Regional Adoption of CCS within the Electric Power Sector.
ECAR, SERC, and ERCOT

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Background and Motivation

- Carbon dioxide capture and storage (CCS) is a technological system with the potential for large-scale CO_2 emissions reductions from electric power generation.

- A complete analysis of the economics of CCS in the electric power sector must go beyond simple technology cost comparisons. Specifically, the analysis must include the economics of:
  - Existing electric generating capacity – efficiency, fuel costs, operating and maintenance costs, emissions.
  - Electricity demand – both the varying nature of the electricity load profile (from Baseload to Peaking) as well as future demand growth.
  - Competing technologies for new generating capacity – capital costs, efficiency, operating and maintenance costs, emissions.
  - Other market factors – e.g., fuel prices, emissions policies, cost of financing, reserve margin requirements, etc.

CCS Deployment at the Regional Level

- Analyze the potential adoption of CCS technologies in three key US electric power regions (ECAR, SERC, and ERCOT) considering jointly:
  - The economics and characteristics of the regional electric power sectors, and
  - The cost and potential supply of regional CO_2 geologic storage reservoirs.

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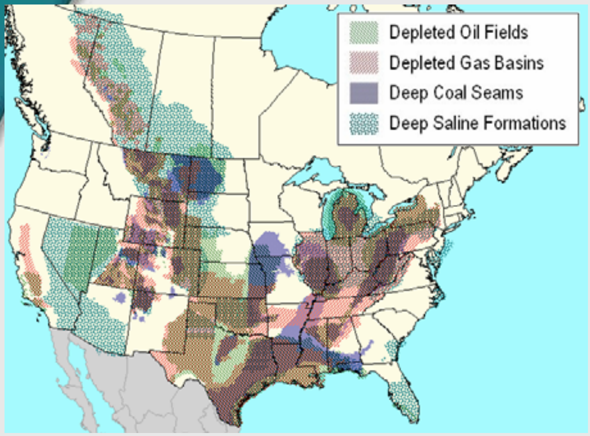
Study Approach

- Model the potential impact of a hypothetical CO_2 emissions limitation policy in these 3 electricity regions (ECAR, SERC and ERCOT), looking out from 2005 to 40 years into the future.
  - Far enough out to envision CCS but close enough that the current capacity and near-term builds matter.

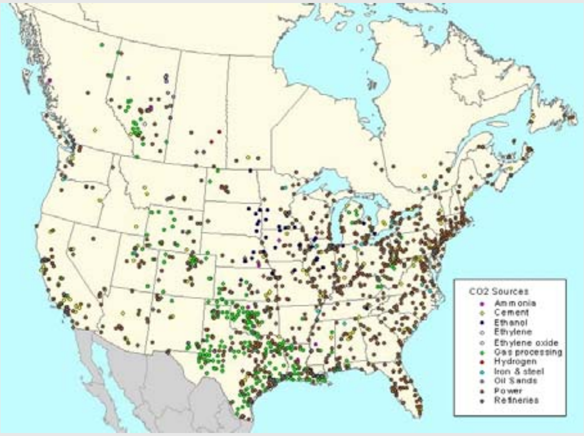
- Integrate the economics of two research tools:
  - The Battelle CO2-GIS model in order to determine the regional capacity and cost of CO_2 transport and storage
  - The Battelle CMEM, an electric power market optimal capacity expansion and dispatch model to determine the investment and operation of electric power technologies with CCS.

North America: An Abundance of CO_2 Storage Potential and a Large Potential User Market for CCS Technologies



3,800+ $GtCO_2$ Capacity within 330 US and Canadian Candidate Geologic CO_2 Storage Reservoirs

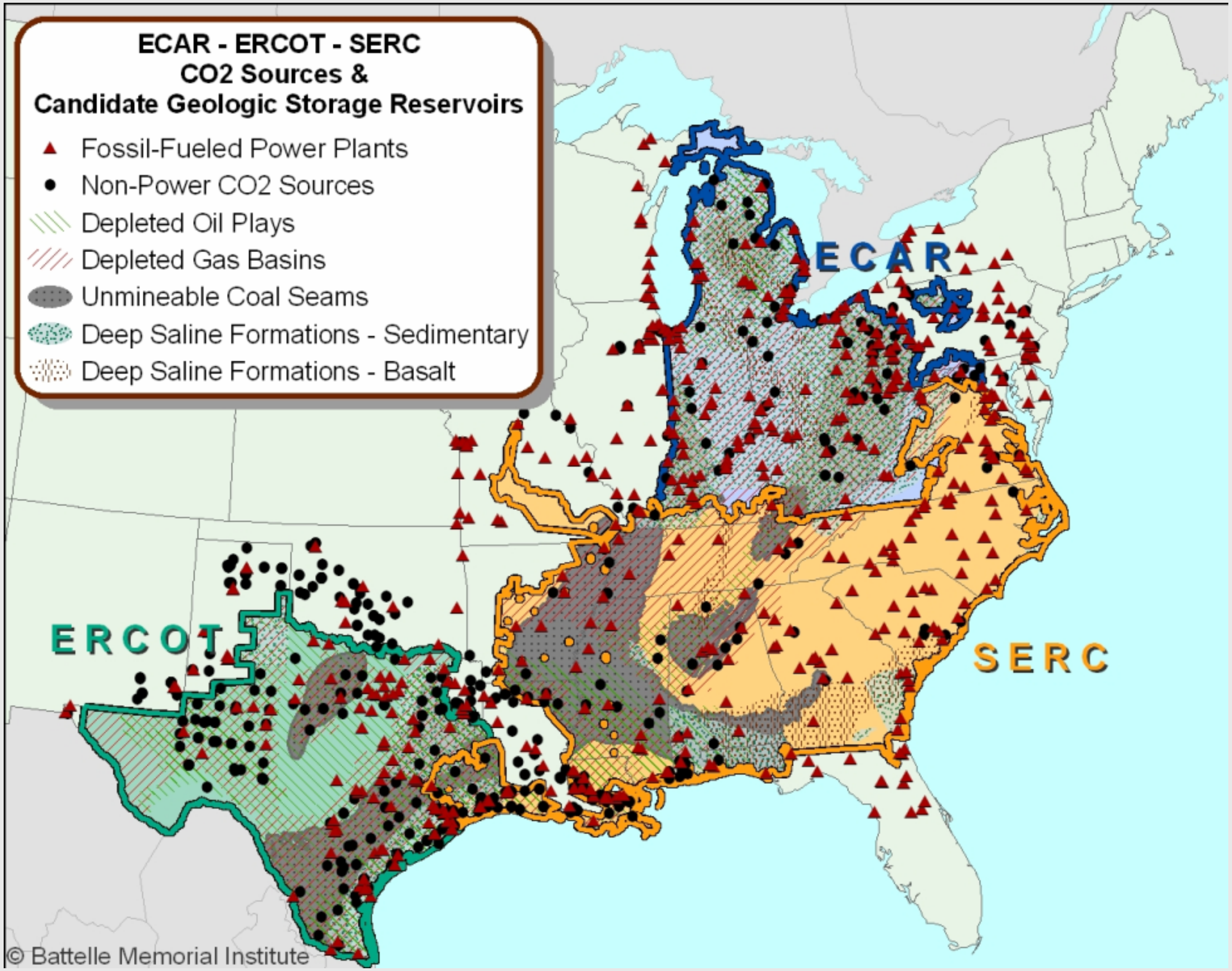
- 3,730 $GtCO_2$ in deep saline formations (DSF)
- 65 $GtCO_2$ in deep unmineable coal seams with potential for enhanced coalbed methane (ECBM) recovery
- 40 $GtCO_2$ in depleted gas fields
- 13 $GtCO_2$ in depleted oil fields with potential for enhanced oil recovery (EOR)



