

# Grid Scale Energy Storage

***MIT Energy Club***

*March 11, 2009*

Ardour Capital Investments, LLC  
***www.ardourcapital.com***

# Grid Scale Energy Storage

**Ardour Capital**

*Introduction*

**Overview & Issues**

*Framework for Evaluation*

**Markets**

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**Technologies**

*What Are These Things*

**Applications**

*How Are They Used*

**Resources**

*More to Learn*

# **Ardour Capital Investments, LLC**



**A leading institution in Energy Technology / Alternative Energy & Power / Clean & Renewable Technologies**

**Publishes extensive industry and company specific research on energy technology for institutional investors**

**Provides a wide range of financial services for both public and private companies**

**Ardour Global Indexes ([www.ardourglobalindexes.com](http://www.ardourglobalindexes.com)) a family of pure-play alternative energy indexes**

**Sponsors annual invitation only Energy Technology Conference**

**Strategic Partnership with Baker & McKenzie LLP**

# Ardour Global Indexes

*The Ardour Global Alternative Energy Index™ (Ardour Family™) includes five indexes which serve as fair, impartial and transparent measures of the performance of the Alternative Energy Industry. The indexes are licensed for UITs, Certificates, ETFs, Futures, and Options on Futures. Dow Jones Indexes (a unit of Dow Jones & Co.) is the calculation agent responsible for compilation, maintenance, calculation, and dissemination.*

## Market Vectors Global Alternative Energy ETF

- **Ticker Symbol:** GEX
- **Exchange Listing:** NYSE
- **Listing Date:** May 2007
- **Manager:** VanEck Global
- **Key Features:**
  - Marginable
  - No Uptick Rule

## Market Vectors Solar Energy ETF

- **Ticker Symbol:** KWT
- **Exchange Listing:** AMEX
- **Listing Date:** April 2008
- **Manager:** VanEck Global
- **Key Features:**
  - Marginable
  - No Uptick Rule

# Ardour Capital Annual E-Tech Conference



## Keynote Speakers:

- 2008** Carol Battershell, *Senior Advisor, Energy Efficiency and Renewable Energy, US DOE*  
Rohit T. Aggarwala, *Director of NYC's Office of Long-term Planning and Sustainability*
- 2007** Andy Karsner, *Asst. Secretary, Office of Energy Efficiency and Renewable Energy, US DOE*  
Ambassador Sichan Siv, *Ambassador to the United Nations Economic and Social Council*
- 2006** Douglas Faulkner, *U.S. Dept of Agriculture's Deputy Under Secretary for Rural Development*
- 2005** Jonathan Foster, *California Clean Energy Fund*
- 2004** Peter Smith, *President-New York State Energy Research Development Authority (NYSERDA)*
- 2003** Joseph J. Rohm, *Executive Director Center for Energy & Climate Solutions*

**Past Presenting Companies:** Active Power (ACPW), American Superconductor Corp. (AMSC), Beacon Power (BCON), Capstone Turbine (CPST), C&D Technologies (CHP), DayStar Technologies (DSTI), Distributed Energy (DESC), Electro Energy (EEEI), Evergreen Solar (ESLR), FuelCell Energy, Inc. (FCEL), Hydrogenics (HYGS), Intermagnetics General (IMGC), Maxwell Technologies (MXWL), Mechanical Technology (MKTY), Medis Technologies (MDTL), Millennium Cell (MCEL), Nova Biosource Fuels (NVBF), Ovation Products (private water filtration company), Pacific Ethanol (PEIX), Plug Power (PLUG), Quantum Fuel Systems (QTWW), SatCon Technologies (SATC), TIR Systems (TIR), Ultralife Batteries (ULBI), Vycon (private flywheel company)

# Energy Storage: Overview & Issues

# Overview

## What Storage is:

- Shock Absorber
- Leverages Existing Assets
- Benefits a Non-Linear System

## What Storage is NOT:

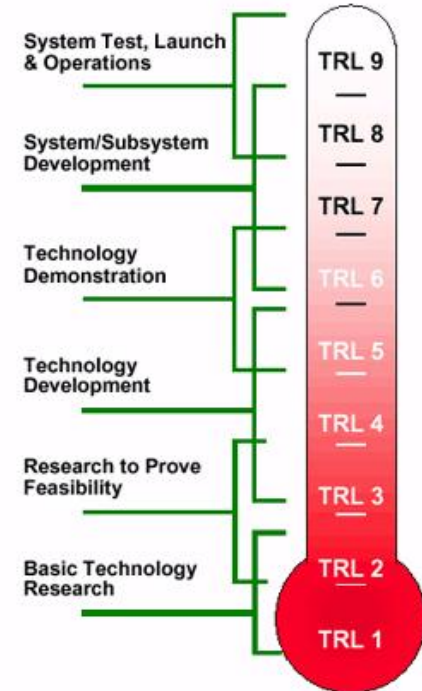
- Generation

## Framework:

- Short Duration - Power
- Long Duration - Energy

## Technology Roadmap

- Technology
- Product
- Solution



## NASA TRL - Technology Readiness Level

# Key Issues

## Power

- Charge/Discharge Rate

## Energy

- Endurance

## Life

- Cycle Life
- Depth of Discharge
- PSoC Operation
- Shelf-Life

## Safety

- Chemical / Mechanical
- Hazmat

## Cost

- Components
- Balance of Plant

## System Design

- “Battery” – Power/Energy
- Battery Management (Charging)
- PCS
- Cooling
- Remote Monitoring

