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National Assessment of Energy Storage for Grid Balancing and Arbitrage

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Energy Storage Analytics Agenda

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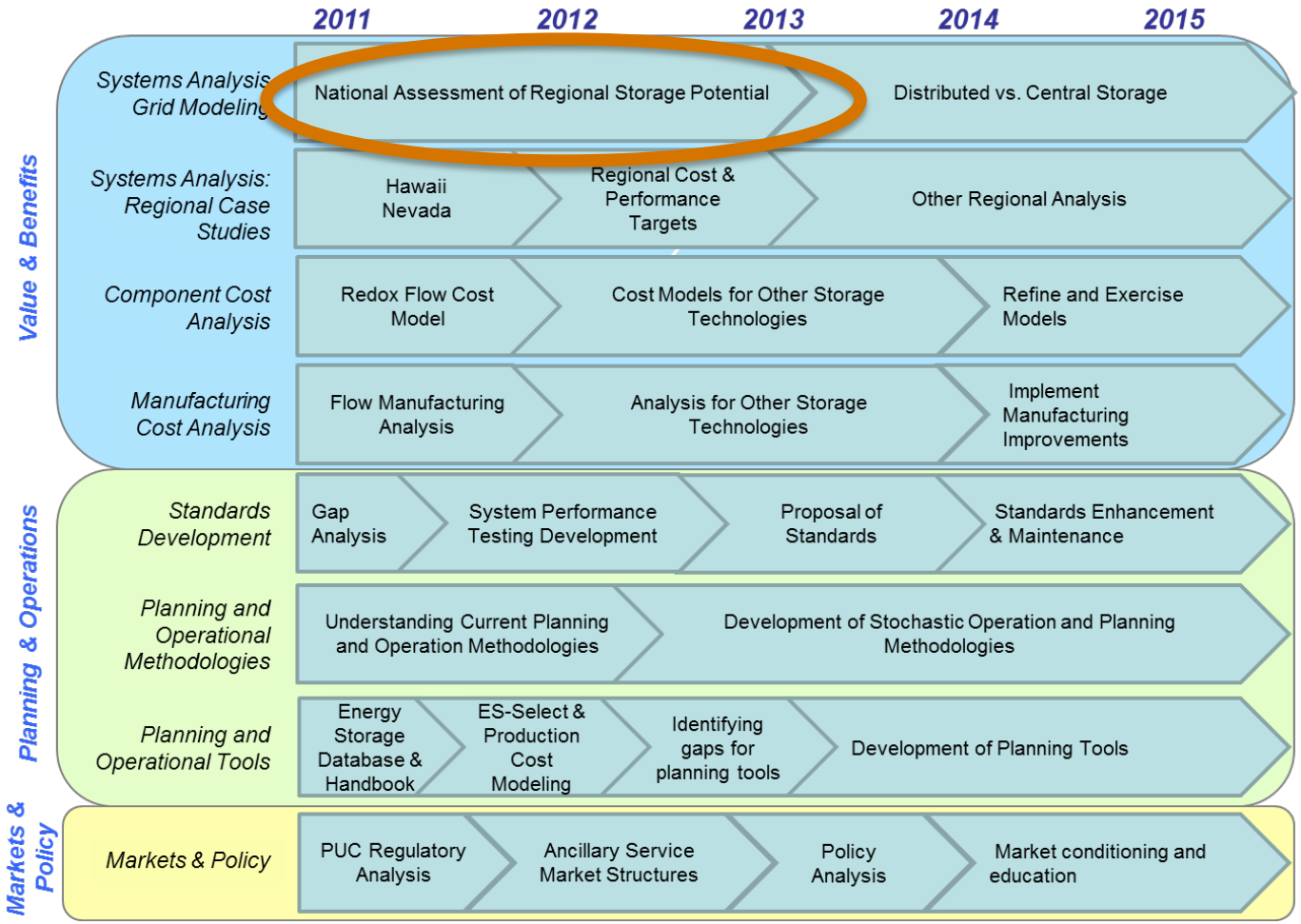

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National Assessment of Energy Storage Considering Regional Differences

