Representation of Renewable Generation Technologies in the U.S. 10-Region MARKAL Model

Paul Friley
Brookhaven National Laboratory
pfriley@bnl.gov
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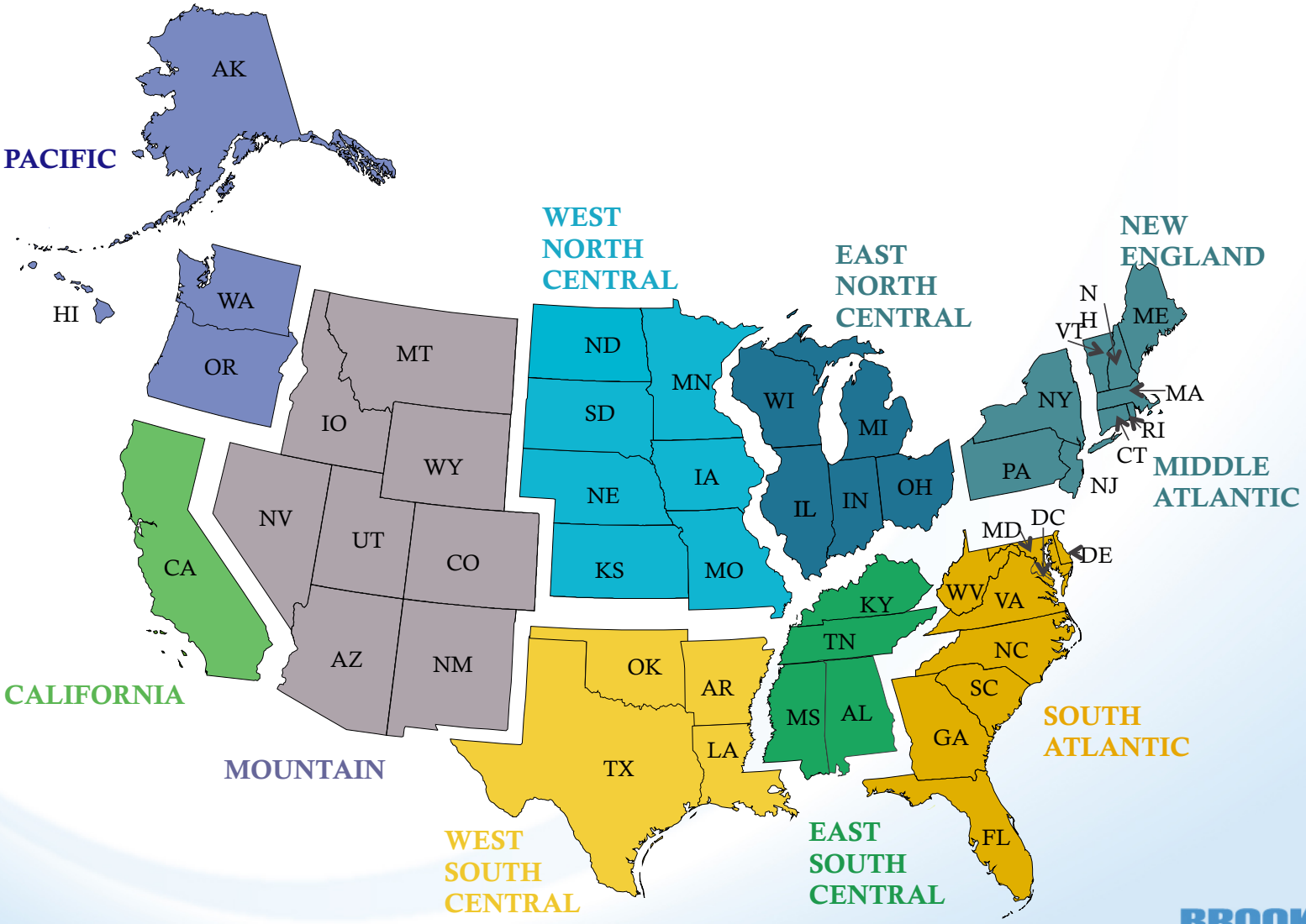
MARKAL Framework

- Well established tool for energy systems analysis.
  - 30 years of development under the auspices of the International Energy Agency. (www.etsap.org)
  - Approximately 100 user institutions in more than 50 countries.
- Bottom-up analysis with explicit technology representation.
  - Includes physical description of energy technologies.
  - Allows for "well-to-wheel" comparison of technologies and technological pathways.
  - Studies the impact of technological change/progress on energy markets.
  - Provides a technology-rich basis for estimating energy dynamics over a multi-period horizon.
- Electric load curve is a user input. Current set up is:
  - 3 seasons – Summer, Winter and Spring/Fall
  - 4 diurnal time slices – seasonal base load, seasonal intermediate, average seasonal peak and seasonal needle peak.

