Representing carbon storage in MARKAL EPAUS9r16a

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Forward

- Objectives of this presentation
  - Describe the revised representation of CO_2 storage within the U.S. EPA's MARKAL modeling framework and evaluate how these revisions affect modeling results
- Intended audience
  - Energy system modelers and analysts who assess the energy technology pathways and alternative scenarios of the future energy system
- Acknowledgments
  - Matt Aitken, Ph.D., derived the regional CO_2 storage resource curves used in this study from detailed capacity data provided by U.S. DOE's Office of Fossil Energy
  - Samaneh Babaee, Ph.D., incorporated these curves into the EPAUS9r database and conducted the modeling shown in this presentation
  - Participation of Drs. Aitken and Babaee, both ORISE fellows, was supported through an Interagency Agreement between the U.S. EPA and the U.S. DOE
  - The MARKAL EPAUS9r database is being developed by a team at the U.S. EPA that also includes Carol Lenox, Ozge Kaplan, Rebecca Dodder, Kristen Brown, Troy Hottle, and Rubenka Bandyopadhyay
- Note on acronyms
  - Please see the extra slides for explanation of acronyms
- Disclaimer
  - The views expressed in this presentation are those of the authors and do not necessarily represent the views or policies of the U.S. EPA

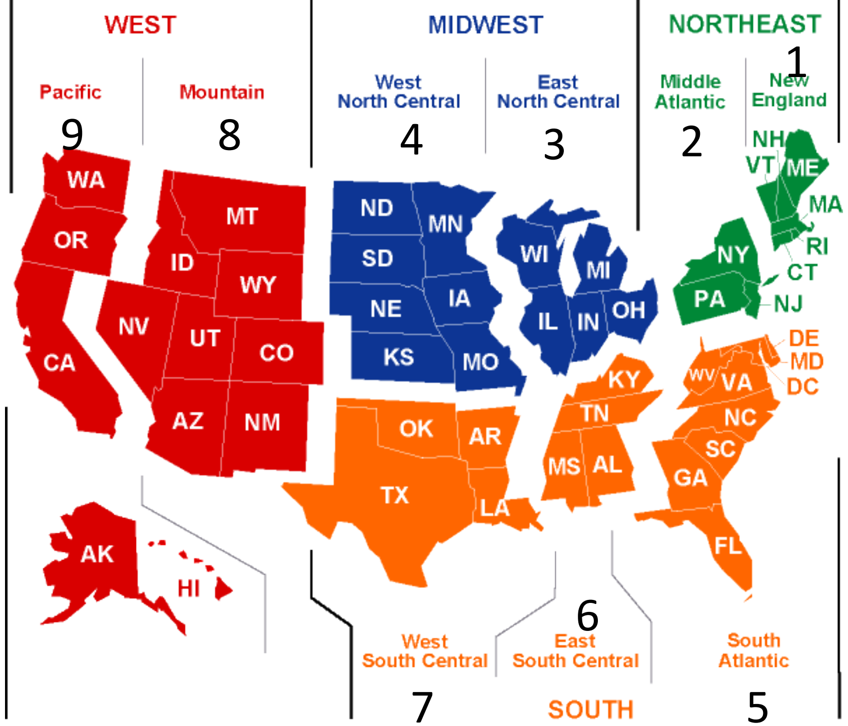
Overview

- MARKet ALlocation model
  - Mixed-integer linear programming formulation of an energy system
  - Includes current and future representations of:
    - fossil and renewable energy resources
    - societal end-use energy service demands
    - conversion technologies (transform resources into useful forms, e.g., refined fuels and electricity)
    - demand technologies (use fuels or electricity to meet end-use energy service demands)
    - emissions or other environmental outputs associated with energy supply, conversion, and use
    - constraints that restrict the operation of the system (e.g., fuels, emissions, market penetration)
  - Other
    - Supports regionalization, endogenous technological learning, elastic demands
  - Objective function
    - Minimize the net present value of energy technology and fuel expenditures over the time horizon
  - Development overseen by the Energy Technology Systems Analysis Programme (ETSAP) of the International Energy Agency (IEA)