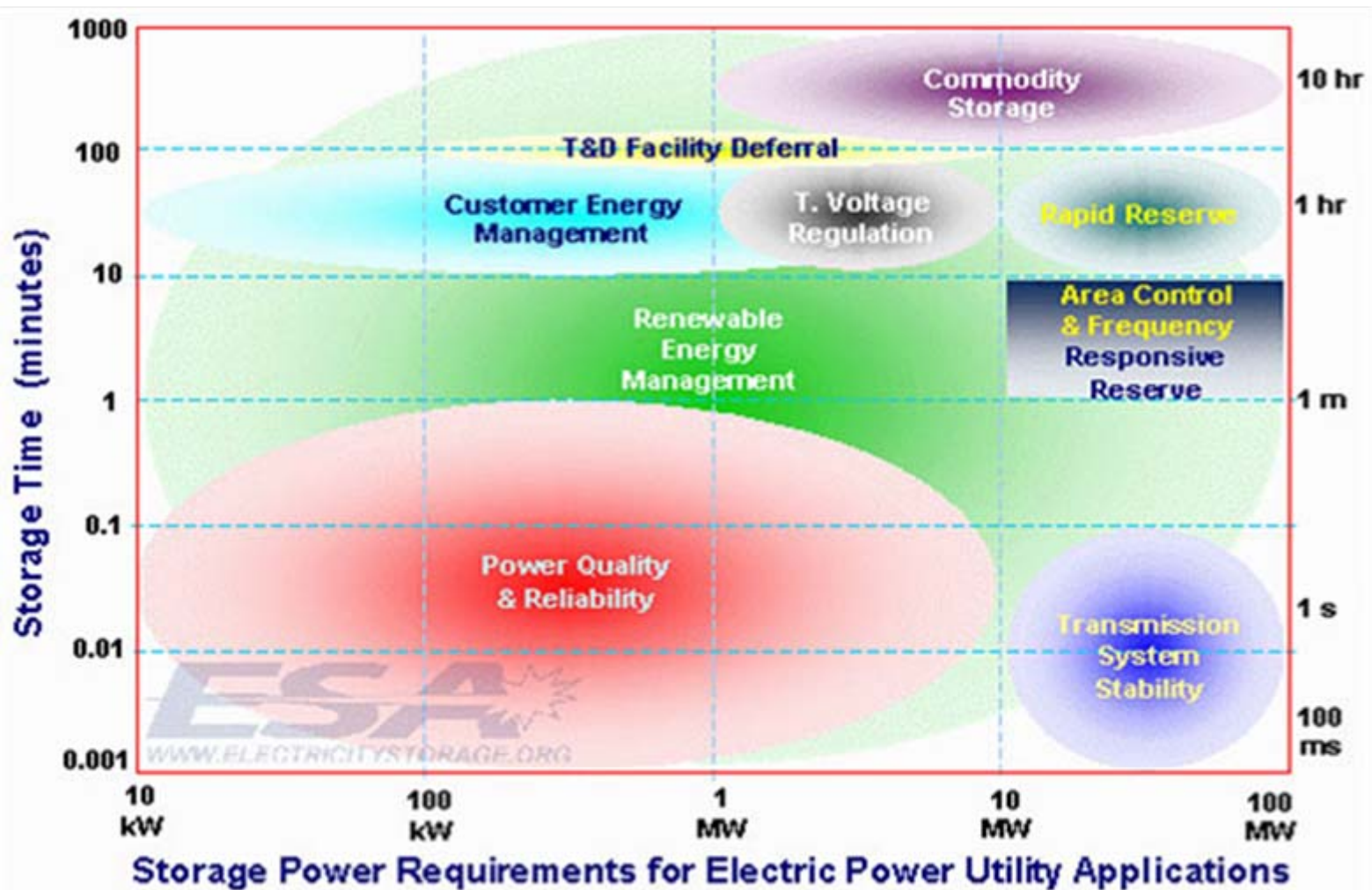
## Manufacturing

- Material Selection
- Modularization
- Scaling
- Certification: UL, CE, FCC, NEC, etc.

