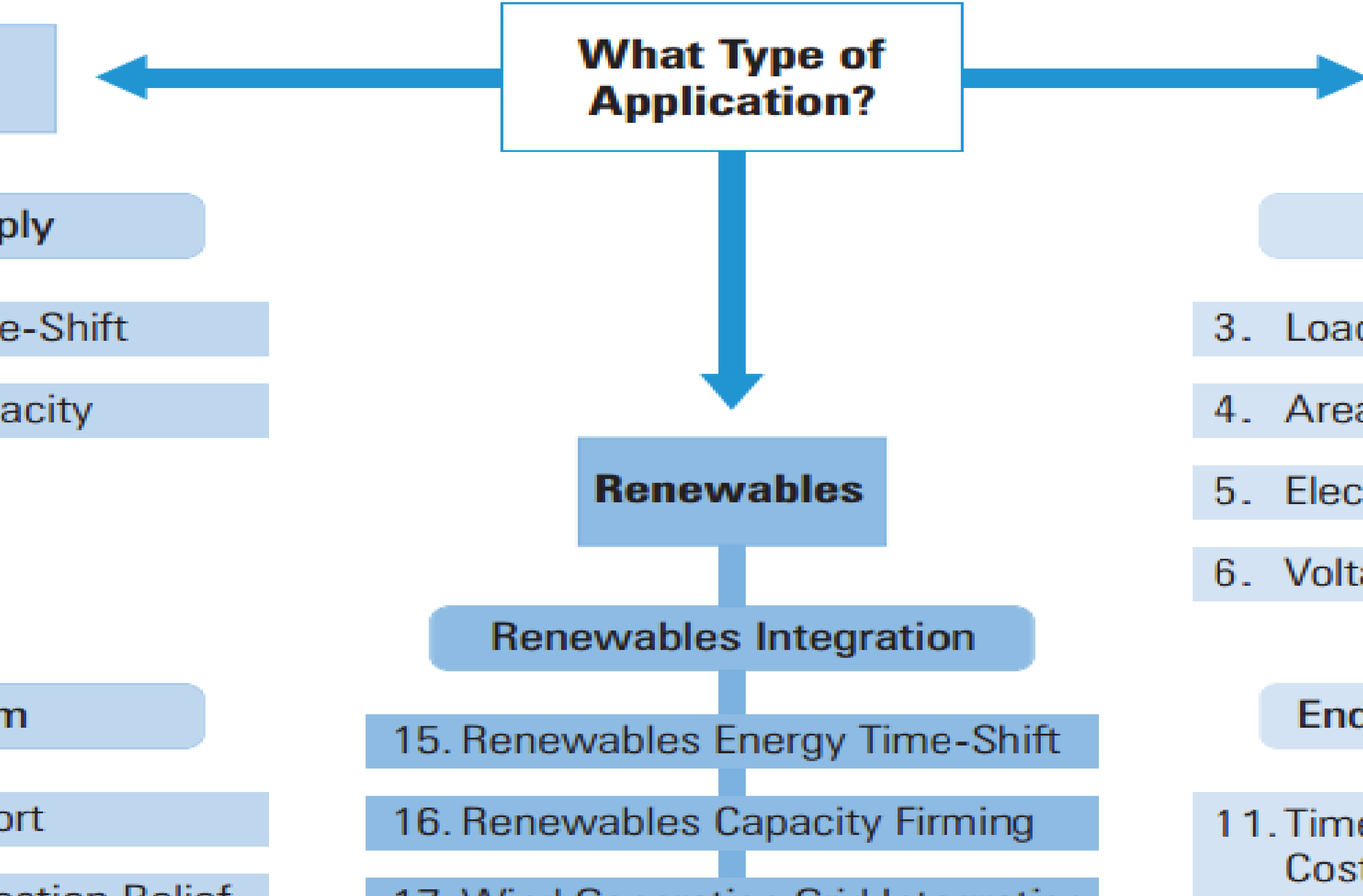
Status and Value Proposition of Energy Storage Technologies

- Dale T Bradshaw
- CEO Electrivation LLC
- consultant to NRECA and CEATI
- 423-304-9284
- dtbradshaw@electrivation.com
- Dale.Bradshaw@NRECA.coop
- Dale.Bradshaw@ceati.com

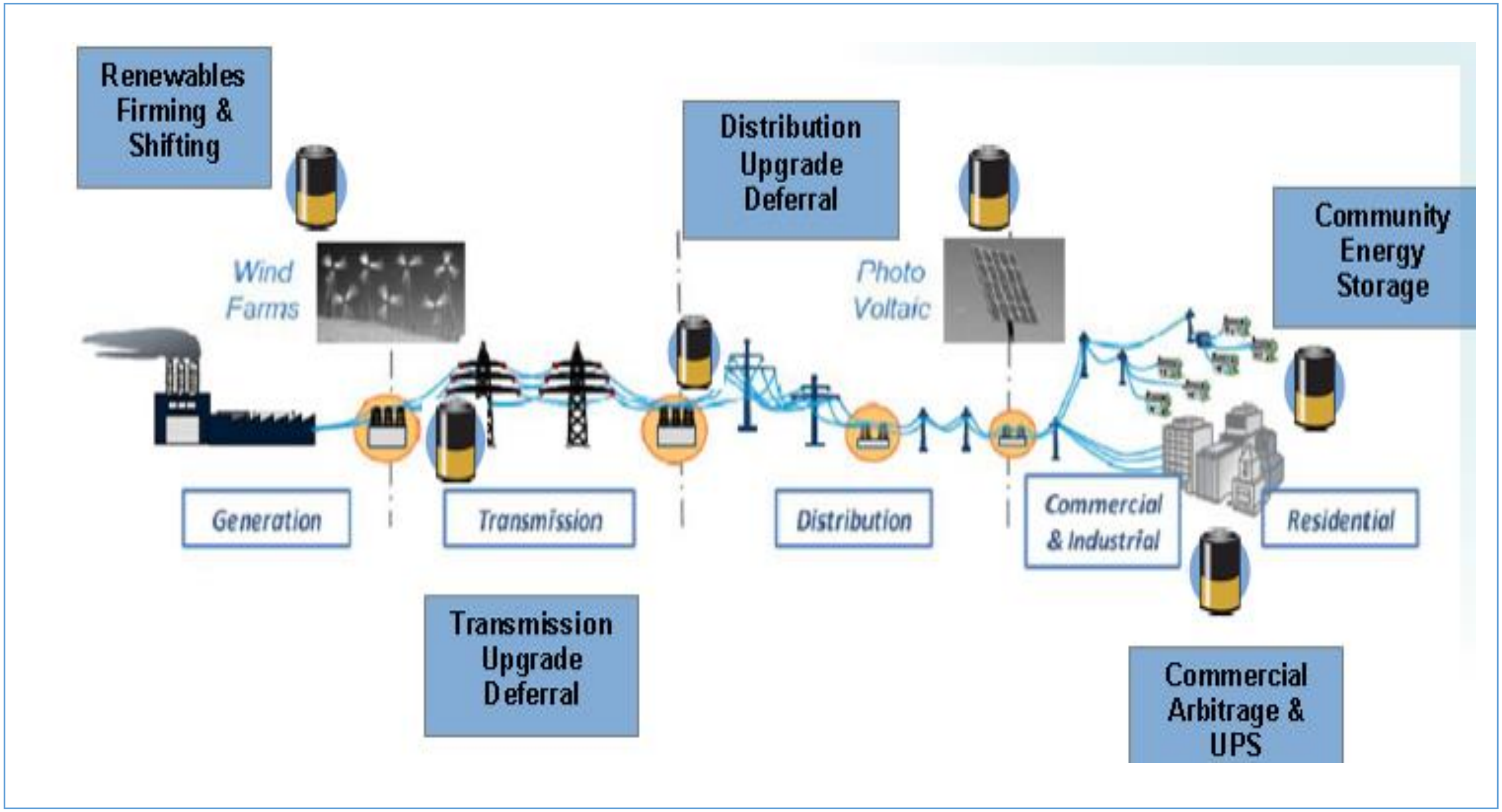
Introduction

The presentation today will give an overview of the Energy Storage Industry as a whole, the status of the Energy Storage Industry today, the prospects for cost reductions and improvements in the future, And key applications for energy storage like managing the intermittency of solar PV and shifting the solar PV output from the middle of the day to the late afternoon peaks in the load.

Various Value Streams



Energy Storage – The Business Case



Energy storage will prove critical in all aspects of generation, transmission, and distribution

Energy Storage Value Streams

Assuming low penetration of renewables

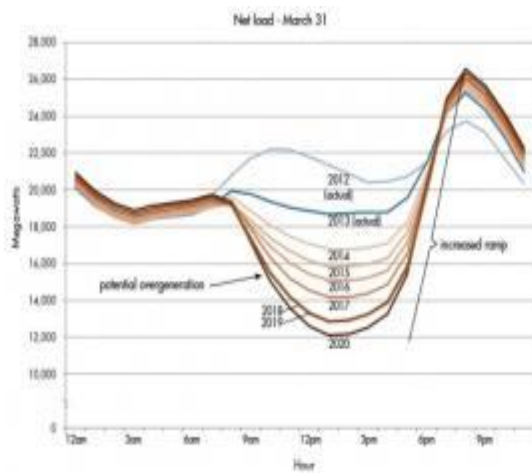
- Trim Daily Peaks
- Capacity credit or demand charge reduction
- Frequency regulation (Value has recently increased with new FERC order 755 allowing ISO/RTOs to pay higher $$ for pay for performance for energy storage)
- T&D capital asset deferral
- Avoid new distribution transformers or transformer banks
- Avoid line reconstructing new transmission lines

