Energy Storage: How much do we need? And how much can we afford?

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IEEE-Northwest Energy Systems Symposium (NWESS)
Seattle, WA

March 22, 2012

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National Relevance of Storage to Provide a Resilient, Low-Carbon Electricity Supply

What questions does the DOE Storage Program address?

- What role could stationary energy storage play in near- and long-term in meeting the Nation's energy objectives?
- To what extent does the value of storage and the need for storage capacity depend on: market designs, regulatory frameworks (such as definition of balancing authorities), and the deployment of variable renewable energy resources?
- What are the optimal technical characteristics for storage technologies in different applications?
- What are the regional differences in the need for energy storage?
- What are the cost performance characteristics for energy storage to be cost competitive at scale?
- What are the challenges to integrate energy storage into grid operations and transmission planning processes?
- What are the best practices, lessons-learned, and success storage of existing energy storage deployments and how can they be applied to guide the future R&D agenda for energy storage?

Analysis Fundamental to the DOE Energy Storage Program

Today's Grid

- ≈35GW intermittent
- ≈5% DR
- 0 mill. EVs
- Few PMUs
- Selected ramping challenges

2025 Grid

- ≈300GW interm.
- ≈10-15% DR
- ≈ 15 mill. EVs
- Many PMUs
- Need to address increasing ramping requirements

Energy Storage Analysis

Grid and Storage Analytics

- System analysis
  - *Grid modeling*
  - *Case studies*
- Develop cost targets for storage for near- and mid-term by applications
- Develop cost model to identify cost reduction options and guide S&T agenda

Evaluation and Market Conditioning

- Case studies evaluations
- Market conditioning
  - *Education*
  - *Policy analysis, design of markets*
  - *Standards development*
  - *Planning tools development*

Needs

- Ramping capabilities
- Clean replacement capacity for plant retirements (old coal, nuclear)
- Transmission expansion to deliver remote wind energy
- Changes in operating procedures
- Innovative market designs to cost-optimally build and dispatch resources

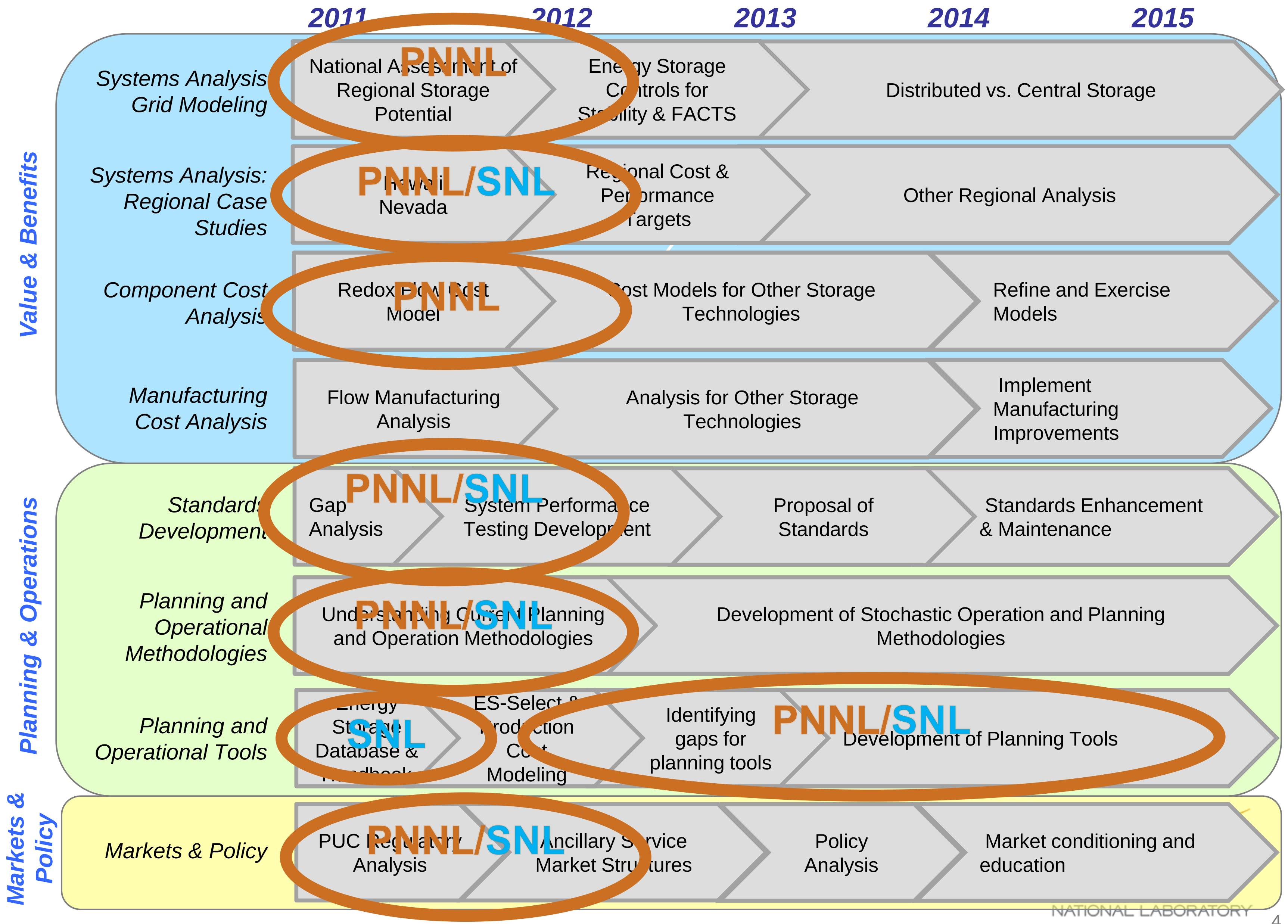
Technologies

- Gas-fired capacity
  - *Combined Cycle*
  - *Combustion Turbine*
- Central Storage
  - *Redox Flow*
  - *NaS*
  - *Li-Ion*
  - *Advance lead*
  - *Others*
  - *Flywheel*
  - *CAES*
- Distributed Storage
- Demand Response
  - *Buildings/industrial*
  - *Electric Vehicles*
- Integration Controls Technologies

Deployment

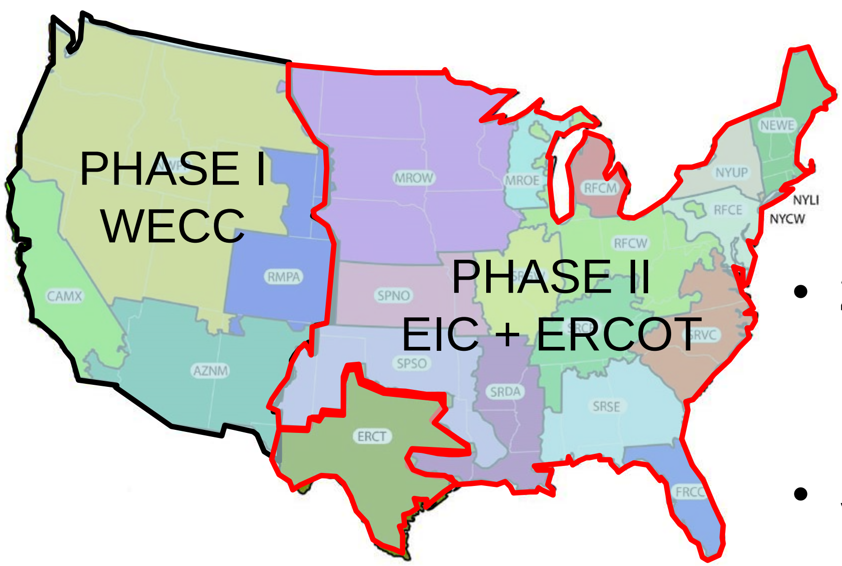
- Fair Market rules to compensate for performance
- Regulatory framework
- Bundling applications
- Identifying location
- Site preparation
- Planning and deployment criteria to match best suited technology for set of applications
- Integration of storage into dispatch strategy

