PUMPED HYDRO ENERGY STORAGE

Energetics, Renewable Integration, and Technical Potential

Journal Article: Energetic implications of curtailing versus storing solar- and wind-generated electricity http://ow.ly/otnvG

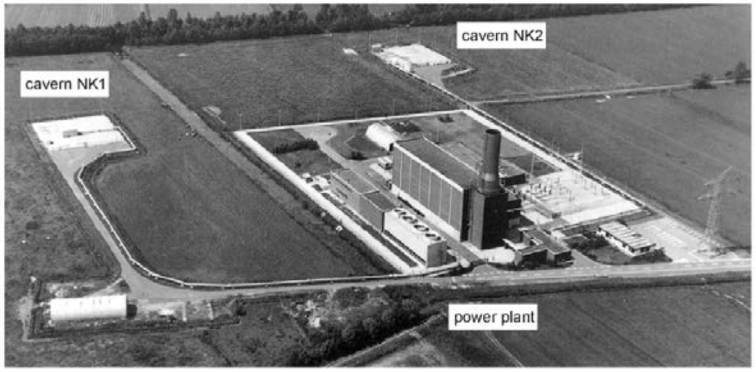
GCEP
Global Climate & Energy Project
STANFORD UNIVERSITY

Charles Barnhart and Sally Benson
Mik Dale, Adam Brandt

Grid-Scale Storage Technologies

- safe
- inexpensive
- made from abundant materials
- high cycle-life
- high round-trip efficiency

- Lead Acid (PbA)
- Sodium Sulfur (NaS)
- Flow (ZnBr, VRB)
- Compressed air energy storage (CAES)
- Pumped hydroelectric storage (PHS)



Energy Stored on Invested

$$ESOI = \frac{\eta D \lambda}{CTG}$$

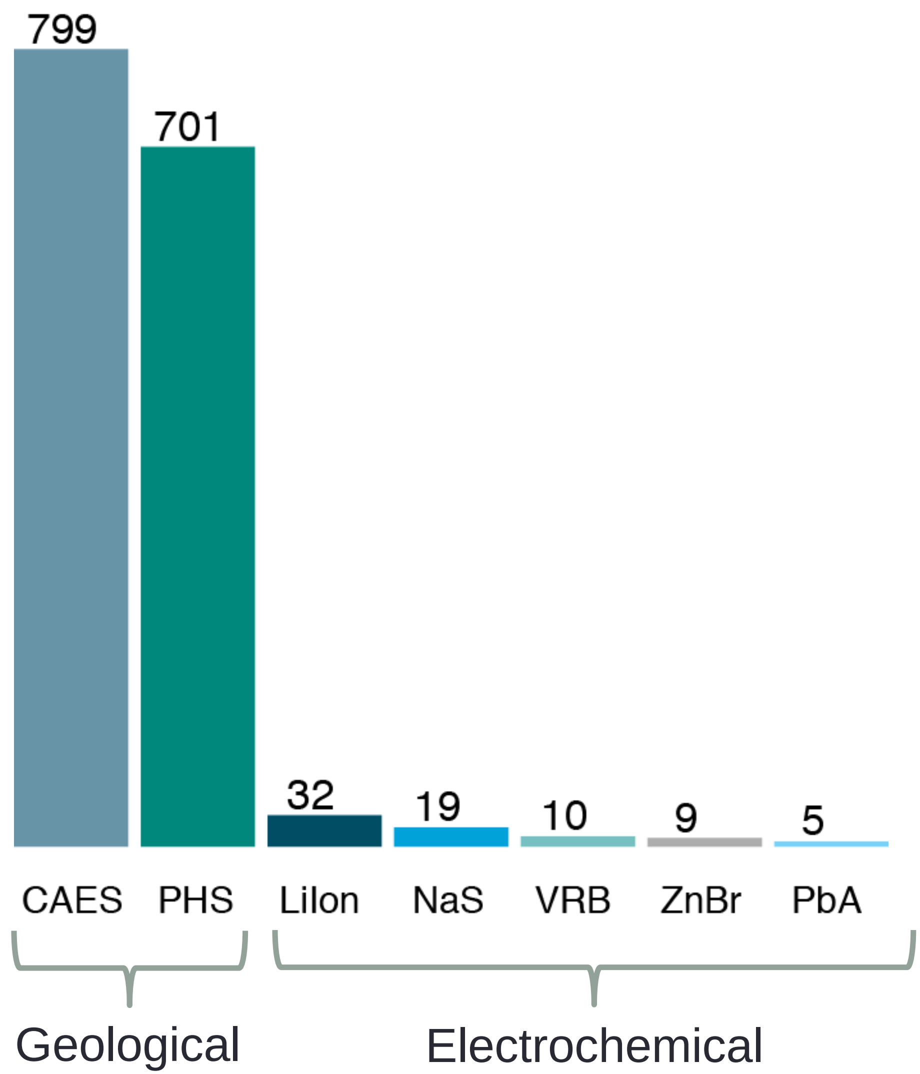
where

$\eta = efficiency$

$D = depth\ of\ discharge$

$\lambda = cycle\ life$

$$CTG = \frac{Cradle\ to\ gate\ embodied\ energy(MJ)}{Storage\ capacity(MJ)}$$



Improving ESOI values—Cycle Life

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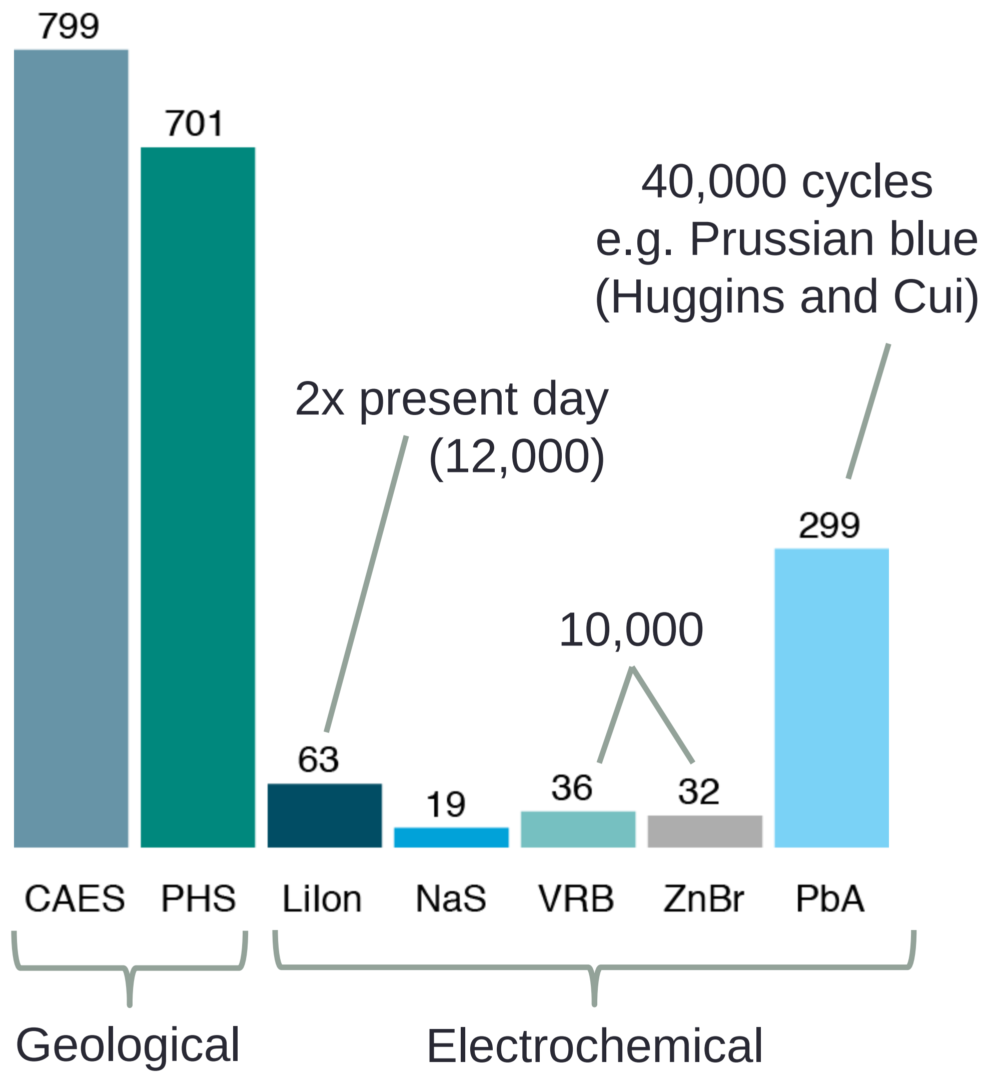


Return on Investment

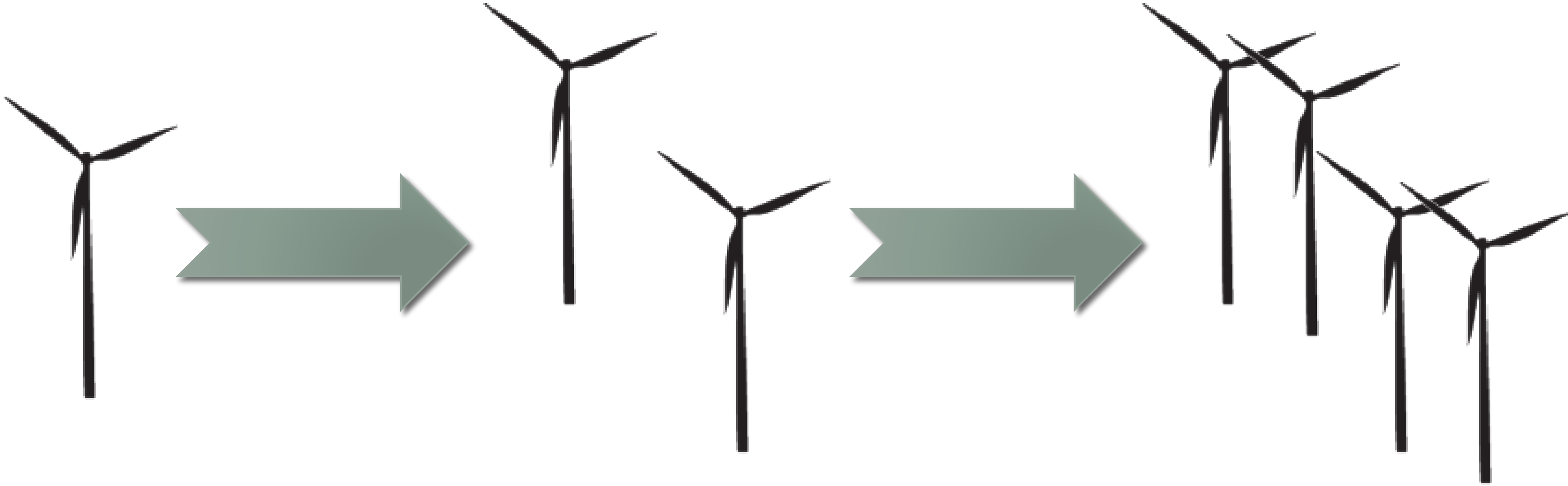
- You have to invest money to make money
- To be profitable you need to make more money than you invest.
- Investments with high rates of return are better than investments with lower rates of return.
- Investments that are more profitable and have shorter breakeven times are easier to grow quickly.

How do these ideas apply to energy systems?

Macroenergetics

- It takes energy to make, operate and decommission the devices and systems needed to produce energy.
- For a device or system to be useful to the global energy system:

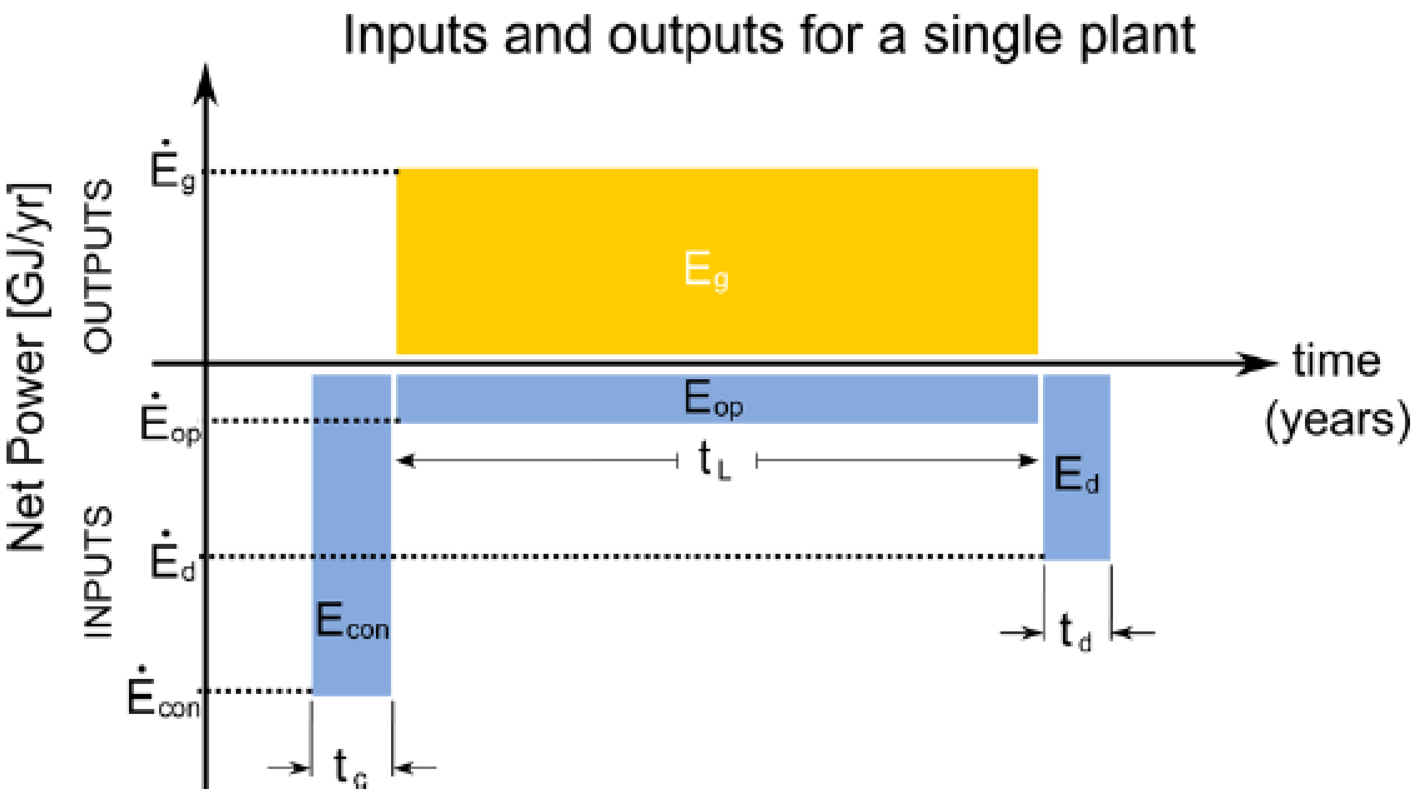
Energy Output > Total Energy Inputs



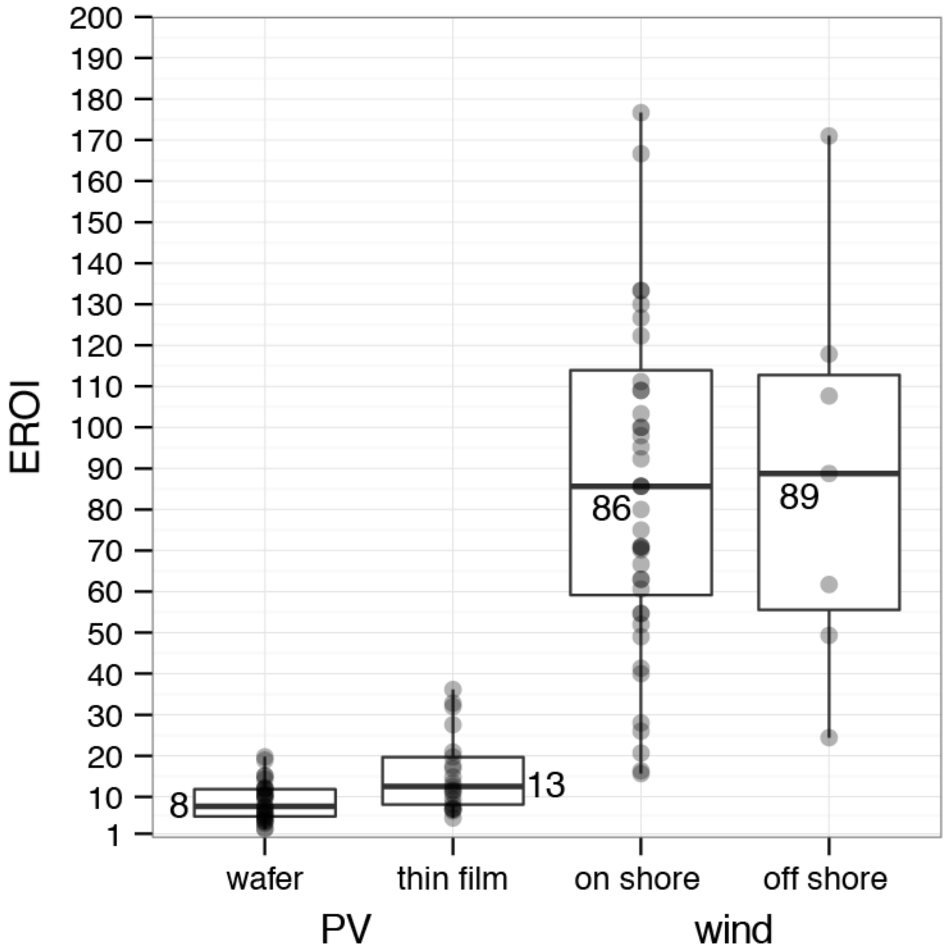
Macroenergetic performance of renewables paired with storage

Energy Return on Energy Investment

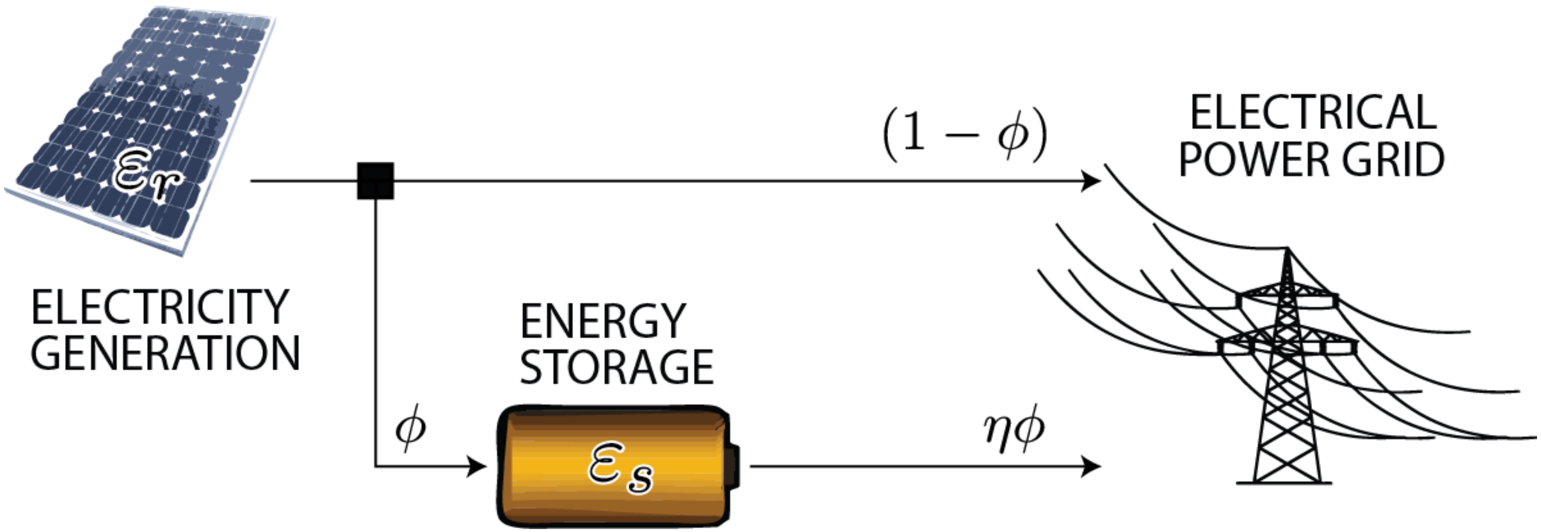
EROI: the sum of the energy outputs compared to the cumulative energy demand (not including primary energy)



Solar PV and Wind Turbine EROI



Embodied Energy and Energy Flows



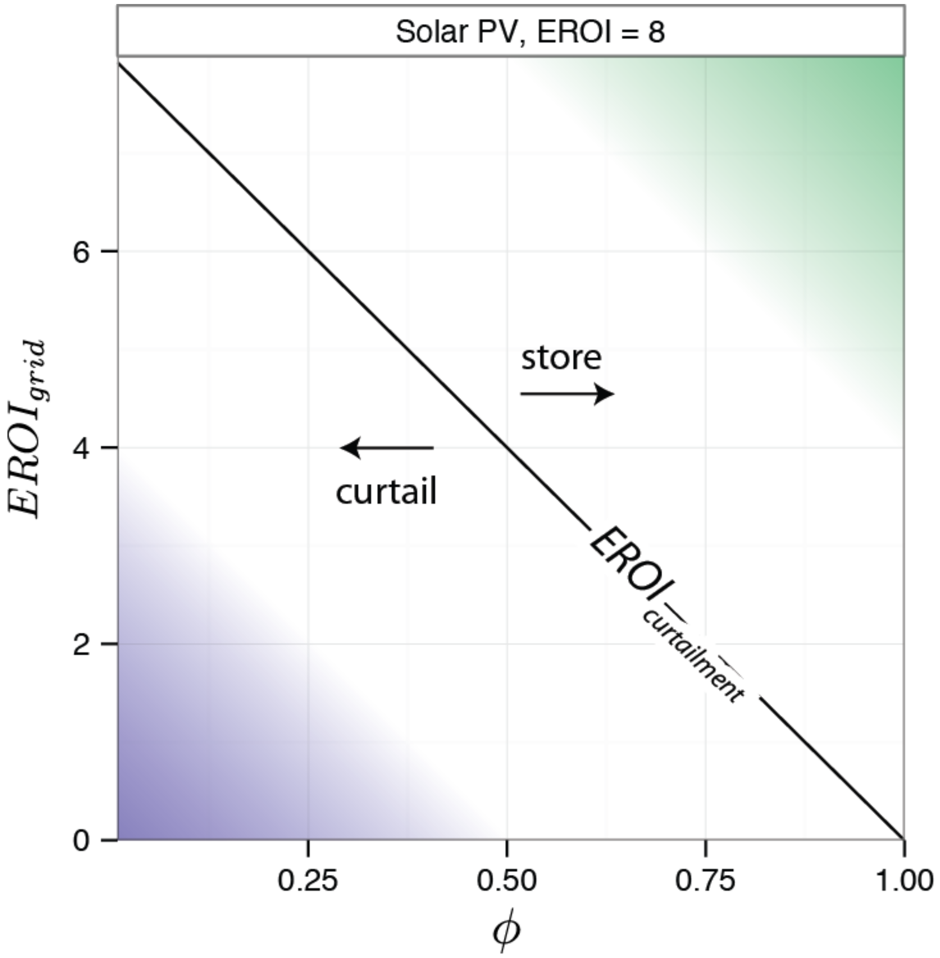
Curtailment of Wind Resources

	2010	2011	2012
ERCOT (Texas)	7.7%	8.5%	3.7%
BPA (Oregon)	0.1%	1.4%	0.7%

Wiser et al., 2013, LBL

Boyd, Oregonian, 2013

Stored Renewable EROI ratios



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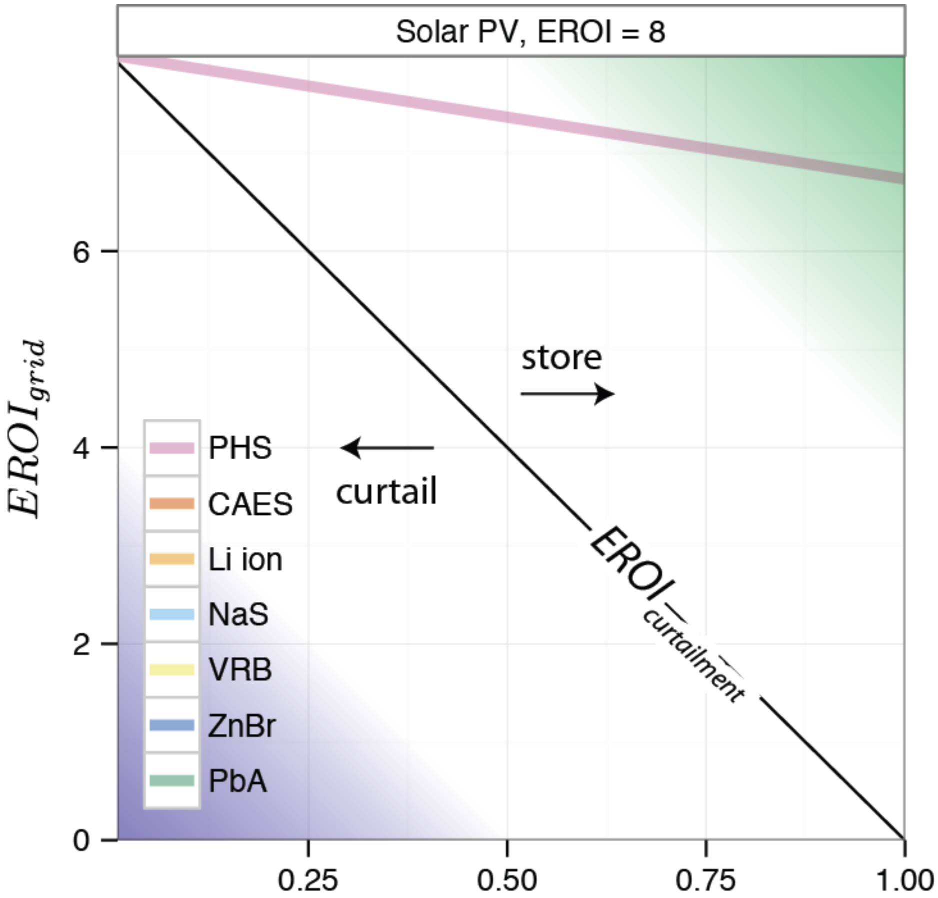