## Integration

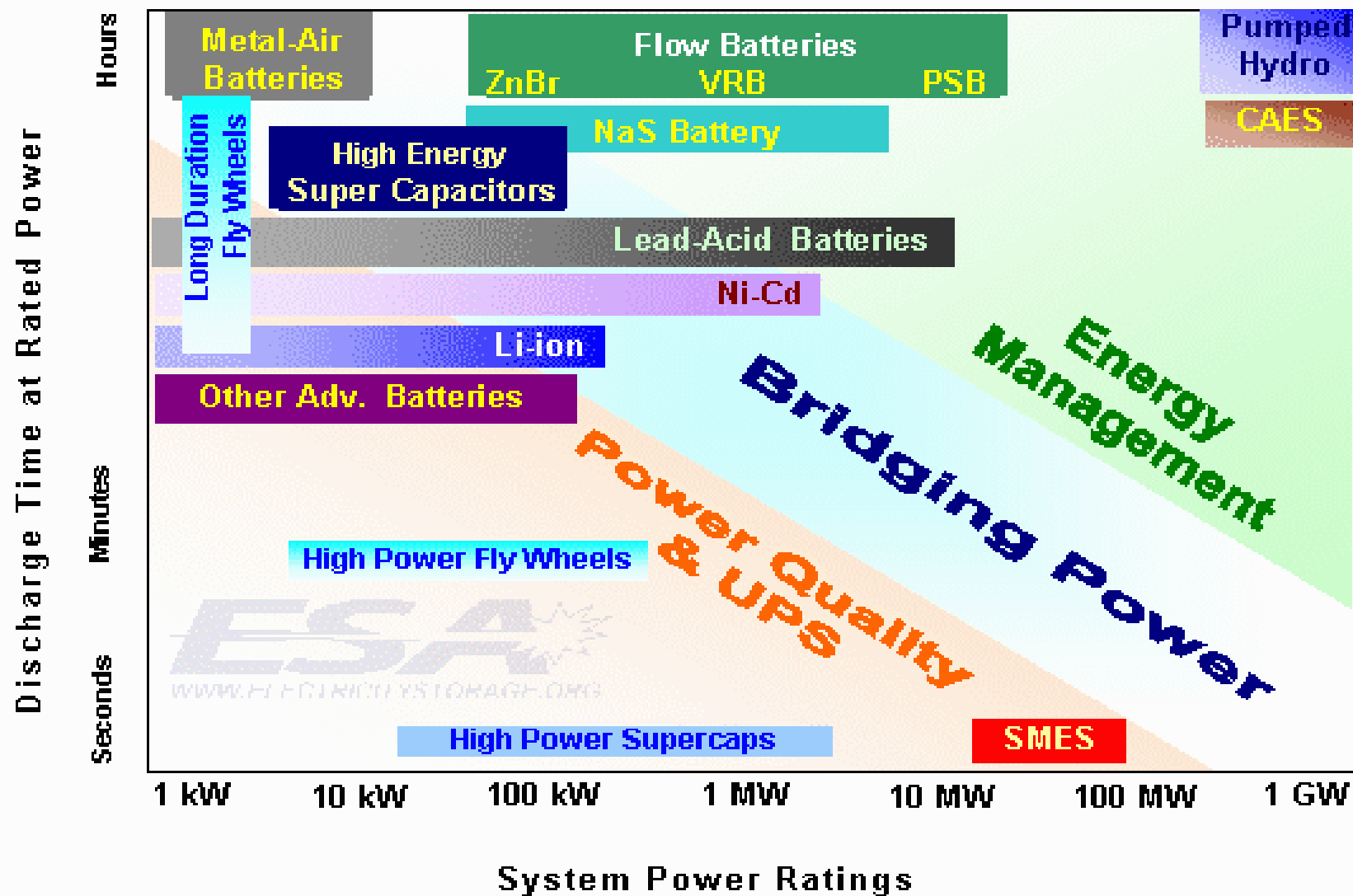
- Interconnection
- Physical Size

# Applications & Unit Sizing

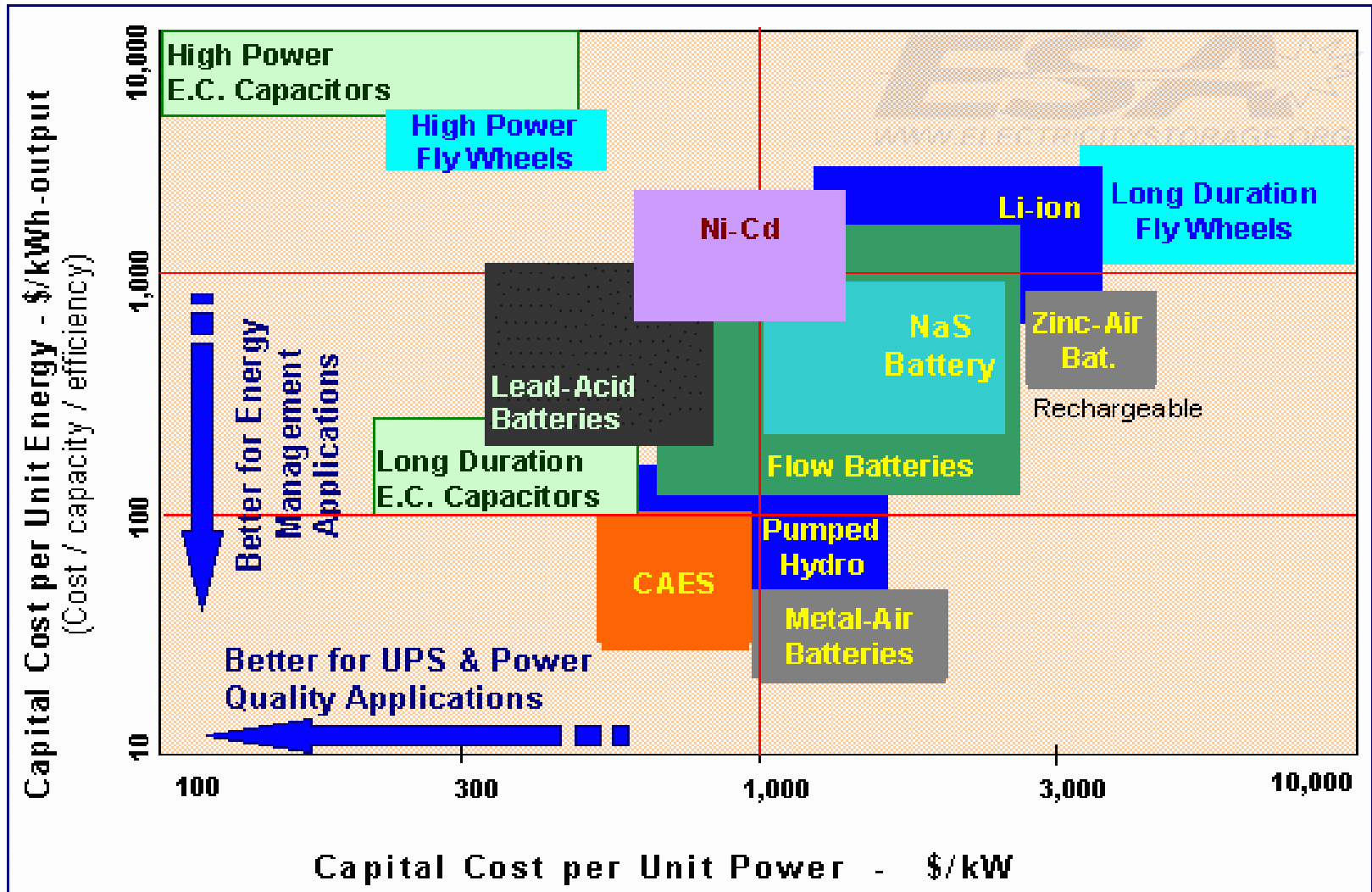


Data from Sandia Report 2002-1314

# Market Roles



# Cycling Issues



# Costs

**Table 4. Storage Technologies Evaluated and Costs**

<b>Technology</b>	<b>Energy- Related Cost (\$/kWh)</b>	<b>Power-Related Cost (\$/kW)</b>	<b>Balance of Plant (\$/kW)</b>
Lead-acid Batteries (Flooded Cell)	150	175	50
Lead-acid Batteries (VRLA)	200	175	50
Ni/Cd	600	175	50
Zn/Br	400	175	0
Na/S	250	150	0
Li-Ion	500	175	0
V-redox	350	175	30
Lead-carbon asymmetric caps	500	350	50
CAES-surface	120	550	50
High-speed flywheel	1,000	300	0
Low-speed flywheel	380	280	0
Hydrogen fuel cell	15	1500	0
Electrolyzer (to accompany fuel cell)	None	300	None

# Energy Storage: Markets

# Market Opportunities

## Wholesale Power

- Commodity Arbitrage
- Ancillary Services

*Load Leveling, System Stabilization  
Frequency Regulation, Spinning Reserves*

## Transmission & Distribution

- Asset Deferral
- Distribution System Stability
- Stand-by Power

*Postpone Transmission Upgrades  
Shock Absorber  
Substation, NOC, Generating Station*

## Renewable Energy

- Wind
- Solar Thermal
- Solar PV

*Firm Delivery, Transmission Design  
Solar Tower, Trough  
Off Grid, Time Shift Delivery*

## Distributed Resources

- Demand Management
- Power Quality
- Standby-Power
- Regenerative Energy

*Peak Shaving, Service Cost Reduction  
Islanding, Microgrids  
Telecom, Datacenter, UPS  
Port Cranes, Subways*

# Wholesale Power

## Commodity Arbitrage

*Load Leveling, System Stabilization*

### Pumped Hydro

- 20,335 MW (US)
- ~7M MWh (US)