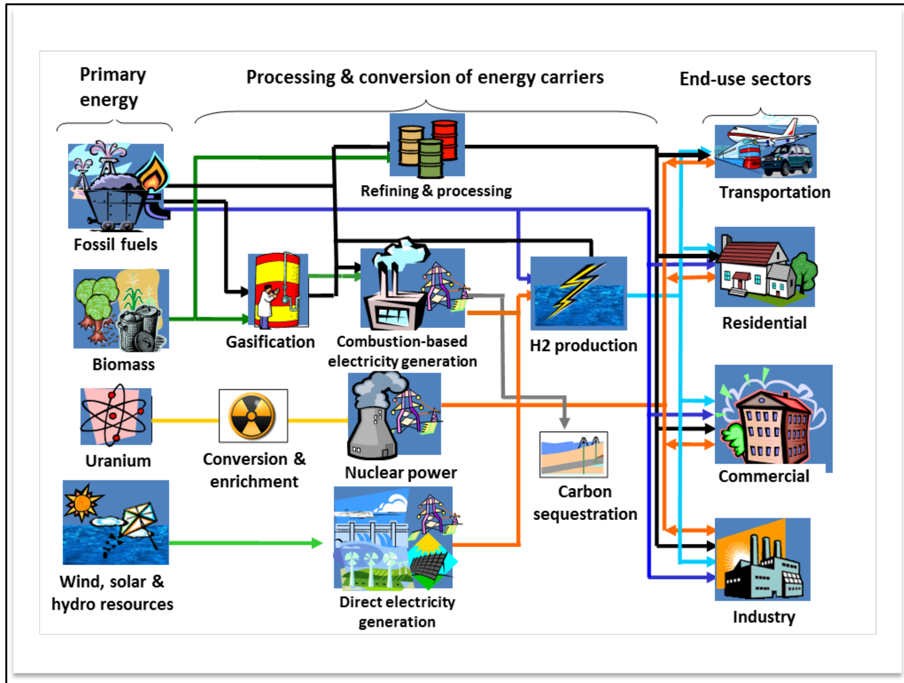
Overview

- EPAUS9r database
  - Primary focus
    - Emissions and environmental impacts of U.S. energy system scenarios
  - Spatial coverage and resolution
    - U.S., at the 9 Census Division resolution
  - Temporal coverage and resolution
    - 2010 through 2055, 5-year increments
    - 12 time slices (seasonal day-AM, day-PM, peak, and night)
  - Sectoral scope
    - Energy system, from import and extraction through end use
    - Electric, industrial, residential, commercial, and transportation
  - Emission factors
    - GHGs: CO_2, N_2O, CH_4
    - Air pollutants: NO_x, SO_2, $PM_{2.5}$, PM_{10}, CO, VOC
    - Other emissions: BC, OC
  - Other environmental factors
    - Water withdrawal and consumption
    - Radiative forcing
    - Mortality costs associated with fine particulate matter
  - Policies represented
    - CSAPR, Tier 3, various NSPSs, state RPSs aggregated to regions
  - Development overseen by the U.S. EPA Office of Research and Development

Regions



Scope



Strengths and weaknesses

- Strengths
  - Full energy system coverage
  - Focus on environmental impacts not included in many energy models:
    - Criteria air pollutants
    - Short-lived climate pollutants
    - Greenhouse gases
    - Energy-related water demands
    - Mortality associated with particulate matter
  - Efficient solution process
  - EPAUS9r database is freely available
  - EPA post -processing tools facilitate analysis of model results
- Weaknesses
  - Software requirements (including licensing cost)
  - Learning curve
  - 9-region database detail results in computationally- and memory-intensive execution, limiting the ability to use valuable features such as endogenous technological learning, elastic demands, or multi-stage decision-making

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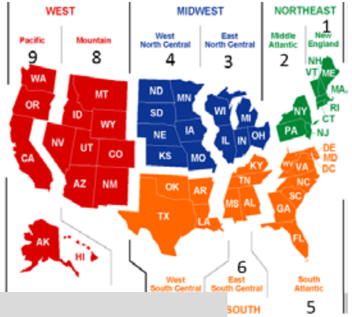
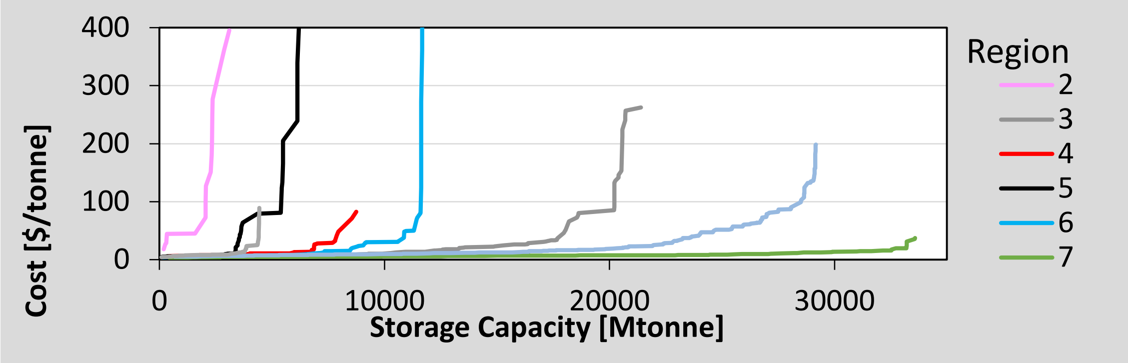
Storage representation