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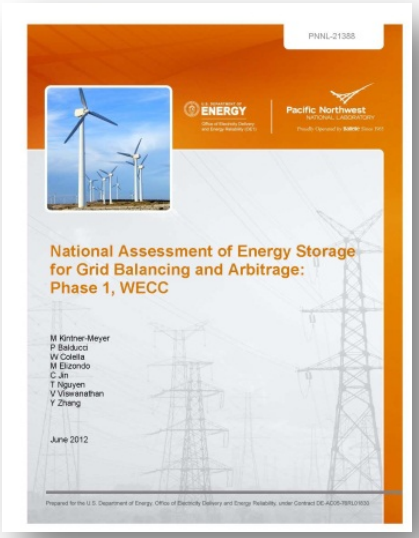
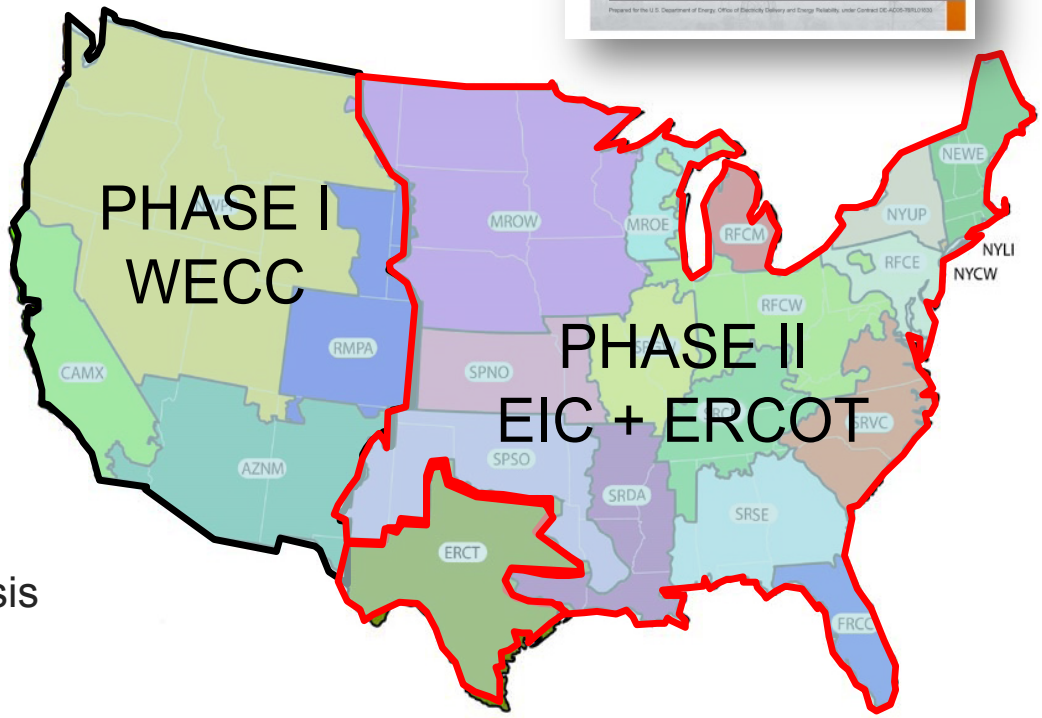
- **Objectives:** Determine:
  - future balancing requirements needed by 2020 to accommodate assumed 20% RPS,
  - market size for storage and respective cost targets for **balancing** and energy **arbitrage** by regions
  - most cost-effective technologies to meet add'l balancing requirements.
- **Value:**
  - Provides plausible market potential estimates of energy storage for the investment community and policy makers in a nine-year forecasting time horizon (2020)
  - Differentiates markets for short- (< 1h) and longer-term storage (>4 hours)
  - Reveals key assumptions and their influence on the outcome of the analysis





Additional Wind Capacity
WECC for a 2020 Grid Scenario

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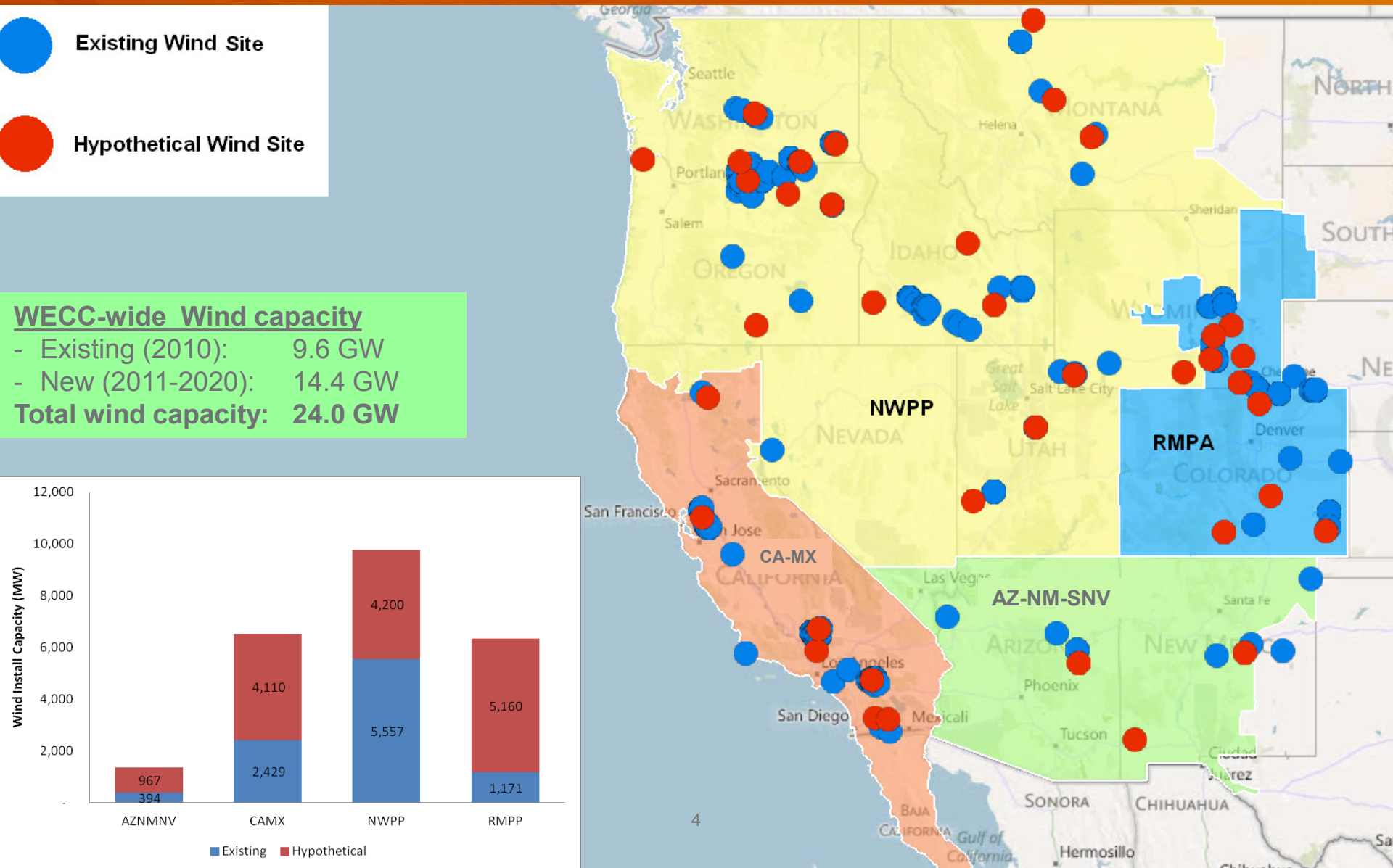