### CAES

- Optimized Combined-Cycle
- 2 Units Operating
- 1 Under Construction



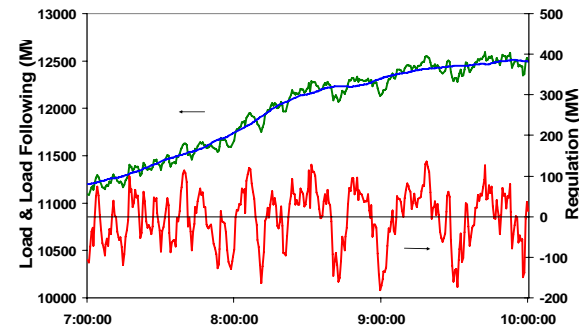
## Ancillary Services

*System Stability*

### Frequency Regulation

- 1% - 4% of system capacity
- ~ \$1+ Billion market

### Spinning Reserves



# Transmission & Distribution

## Asset Deferral

*Postpone Transmission Upgrades*

~500 Chock Points<sup>1</sup>

- Relieve short-term capacity constraints
- Step-function expansion



## Distribution System Stability

*Shock Absorber*

T vs. D – Flexibility at Substations

- 1-2 MW
- 4-8 Hrs



## Stand-by Power

*Substations, NOC, Generating Stations*

Backup Power / Emergency Restart

- 100,000 Substations
- 2,800 Power stations



# Renewable Energy

## Wind

*Firm Delivery, Transmission Design*

Resource—Variable, Not Intermittent

Support Higher Value PPA

Transmission System Utilization

Build to Resource, not Transmission Limit



## Solar Thermal

*Solar Tower, Trough*

Steam Generation Support

Expand Collector Field

Molten Salt, Steam



## Solar PV

*Off Grid, Time Shift Delivery*

Cloud Transients

Shift Mid-Day to Evening Peak



# Distributed Resources

## Demand Management

*Peak Shaving, Service Cost Reduction*

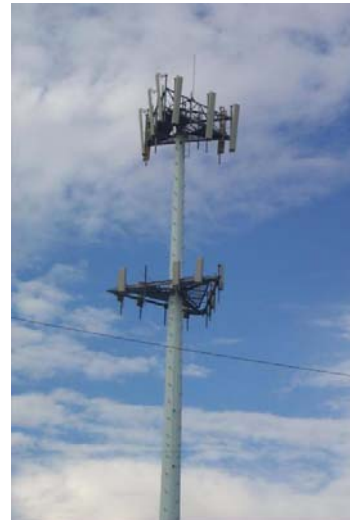
~36,000 large stores  
Demand Charge Reduction  
HVAC (Thermal Storage)



