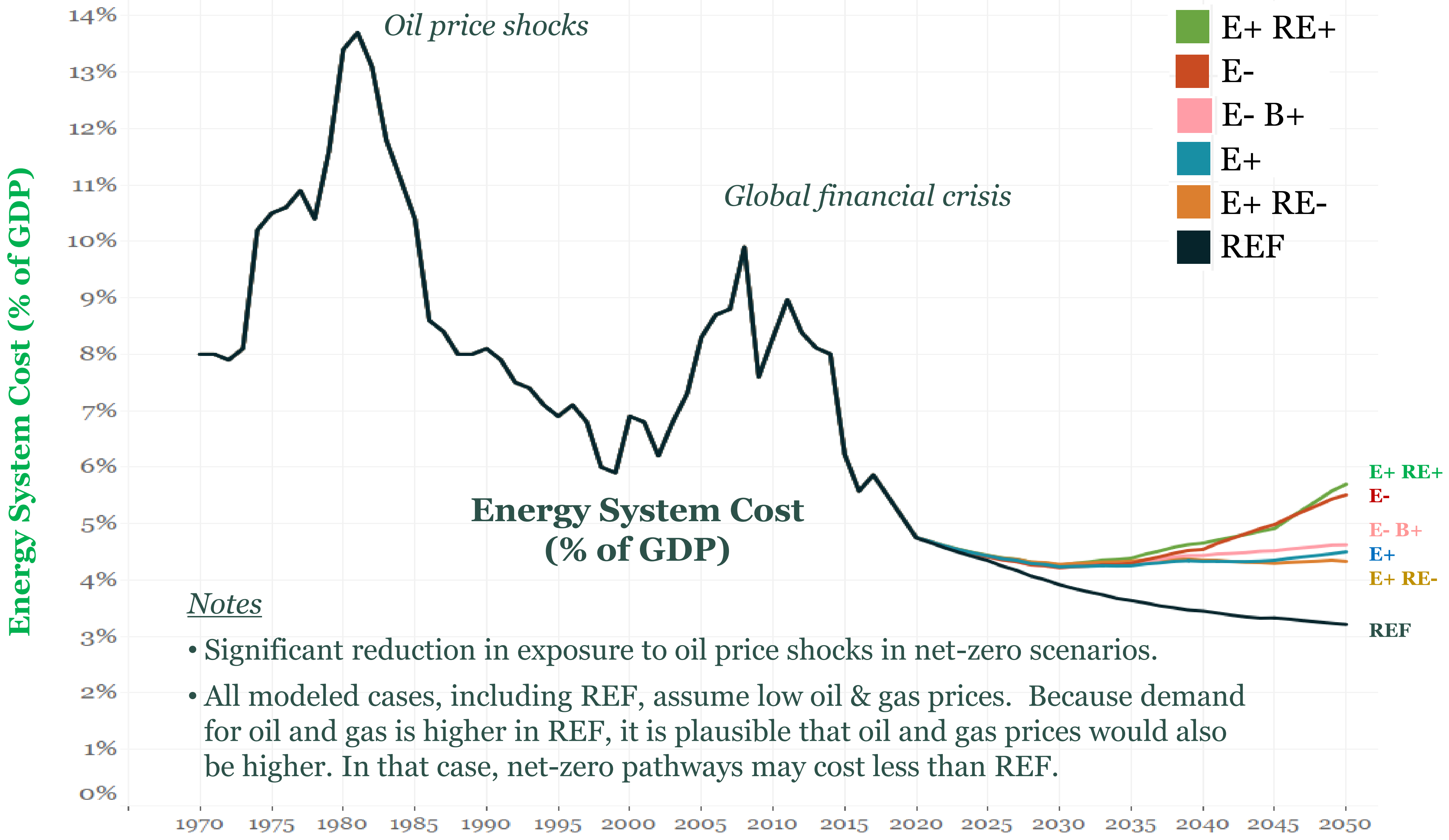
E. Larson, C. Greig, J. Jenkins, E. Mayfield, A. Pascale, C. Zhang, J. Drossman, R. Williams, S. Pacala, R. Socolow, EJ Baik, R. Birdsey, R. Duke, R. Jones, B. Haley, E. Leslie, K. Paustian, and A. Swan, *Net-Zero America: Potential Pathways, Infrastructure, and Impacts*, interim report, Princeton University, Princeton, NJ, December 15, 2020.
Full report available for download at https://environmenthalfcentury.princeton.edu/.

PRINCETON UNIVERSITY
andlinger center for energy + the environment
High Meadows Environmental Institute
Carbon Mitigation Initiative

FIVE MODELED LEAST-COST PATHS TO NET-ZERO IN 2050 SHOW IMPLICATIONS OF DIFFERENT APPROACHES



BIG, BUT AFFORDABLE, TRANSITION: SHARE OF GDP SPENT ON ENERGY IS BELOW HISTORICAL LEVELS



ALL PATHS EMPLOY SIX KEY PILLARS OF DECARBONIZATION

1. End-use energy efficiency and electrification
2. Clean electricity: wind & solar generation, transmission, firm power
3. Bioenergy and other zero-carbon fuels and feedstocks
4. CO_2 capture, utilization, and storage
5. Reduced non-CO_2 emissions
6. Enhanced land sinks

PRINCETON UNIVERSITY

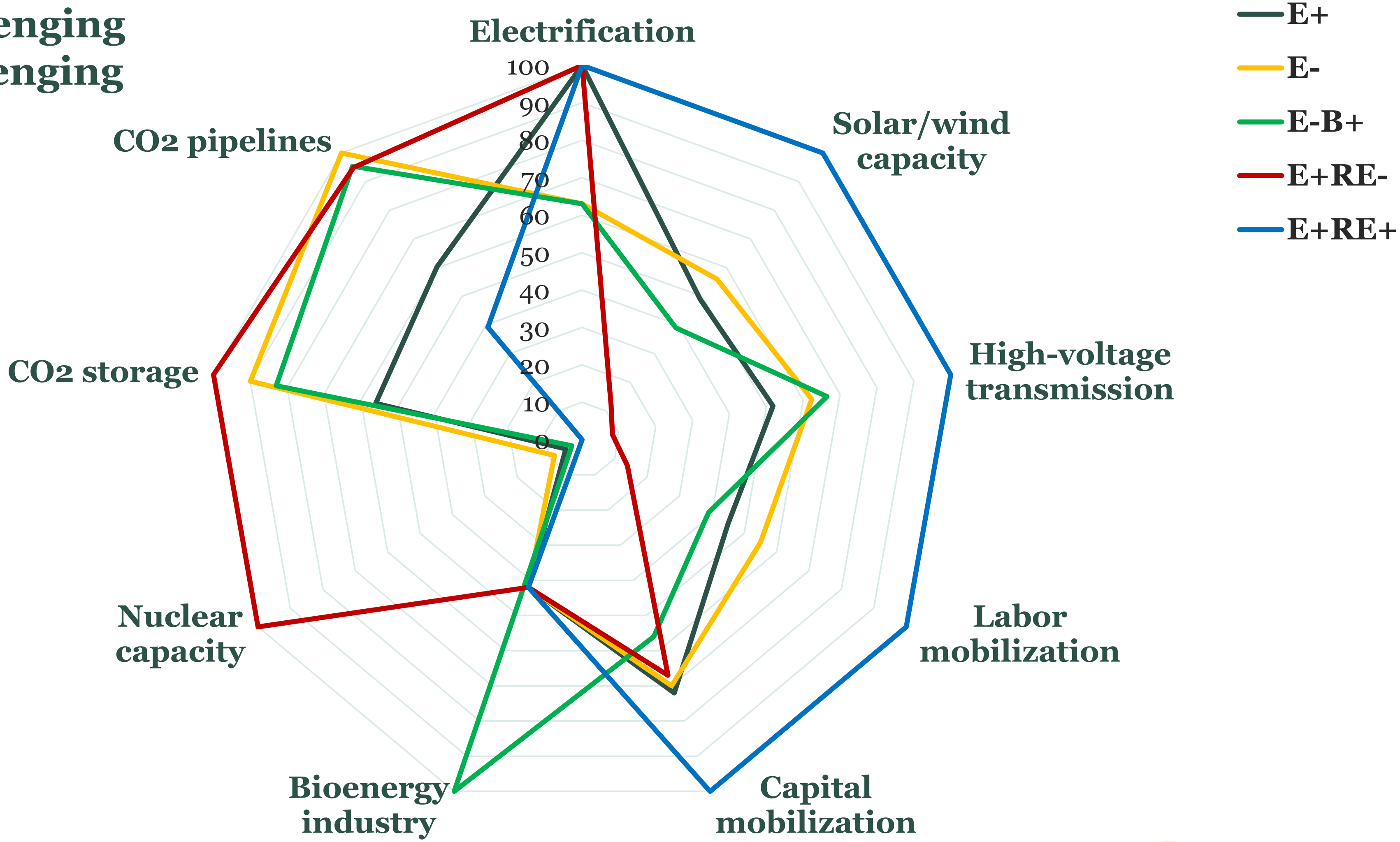
andlinger center for energy+the environment