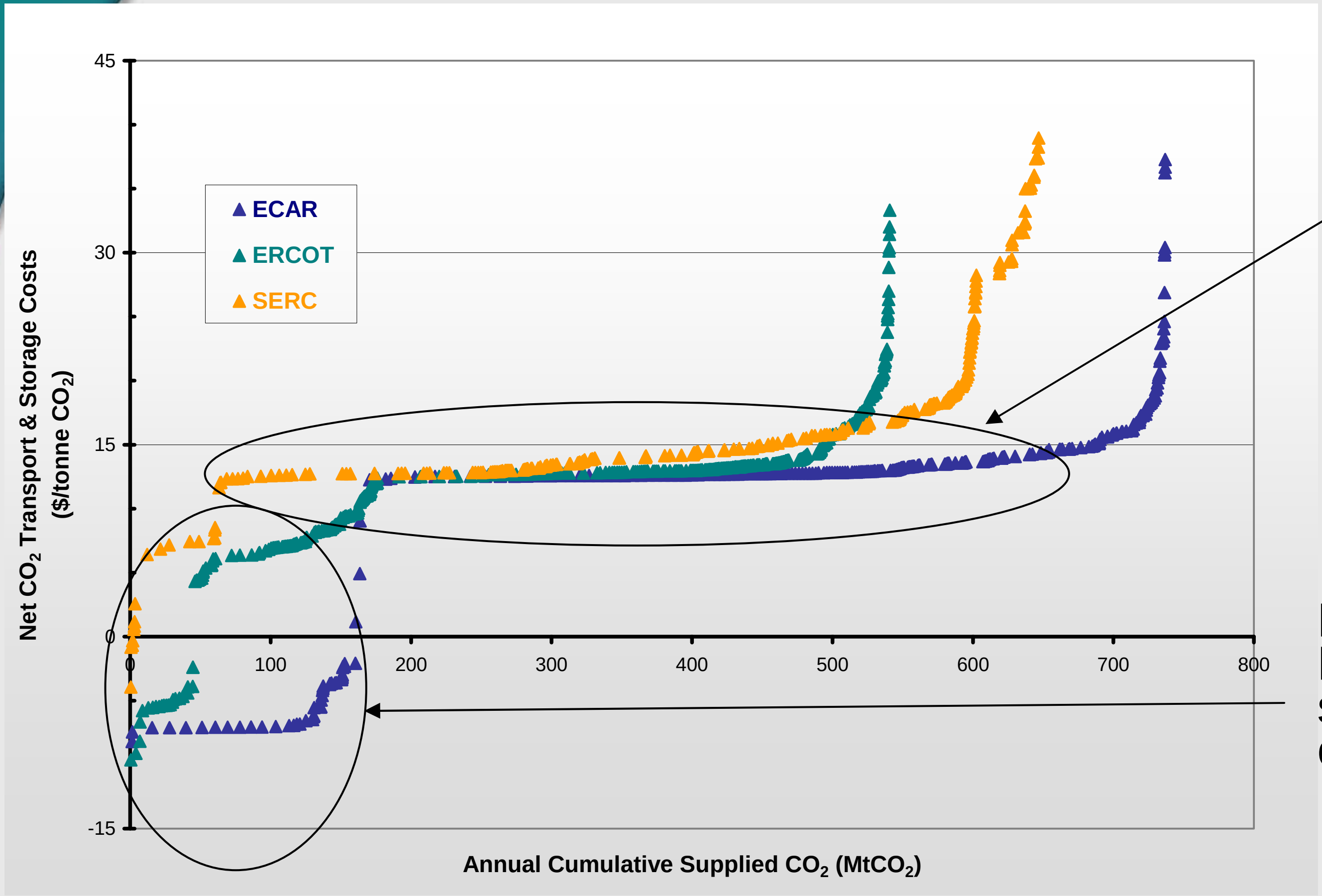
2,082 Large Sources (100+ $ktCO_2$/yr) with Total Annual Emissions = 3,800 $MtCO_2$/yr