Timeline of the DOE Analysis Agenda



PNNL National Assessment of Energy Storage Systems for 2020

22 NERC Sub-regions



PHASE I release in Spring 2012

PHASE II release in Summer 2012

- **Market size potential by cost target and sub-region:**
  - For balancing service (Intra-hour)
    - MW power rating
    - MWh energy capacity
    - ranking of Life-Cycle-Cost by technology
  - For arbitrage
    - MW power rating
    - MWh energy capacity that are economically viable
- **2020 Grid Definition**
  - Nationwide 20% RPS
  - Individual state RPS are honored
- **Sensitivities**
  - Wind forecasting error
  - Low/high natural gas expectations

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Value of National Assessment

- Provides plausible market potential estimates of energy storage for the investment community and policy makers in a 9-year forecasting time horizon (2020)
- Indicates relative competitiveness among main categories of storage technologies as well as competitiveness versus Demand Response and traditional generation and transmission
  - Allows to estimate/set cost/performance target for specific markets and specific regions
- Differentiates the markets for
  - Short-term storage (< 1h) and
  - Longer-term storage (>6 hours)
- Reveals key assumptions and their influence on the outcome of the analysis

Balancing Analysis

and

Storage Opportunities < 1 hour

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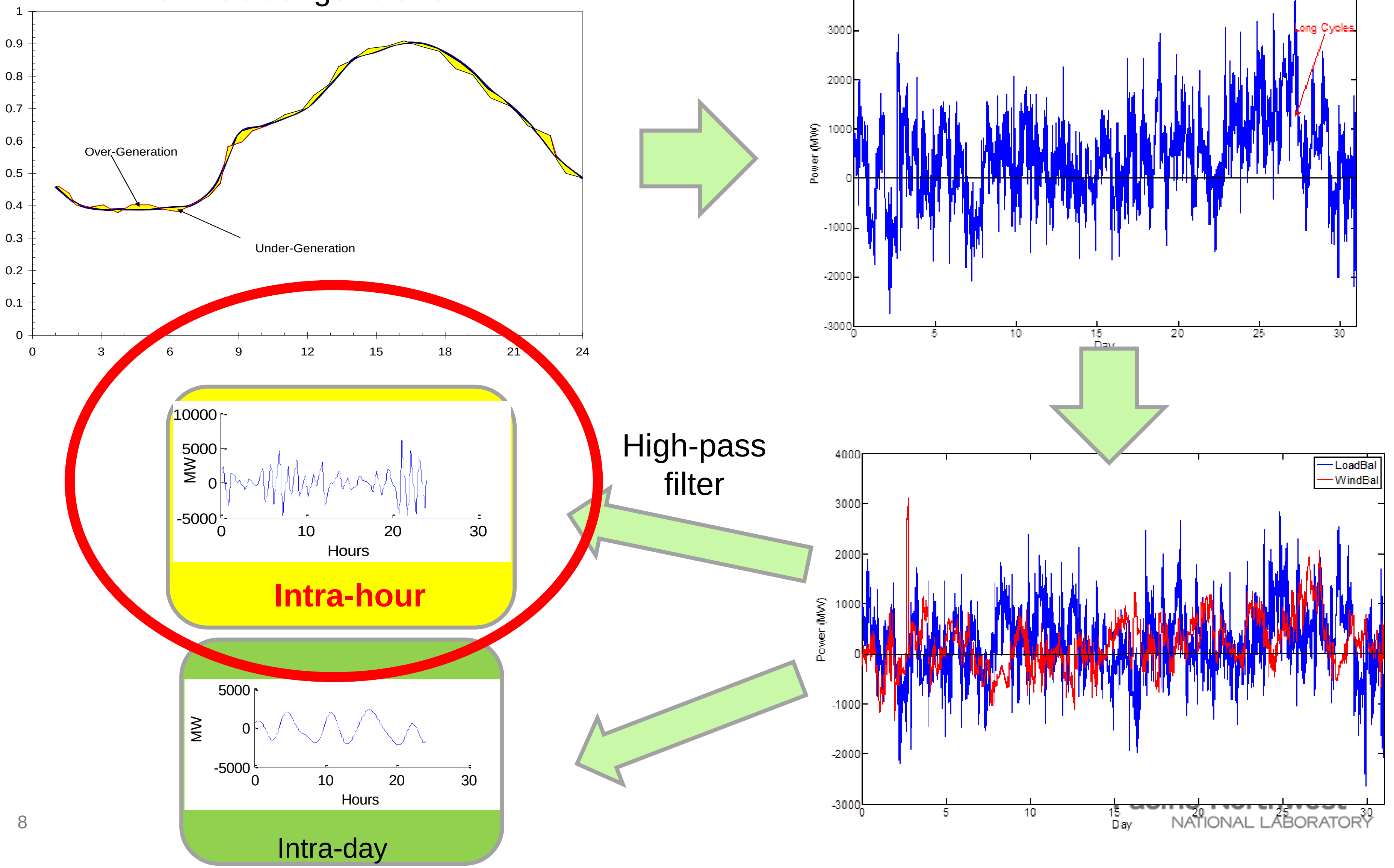
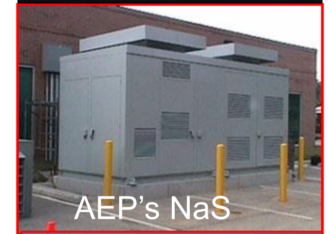
Balancing Services Definition

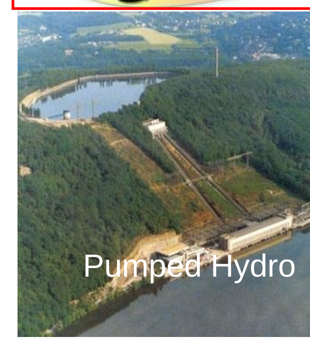
Mismatch between scheduled and actual generation



Scenario Definition:

- **Balancing Services:**
  - Scope: WECC, 2020
    - Assume 24.0 GW of total installed capacity of wind.
      - Existing wind capacity 9.6 GW
      - Added capacity 14.4GW
  - Technology choices
    - Combustion turbine
    - NAS batteries
    - Li-Ion batteries
    - Redox-Flow
    - CAES
    - Flywheels
    - Demand response (EV)
    - Pumped hydro





