Prepared for USEA-USDOE
Workshop on Models for Deployment of CCUS Hubs

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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

https://netzeroamerica.princeton.edu

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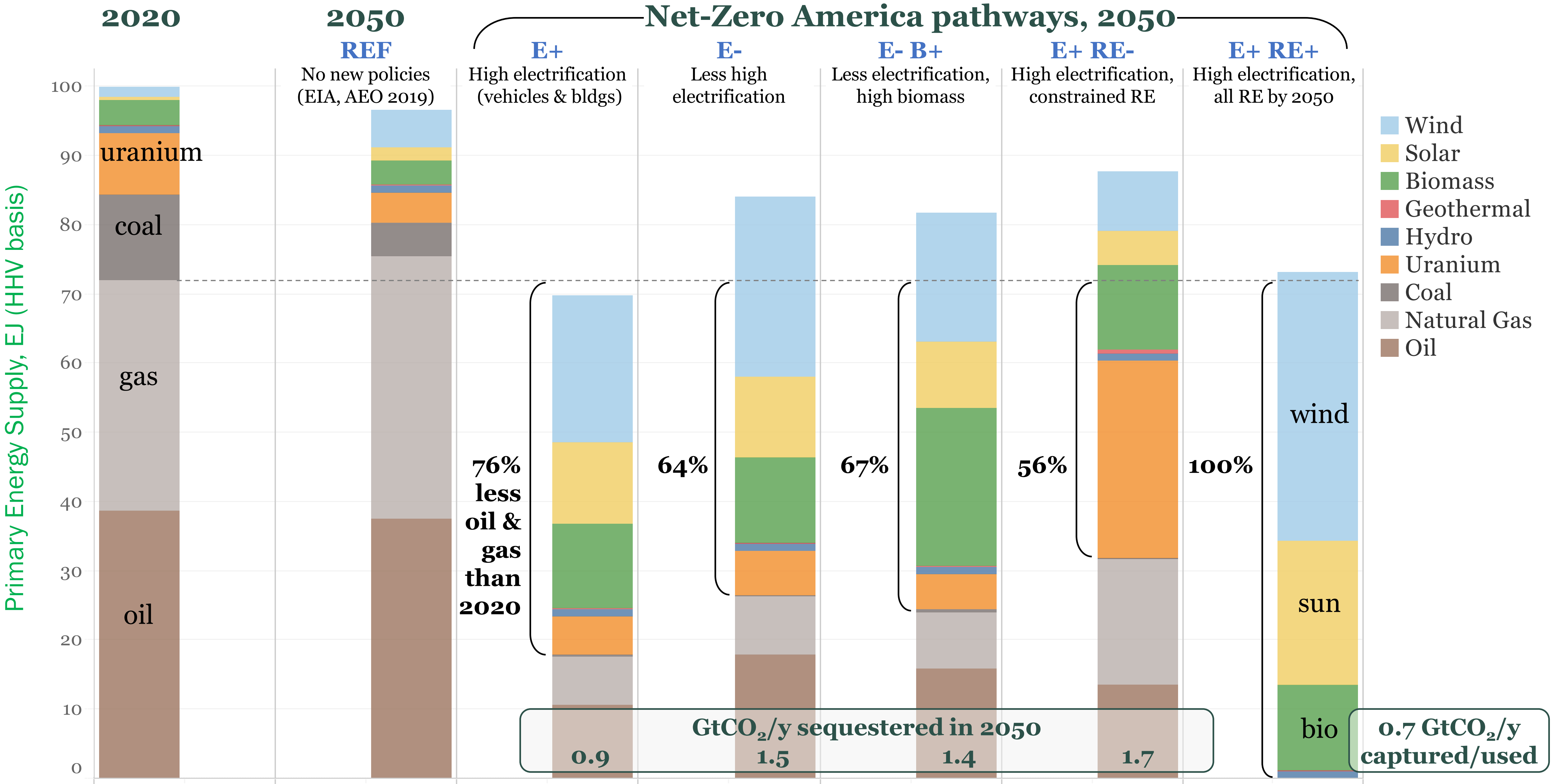
Five modeled least-cost paths to net-zero in 2050 show implications of different approaches