- 1,185 electric power plants
- 447 natural gas processing facilities
- 154 petroleum refineries
- 53 iron & steel foundries
- 124 cement kilns
- 43 ethylene plants
- 9 oil sands production areas
- 40 hydrogen production
- 25 ammonia refineries
- 47 ethanol production plants
- 8 ethylene oxide plants

CO_2 Sources and Potential Storage Reservoirs in the Three Regions



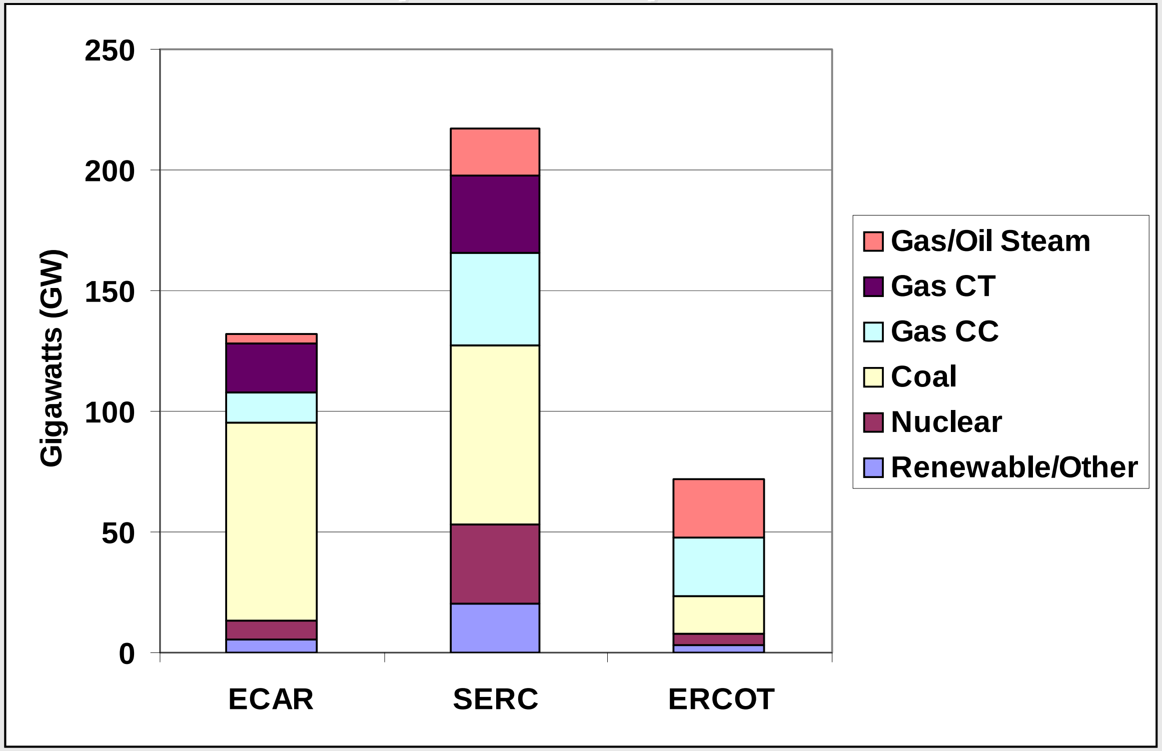
CCS Transport and Storage Annual Cost Curves from CO2-GIS Model



Deep saline formations and depleted gas fields supply majority of storage capacity in these regions.

EOR and ECBM based storage opportunities

Existing Electric Generating Capacity in ECAR, SERC, and ERCOT



- ECAR is dominated by coal, relatively little nuclear, with several new gas plants being built in recent years.
- SERC has relatively more nuclear, abundant coal capacity, older gas/oil steam, and has had enormous recent construction of gas capacity.
- ERCOT historically has had gas/oil steam capacity, coal (including lignite), and also has had a boom in new gas capacity in recent years.

Power Market and Average Fuel Cost Assumptions (2006 to 2045)

	ECAR	SERC	ERCOT
2004 Peak Load (GW)	101	151	60
Forecast Load Growth (%/yr)	1.8	1.5	1.9
Capacity Reserve Margin	15 %	15 %	15 %
Capital Charge Rate for New Capacity	15 %	15 %	15 %
Delivered Gas Price ($/mmBtu) (2006,2015,2025)	5.10, 4.50, 5.34	5.35, 5.09, 5.75	4.64, 4.40, 5.05
Delivered Coal Price ($/mmBtu) (2006,2015,2025)	1.23, 1.18, 1.19	1.62, 1.51, 1.59	1.21, 1.16, 1.19

Peak Load from NERC. Growth extrapolated from ECAR, SERC, and ERCOT FERC form 714 filings. Reserve margins and capital charge rate assumed based on current practice. Gas and Coal prices to 2025 EIA's AEO 2005 and extrapolated after 2025.