## Power Quality

*Islanding, Microgrids*

Bridging Power  
\$119 - \$188 Billion Losses in US



## Stand-by Power

*Telecom, Datacenter, UPS*

200,000 Cell Tower  
36,000 Central Office

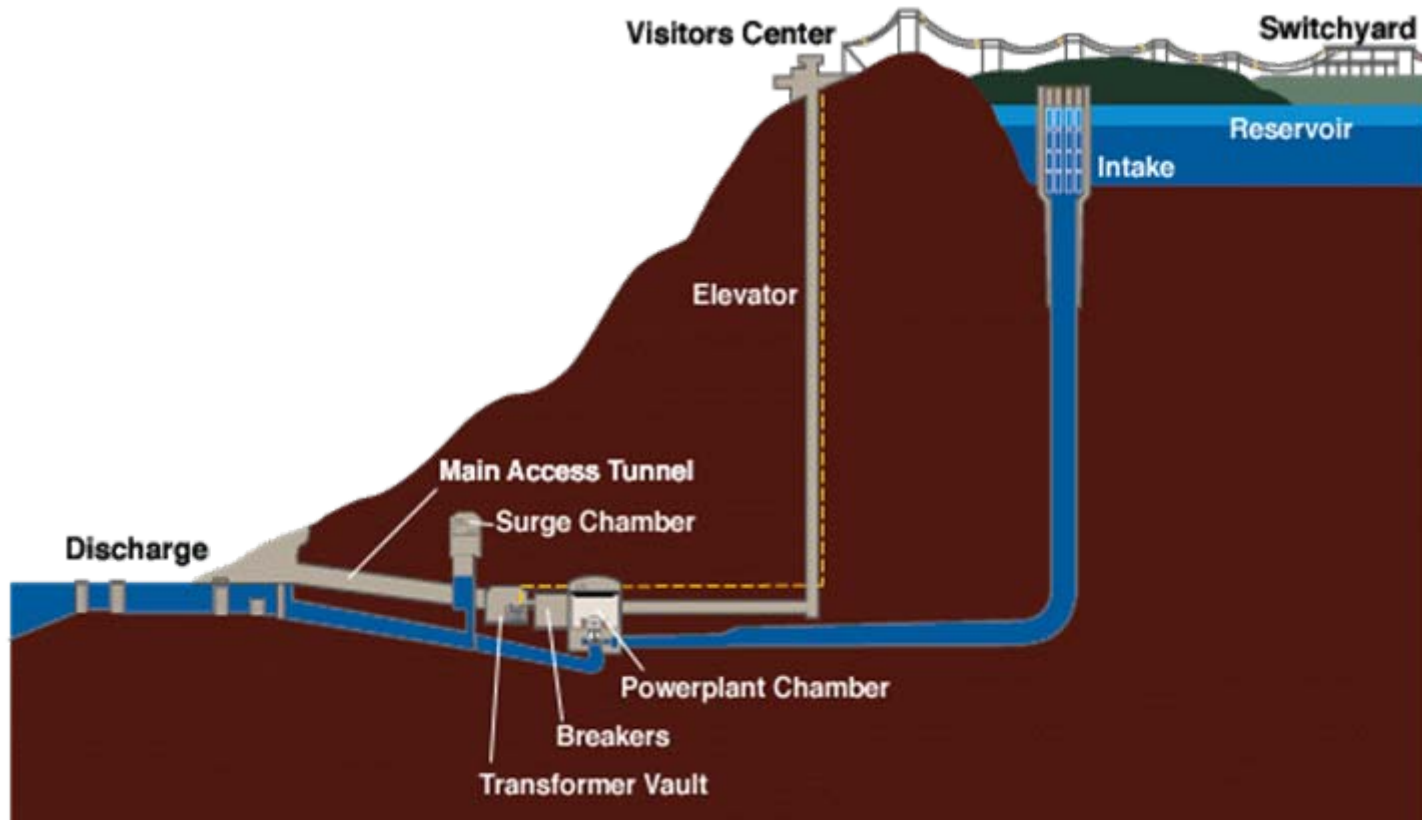