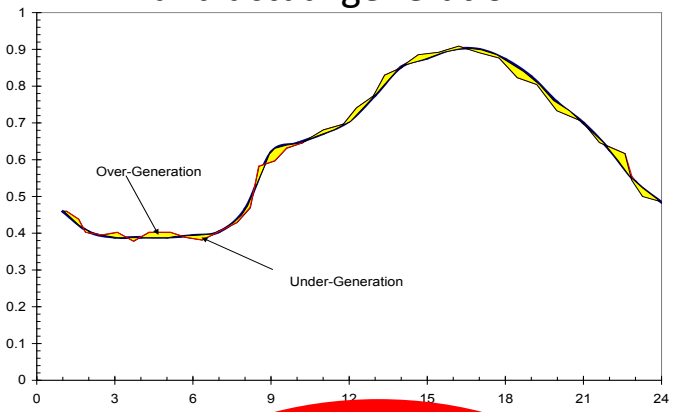
WECC-wide Wind capacity

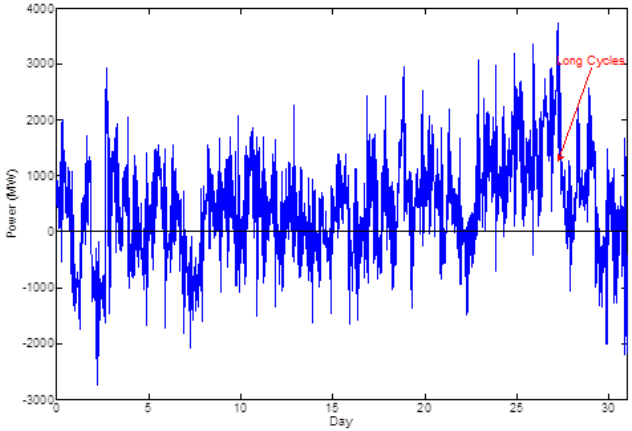
- Existing (2010): 9.6 GW
- New (2011-2020): 14.4 GW

Total wind capacity: 24.0 GW

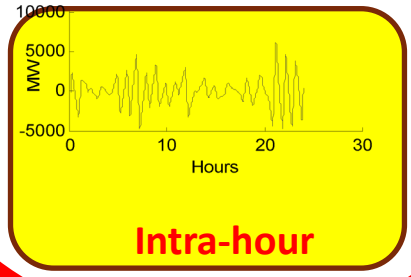
Definition of Intra-hour Balancing Services

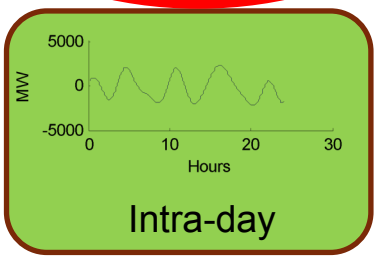
Mismatch between scheduled and actual generation