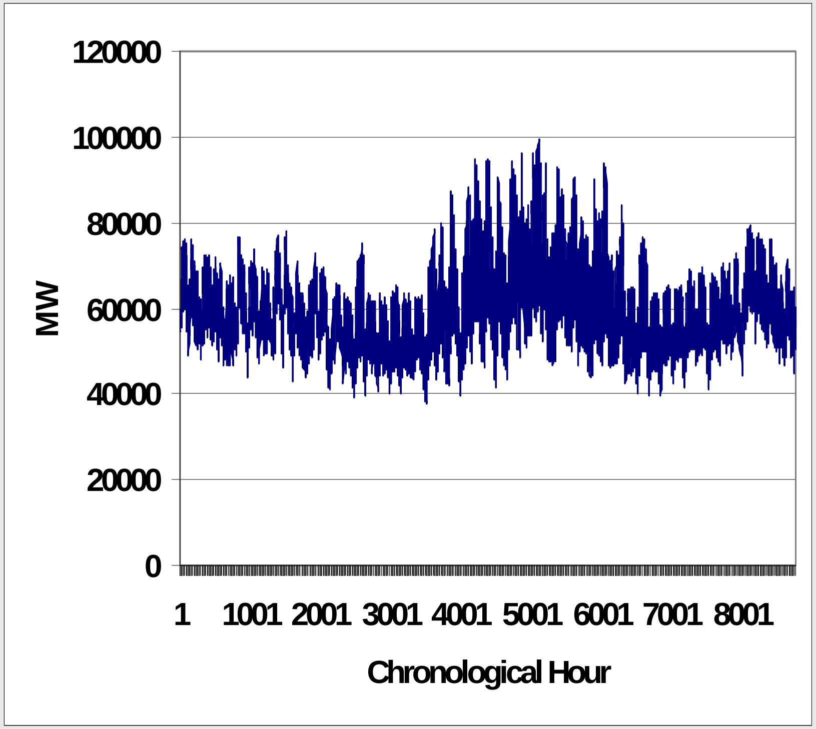
Regional Power Plant Assumptions

- Characteristics of existing power plant fleet is critical.
  - In each region, existing fleet aggregated into 15-20 bins for this study, based on technology, fuel, efficiency, and age.
  - Study assumes electric capacity remains unless economics dictate retirement (carbon shadow implications).
  - Future operating and maintenance costs increase with plant age.

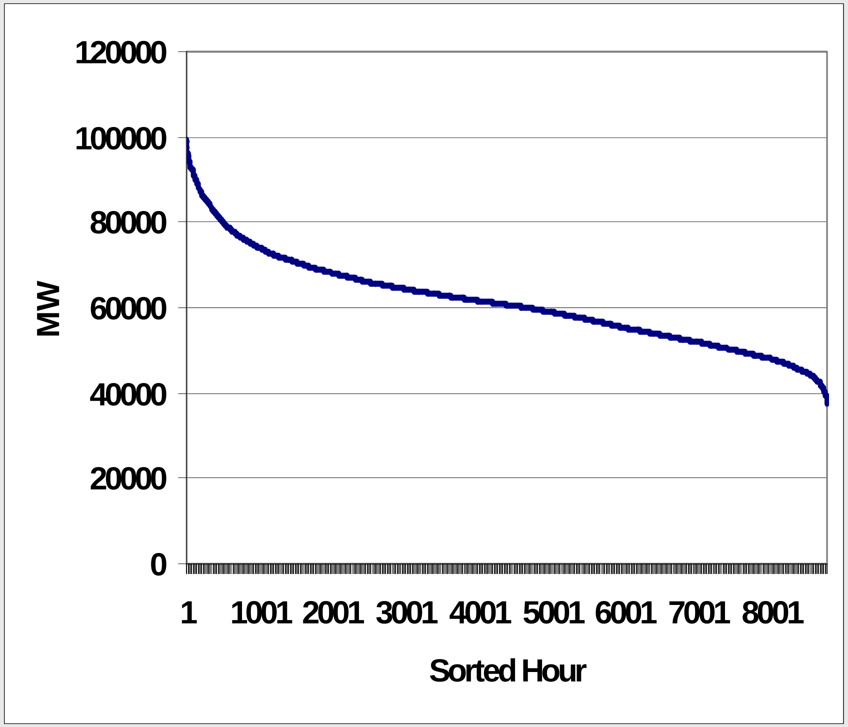
- Options for new electric generating capacity include new pulverized coal (PC), IGCC, and gas CC, each with an option for CCS (either when built or later as retrofit).
  - Retrofit of existing PC to CCS is also considered, as are retirements of all types of plants.
  - Simple cycle gas combustion turbines (CTs) are also considered.
  - Current nuclear capacity remains, renewable power grows with load growth
  - Capital costs, efficiencies, and operating and maintenance costs of new plants from EIA AEO 2005 assumptions.

Electricity Demand and the Load Duration Curve (ECAR as an Example)

ECAR 2002 Hourly Demand



ECAR Load Duration Curve
(Sorted Hourly Demand)



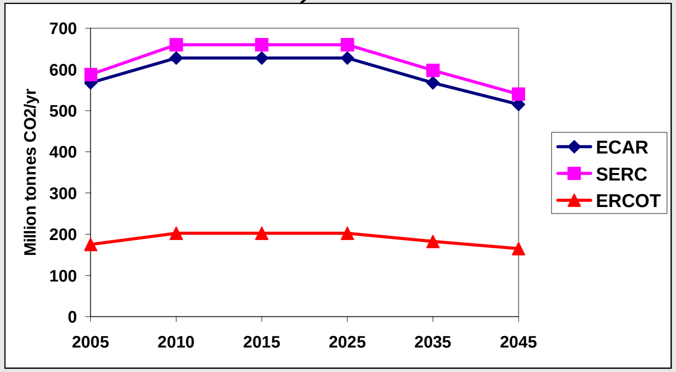
- Load Duration Curve is a key driver of the economic trade-offs involved in determining the mix of new capacity to be built.

Electric Power Modeling

- Battelle Carbon Management Electricity Model (CMEM)
  - Intertemporal optimization model: computes the future powerplant capacity mix and generation dispatch that minimizes the total system cost of meeting electricity demand and carbon management constraints.
- CMEM's inputs include the load duration curve and market assumptions shown above, carbon emissions constraints, existing plant characteristics, and cost and performance specifications of new plant technologies.
- While determining the least-cost capacity and generation solution, CMEM computes prices of electricity and carbon emissions that result from the interaction of the constraints and the technologies available.