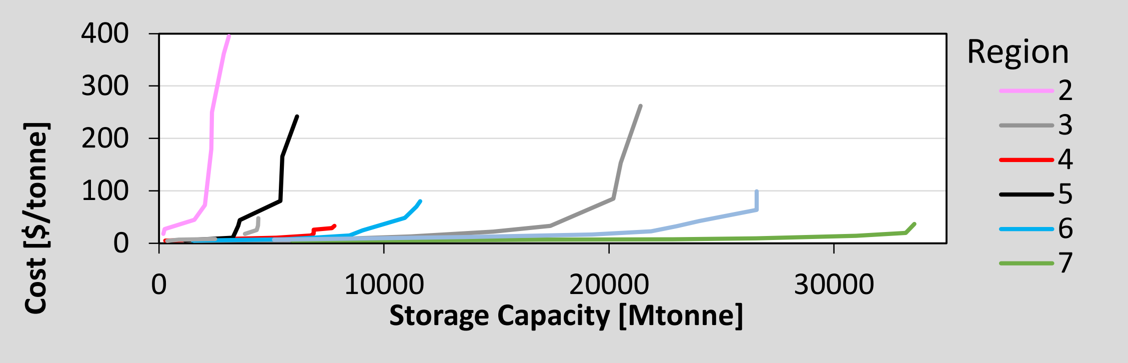


Full curves

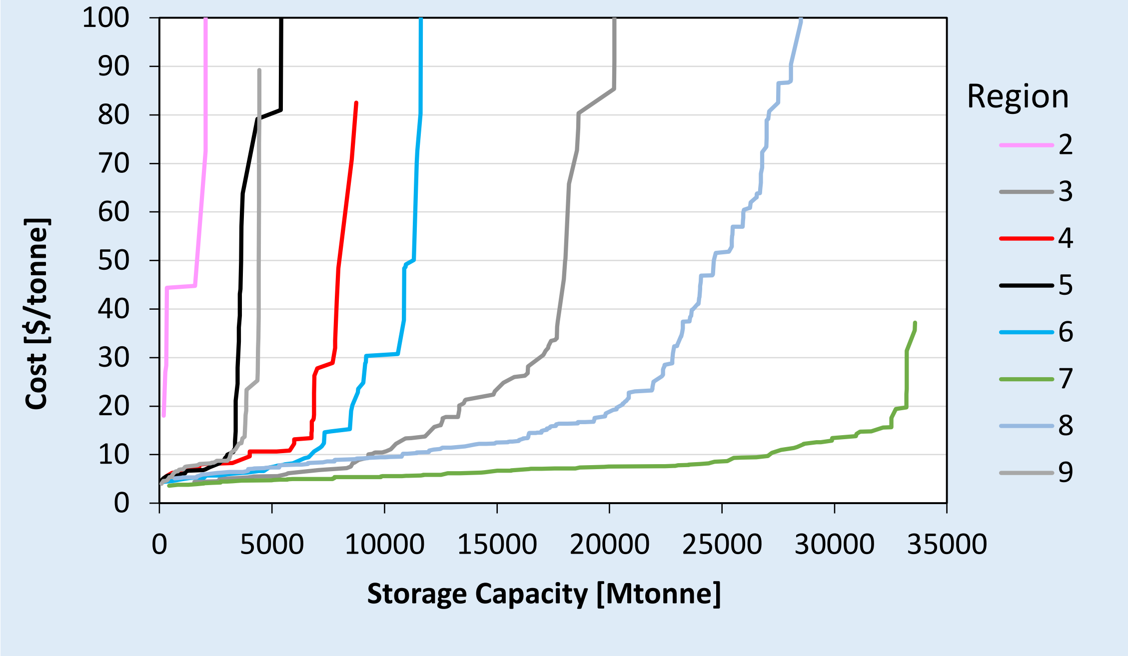
Aggregated regional supply curves developed from DOE data