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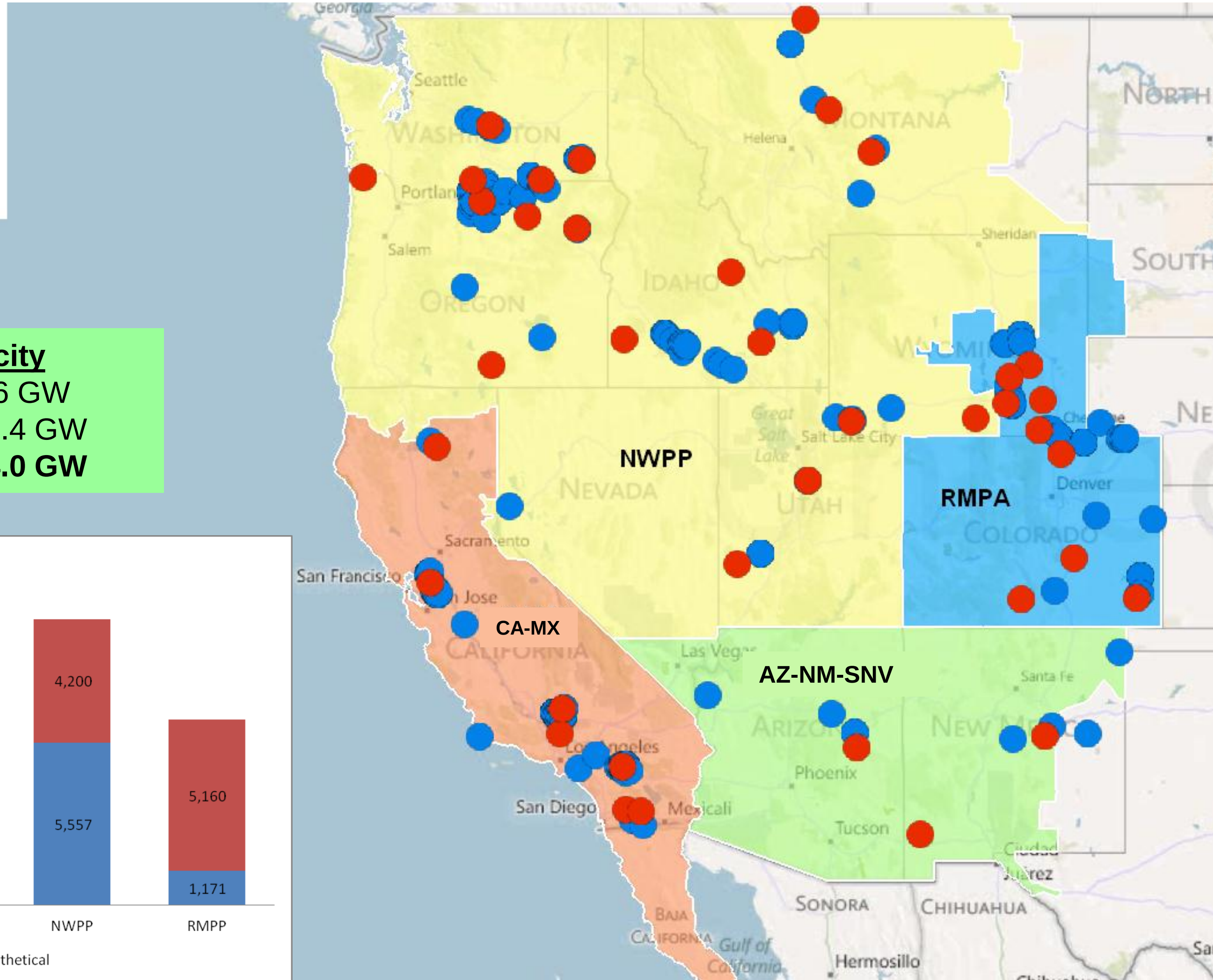
Assessment for WECC for a 2020 Grid Scenario

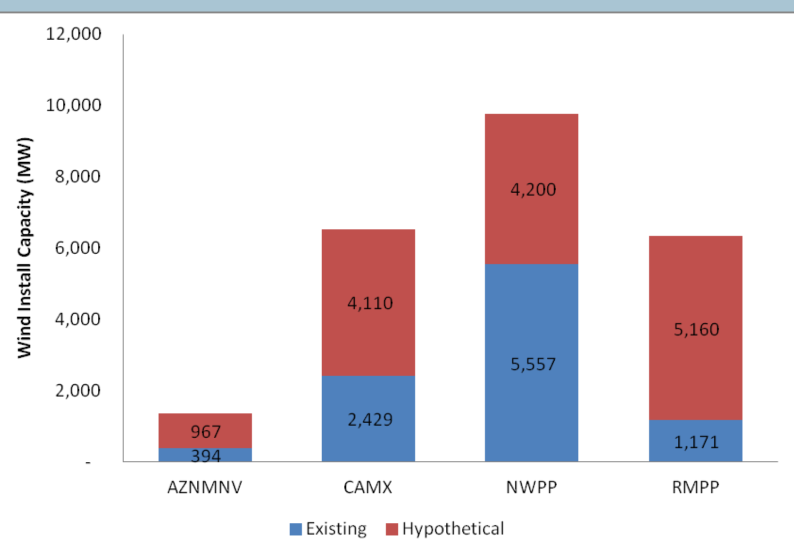
Existing Wind Site

Hypothetical Wind Site

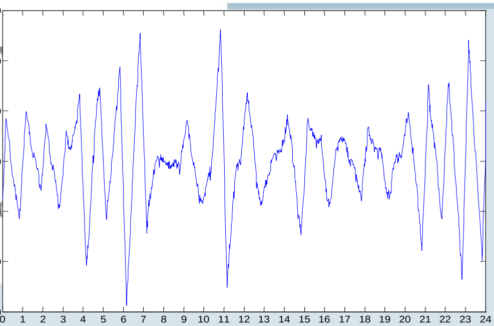


<u>WECC-wide Wind capacity</u>
- Existing (2010): 9.6 GW
- New (2011-2020): 14.4 GW

