Multiscale Electricity Modeling for Evaluating Carbon Capture and Sequestration technologies (MEME-CCS)

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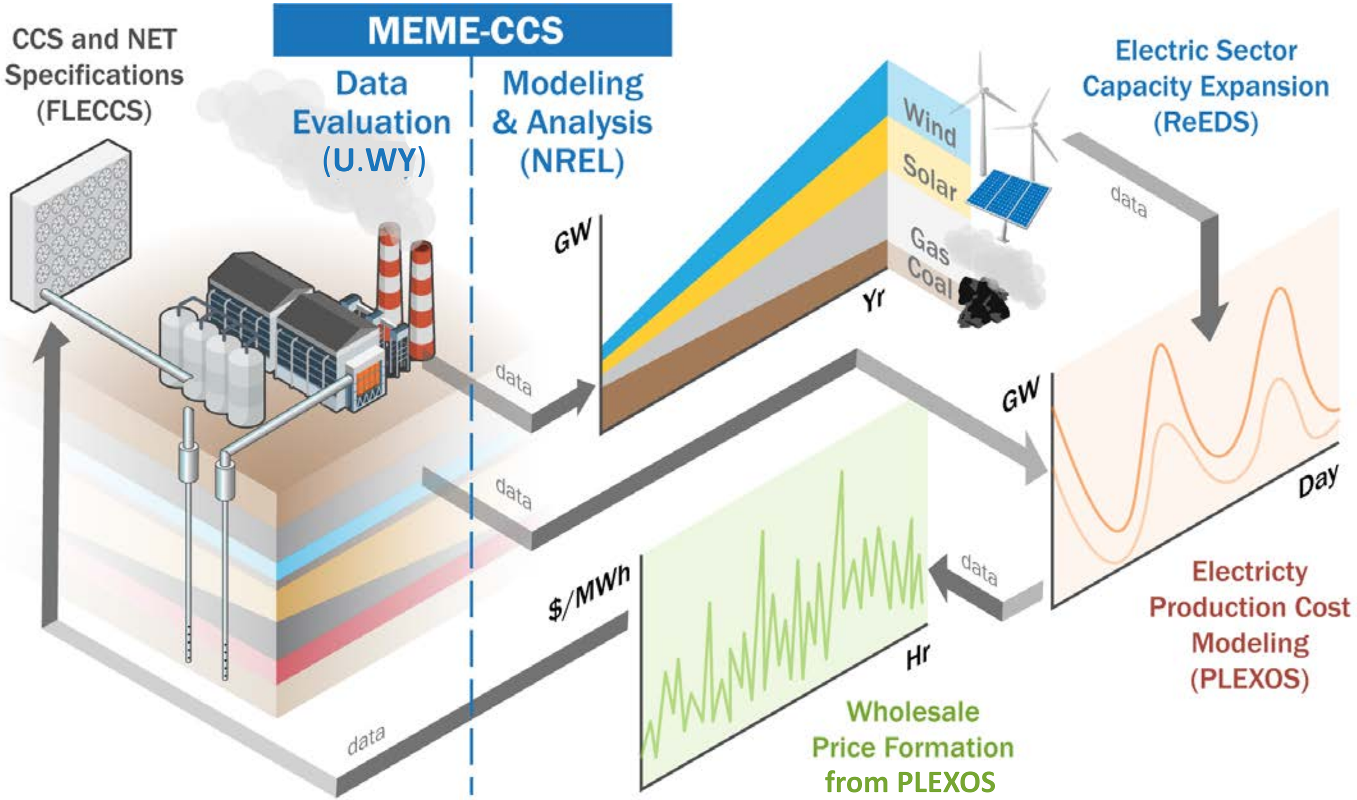
A multimodel platform uses capacity expansion and production cost models with FLECCS technology data.



CCS = carbon capture and sequestration
NET = negative emissions technology
U.WY = University of Wyoming
NREL = National Renewable Energy Laboratory

GW = gigawatt
MWh = megawatt-hour
FLECCS = ARPA-E program for flexible CCS technology development

Prices are model outputs dependent on the infrastructure and dispatch.