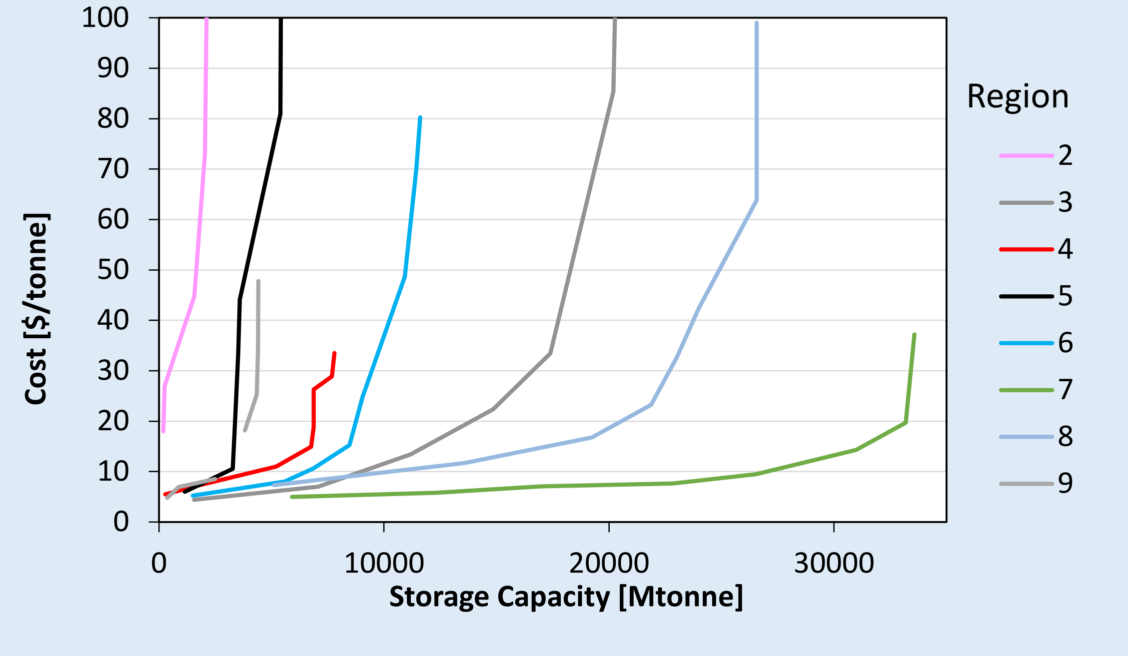


MARKAL representation (piece-wise linear approximation)



Detail: $0-$100/t





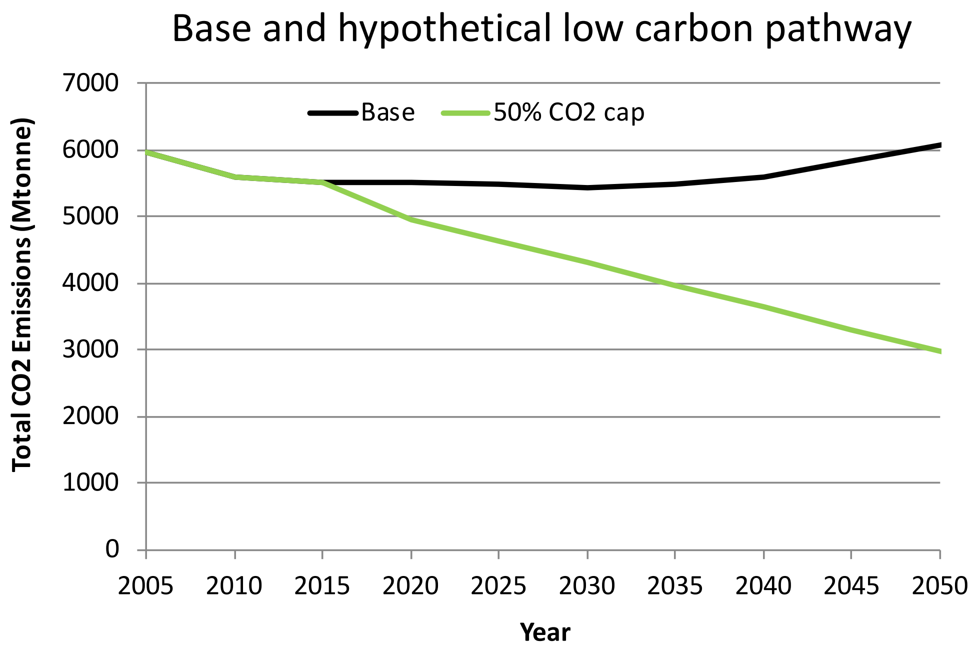
Notes: Prior to development of supply curves, a flat value of 9.7$/tonne was used
Region 1 is estimated to have very limited storage resources, which are approximated to be zero

CCS assumptions and data sources

- CO_2 capture is included for existing pulverized coal (PC) plants, new PC plants, existing natural gas combined-cycle (NGCC) plants, new NGCC plants, integrated coal gasification combined-cycle (IGCC) plants, and biomass gasification plants
  - Capture costs and efficiencies, as well as energy penalty, are adapted from the Annual Energy Outlook
  - Commercial-scale CCS (new and retrofit) is modeled as not being available until 2025
- CO_2 storage cost, capacity, location, area and structure data for each formation of each site are drawn from the FE/NETL CO_2 Saline Storage Cost Model (2014)
- CO_2 emissions data associated with each power plant are based on EPA's 2013 Greenhouse Gas Emissions from Large Facilities website and kept constant through 2055
- The footprint of each storage formation assumed to be a circle (Area is obtained from Saline Storage Cost Model, radius is calculated)
- A plant must be located within the circle of a storage formation for the associated emissions to be stored
  - Pipelines that would expand utilization of storage are not considered currently, but could be considered in future work
- CO_2 storage capacity of each site is equal to the cumulative mass of CO_2 already injected to a site plus the total CO_2 emissions released by all point sources contained within a formation boundary from 2020 to 2055