BNL 10-Region Model Regions



Renewable Generation in MARKAL

Non-Intermittent Renewables

- Biomass
  - Biomass Steam
  - BGCC
  - BGCC w/CCS
  - Co-firing with coal
  - Biomass Cogen
- Geothermal
  - Traditional dual flash/binary cycle
  - Near-field EGS
  - EGS
- Hydro
  - One technology now, would like to break out reservoir and run-of-river
- MSW

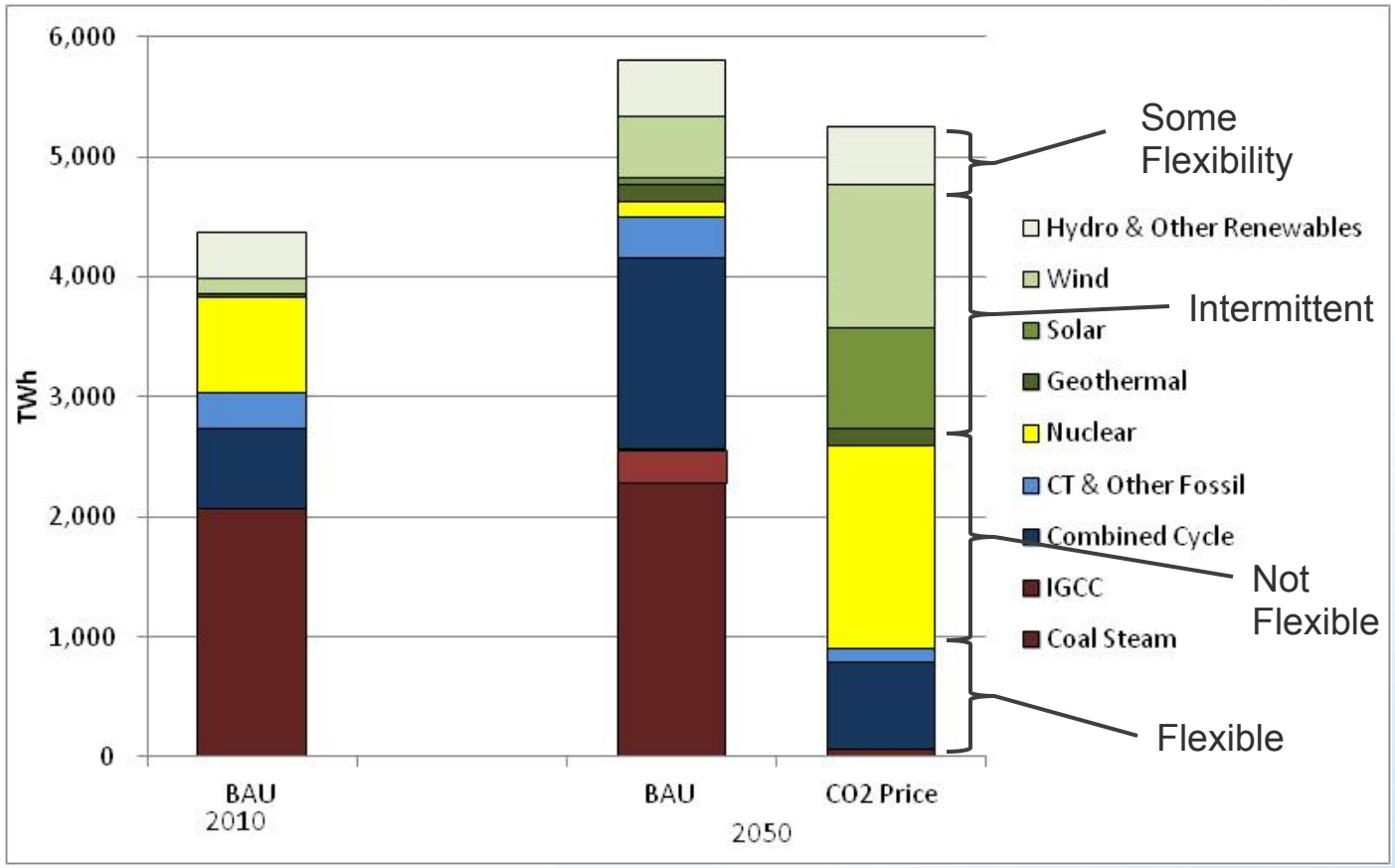
Intermittent Renewables

- Solar
  - CSP
  - Central PV
  - Distributed PV
    - Commercial
    - Residential
- Wind
  - Onshore
    - Class 3
    - Class 4
    - Class 5
    - Class 6
  - Offshore
    - Shallow Classes 5, 6 & 7
    - Transitional Classes 5, 6 & 7