High Meadows Environmental Institute

Carbon Mitigation Initiative

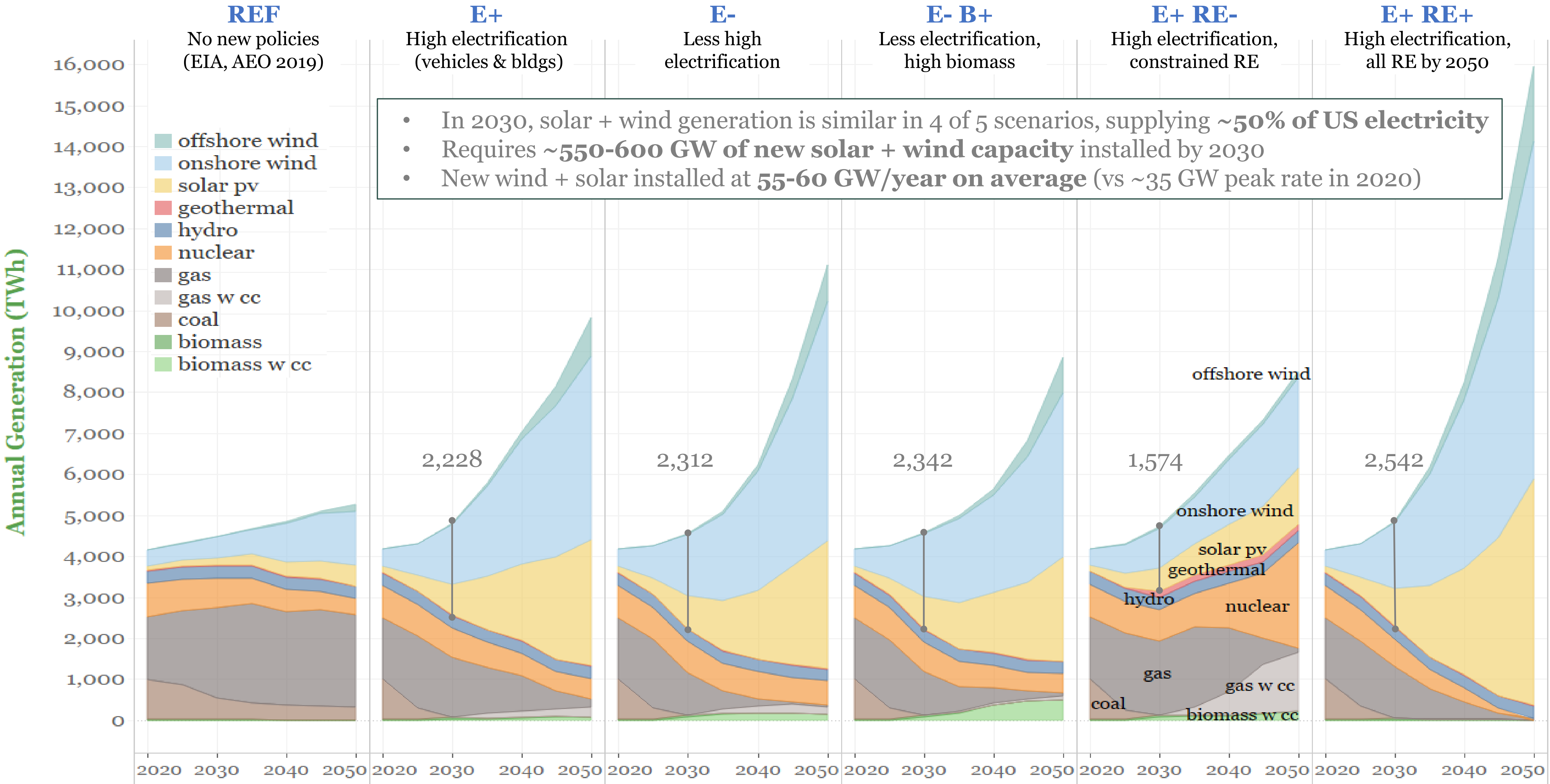
CHALLENGES RELATIVE TO BUSINESS-AS-USUAL IN EXECUTING THE TRANSITION VARY ACROSS NET-ZERO PATHWAYS