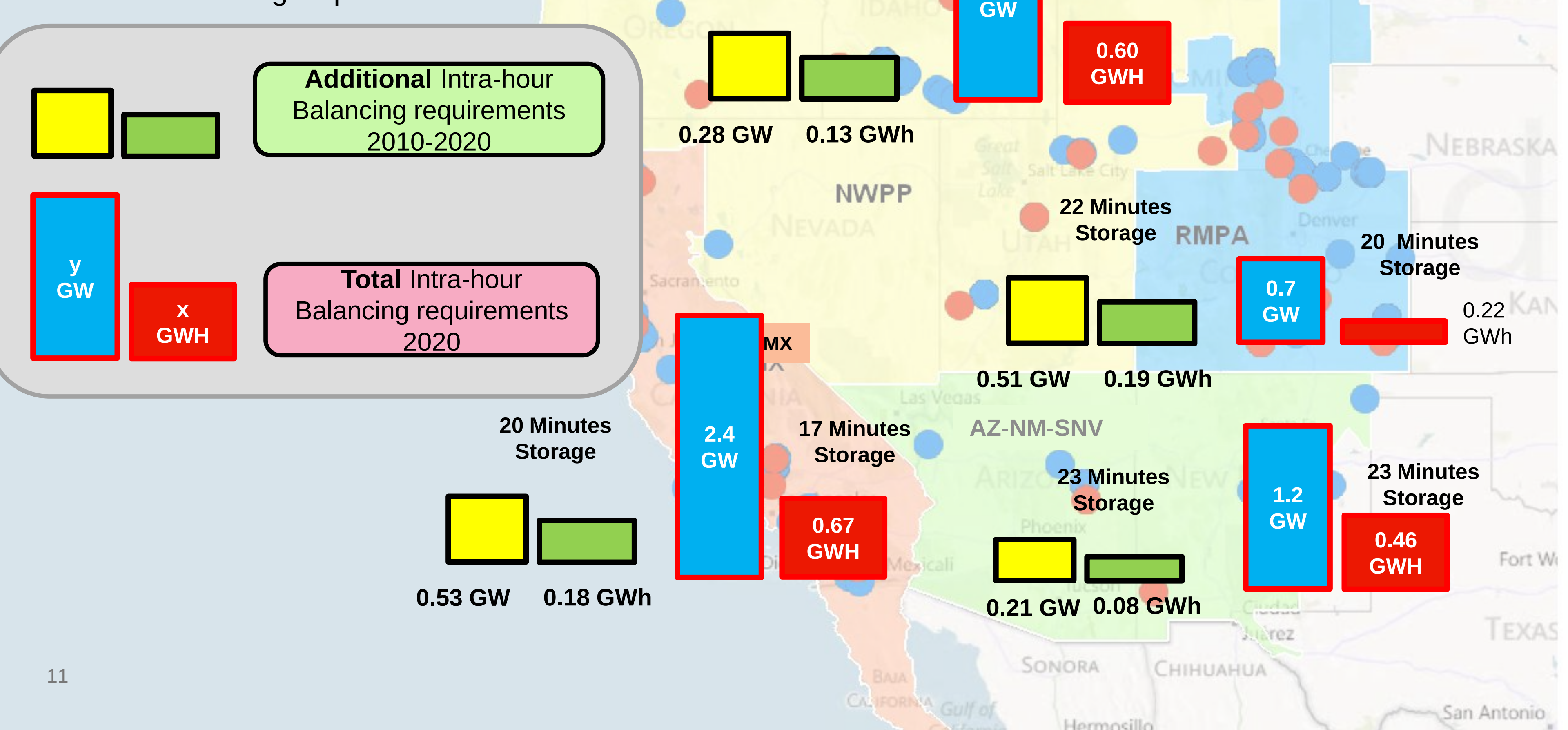
Total wind capacity: 24.0 GW



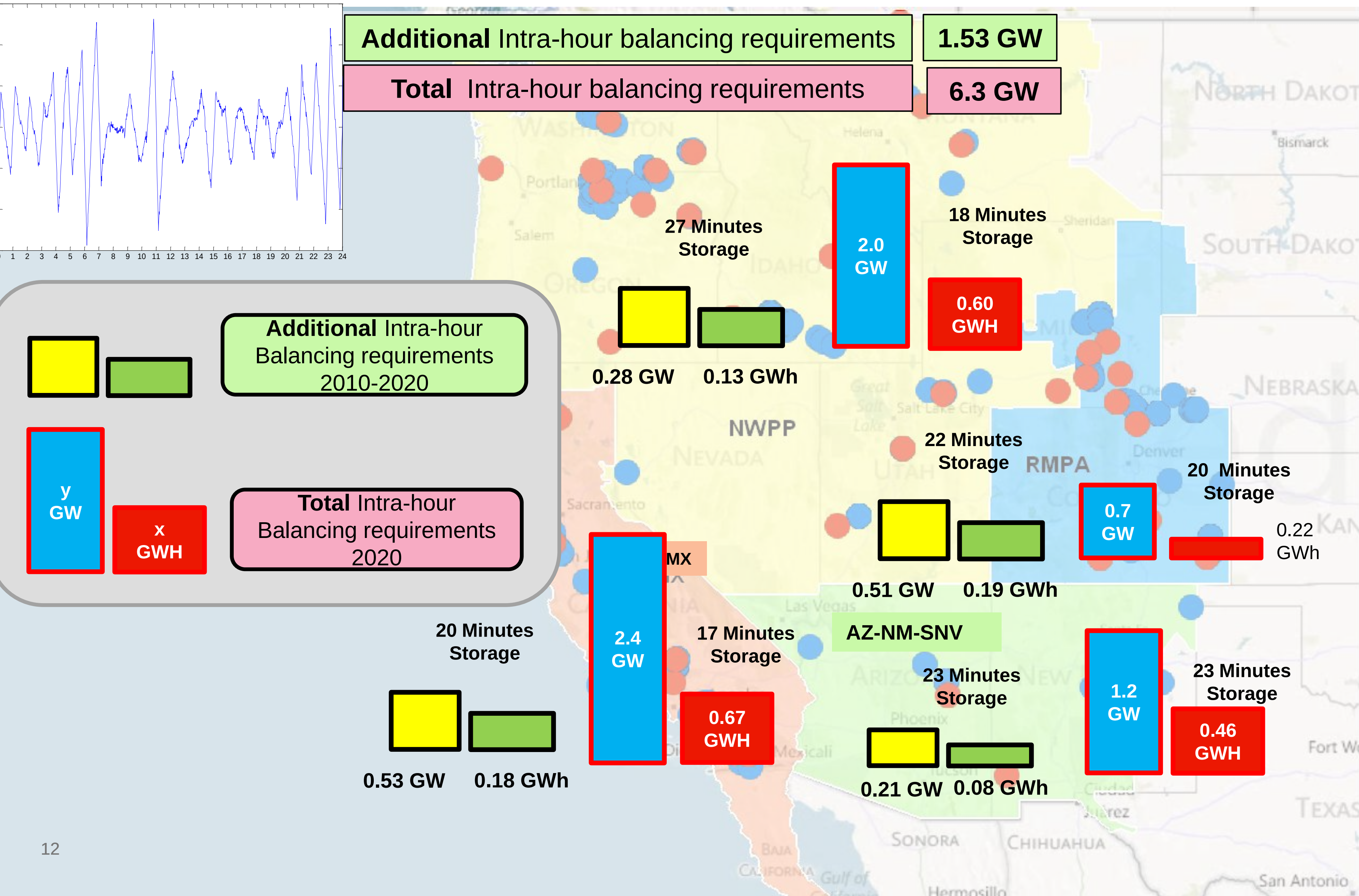
Intra-hour Balancing Requirements for WECC for a 2020 Grid Scenario



Intra-hour balancing requirements



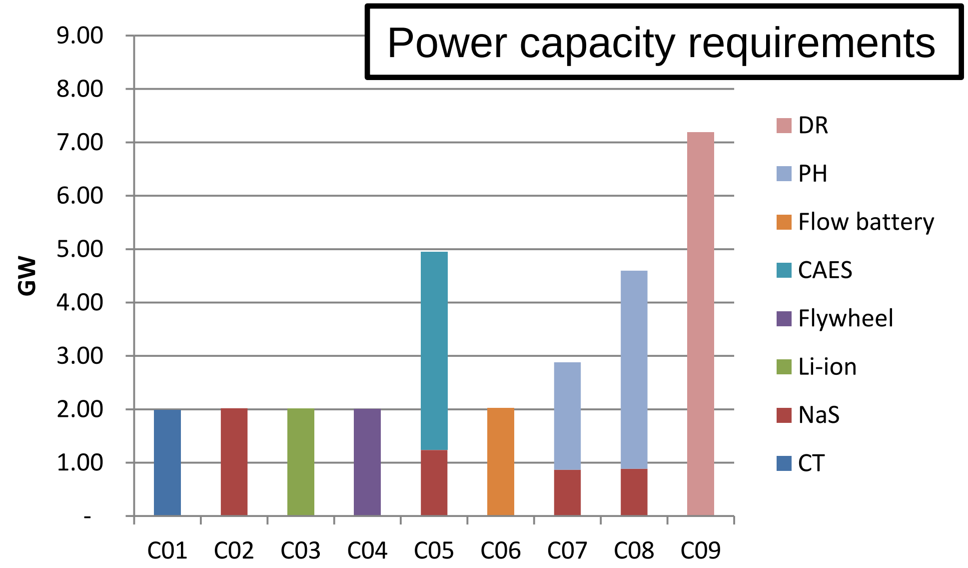
Intra-hour Balancing Requirements for WECC for a 2020 Grid Scenario

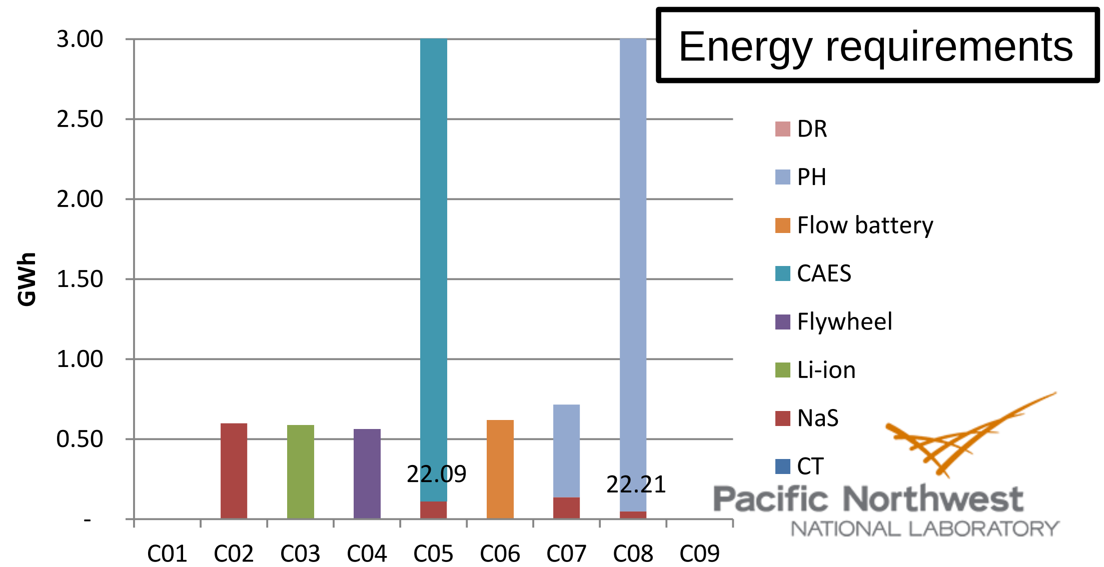


Capacity and Energy Requirements of all Technologies to meet Total Intra-hour Balancing in 2020