All paths employ six key pillars of decarbonization

Energy/Industrial System

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

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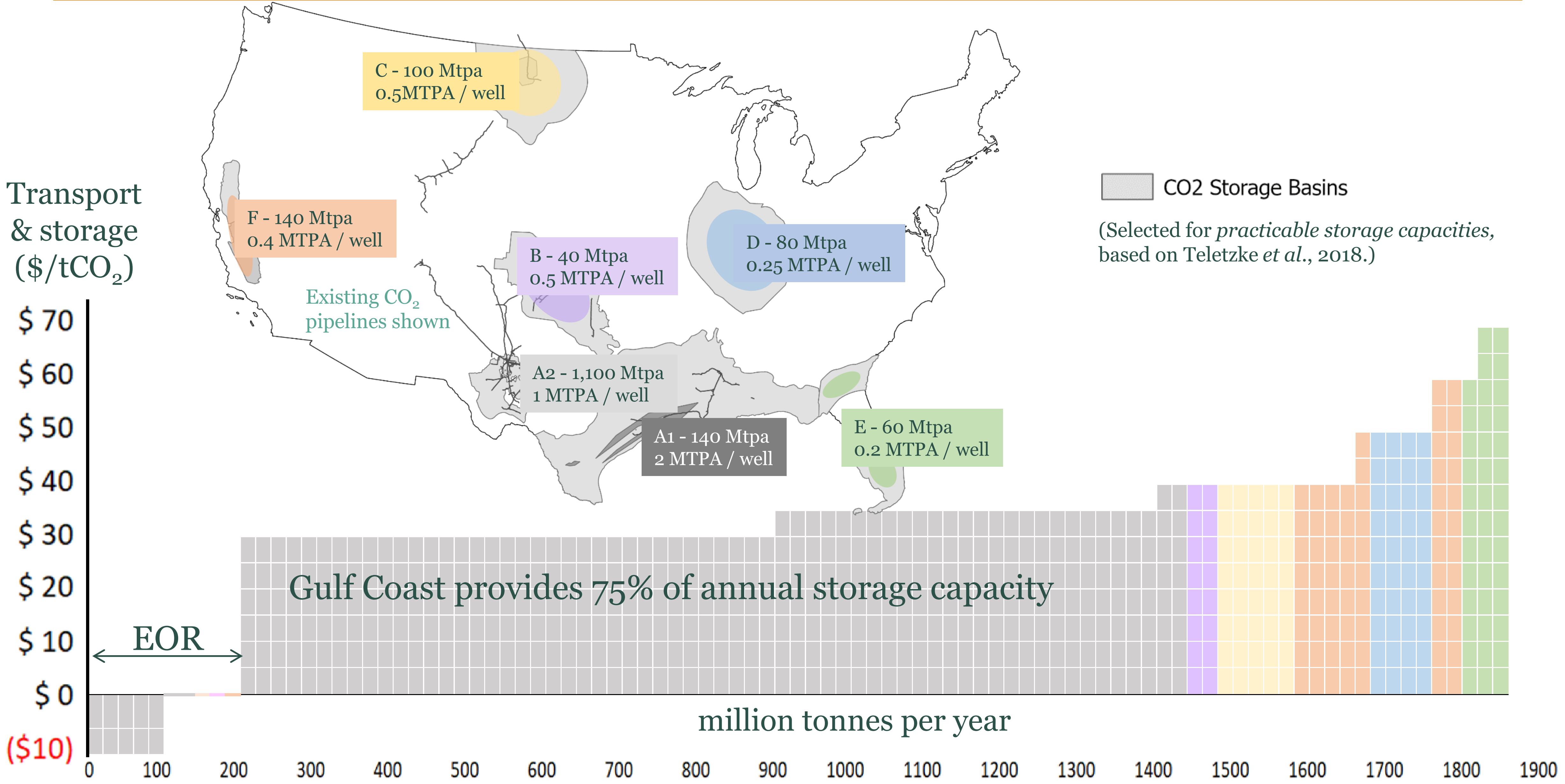
CO_2 transport network design combines state-of-art understanding of storage basins and geospatial downscaling of CO_2 point sources.

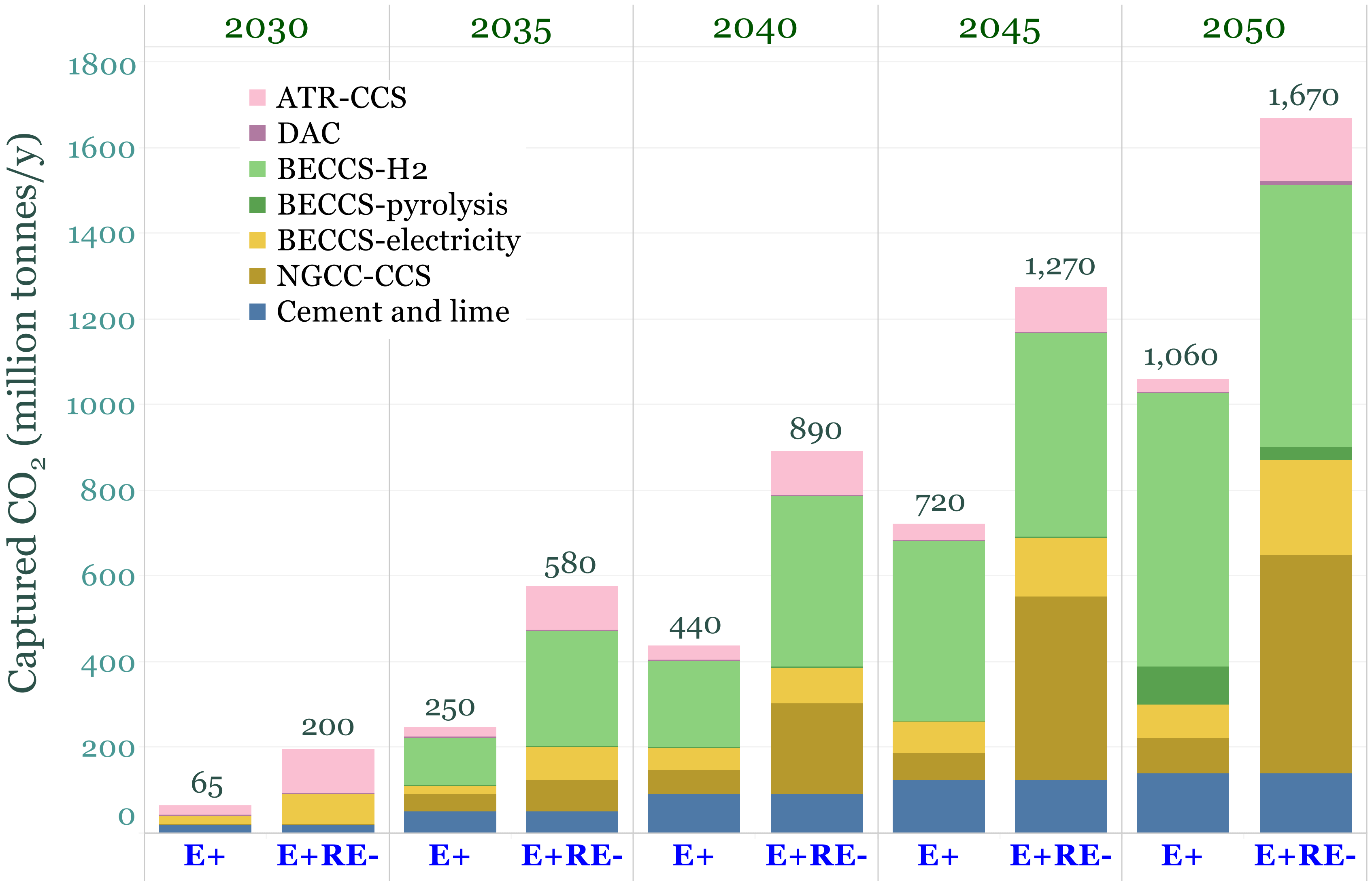
1. Most prospective storage basins identified based on practicable storage capacity [Teletzke *et al.*, 2018].
2. Notional supply-cost curve for CO_2 transport and storage established using expert judgement and industry consultation (BP, ExxonMobil, Occidental), assuming shared transport infrastructure.
3. Least-cost optimization model of energy/industrial system decides levels of CCS in power sector, fuels production and industry in 5-year time steps across 14 regions for the U.S.
4. “Downscaling” analysis for each region defines locations for each facility at county level.
5. Notional CO_2 trunk line network drawn ‘by eye’ to serve major clusters of point sources; point source downscaling then repeated to locate all point sources within 200 km of trunk lines. Spur lines added to connect point sources to trunk lines using shortest distance following existing ROWs*.
6. Trunk and spur lines sized and costed using NETL CO_2 Transport Cost Model.
7. Build schedule delivers CO_2 transport infrastructure in advance of start of CO_2 capture activity.
8. Original supply-cost curve assumptions for transport and storage validated against levelized T&S cost calculated using infrastructure build schedule and NETL cost model.