<u>ordinal ranking</u>
100 = most challenging
0 = least challenging



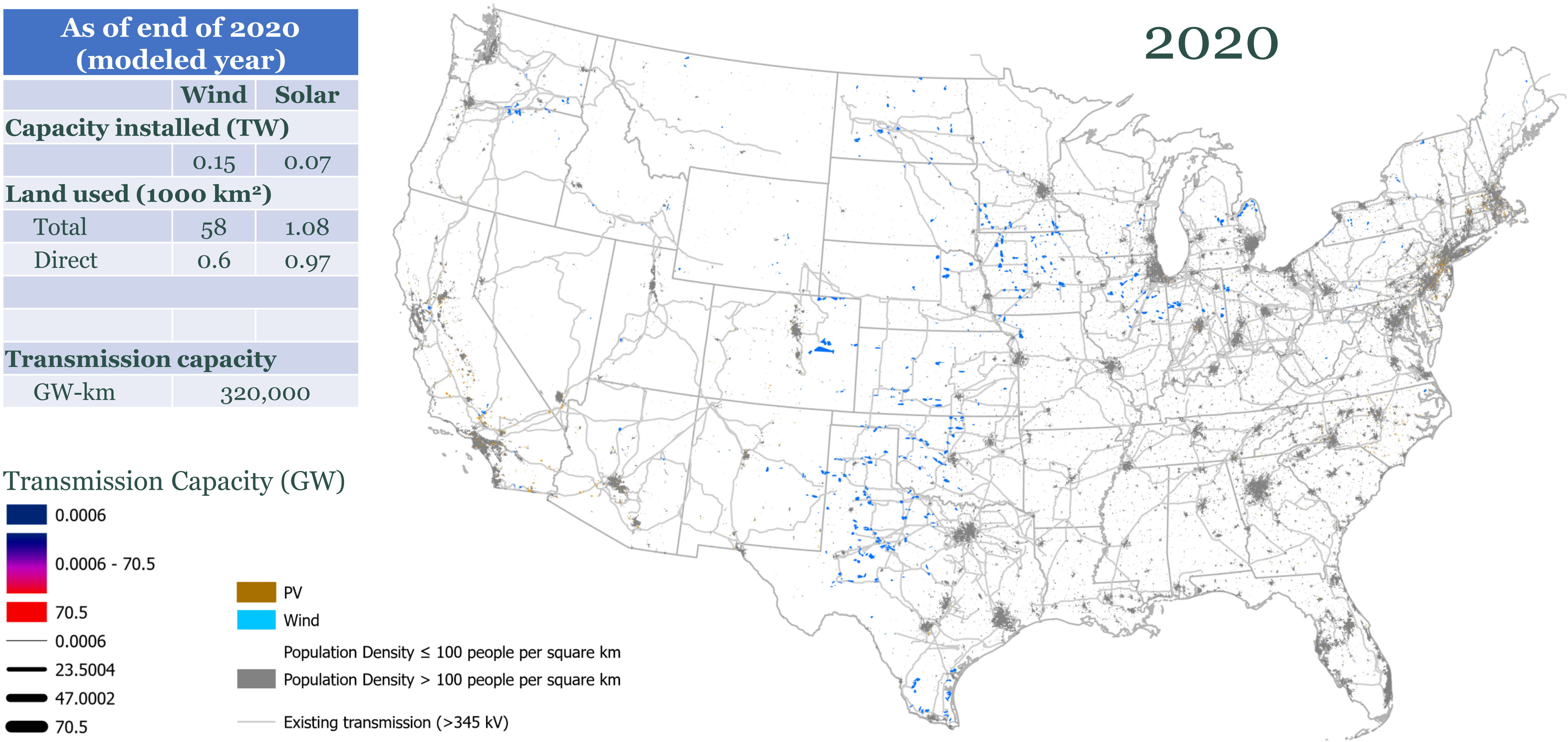
PRINCETON UNIVERSITY
andlinger center for energy+the environment
High Meadows Environmental Institute
Carbon Mitigation Initiative

SOLAR AND WIND ARE CORNERSTONES FOR EACH PATH



EXTENSIVE SOLAR, WIND & TRANSMISSION BUILD ACROSS U.S.

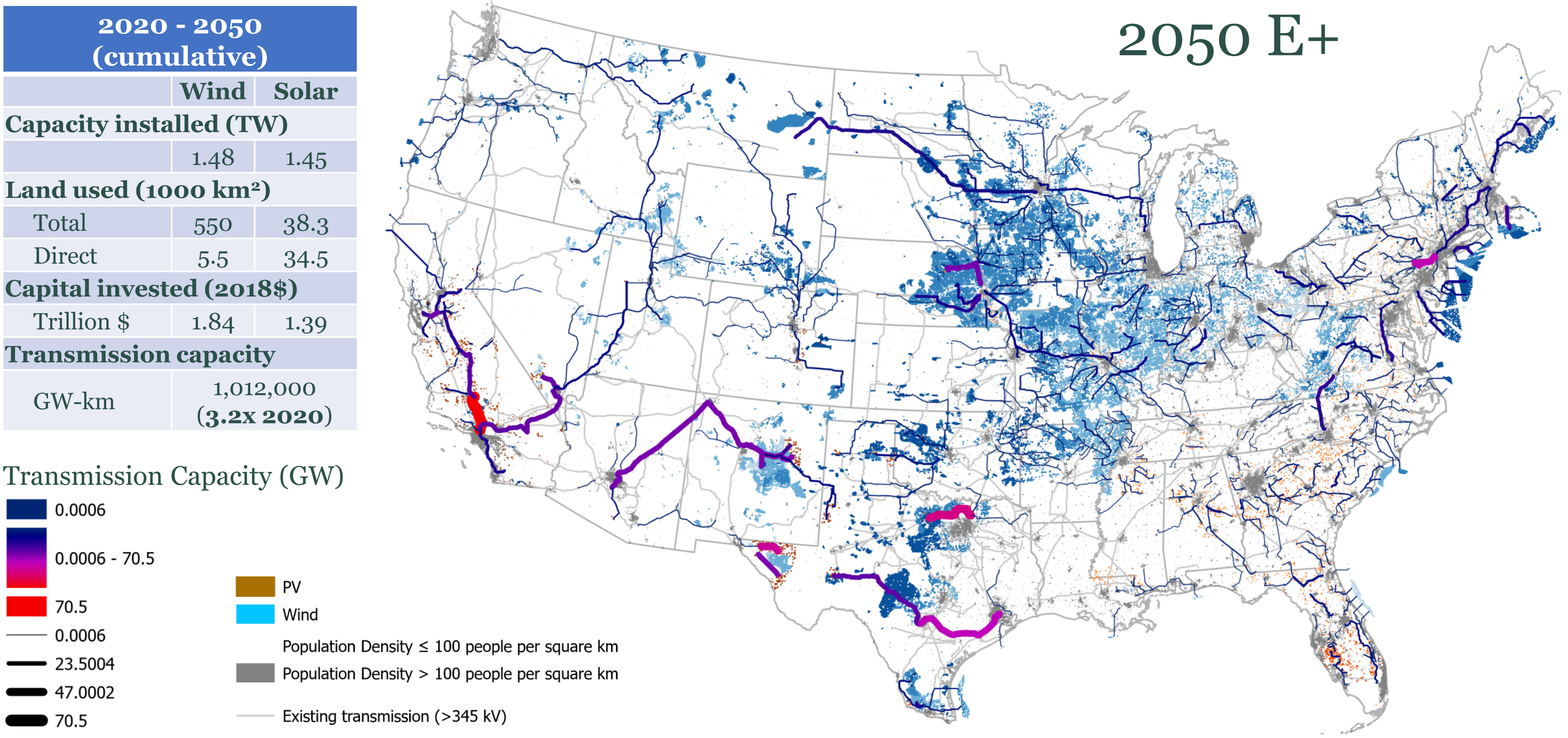
As of end of 2020 (modeled year)		
	Wind	Solar
Capacity installed (TW)		
	0.15	0.07
Land used (1000 km²)		
Total	58	1.08
Direct	0.6	0.97
Transmission capacity		
GW-km	320,000	



Note: Transmission expansion is visualized along existing rights of way (>160 kV); paths are indicative not definitive.