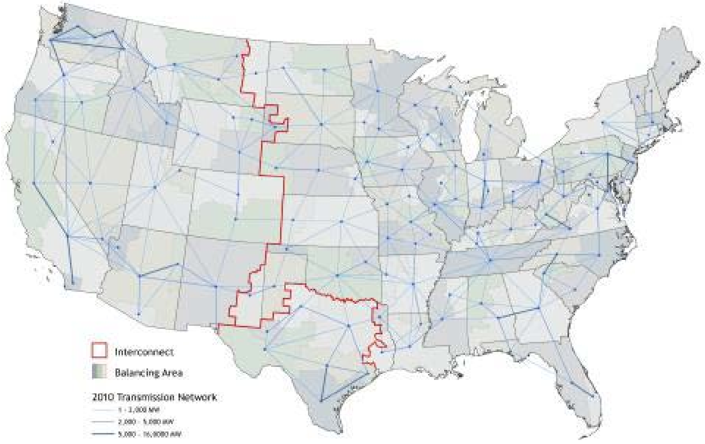
1. Define infrastructure investment drivers in ReEDS (fuel prices, technology costs, CO_2 price).
2. Project future infrastructure in ReEDS for contiguous U.S. (location and capacity of generation, storage, and transmission).
3. Use ReEDS-PLEXOS conversion tool to downscale capacity to individual generation/storage units and assign additional operating parameters.
4. Simulate zonal hourly dispatch of future infrastructure in PLEXOS, using consistent operating drivers (fuel price, CO_2 price).
5. Dispatch solution includes locational marginal prices for each zone.
6. Zonal prices are aggregated to market regions by load-weighted averaging.

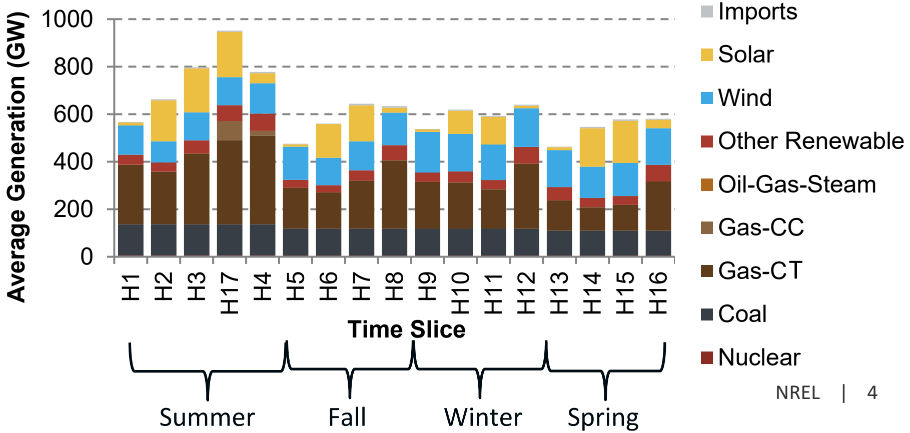
This procedure can produce prices for all market and non-market regions in the U.S. for any ReEDS scenario and modeled year.

Data available at https://data.nrel.gov/submissions/181

The Regional Energy Deployment System (ReEDS) projects deployment of grid technologies.

- Open-access, NREL-developed code and data.
- Continuous linear program minimizes total discounted cost of electric sector investment and operation.
- Invests in the least-cost mix of generation, storage, transmission, and carbon mitigation technologies.
- Solves any set of years through 2050 with 17 intra-annual time-slices and 7-years of hourly data to characterize variable renewables and storage.
- Includes 134 balancing areas (BAs) .
- Satisfies energy and capacity requirements under resource, transmission, policy, and power system constraints.





FLECCS technologies in ReEDS require new variables, parameters, and constraints.

- New variables correspond to subsystems that can be operated independently.
  - Power used for CCS
  - Power used for DAC
  - Energy-equivalent storage level for CCS storage system
- New parameters, constraint terms, and constraints relate variables to each other and grid operation.
  - Max CCS/DAC power (relative to other systems, or based on assumed sizing)
  - CCS/DAC energy requirement per CO_2 captured
  - Energy-equivalent storage level tracking and storage capacity limit
  - Allowable source of CCS/DAC power (grid vs. NGCC)
- Data template populates parameters used in model constraints and objective function.