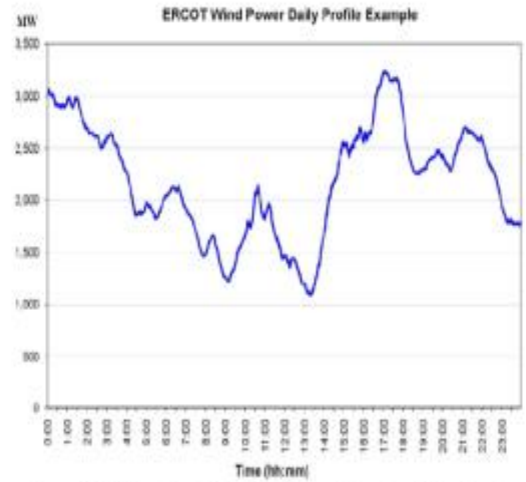
Energy Storage Value Streams

Assuming low penetration of renewables

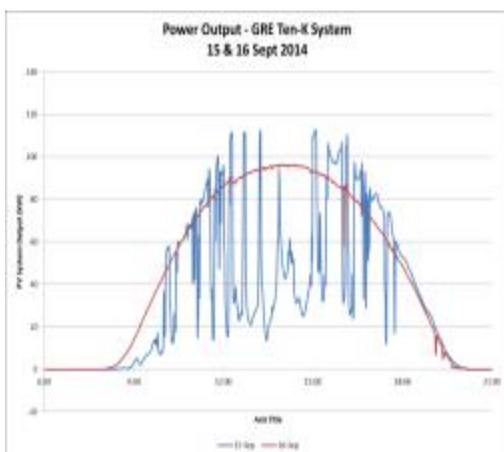
- Arbitrage value (low value due to relatively low price for natural gas)
- Firming and Shifting Renewables
  - Improve thermal plant efficiency/reliability
  - Reduce CO_2 emissions from thermal plants
  - Reduce NO_x and SO_x emissions from coal plants and NO_x emissions from NGCC
  - Reduce congestion and line losses
  - Eliminate rapid ramp rate requirements

Issues Confronting Utilities and Markets

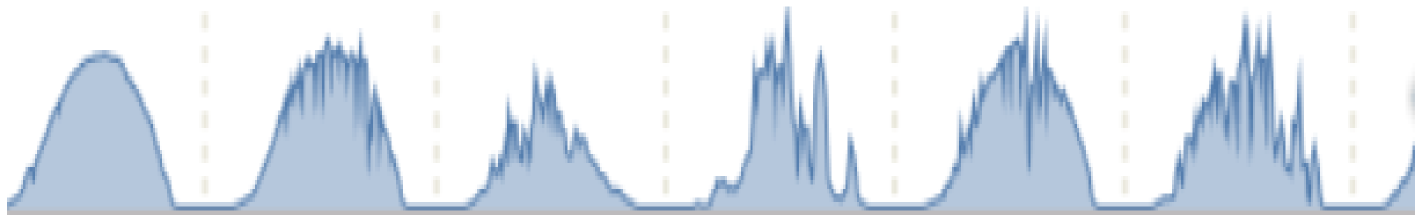




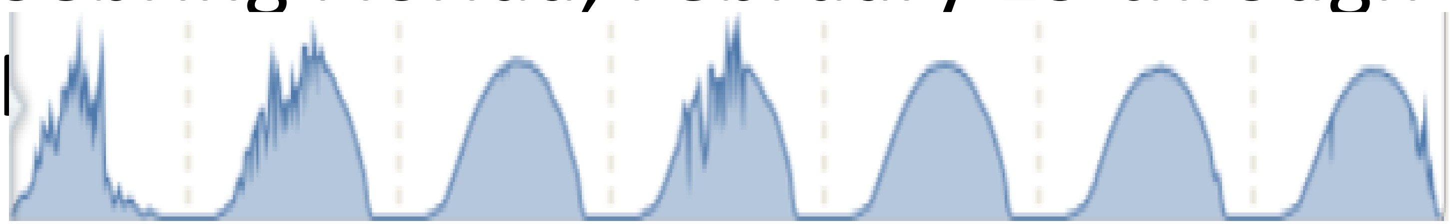
(from NREL's *Analysis of Wind Power Ramping Behavior…*)



Managing Solar Intermittency



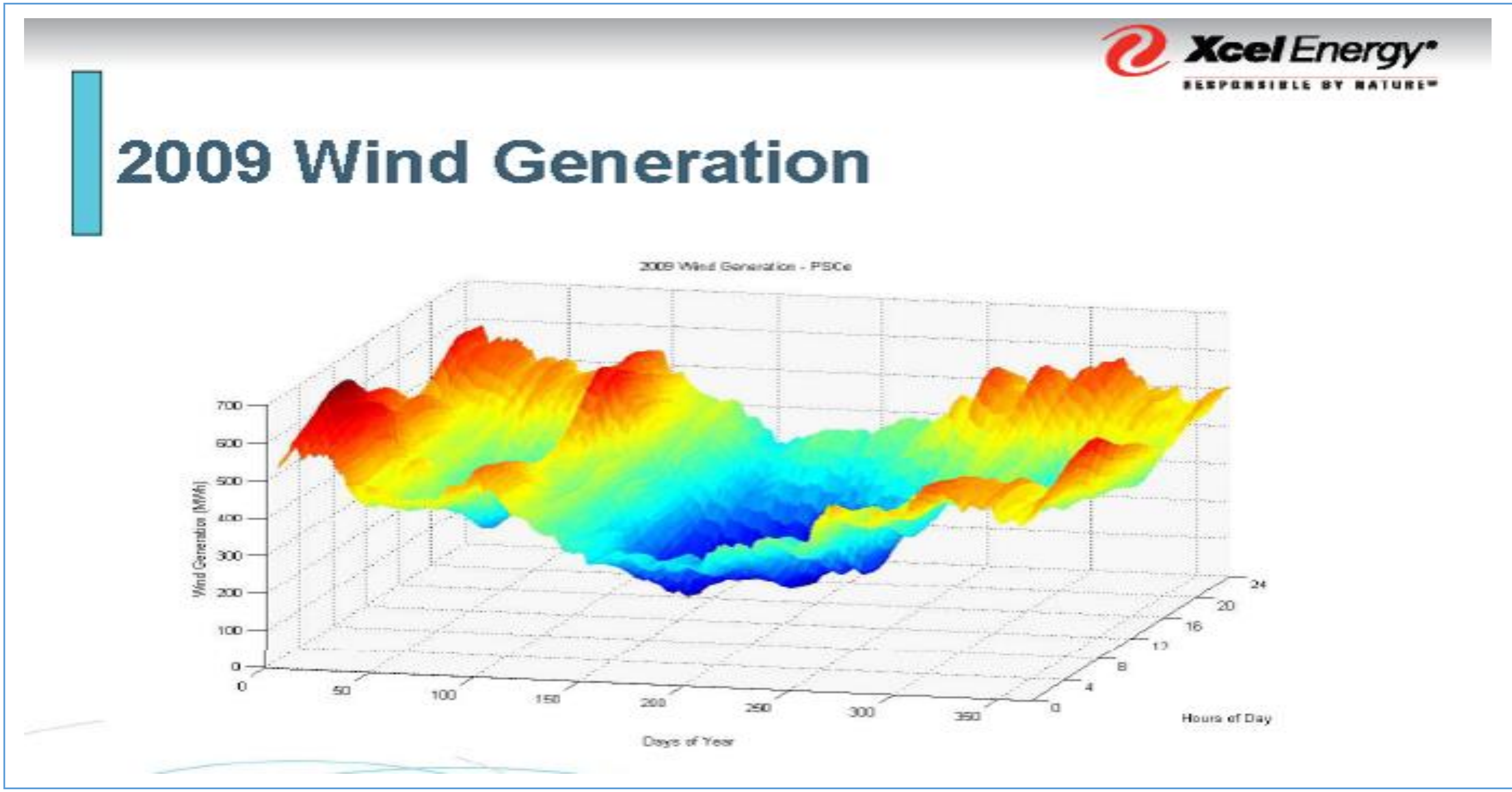
Sebring Florida, February 19 through



Sebring Florida, February 12

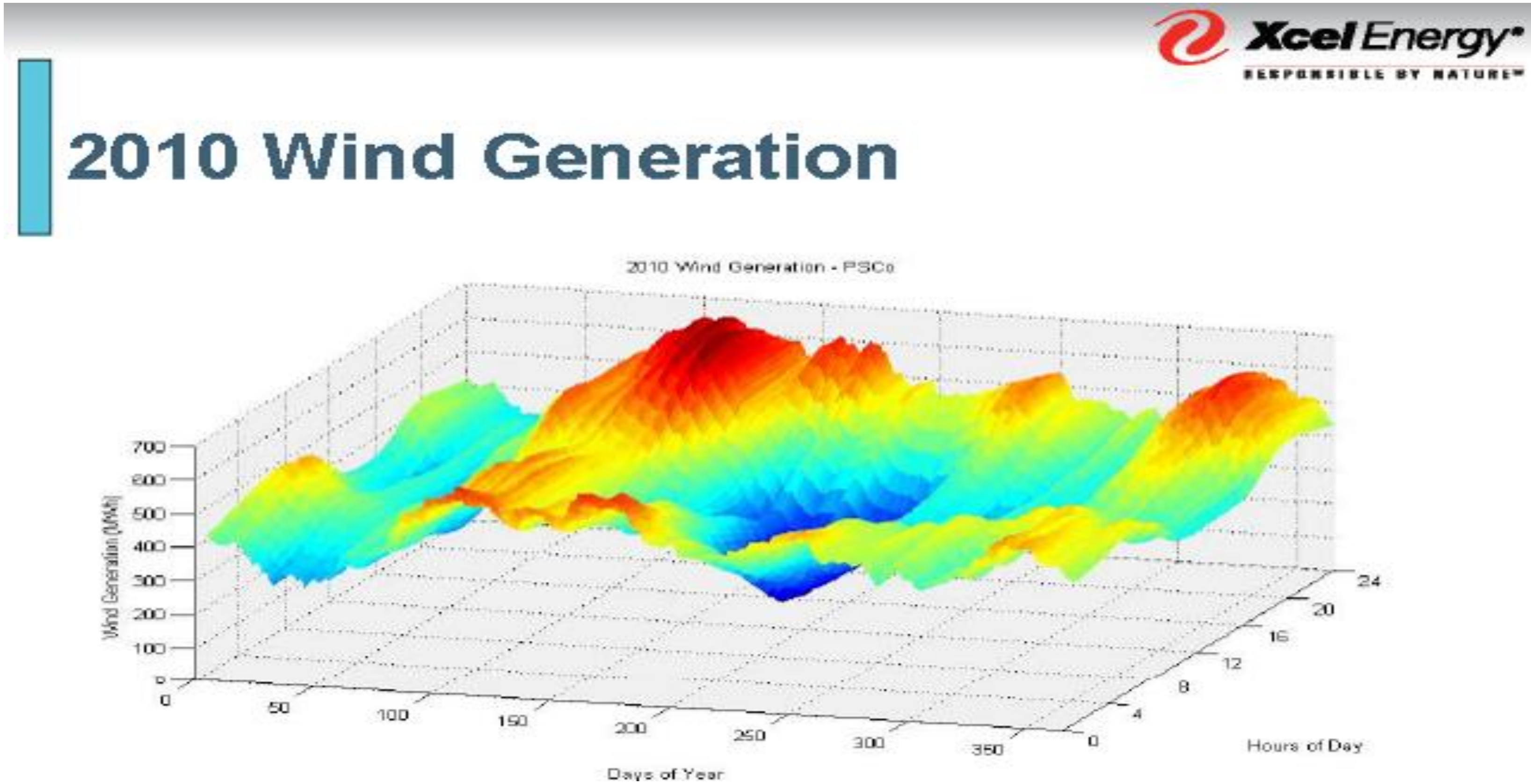
Sebring Florida, January 27 through February 2