* Existing ROWs include natural gas, NH_3 and CO_2 pipelines, railways, interstate highways, and > 220kV electricity transmission lines, as mapped in Edwards and Celia, “Infrastructure to enable deployment of carbon capture, utilization, and storage in the United States,” *PNAS*, 115(38): E8815-E8824, 2018.

Notional CO_2 storage capacity appraised, permitted and developed in 2050 is up to 1.8 billion t/y, mostly in Gulf Coast



Some capture plants online by 2030, followed by rapid growth in 2030s and 2040s. E+ and E+RE- pathways are shown here.



CO_2 captured and injected in 2050 is 1.3x to 2.4x the volume of current annual US oil production (*at reservoir pressure*).

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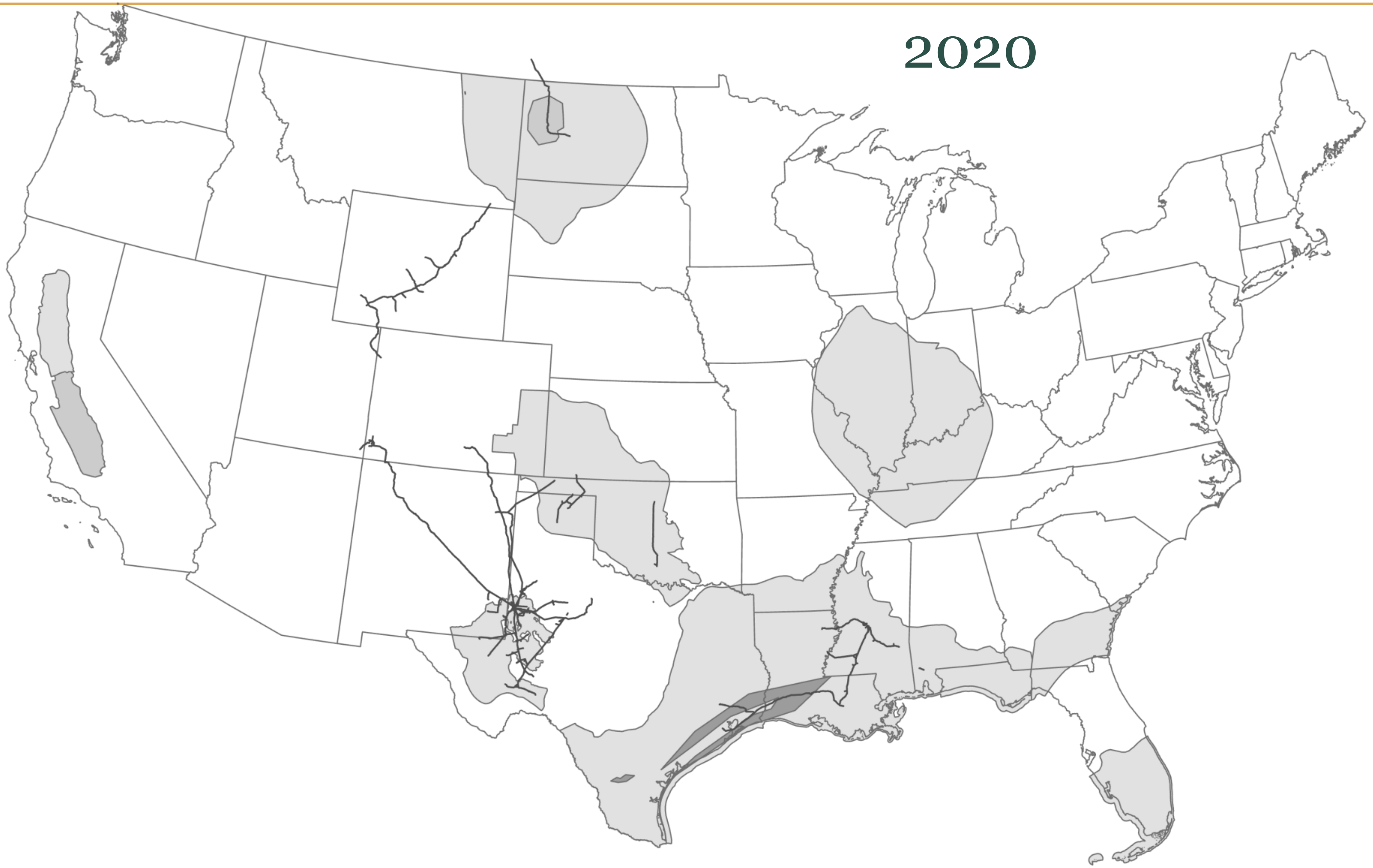
Existing CO_2 pipeline network