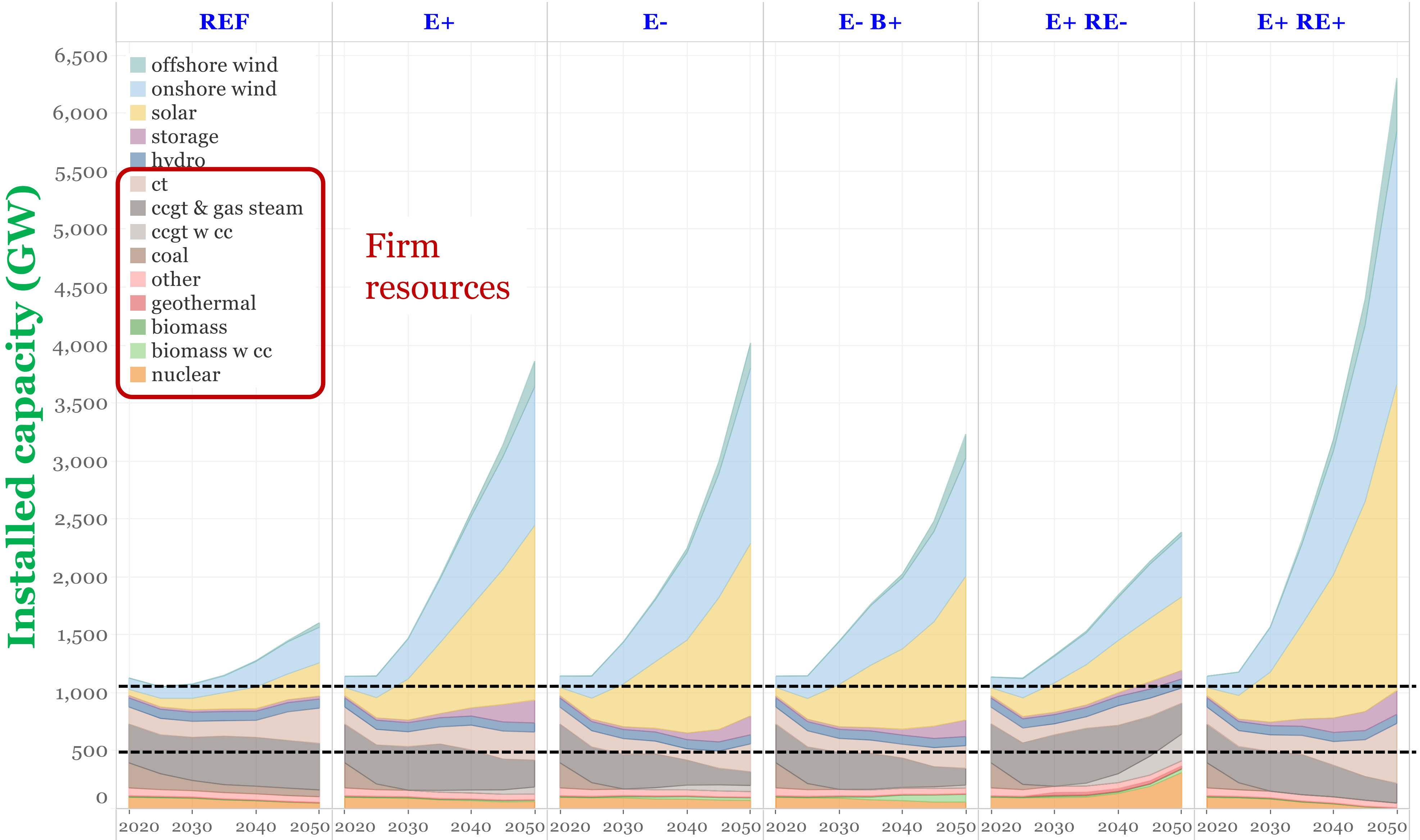
EXTENSIVE SOLAR, WIND & TRANSMISSION BUILD ACROSS U.S.

2020 - 2050 (cumulative)		
	Wind	Solar
Capacity installed (TW)		
	1.48	1.45
Land used (1000 km²)		
Total	550	38.3
Direct	5.5	34.5
Capital invested (2018$)		
Trillion $	1.84	1.39
Transmission capacity		
GW-km	1,012,000 (3.2x 2020)	



Note: Transmission expansion is visualized along existing rights of way (>160 kV); paths are indicative not definitive.

CLEAN FIRM CAPACITY IS KEY; H_2 TURBINES PLAY BIG ROLE



Note:
To reduce the carbon intensity of CCGT and CT generation, H_2 is blended as an increasing fraction of fuel to these units, up to an exogenously specified cap of 60% (HHV basis).
In sensitivities with 100% H_2 firing allowed, the model prefers 100% blend which modestly reduces total energy system costs.

Firm capacity (across all years)