Intermittency of Wind Generation for Xcel Energy in Colorado 2009



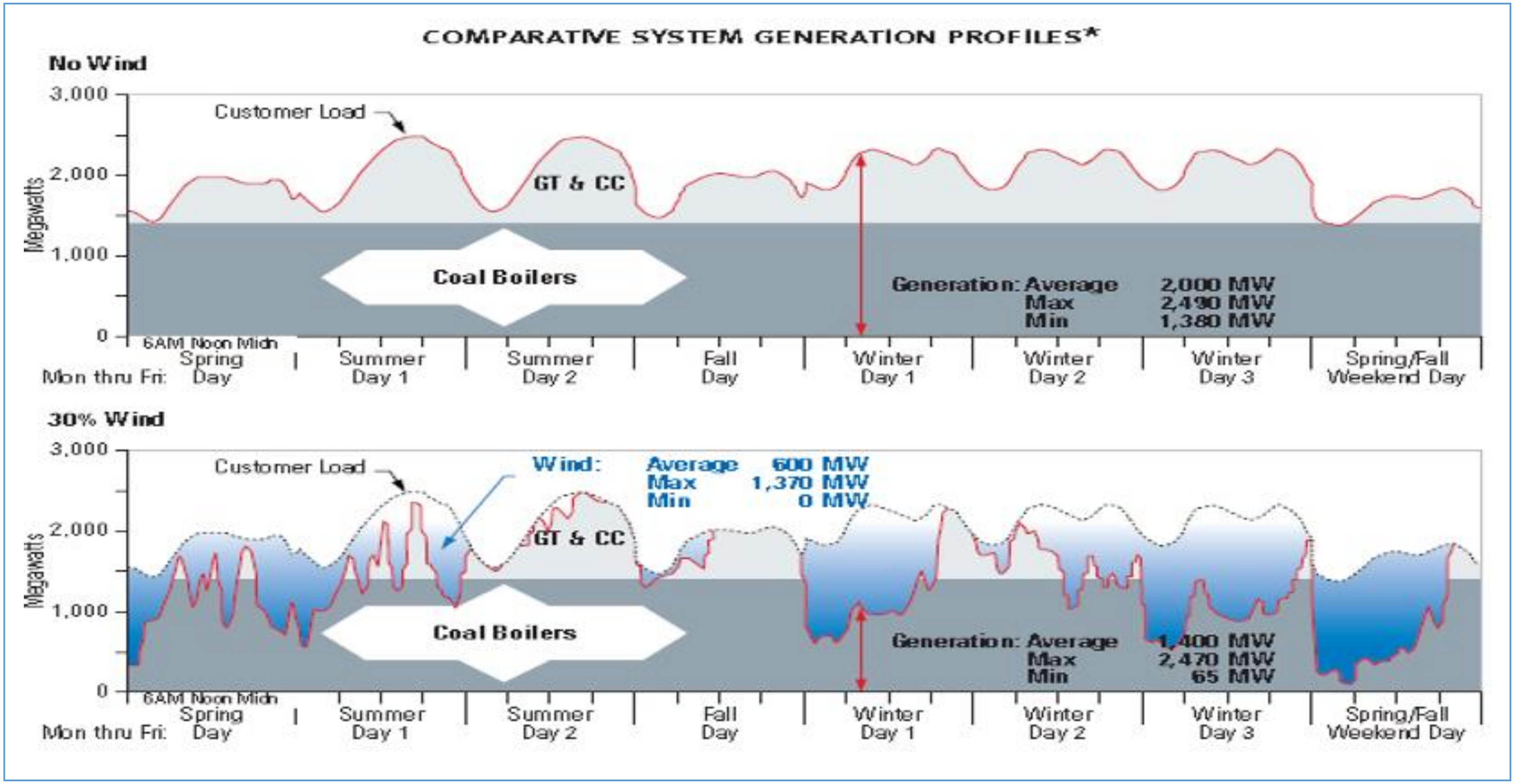
"Coal-Cycling Costs in Public Service of Colorado", Keith Parks, Conventional Generator Cycling and Variable Generation Workshop June 14th, 2011

Intermittency of Wind Generation for Xcel Energy in Colorado



"Coal-Cycling Costs in Public Service of Colorado", Keith Parks, Conventional Generator Cycling and Variable Generation Workshop June 14th, 2011

Impact of 30% Wind Generation for Typical G&T



Energy Storage Value Streams

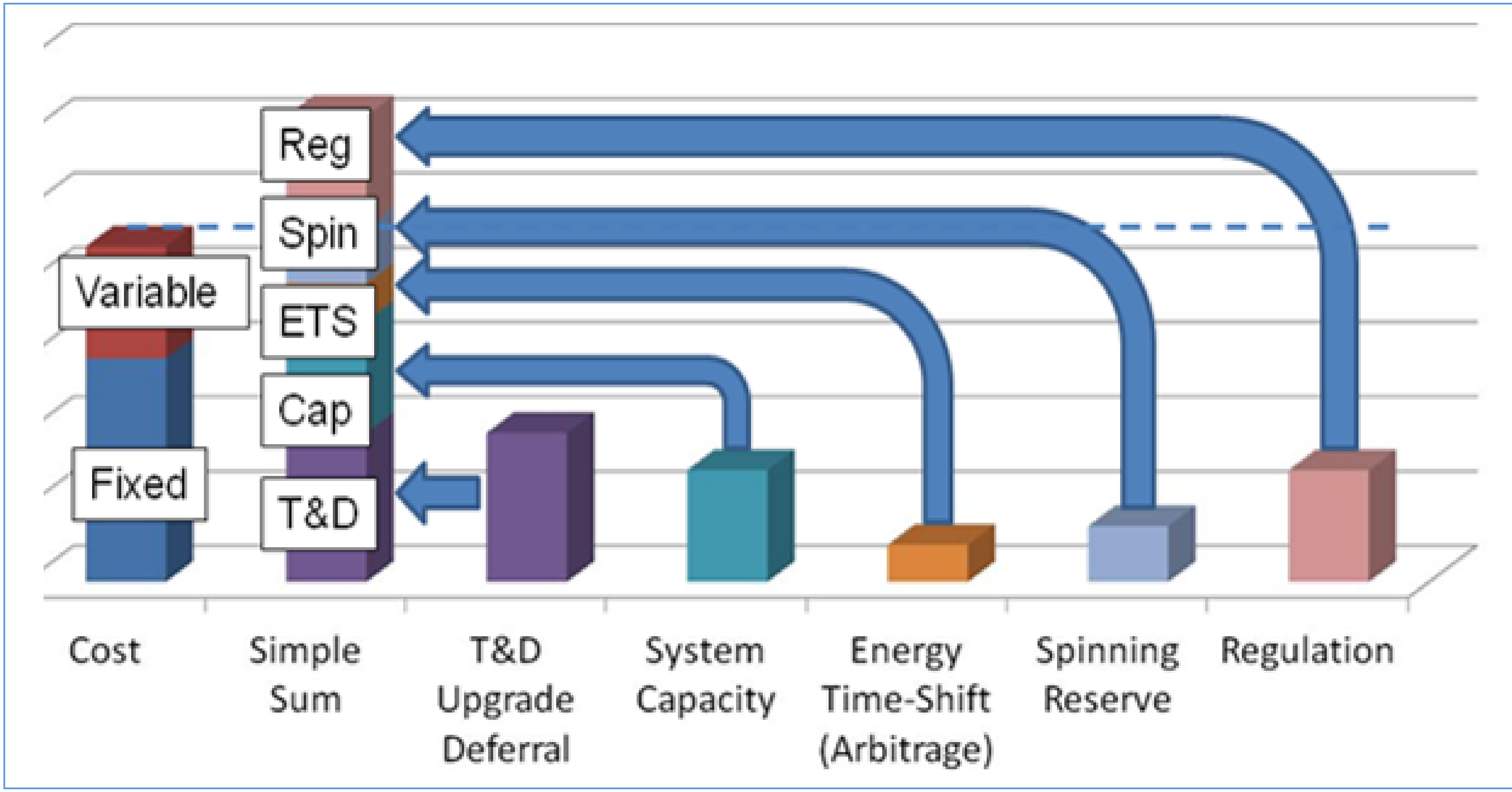
Assuming high penetration of renewables

- Avoid damage to coal-fired power plants (worth $3/Mwh to $10/MWh) or $500/kW to $1700/kW NPV
- Prevent spilling of wind energy at night
- Additional need for frequency regulation
- Dynamic Voltage-Ampere Reactive power support
- Improved service reliability

Energy Storage Value Streams?