CO_2 storage assumptions and data sources

- Transportation costs are not accounted in the modeling assumptions.
  - Transportation cost = $0.01/tonne-mi (IPCC 2005)
  - The vast majority of point sources lie either adjacent to or within 100 mi of the potential storage opportunities in North America (IEA 2005)
  - Transport costs are unlikely to significantly affect the supply curve costs.
- No enhanced oil recovery (EOR) representation in the model
- Scenarios used to test the formulation:
  - Base and a hypothetical 50% system-wide CO_2 cap by 2050, relative to 2005



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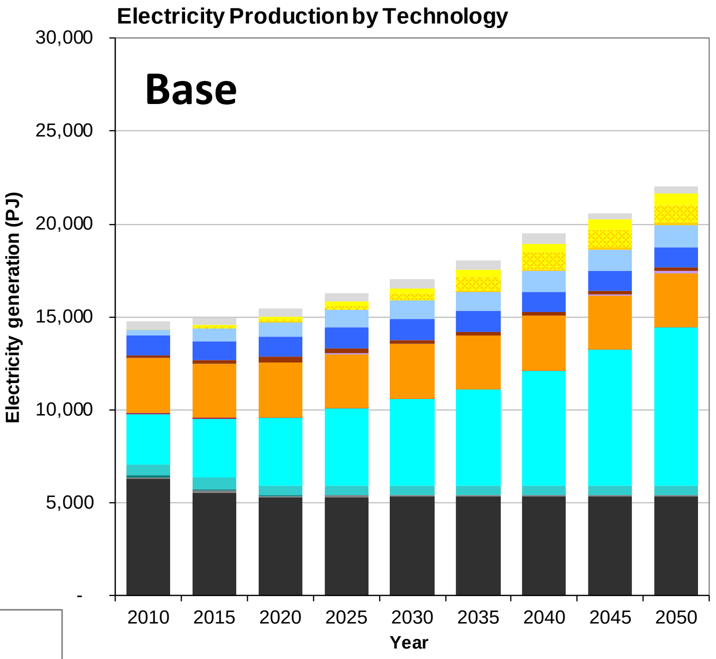
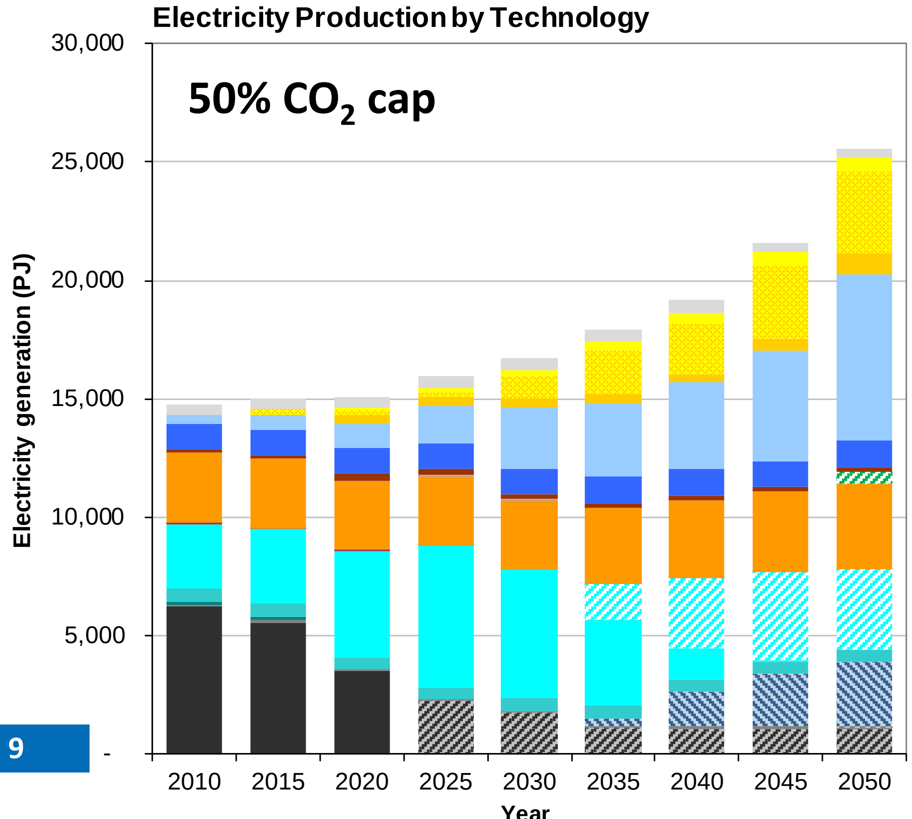
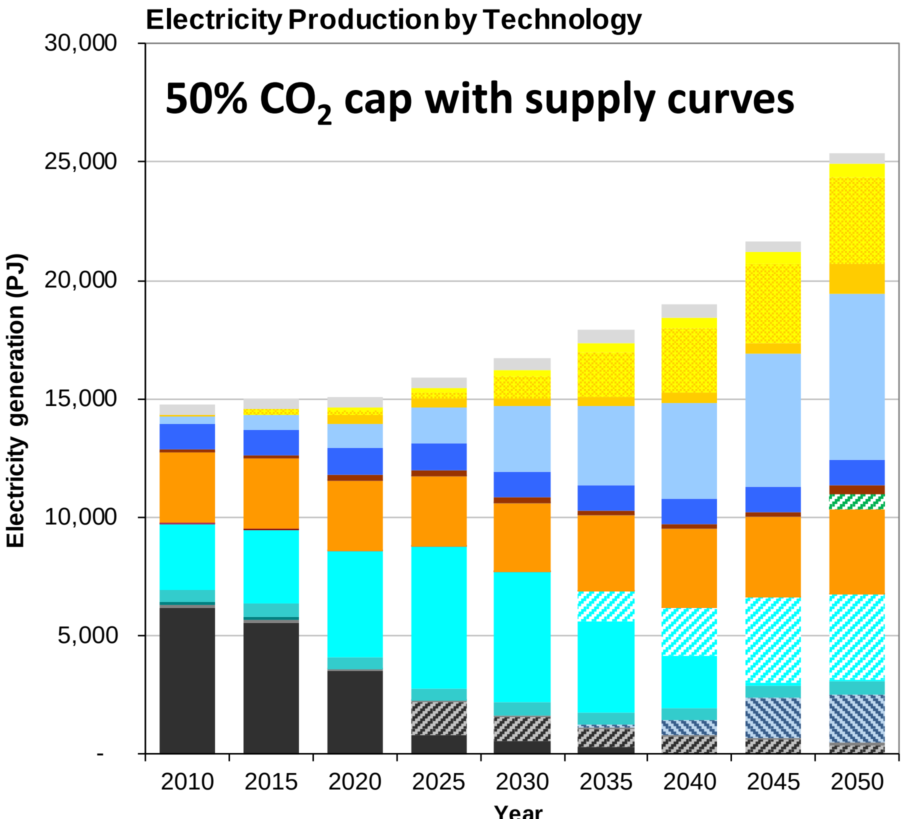
CCS illustrative results