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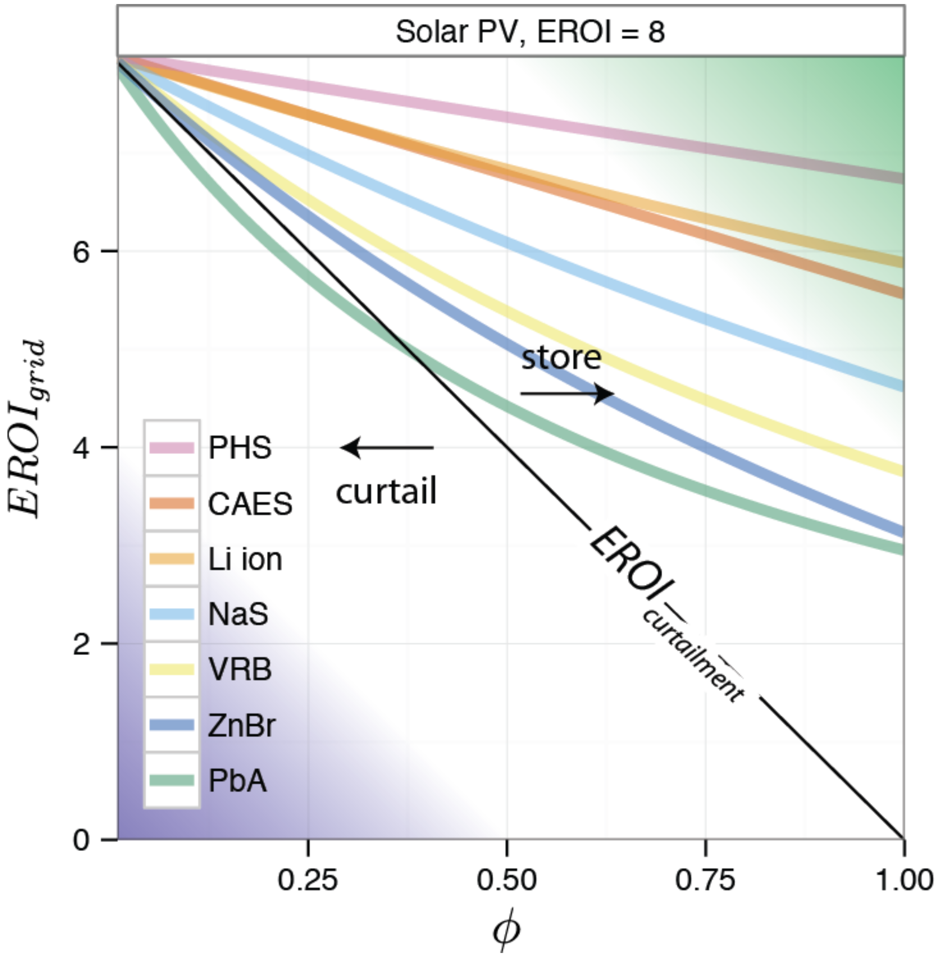

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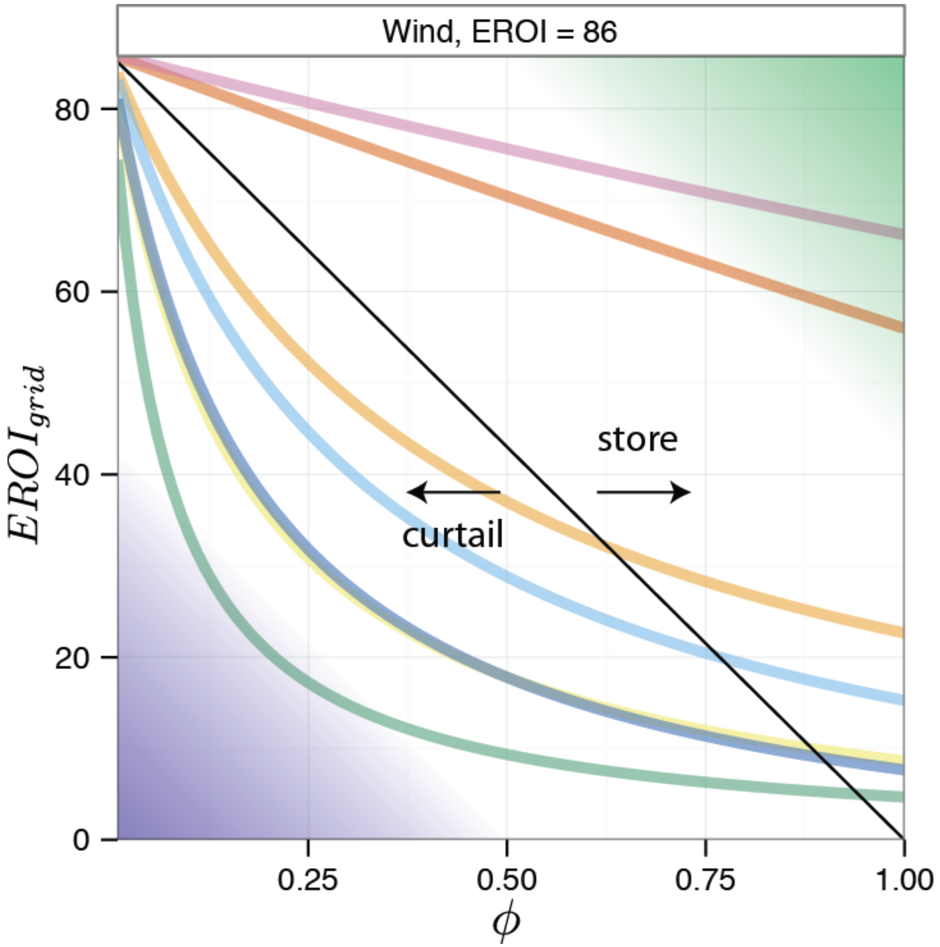
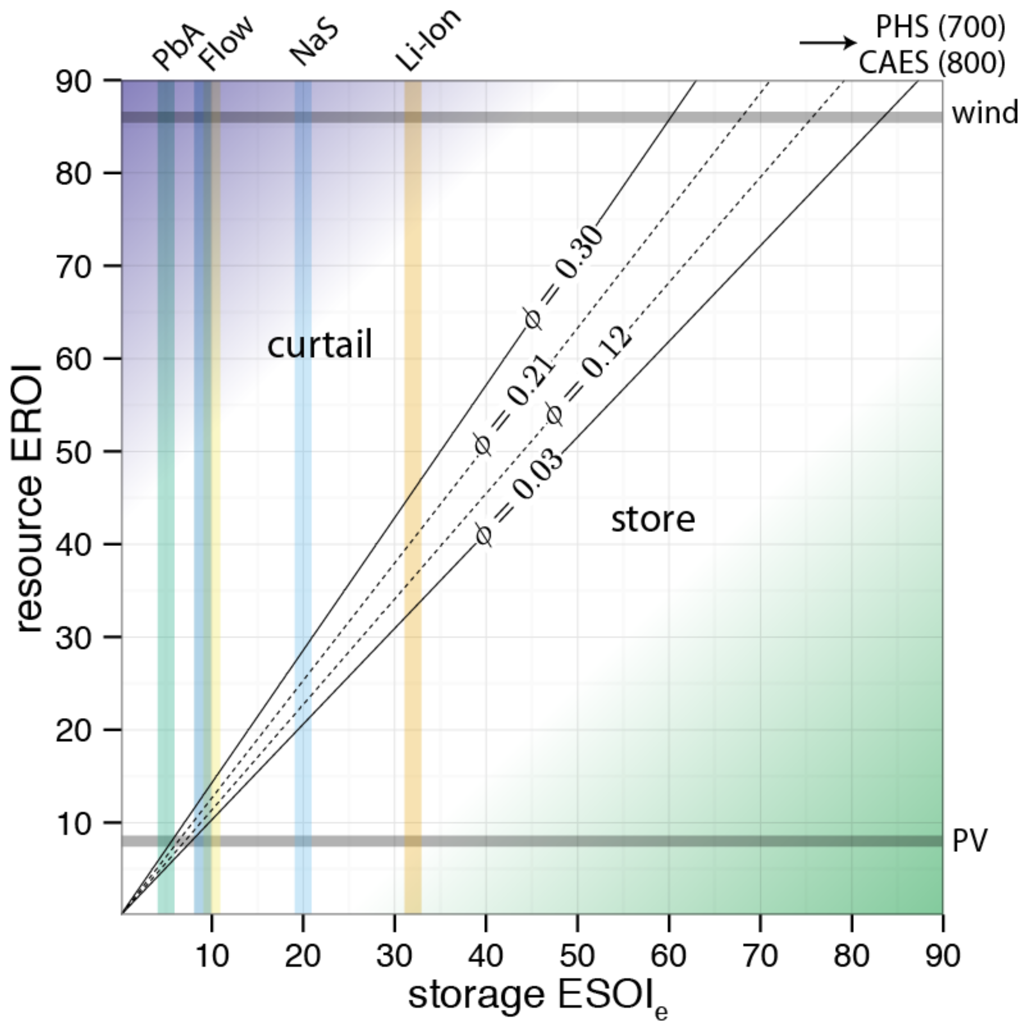


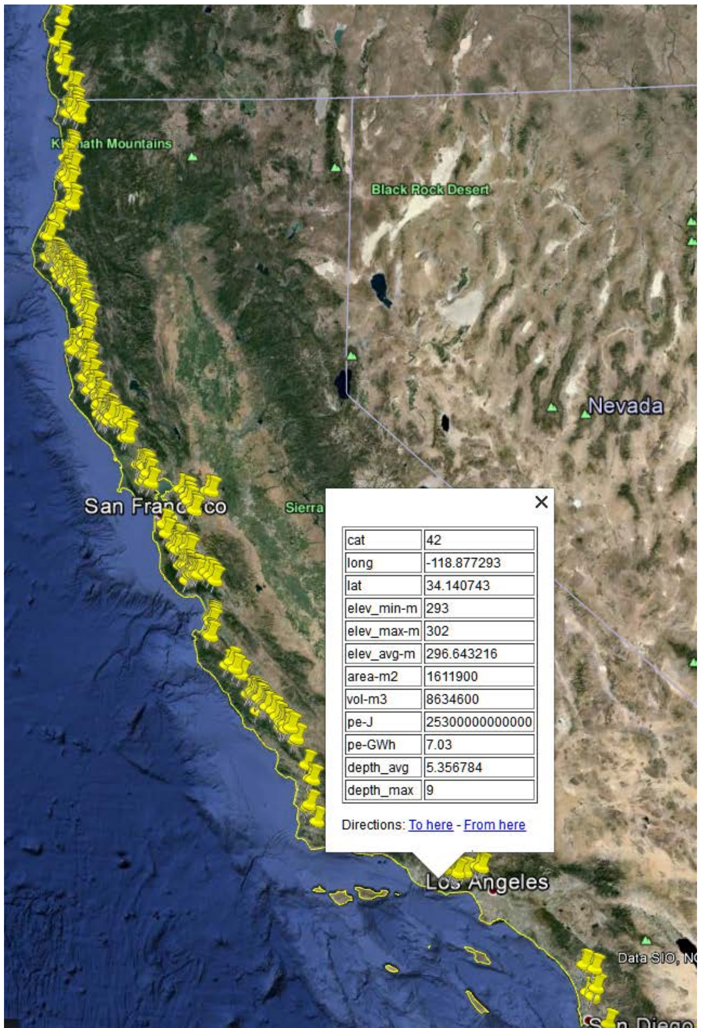
To Store or Curtail?

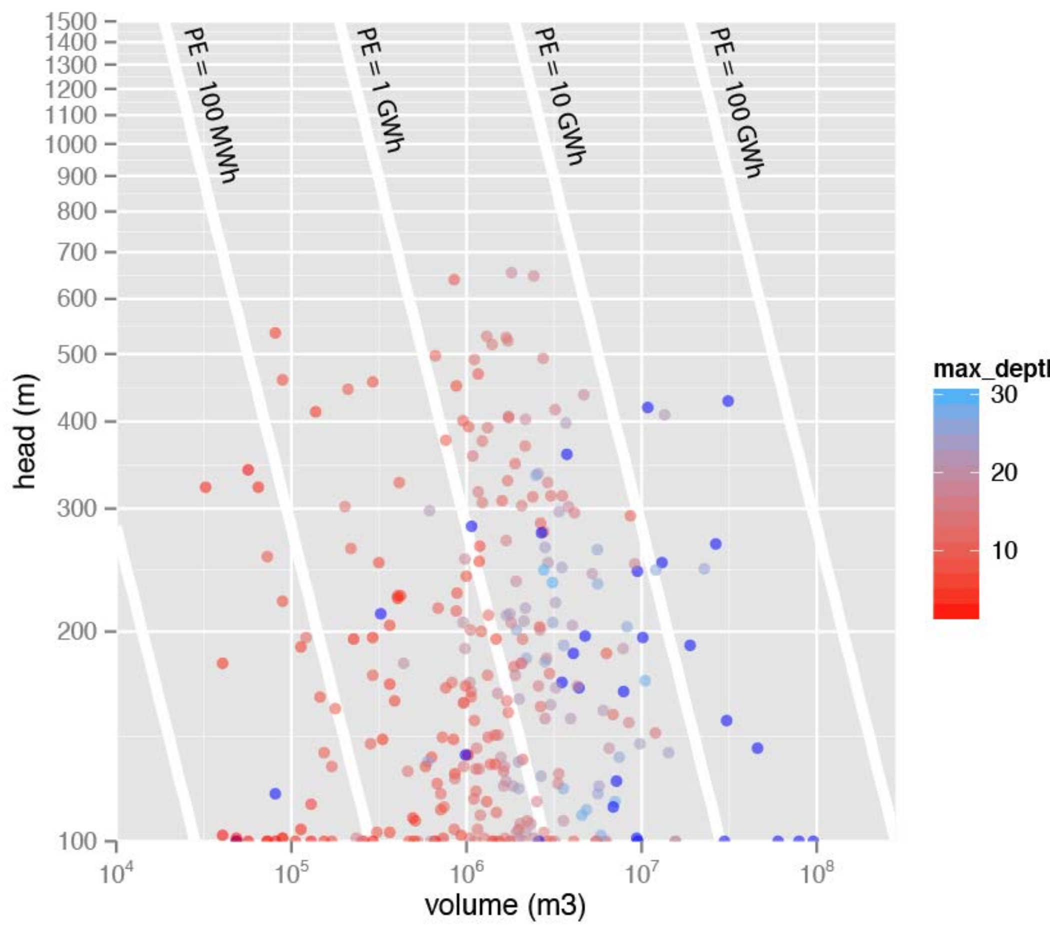


Geological Limits on PHS

Okinawa Yanbaru Seawater PHS, 30 MW, 235 MWh

Coastal PHS technical potential





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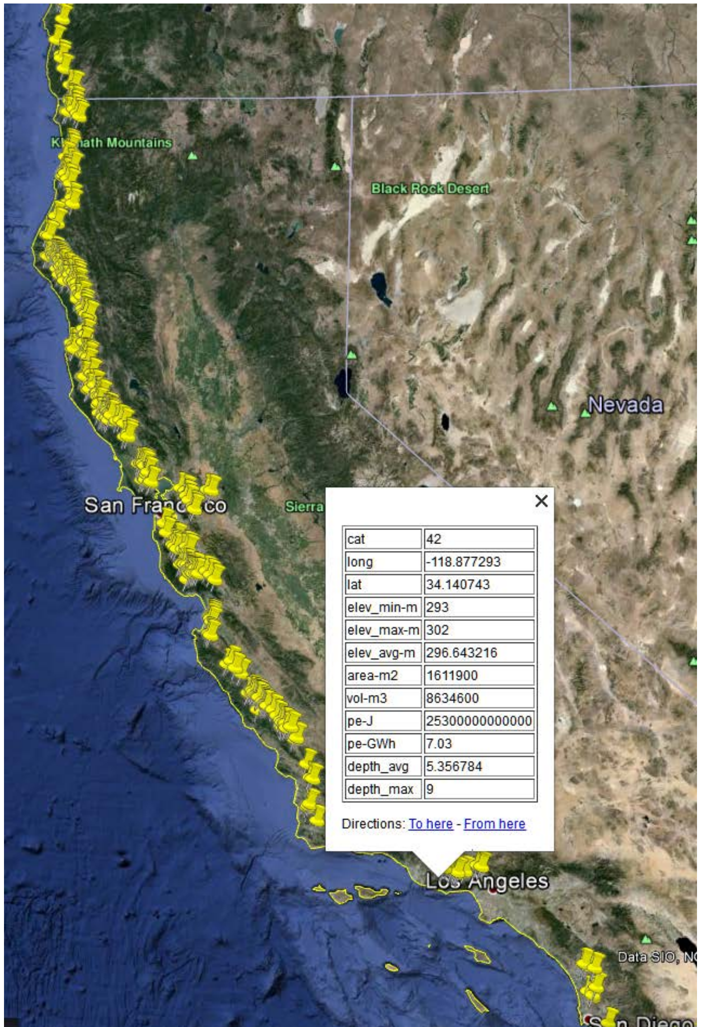
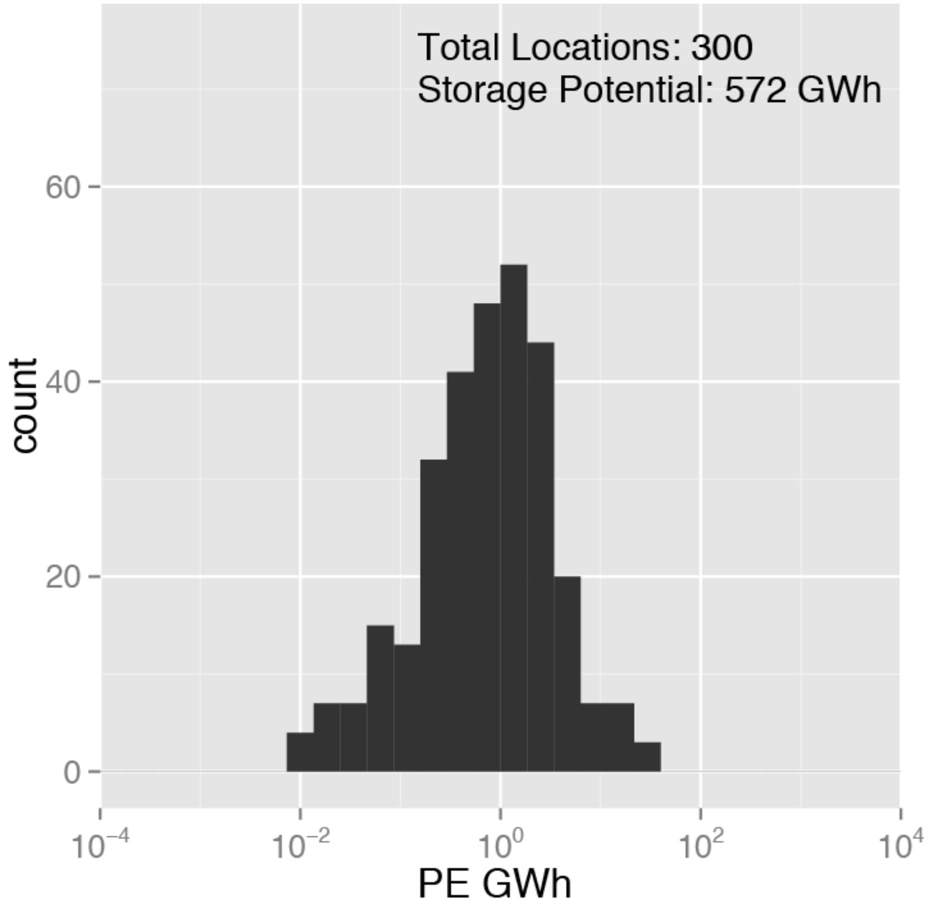




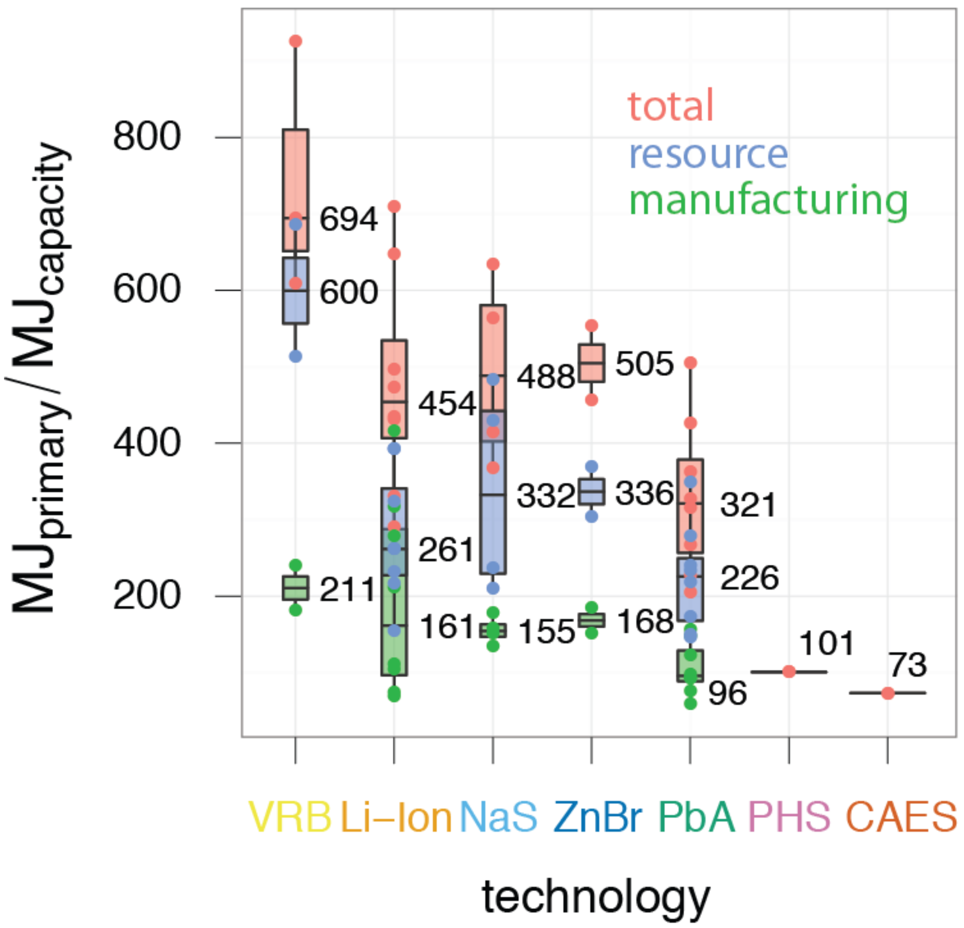
California electricity consumption: 630 GWh/day

Conclusions and Recommendations

- Macroenergetic analysis provides a unique and important perspective on the sustainability of energy choices
- Battery storage is energetically expensive
- PHS stores renewable energy at net energy benefit to society
- The technical potential for PHS is comparable to daily electricity consumption.