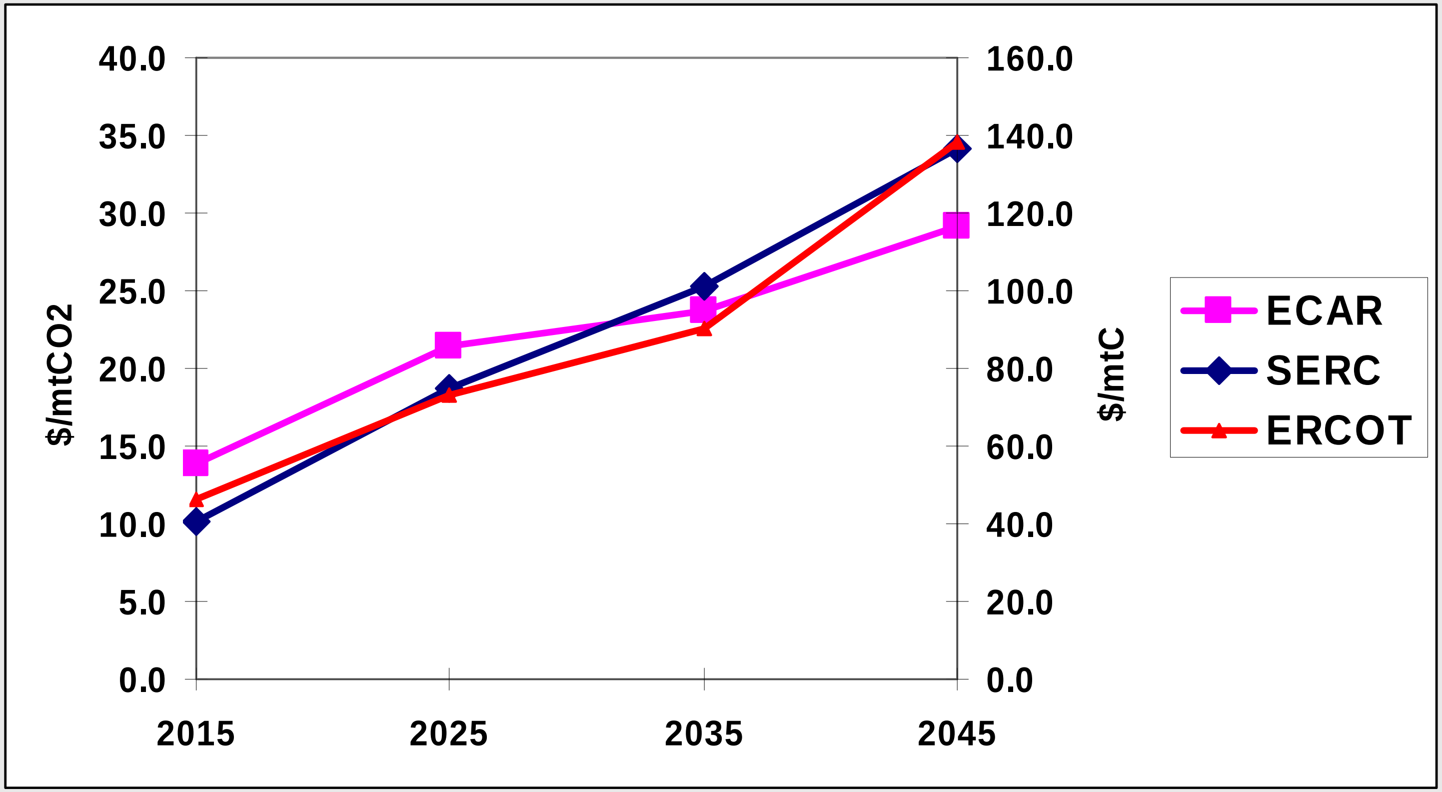
Regional CO_2 Emissions Limits Scenario

- Analyze the impact of a hypothetical carbon emissions limitation policy to the year 2045, to illustrate the potential adoption of CCS technologies.
  - 2005-2010 – no limit.
  - 2010-2025 – annual electric CO_2 emissions held at 2010 levels.
  - After 2025 – annual electric CO_2 emissions decline by 1%/year.



- These targets must be maintained against the background of continued load growth.
  - e.g., annual electricity demands will more than double.

