Opportunities and Challenges for CCUS in the Power Sector

PRESENTED BY

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PRESENTED AT

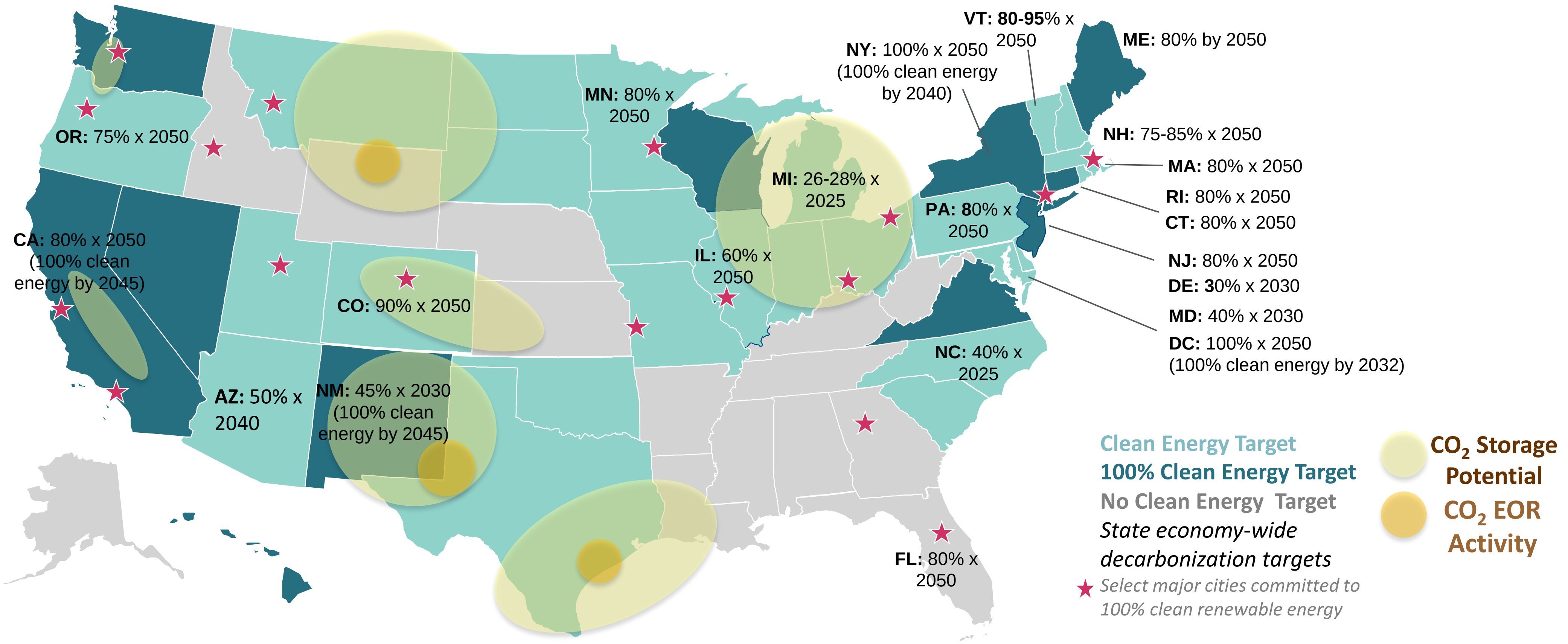
Carbon Capture Coalition Webinar: Carbon Capture and the Power Sector