North West Power Pool

Case	Technology	GW	GWh
C1	Combustion turbine	1.99	-
C2	NaS	2.02	0.60
C3	Li-ion	2.02	0.59
C4	Flywheel	2.00	0.56
C5	CAES 2 modes	3.71	22.09
	7 min waiting period, NaS	1.24	0.11
C6	Flow battery	2.03	0.62
C7	PH multiple modes	2.01	0.58
	4 min waiting period, NaS	0.87	0.14
C8	PH 2 modes	3.71	22.21
	4 min waiting period, NaS	0.89	0.05
C9	DR	7.19	-





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Cost Performance Characteristics (2020)

Parameter	NaS Battery	Li-ion Battery	Pumped Hydro	Combustion Turbine	Combined Cycle	Demand Response	CAES	Flywheel	Redox Flow Battery
Battery Capital Cost – Energy Capacity $/kWh	290 (181-331)	510 (290-700)	10				3	115 (81-148)	131 (88-173)
System Capital Cost – Power Demand $/kW			1,890 (1,640-2,440)	990	Not Used	620	850 (500-1,140)	610 (200-820)	775 (608-942)
PCS ($/kW)	150	150							150
BOP ($/kW)	50	50						50	50
O&M fixed $/kW-year	3	3	4.6	10.24	14.93		7	18	5
O&M fixed $/kW-year (PCS)	2	2							2
O&M variable cents/kWh	0.7	0.7	0.4	0.9	0.4		0.3	0.1	0.1
Round trip efficiency	0.78	0.80	0.81	0.315			0.50	0.85	0.75

Redox flow – assume peak power/rated power = 1.4
Stack cost 2020 - $352-639/kW (average = 496/kW)

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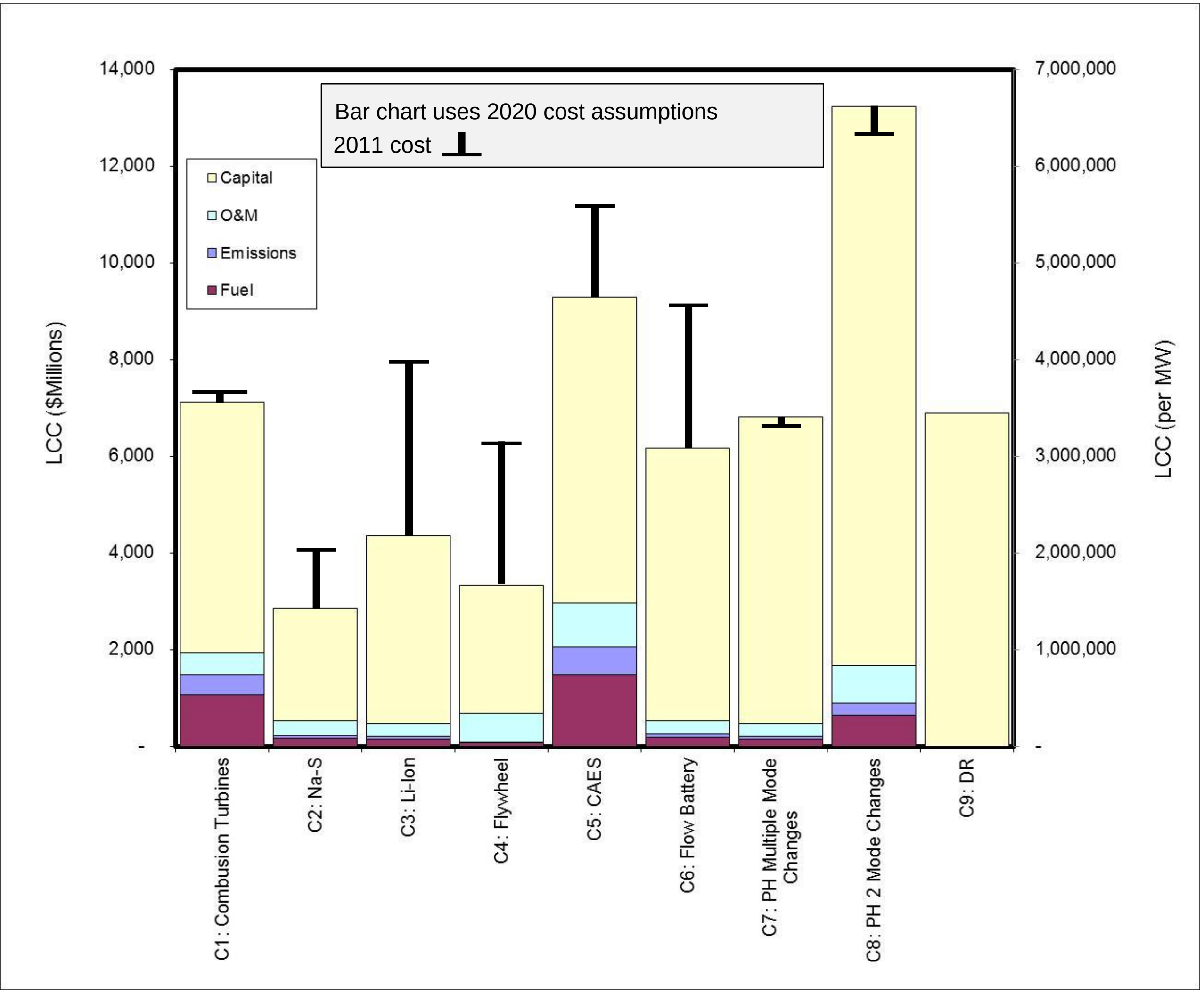
Life-Cycle Cost Results



Key outcomes

- Results are capital cost driven
- Na-S, Flywheels, and DR, PH at current cost are cost competitive (LCC) today
- Li-ion, Redox-Flow will be cost-competitive with CT
- Consistent with current activities in the storage market. Primarily 15-20 minute products

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Hybridization Opportunities

- Motivation: identifying cost optimal hybrid system where we pair the complementary technologies (slow and fast responding devices)

- Results
  - Unless there are physical constraints (e.g., ramp limits), the optimal solution is determine solely by capital cost
  - Our minute by minute simulation did NOT find limiting ramp rates of any investigated technologies
  - Unless you looking at power-quality or sharp transients, hybridization may be only driven by cost.
  - Different tools, such as PLSF must be used to analyze advantages of hybrid systems