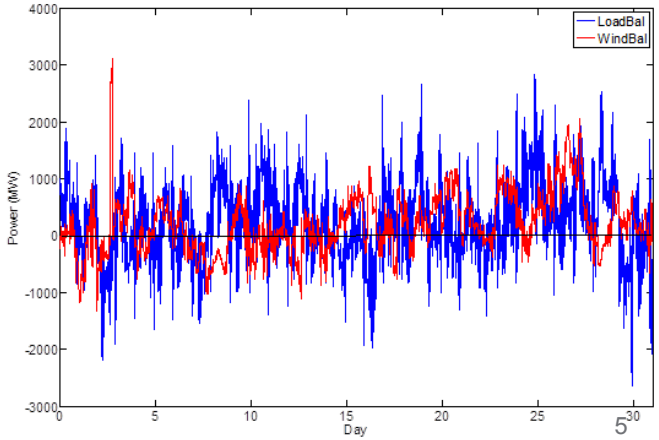




High-pass filter







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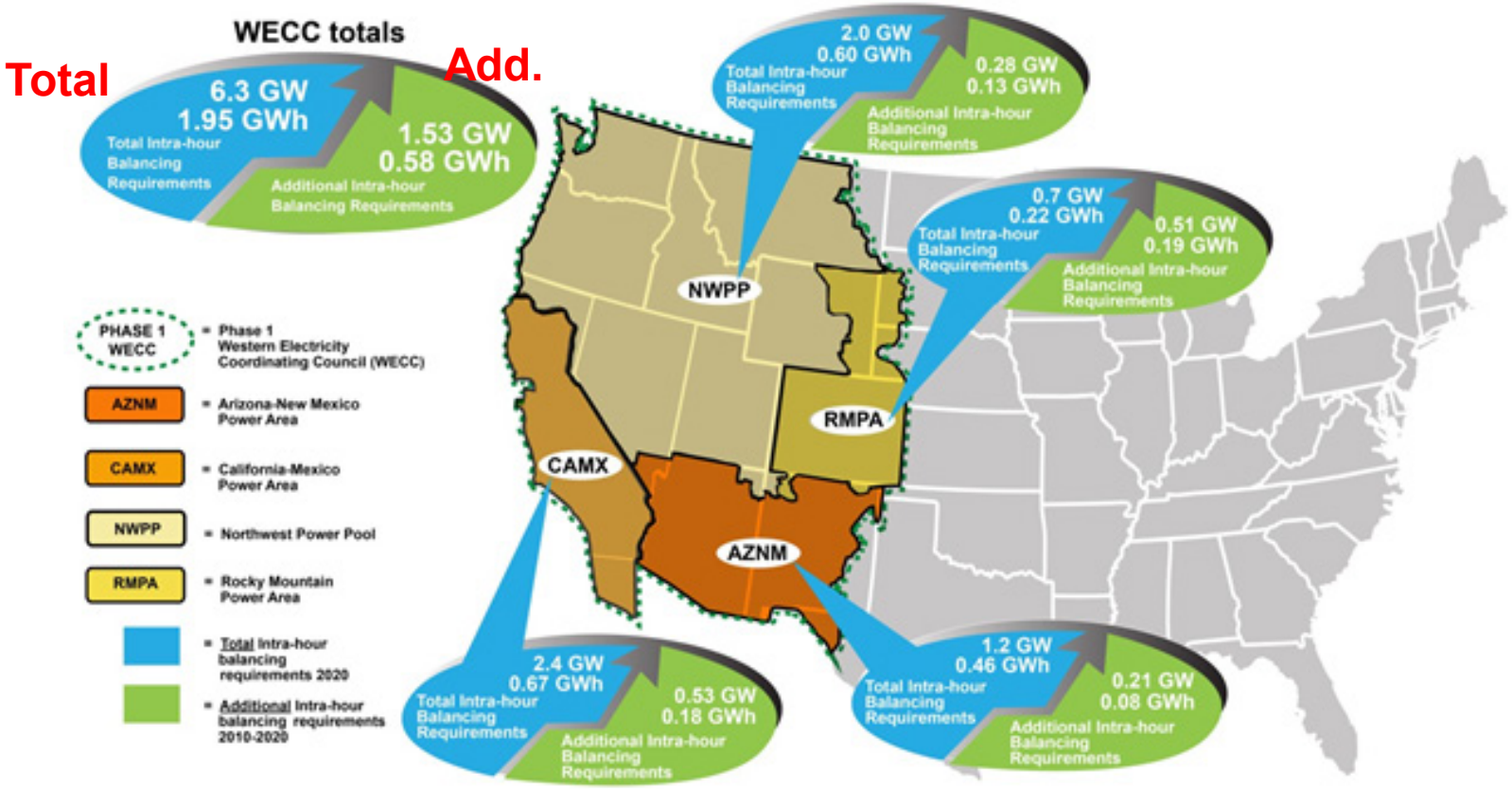
Balancing Requirements: WECC

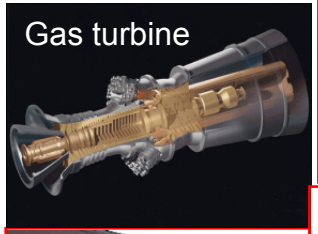


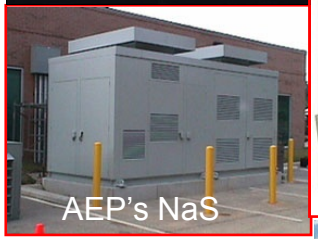
- **Additional** Intra-hour Balancing Requirements: 1.53 GW, 0.58 GWh (~20 minutes)
- **Total** Intra-hour Balancing Requirements: 6.3 GW, 1.95 GWh (~20 minutes)