Scenario Results: CO_2 Emissions Prices

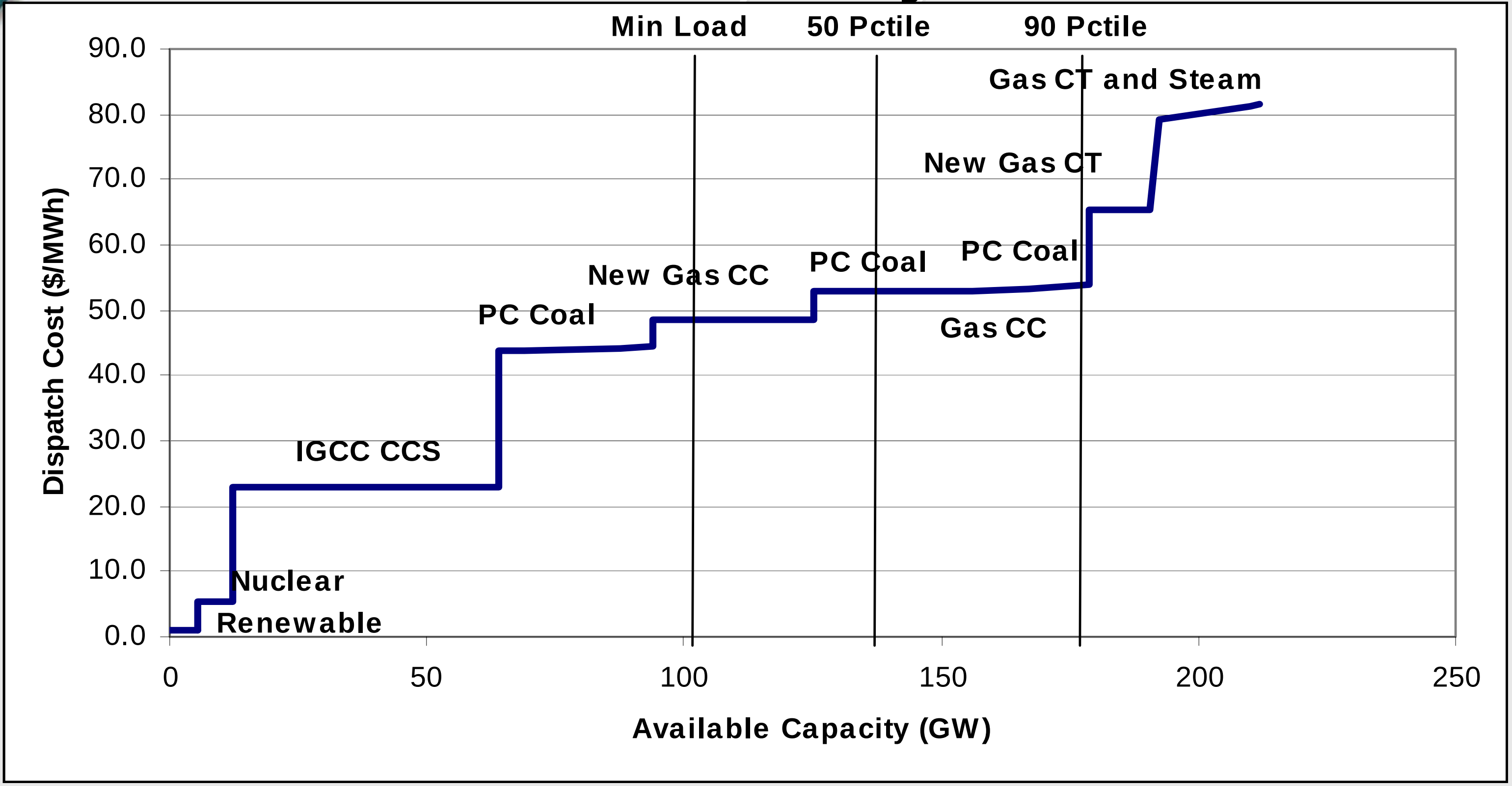


- ►CO_2 price results reflect all the economic trade-offs involved in serving electricity demand within carbon constraints, given the technological options available.
- ►CO_2 price results also incorporate the cost and availability of CCS storage opportunities.

Results: Electricity Generation Supply Curves

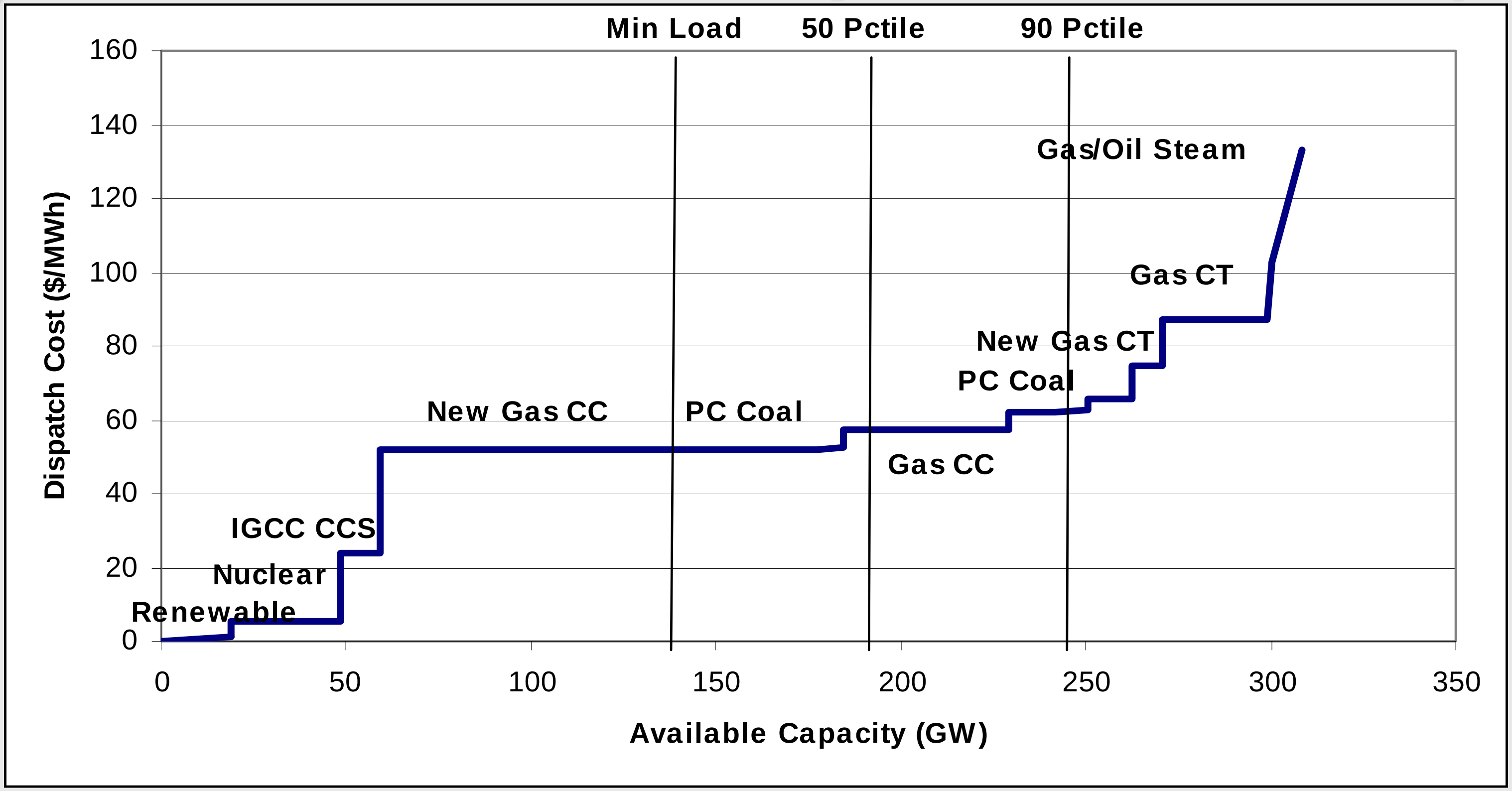
- An electricity generation supply curve is a plot of the dispatch cost (fuel and other variable operating costs) on the vertical axis versus the cumulative amount of capacity available (derated for availability) at each dispatch cost on the horizontal axis.
- Supply curves can be derived from the results of a capacity expansion and dispatch model such as CMEM.
- Supply curves provide an extremely useful depiction of the capacity mix in a manner that provides insight into capacity factors (how much a plant operates) and electricity prices.
  - With load (or demand) levels plotted as vertical lines on the supply curve – all capacity to the left of each load level is economical to dispatch at that load level.
  - And the short-term price at that point should also be given by the dispatch cost at that load level.