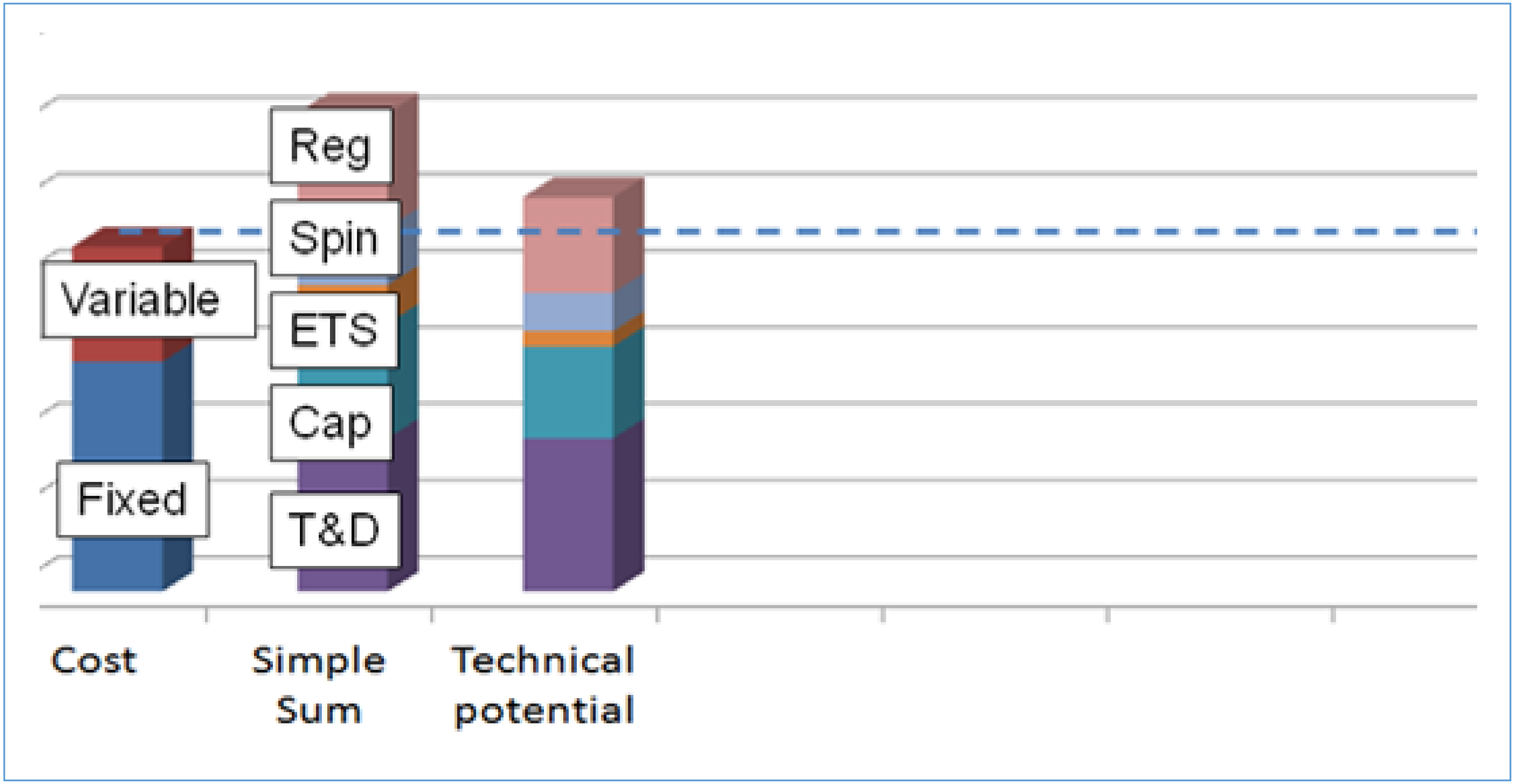
- Energy Storage requires multiple value steams, which can pay for the installed costs of a unit.
- Energy Storage offers more value to distribution cooperatives than G&Ts.
- Energy Storage is cost effective today when the right applications are paired with an appropriate technology.
- Energy Storage is essential to manage renewables.
- **Co-ops are likely to be early adopters**

Comparison of Cost and Benefits of Energy Storage



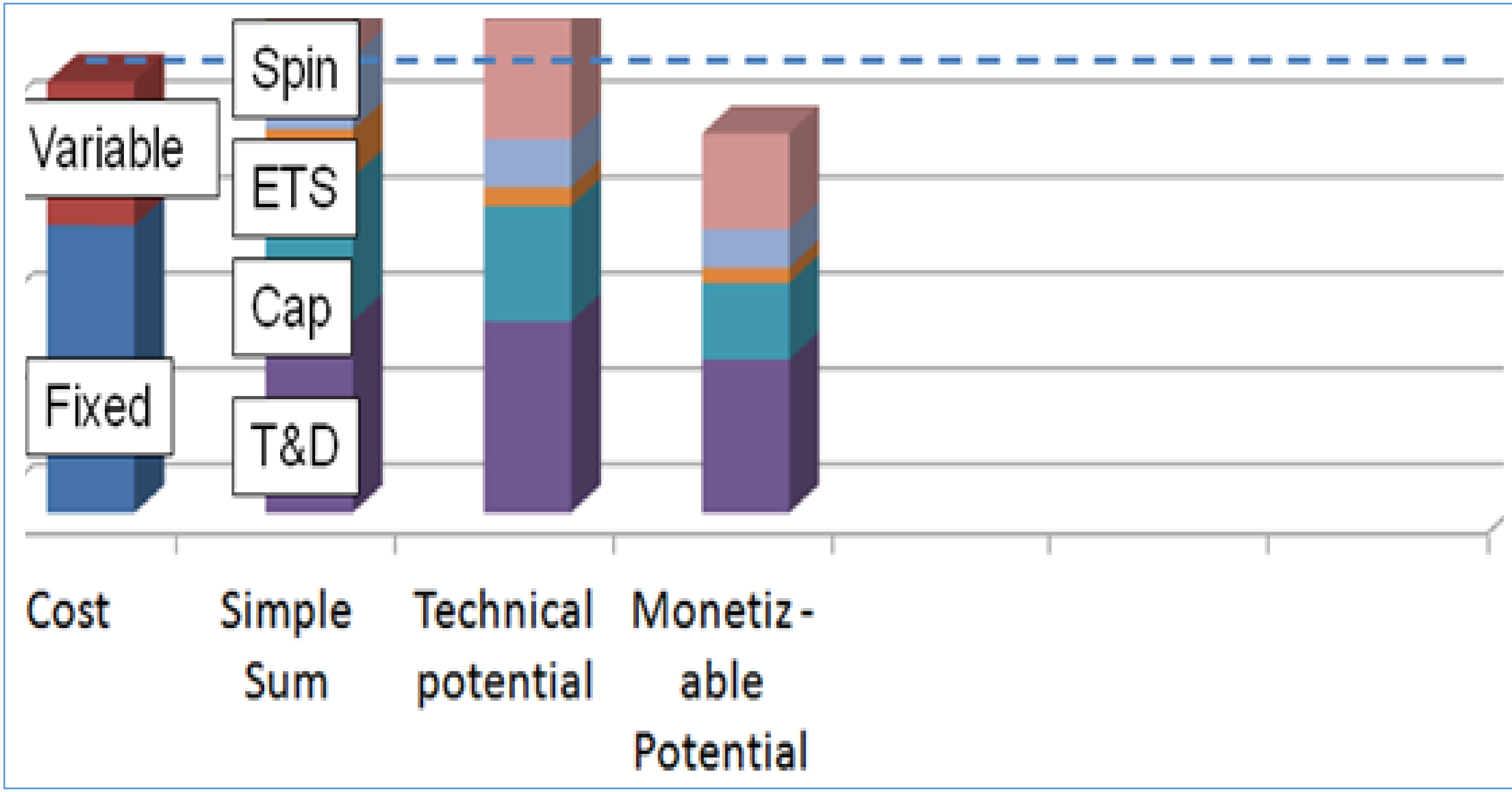
Cost-Effectiveness of Energy Storage in California, Application of the EPRI Energy Storage Valuation Tool to Inform the California Public Utility Commission Proceeding R. 10-12-007,EPRI report # 3002001162

Benefit Stacking of Energy Storage as a Simple Sum



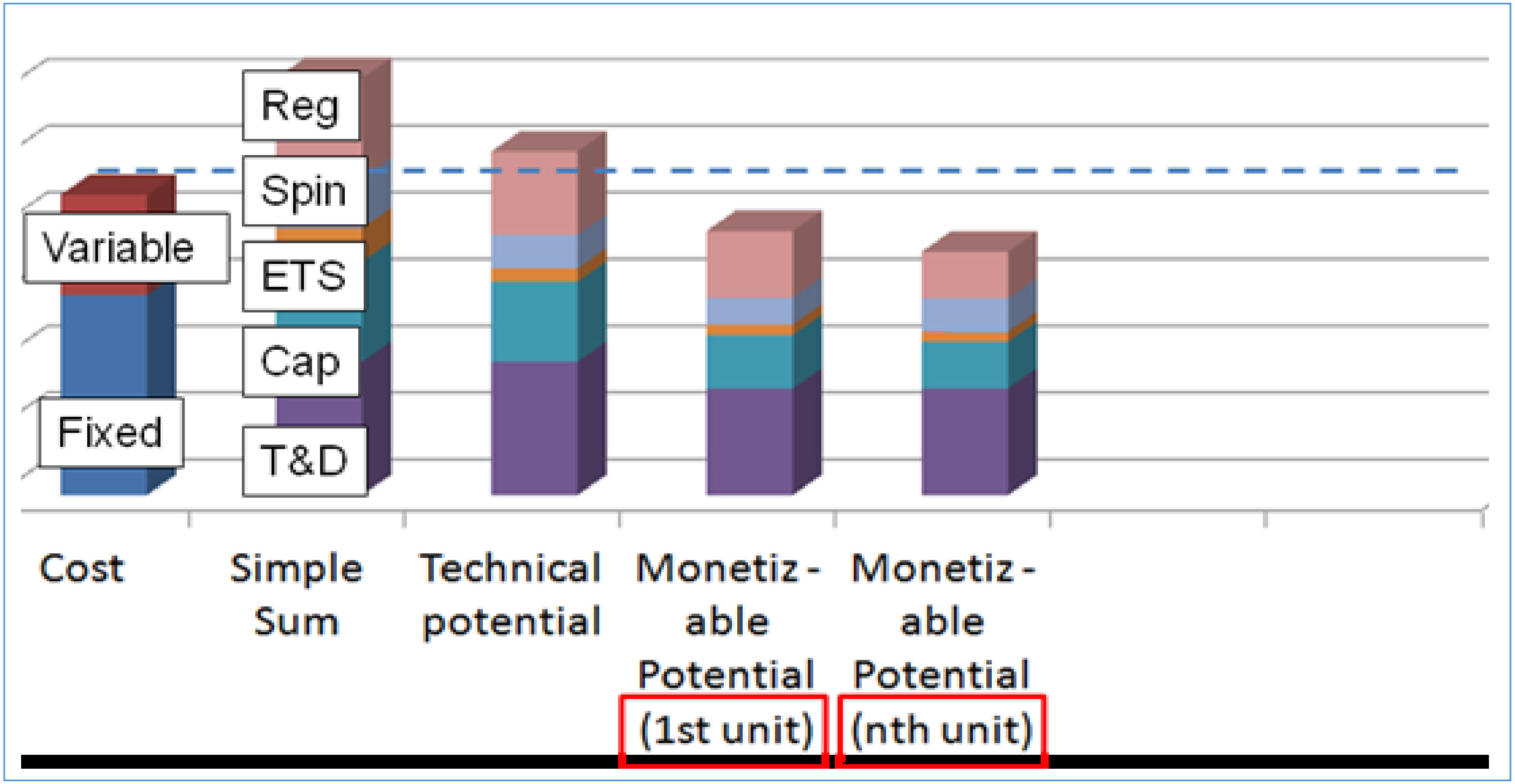
Cost-Effectiveness of Energy Storage in California, Application of the EPRI Energy Storage Valuation Tool to Inform the California Public Utility Commission Proceeding R. 10-12-007,EPRI report # 3002001162