National electric sector response to CO_2 constraint

- Existing coal plants
- Existing coal with CCS retrofit
- New coal plants
- New coal plant with CCS retrofit
- IGCC with CCS
- Natural gas turbine
- NGCC
- NGCC with CCS retrofit
- Nuclear power
- Biomass gasification with CCS
- Geothermal
- Hydropower
- Wind
- Solar Thermal
- Solar PV (central)
- Solar PV (distributed)
- Industrial CHP







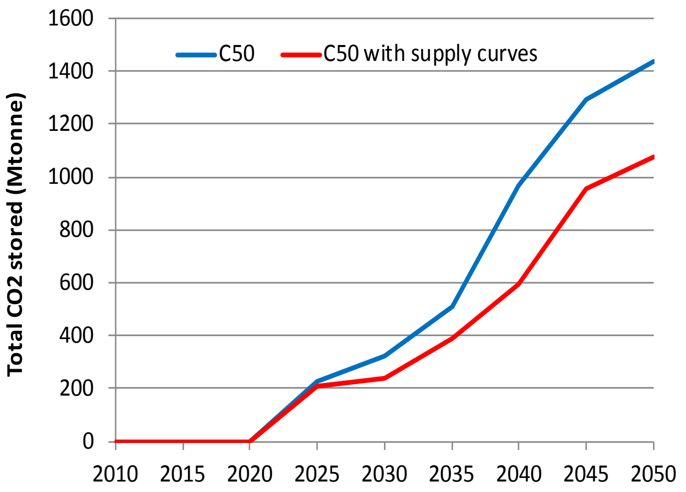
Nationally, there is less CCS using the regional supply curves