Cradle to Gate Energy Costs



Improving ESOI values—efficiency

$$ESOI = \frac{\eta D \lambda}{CTG}$$

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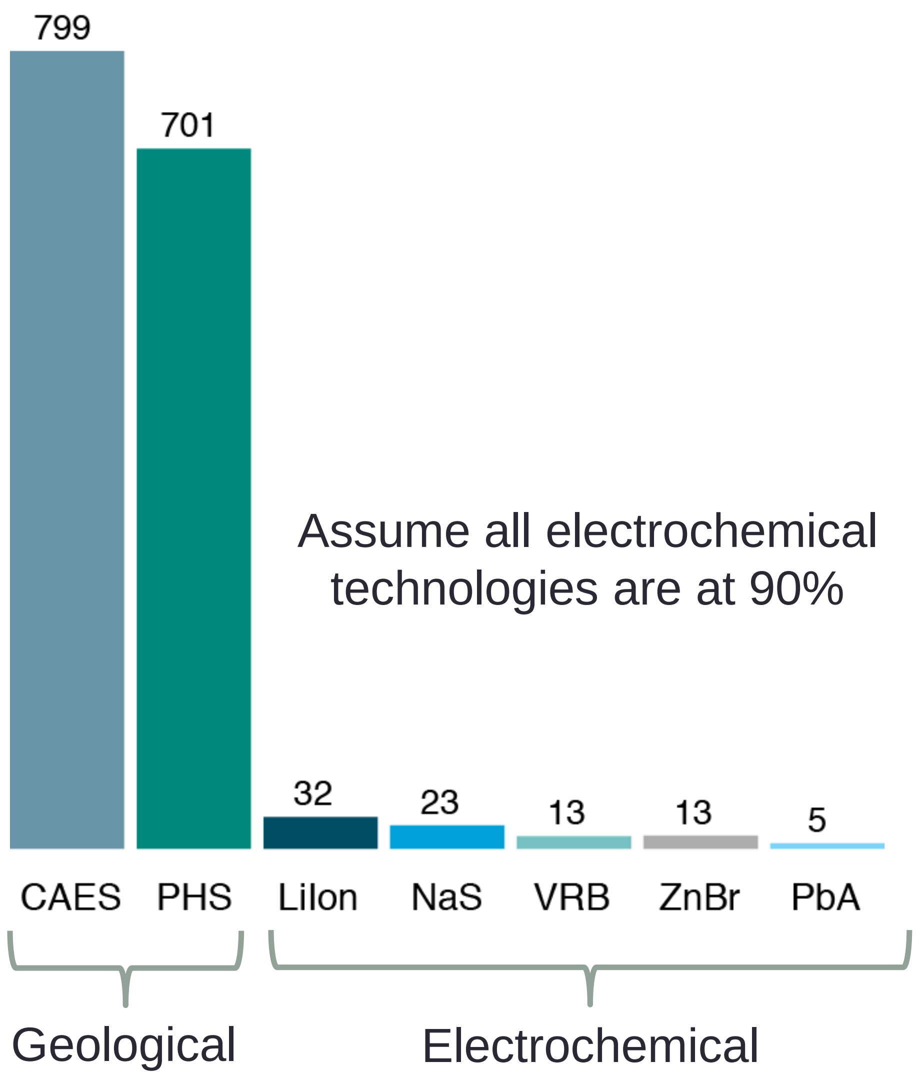

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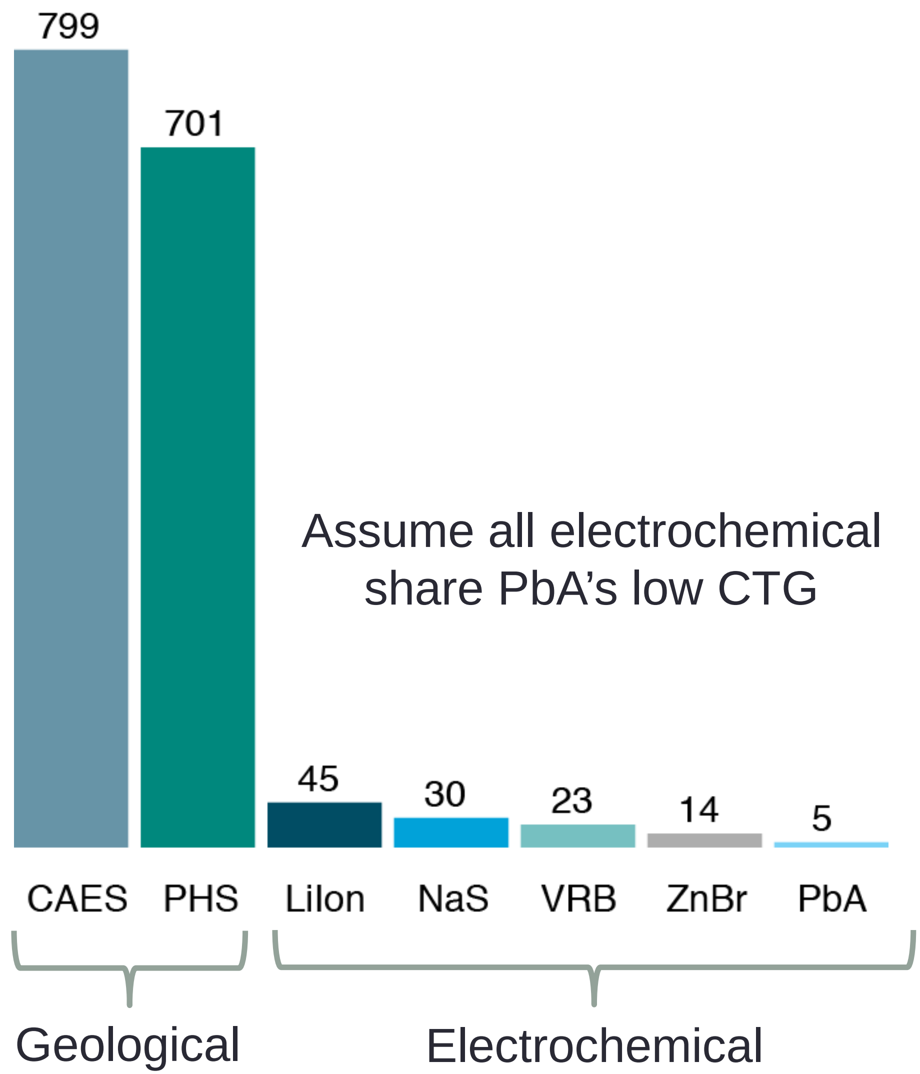
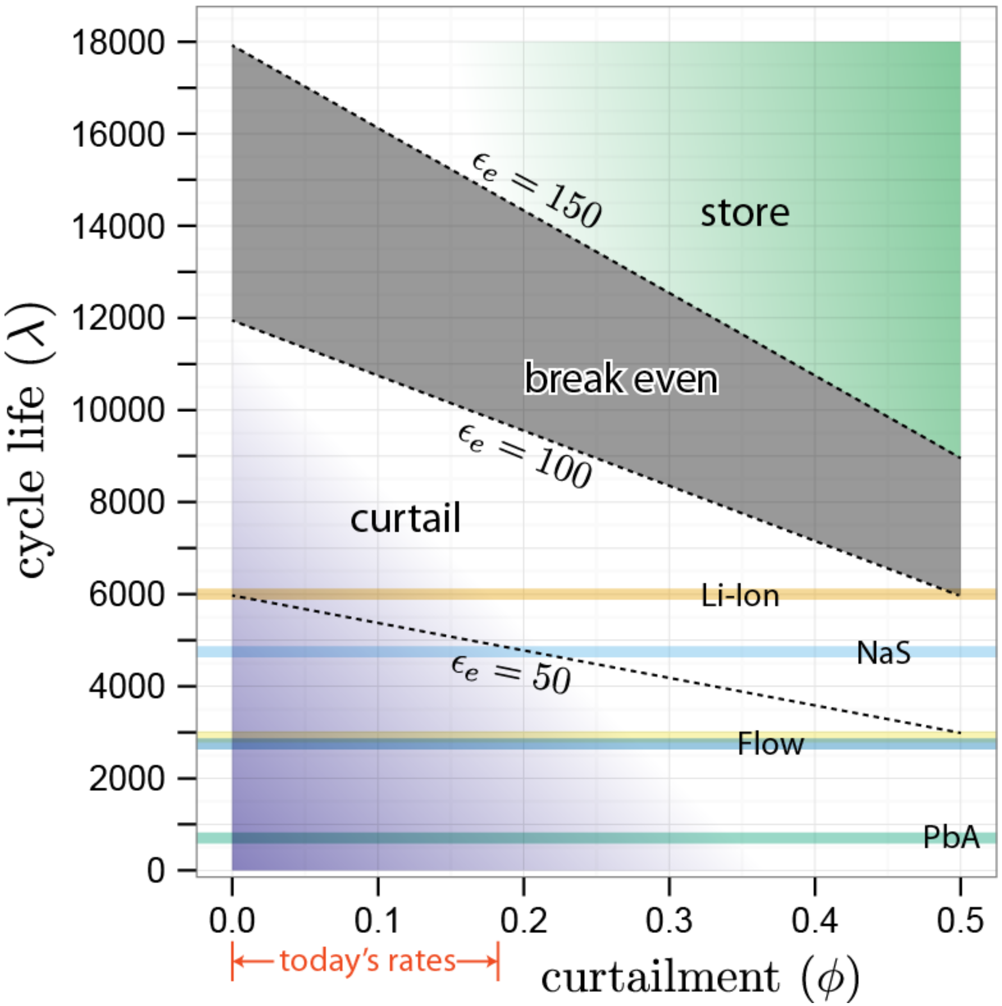


Cycle Life Goals

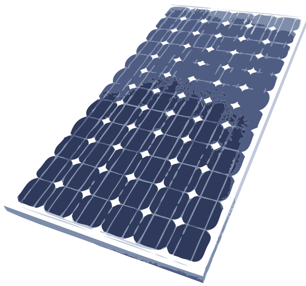
$$\frac{ESOI_e}{EROI} \Rightarrow \begin{cases} \text{store if } > 1-\phi \\ \text{curtail if } < 1-\phi \end{cases}$$

$$ESOI = \frac{\lambda \eta D}{\epsilon_e}$$

$$\lambda > (1-\phi) EROI \frac{\epsilon_e}{\eta D}$$

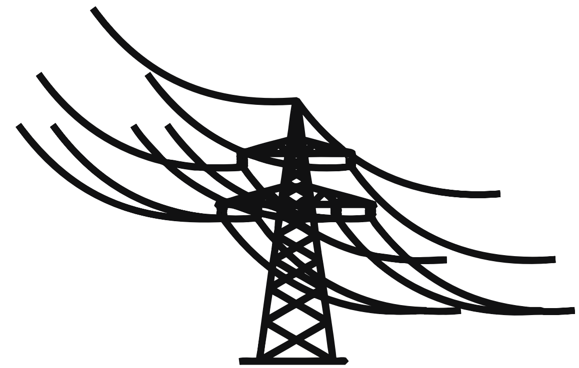


Theoretical Framework



ELECTRICITY

RAGE



$$EROI_c = EROI(1-\phi)$$

$$EROI_g = \frac{1-\phi+\eta\phi}{\frac{1}{EROI}+\frac{\eta\phi}{ESOI_e}} \quad \left[\frac{kWh_e \ \text{generated}}{kWh_e \ \text{embodied}}\right]$$

A trade off between cycle life and efficiency

$$ESOI_e > (1-\phi)EROI_R$$

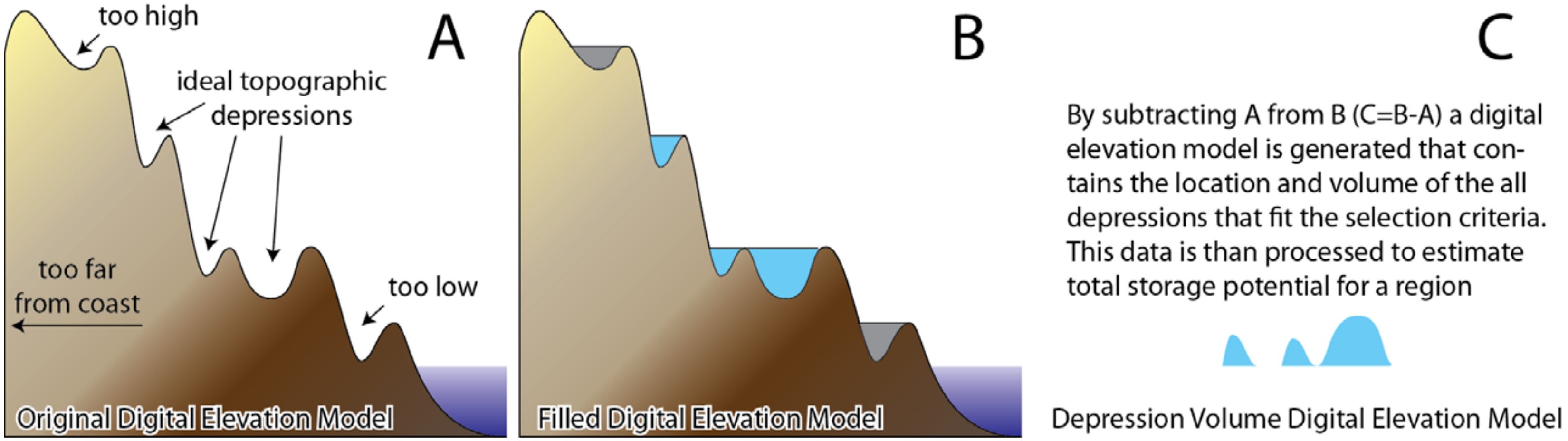
EROI_wind = 86

Tech	η	λ	DOD	CTG_e	ESOI_e	Min ESOI Φ=0.5	Minimum λ
Li-Ion	0.9	6000	0.8	136	32	81.7	15432
NaS	0.75	4750	0.8	146	20	81.7	19880
PbA	0.9	700	0.8	96	5	81.7	10893
VRB	0.75	2900	1	208	10	81.7	22658
ZnBr	0.6	2750	0.8	151	9	81.7	25701
CAES	0.7	25000	1	22	797	81.7	2568
PHS	0.85	25000	1	30	704	81.7	2884

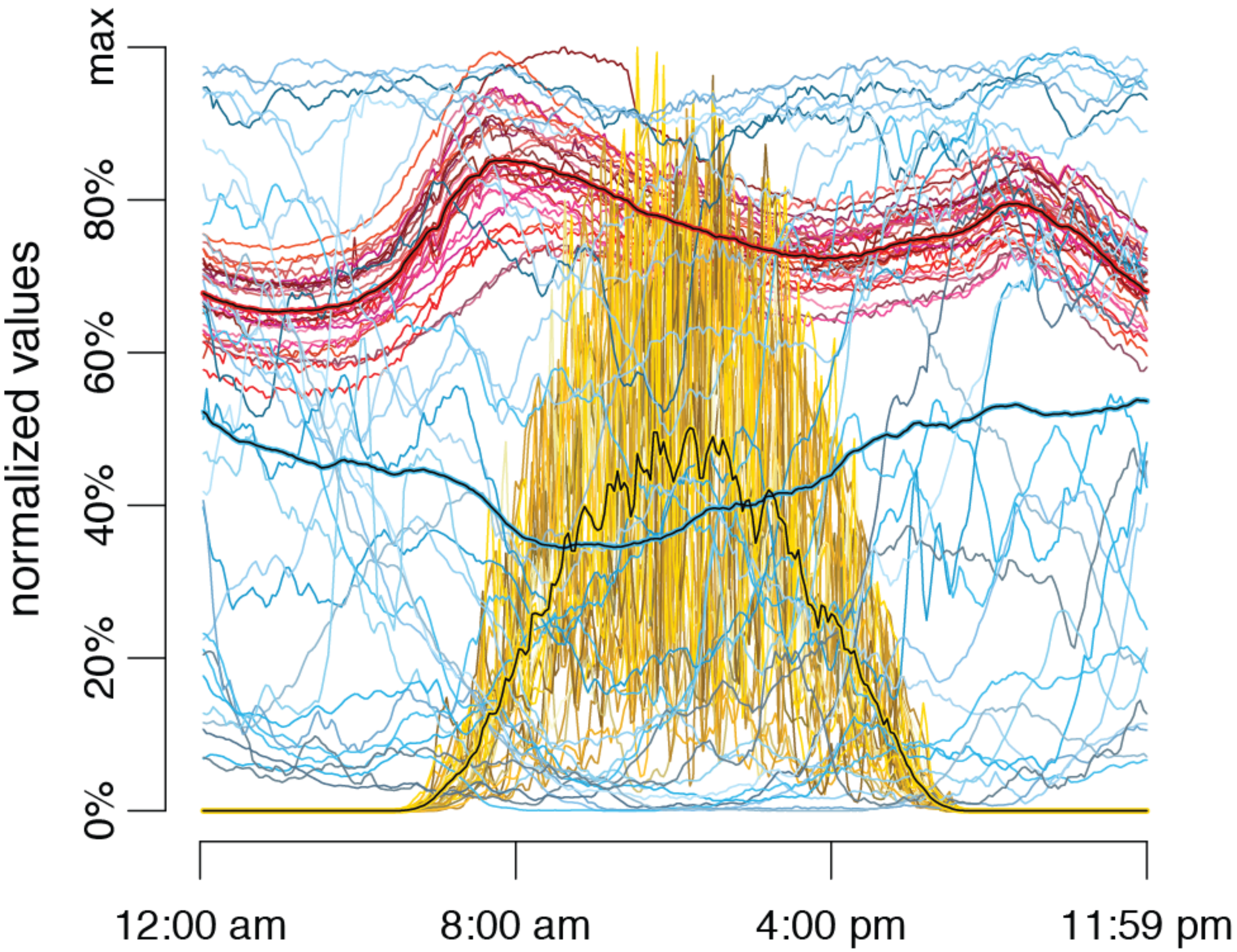
$$ESOI = \frac{\lambda \eta D}{\epsilon_e}$$

$$\lambda > (1-\phi)EROI\frac{\epsilon_e}{\eta D}$$

Topographic detection of PHS



Wind Turbines and Solar PV generate variable and intermittent power



Storage as the solution

"California adopts first-in-nation energy storage plan"

San Jose Mercury News October 17, 2013

"Storage really is the game changer in the electric industry. And while this new policy is not without risk, the potential rewards are enormous."