- ~ 80 million tCO_2/yr transported
- ~ 8,500 km of pipelines
- Servicing enhanced oil recovery operations
- Majority in Permian Basin (West Texas and southeast New Mexico)



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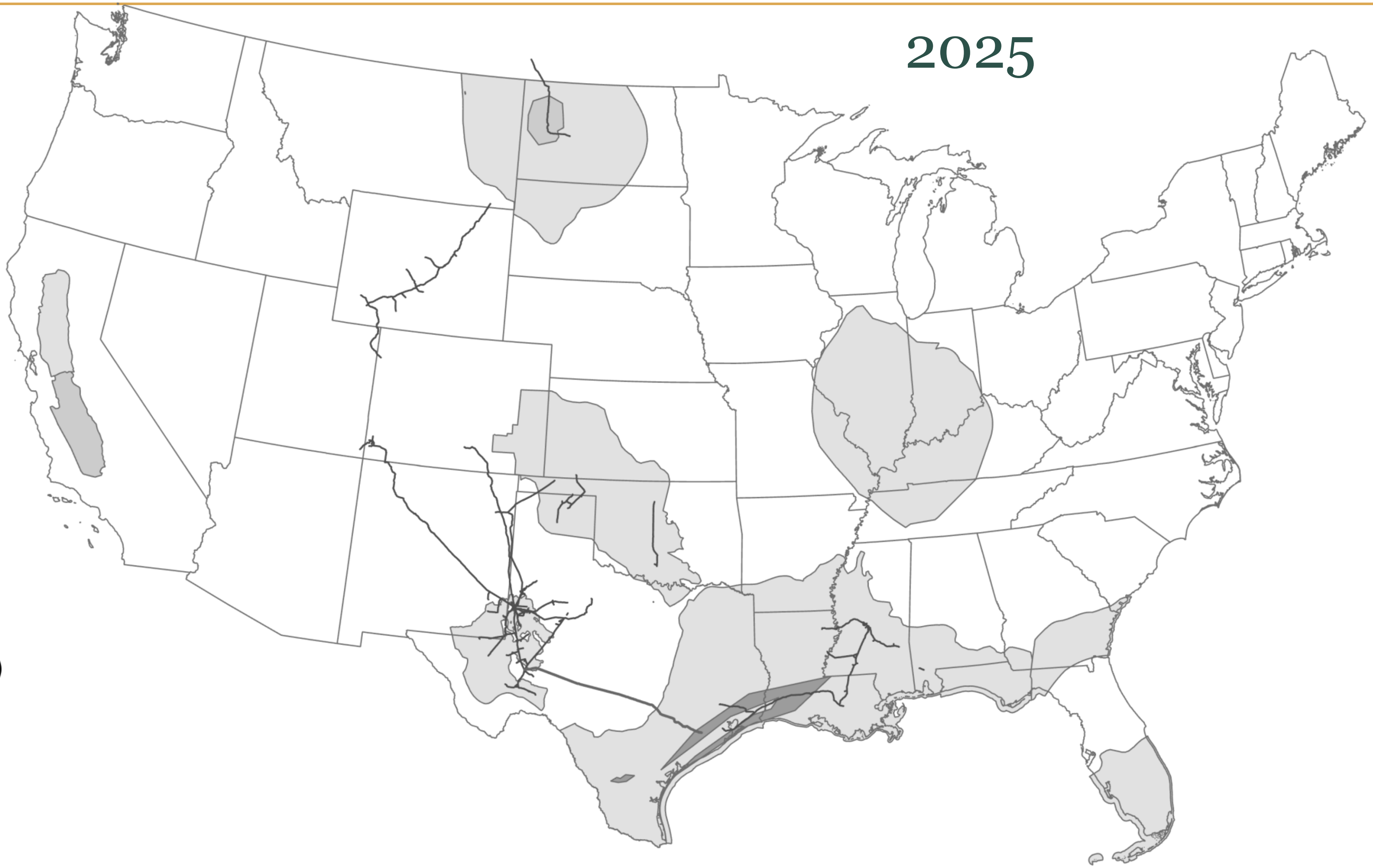
Trunk line construction begins before 2025 with connection between Permian Basin and Gulf Coast