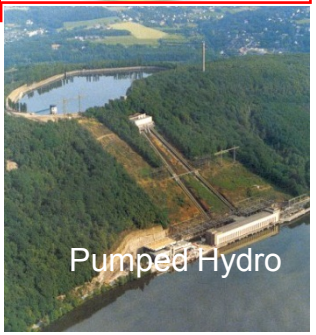
- For every one unit of wind capacity power, approximately 0.06 to 0.21 units of intra-hour balancing

Technology Options to Meet Balancing Requirements

- What are the most cost-effective technology options for serving balancing requirements?
  - Na-S (Sodium Sulphur) batteries
  - Li-Ion (Lithium Ion batteries)
  - Flywheel
  - CAES (Compressed Air Energy Storage)
  - Redox-Flow batteries
  - Pumped Hydro Storage
  - Demand Response and
  - Combustion turbine as a base-case technology
  - Hybrid-energy storage system (combining fast and slower reacting components)







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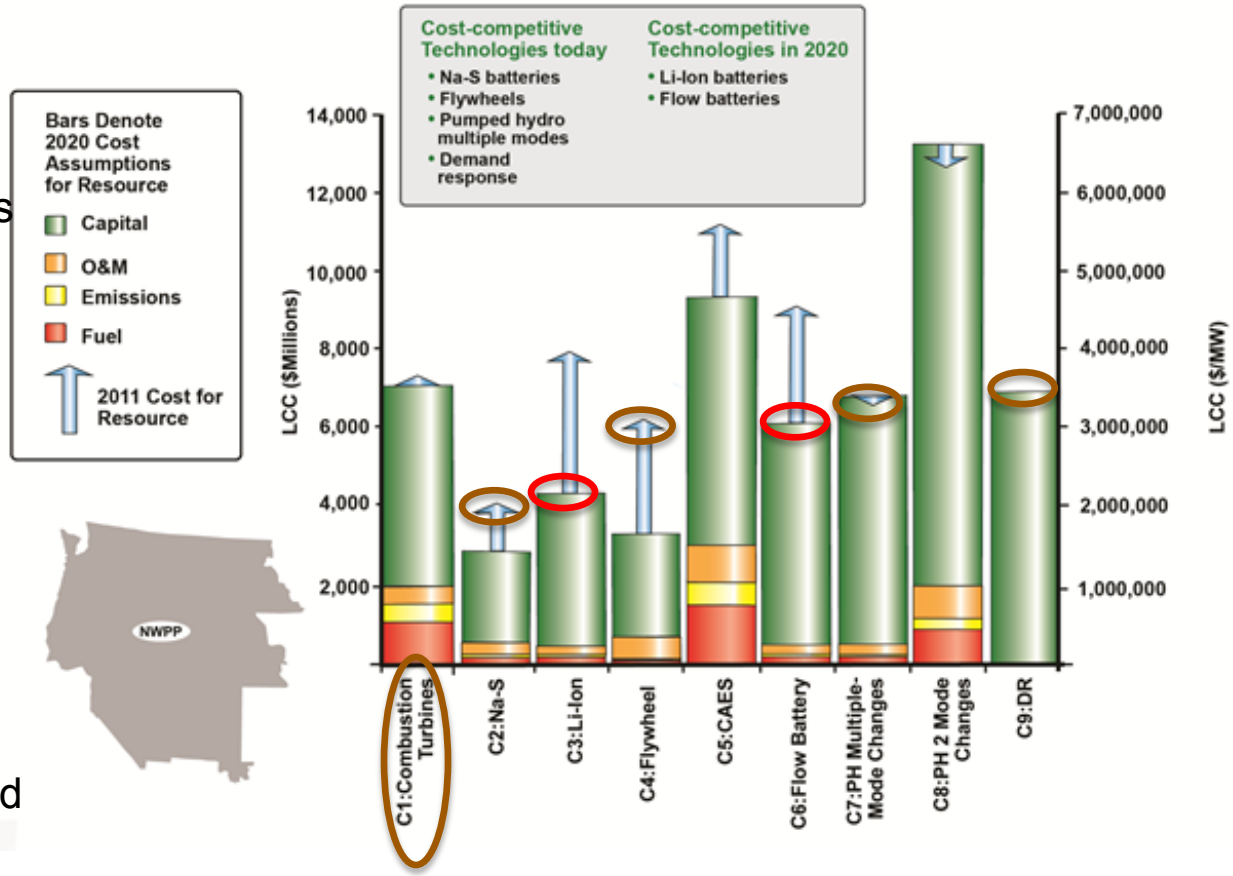
Key Findings

Life Cycle Costs

- Results from detailed analysis indicate the most cost-effective technological solutions for meeting balancing requirements
  - **Today** are:
    - Na-S batteries
    - Flywheels
    - Pumped hydro
    - Demand response (EV smart charging)
  - **By 2020**:
    - Li-ion batteries
    - Redox flow batteries
- Competitiveness of storage will improve as the cost of advanced technology is expected to decline in the next 10 years