Examples for PCC technology without storage or DAC

<u>CO_2 emissions accounting</u>

EMITTED_CO2 (tCO_2) =

base_NGCC_emissions rate (tCO_2/MWh) x hours (h) x [GENERATION (MW) + CCS_POWER (MW)]

- CO2_removal_per_energy (tCO_2/MWh) x hours (h) x CCS_POWER (MW)

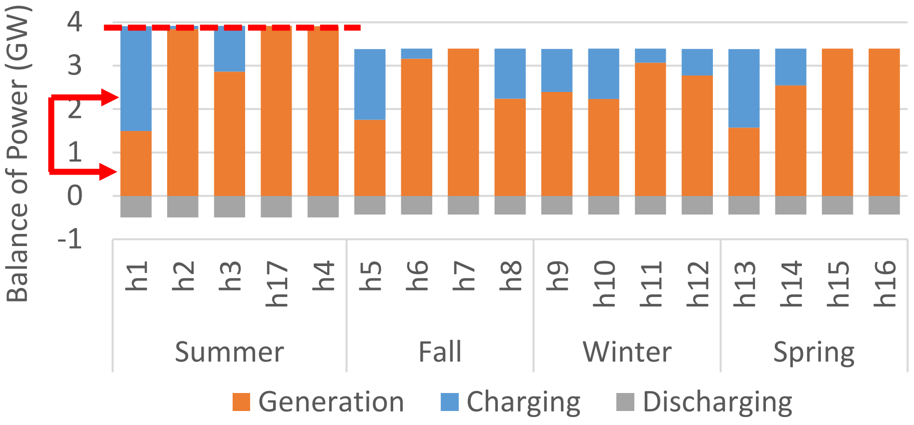
<u>Plant capacity limits</u>

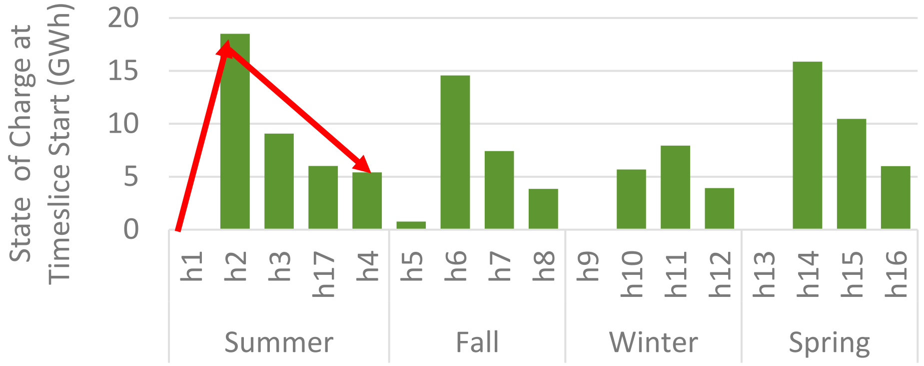
CAPACITY (MW) ≥ GENERATION (MW) + CCS_POWER (MW)

Methods and results are preliminary and for demonstration purposes only.

ReEDS represents operational flexibility at the diurnal timeslice resolution.

- Time slices represent chronological diurnal time periods.
- CCS flexibility is captured within this reduced-form dispatch.
- Example results for flexible CCS with storage
  - NGCC fuel consumption remains constant in a season.
  - Power balance between grid vs storing capture energy varies in response to need.
  - Energy storage is charged when net load is low and discharged when it is high.





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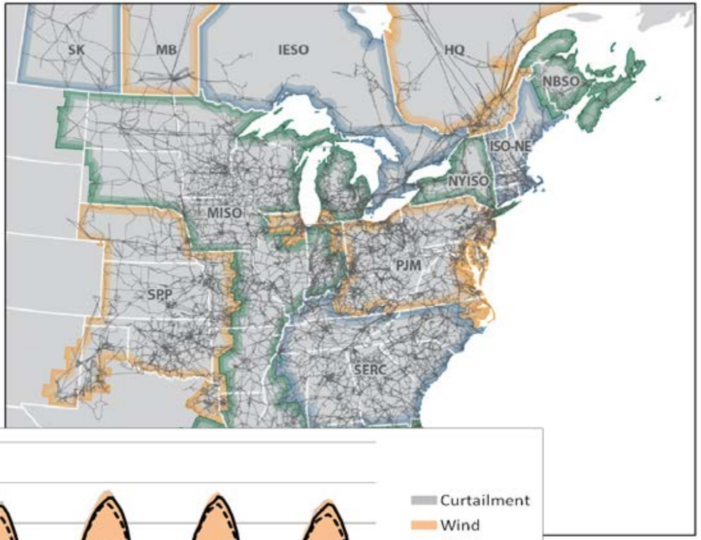
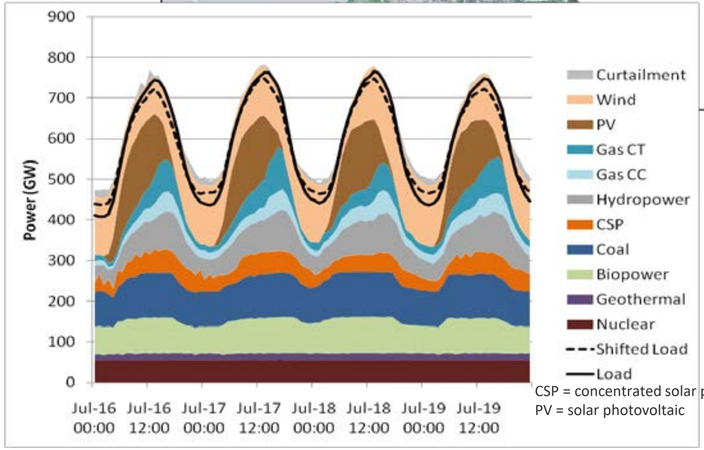
PLEXOS simulates detailed hourly dispatch of a future system from ReEDS.