## Regenerative Energy

*Port Cranes, Subways*

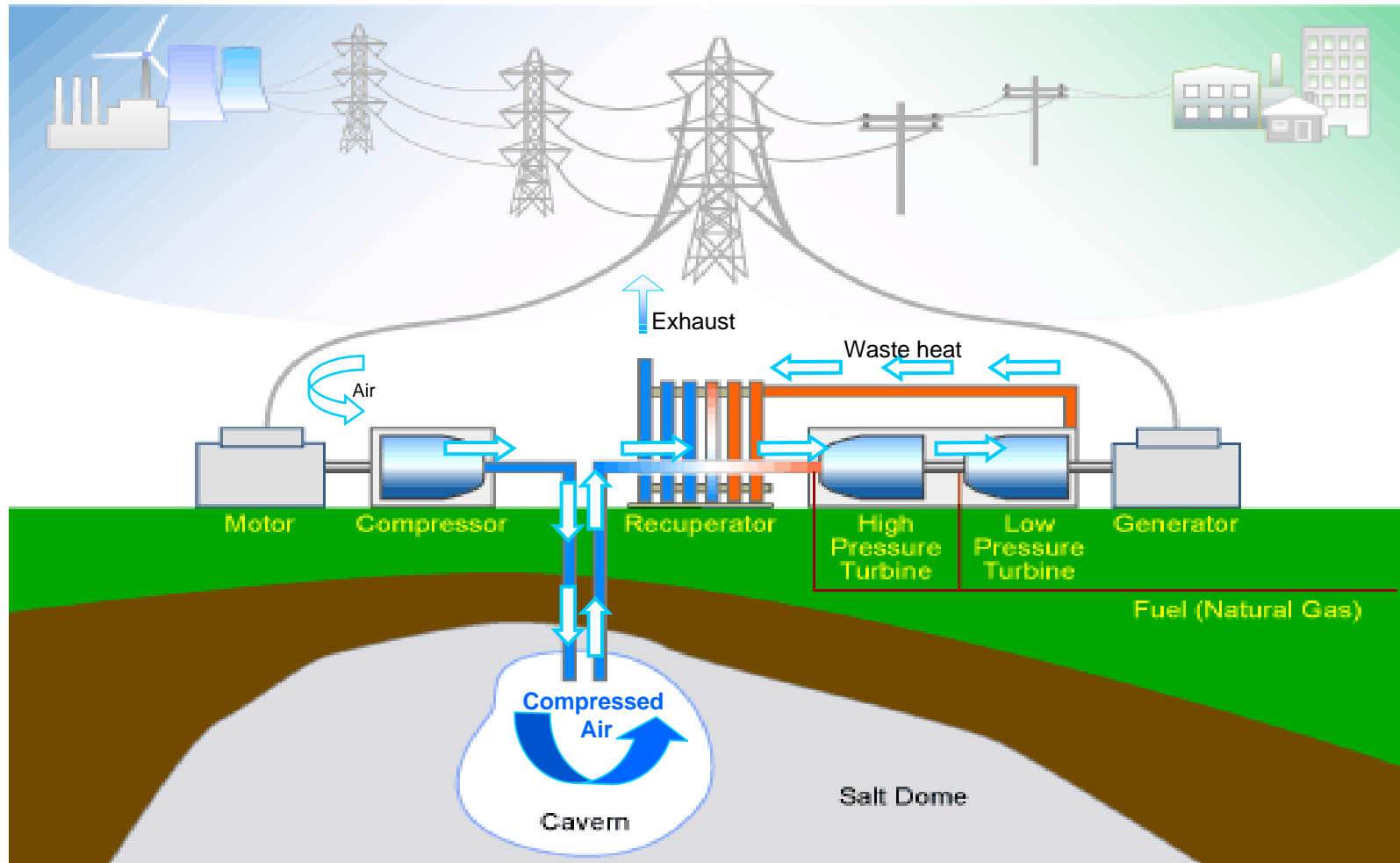


# Energy Storage: Technologies

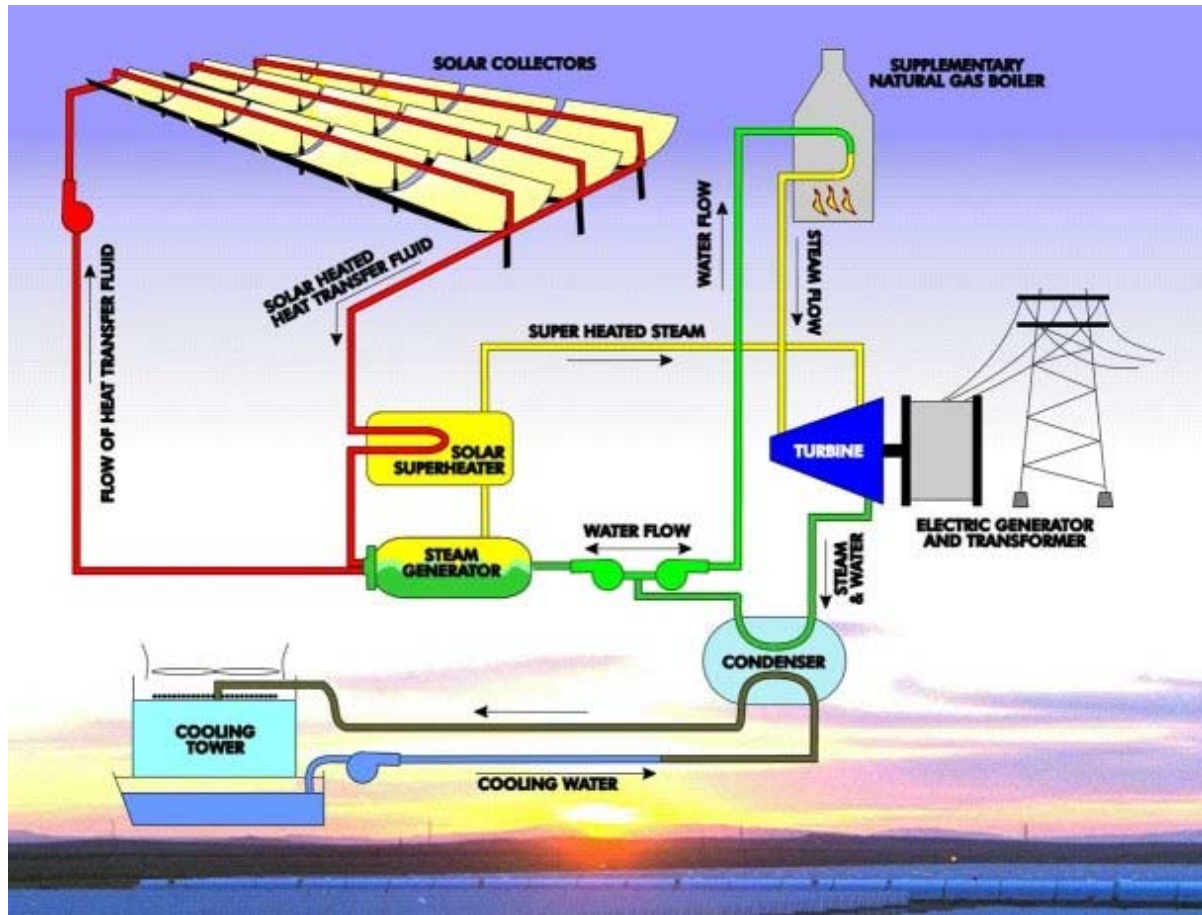
# Pumped Hydro Storage



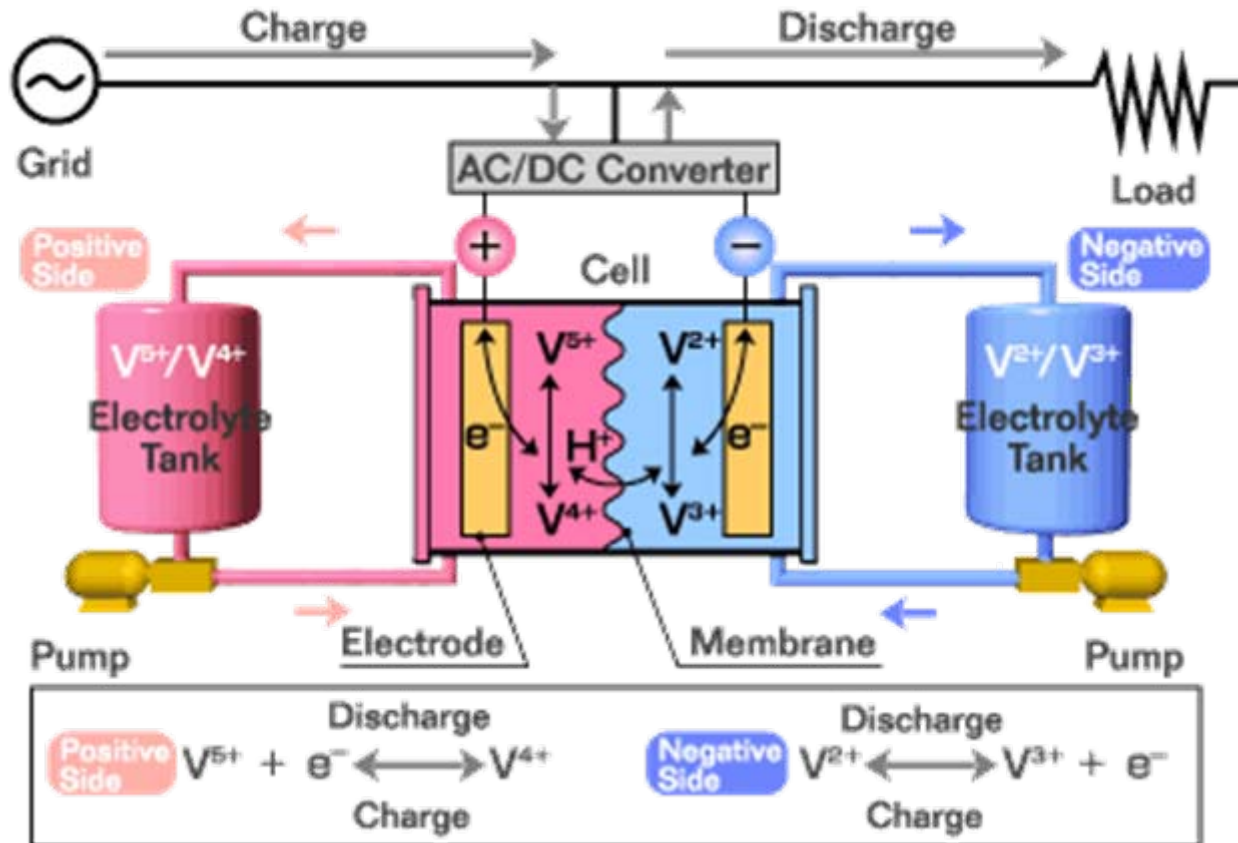
# Compressed Air Energy Storage (CAES)