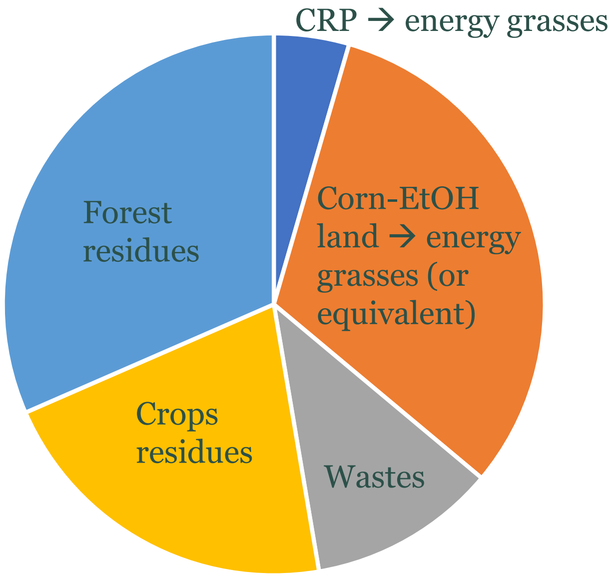
~500-1000 GW

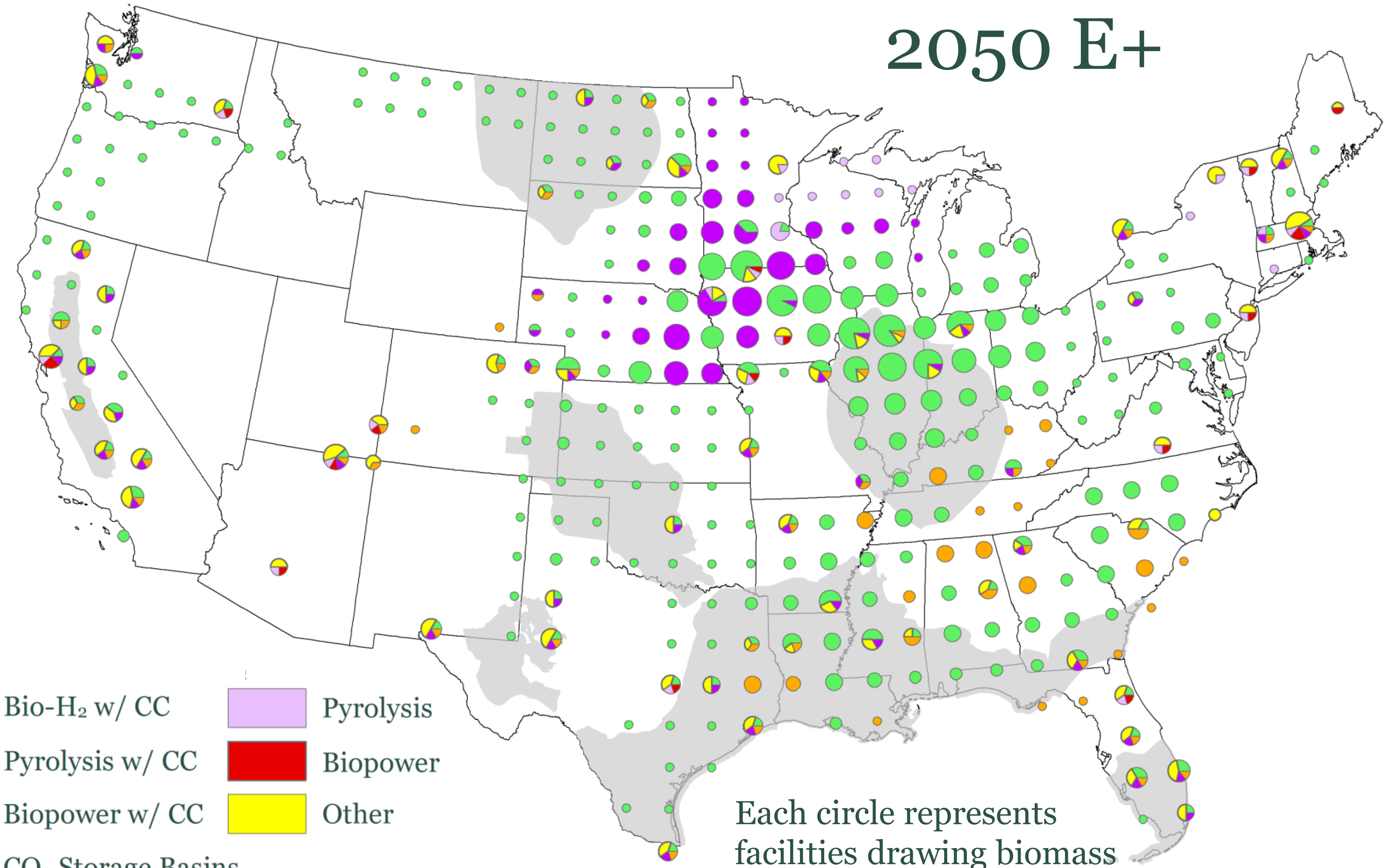
RETURN TO TABLE OF CONTENTS

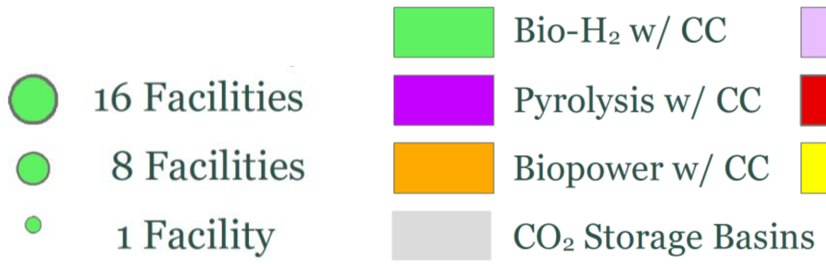
750 B$ IN CAPITAL INVESTED ACROSS RURAL AMERICA BY 2050 TO BUILD AN ENTIRELY NEW BIOENERGY INDUSTRY

2050 non-food biomass use:

- 618 million dry t (12.2 EJ)
- 17% of primary energy
- Sources:







Average facility capacity is 2,100 dry t/day biomass input

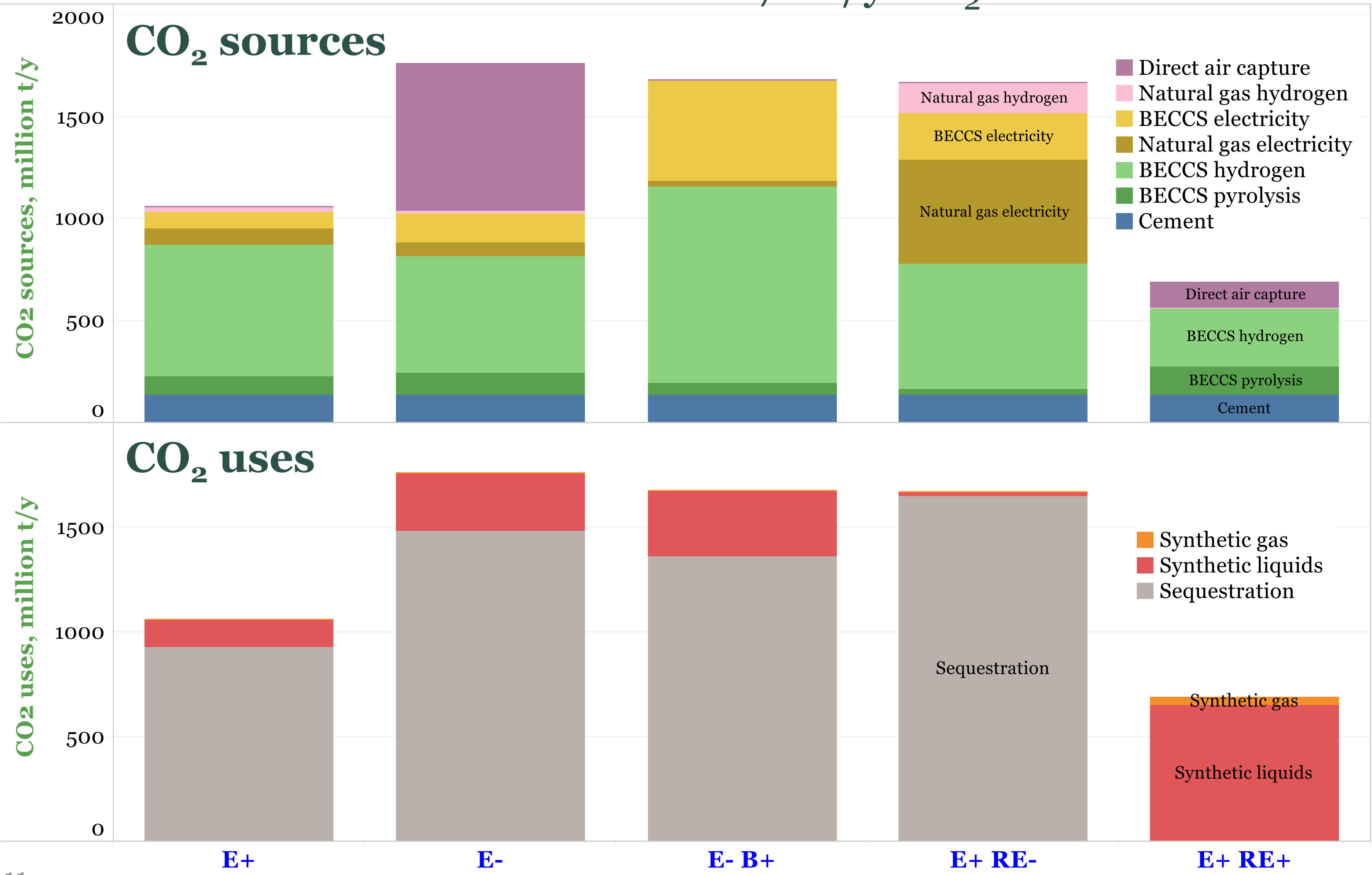
Other includes a collectively small level of biomass converted to diesel, synthetic methane, and/or electricity.

Each circle represents facilities drawing biomass from a surrounding grid cell area 100 mi x 100 mi.

CO_2 CAPTURE AND SOME CO_2 UTILIZATION IN ALL PATHWAYS; SIGNIFICANT CO_2 STORAGE IN ALL BUT ONE PATHWAY

By 2050

- 0.7 to 1.8 Gt/y CO_2 captured.
- 0.9 to 1.7 Gt/y CO_2 sequestered.
- 0.1 to 0.7 Gt/y CO_2 converted to fuels.