Opportunity for

Storage > 1 hour Duration

Cost Targets for Storage >1 Hour Duration

Net revenue (energy+capacity) > cost recovery

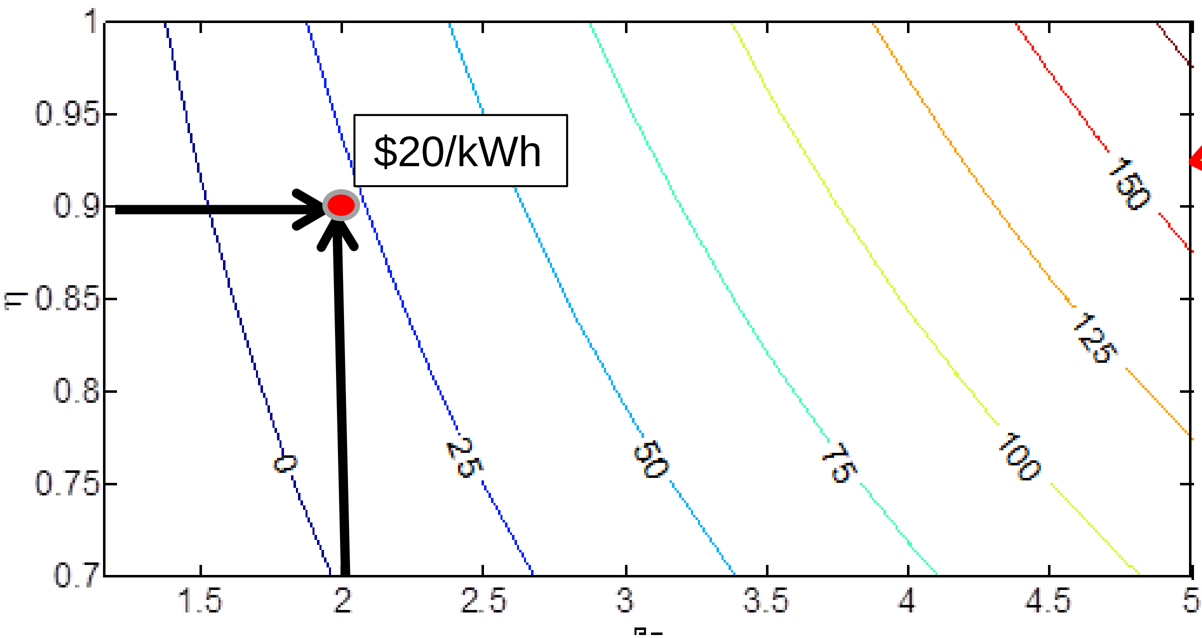
Annual net revenue = $f\,(\eta, p_p, p_o, No\ of\ days)$

Annual Cost recovery = $f\,(C_{PCS}, C_{Sto}, \alpha, d)$

Assumptions

- C_{PCS} = \$150/kWh
- D = 260 days
- d= 8 hour
- α = 0.12
- p_o = \$40/MWh

Incremental capital cost of storage [\$/kWh]

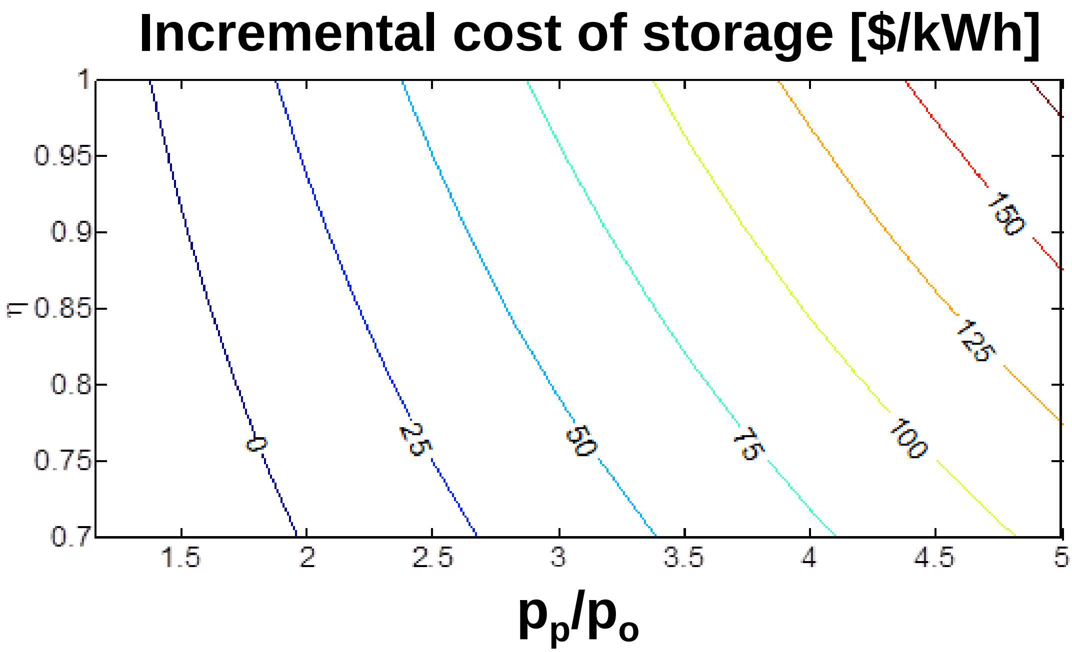


p_p/p_o

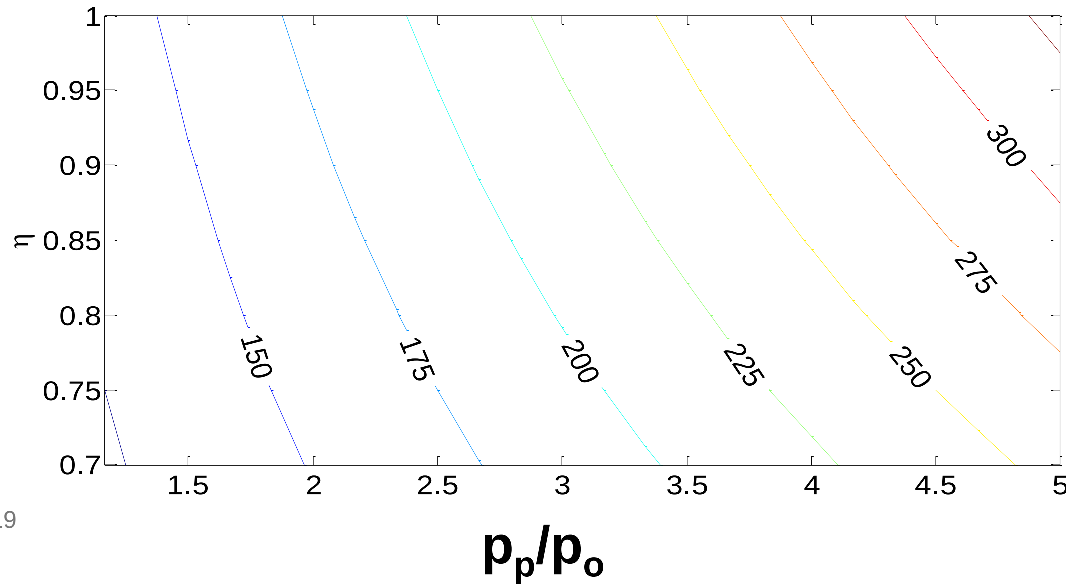
Key Outcomes

- **Energy** low value, thus cost targets must be unrealistically low (>\$100/kWh)
- currently incr. capital cost \$300-\$1000/kWh
- **Capacity** value must be utilized for 4-8 h storage to be economically viable

Cost Targets to Justify Storage for Energy Arbitrage?