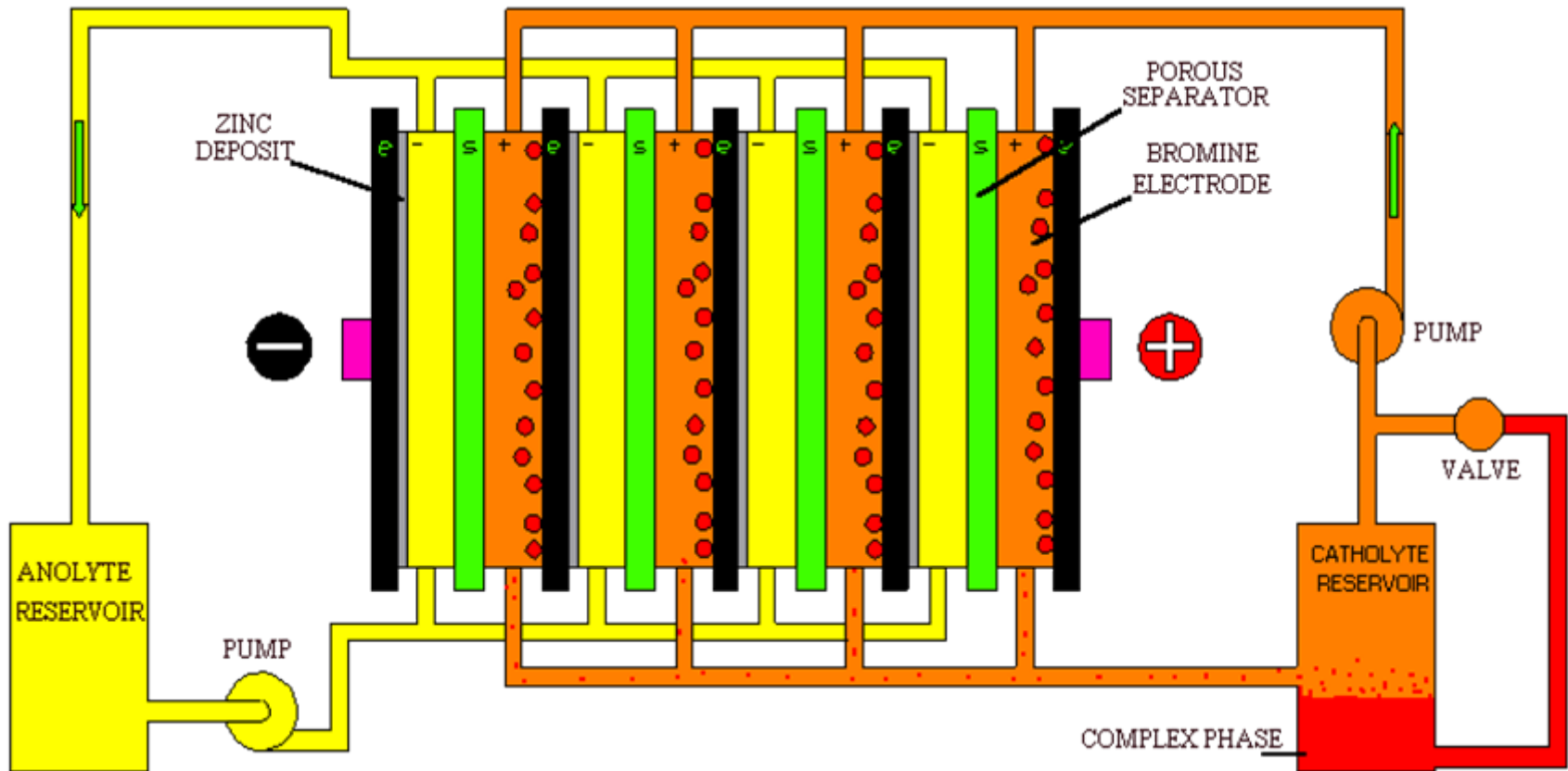
# Thermal Energy Storage – Molten Salt



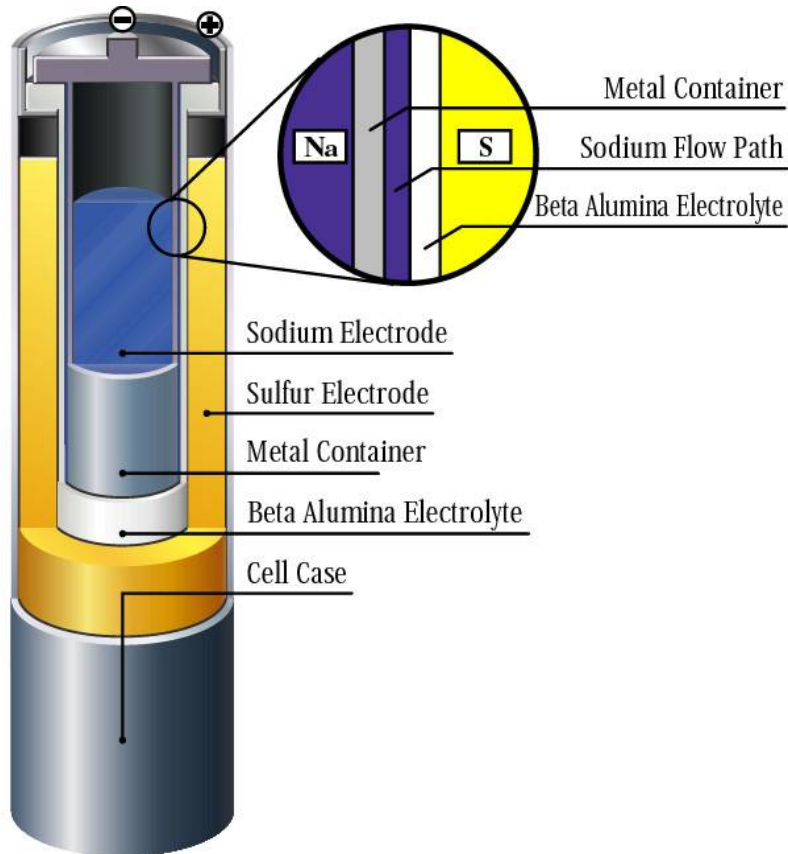
# Flow Battery – Vanadium Redox



# Flow Battery – Zinc Bromide

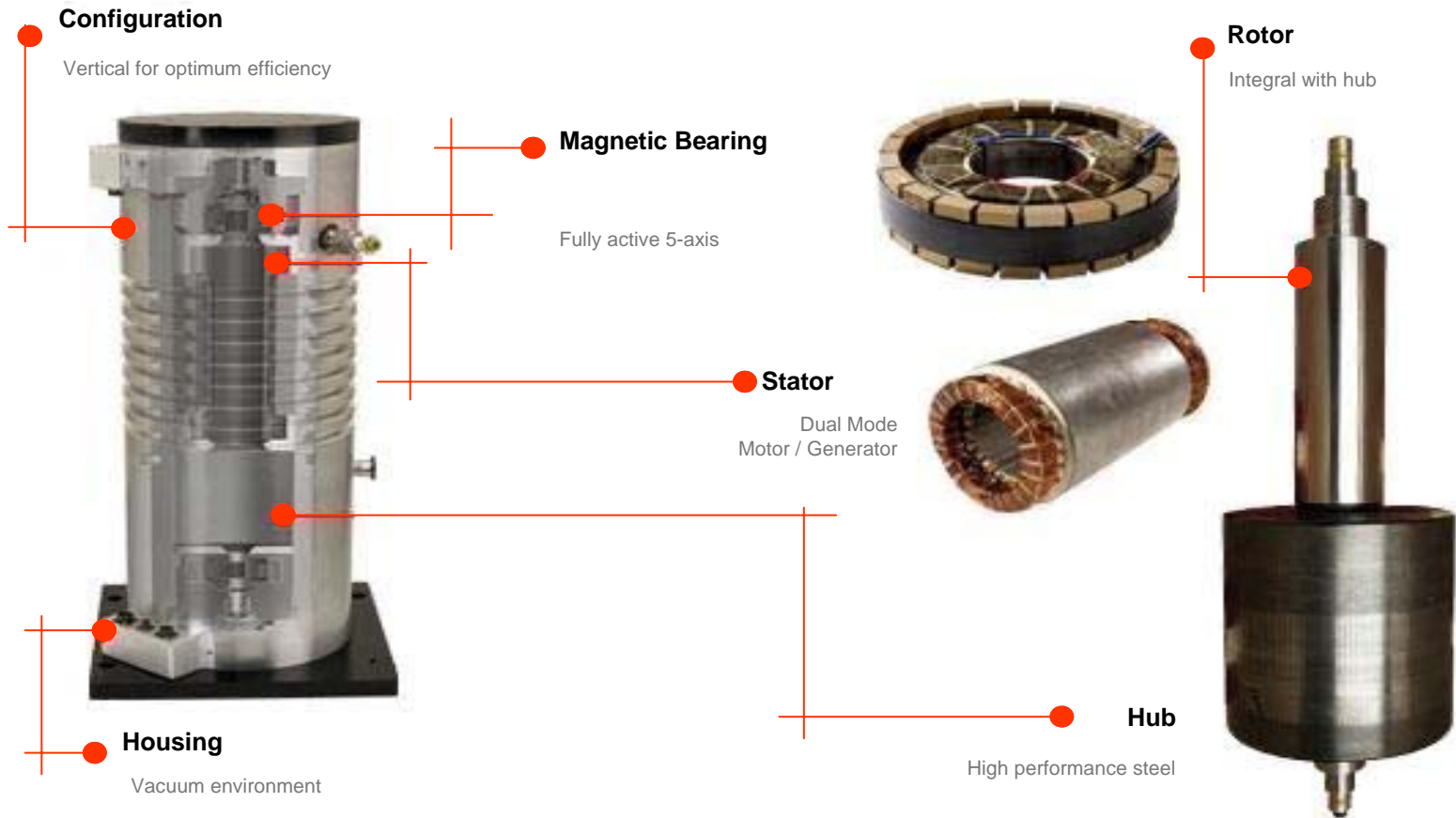


# Sodium Sulfur (NAS) Battery

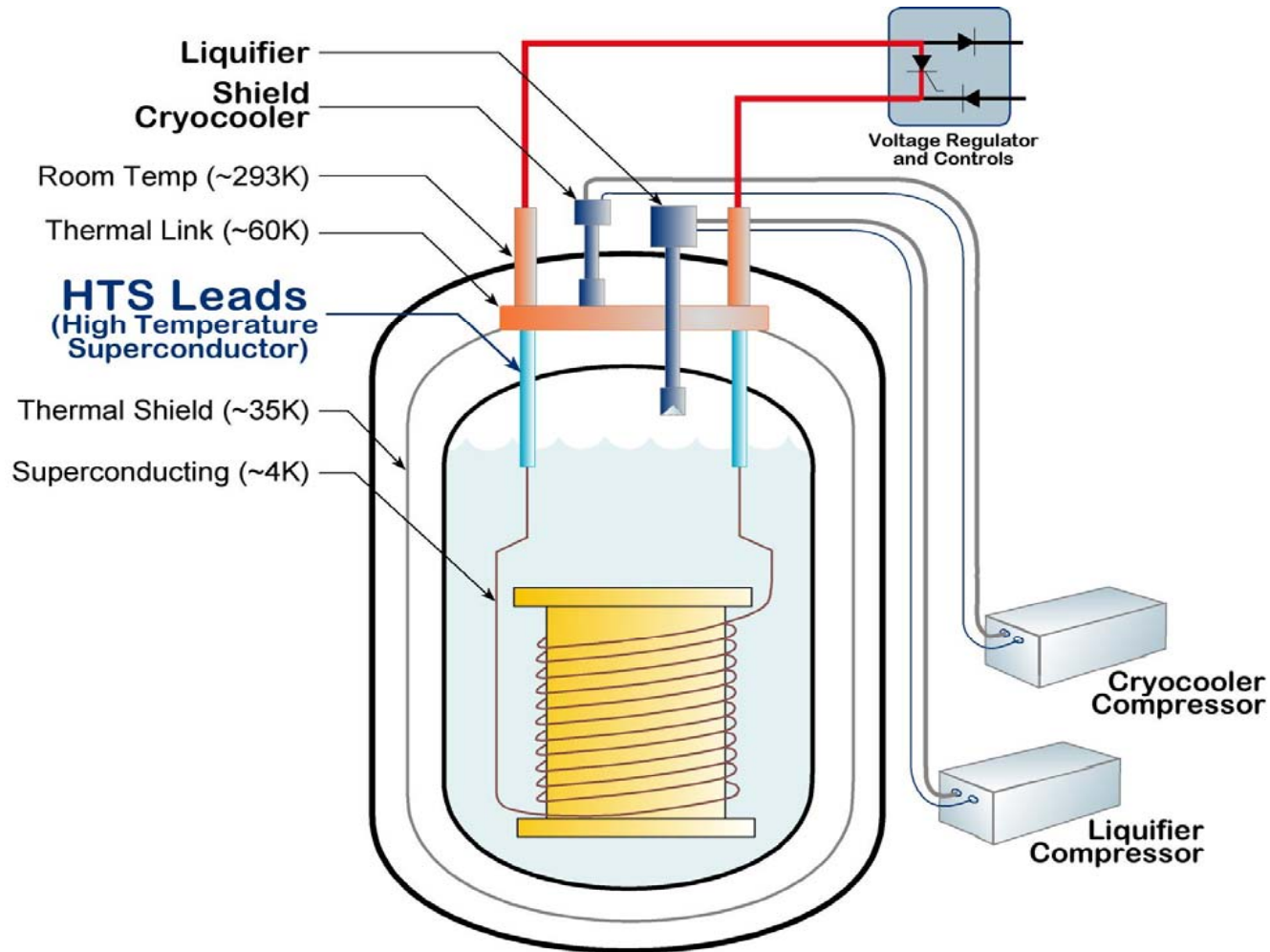


- **Low resistance, high efficiency due to**
  - Beta Alumina tube
  - Sulfur electrode design
- **High durability due to**