CCS illustrative results

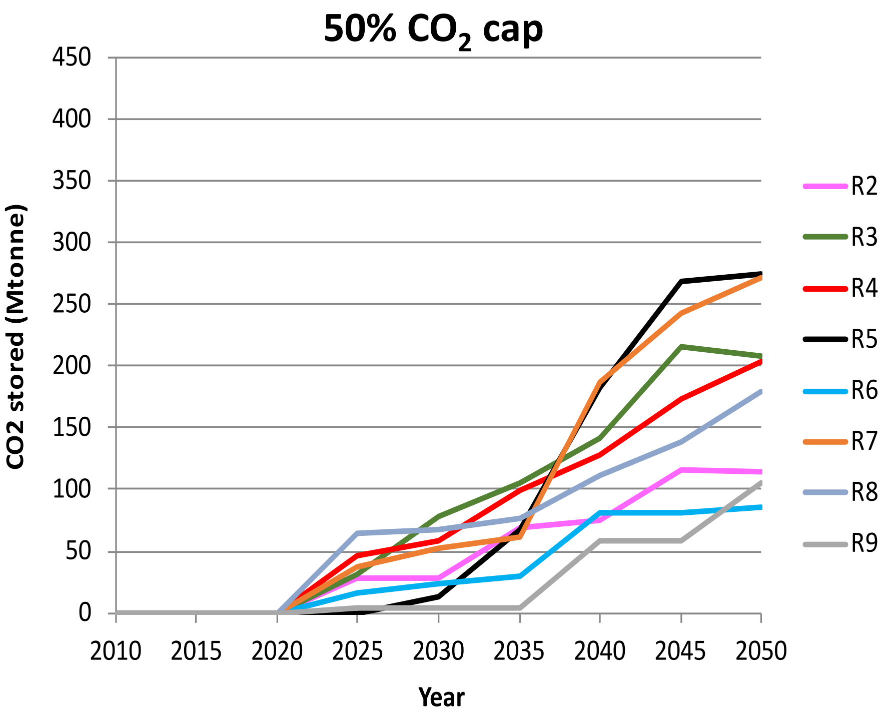
Comparison of old and new representations

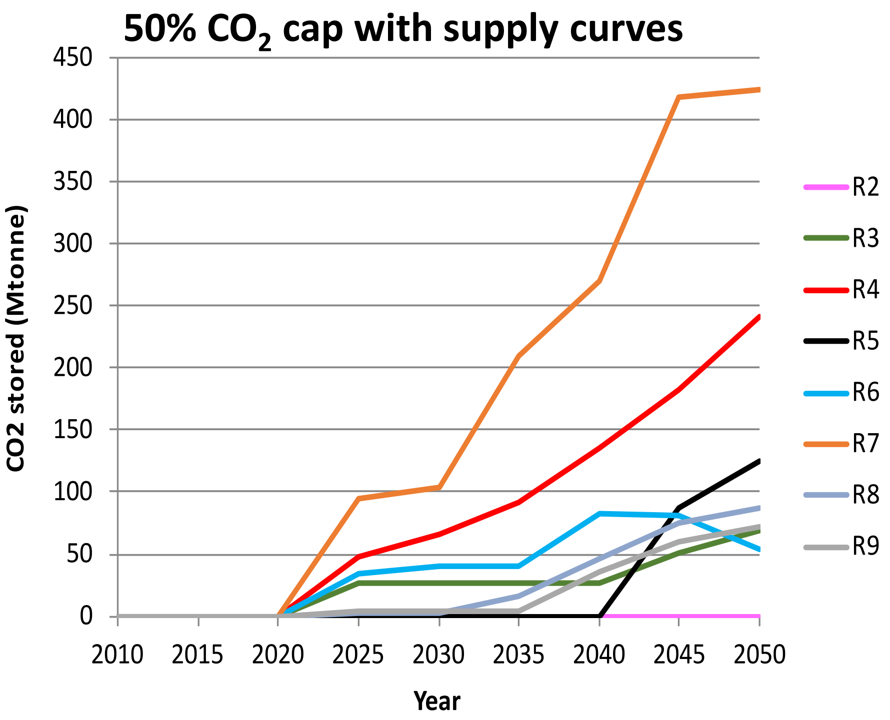
- The new representation (using supply curves) results in a lower total quantity of CO2 storage under this hypothetical scenario.
- Region 7 (AR,LA,OK,TX) sees substantial increases using the supply curve. Region 4 is approximately the same. Storage in other regions falls.

National storage totals



Regional storage totals





There are fairly big differences in where CO_2 is being stored when the supply curves are introduced

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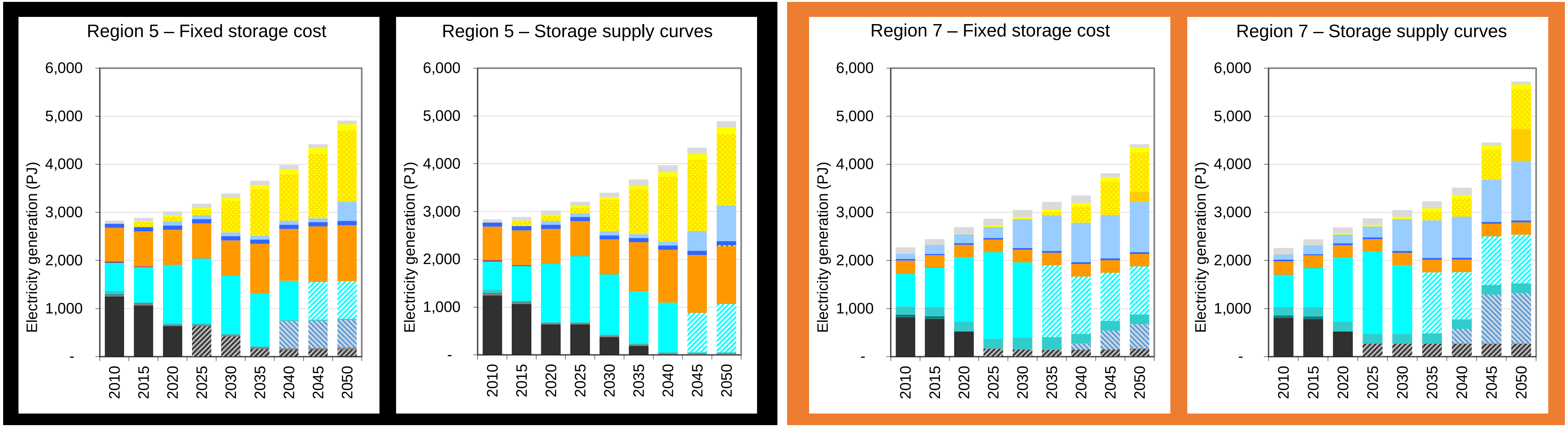
CCS illustrative results