E+ scenario

No CO_2 flow in this period
700 km new pipelines
Capital in-service: $70B



CO2 point source type

- CO2 point sources
- BECCS - power and fuels
- Cement w/ ccs
- Natural gas power ccs oxyfuel

CO2 captured (MMTPA)

- 0.0006449
- 7.9144
- 15.8282
- 23.7419

Trunk lines (capacity in MMTPA)

- < 100
- 100 - 200
- > 200

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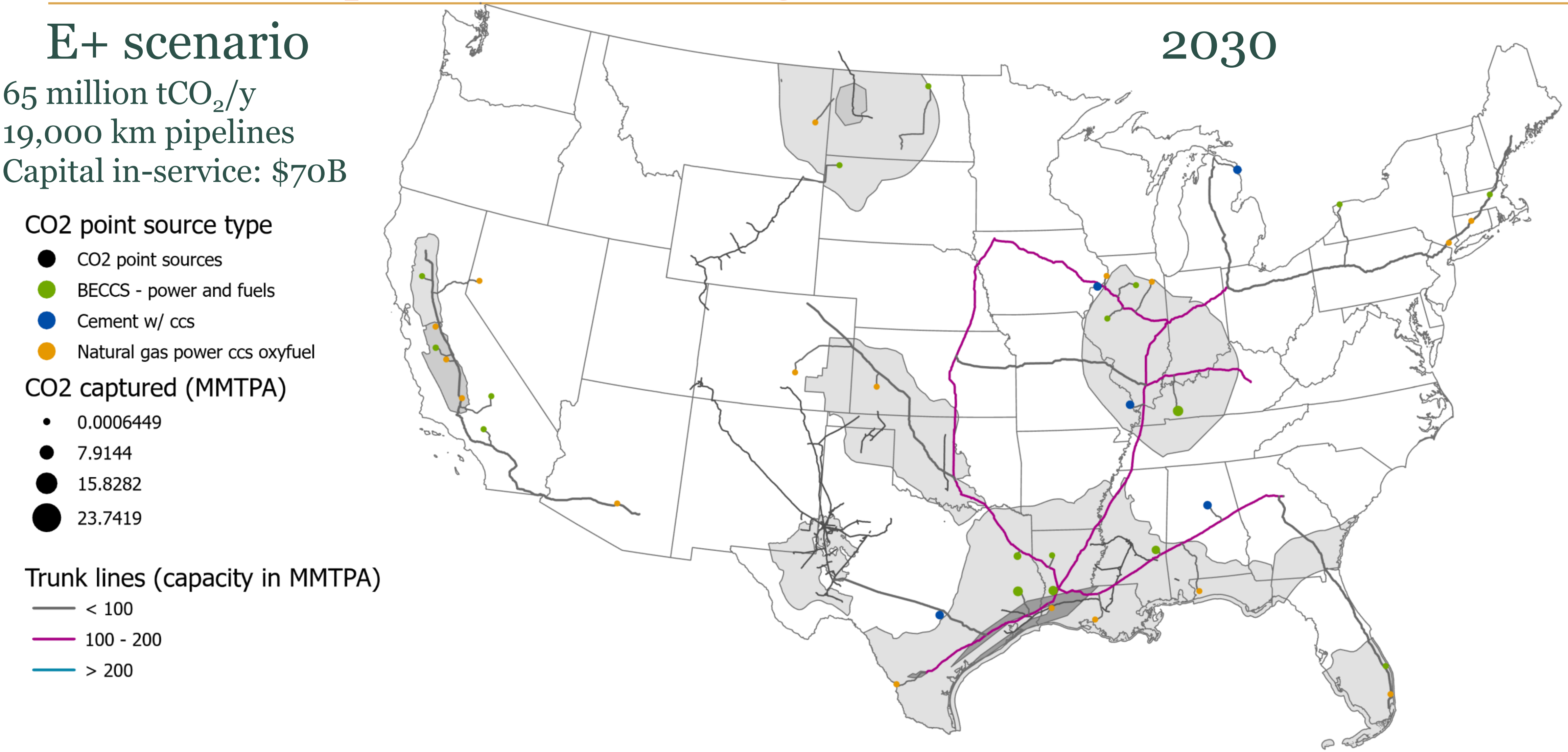
Trunk line build out continues and initial CO_2 capture plants come online, with spur lines connecting to trunk network