NOVEMBER 16TH, 2020

THE Brattle GROUP

States, Cities, and Utilities are Mandating Clean Electricity

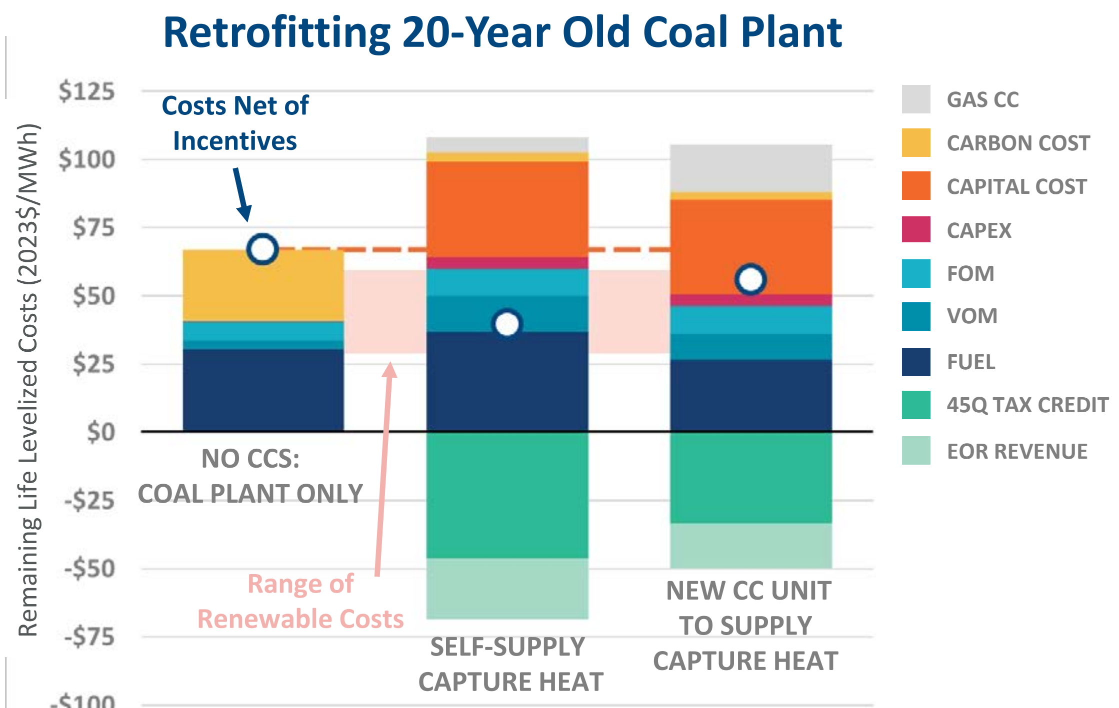
States and cities setting aggressive economy-wide decarbonization goals will require a clean electricity grid. The U.S. has enormous geologic storage potential (over 2,000 gigatonnes), though much appraisal work remains. Yet, as of now, many policies and mandates exclude CCS as a technology eligible to contribute to decarbonization.