- Versatile commercial model without source-code access.
- Mixed-integer linear program finds generation, storage, transmission, and carbon mitigation technology utilization that minimizes system operating costs.
- Solves at ReEDS spatial resolution and hourly time resolution for a year, typically using a 24-hour hourly solve with a coarser 24-hour look-ahead.
- Co-optimizes requirements for energy and ancillary services under detailed power system operating constraints (e.g., startup costs, ramp rates).
- ReEDS to PLEXOS conversion tool downscales a future infrastructure mix for use in PLEXOS.
  - New capacity is broken up into individual units.
  - Retirements are applied.
  - Inter-BA transmission capacity is expanded.

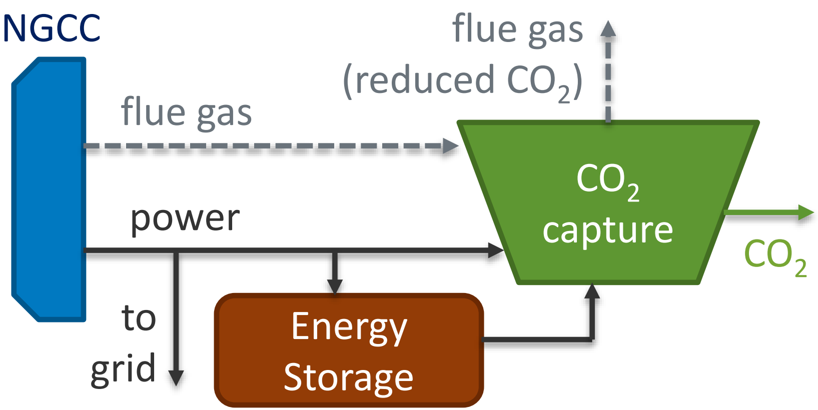




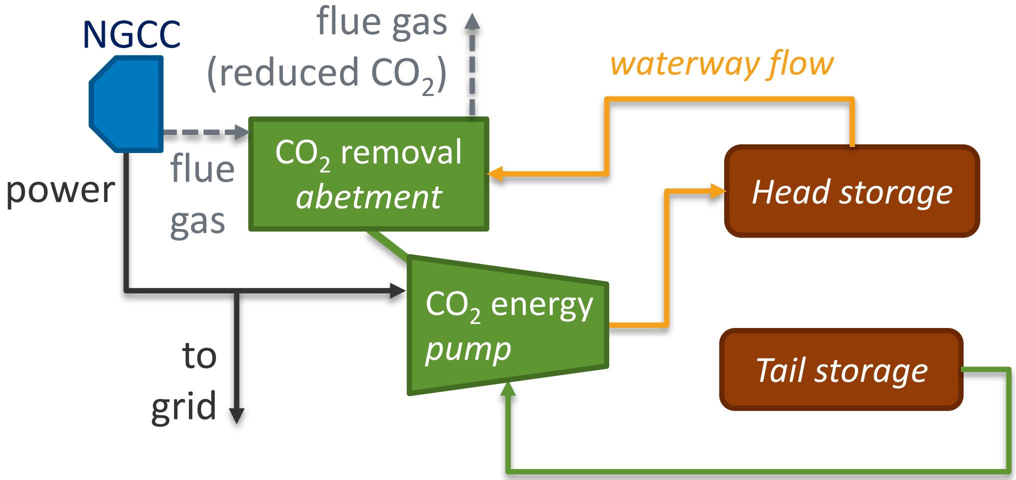
CSP = concentrated solar power
PV = solar photovoltaic

FLECCS technologies in PLEXOS require innovative use of model objects.

Simple Process Flow Diagram



PLEXOS Object Representation



- Constraints relate power, CO_2 flows, and commitment status (on/off) between components.
- Data template values parameterize constraints.
- We can restrict power input to be from NGCC or allow grid power.