E+ scenario

65 million tCO_2/y
19,000 km pipelines
Capital in-service: $70B



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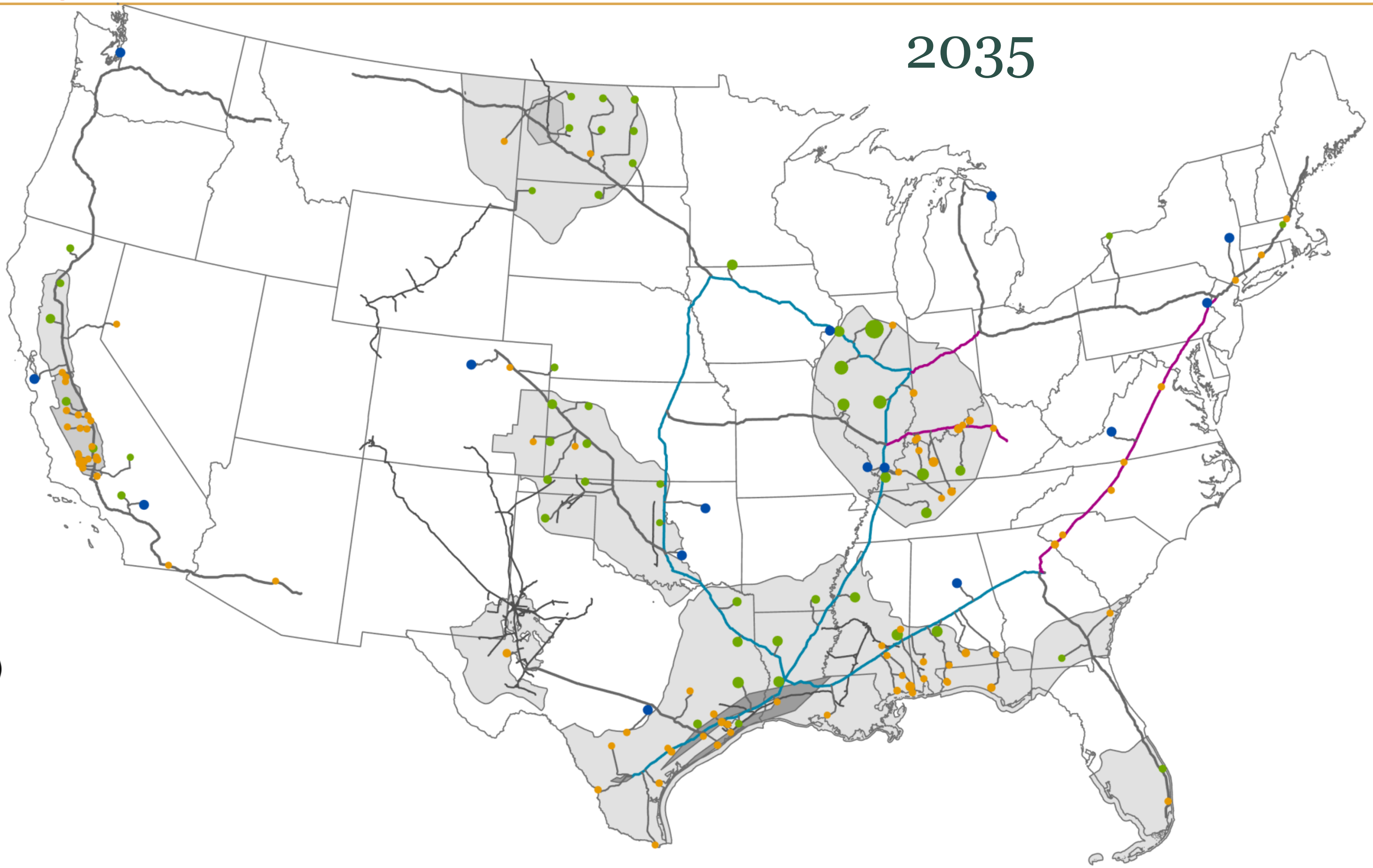
Trunk network routes complete; some sections add parallel lines as more capture projects are built and connected

E+ scenario

246 million tCO_2/y
41,000 km pipelines
Capital in service: $115B



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More individual trunk line duplications as number of capture projects continues to grow

E+ scenario

435 million tCO_2/y
51,000 km pipelines
Capital in service: $125B

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- Natural gas power ccs oxyfuel