Detailed Production Cost Modeling Estimates the Revenue Opportunities

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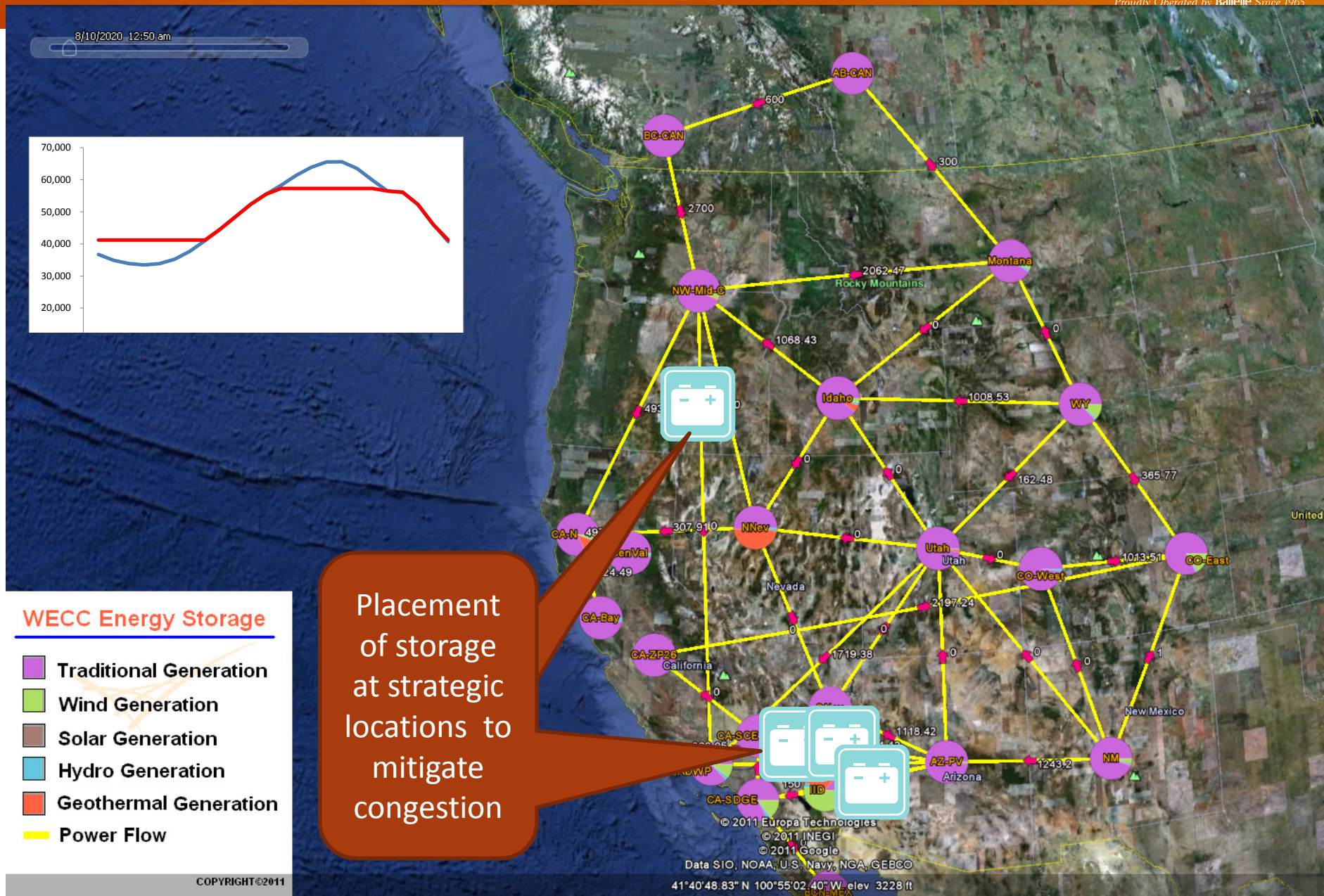