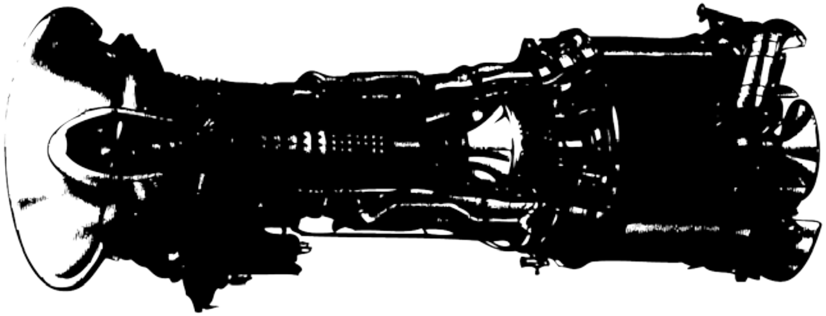
-Commissioner Mike Florio

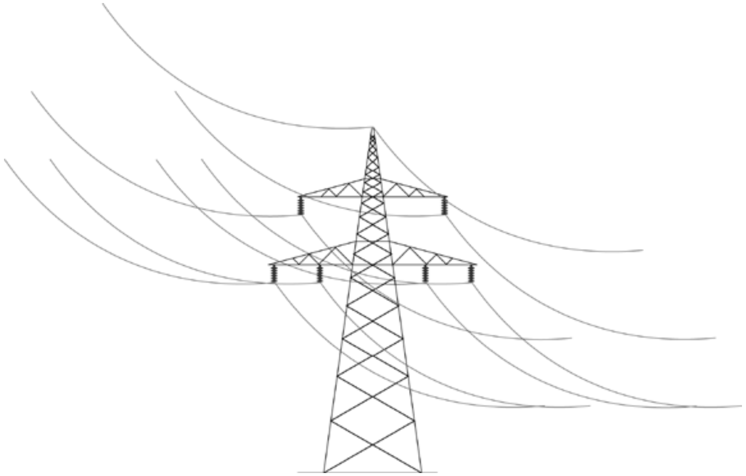
1.3 GW of Storage by 2020

***cf.* Helms Pumped Hydro 1.2 GW,**

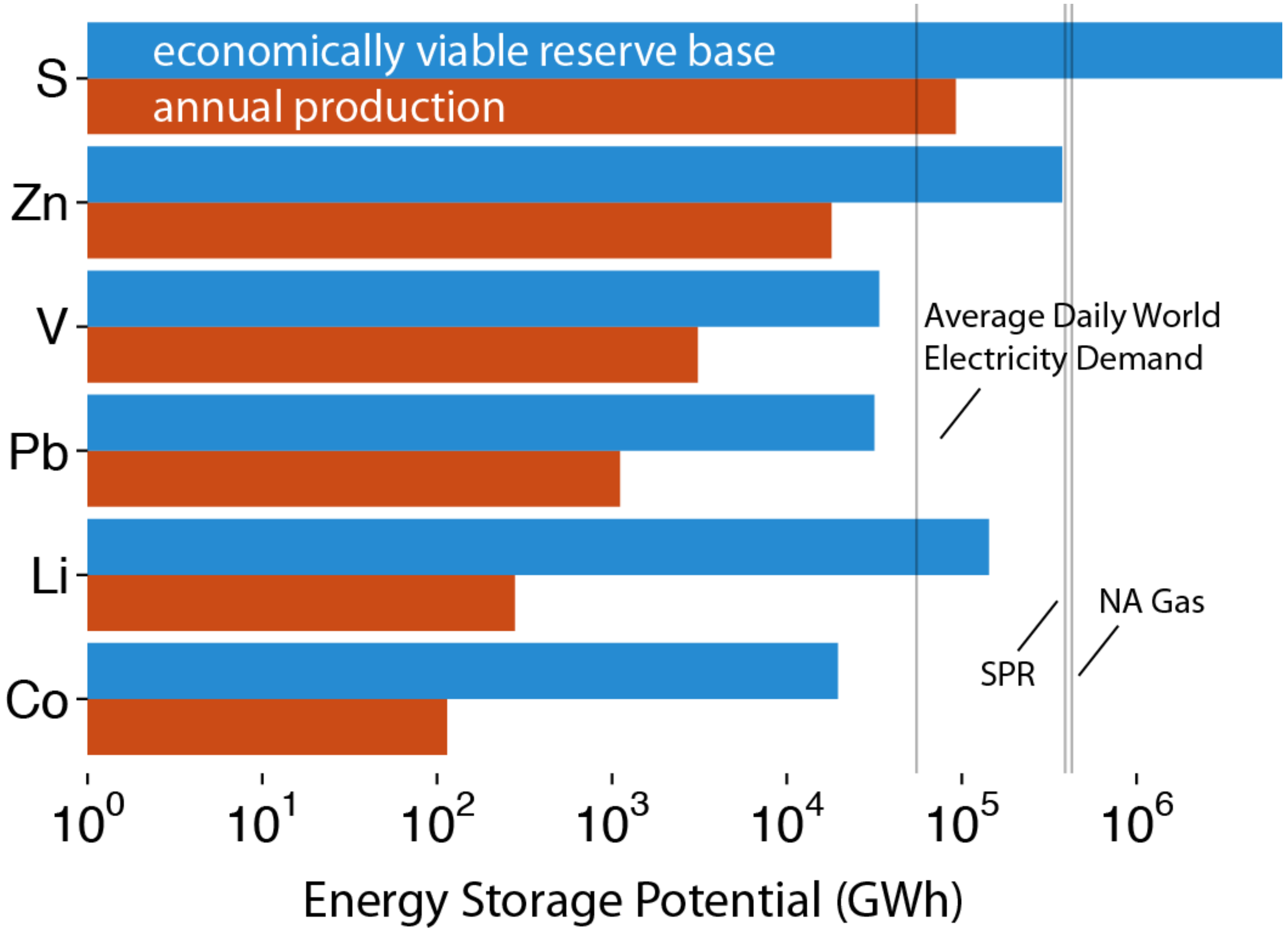
~200 GWh, Sierra Foothills, 1984

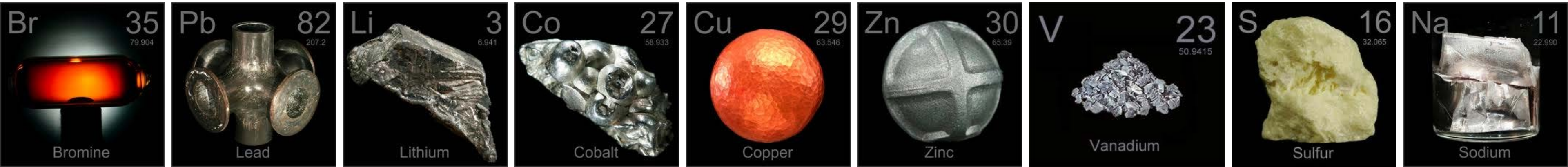
Other options for grid flexibility



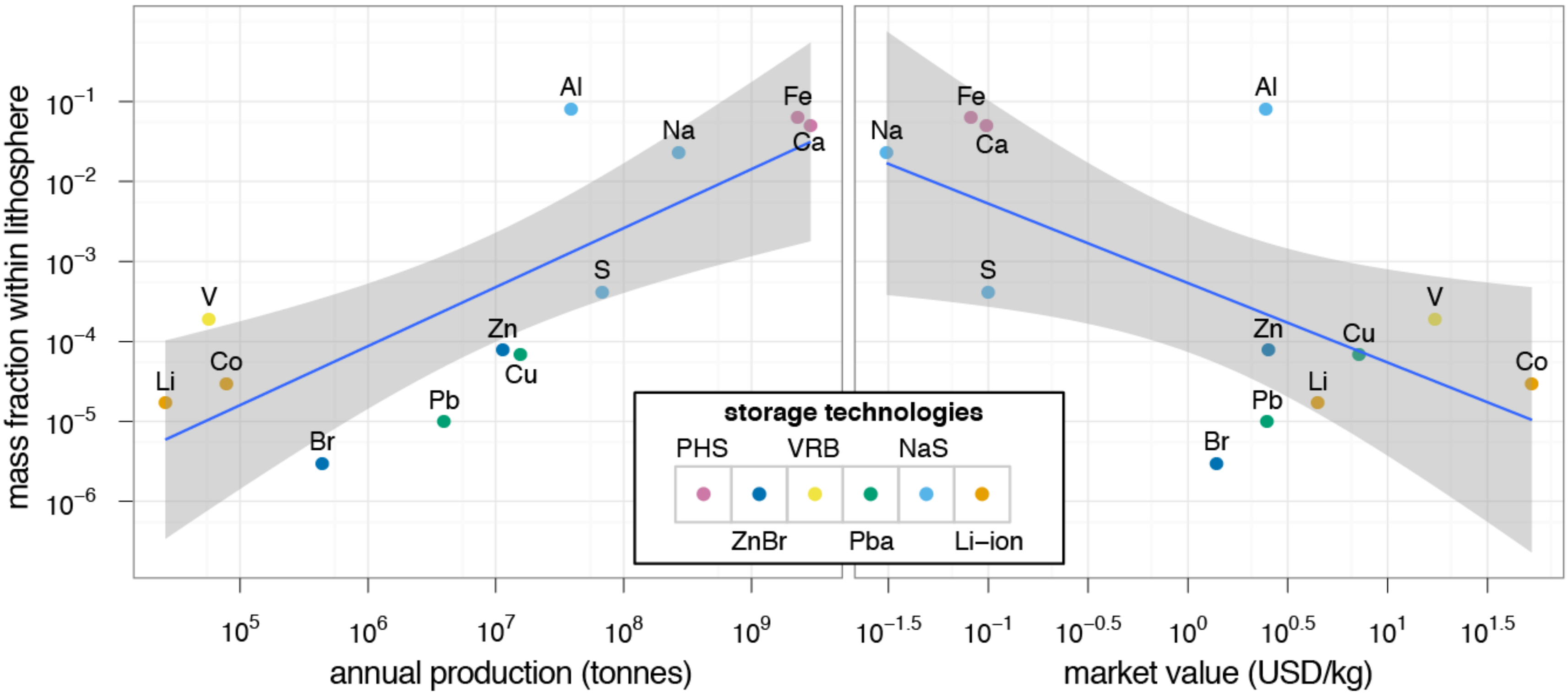


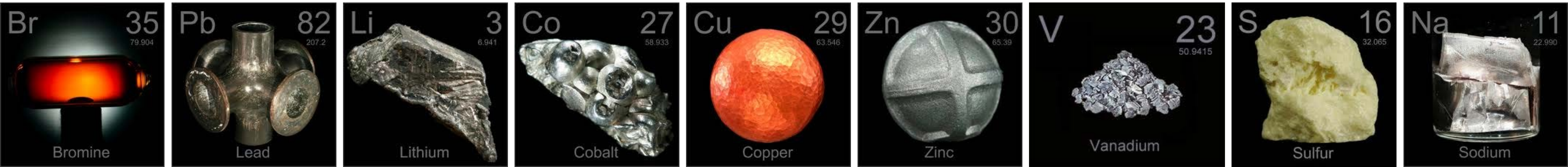
Energy Storage Potential of Materials



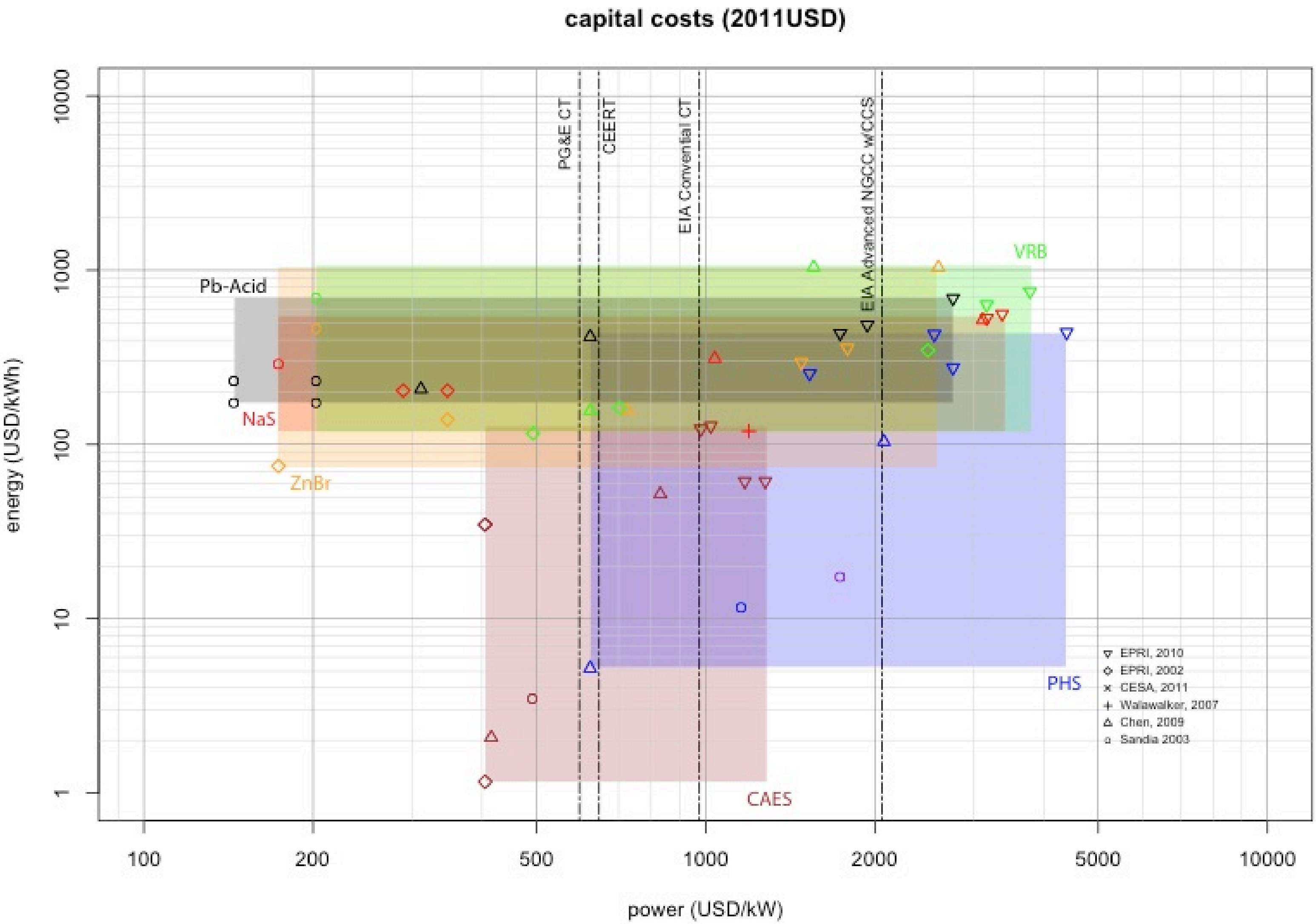


Materials for Energy Storage

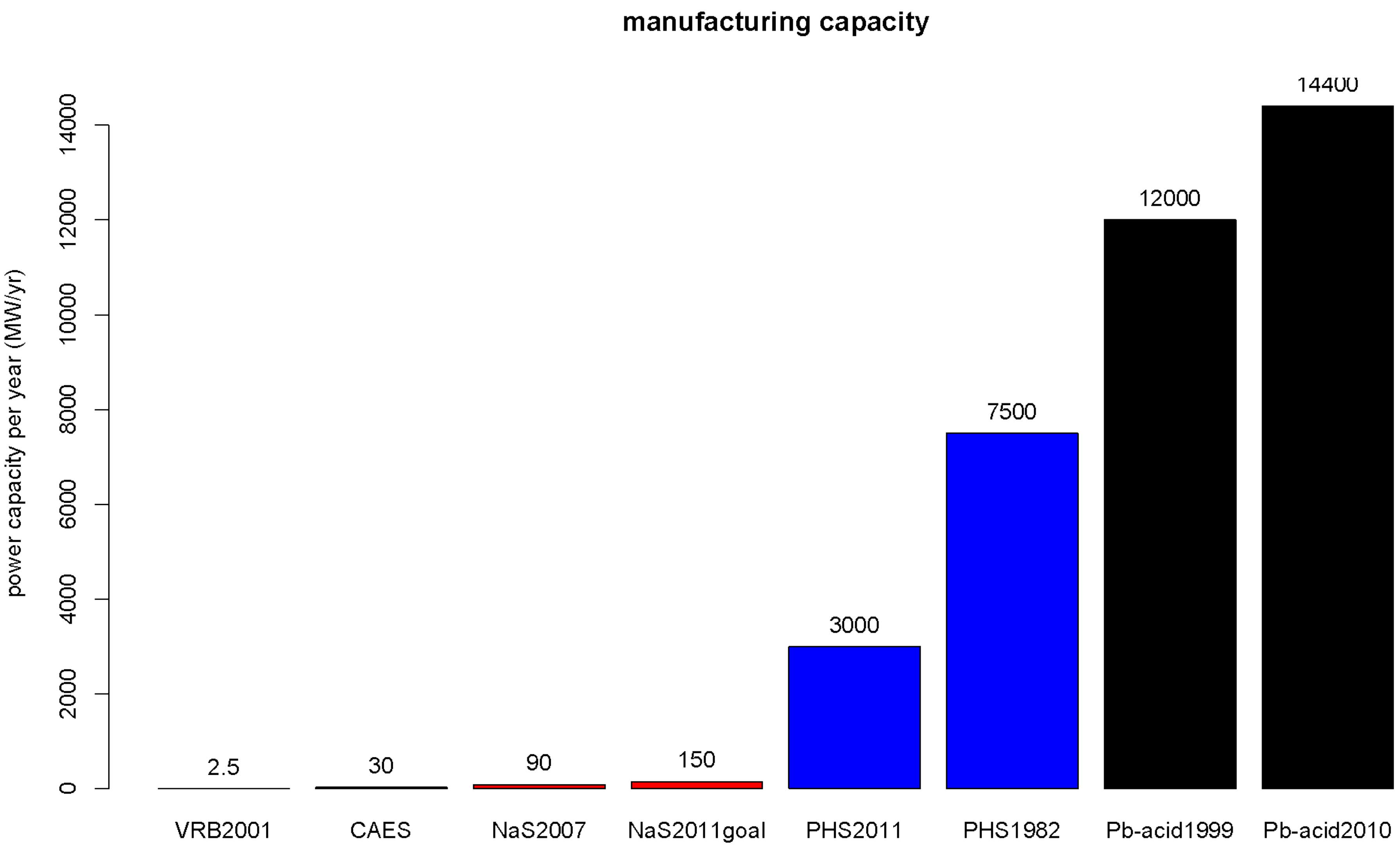




Capital Cost of Storage Technologies



Manufacturing Rates of Storage



California Public Utilities Commission – Workshop on Pumped-storage

Scott Flake P.E., Director Power Generation and Project Development

Sacramento Municipal Utility District

January 16, 2013

Powering forward. Together.

SMUD™

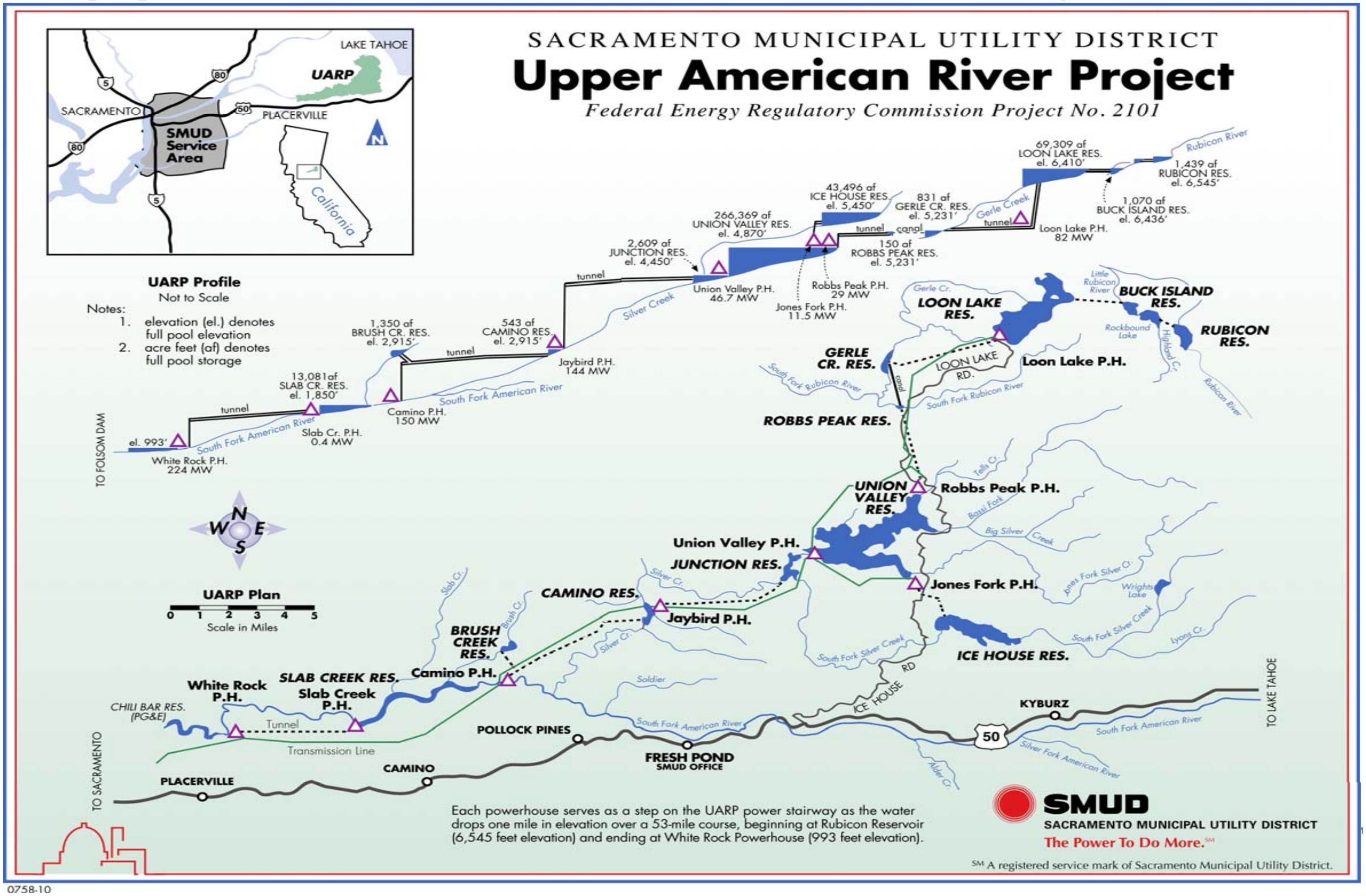
Presentation Overview

1. Iowa Hill Project Overview
2. Project Benefits
3. Environmental and Community Issues
4. Financial and economic business cases

1. Iowa Hill Project Overview

- 400 MW, 3-unit Variable speed plant
- Underground construction
- Uses existing lower reservoir and transmission lines.
- New upper reservoir is off stream.
- Estimated cost $690 Million plus contingency, network upgrades and CM costs.

Upper American River Project



Why Iowa Hill?

- Pumped-storage provides large amounts of ***dispatchable capacity***.
- Pumped-storage is a ***proven and reliable*** technology.
- Increased demand for dispatchable capacity is driven by ***intermittent resources*** (wind, solar) ***RPS*** and ***greenhouse gas*** legislation/regulation (reduced reliance on fossil fuels).

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Rendering of Iowa Hill

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2. Project Benefits

- Iowa Hill is designed to support increasing variable resources required by RPS regulation, with constraints on NG flexible capacity in a carbon constrained regulatory environment, while maintaining FERC/NERC grid reliability requirements.
- Provides dispatchable zero-GHG capacity and ancillary services.
- California examining GHG reduction goals beyond 2020 – target is 80% reduction
- SMUD has more aggressive goals for GHG reductions – 90% below 1990 levels by 2050.

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Permitting Requirements

- FERC Licensing ($3M cost)
- 401 Water Quality Certification
- 404 Permit
- Endangered Species Biological Opinion
- Streambed Alteration Agreement
- Special Use Permit(s)
- Local Drilling Permits

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3. Environmental and Community

- Proper siting is critical for all projects including closed loop projects.
- Some key aspects included in Iowa Hill design are:
  - No new dams on streams or waterways.
  - Use of existing facilities like the existing lower reservoir at Slab Creek and the use of existing transmission lines.
  - Commitment to a collaborative permitting process and extensive community outreach.

4. Financial and Economic Business cases

- Economic business case evaluated on market products. Payback is on the order of several decades.
- Market does not represent many of the products needed to "Keep the Lights On" – Flexible Capacity
  - Voltage control
  - Inertia
  - Frequency control, etc.
- Financial markets need certainty and long term contracts.

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Iowa Hill Construction Costs

	COST
Pre-construction Geotechnical / Design Work	$30,000,000
General Conditions	$38,284,351
Access Roads & Staging	$18,199,000
Upper Reservoir	$110,639,000
Access Tunnels	$16,363,000
Ventilation Shafts and Tunnels	$24,012,000
Water Conductors	$112,026,000
Powerhouse Cavern	$50,117,000
Re-conductor Existing UARP Transmission Lines	$45,000,000
Electrical Mechanical Equipment	$241,586,205
Total Construction Cost	**$686,226,556**

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Value Stream Modeling Results Comparison IH to Recip. Engines

	Production Cost Savings ($ Million)			Production Cost Savings ($/kw-year)		
	IH w AS trading	IH wo AS trading	Recip w AS trading	IH w AS trading	IH wo AS trading	Recip w AS trading
TEPPC-Base	12	11	3	30	28	11
CA High-Wind & WI Base	12	11	2	30	28	7
CA High-Mix & WI Base	19	18	3	48	45	8
WI High-Wind	43	47	10	108	118	36
CA High-Mix & WI High-Wind	52	53	17	130	133	48

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Other Benefits from Modeling

- Adjustable-speed turbines provide more benefits than fixed-speed turbines (65% more saving in High-Wind)
- Reduction in variable generation curtailment (valued up to $1.5M/year in SMUD BA and $35M/year in study area)
- Reduce reserve shortfall and increasing reliability
- Reduce starts and ramping of thermal units
- Improve UARP operating efficiency
- Avoidance of new generation capacity
- Significantly greater operational savings in dry water years

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SWAN LAKE PUMPED STORAGE

PROJECT STATUS, SYSTEM BENEFITS AND BARRIERS

California Public Utilities Commission

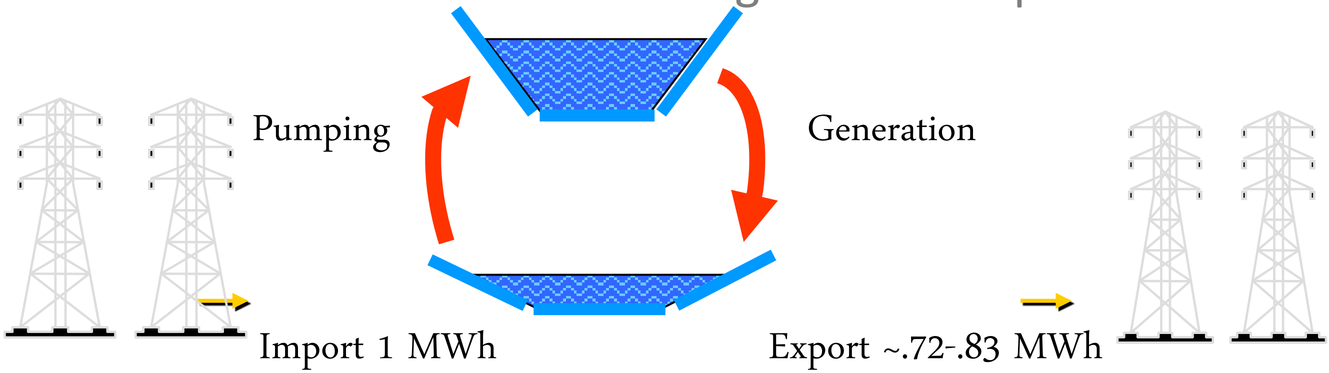
Technical Workshop

San Francisco, CA

January 16, 2014

AGENDA – PUMPED STORAGE IN CALIFORNIA

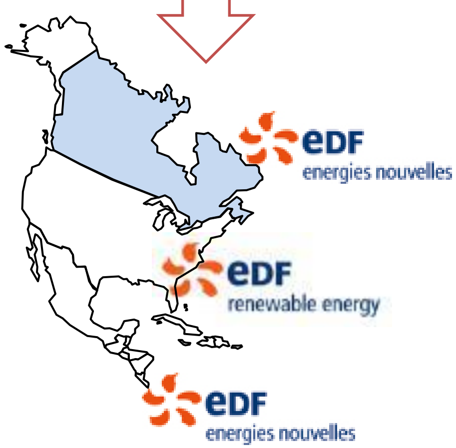
- EDF Renewable Energy and EDF Group capabilities
- Swan Lake Project details
- California has substantial needs for storage resources. Pumped Storage provides benefits including grid scale storage + short and longer duration services that span the spectrum of ancillary services and characteristics needed for the grid
- Challenges to Pumped Storage: among other challenges, future projects require meaningful regulatory action from the CPUC and other agencies if its potential is to be realized
- Recommendations



EDF RENEWABLE ENERGY (FORMERLY ENXCO)