ECAR 2045 Electric Supply Curve: (CO_2 flat from 2010-2025, 1%/yr decline to 2045)



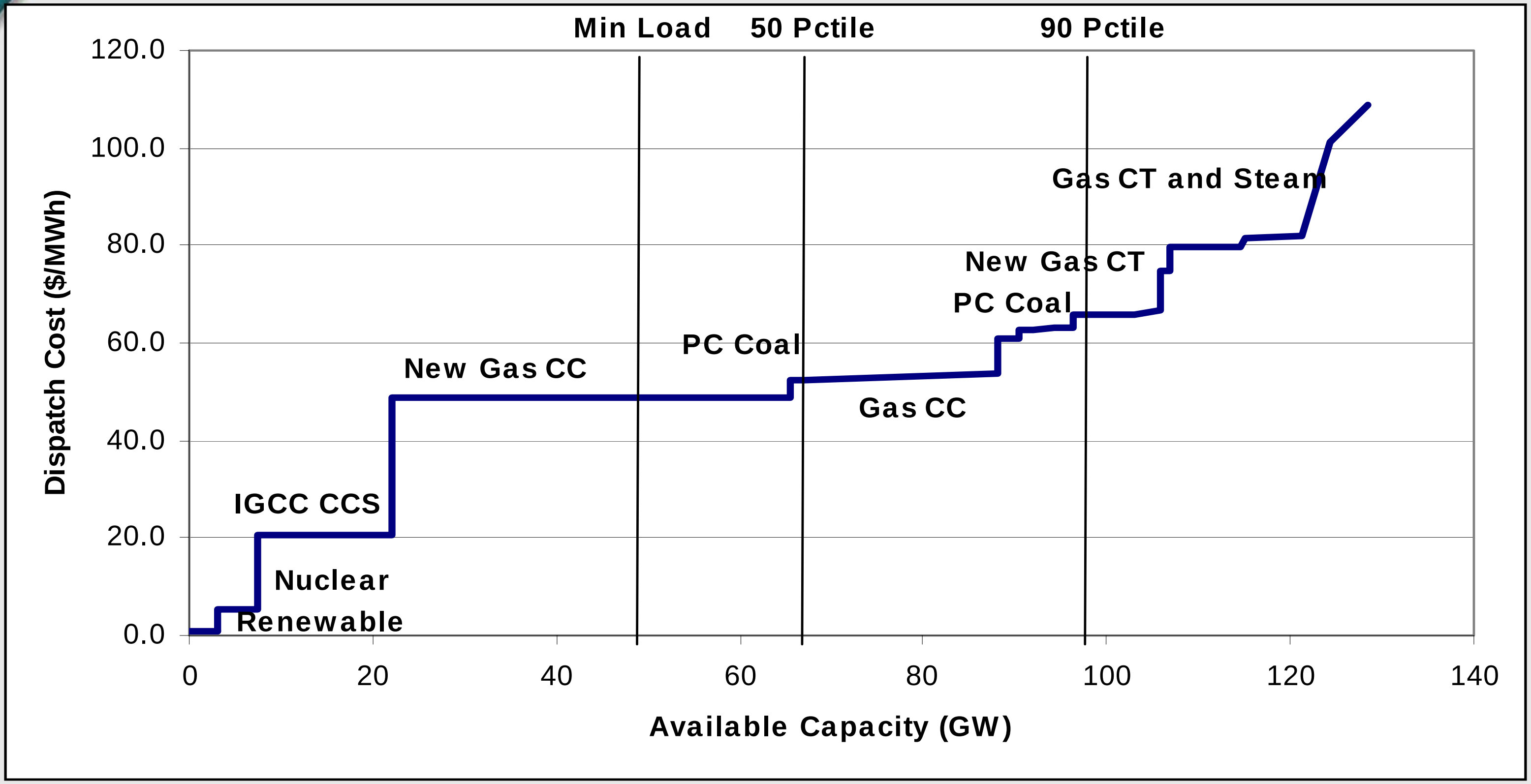
- Substantial builds of IGCC with CCS (>50 GW). Also substantial builds of new (where new means post 2005) gas combined cycle (CC), some new gas combustion turbines (CT).
- More efficient existing (pre-2005) PC Coal (Pulverized Coal) still operates as baseload. Less efficient PC Coal falls behind new gas CC in dispatch.