Cost target based on
- **Energy** value only



Cost target based on
- **Energy** value and
- **Capacity** value of $150/kW-yr

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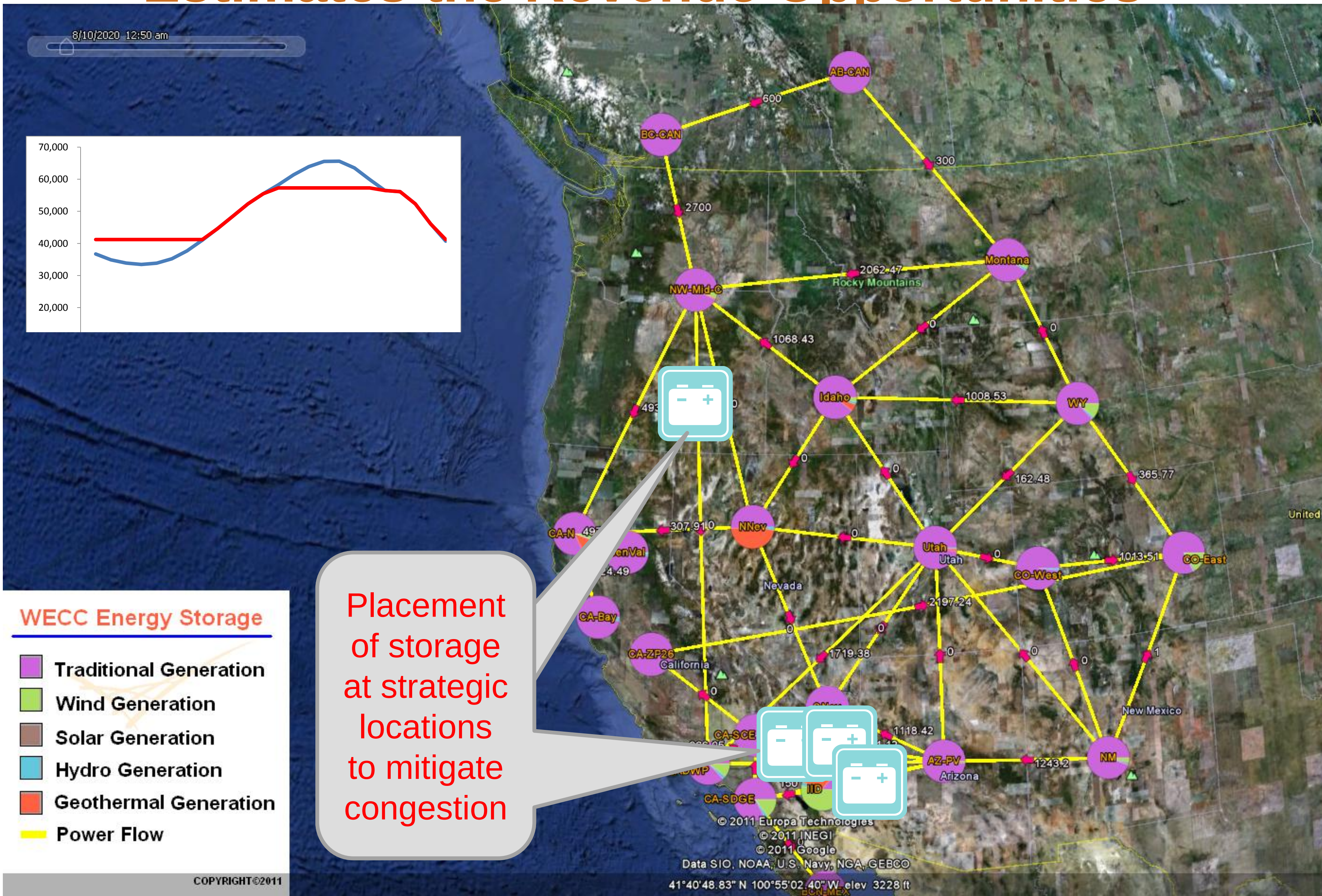
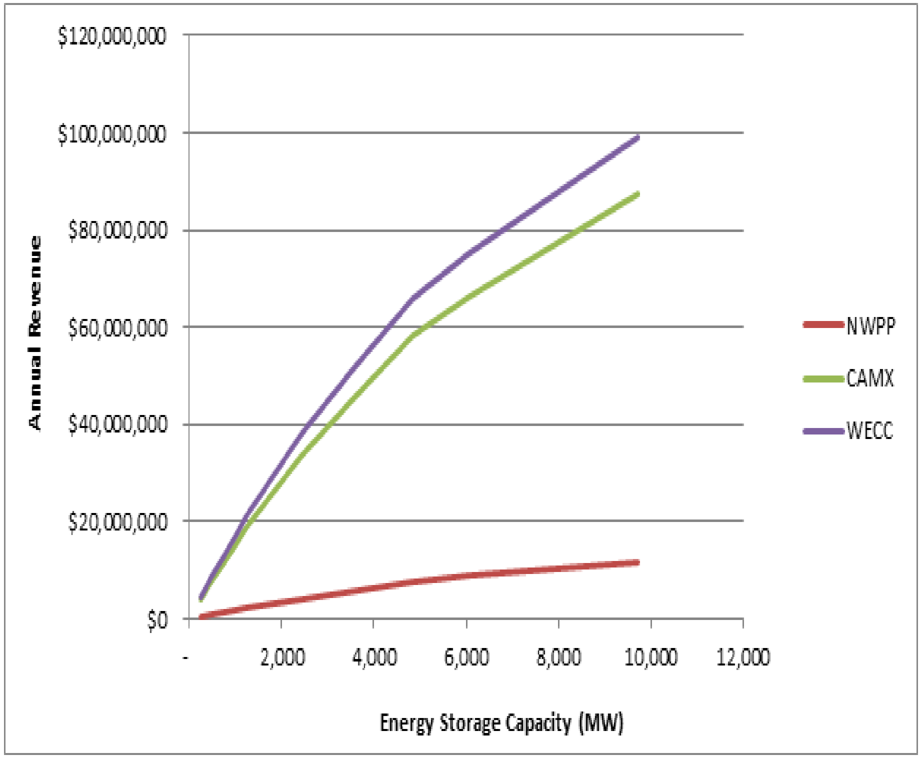
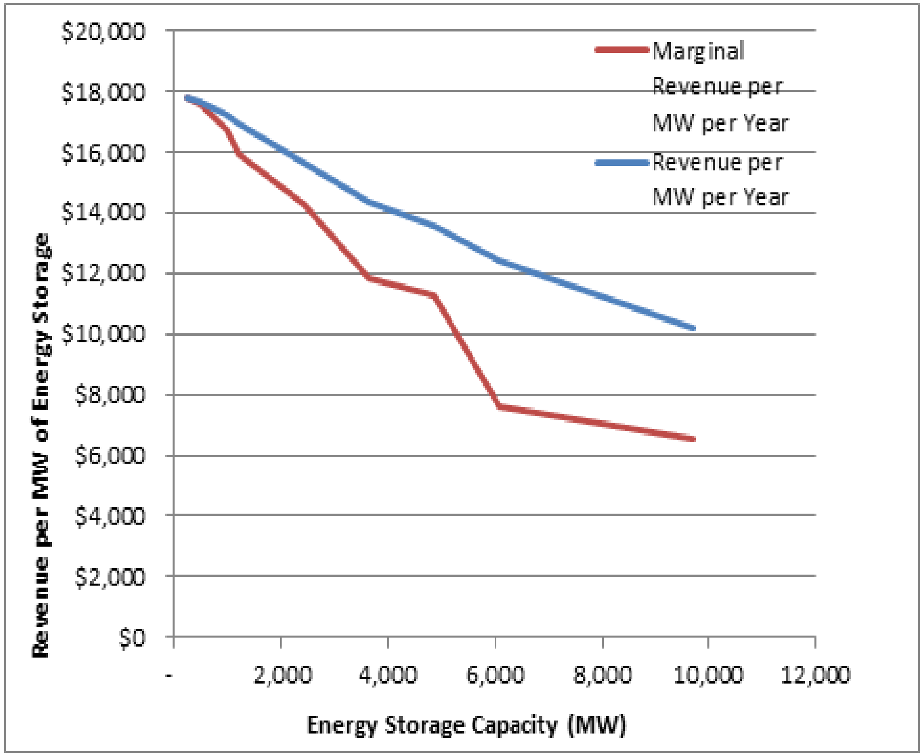
Detailed Production Cost Modeling Estimates the Revenue Opportunities