100% Owner of EDF EN Group

100% Owner of EDF Renewable Energy, EDF EN Canada Inc. and EDF EN Mexico



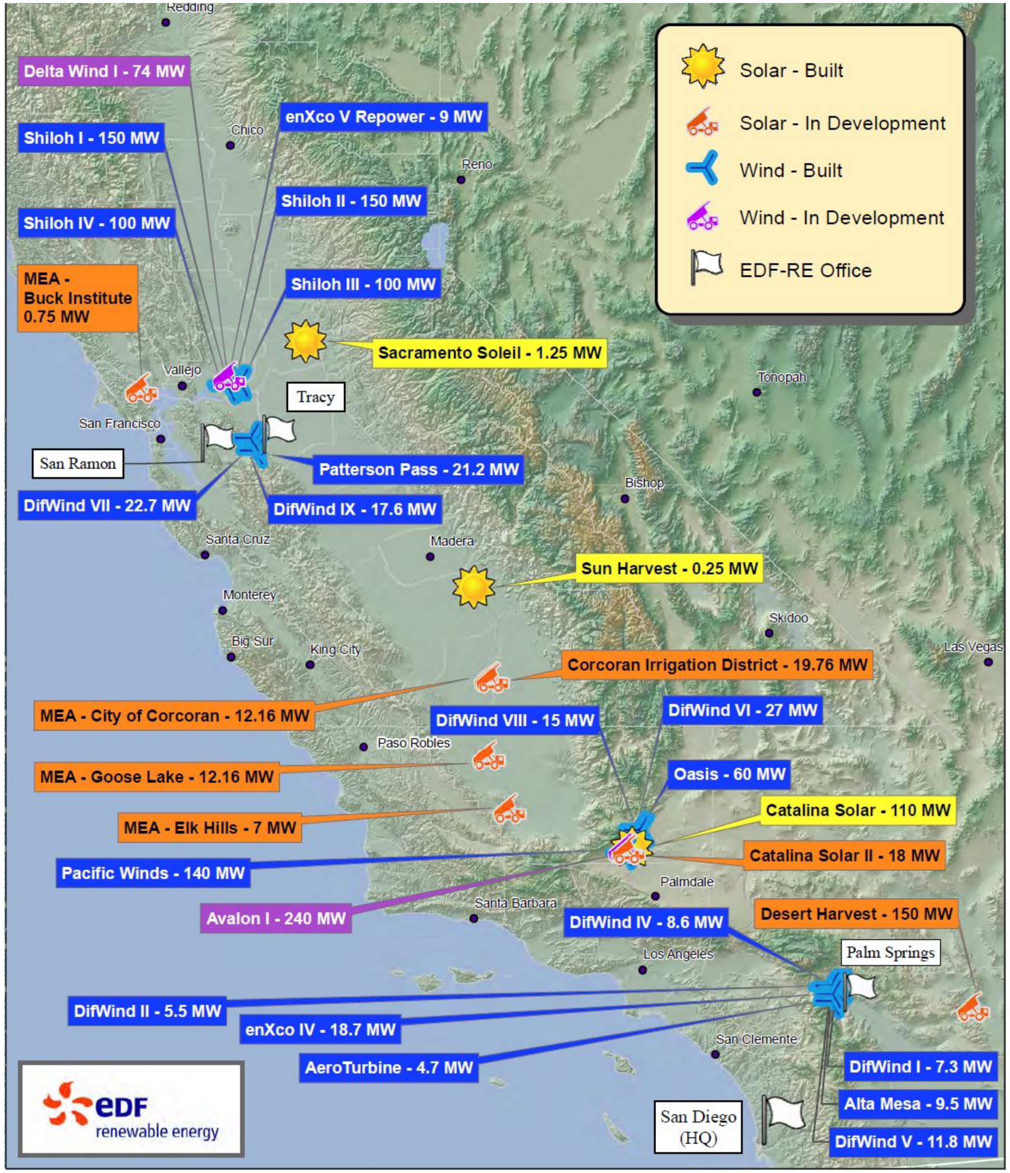
EDF Group (2012)

Employees (World)	160,000
Installed Capacity	140 GW
Installed Renewables	3.3 GW
Sales	€72.7bn ($US98.8bn)
EBITDA	€16.1bn ($US21.9bn)
S&P	A+
Worldwide Customers	39.3MM
Headquarters	Paris, France

EDF Renewable Energy (2012)

Employees (N America)	873
Installed Capacity	2382 MW
Commissioned in 2012	1057 MW
O&M Portfolio	6347 Turbines
	2.3MM Solar Panels
Years in Business	25
Headquarters	San Diego, CA

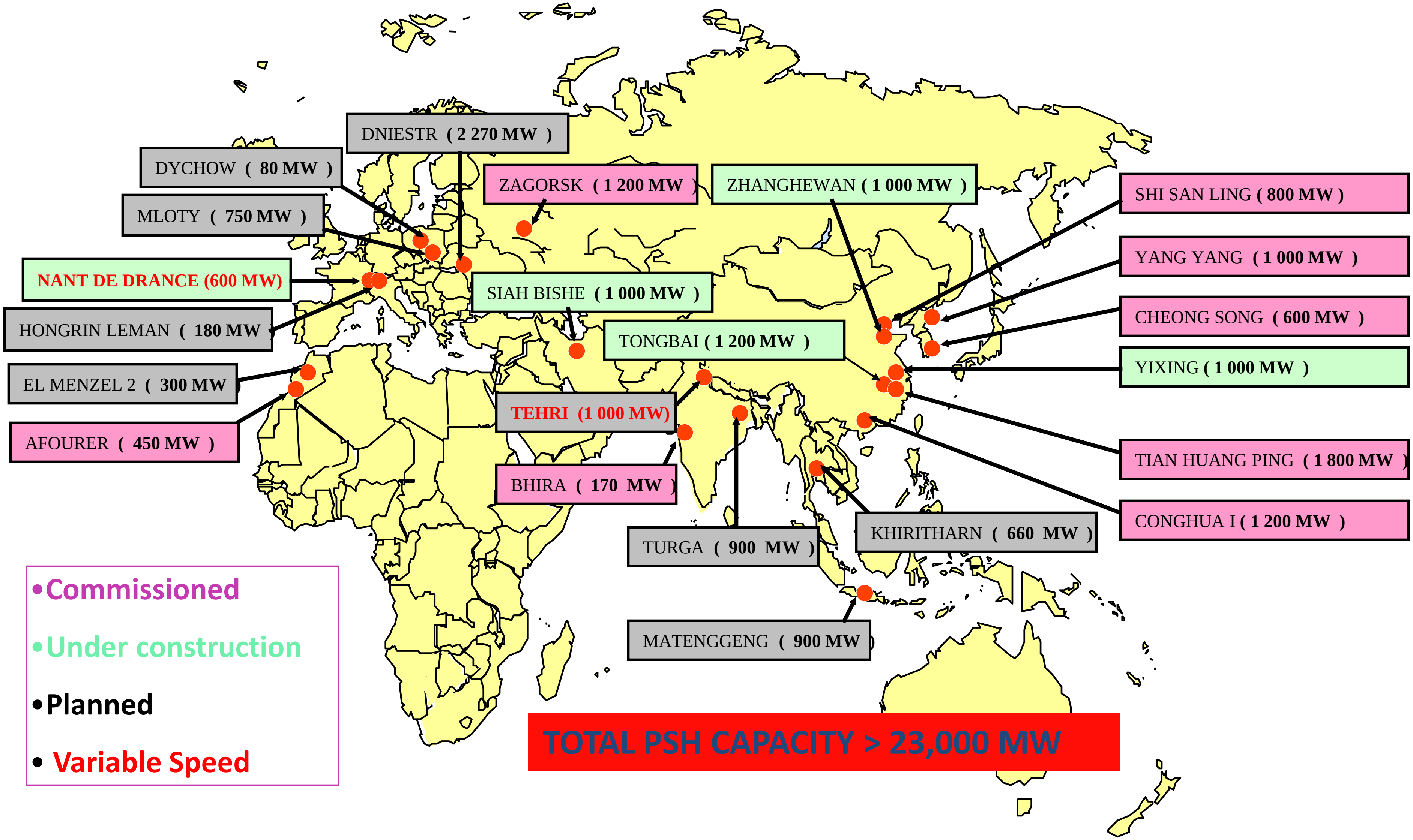
EDF-RE AND CALIFORNIA



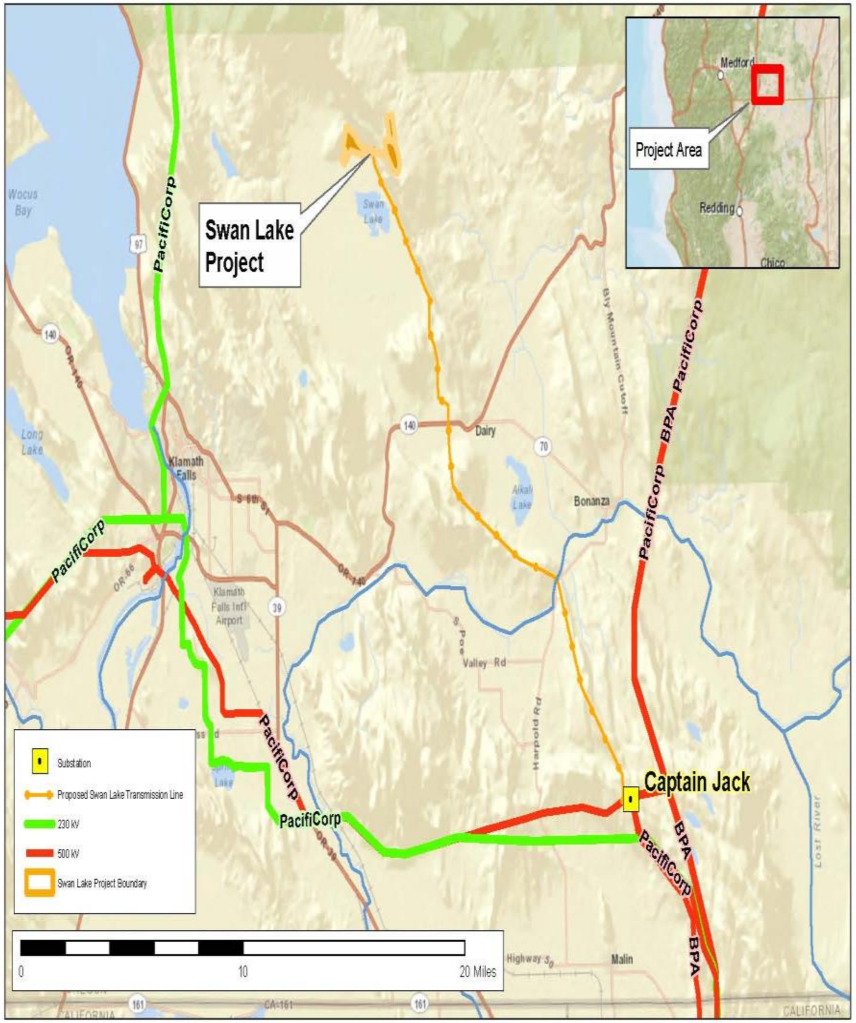
- North American HQ is San Diego, with offices in San Ramon, Tracy and Palm Springs
- "Born and raised" in California
- We have California projects in various stages of development
- We have sold projects to, or entered into PPAs with, all segments of the utility community in California (IOUs, munis)

EDF'S PUMPED STORAGE HYDRO GLOBAL PRESENCE

Global Overview of EDF Pumped Storage Hydro Projects



SWAN LAKE PROJECT OVERVIEW



Location:

- Approximately 11 miles NE of Klamath Falls, Oregon
- Project Area: 837 Acres
- Private and BLM Property
- Water Availability:
  - Leased groundwater rights, preliminary OWRD approval
- Transmission Access
  - South of Malin; near COB; PacifiCorp and CAISO

- **Total Capacity: 600MW - System Need Dependent**
- Project Head: 1265 feet
- Hybrid Penstock Design
  - Upper half of penstock above ground
  - Lower half of penstock below grade
  - EDF-CIH approved preliminary design.
- Below-Grade Power House and Substation
- Closed-Loop System
  - New upper and lower reservoirs
  - No impact to existing water ways
  - Initial fill and evaporation from existing ground water wells
  - Water rights have been secured

EDF renewable energy

STORAGE TECHNOLOGY AND TIME SCALE COMPARISONS

Seconds to 15 Min

- Super capacitors
- Flywheels
- Batteries
- **Pumped storage (includes inertia, primary and secondary frequency control)**

1 Hour to 4 Hours

- Batteries
- Compressed air energy storage (CAES)
- **Pumped-storage**

Several Days

- **Pumped-storage**

15 Min to 1Hour

- Batteries
- Compressed air energy storage
- **Pumped storage**

4 Hours to 1 Day

- CAES
- **Pumped-storage**

Pumped Storage provides grid scale storage + short and longer duration Ancillary Services; spans the spectrum of capacity services

STORAGE & ANCILLARY SERVICES

Benefits

- Flexible capacity for Renewables Integration:
  - Helps fulfill current and future RPS targets
  - Hedges against natural gas price spikes and shortages and overreliance on gas, helps avoid need for gas storage
  - Help in the Reduction of Greenhouse Emissions, and reduces vulnerability of energy supply infrastructure and demand due to effects of climate change
  - Supports job growth
  - Pumped Storage addresses all timescales of the US ancillary service market
- PSH Provides Superior Intra-Hour Flexibility:
  - Superior AGC response for regulation
  - Superior ramping capability for early load following period (as well as for longer duration ramping needs)
- Optimize Off-Peak Generation; benefits as a load:
  - Shave off-peak gen/ decrease wind curtailment; Can serve as load when needed

A complementary option to help stabilize the grid and provide greater operating flexibility, as part of comprehensive package

STORAGE & ANCILLARY SERVICES

Challenges

- Market Deficiencies
  - The duration of the limited existing Ancillary market insufficient for long term private sector investment
  - Providing revenue certainty to bulk storage projects sufficient to attract investors
  - Struggle over Generation or Transmission/Existing Market Rules and Impact on Energy Storage Value
- Environmental Issues for Pumped Storage Siting:
  - The concept of “closed-loop” pumped storage is now the standard approach because it presents minimal to no impact to existing rivers
- Fluctuating power from available wind energy and other renewable forms of production have to be integrated.
  - Greater net load grid impacts
  - Minimum load challenges
  - Difficult to Predict
  - Might not be there when you need it.....
  - Might have too much of it when you don’t…

PUMPED STORAGE BENEFITS AND VALUES

- Regulation Reserve; (value contributions include inertial response, governor response or primary frequency control, and regulation reserve or secondary frequency control)
- Flexibility Reserve/ load following
- Contingency Spinning, non-spinning and replacement reserves
- Energy arbitrage/ load leveling
- Integration of variable energy resources (VERs)
- Capacity
- Portfolio effects/ reduced cycling of thermal units/ reduced fuel and O&M expense
- Reduced transmission congestion
- Reduced environmental emissions
- Transmission deferral
- Voltage support
- Black start capability

EDF RE DETAIL PUMPED STORAGE MODELING

- Our Swan Lake project modeling is building on the approach used by Argonne National Laboratory, et al.; we are identifying intra-hour values, portfolio values, avoiding renewable curtailment, other values so that what Pumped Storage contributes to the system in all material time frames is made clear.

- Modeling the Western Interconnect and CAISO without and then with Swan Lake, using Plexos, a power system operation simulation software package by Energy Exemplar as described by ANL today.

- Using 2022 as the future year for analysis, based primarily on the recent vintage 2022 WECC TEPPC data base, with careful assumption vetting.

- Measuring Day Ahead (DA) and Hour Ahead (HA) measurement for all hours; Real Time (RT) 5 minute step measured for 4 typical weeks for 4 seasons, but evaluating doing for 12 typical weeks for 12 months.

- Diversion from Argonne National Lab study approach:

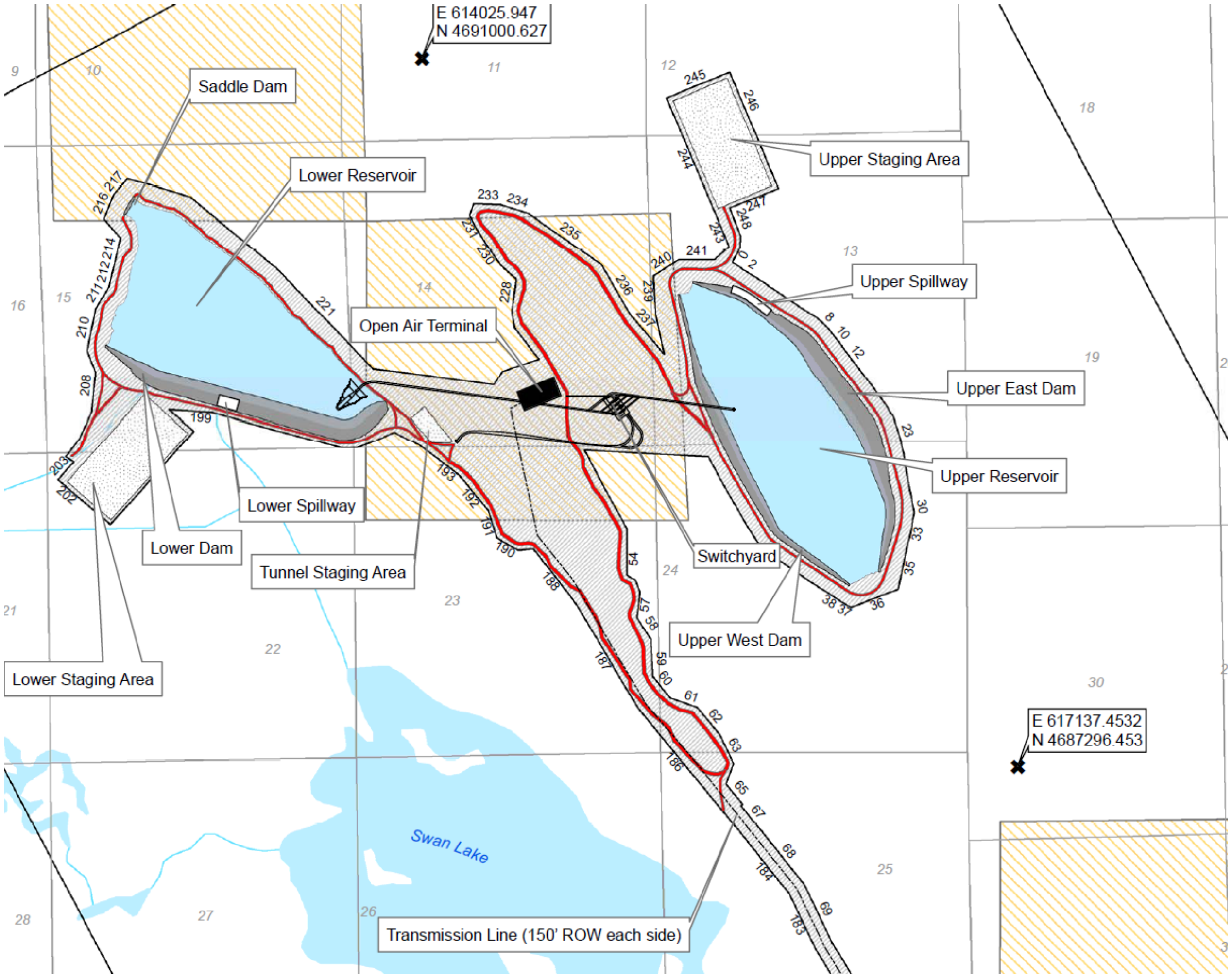
  - Only base RE scenario studied (using all 2022 legal requirements in WI states); no high RE scenario
  - All existing fixed speed Pumped Storage in base case; Swan Lake only variable speed Pumped Storage added
  - SL direct interconnect into CAISO
  - Nodal representation of transmission system in CA, OR,W, NV; rest of WI zonal
  - Thermal start up costs will include not only fuel but also related incremental O&M (from Aptex)
  - Assessing avoided GHG emissions value post-modeling
  - Updating of TEPPC on retirements, topology, hydro system operation
  - Additional case for head to head comparison with CCCT (600 MW @ California-Oregon Border)
  - Adding high gas price case and low/high water year case

UTILITY STORAGE RECOMMENDATIONS

- Identify and measure value streams and compensate more of them.
- Include intra-hour values and portfolio effects in value determination.
  - Focus on critical time parameters for effective integration of renewables: especially intra-hour; morning dec ramp; evening inc ramp.
- Provide recognition of fast and accurate frequency regulation performance, as encouraged by FERC in order No 784, and corresponding premium incentive
  - Prorata with performance exceeding thermal fleet average.
- Provide premium incentive for premium ramping capability
  - Compare PSH resource ramp speed with fleet average of resources committed HA.
- Provide long term contract term availability for Pumped Storage as a preferred resource; 30 year term best.
- Reward premium Pumped Storage performance over thermal fleet in time frames of particular significance to the system; i.e., intra-hour, morning dec ramp and early evening inc ramp.

APPENDIX

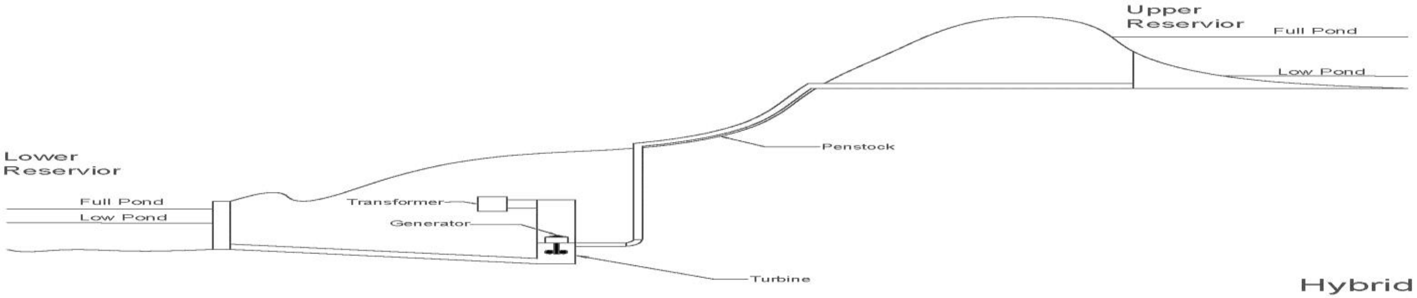
SWAN LAKE SITE PLAN



HYDRAULIC CONVEYANCE & POWER HOUSE

Design

- Hybrid water conveyance, mainly for geological reasons
  - **Penstocks at the Upper end**
  - **Underground Tunnel at the lower end to a subsurface Powerhouse**



- Moderate visual impact
- Limit the up-front costs
- Remain within the boundaries determined in the Preliminary FERC Permit
- Locate the power plant “far” from the active fault passing under the left extremity of the lower dam that is assumed to be active
- Remain in the expected “good rock” ,i.e. Pliocene basalt of Bear Wallows and avoid as much as possible tertiary sediments (Ts)

GEOPHYSICAL INVESTIGATION

- Swan Lake North will analyze and evaluate field data, test results and reporting to determine the feasibility of the plant site with respect to the suitability of geophysical characteristics

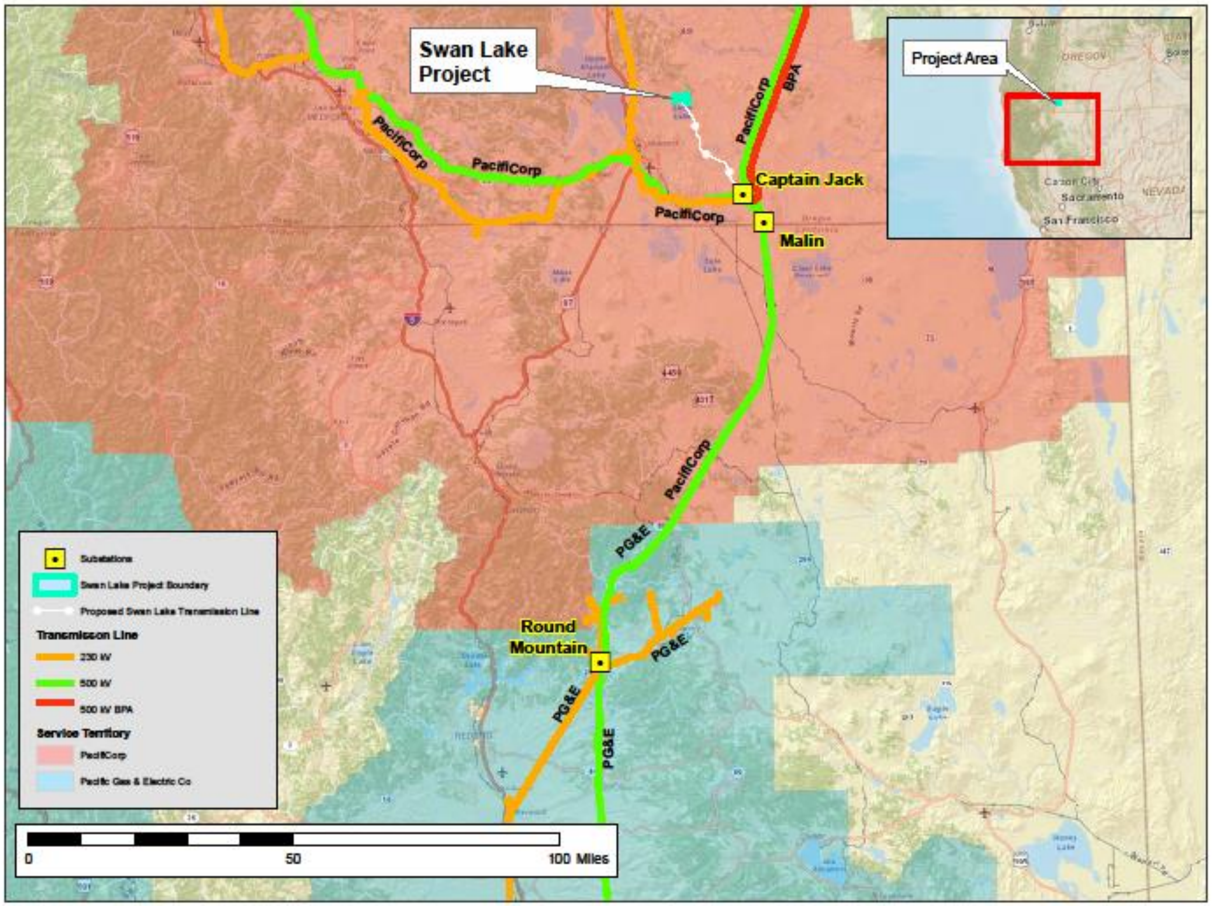
- Field Work for Phase 1 - Lower Reservoir - Initial Studies Complete
  - 6 Standard Penetration Tests, ranging in depths from 35 to 65 feet
  - 1 Core Borehole, 120 ft deep
  - 3 Seismic Refraction Profiles , ranging in lengths from 4,211 to 6,246 feet

  - Objective:
    - Suitability of Soil – A bed of silt estimated to be up to 30 feet deep in places covers the lower reservoir floor. For some soils, potential for liquefaction to occur in the event of an earthquake. Determine depth of soils with liquifaction concern and potential for liquefaction. Initial results positive; limited to 1.5 meter shallow layer.
    - Evaluation of the impact of the lower escarpment fault on the primary dam and escarpment interface; pending.