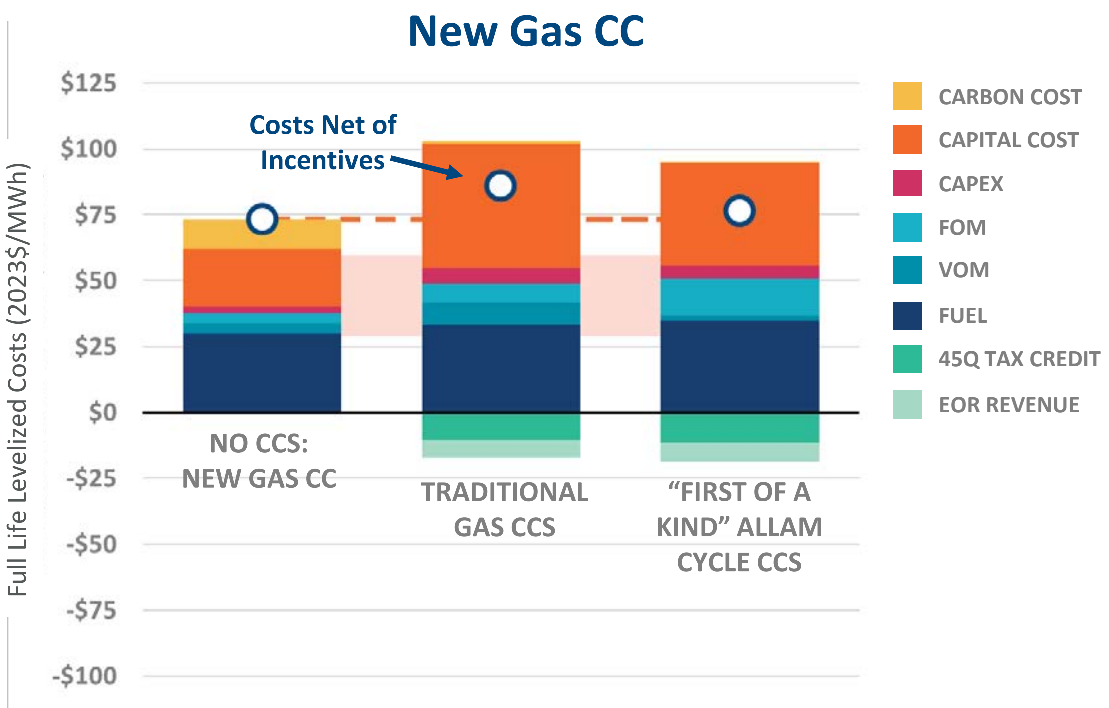


Sources: Center for Climate and Energy Solutions (C2ES), Sierra Club, National Conference for State Legislatures. Includes states with executive orders for clean energy commitments; various sources.

Costs of Power-CCUS vs. New Renewables *Today*

Today, CCUS incentives can offset the costs to retrofit a coal power plant. For gas, however, lower incentives per MWh leave a $14-22/MWh financing gap ($3-13/MWh with a carbon price) using current-day technology. In both cases, however, CCS cannot compete with new solar and wind in its current form in a low-renewable penetration grid *today*





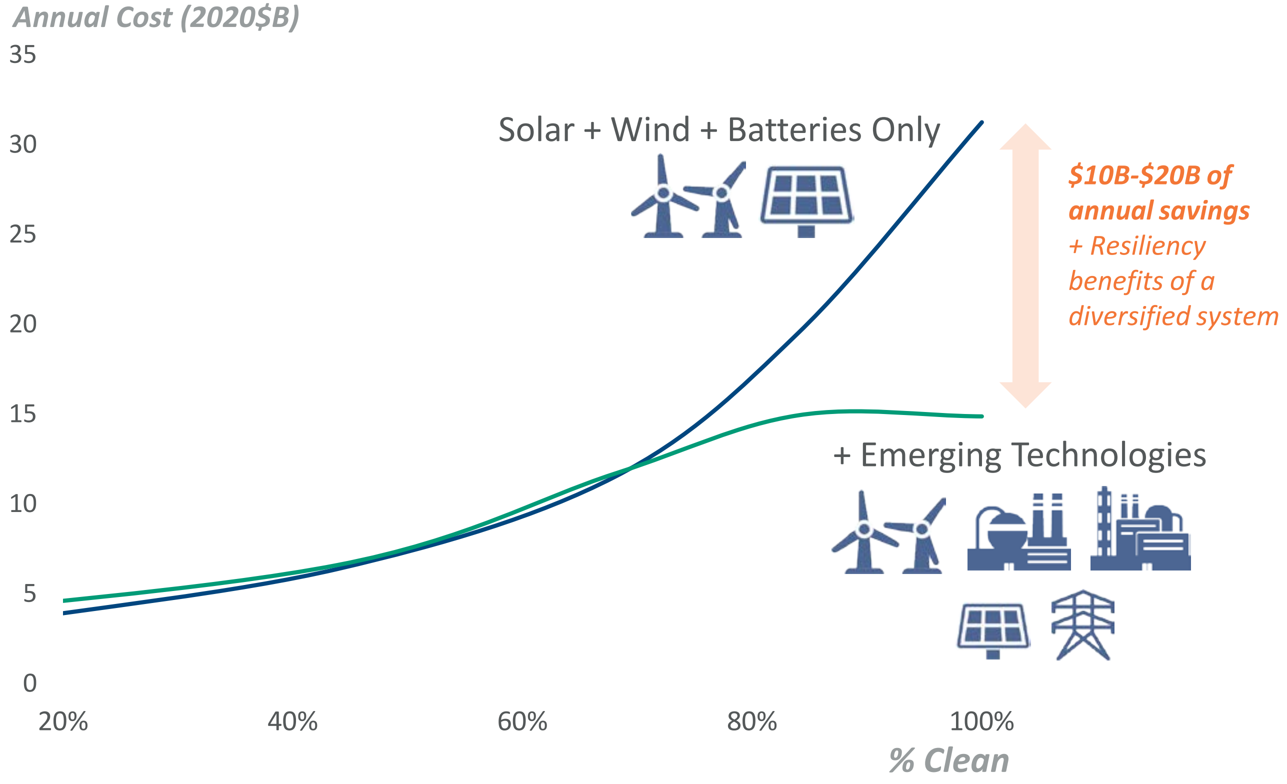
Notes: Sizes of coal plant (1,150 MW) and gas plant (375 MW) are consistent with typical baseload plant in industry and assumed to run at a 65% capacity factor. Assume a carbon price escalating from $20 to $40/tonne and EOR revenues equal to 38% of projected WTI prices. Sources: EIA Annual Energy Outlook (coal and gas capital and operating costs). For more details, please see recent Brattle Study. National Energy Technology Laboratory (Allam cycle CCS costs). Lazard (renewable costs, unsubsidized, escalated to $2023).