Technical Reality - Benefit Stacking of Energy Storage



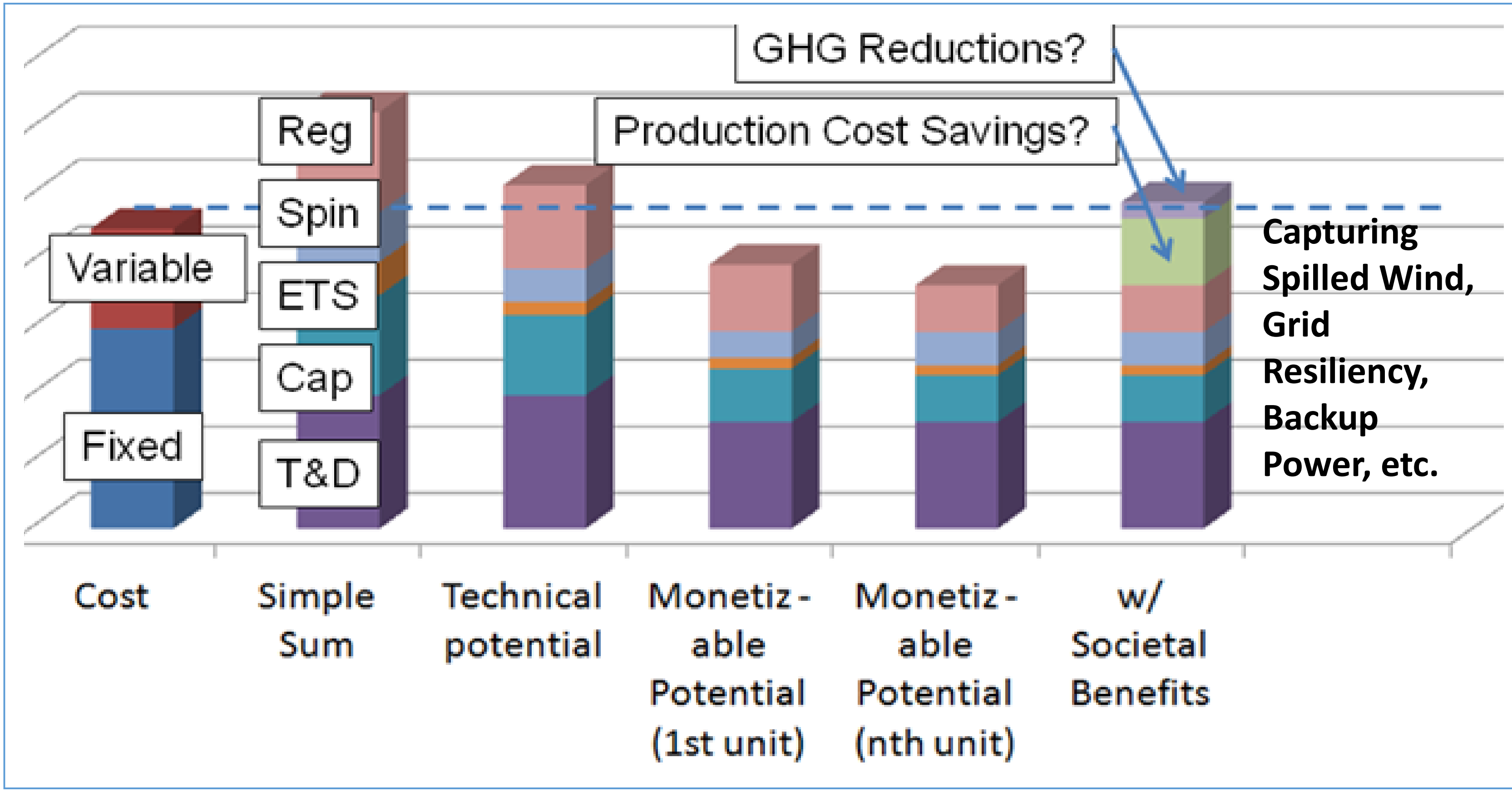
Cost-Effectiveness of Energy Storage in California, Application of the EPRI Energy Storage Valuation Tool to Inform the California Public Utility Commission Proceeding R. 10-12-007,EPRI report # 3002001162

Technical Reality - Benefit Stacking of Energy Storage



Cost-Effectiveness of Energy Storage in California, Application of the EPRI Energy Storage Valuation Tool to Inform the California Public Utility Commission Proceeding R. 10-12-007,EPRI report # 3002001162

Technical Reality - Benefit Stacking of Energy Storage



Cost-Effectiveness of Energy Storage in California, Application of the EPRI Energy Storage Valuation Tool to Inform the California Public Utility Commission Proceeding R. 10-12-007,EPRI report # 3002001162

The value of energy storage for fast and flexible generation Versus RICE and AGT

- Energy storage can respond in seconds and potentially in milliseconds to changes in load demands depending on the latency of communications
- Energy storage can follow the variability in load demand impacted by the variation in output from wind generators and solar PV which can occur in minutes to seconds
- Energy storage can respond to request to ramp up in output (discharge) as well as to ramp down in output (recharge)
- Energy storage can utilize the opportunities of low off-peak pricing and especially negative locational marginal prices
- Fast and flexible thermal generation can usually only respond to ramp up requests but can only respond to ramp down requests if they are already dispatch and in operation

Energy Storage at Electric Cooperatives

- PowerSouth (McIntosh) CAES (Alabama)
- GVEA Nicad (Alaska)
- KIUC Solar City/Tesla Li ion(Kawai)
- Kodiak Xtreme (Alaska)
- MVEC Residential Storage Demo (Minnesota)
- Kotzebue – SAFT Li ion for microgrid (Alaska)
- OPC Rocky Mountain Pumped Hydro

The Market is Getting (Over?)Crowded

ALEVO

eos

AQUION ENERGY

ecoult
energy storage solutions

NAS
Sodium Sulfur Battery
ENERGY STORAGE SYSTEM

saft

ViZn ENERGY

UET

A123 SYSTEMS

JuiceBox

STEFFES CORPORATION

VIONX ENERGY

PRIMUS POWER

TESLA

electrovaya

SUNVERGE

ZBB energy corporation

AMBRI

LightSail Energy

Isentropic®

VIONX ENERGY

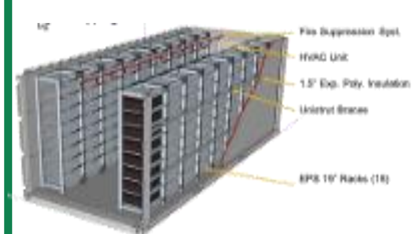
energypower SYSTEMS

FIAMM SO|NICK

Advanced Battery Concepts
Better Batteries, Better World®

Storage Technologies

- Lithium ion
  - Minutes to hours
  - 3650 to 5000 cycles @ 70% Depth of Discharge or DOD
  - Mature technology, yet new innovations
  - Large systems require MANY small batteries
  - <\$400/kWh now and <\$300/kWh in 2017
  - Difficult to recycle
- Advanced Lead Acid
  - to hours
  - 1000s of cycles
  - Based on mature manufacturing technology
  - Cycling much improved with lead carbon up to 20,000 cycles
  - Batteries can be recycled



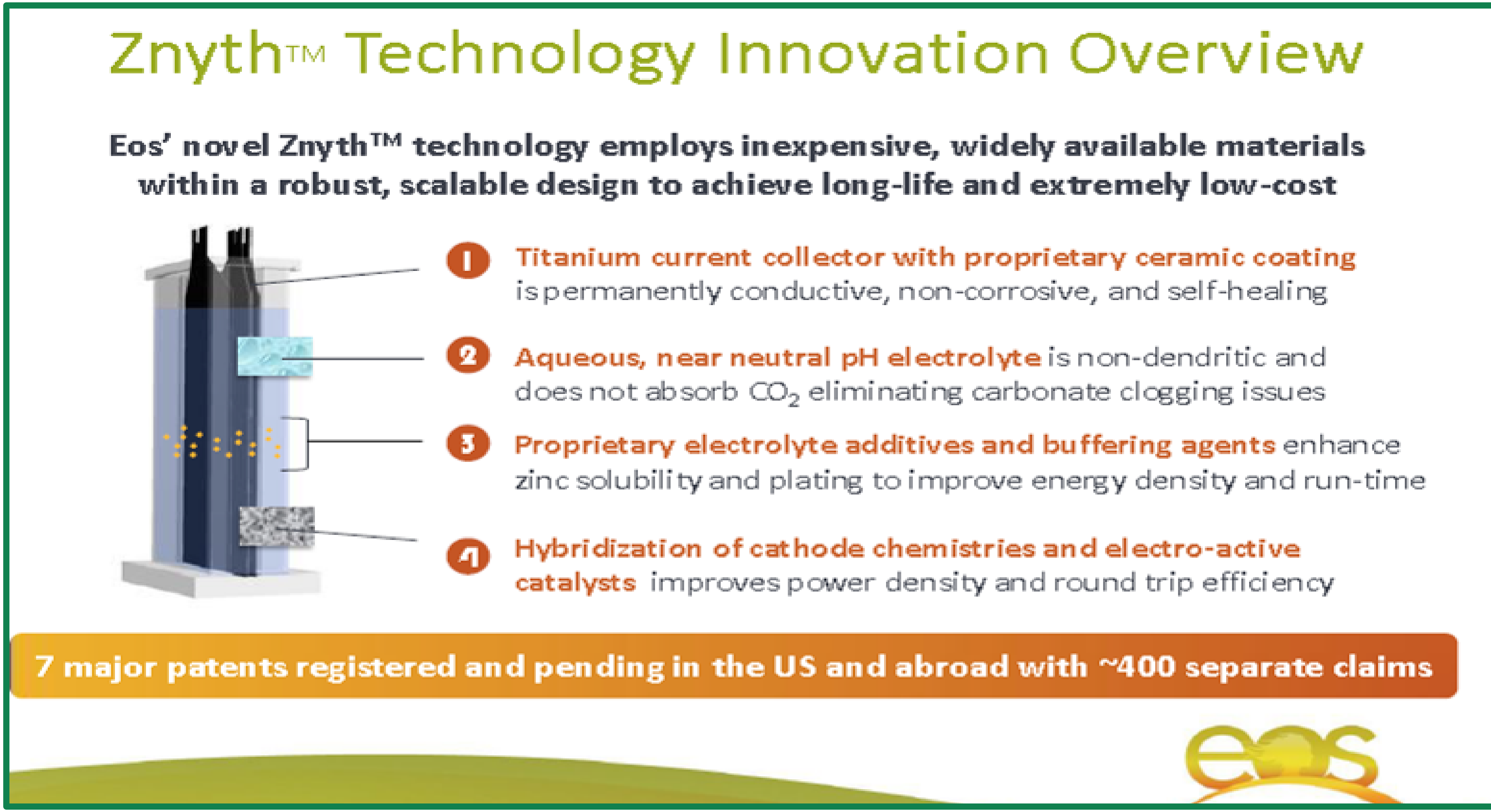
Storage Technologies (continued)