Revenue Expectations from Energy Arbitrage





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**

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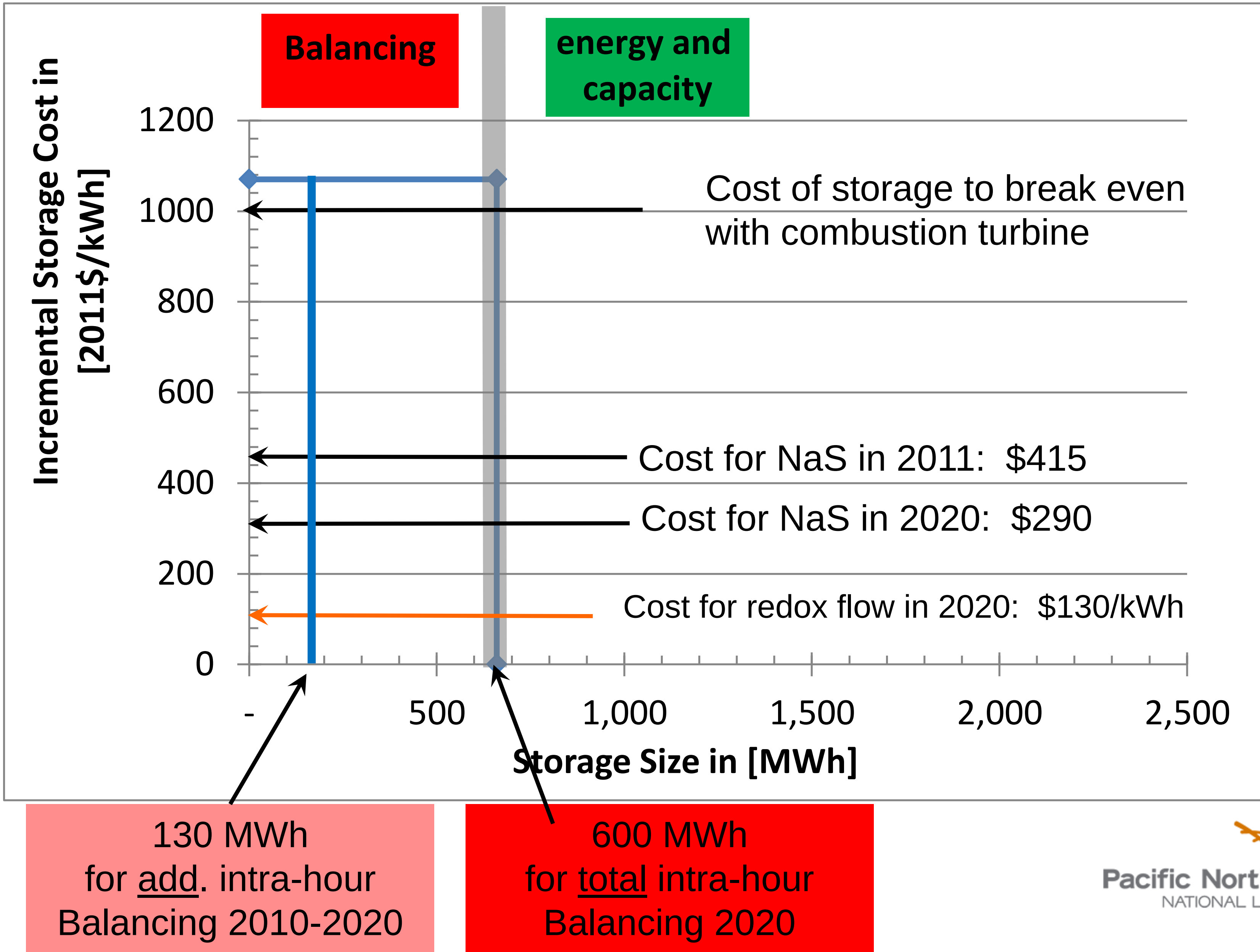
Market Potential for Storage in NWPP



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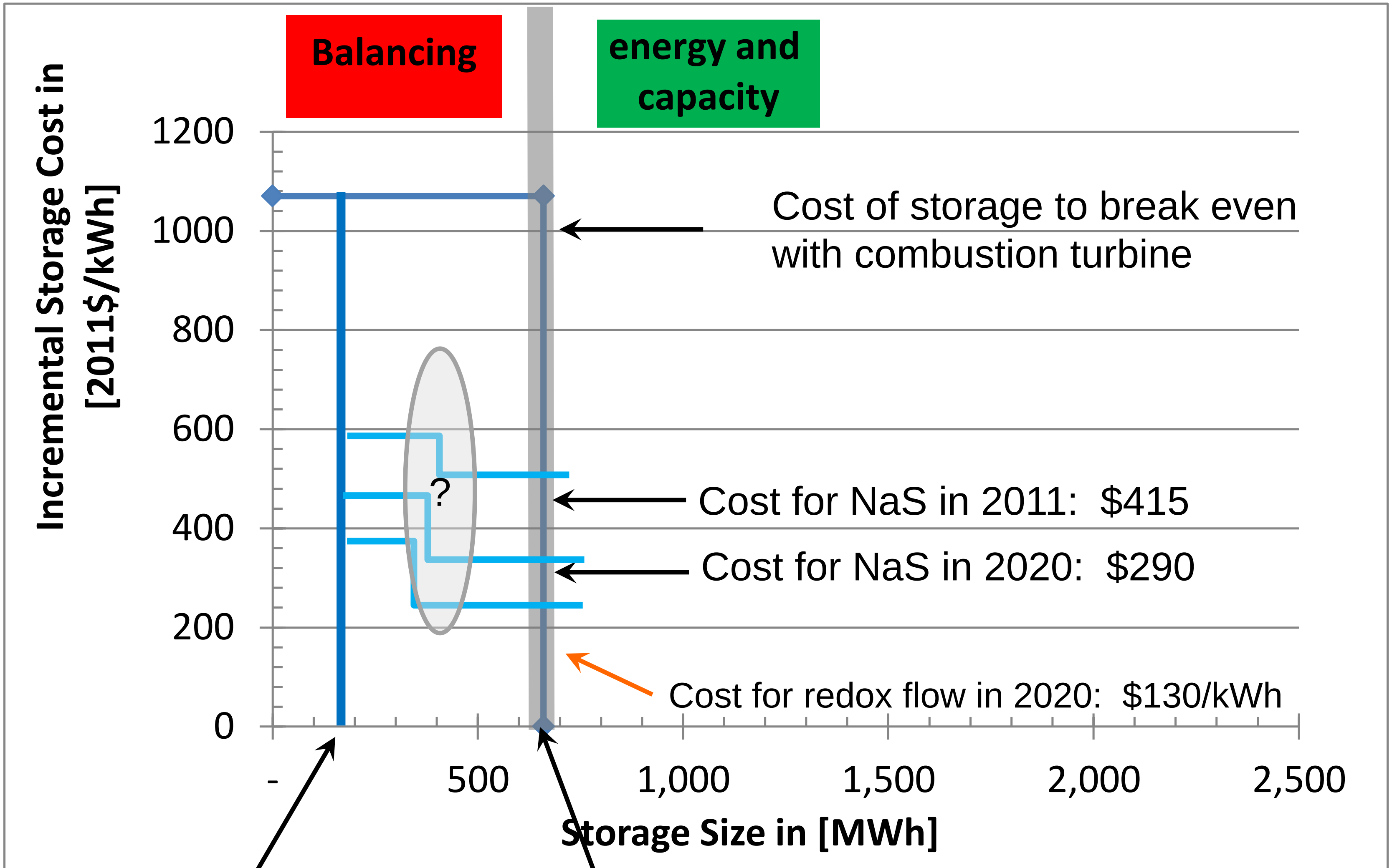
Market Potential for Storage in NWPP



130 MWh
for add. intra-hour
Balancing 2010-2020

600 MWh
for total intra-hour
Balancing 2020

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