Data Sources

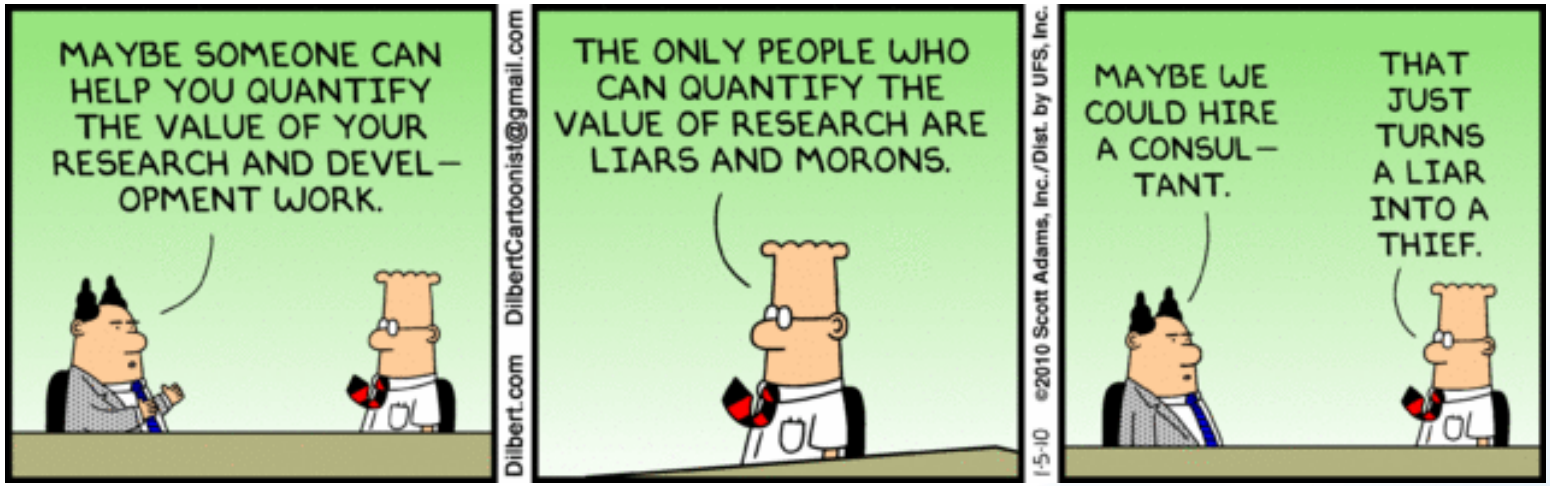
- For most technologies, the technology cost and performance data derived from NEMS. For BGCC with CCS, cost and performance is based on BGCC with incremental cost and energy penalty based on difference between IGCC and IGCC with CCS.
- Renewable resources are mapped from NEMS EMM regions to MARKAL regions using the NEMS EMM to RDM mapping with a bit of work to break out California.
- Non-intermittent plants are dispatched on merit order.
- Intermittent generation (i.e. solar and wind) are treated as fixed dispatch technologies with dispatch governed by seasonal and time of day averages. Again, this data is taken from NEMS and remapped to the MARKAL regions.

2050 Generation in Two Cases



The Tricky Bit (or how to handle capacity credit and ancillary services)

- MARKAL's peaking equation governs the amount of capacity required for each period. Essentially, MARKAL calculates the peak load for each period, adds a reserve margin and this is the lower bound for the sum of the "discounted" generation capacity.
- Generation capacity is discounted by the "peak(con)" parameter. The factor is calculated as follows
  - Dispatchable technologies = 1 - forced outage rate
  - Intermittent technologies = peak period capacity factor.
- Additionally, for intermittent technologies the peak contribution is discounted as the market share of intermittent generation increases in a region.
- Ancillary services are not currently modeled.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THAT JUST TURNS A LIAR INTO A THIEF.