- Field Work for Phase 2 - Upper Reservoir, Conveyance, Shafts, Powerhouse - Pending
  - 5 Core Boreholes, ranging in depths from 60 to 660 feet
  - 2 Seismic Refraction Profiles at 1,981 and 6,246 feet in length

- Suitable geophysical characteristics to support the Lower Reservoir will be a prerequisite for the option to commence with Phase 2.

SWAN LAKE POTENTIAL INTERCONNECTION



- PacifiCorp Large Generation Interconnection Request submitted in August, 2013
- Planning on gentie to vicinity of Malin; route included in FERC draft license application.
- Study interconnection on PacifiCorp-owned line segment south of Malin; subject to Facilities sharing agreement with PG&E/CAISO
- Will include preferred substation location in final FERC application.

EDF renewable energy

MODEL FEATURES- BIG PICTURE

- Measures Benefits and Costs DA, HA, RT; adds intra-hour measurement down to 5 minute timing, captures intra-hour value.
- Co-Optimizes Energy Arbitrage and Ancillary Services; evaluates Ops reserves (Reg and Flex up and down), Contingency Reserves (spin and non-spin), integration of Variable Energy Resources, capacity value, portfolio effects (e.g., reduced cycling and starts), to produce production cost reductions or AS revenue.
- Captures almost all Ancillary Service benefits and portfolio effects (a couple of AS like voltage support and black start are not captured in the model but will be evaluated outside the model.)
- Identifies congestion reduction, transmission deferrals, emissions reductions of SOx, NOx, CO2, other emissions, although not all are currently monetizable.
- The goal is to identify and accurately quantify as many value streams as possible, and to identify which can be described as social benefits and targeted for potential policy change to support monetization.

STORAGE WHITE PAPER

- The purpose of the Storage White Paper is to provide a concise source for information on the value of energy storage technologies and techniques analysts use to quantify that value.
- It is intended to accompany the Swan Lake modeling study and to provide a summary of pertinent information and a guide to recent reports about storage, as a tool for regulators and staff, intervening stakeholders and others who may participate in regulatory proceedings in CA and/or the NW states, to push forward a relatively high level discussion of storage attributes, benefits, costs, challenges, and policy considerations, to improve recognition and support of storage in the market.
- The White Paper effort is being headed by Ken Dragoon of Ecofys, an international sustainable energy consulting firm, with a very extensive Advisory Panel including representatives of regional investor owned and municipal utilities, PUC staffs, advocacy groups, Federal Laboratories, universities, power councils and similar entities. (see appendix)
- The White Paper is in draft process now, Goal is final draft by January 16, final review and availability to follow up on January 16 CPUC workshop.

WHITE PAPER ADVISORY PANEL

Advisory Panel Members:

Eddie Abadi – Bonneville Power Administration
Dick Adams – Pacific Northwest Utilities Conference Committee
Ellis Arzu - EDF Renewable Energy
Jamie Austin - Pacificorp
Mark Avery – Salt River Project
Frank Bergh – Nordex
Damian Buie - EDF Renewable Energy
Ronald Bushner - Hawaii Electric Company
Yong Cai – Sacramento Municipal Utility District
Gillian Charles – Northwest Power and Conservation Council
David Clement – Seattle City Light
Stephen Enyeart - Bonneville Power Administration
Erin Erben – Eugene Water & Electric Board
John Fazio - Northwest Power and Conservation Council
Christopher Fecke-Stoudt – K.R. Saline & Associates
Hassan Ghoujehbaklou – San Diego Gas & Electric
Michael Goggin – American Wind Energy Association
Adam Green – Solar Reserve
Tao Guo – Energy Exemplar
Douglas A. Halamay – Oregon State University
Udi Helman – BrightSource Energy
Alan Hickenbottom – Christianson Electric
Matthew Hunsaker – Western Electricity Coordinating Council
Steve Johnson – Washington Utilities and Transportation Commission
Rebecca Johnson – Western Interstate Energy Board
Brendan Kirby - Private Consultant
Ben Kujala - Northwest Power and Conservation Council
Larry La Bolle – Avista Corporation
Jimmy Lindsay – Renewable Northwest Project
Clyde Loutan – California ISO
Pavel Mardilovich – NRG Independence
Michael Milligan – National Renewable Energy Laboratory
Dora Nakafuji – Hawaii Electric Company
Rebecca O'Neil – Oregon Department of Energy
John Ollis – Portland General Electric
Rich Pagoaga, Jr. – Idaho Power Company
Leah Parks Schoinas – ElectricityPolicy.com
Glenn Patterson – Christianson Electric
Dana Peck - EDF Renewable Energy
Robert Petty - Bonneville Power Administration
Will Price - Eugene Water & Electric Board
Greg Probst - EDF Renewable Energy
Ron S. Sporseen – PK Energy Solutions
Ishwar Saini – Macquarie Group Limited
Steve Simmons - Northwest Power and Conservation Council
Andrew Speer - Bonneville Power Administration
Jun Wen – Southern California Edison
Keith White – California Public Utilities Commission
Cameron Yourkowsky - Renewable Northwest Project
Janice Zewe - Sacramento Municipal Utility District
Nan Zhang – Energy Exemplar
Carl Zichella – Natural Resources Defense Council

Eagle Crest
Energy Company

Eagle Mountain

Pumped Storage Hydroelectric Project

Eagle Mountain Project

- Conventional, broadly used and proven technology
- Closed loop, off-stream hydroelectric power project incorporating advanced and proven turbine and electronic control technologies which provide 1,300 MW of generating capacity
- Minimal water use and impact on water resources (unlike traditional hydroelectric development)
- Most local, state, and federal permits in hand -- expected to be fully permitted in early 2014

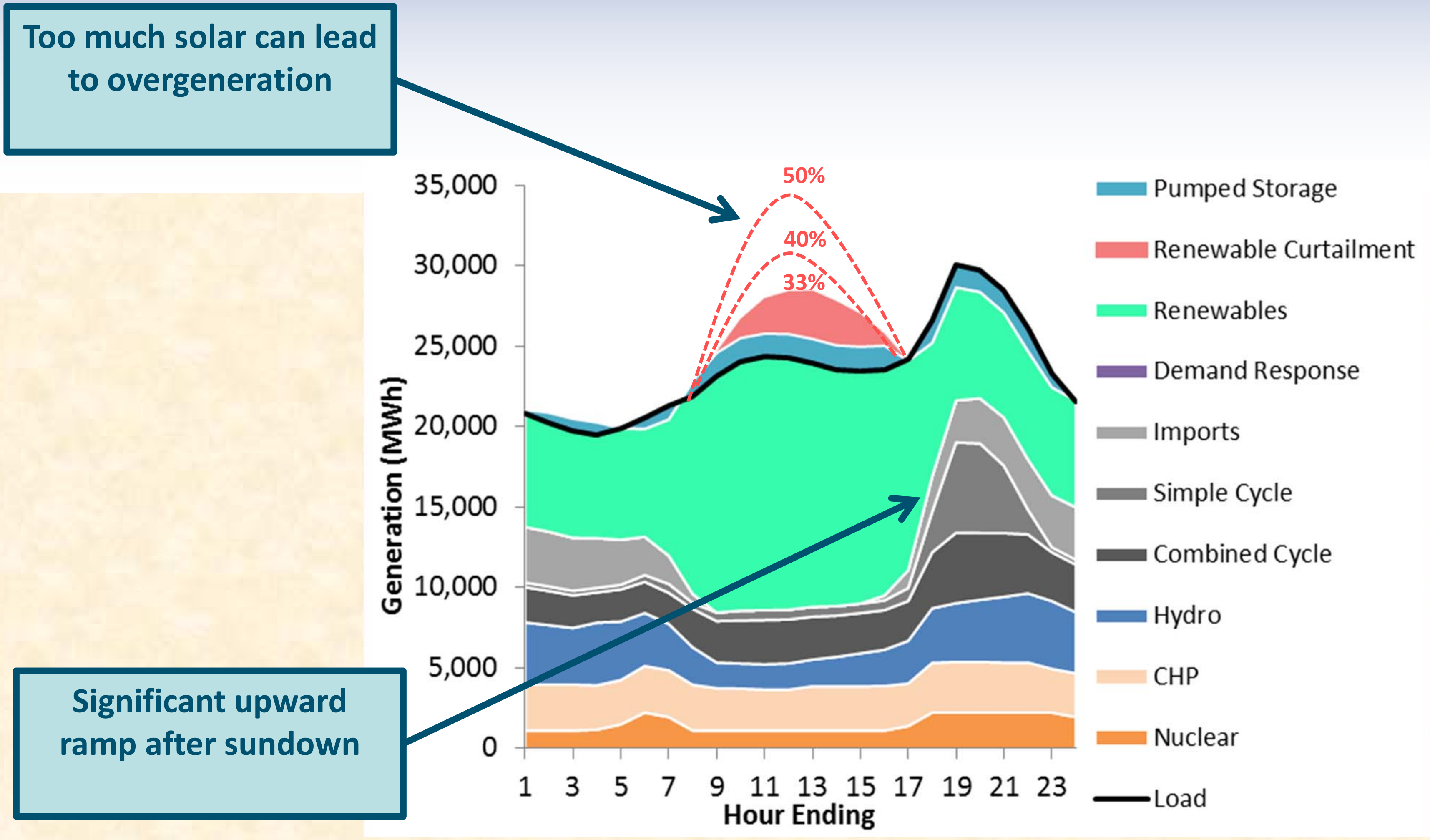
Eagle Mountain Project

- A 40-year, cost-effective energy infrastructure investment
  - Estimated cost between $1,500 and $2,000 per kW of installed generating capacity
  - $1.95-$2.6 billion total project cost
- Construction ready in 2015 with substantial economic benefits to California
  - In-state construction expenditures of almost $800 million: 2,280 jobs, $8.9 million in state taxes
  - In-state operations expenditures of $15 million annually: 260 jobs, $11.5 million in state taxes

California's Energy Challenges

- Reduce GHG emissions to 1990 levels by 2020, *and 80% by 2050*
- Integrate intermittent renewable energy at the lowest cost while maintaining reliability
- Maximize value of $90 billion investment in renewable resources by avoiding the need to curtail renewable generation due to overgeneration
- Integration and overgeneration challenges are magnified when renewable penetration goes beyond 33% RPS

Integration Challenges are Magnified Above 33% Renewables

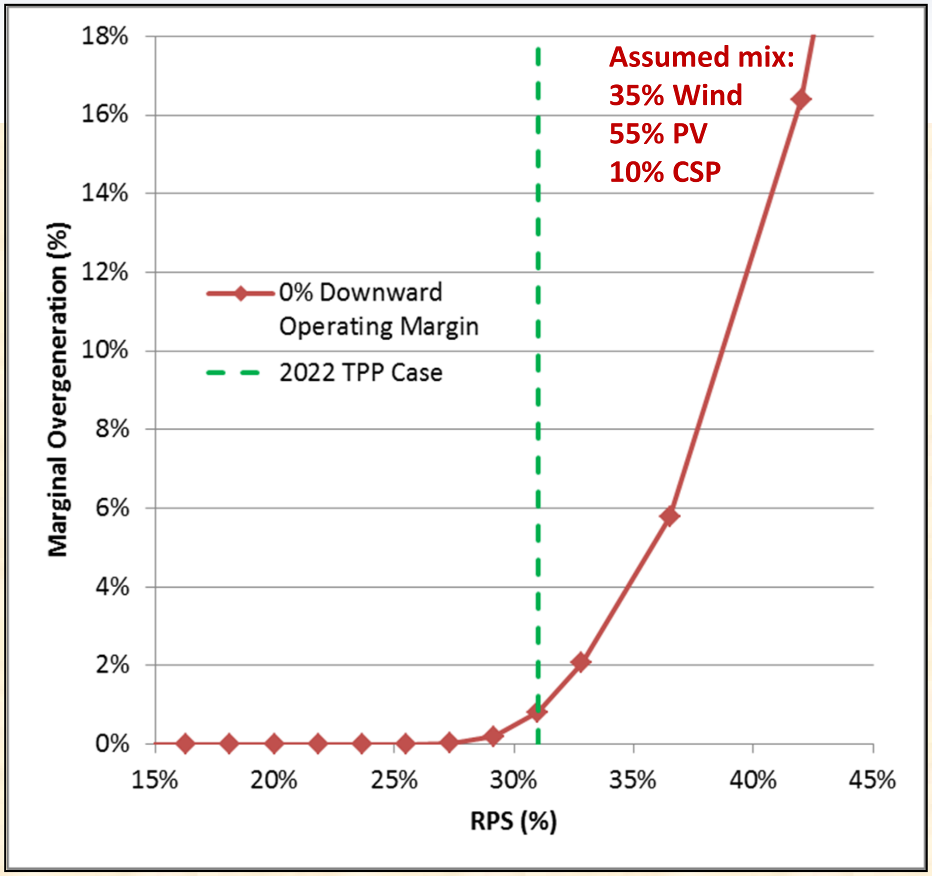


Reprinted from Presentation to CA Bar Association by Arne Olson, E3 Partner

Overgeneration Increases Exponentially as RPS Increases

- Potential for overgeneration becomes significant starting at around 33% RPS
- California will need to find ways to use, export or store surplus renewable energy
- Solutions will have a big impact on GHG reductions and cost

Overgeneration as a Percent of the next MWh of RPS resources



Reprinted from Presentation to CA Bar Association by Arne Olson, E3 Partner

Pumped Storage Gets at the Problems

Pumped storage reduces GHG emissions compared to natural gas generation when effectively integrated with intermittent renewable resources, and improves utilization of existing transmission from renewable resource zones.

- Eagle Mountain capable of providing 1,300 MW of flexible generation for up to 18.5 hours; i.e. ~22,000 MWh from stored renewable energy
- Can serve as 1,300 – 2,600 MW of load/ramp to avoid curtailment during over-generation (caused by flexibility or transmission constraints), reducing need for downward ramping capability for fossil resources
- Ability to operate intermittently in response to system conditions
  - 10 MW/second ramp rate allows unparalleled 2,600 MW swing in less than 10 minutes
  - The project can be designed utilizing advanced electronic control systems to respond to system signals within a fraction of a second

Challenges:
Regulatory Barriers to Pumped Storage

Regulatory silos at multiple agencies

- CPUC has separate proceedings to consider:
  - "long-term" procurement (LTPP)
  - reliability and, potentially, flexible capacity needs (RA)
  - policy-driven procurement (RPS, storage proceeding, etc.)
- CAISO: Need more integration of processes to deal with transmission (TPP) and generator interconnection (GIDAP)
- CEC: load, renewable, and efficiency forecasting; big-picture policy planning (IEPR)

Challenges:
Regulatory Barriers to Pumped Storage

Pumped storage falls between the cracks

- LTPP scope too narrow to consider investments for 2050 climate goals;
- LTPP Planning Assumptions & Scenarios ignore pumped storage entirely
- Local Capacity Requirements do not include storage-supported transmission upgrades to reduce the need to serve local needs with "in-area" resources
- CAISO's interconnection process may need to be revised to model pumped hydro accurately
- Market structure may need reform to capture products and services offered by storage that will be important in California energy markets, *e.g.,* dispatchable load to address overgeneration

Breaking Down Barriers to Pumped Storage Development

The right analytical questions must be asked

- What is the nature and extent of projected renewable curtailments? What is the value of avoiding such curtailment, especially considering impacts on renewable resource viability?
- How can storage most effectively be combined with intermittent renewable resources to optimize utilization? In what geographic regions?
- What intra- and inter-agency studies and procedures are required to evaluate and capitalize on the benefits of pumped storage to California's energy portfolio *and* transmission system?

Breaking Down Barriers to Pumped Storage Development (cont'd)

The right models must be developed:

- CPUC should develop stochastic modeling tools which accurately evaluate the full complement of pumped storage projects' potential benefits and evaluate the cost effectiveness of pumped storage projects over a 40-year period.

- CPUC and CAISO should expand the time horizon out to which they model procurement and transmission needs – pumped storage facilities are necessary for the long term, not just "near term" 2020 needs.

Breaking Down Barriers to Pumped Storage Development (cont'd)

The models must be implemented:

- Incorporate results into future LTPP and TPP processes, thus allowing cost-effective pumped storage projects to be identified and built.
- Expand the preferred resource study to assess whether resources outside the basin combined with utility scale storage can significantly reduce the need for additional conventional generation in the basin.
- Incorporate pumped storage evaluation modeling into the CAISO interconnection process.

Eagle Crest
Energy Company

Eagle Mountain

Pumped Storage Hydroelectric Project

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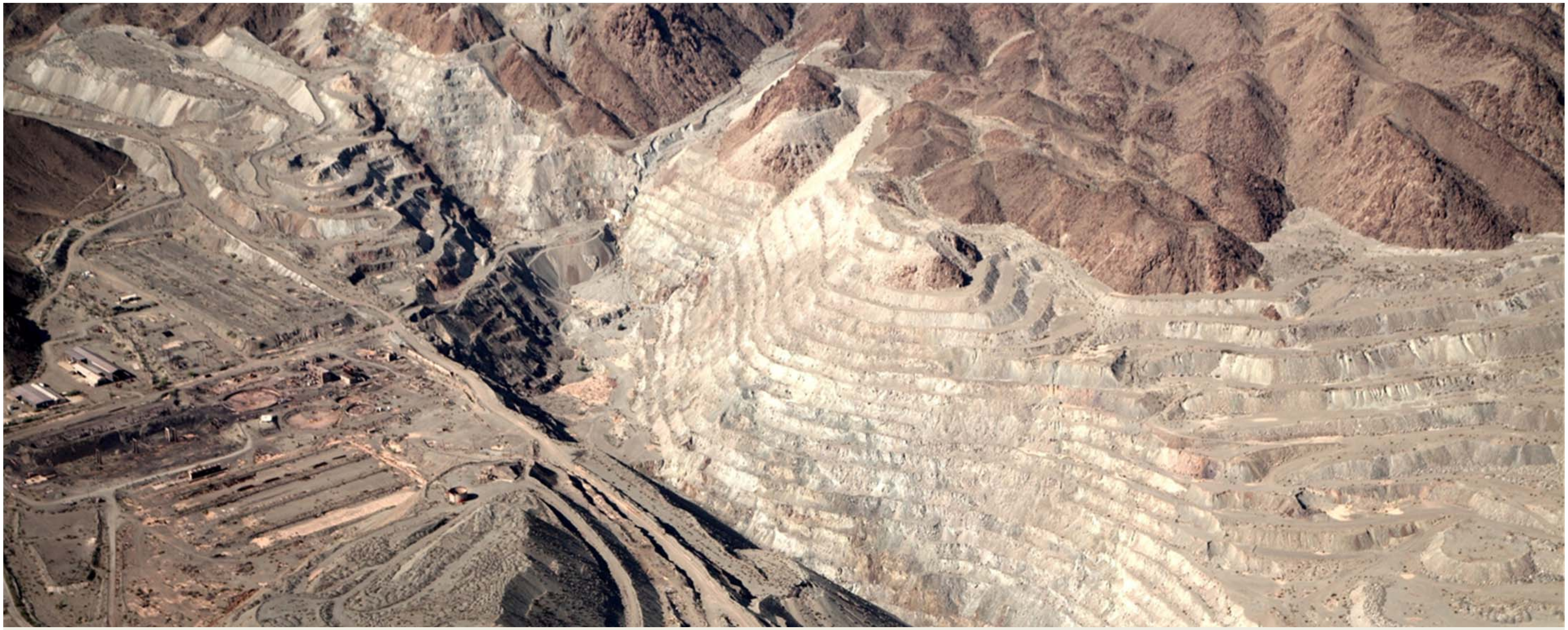


Eagle Mountain Pumped Storage Project

APPENDIX 1
REFERENCE MATERIALS

Resources Regarding Studying and Modeling Pumped Storage

- Energy+Environmental Economics (E3), "Investigating a Higher Renewables Portfolio Standard in California" (January 2013)
  - Excerpt from Website: In an ambitious, forward-looking study jointly sponsored by California's five largest electric utilities, E3 evaluated the operational challenges, potential solutions, and cost consequences of a higher Renewables Portfolio Standard (RPS) in California by 2030. The study benefited from technical input from the CAISO as well as independent review from a distinguished four-member advisory panel. The study utilized E3's first-in-class Renewable Energy Flexibility (REFLEX) model on ECCO International's ProMaxLT production simulation platform. The report and associated materials are available below.
  - Available at: http://www.ethree.com/public_projects/renewables_portfolio_standard.php

- National Renewable Energy Laboratory (NREL), "The Role of Pumped Storage Hydro Resources in Electricity Markets and System Operation" (May 2013)
  - Excerpt from Abstract: "This paper will introduce some of the issues that may limit the ability to fully value pumped storage hydro plants in today's markets and propose some solutions to those problems."
  - Available at: http://www.nrel.gov/docs/fy13osti/58655.pdf

Resources Regarding Studying and Modeling Pumped Storage (cont'd)

- Electric Power Research Institute (EPRI), "Quantifying the Value of Hydropower in the Electric Grid: Final Report" (2013)
  - Excerpt from Abstract: "The report summarizes research to Quantify the Value of Hydropower in the Electric Grid. This 3-year DOE study focused on defining value of hydropower assets in a changing electric grid. Methods are described for valuation and planning of pumped storage and conventional hydropower."
  - Available at: http://www.epri.com/abstracts/Pages/ProductAbstract.aspx?ProductId=000000000001023144

- EPRI, "Results from Case Studies of Pumped-Storage Plants" (2012)
  - Excerpt from Abstract: Detailed plant performance analyses were conducted using unit and plant performance characteristics and 1-minute plant operational data from 2008, 2009, and 2010 for five pumped-storage plants. . . . This report describes results from detailed performance analyses that evaluated reductions in overall plant efficiencies under a variety of operation-related and market-related conditions for the plants."
  - Available at: http://www.epri.com/abstracts/Pages/ProductAbstract.aspx?ProductId=000000000001023142

Resources Regarding Studying and Modeling Pumped Storage (cont'd)

- The Pennsylvania State University (Penn State), "Financial Considerations of Using Pumped Hydroelectric Storage to Increase the Penetration of Wind and Solar Generation" (2012)
  - Excerpt from Abstract: "This paper will address the financial aspects of using [pumped hydro storage] to firm and time shift the inherently variable wind and solar power generation in the Mid-Atlantic States."
  - Available at (purchase required): http://proceedings.asmedigitalcollection.asme.org/proceeding.aspx?articleid=1694743