Low-Emission Firm Generation Can Significantly Reduce Costs of a Deeply Decarbonized Grid

Including emission-free "firm" generation technologies in the solution set can significantly reduce the costs of deep decarbonization, as the *value* of intermittent renewable energy falls rapidly at high levels of decarbonization due to their correlated and intermitent generation, and uncertainty

- In a renewables-and-storage-only system, costs exponentially rise as correlated renewable output requires need to over-build capacity to meet load reliably year-round
  - Transmission development would help, but has proven difficult thus far
- Numerous studies have estimated substantial value of firm clean generation at decarbonization levels beyond 50%
  - Annual savings of *billions* in PJM, New England, and New York State
- The technologies that will support renewables will depend by region and on future costs
  - CCUS could play a big role in states with low performing solar and/or wind, cheap local natural gas resources, and suitable geologic storage

Brattle GridSIM Capacity Expansion Modeling of Decarbonizing New England Electricity System



Notes: See Appendix for details about Brattle GridSIM Modeling Tool

Impediments, Barriers, and Challenges of CCUS Remain for Power Generation

1. **Economics remain challenging** for retrofits and new CCUS power plants *today*, which hampers development *for tomorrow*
   - Lack of carbon pricing and CCUS mandates makes economic incentives limited, especially for natural gas plants which face revenue gap
   - New renewable energy remains most cost-effective clean MWh until integration, resilience, or redundant overbuilding with storage become concerns
2. **Carbon policy risk** is decreasing, but still remains. Policy ambiguity also hampers long-term development
   - Uncertainty exists regarding whether CCUS will be eligible under clean energy standards (e.g. California's SB100)
   - Mandate mechanisms are likely to be part of solutions, but will reduce market price signals for other technologies to participate in decarbonization
3. **Lack of metrics and criteria** for evaluating long-term resiliency risks and cost-effective planning for deeply decarbonized grid
   - Scale of system flexibility in a deeply decarbonized grid is unprecedented. Need to develop prevention criteria for resiliency to promote all technological solutions
4. Current **utility regulations** lack scope for considering costs and benefits beyond their power systems for a clean economy
   - Chicken-and-egg problems arise for organizing CCUS infrastructure: Facilities are reluctant to sign contracts before pipelines and storage projects are permitted, but storage and pipeline difficult to finance absent these contracts. Need for broader coordination and planning of CCUS infrastructure
   - Upstream fossil extraction emissions and pollution need to be addressed to provide environmental benefit
5. **Experience, confidence, and demonstrated successes remain limited** for power CCUS projects
   - Previous project cost-overruns (Boundary Dam) raise doubts, despite some successes (Petra Nova) and estimates of cost-improvements for future projects
   - Interest is growing, as states move to more stringent decarbonization goals, studies show CCUS can play significant role under the right conditions

Need to Shift Policy and Thinking from One-off Retrofits to System-Wide Planning for CCUS

Utilities and regulators need to shift their perspective of CCS as a "retrofit technology" to a technology that should be evaluated as part of a larger solution set that substantially reduces costs of achieving a clean grid.