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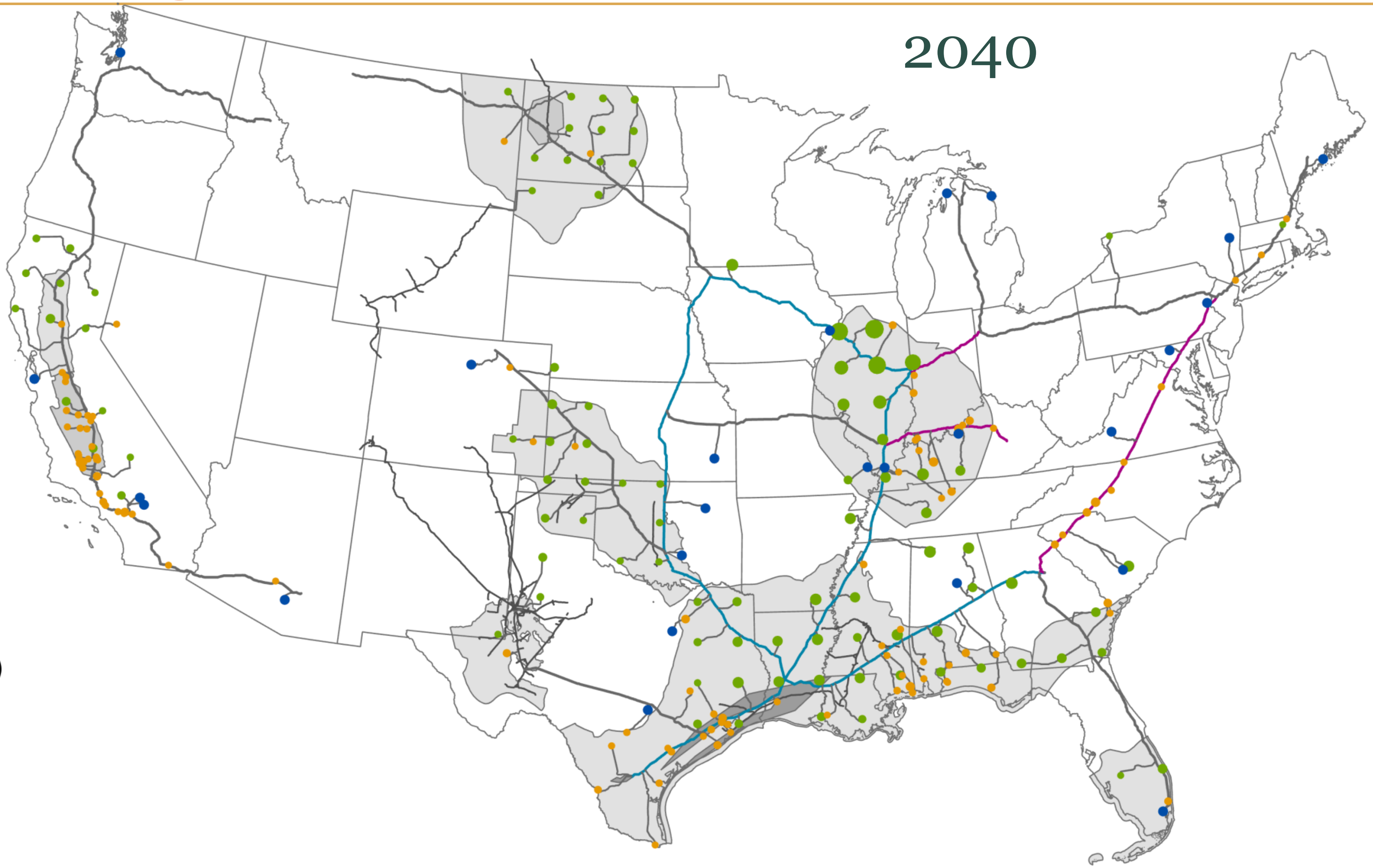

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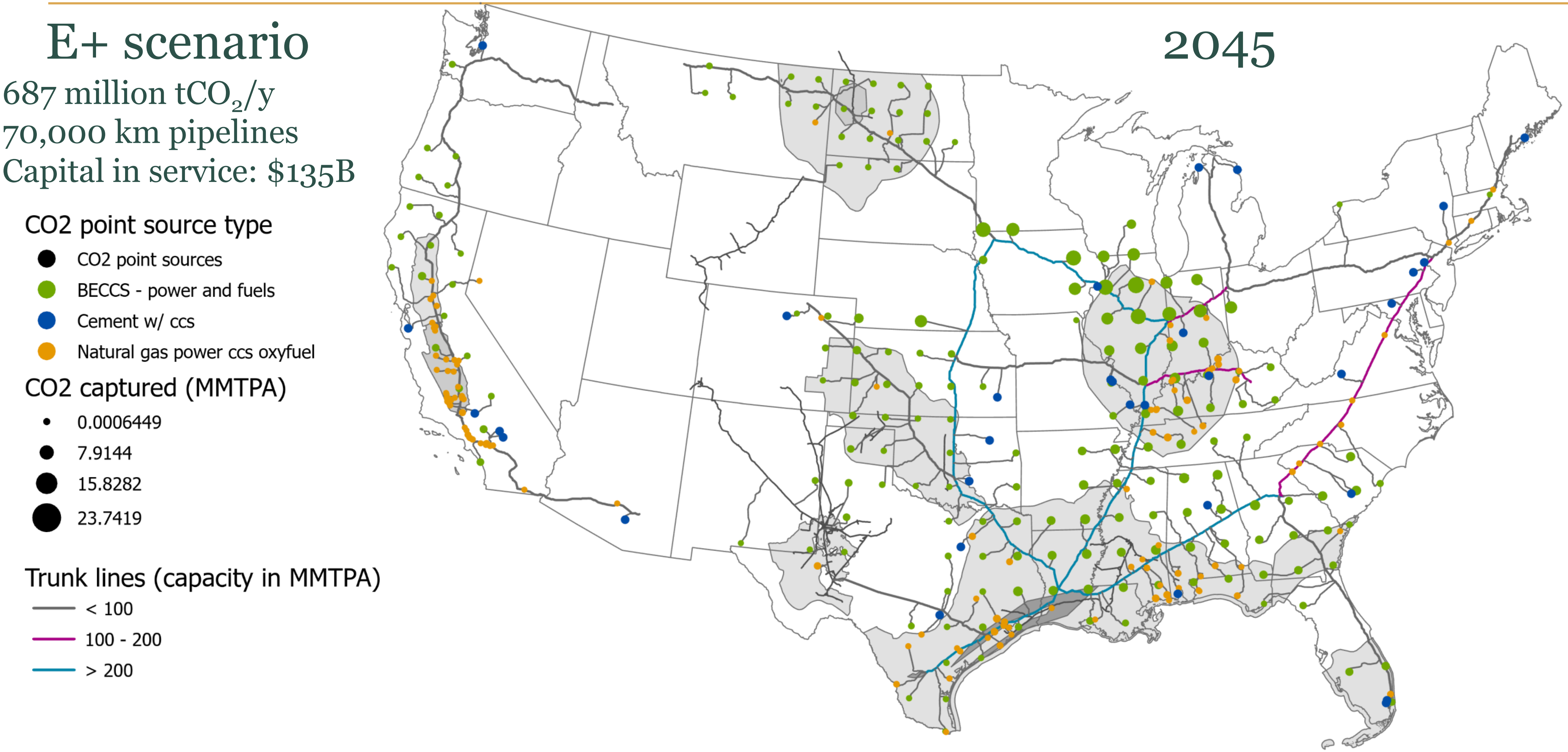
CO_2 capture plants connected to trunk lines grow rapidly