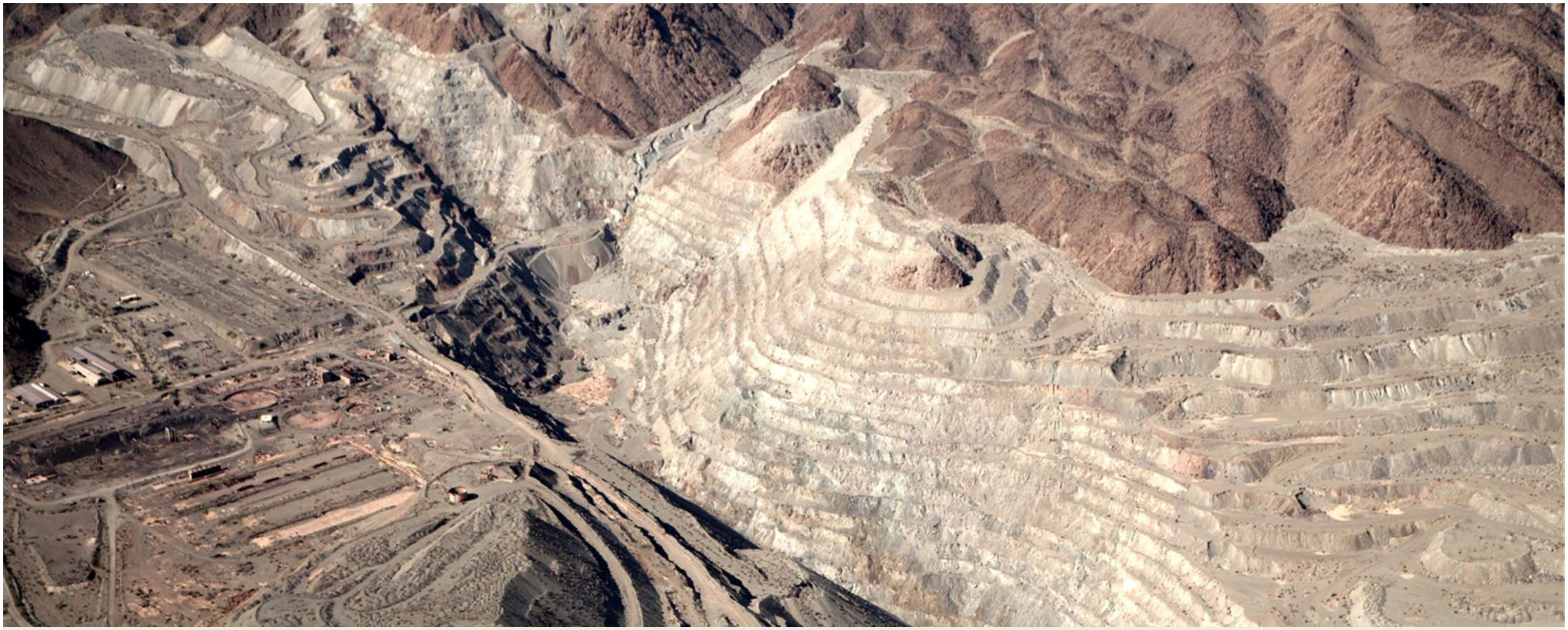
- Penn State, "Mitigating the Variability of Wind and Solar Energy Through Pumped Hydroelectric Storage" (2012)
  - Excerpt from Abstract: "A computer model with one minute granularity is constructed in order to study the operational requirements of [pumped hydro storage]. . . .Preliminary results show the profound effects of increased penetration of renewable energy on an electric grid."
  - Available at (purchase required): http://proceedings.asmedigitalcollection.asme.org/proceeding.aspx?articleid=1694742

Resources Regarding Studying and Modeling Pumped Storage (cont'd)

- Pacific Northwest National Laboratory, "National Assessment of Energy Storage for Grid Balancing and Arbitrage: Phase 1, WECC" (June 2012)
  - Key Outcomes include: (1) "Total Balancing Market in the WECC is Estimated to be 6.32 GW Assuming about 24 GW of Installed Wind Capacity in 2020"; (2) "Each Technology Option Requires its Own Size to Meet the Future Balancing Needs"; (3) "Competitiveness of Storage Technologies: Na-S Batteries, Flywheels, Pumped Storage ... compete today ..."; (4) Energy Storage Devices are not Expected to Achieve Cost Recovery when Deployed for Arbitrage Services; and (5) Hybrid System Offer No Technical Performance Advantages...."
  - Available at: http://energyenvironment.pnnl.gov/pdf/PNNL-21388_National_Assessment_Storage_Phase_1_final.pdf

Resources Regarding Studying and Modeling Pumped Storage (cont'd)

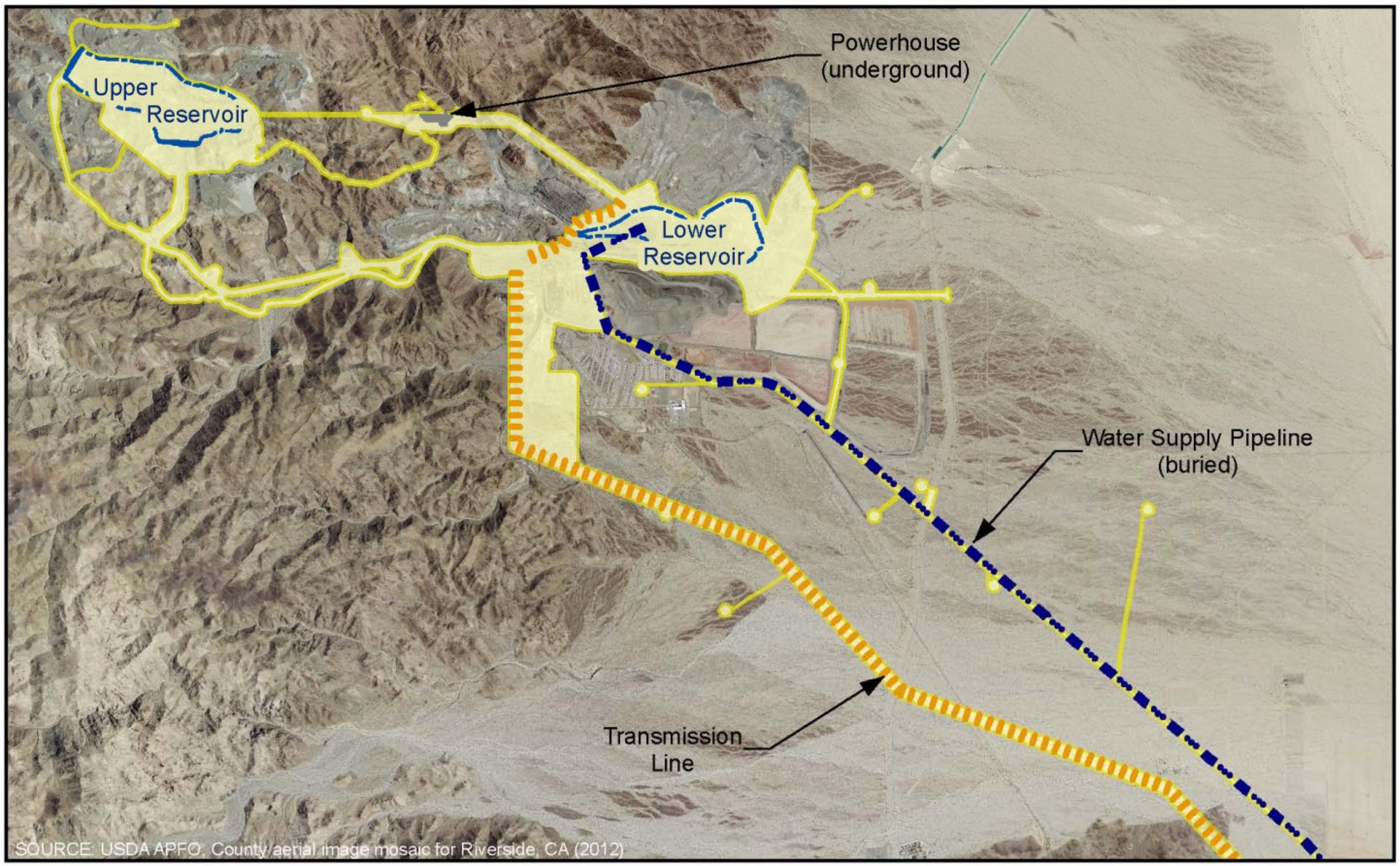
- State Utility Forecasting Group, "Utility Scale Energy Storage Systems: Benefits, Applications, and Technologies" (June 2013)
  - Excerpt from Website: "This report focuses on six general benefits of incorporating bulk energy storage systems into the electricity grid including: (1) enabling time-shift of energy delivery, (2) supplying capacity credit, (3) providing grid operational support, (4) providing transmission and distribution support, (5) maintaining power quality and reliability, and (6) allowing integration of intermittent renewables generation."
  - Available at: http://www.purdue.edu/discoverypark/energy/SUFG/ 3
- Midcontinent Independent System Operator (MISO), "Manitoba Hydro Wind Synergy Study: Final Report" (June 2013)
  - Excerpt from Executive Summary: "MISO completed its first comprehensive study that looks at the synergy between hydro power and wind power in June 2013. The purpose of the study, called the Manitoba Hydro Wind Synergy Study, assessed how Canadian hydro power can work with MISO wind to provide benefits to MISO."
  - Available at: https://www.misoenergy.org/Library/Repository/Meeting%20Material/Stakeholder/Planning%20Materials/Manitoba%20Hydro%20Wind%20Synergy%20TRG/Manitoba%20Hydro%20Wind%20Synergy%20Study%20Final%20Report.pdf



Eagle Mountain Pumped Storage Project

APPENDIX 2
PROJECT DETAILS

Eagle Mountain Central Project Area



Eagle Mountain Economic Benefits Over Life of Project

- Riverside County
  - $361.9 million income
  - $224.0 million taxes
- California, including Riverside County
  - $1,012.5 million income
  - $260.5 million taxes

Environmental Mitigation

- 5 years of environmental review to-date
- FERC prepared Environmental Impact Study (EIS)
- SWRCB (Water Board) prepared Environmental Impact Report (EIR)
- USFW prepared a Biological Opinion
- CA DFW prepared Consistency Determination
- SHPO and FERC developed a Programmatic Agreement to satisfy requirements of the National Historic Preservation Act

Water Resources

- Potential effects on the Chuckwalla Valley Groundwater Basin studied exhaustively (by FERC and the SWRCB)
- Project will use <1% of total Chuckwalla Valley aquifer volume
- Projected drawdown attributable to Project is ~4' over 50-year license period, with aquifer recovery over the following 17 years
- Mitigation adopted to protect neighboring wells

Biological Resources

- ***Biological Resources requiring consideration:*** desert tortoise, bighorn sheep, eagles and other raptors, desert vegetation
- ***Mitigation includes:***
  - transmission route completely avoiding a Desert Wildlife Management Area (DWMA)
  - Habitat replacement *(desert tortoise)*
  - Fencing *(bighorn sheep, other wildlife)* and Netting *(birds)*
  - Monitoring

Cultural Resources

- ***Cultural Resources requiring consideration:*** World War II Desert Training Center, Historic mine operations of the Kaiser Eagle Mountain Mine
- ***Mitigation includes:***
  - routing of pipeline and transmission lines to avoid sensitive resources
  - inventory of historic Town of Eagle Mountain mine-worker housing area
  - monitoring throughout construction

KEY RESOURCE AREAS:

Air Quality/Greenhouse Gases (GHG)

- Air emissions during construction exceed Air District standards for a 3-4 year period
  - ***Mitigation***: minimization of construction equipment emissions, use of electric-powered equipment where feasible
- After construction, Project provides ***air quality benefits***: (1) net reduction in emissions from regional energy generation, (2) contributes to integration of higher percentage of renewable energy generation sources, (3) reduces reliance on natural gas-fired power plants

KEY RESOURCE AREAS:

Aesthetics/Visual Resources

- Bureau of Land Management's *Visual Resource Assessment* method determines unavoidable visual intrusion at Interstate 10 crossing
- ***Visual intrusion mitigation:***
  - routing parallel to existing transmission corridor
  - reduced visibility from Interstate 10
  - crossing Interstate 10 in a transmission corridor adjacent with local solar power projects

Land Use Compatibility

- ***Land Use requiring consideration:*** Joshua Tree National Park, 3 nearby solar projects, federally designated desert tortoise wildlife management area (DWMA), BLM lands requiring right-of-way, private community of Lake Tamarisk, future Eagle Mountain Landfill (which is no longer proposed)
- ***Mitigation includes:*** (1) routing of pipeline/transmission lines to avoid DWMA and Lake Tamarisk community, (2) participation to control ravens around the reservoirs, (3) installation of limited security lighting to avoid visual intrusion on NPS wilderness areas

Modeling and Analysis of Value of Advanced Pumped Storage Hydropower in the U.S.

CPUC Technical Workshop on Pumped Storage

January 16, 2014

Vladimir KORITAROV
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Argonne, IL 60439
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Project Summary & Team

- Project Team led by Argonne National Laboratory was awarded funding by the U.S. Department of Energy for the study**: Modeling and Analysis of Value of Advanced Pumped Storage Hydropower in the U.S.**

- Team members:
  - **Argonne National Laboratory (Argonne)** – Project Lead
  - **Siemens Energy, Inc.**
  - **Energy Exemplar, LLC.**
  - **MWH Americas, Inc.**
  - **National Renewable Energy Laboratory (NREL)**

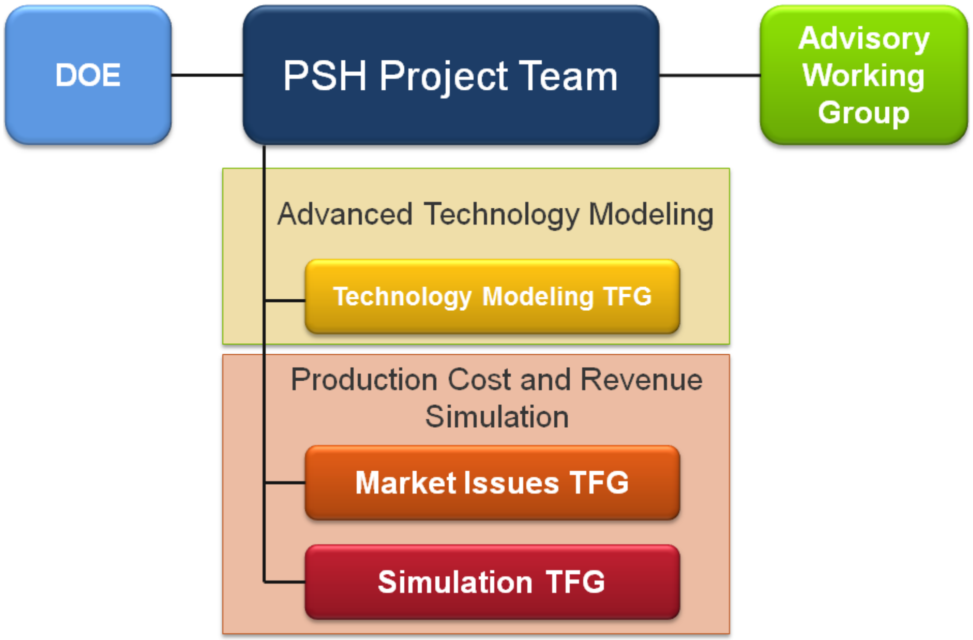
- Project website: http://www.dis.anl.gov/psh

Project Goals & Objectives

Develop detailed models of advanced PSH plants to analyze their technical capabilities to provide various grid services and to assess the value of these services under different market structures.

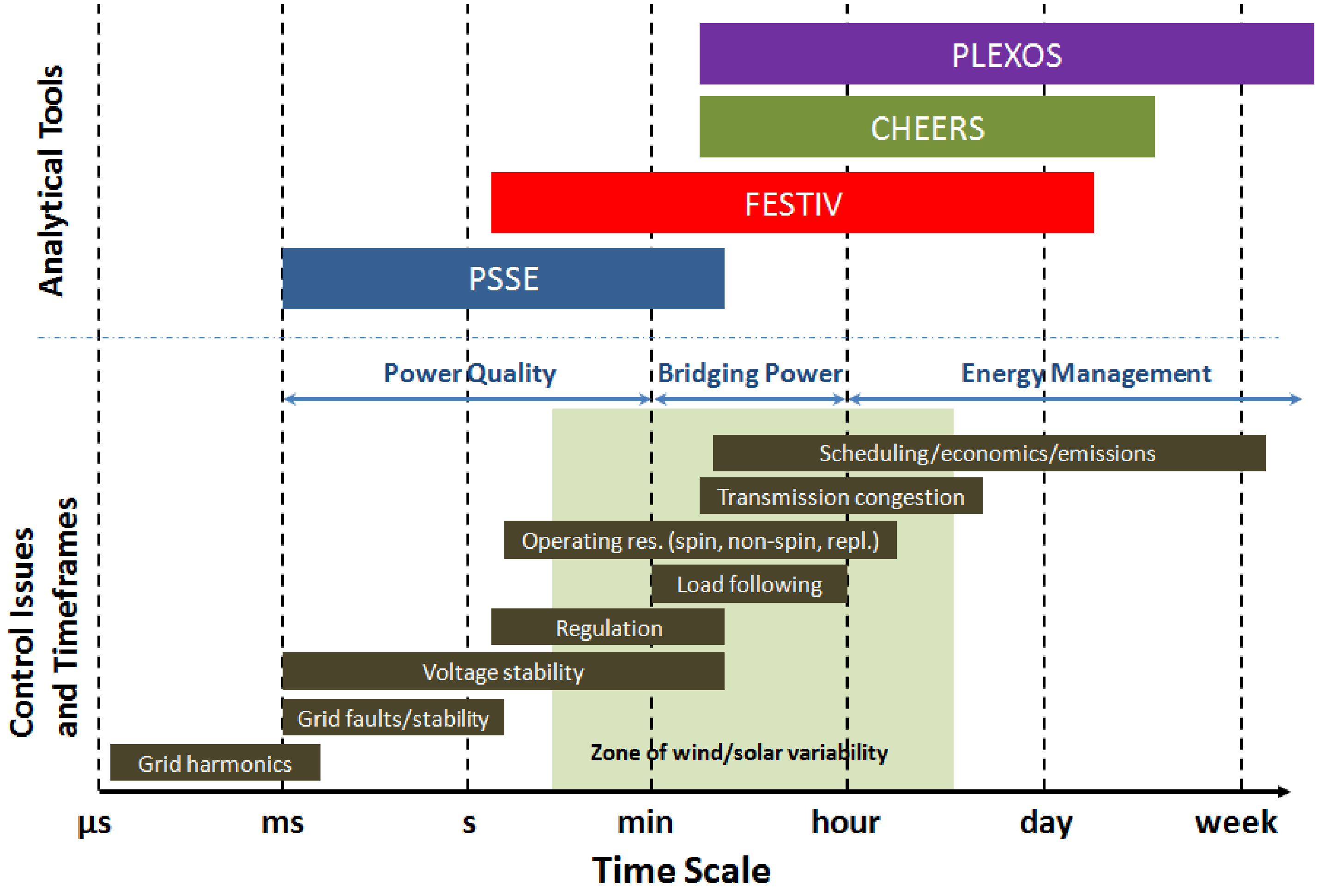
Main Objectives:

- Improve modeling representation of advanced PSH plants
- Quantify their capabilities to provide various grid services
- Analyze the value of these services under different market conditions and levels of variable renewable generation
- Provide information on full range of benefits and value of PSH



Analysis Addressed Wide Range of Control Issues & Timeframes

- Analysis aimed to capture PSH dynamic responses and operational characteristics across different timescales, from a fraction of a second to days/weeks.



Advanced Technology Modeling

Model Development

- Technology Modeling TFG has developed vendor-neutral dynamic models for advanced PSH technologies and described them in three reports:
  - ✓Review of existing CH and PSH models in use in the United States
  - ✓Dynamic simulation models for adjustable speed PSH
  - ✓Dynamic simulation models for ternary PSH units
- Draft models and reports were reviewed by the AWG members
- Reports have been cleared for unlimited distribution and are now publicly available.

Integration and Testing of Dynamic Models

Model Integration and Testing

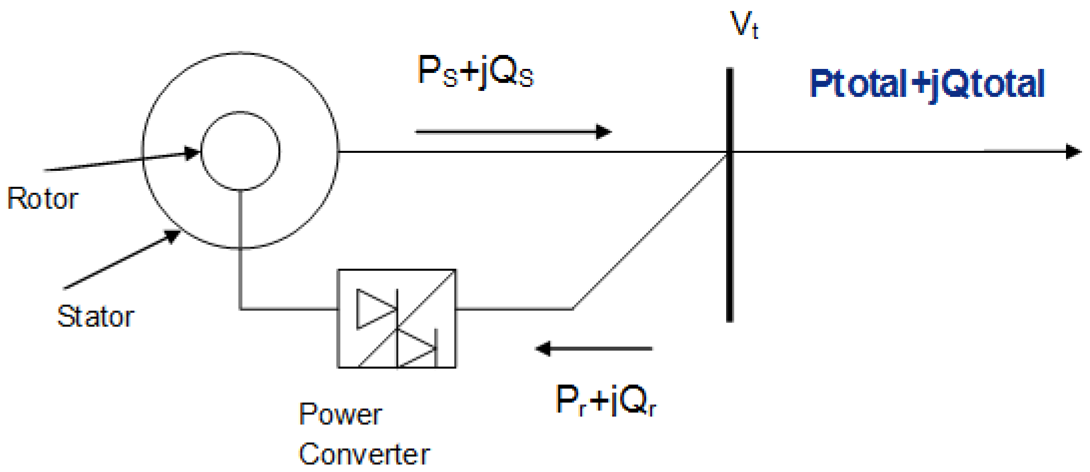
- Dynamic models for adjustable speed PSH and ternary units were coded and integrated into the PSS®E model
- Testing of these models for both generating and pumping mode of operation was performed using PSS®E test cases and dynamic cases for Western Interconnection (WI)
- Additional AGC studies have been performed for SMUD balancing authority
- Published a report on frequency regulation capabilities of advanced PSH technologies

PSH Provides Various Services and Contributions to the Power System

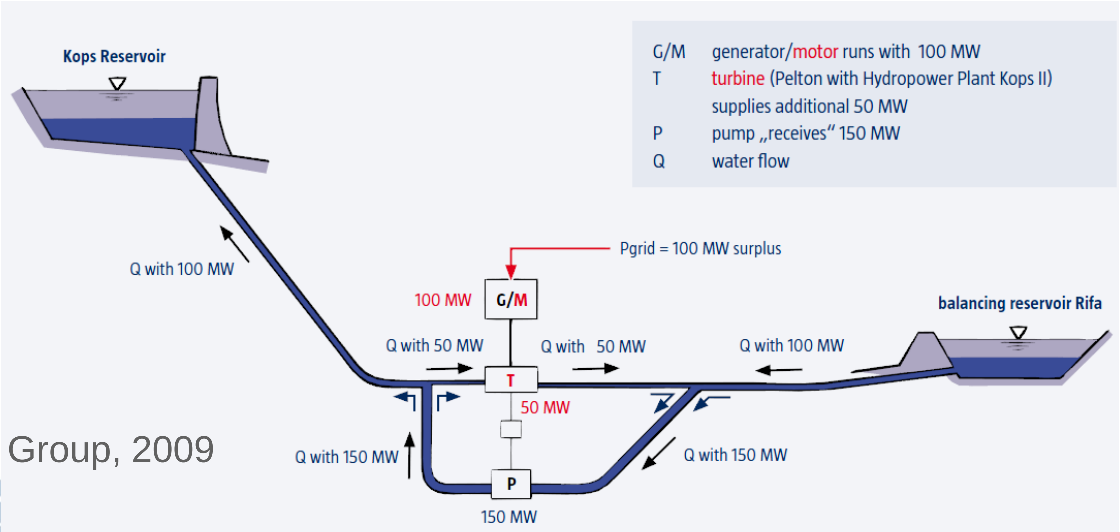
	PSH Contribution
1	Inertial response
2	Governor response, frequency response, or primary frequency control
3	Frequency regulation, regulation reserve, or secondary frequency control
4	Flexibility reserve
5	Contingency spinning reserve
6	Contingency non-spinning reserve
7	Replacement/Supplemental reserve
8	Load following
9	Load leveling / Energy arbitrage
10	Generating capacity
11	Integration of variable energy resources (VER)
12	Portfolio effects
13	Reduced cycling of thermal units
14	Reduced transmission congestion
15	Voltage support
16	Improved dynamic stability
17	Reduced environmental emissions
18	Energy security
19	Transmission deferral
20	Black start capability

Adjustable Speed PSH Technologies Provide Even More Flexibility than Conventional Fixed-Speed PSH

- Adjustable speed PSH with doubly-fed induction machines (DFIM):



- Ternary units with hydraulic short circuit:



Source: Illwerke VKW Group, 2009

Additional Benefits of Adjustable Speed PSH

- More flexible and efficient operation in generation mode
  - Minimum unit power output as low as 20%-30%
  - Increased efficiency and lifetime of the turbine at partial loads by operating at optimal speed
- Frequency regulation capabilities also available in the pumping mode
- Electronically decoupled control of active and reactive power
  - Provides more flexible voltage support
- Improved dynamic behavior and stability of power system
  - Improved transient stability in case of grid faults (e.g., short circuit faults in the transmission system)
  - Reduced frequency drops in case of generator outages
- Better compensation of variability of renewable energy sources
  - More flexible and quicker response in generating (turbine) mode
  - Variable power in pumping mode to counterbalance variability of wind
  - Excellent source of frequency regulation during the off-peak hours

PLEXOS Model was Used for Production Cost and Revenue Simulations

- Focus on western U.S. (several levels of geographical scope, including entire WI, CAISO/California, and individual balancing authority - SMUD)

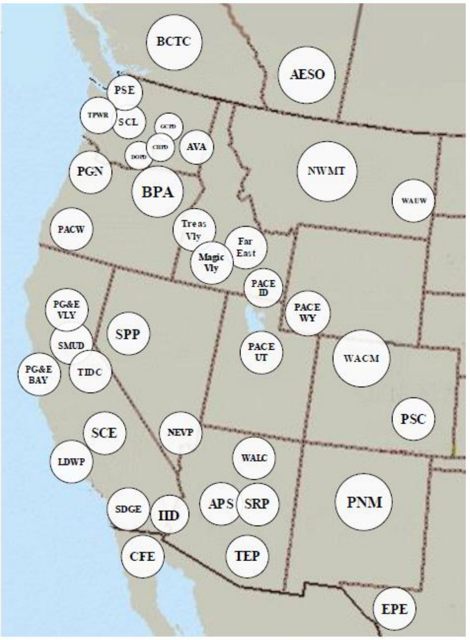
- A "future year" (FY) representation of the WI system is largely based on WECC's long-term projections for 2022

- Simulation Period:
  - DA simulations (hourly time step) for entire year to determine maintenance schedule of thermal units and annual-level PSH economics
  - DA-HA-RT sequential simulations (hourly and 5-minute time step) for typical weeks (third week in January, April, July, and October) to analyze PSH operation under conditions of variability and uncertainty of renewable resources

PLEXOS Inputs were Based on TEPPC 2022 Common Case

- WECC's TEPPC 2022 case served as foundation for building FY cases (certain case parameters and data varied depending on scenario assumptions)
- Both cost-based and market-based approaches were used in analysis
- Two levels of variable energy resources were analyzed:
  - Base RE scenario (RPS mandate)
  - High RE scenario (High Wind from WWSIS-2)
- PLEXOS simulations of WI and California were performed at nodal (bus) level

TEPPC Load Bubbles



Legend

AESO	Alberta Electric System Operator
APS	Arizona Public Service
AVA	Avista
BCTC	British Columbia Transmission Corp
BPA	Bonneville Power Administration
CFE	Comision Federal de Electricidad
CHPD	Chelan Co PUD
DCPD	Douglas Co PUD
EPE	El Paso Electric
Far East	Far East (Idaho Power)
GCPD	Grant Co PUD
IID	Imperial Irrigation District
LDWP	Los Angeles Dept of Water & Power
Magic Vly	Magic Valley (Idaho Power)
NEVP	Nevada Power
NWMT	Northwestern Montana
PACW	PacifiCorp West
PACE ID	PacifiCorp East – Idaho
PACE UT	PacifiCorp East – Utah
PACE WY	PacifiCorp East – Wyoming
PG&E Bay	Pacific Gas & Electric Bay Area
PG&E VLY	Pacific Gas & Electric Valley Area
PGN	Portland Gen Electric
PNM	Public Service New Mexico
PSC	Public Service Colorado (Xcel)
PSE	Puget Sound Energy
SCE	Southern California Edison
SCL	Seattle City Light
SDGE	San Diego Gas & Electric
SMUD	Sacramento Municipal District
SPP	Sierra Pacific Power
SRP	Salt River Project
TEP	Tucson Electric Power
TIDC	Turlock Irrigation District
TPWR	Tacoma Power
TreasVly	Treasure Valley (Idaho Power)
WACM	Western Area Power Admin Colorado/Missouri
WALC	Western Area Power Admin Lower Colorado
WAUW	Western Area Power Admin Upper Missouri

- 39 load regions in WI
- 8 spinning reserve sharing groups
- 20 flexibility & regulation reserve sharing groups

PLEXOS Modeling of California in 2022

Simulation runs for California were performed using market-based approach (cost-based approach was applied for WI and SMUD):

<u>**California simulations:**</u>

- ***Annual runs*** for Base and High-Wind scenarios (DA runs with hourly time step and co-optimization of energy and ancillary services):
  - Without PSH plants
  - With existing conventional (fixed-speed) PSH plants in California
  - With existing FS PSH and 2 adjustable speed PSH (at Iowa Hill and Eagle Mountain locations)
- ***Weekly runs*** for four typical weeks in different seasons (January, April, July, and October) applying three-stage approach (DA-HA-RT) and co-optimization of energy and ancillary services:
  - Without PSH plants
  - With existing conventional (fixed-speed) PSH plants
  - With existing fixed-speed PSH and 2 adjustable speed PSH (at Iowa Hill and Eagle Mountain locations)

California: System Production Costs in 2022

- Baseline RE scenario:

Base Renewable Scenario	Total Generation	PSH Generation	Production Cost	Annual Cost Reduction		Annual Cost Reduction per kW of PSH Capacity	
	GWh	GWh	$ Million	$ Million	%	Total PSH MW	$/kw-year
No PSH	265,538	-	5,078	-	-	-	-
With FS PSH	267,001	2,725	4,967	111	2.18%	2626	42.10
With FS&AS PSH	269,374	5,313	4,907	171	3.36%	4425	38.60

Annual operating costs savings

- High-Wind RE scenario:

High-Wind Renewable Scenario	Total Generation	PSH Generation	Production Cost	Annual Cost Reduction		Annual Cost Reduction per kW of PSH Capacity	
	GWh	GWh	$ Million	$ Million	%	Total PSH MW	$/kw-year
No PSH	253,872	-	4,120	-	-	-	-
With FS PSH	256,069	5,299	3,934	186	4.52%	2626	70.91
With FS&AS PSH	257,018	9,456	3,745	376	9.12%	4425	84.97

Significant cost savings

California: Curtailments of RE Generation in 2022

- Baseline RE scenario:

CA Renewable Curtailment in the Base Renewable Scenario			
		Renewable Curtailment Reduction	
Case	GWh	GWh	%
No PSH	155	-	0%
With FS PSH	46	108	70%
With FS&AS PSH	14	141	91%

With additional AS PSH, curtailments of RE almost eliminated

- High-Wind RE scenario:

CA Renewable Curtailment in the High-Wind Renewable Scenario			
		Renewable Curtailment Reduction	
Case	GWh	GWh	%
No PSH	618	-	0%
With FS PSH	380	238	39%
With FS&AS PSH	275	343	55%

California: PSH Provisions of System Reserves in 2022

- Baseline RE scenario:

Base Renewable Scenario	Base - No PSH		With FS PSH		With FS&AS PSH	
	Total Req. (GWh)	PSH Provision (GWh)	Total Req. (GWh)	PSH Provision (GWh)	Total Req. (GWh)	PSH Provision (GWh)
Non-Spinning Reserve	8,505	-	8,505	7,090	8,505	7,905
Spinning Reserve	8,505	-	8,505	224	8,505	2,463
Flexibility Down	3,130	-	3,130	47	3,130	1,098
Flexibility Up	3,130	-	3,130	13	3,130	341
Regulation Down	3,810	-	3,810	171	3,810	1,264
Regulation Up	3,839	-	3,839	164	3,839	1,109

Due to AS PSH flexible pumping

- High-Wind RE scenario:

High-Wind Renewable Scenario	Base - No PSH		With FS PSH		With FS&AS PSH	
	Total Req. (GWh)	PSH Provision (GWh)	Total Req. (GWh)	PSH Provision (GWh)	Total Req. (GWh)	PSH Provision (GWh)
Non-Spinning Reserve	8,505	-	8,505	4,774	8,505	5,492
Spinning Reserve	8,505	-	8,505	247	8,505	2,022
Flexibility Down	4,804	-	4,804	141	4,804	1,934
Flexibility Up	4,804	-	4,804	26	4,804	200
Regulation Down	4,394	-	4,394	377	4,394	1,761
Regulation Up	4,442	-	4,442	144	4,442	1,201

Due to AS PSH flexible pumping

California: System Emissions in 2022

- Baseline RE scenario:

Base Renewable Scenario	CO2	NOx	SO2	Emission Reduction (ton)			Emission Reduction (%)		
	Ton	ton	ton	CO2	NOx	SO2	CO2	NOx	SO2
No PSH	65,429,529	53,681	6,006	-	-	-	0.0%	0.0%	0.0%
With FS PSH	64,741,362	53,512	6,093	688,166	170	(87)	1.1%	0.3%	-1.5%
With FS&AS PSH	64,625,964	53,568	6,165	803,565	113	(160)	1.2%	0.2%	-2.7%

- High-Wind RE scenario:

High-Wind Renewable Scenario	CO2	NOx	SO2	Emission Reduction (ton)			Emission Reduction (%)		
	Ton	ton	ton	CO2	NOx	SO2	CO2	NOx	SO2
No PSH	51,515,736	44,936	5,334	-	-	-	0.0%	0.0%	0.0%
With FS PSH	49,692,105	44,010	5,350	1,823,631	925	(16)	3.5%	2.1%	-0.3%
With FS&AS PSH	47,904,187	43,177	5,427	3,611,549	1,759	(93)	7.0%	3.9%	-1.7%

PSH plants reduce CO2 and NOx emissions under both scenarios

California: Thermal Generator Cycling in 2022

- Baseline RE scenario:

Base Renewable Scenario	Total Number of Thermal Starts	Total Thermal Start Cost	Cost Reduction	
		$ Million	$ Million	%
No PSH	18,514	56	-	-
With FS PSH	14,646	46	10	17.35%
With FS&AS PSH	12,134	36	20	35.40%

- High-Wind RE scenario:

High-Wind Renewable Scenario	Total Number of Thermal Starts	Total Thermal Start Cost	Cost Reduction	
		$ Million	$ Million	%
No PSH	17,862	54	-	-
With FS PSH	14,351	44	11	19.56%
With FS&AS PSH	11,864	35	20	36.42%

FS & AS PSH plants reduce cycling cost of thermal units by one third

California: Thermal Generator Ramping in 2022

- Baseline RE scenario:

Base Renewable Scenario	Total Thermal Generator Ramp Up	Total Thermal Generator Ramp Down	Ramp Up Reduction		Ramp Down Reduction	
	GW	GW	GW	%	GW	%
No PSH	4,273	6,603	-	-	-	-
With FS PSH	3,623	5,552	650	15.20%	1,052	15.93%
With FS&AS PSH	2,924	4,456	1,349	31.56%	2,147	32.51%

Ramping of thermal units reduced by one third

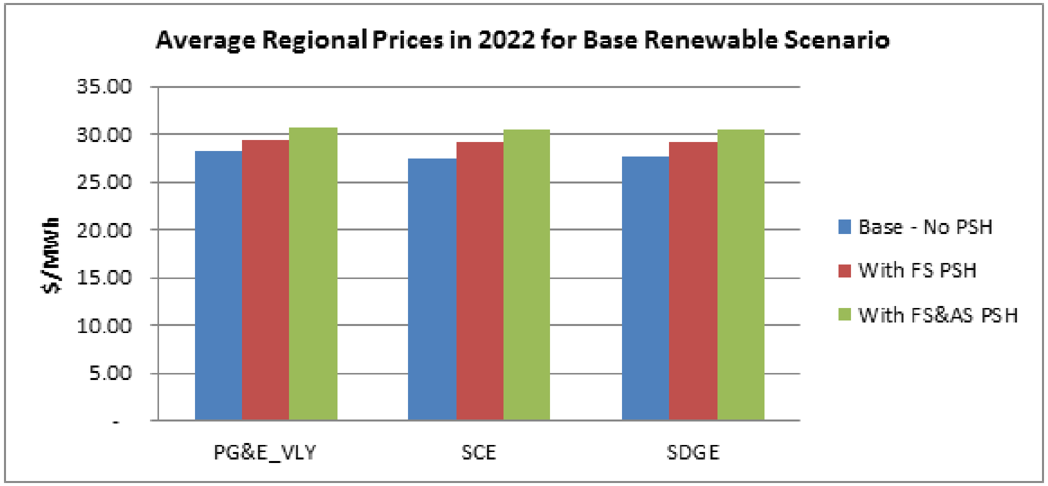
- High-Wind RE scenario:

High-Wind Renewable Scenario	Total Thermal Generator Ramp Up	Total Thermal Generator Ramp Down	Ramp Up Reduction		Ramp Down Reduction	
	GW	GW	GW	%	GW	%
No PSH	3,609	5,681	-	-	-	-
With FS PSH	3,078	4,737	531	14.71%	945	16.63%
With FS&AS PSH	2,396	3,738	1,214	33.63%	1,943	34.20%

Ramping of thermal units reduced by one third

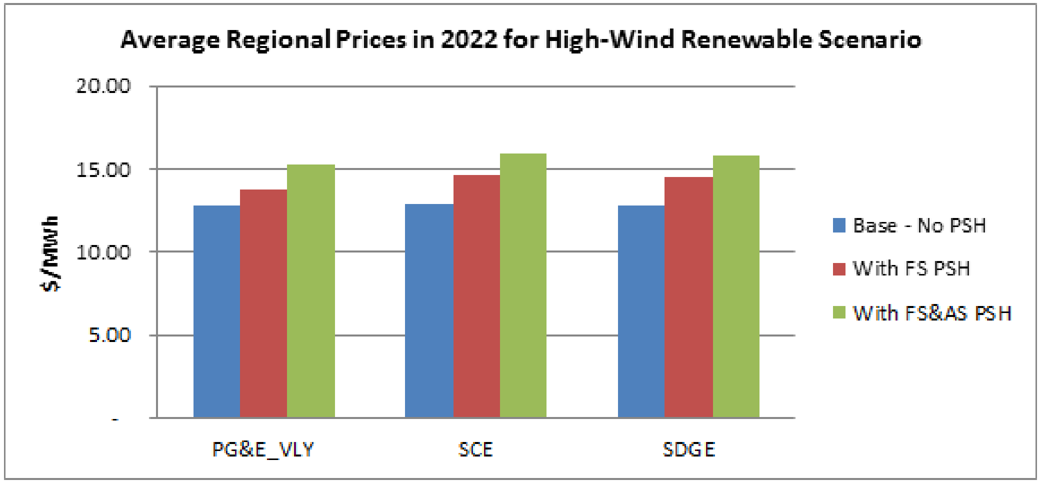
California: Regional LMPs in 2022 Are Significantly Lower under High-Wind RE Scenario

- Baseline RE scenario:



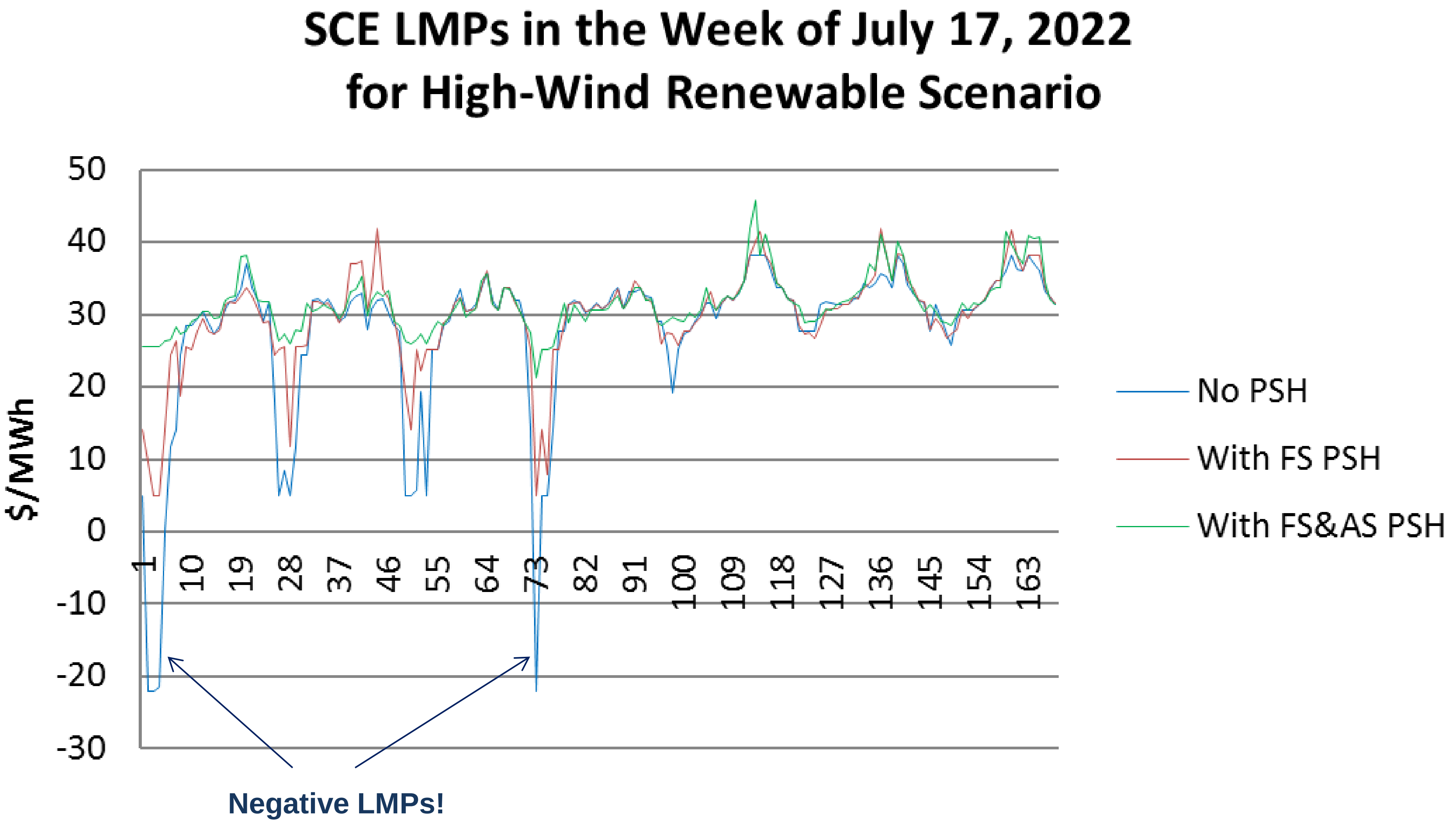
Average LMPs:
27-30 $/MWh

- High-Wind RE scenario:



Average LMPs:
13-16 $/MWh

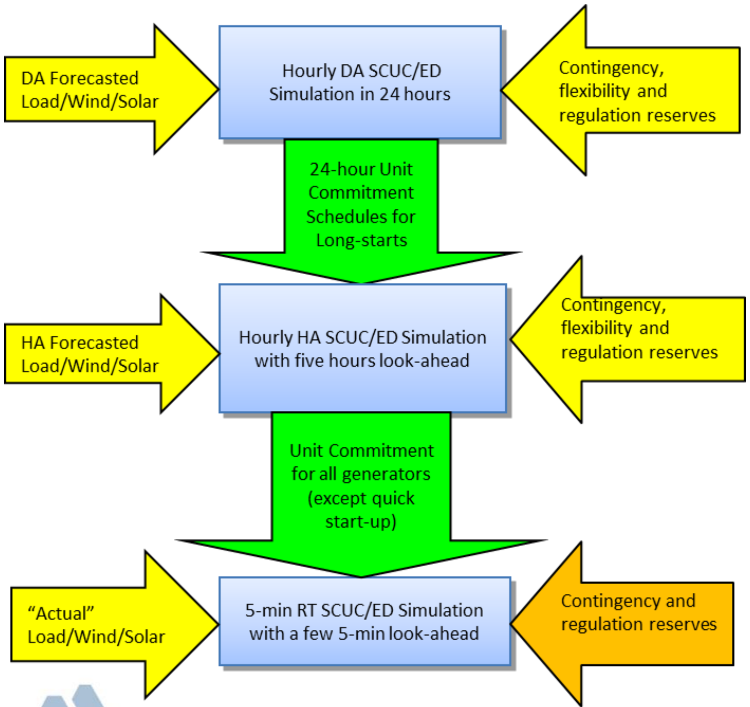
PSH Provides Load for RE Generation during Off-Peak Hours (Reduces RE Curtailments and Negative LMPs)



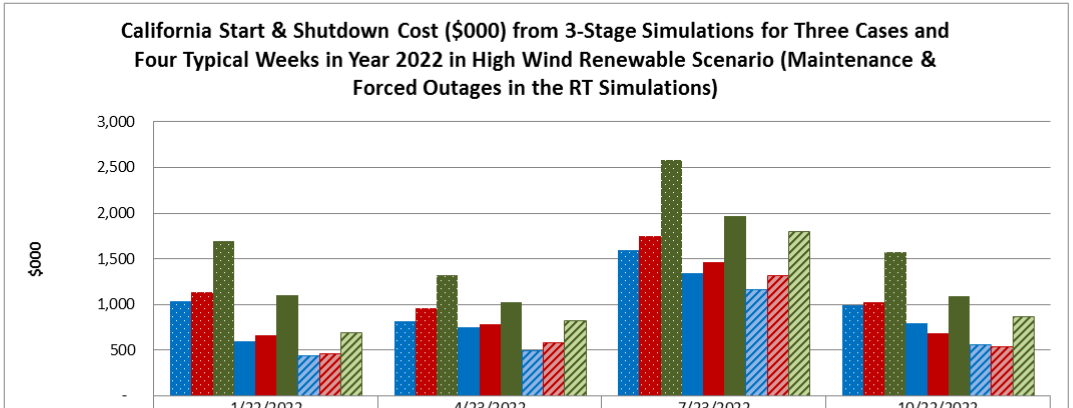
California: 3-Stage DA-HA-RT Modeling

- Detailed simulation (5-minute time step in RT simulations) of four typical weeks in different seasons of 2022 under High-Wind RE scenario
- Simulated: 3rd weeks of January, April, July, and October
- 3rd week in July is the peak load week

3-Stage Sequential Simulation



Results for Start and Shutdown Costs under High-Wind Scenario



	1/22/2022	4/23/2022	7/23/2022	10/22/2022
No PSH DA	1,032	821	1,595	990
No PSH HA	1,138	954	1,750	1,024
No PSH RT	1,690	1,320	2,580	1,575
FS PSH DA	595	753	1,344	799
FS PSH HA	667	781	1,468	686
FS PSH RT	1,104	1,027	1,973	1,085
FS&AS PSH DA	439	489	1,157	559
FS&AS PSH HA	464	578	1,313	541
FS&AS PSH RT	695	819	1,796	870

California: Summary of 3-Stage DA-HA-RT Modeling Results

Summary of 5-minute RT simulation results for High-Wind renewable generation scenario

High-Wind Renewable Scenario	Average Cost Savings or Decrease in Ramping Needs over the Four Simulated Typical Weeks in 2022			
	System Production Costs	Startup and Shutdown Costs	Ramp Up of Thermal Generators	Ramp Down of Thermal Generators
	%	%	%	%
No PSH	-	-	-	-
With FS PSH	5.01	27.58	9.76	15.10
With FS&AS PSH	7.27	41.67	33.05	64.16

Questions?

THANK YOU!

UNDERSTANDING CURRENT STATE OF PUMPED STORAGE BENEFITS AND BARRIERS

Michael L. Jones
Director, Power Generation
Pacific Gas and Electric Company

California Public Utilities Commission Technical Workshop

January 16, 2014

Benefits: Proven

The only PROVEN large storage technology able to support Grid Operations

30 years of operation at Helms Pumped Storage facility – robust licensing and regulatory oversight of safety, environmental, and reliable operations

930 MW pumping to 1,212 MW generating
Of SUSTAINED Energy/Capacity/Ancillary Services

Spin/Load following (240 MW/Min)
Non-Spin (0 to 1,212 MW in less than 10 min
Regulation (AGC)
Inertia: 3 million lbs of rotating equipment

Benefits: New Technology

While pumped storage is tried and true technology, there are additional technology enhancements that make it even more valuable:

Variable Speed Pumping

Ternary Design (pump and turbine on the same shaft)

Both can provide for demand side regulation and even "SMARTER GRID" benefits

Barriers: Uncertainty

Market

Planning and evaluation process:

- **Recognition of Value**

Large-scale:

- **Economies of scale comes with a large commitment**

Development lead time:

- **Robust licensing and regulatory oversight**
- **Appropriate approval path for either Independent or Utility Owned resources**