CO_2 sources

Direct air capture

Natural gas hydrogen (autothermal reforming)

BECCS electricity (gasifier-Allam cycle)

Natural gas electricity (Allam cycle)

BECCS hydrogen (gasifier/water gas shift)

BECCS pyrolysis (hydrocatalytic)

Cement via 90% capture (post-combustion).

CO_2 uses

Synthetic liquids = synthesis of fuels from H_2 + CO_2.

Synthetic gas = methane synthesis from H_2 + CO_2.

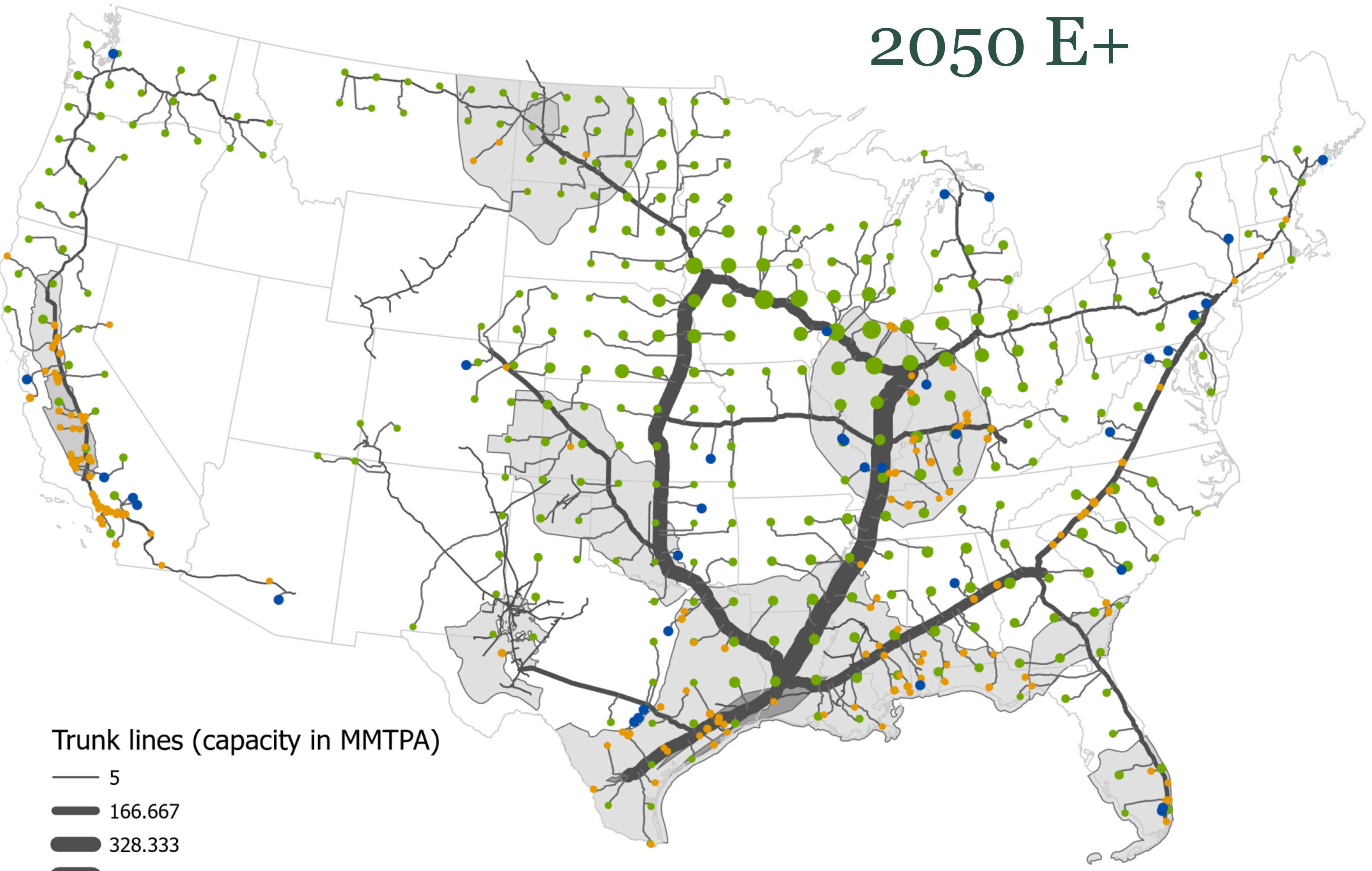
Sequestration = geological storage

RETURN TO TABLE OF CONTENTS

A NEW NATIONAL CO_2 TRANSPORT & STORAGE NETWORK

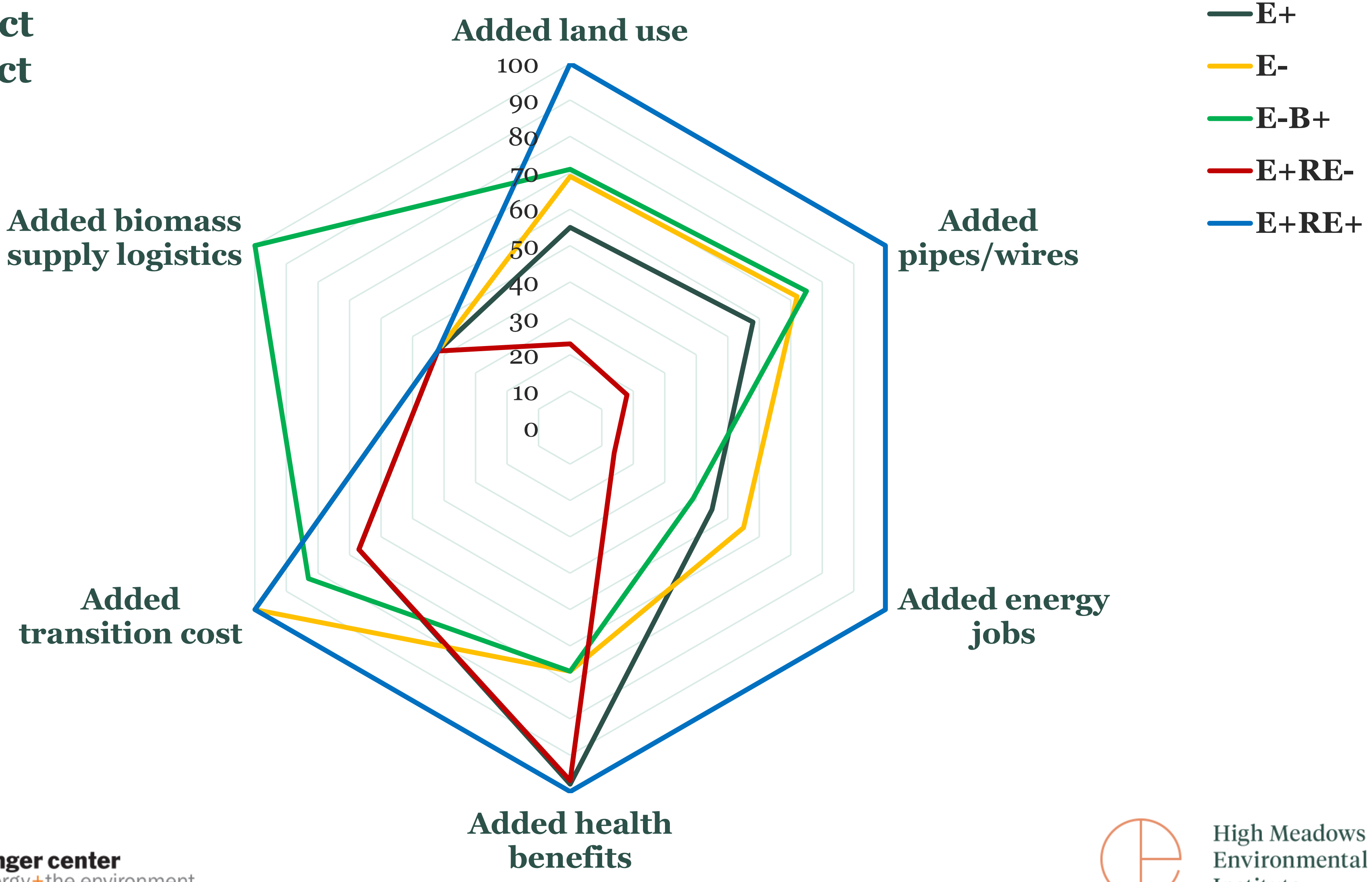
The 2050 U.S. CO_2 transport network

- **~1 billion tCO_2/yr** transported
- **~106,00 km** of pipelines
- **$170 billion** in capital