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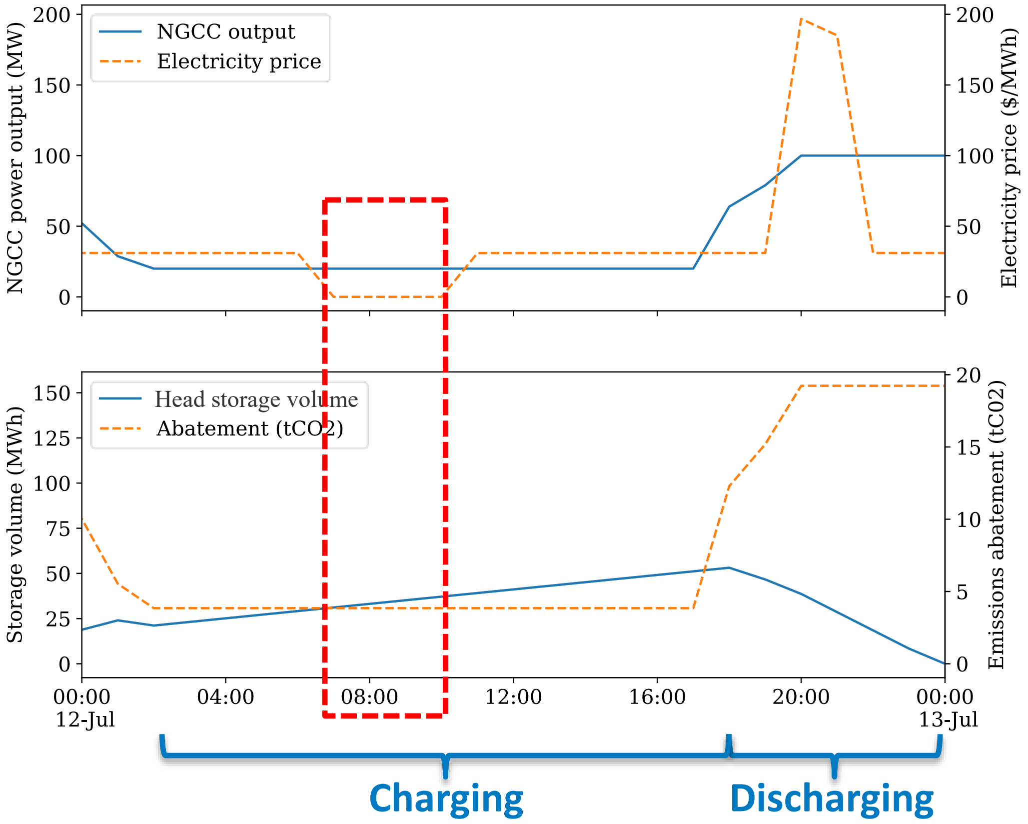
Hourly dispatch can reflect FLECCS technology operating modes.

- Zero price: charging from grid
- Low price: charging from NGCC while running CO_2 capture from NGCC
- High price: discharging while running CO_2 capture from storage



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Scenario modeling will evaluate technology deployment and operation.

- Core scenarios will vary CO_2 prices and FLECCS competitiveness.
  - CO_2 prices: linear path to \$150–\$300/tCO_2 in 2050
  - FLECCS competitiveness
    - Reference: default 2021 data and assumptions
    - Best case: low gas prices, high variable renewables, high costs and limited availability of other flexible low-carbon technologies (e.g., batteries, demand management, bio-CCS, standalone DAC, H_2)
    - Worst case: high gas prices, high variable renewables, low cost and high availability of other flexible low-carbon technologies
  - Initial results might prompt scenario adjustment or expansion.
- Scenarios will consider only one FLECCS technology at a time.
- Multiple modeling iterations could consider alternative FLECCS technology configurations given alternative data templates.