Regional electric sector response to CO_2 constraint

Regions 5 (Southeast) and 7 (West South Central) have the largest decrease and increase in CCS, respectively, after addition of CO_2 storage supply curves

- Existing coal plants
- Existing coal with CCS retrofit
- New coal plants
- New coal plant with CCS retrofit
- IGCC with CCS
- Natural gas turbine
- NGCC
- NGCC with CCS retrofit
- Nuclear power
- Biomass gasification with CCS
- Geothermal
- Hydropower
- Wind
- Solar Thermal
- Solar PV (central)
- Solar PV (distributed)
- Industrial CHP



With more limited storage resources, Region 5 increases output from renewables

With its significant storage resources, Region 7 increases electricity production and exports to surrounding regions

Potential future directions

- Increase resolution of piece-wise storage resource curves for costs less than $50/t?
- Explore how the new CO_2 storage resource curves affect the national and regional competitiveness of CCS relative to renewables
- Explore addition of capacity growth constraints to examine more realistic scenarios of CCS expansion
- Explore considerations related to pipelines and how they could expand access to storage capacity
- Add an EOR component to the CO_2 storage resource curves
- Examine electricity trade from one region to another to determine whether the expansion of electricity production in Region 7 is reasonable
- Integrate new supply curves into the version of the US EPAUS9r MARKAL database that is publically distributed as well as into the TIMES database that is under development

Questions?

- Contact information

EPAUS9r MARKAL and TIMES databases:

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Extra slides

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Abbreviations

Abbreviation	Corresponds to:
BC	Black Carbon
CCS	Carbon Capture and Storage
CH4	Methane
CHP	Combined Heat and Power
CO	Carbon Monoxide
CO2	Carbon Dioxide
CSAPR	Cross-State Air Pollution Rule
EOR	Enhanced Oil Recovery
EPAUS9r	U.S. EPA MARKAL 9-region database
ETSAP	Energy Technology Systems Analysis Programme
FE	Fossil Energy
IEA	International Energy Agency
IGCC	Integrated Gasification Combined Cycle (coal)
IPCC	Intergovernmental Panel on Climate Change
MARKAL	MARKet ALlocation (model)

Abbreviation	Corresponds to:
N2O	Nitrous Oxide
NETL	National Energy Technology Laboratory
NGCC	Natural gas combined-cycle (turbine)
NOx	Nitrogen Oxides
NSPS	New Source Performance Standards
OC	Organic Carbon
ORISE	Oak Ridge Institute for Science and Education
PC	Pulverized Coal
PM2.5	Particulate Matter of diameter below 2.5 microns
PM10	Particulate Matter of diameter below 10 microns
PV	Photovoltaic
RPS	Renewable Portfolio Standard
SO2	Sulfur Dioxide
VOC	Volatile Organic Compounds
U.S. DOE	United States Departed of Energy
U.S. EPA	United States Environmental Protection Agency

References

- Key data sources
  - EIA's Annual Energy Outlook 2016: https://www.eia.gov/outlooks/archive/aeo16/
  - EPA's GHG emissions data for large facilities: https://ghgdata.epa.gov/ghgp/main.do#
  - FE/NETL Saline Storage Cost Model (2014): https://www.netl.doe.gov/research/energy-analysis/analytical-tools-and-data/co2-saline-storage
  - IPCC estimate (2005) of CO2 transportation costs (via pipeline): https://yosemite.epa.gov/oa/eab_web_docket.nsf/Filings%20By%20Appeal%20Number/3363DB0869310D6F85257A250066D736/$File/Exhibit%2064a%20to%20Revised%20Petition%20for%20Review%20...12.64a.pdf
  - IEA 2005 characterizations of storage resources: https://hub.globalccsinstitute.com/sites/default/files/publications/95736/building-cost-curves-co2-storage-european-sector.pdf