A SUCCESSFUL TRANSITION TO NET-ZERO IN 2050 IMPLIES IMPACTS (RELATIVE TO BUSINESS-AS-USUAL) THAT VARY ACROSS PATHWAYS

<u>ordinal ranking</u>
100 = most impact
0 = least impact

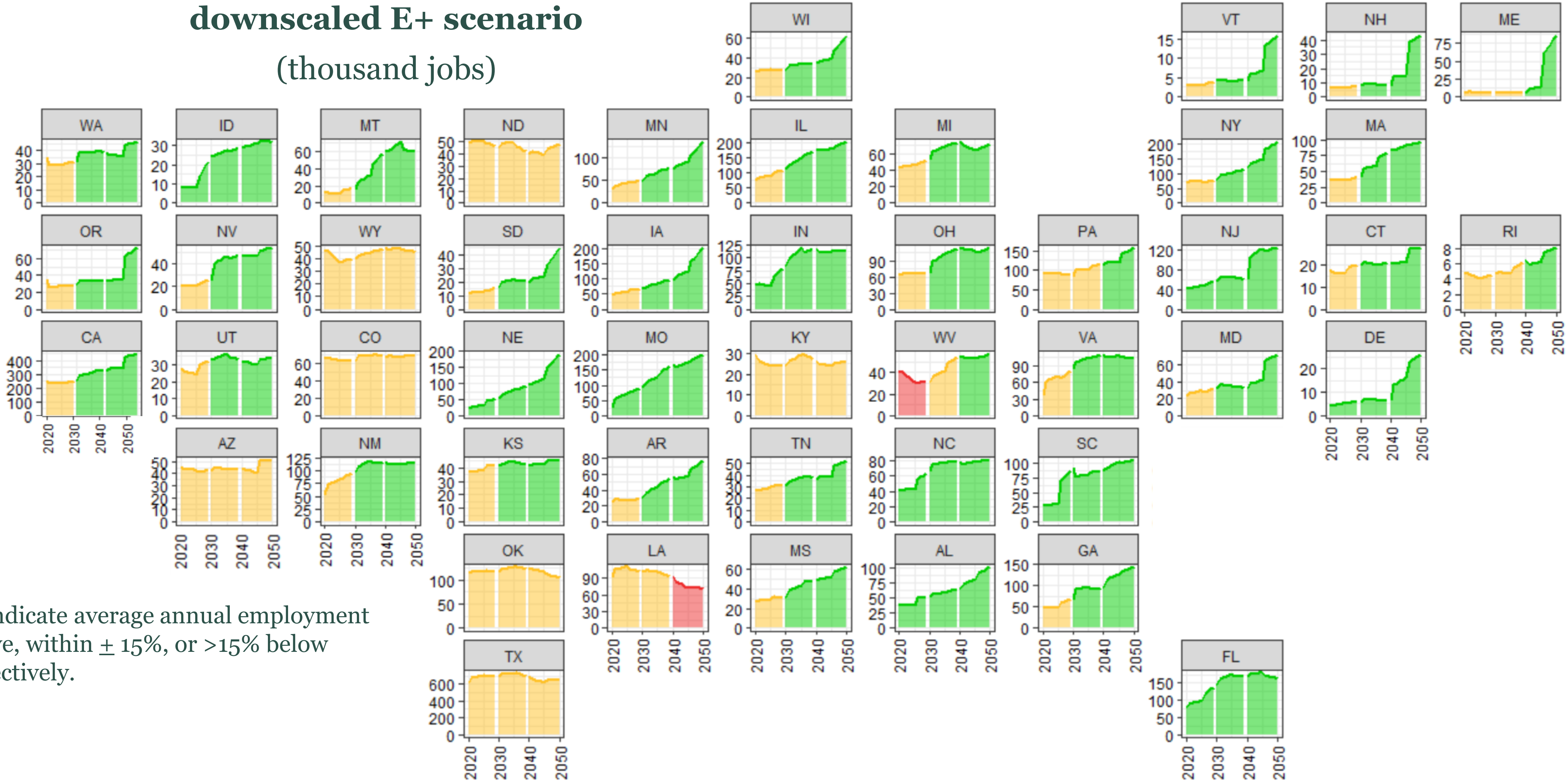


PRINCETON UNIVERSITY
andlinger center for energy+the environment
High Meadows Environmental Institute
Carbon Mitigation Initiative

MOST STATES SEE NET GROWTH IN ENERGY-RELATED EMPLOYMENT, BUT MAJOR SHIFTS IN LOCAL ECONOMIES MUST BE MANAGED

Annual employment based on downscaled E+ scenario

(thousand jobs)

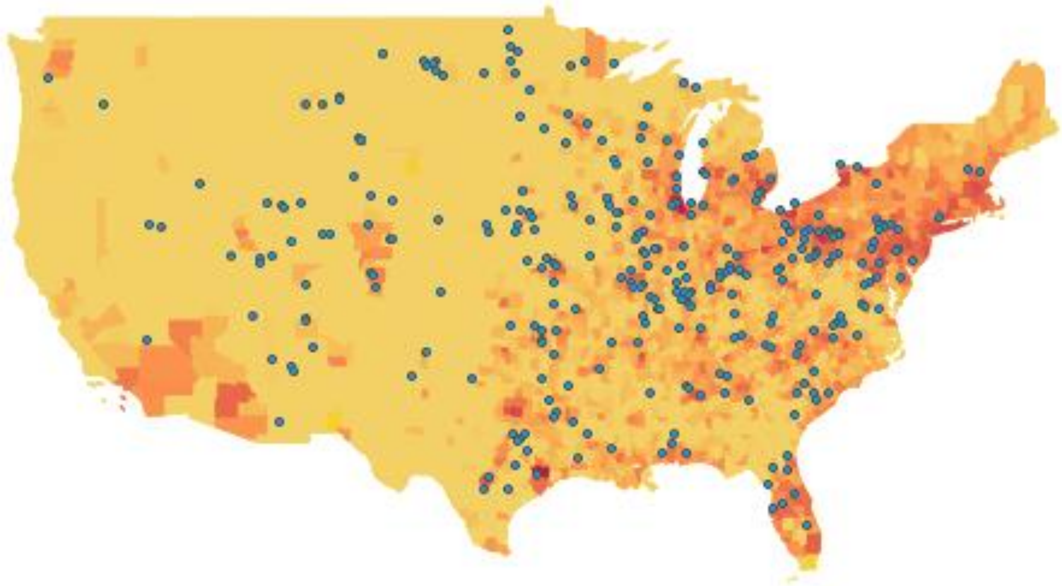


Green, yellow, and red indicate average annual employment in a decade is >15% above, within ± 15%, or >15% below 2021 employment, respectively.