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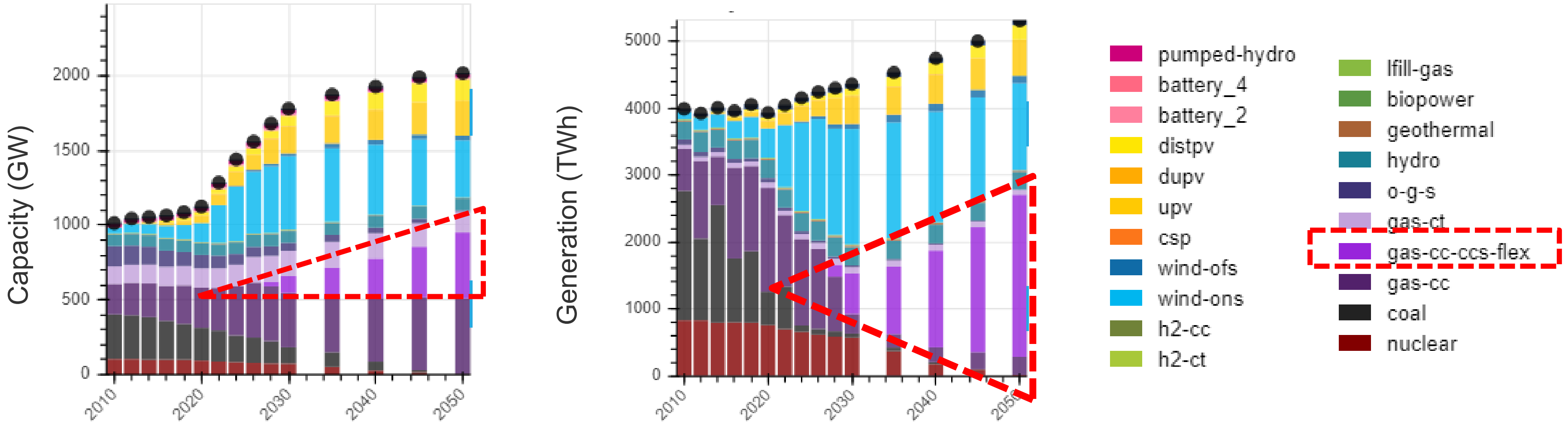
ReEDS results will show total investment in FLECCS versus other technologies.



- Capacity and generation mix shows market share and how FLECCS and other technologies compete and complement.
- Investment versus dispatch can demonstrate value for electricity demand versus planning and operating capacity reserves.

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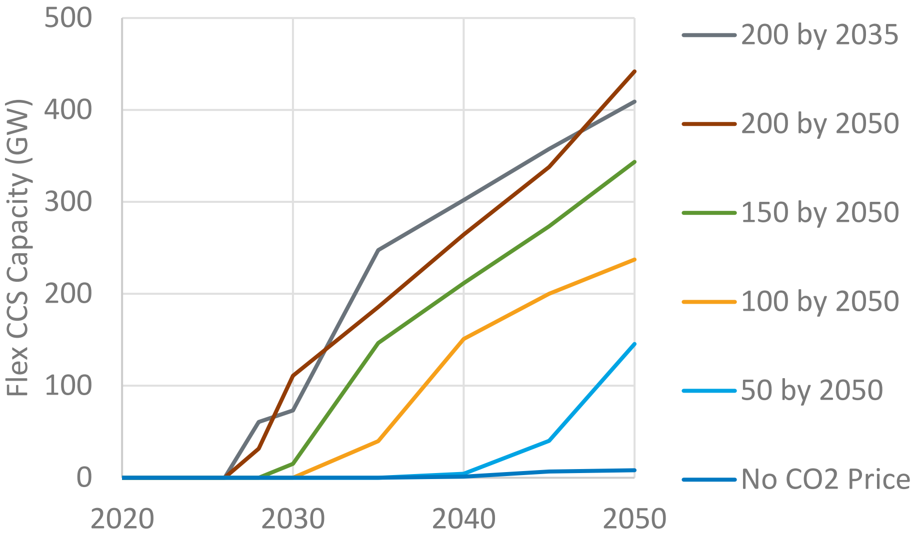
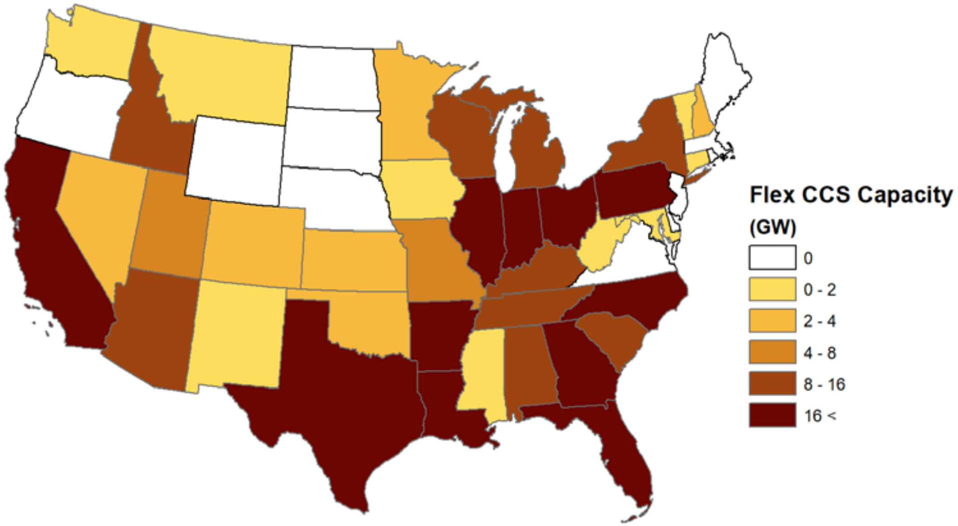
Deployment will be scenario-dependent and vary by region.