- Zinc Flow Batteries
  - 4 to 20 hours
  - >10000 cycles @ 100% DOD
  - Rapidly Developing technology and systems integration
- Vanadium Redox Flow Batteries
  - 10,000 to >100,000 cycles
  - Replace cells every 10 to 20 years (15% of investment)
  - Advanced Electrolytes have improved longevity
  - Potential low cost (<$300/kWh)
  - UET’s order for world’s largest battery at 10 X 20 MW and 80 MWh

Advanced Batteries

- Sodium Sulphur
  - 3,000 to 5,000 cycles 100% DOD?
  - Large capacities
  - Mature technology
  - NGK is Market leader
  - ~$500/kWh
  - Need for a back up generator
- Sodium Nickel Chloride
  - High temperature, but long cycle life
  - Could be good for high-use applications
  - ~$700/kWh
- Aqueous Ion Hybrid
  - Designed for longer durations
  - 10,000 cycles
  - <$400/kWh
- Liquid Metal Batteries (Ambri)
  - Novel idea – no moving parts
  - Could be extremely low cost option
  - New technology, first field demos soon

EOS Energy Storage Zynth^{TM} Zinc Hybrid Cathode



Key advantage is no forming damaging dendritic crystals

EOS Energy Storage (Zinc Air) Possible Pricing in the Future

Eos Aurora® 1000|4000 Product is Uniquely Designed to Meet Market Need for Energy Storage

Pictured: 500 kW|2 MWh Subsystem

Low Price	**$160/kWh** (>10MW) **$200/kWh** (<10MW)
Long Life	**5,000 cycles** at 100% DOD
Energy Dense	18 kWh/m³ (DC system level)
Efficiency	75% at 100% DOD
Safety	Non-flammable electrolyte; non-hazardous and non-corrosive when shipped

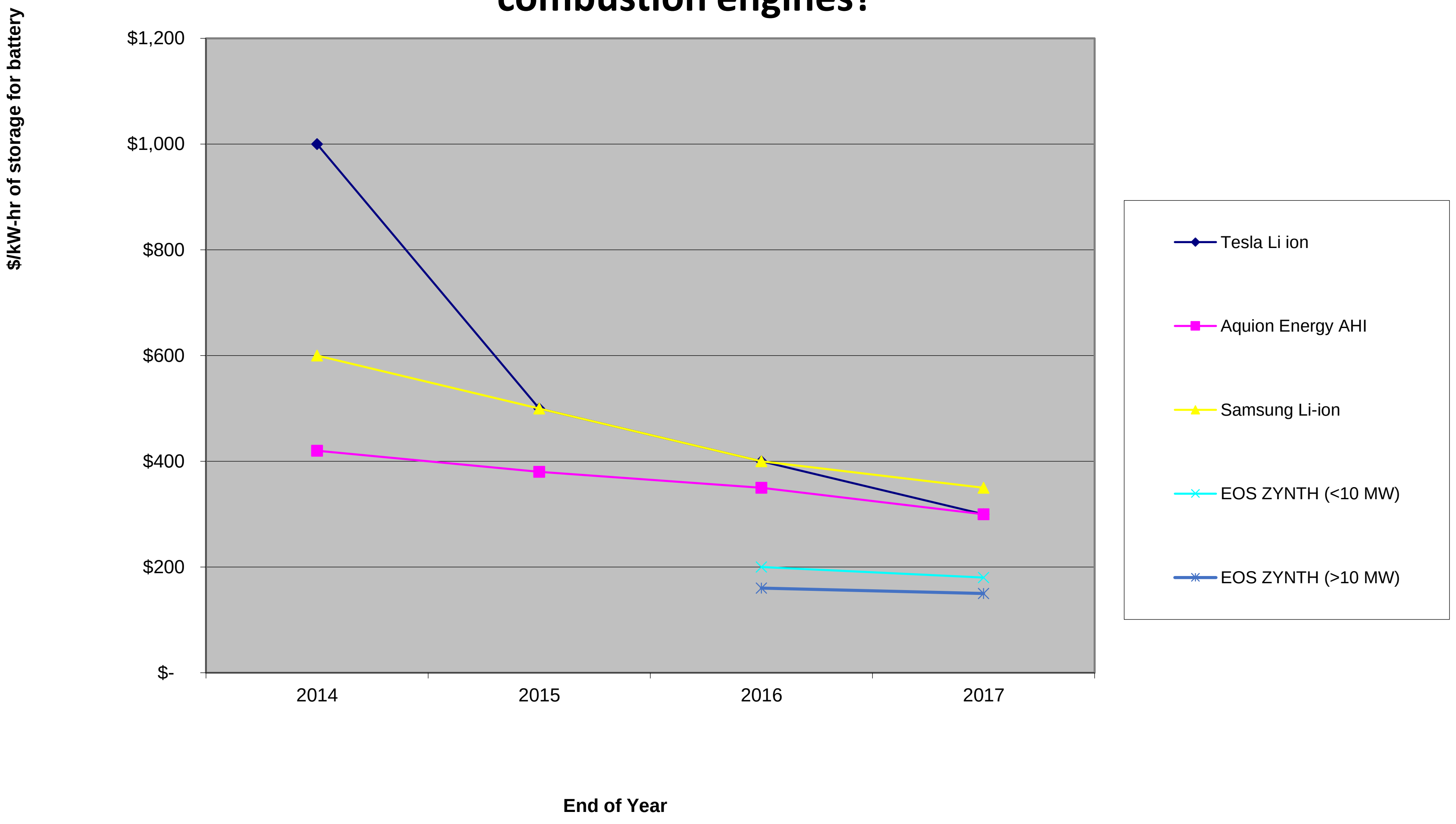
Aurora 1000|4000 System

1 MW|4 MWh DC battery system

- Proprietary Znyth™ (zinc hybrid cathode) chemistry employs abundant, low-cost materials and manufacturing methods
- Aqueous electrolyte enables system safety
- System supports 100% depth of discharge
- Operating temperature range of 10-45°C mitigates need for dedicated heating/cooling
- Outdoor rated, plug-and-play Energy Stack™ design reduces onsite installation cost
- 250kW sub-systems aggregated for flexible system size/configuration
- Includes Battery Management System

Projected Costs for Energy Storage (IMHO)

Are advanced batteries becoming competitive with new frame gas turbine's, aeroderivative gas turbine's, or reciprocating internal combustion engines?



What about Compressed Air Energy Storage (CAES), Liquid Air Energy Storage (LAES), and Isothermal CAES ICAES)?

- These systems will have low incremental costs for each hour of storage and appeared very promising:
  - ✓ LAES Capital cost of <$200/kWh (note kWh is a capital cost of kW output per hour of storage)
  - ✓ CAES and I CAES incremental capital cost of $1/kWh to $5/kWh
- Response time for these systems is analogous to other fast and flexible fossil generation resources
  - ✓ CAES can respond in 10 to 15 minutes expansion or discharge
  - ✓ When used daily the LAES can respond in minutes
  - ✓ ICAES can respond in minutes
- ✓ **But with the low prices for natural gas and the relatively low efficiency for the hybrid gas-fired CAES and LAES and the all electric ICAES systems, none of these systems can dispatch competitively with legacy combined cycle gas turbine's and even high efficiency combustion turbines; thus they will rarely operate and until natural gas prices exceed $7/MMBtu (for the ICAES) and at higher prices for the CAES and LAES**

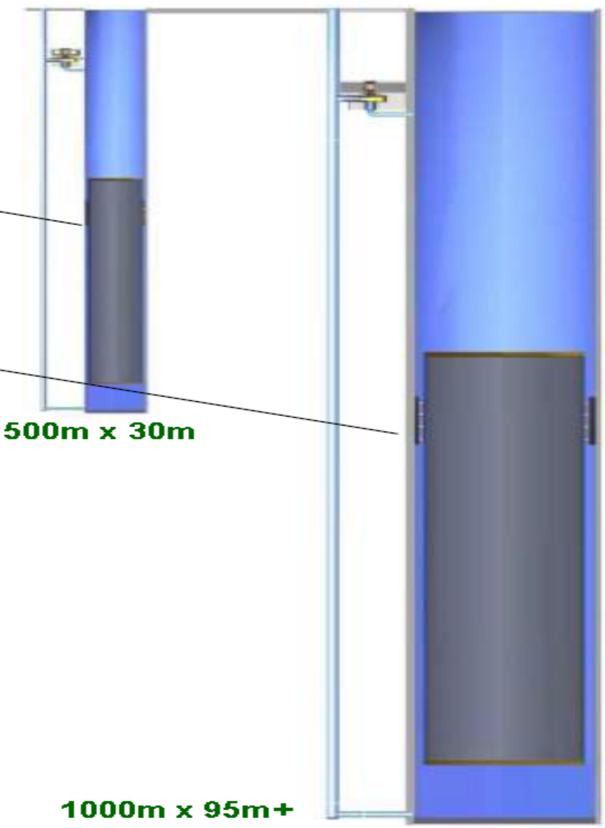
What about Underground Pumped Hydroelectric Storage?Gravity Power