Note: Spatial redistribution of solar and wind manufacturing facilities and increasing the domestic manufacturing share offer opportunities to ameliorate losses in fossil fuel extraction states. For assumptions used here in siting solar and wind manufacturing jobs.

CLEAN ELECTRICITY AND ELECTRIFYING VEHICLES DELIVER LARGE AIR QUALITY AND PUBLIC HEALTH IMPROVEMENTS ACROSS STATES

2020



Coal Plants

premature deaths per county (log scale)

- 300

Coal power plant

Motor Vehicles

premature deaths per county per 100,000 people

0 20

200,000-300,000 PREMATURE DEATHS AVOIDED THROUGH 2050 BY A NET-ZERO TRANSITION (~$2-3T IN DAMAGES)

2050
E+

Coal Plants

premature deaths per county (log scale)

- 300

Coal power plant

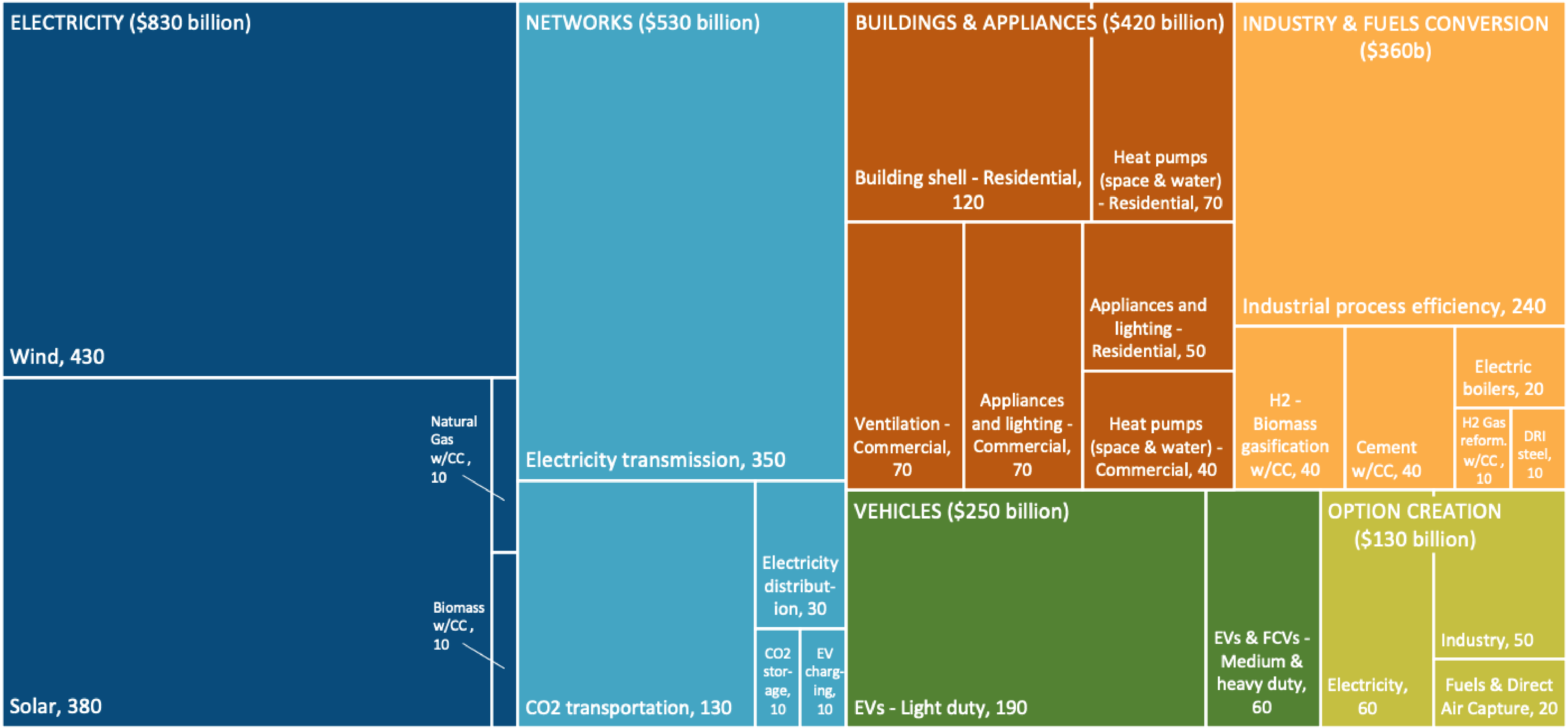
Motor Vehicles

premature deaths per county per 100,000 people

0 20

ENERGY SPENDING IS MUCH MORE CAPITAL INTENSIVE: 2.5 T$ OF ADDITIONAL CAPITAL SPENT OVER THE NEXT DECADE

Total additional capital invested, 2021-2030, by sector and subsector for any of the net-zero pathways vs. REF (billion 2018$)



Includes capital invested pre-financial investment decision (pre-FID) and capital committed to projects under construction in 2030 but in-service in later years.
All values rounded to nearest $10b and should be considered order of magnitude estimates. Incremental capital investment categories totaling less than $5B excluded from graphic.
Other potentially significant capital expenditures *not* estimated in this study include establishment of bioenergy crops, decarbonization measures in other industries besides steel and cement, non-CO_2 GHG mitigation efforts, and establishing enhanced land sinks.

NET-ZERO BY 2050 REQUIRES AGGRESSIVE ACTION TO START NOW. EIGHT KEY PRIORITIES FOR THE 2020'S:

1. Build societal commitment, investment environment, and delivery capabilities
2. Improve end-use energy productivity and efficiency
3. Electrify energy demand, especially transportation and buildings
4. Decarbonize and expand electricity
5. Prepare for major expansion and transformation of the bioenergy industry
6. Build infrastructures: electricity transmission and CO_2 transport/storage
7. Enhance land sinks and reduce non-CO2 emissions
8. Innovate to enlarge the net-zero-carbon technology toolkit

Upcoming Webinars

- State of the U.S. Energy Storage Industry: 2020 Year in Review (2/25)
- Designing Hybrid Combined Heat and Power Systems: An Introduction to New Features in NREL's REopt Lite Tool (3/2)
- Solar+Storage for Puerto Rico Fire Station Resilience (3/3)
- Building Community Resilience Hubs: A Conversation with the Asian Pacific Environmental Network and RYSE Center (3/10)
- ConnectedSolutions: How a New Program Improves the Economics and Social Benefits of Solar+Storage in Massachusetts and Beyond (3/12)
- Collaborating with Community-Based Organizations: An Energy Justice Primer for States (3/23)

Read more and register at: www.cesa.org/webinars

CleanEnergy States Alliance

Thank you for attending our webinar

Warren Leon
Executive Director
Clean Energy States Alliance
wleon@cleanegroup.org

Learn more about the **100% Clean Energy Collaborative** at
www.cesa.org/projects/100-clean-energy-collaborative