- FLECCS technology deployment can be compared across scenarios to see what conditions lead to investment.
- Regional deployment can demonstrate more attractive locations for FLECCS technologies.

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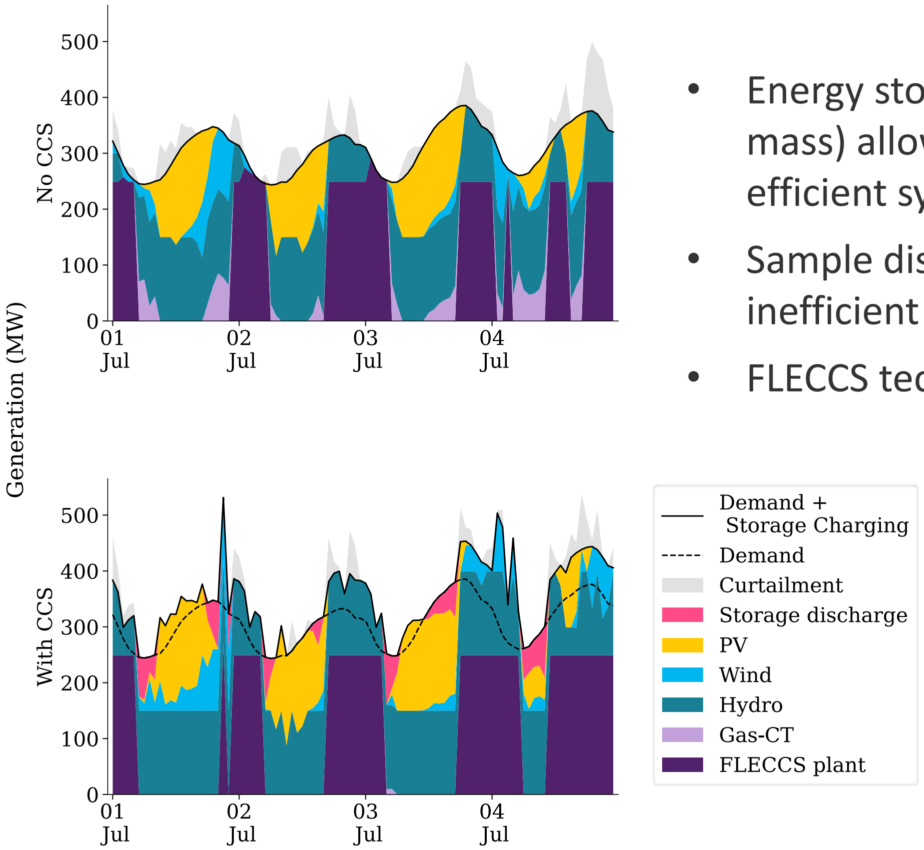
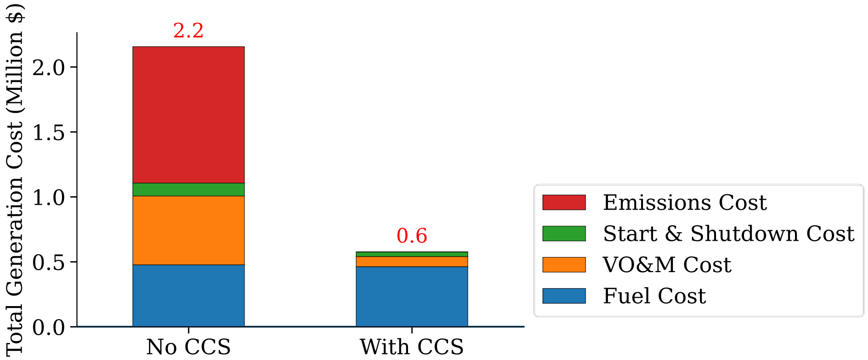
PLEXOS will show competitiveness in economic dispatch.