- **Clean energy targets** need to consider a broad solution set to ensure cost-effective deep decarbonization
  - Policies such as net-zero targets and clean energy mandates that include CCUS along with other complementary technologies key to cost-effective clean electricity system
- **Regulated utilities** and **state commissions** may be well positioned to serve as integrator, facilitating CCUS development in long-term integrated planning that considers economy-wide state energy sources, uses, and goals
  - Integrated planning for CO_2-pipeline infrastructure (if necessary) can help overcome chicken-and-egg challenges, facilitate cross-industry collaboration to reduce transport and geologic storage costs (e.g. cement or steel manufacturing), take into consideration local resource and job growth, and possible grow utility rate-base
  - Shift required from focusing on electricity-system-only planning to economy-wide decarb planning, and how CCUS infrastructure development could reduce economy-wide costs (e.g. to non-electric industrial processes needing carbon takeaways)
- **CCUS provides opportunity to utilize existing infrastructure** and preserve jobs, especially in areas where transmission solutions remain unfeasible due to various political and geographical constraints
- **Wholesale market incentives that scale with the amount of realized carbon abatement**
  - Forward Clean Energy Market offers advanced features to dynamically vary payment rates for credits based on the realized carbon abatement at any point in time
- **Emerging CCUS technology looks promising if incentives drive continued technology investment and development**. New Allam-Cycle power plants project low costs, small footprints, and reduced (or no) water needs – perhaps with little loss of load following capability

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Appendix

GridSIM: Brattle's next-gen capacity expansion model

Features

- Designed to simulate **highly-decarbonized systems**
- Detailed representation of **power systems** and **markets**
- **Co-optimized** modeling of energy, ancillary, and capacity markets
- Chronological commitment and dispatch to robustly model **storage**
- Modeling of emerging technologies such as **renewable natural gas**

Example Insights

- How to balance a **100% carbon-free** grid?
- How are **nuclear** revenues affected by 70% renewable energy?
- How does the cost of **offshore wind** affect the future resource mix?

gridSIM

GridSIM model framework

INPUTS

Supply
- Existing resources
- Fuel prices
- Investment/fixed costs
- Variable costs

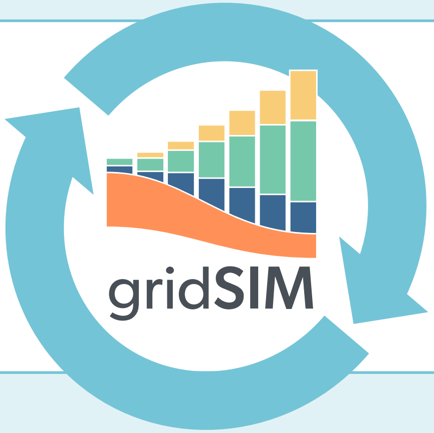
Demand
- Representative day hourly demand
- Capacity needs

Transmission
- Zonal limits
- Intertie limits

Regulations, Policies, Market Design
- Capacity market
- Carbon pricing
- State energy policies and procurement mandates

GridSIM OPTIMIZATION ENGINE

Objective Function
- Minimize NPV of Investment & Operational Costs



Constraints
- Market Design and Co-Optimized Operations
  - Capacity
  - Energy
  - Ancillary Services
- Regulatory & Policy Constraints
- Resource Operational Constraints
- Transmission Constraints

OUTPUTS

- **Annual Investments and Retirements**
- **Hourly Operations**
- **Supplier Revenues**
- **Emissions and Clean Energy Additions**
- **Market Prices**
- **System & Customer Costs**

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