Placement of storage at strategic locations to mitigate congestion

Revenue Expectations from Energy Arbitrage

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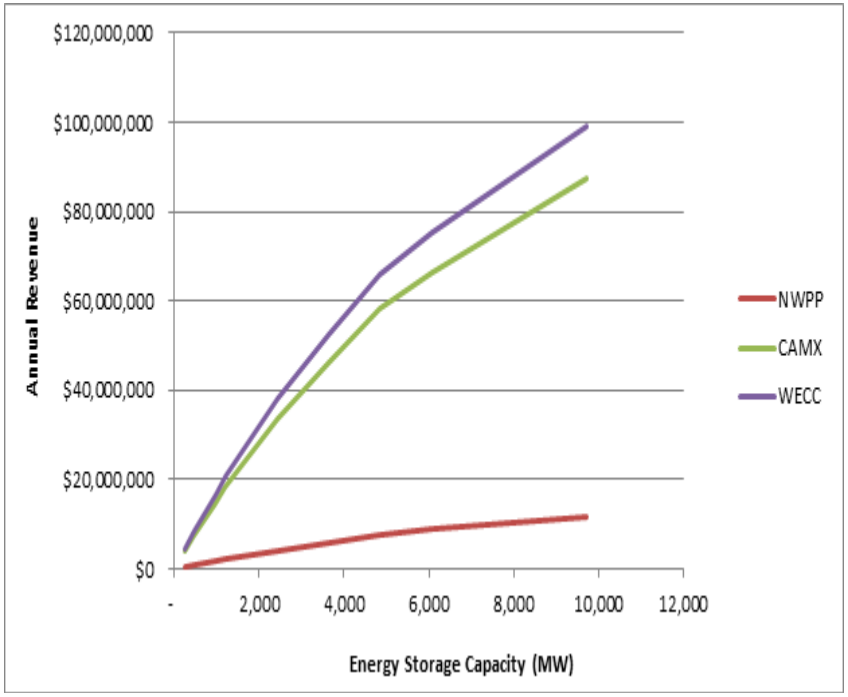
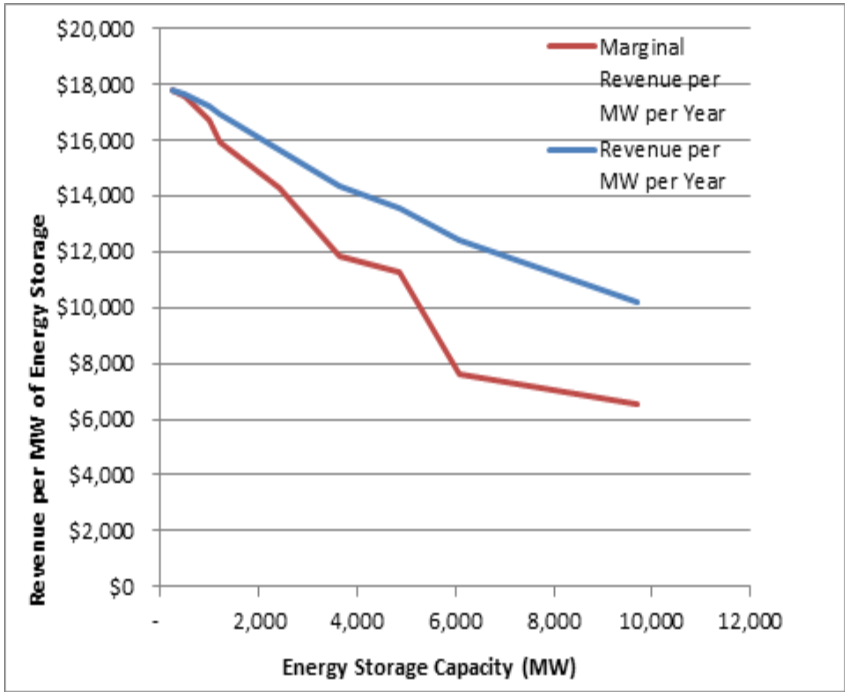