- Energy storage (via O_2, H_2, chemical solvent, or thermal mass) allows for less cycling of the FLECCS plant and more efficient system operation.
- Sample dispatch shows FLECCS nearly eliminates use of inefficient Gas-CT.
- FLECCS technologies can reduce system operating costs.





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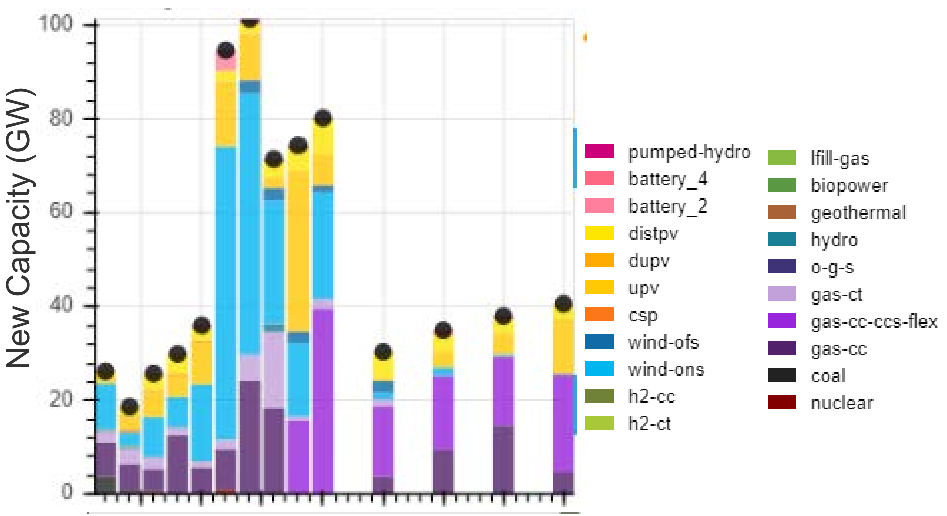
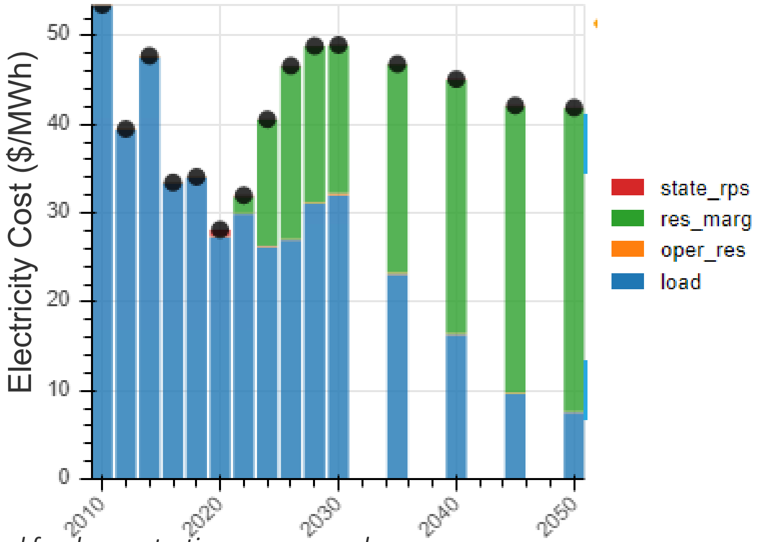
Models will produce many metrics to evaluate FLECCS systems.

- Technology-level
  - Capacity deployment
  - Operational capacity factor (overall and by mode)
  - CO_2 emissions
- Grid-level
  - Total investment and operating cost (and composition)
  - Costs of energy and capacity
  - CO_2 emissions
  - Fossil resource use





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Project outputs will be made publicly available.

- FLECCS model features in ReEDS to be included in v2022 release in GitHub, mid/late 2022: https://github.com/NREL/ReEDS_openaccess
  - Features will be controlled by several model switches.
  - Data for FLECCS parameterizations will adhere to NDA restrictions.
  - It is possible to share beta version code if necessary.
- FLECCS configurations in PLEXOS could be documented and released as a technical report or journal article.

Next Steps

- Iterate as necessary with teams on data template values to ensure completeness and clarity
- Finalize representations of complex storage and DAC-hybrid technologies
- Execute model scenarios using FLECCS team data
  - Some initial runs might not include full ReEDS-PLEXOS integration
  - Initial 2-week turnaround with goal of 1-week for future iterations
  - Schedule and priority will largely follow FLECCS team deadlines

Thank You

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