E+ scenario

687 million tCO_2/y
70,000 km pipelines
Capital in service: $135B



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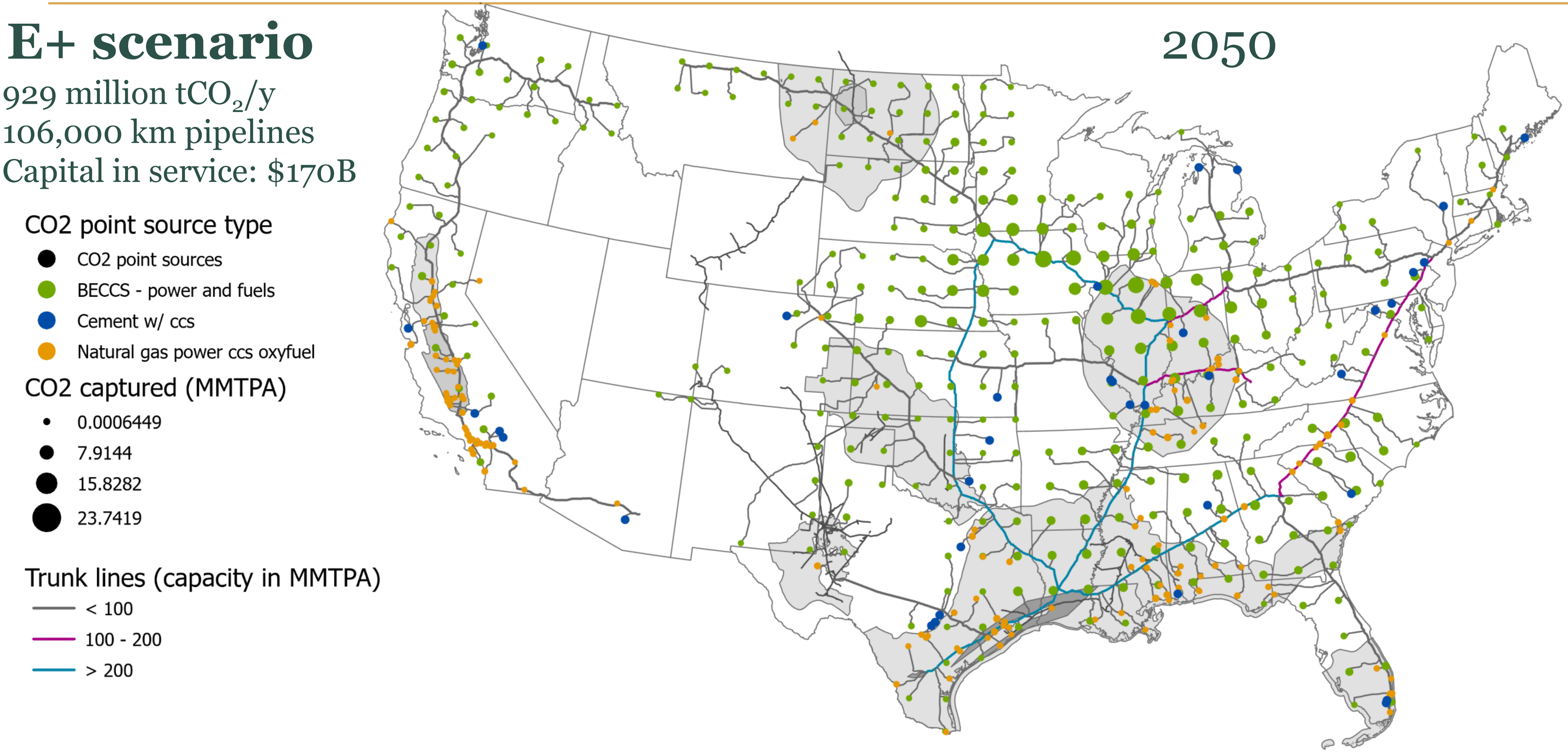
2050 totals: 21,000 km trunk lines + 85,000 km spur lines (equivalent to ~22% of US natural gas transmission pipeline total)

E+ scenario

929 million tCO_2/y
106,000 km pipelines
Capital in service: $170B



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Capital for national CO_2 collection and transport network is \$170 to \$230 billion, or ~ \$11 to \$16/tCO_2 when amortized across all users

Costs (2020$)*	E+	E- B+
Trunk lines		
Total length, km	21,100	25,400
Total installed capital cost, billion 2020$	101	135
National network-access charge, \$/tCO_2 delivered	11.3	7.6
Center-East network-access charge, \$/tCO_2 delivered	11.3	7.4
West network-access charge, \$/tCO_2 delivered	11.6	10.4
Spur lines		
Total length, km	85,800	85,700
Total installed capital cost, billion 2020$	69	88
National network-access charge, \$/tCO_2 delivered	4.6	3.0
Total trunk + spur lines		
National network-access charge, \$/tCO_2 delivered	15.9	10.6

Higher charge for West than for Center-East trunk network

* Costs, including pipelines and compressors, were estimated using the DOE/NETL CO_2 Transport Cost Model (version 2b).

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