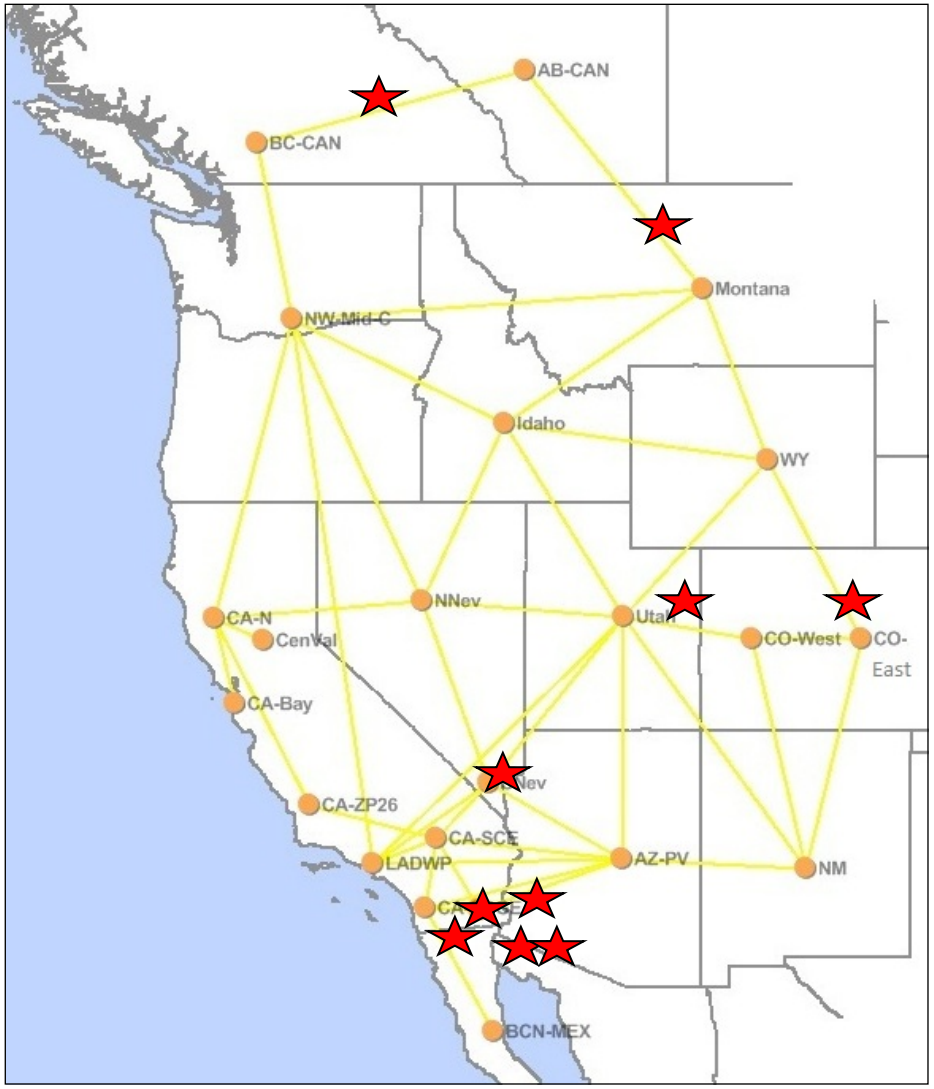
Key Outcomes

- Wholesale energy value is low and is insufficient to solely justify storage >1 hour
- Capacity value necessary for business case of storage >> 1hour

Key Findings: Arbitrage Services

Arbitrage Opportunities

- Arbitrage revenue expectations fall far short of levels required for capital recovery
- Much larger market size for energy storage is possible in WECC if price points are reached
  - $90/kWh is the price point for arbitrage assuming a capacity credits of $150/kW/year for Li-Ion, NaS and flywheels
  - This analysis is limited, excluding several potential value streams (e.g., power quality, and T&D deferral)



Key Congestion Paths in the WECC

Next Steps

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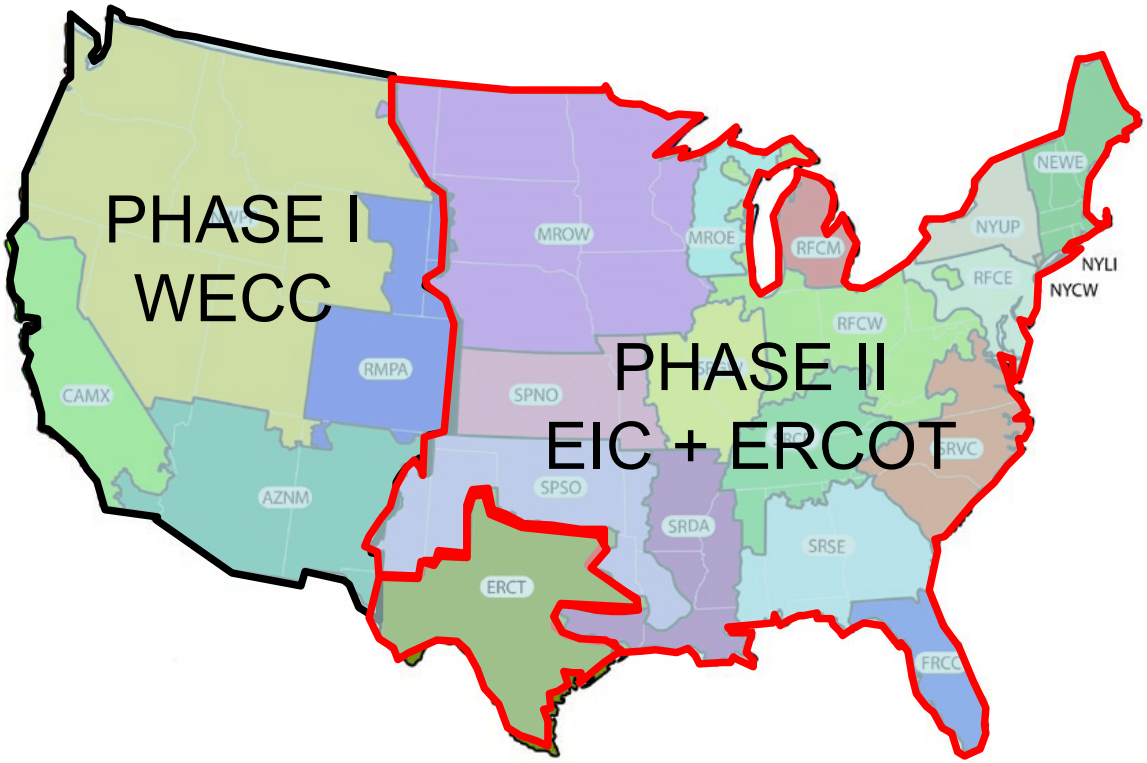
Completion of National Assessment Phase II in December 2012

National Assessment: Phase I- Report available at:

http://energyenvironment.pnnl.gov/pdf/PNNL-21388_National_Assessment_Storage_Phase_1_final.pdf



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