SERC 2045 Electric Supply Curve: (CO_2 flat from 2010-2025, 1%/yr decline to 2045)



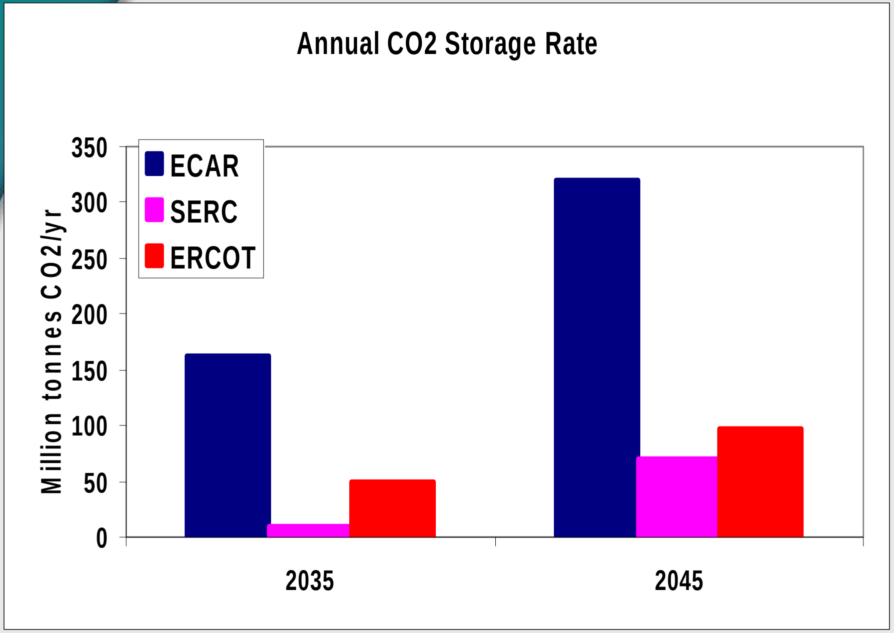
- New (post-2005) builds dominated by gas CC, much less investment in IGCC with CCS.
- New gas CC operates as baseload, with existing (pre-2005) PC Coal serving a reduced role from baseload to serving more intermediate load.

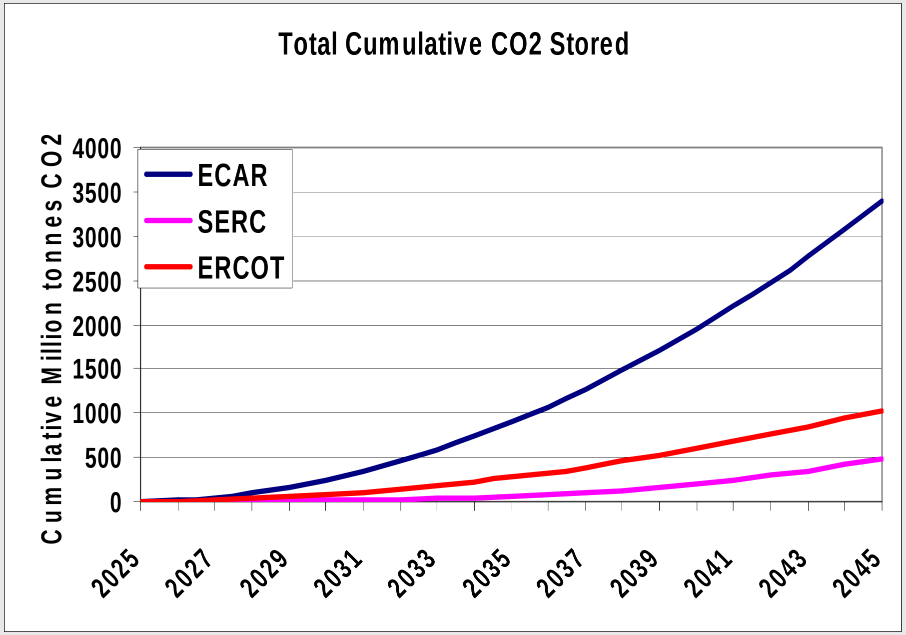
ERCOT 2045 Electric Supply Curve: (CO_2 flat from 2010-2025, 1%/yr decline to 2045)



- New (post-2005) builds balanced between IGCC with CCS and new gas combined cycle (CC) capacity.
- New IGCC CCS and New Gas CC operate as baseload, with existing (pre-2005) PC Coal serving a reduced role from baseload to serving more intermediate load.

CO_2 Storage by Region (CO_2 flat from 2010-2025, 1%/yr decline to 2045)





- By 2045, ECAR and ERCOT are capturing about 40% and 35% of their total electric power sector CO_2, respectively (with SERC at about 12%).
- Under a CO_2 policy of this magnitude, value-added storage reservoirs in these regions are consumed and CO_2 storage shifts to an even larger reliance on deep saline formations and depleted gas fields.
- Cumulative storage amounts, while significant, are still small relative to the total potential storage capacity in these regions (e.g., 150 to 300 billion tonnes of potential storage capacity in deep saline formations alone).

Final Points

- Under the hypothetical CO_2 target examined here, the penetration of CCS could be substantial.
  - Could be much more penetration in the second half of the century with energy demand growing and emissions limits becoming tighter.
  - Penetration also increases with higher gas prices or lower CCS costs.
  - Could also see investment in natural gas CC with CCS as tightening CO_2 limits force reductions beyond baseload and into intermediate load.

- Negative-cost storage opportunities may be realized but will not likely set the long-run market price that will determine the use of CCS technologies in the electric power sector.

- An economically-consistent analysis of CCS in electric power must consider the dynamics of the electric generation market.
  - The response of existing capacity is not straightforward in that, depending on the CO_2 price, the economic choice may be to remain in production but at operate at a different capacity factor rather than to retrofit with CCS or to retire.