GRAVITY POWER

GPM Products Range

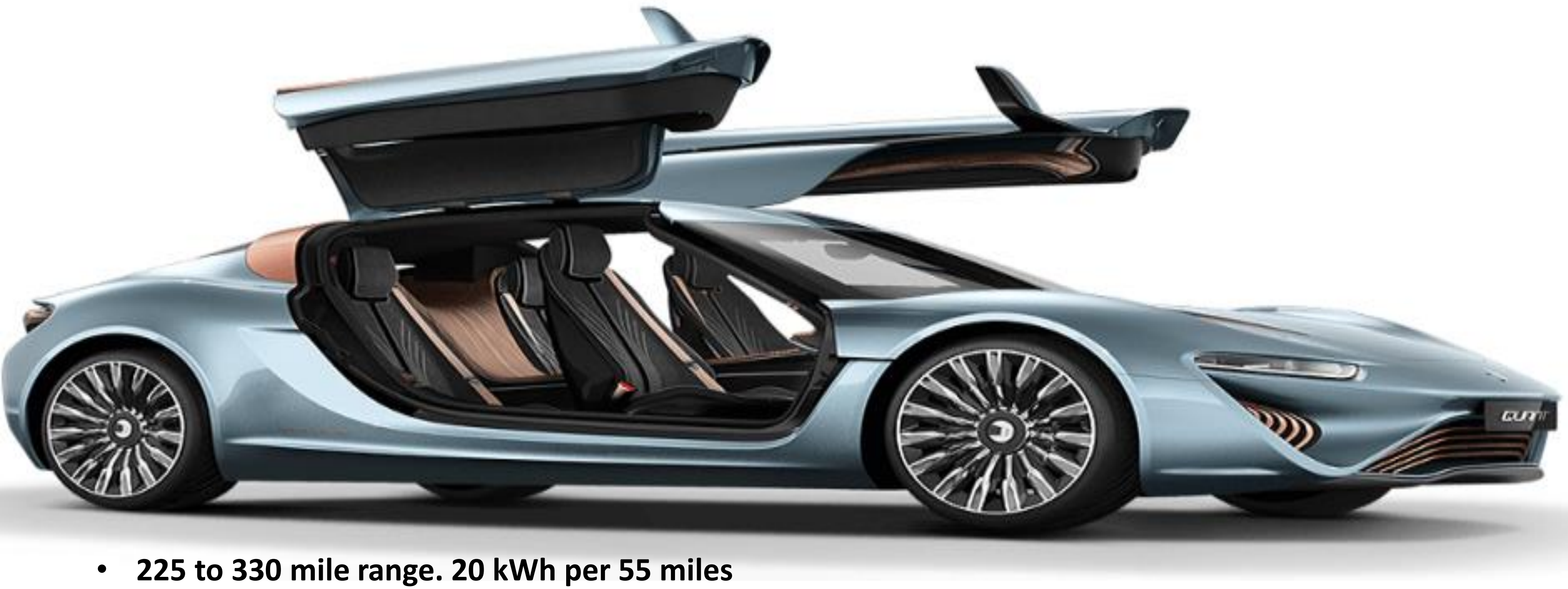
Small Plant
- 40 MW capacity x 4 hours
- Cost/kW: $4390

Medium & Large Plants
- 200-1600+ MW capacity x 4 hours
- Cost/kW: $2050-950



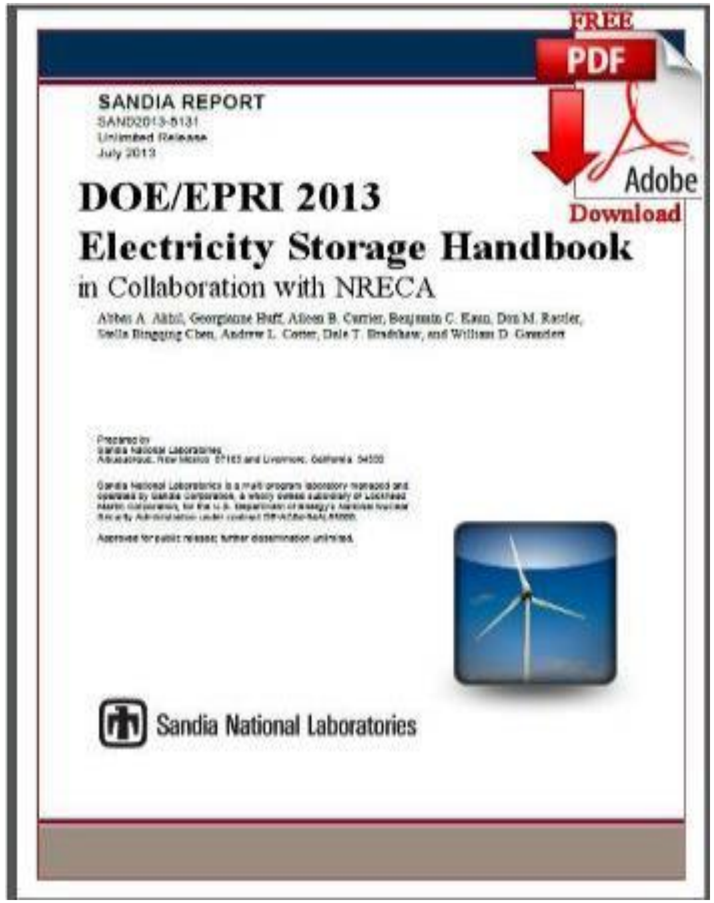
- Babendererde developed prices vetted by Hochtief
- Prices based on costs in Germany
- Prices include 10% contingency and 15% profit
- Classical PSH systems cost $1500 - $5000/kW

The German Quant e-Sportlimousine
NanoFlowcell with Salt Water Electrolyte Flow Cell



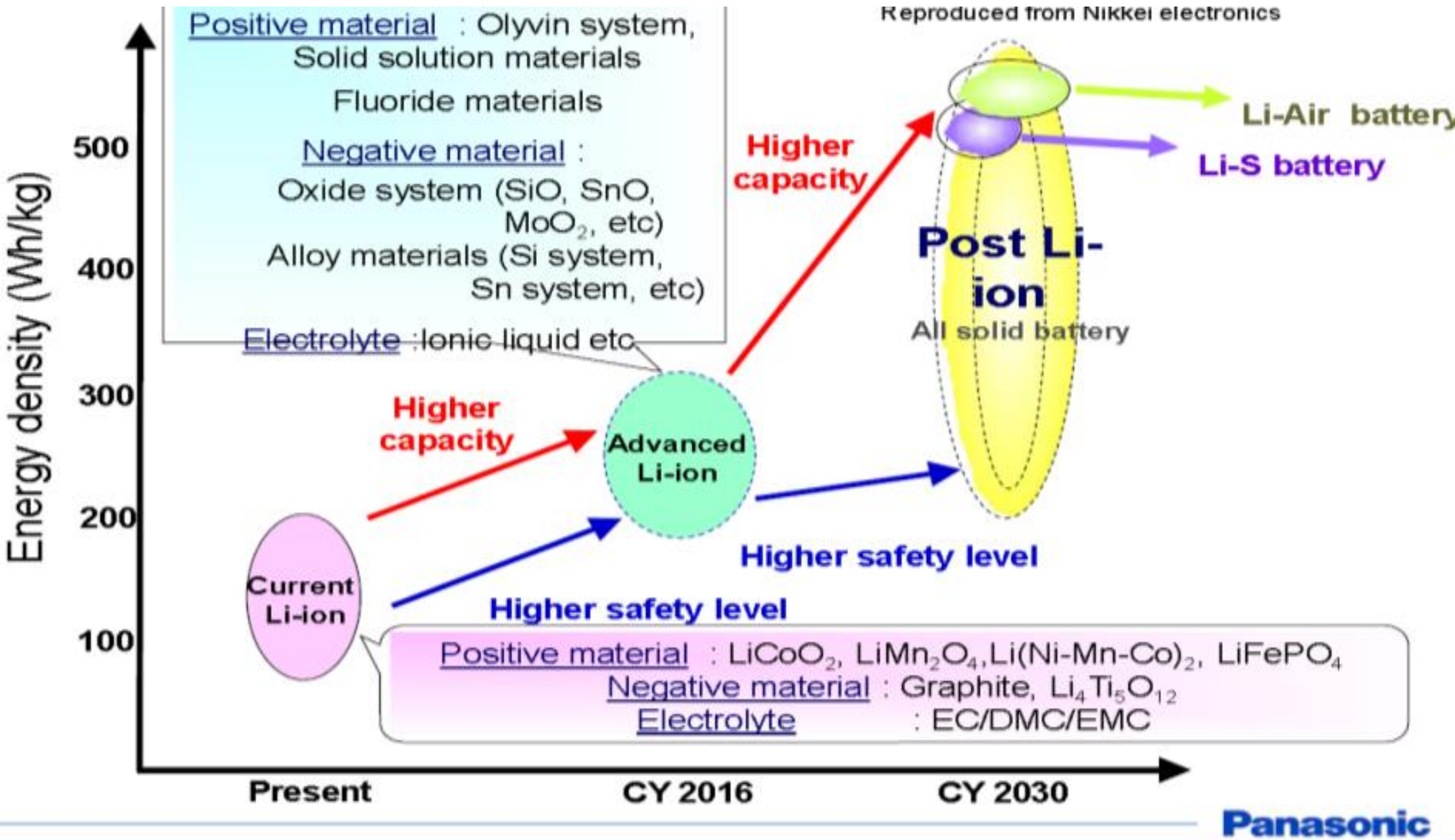
- **225 to 330 mile range. 20 kWh per 55 miles**
- **920 horsepower (680 kW).**
- **0 to 62 mph in 2.6 seconds**
- **Top speed of 217.5 mph**
- **Rapid charge or change out electrolyte**
- **NanoFlowcell has five times the energy density of Li-ion**
- **600 V and 50 A**

Resources



DOE / EPRI Energy Storage Handbook in collaboration with NRECA

Developments for Next Generation Batteries

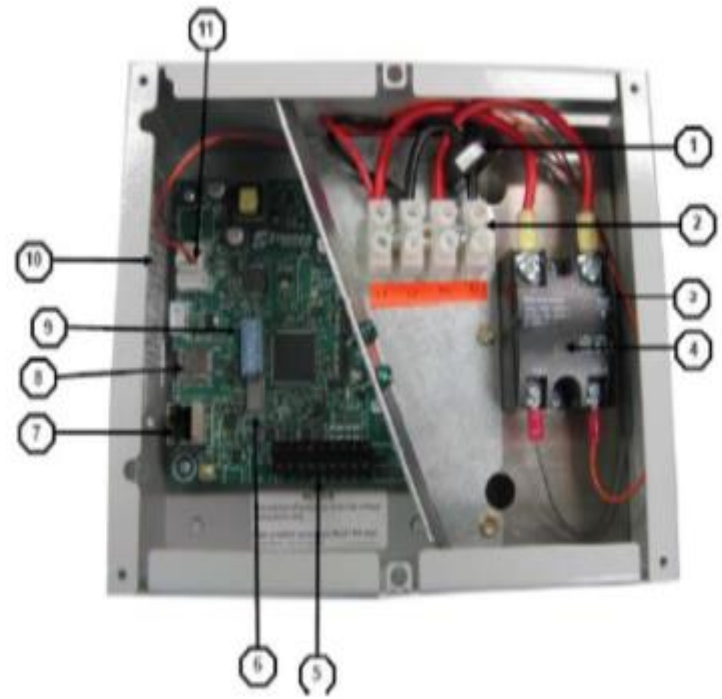


What about thermal energy storage?

Grid interactive Energy Thermal Storage (GETS) water heating for demand charge reduction, spinning reserve, fast frequency response services, plus management of the intermittency of renewables

GETS Water Heating

Via the 2-way real-time controller



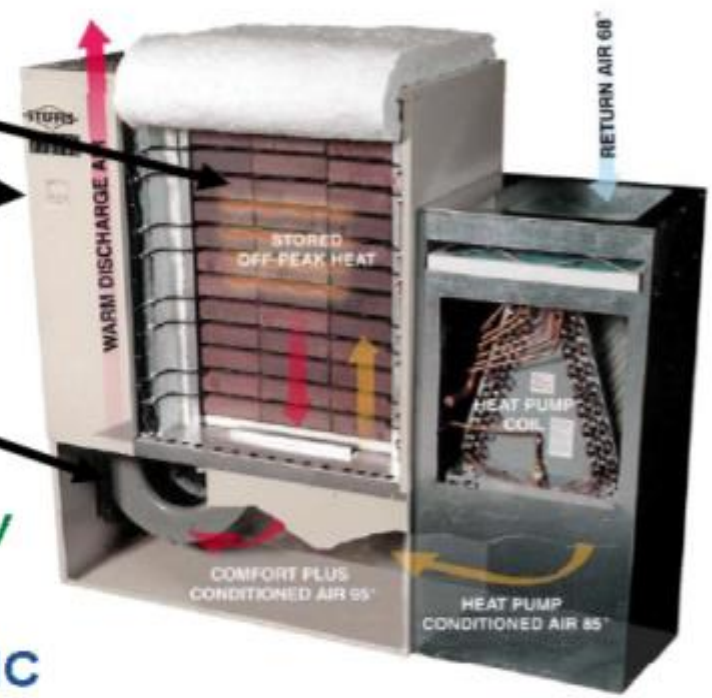
What about Electric Thermal Storage For Space Heating?

Over 100,000 units already installed in 20 years

Storage of Renewable or Off-Peak Electricity in the form of Heat

100,000 installations in North America = 10 Gwh "Thermal Battery"

- Electricity is stored as heat in a well insulated brick core.
- On-board Microprocessor based control system regulates charging and discharging.
- Internal blower system delivers the heat to the conditioned space as needed to maintain comfort 24/7.
- **Storage occurs based on availability of renewable or off-peak energy or as signaled by the utility for ancillary services.**



It's FULLY AUTOMATIC

All heating is accomplished by using off-peak or renewable energy

Example of Wide Range of Electric Thermal Storage Products

Residential:

- Room Heaters, Furnaces, Hydronic
- 2kW to 45kW input
- 14kWh to 240kWh Storage

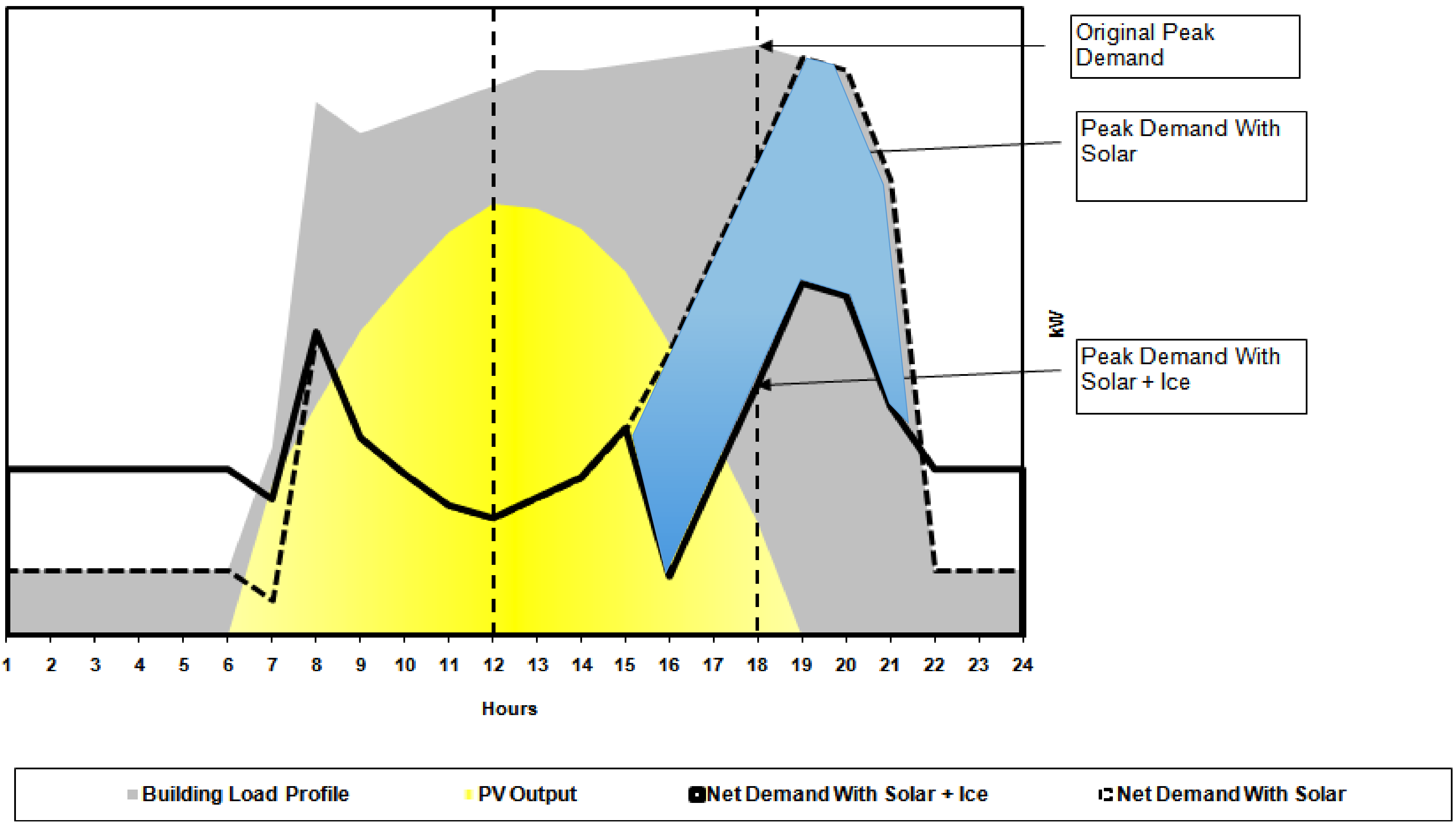
Commercial & Industrial:

- Furnaces and Hydronics
- 50kW to 160kW input
- Up to 960kWh Storage

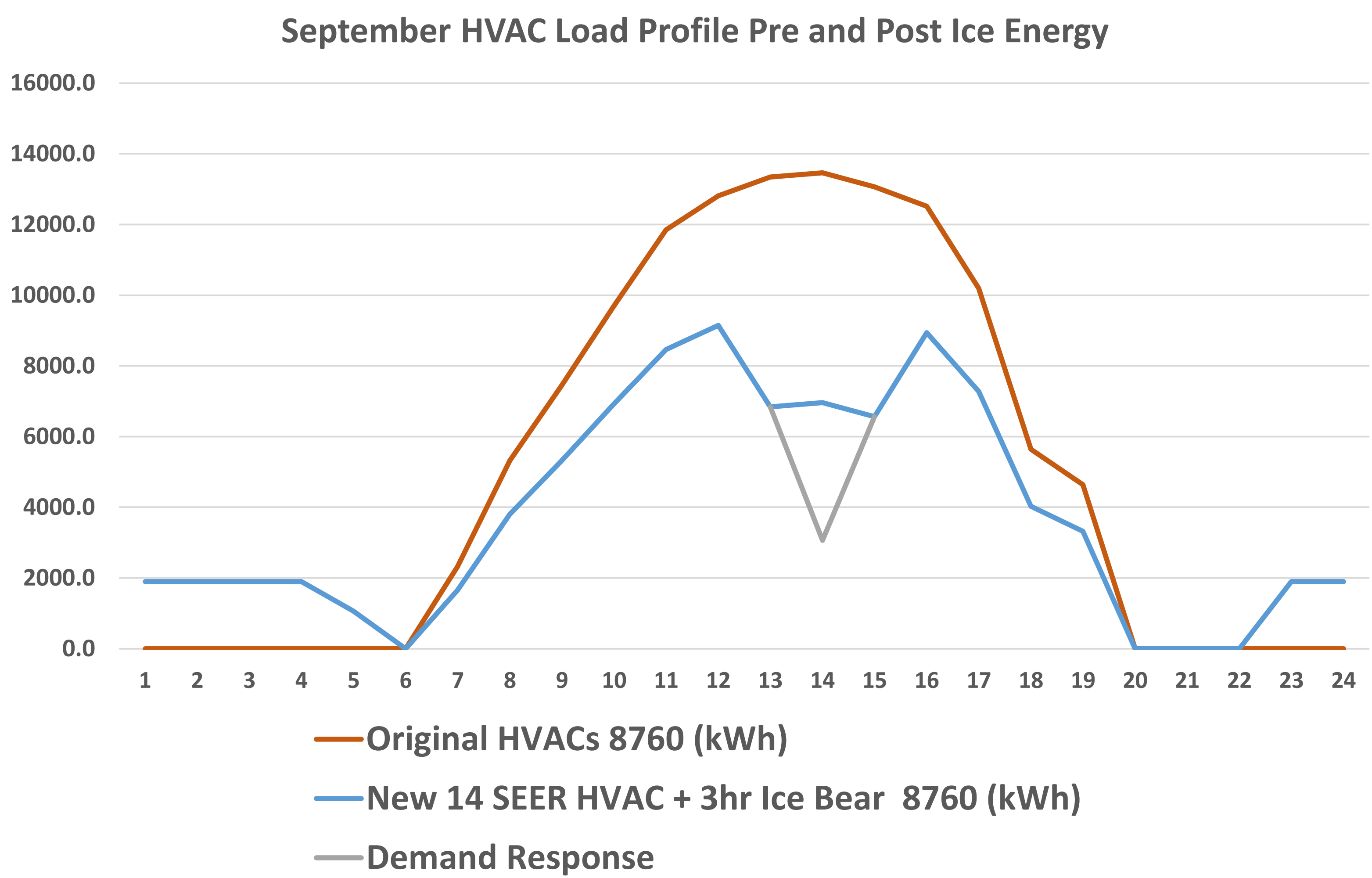
Solar PV and Thermal Energy Storage technology and operation integration with Ice Energy Ice Bear producing ice at night and using ice to reduce HVAC during Daily peak

Utility, Large Big Box Retail, Solar & Storage Project

Solar and Thermal Energy Storage Integration



10 MW Ice Bear, DR, and HVAC Replacement Load Profile Comparison



Questions?

Dale Bradshaw

Dale.bradshaw@nreca.coop

dtbradshaw@electrivation.com