  - Corrosion protection layer
  - Sulfur electrode design
- **High energy density due to**
  - Cell properties and design
- **Intrinsic safety due to**
  - Incorporation of safety tube

# Flywheel

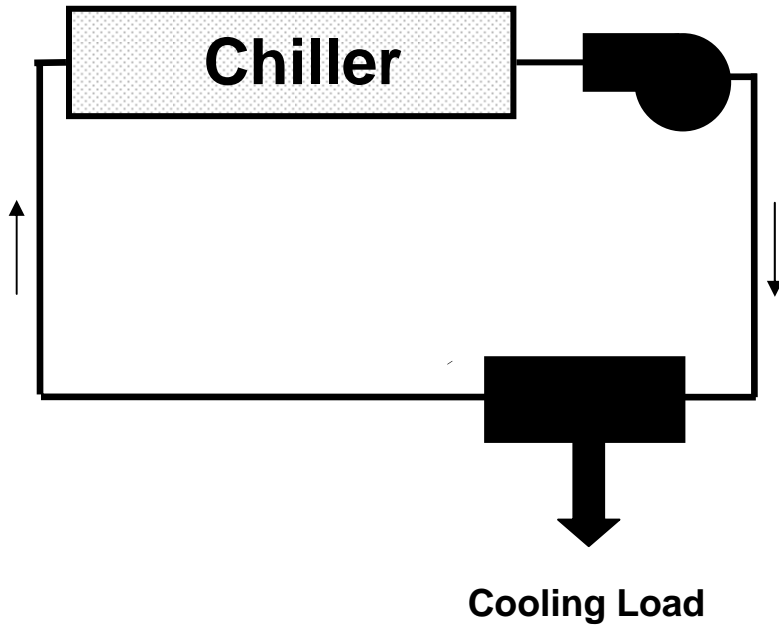


# Superconducting Magnetic Energy Storage (SMES)

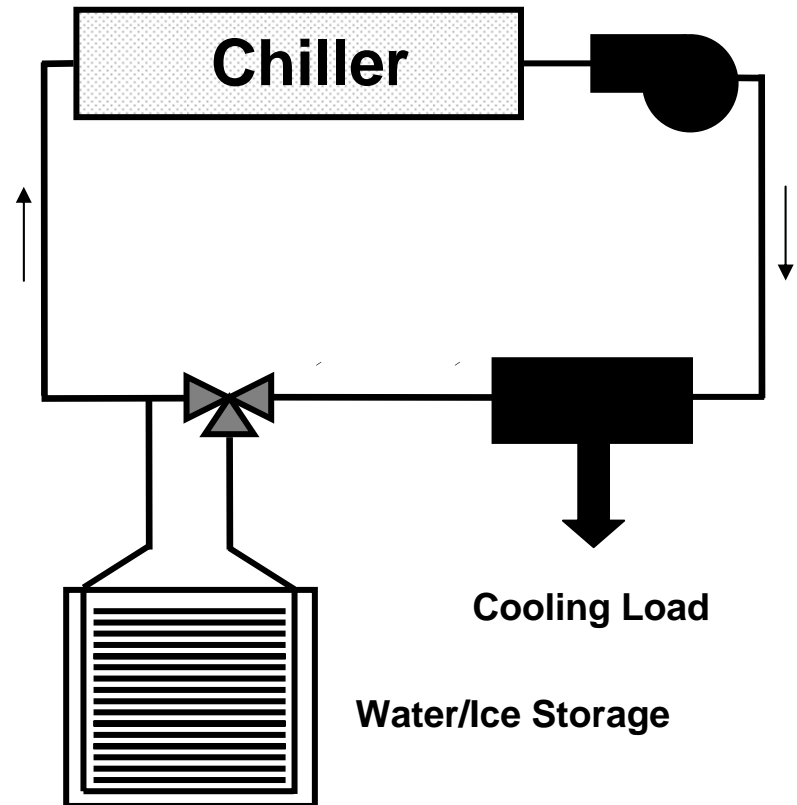


# Thermal Energy Storage - Ice

Standard Building Cooling System  
-- Without TES

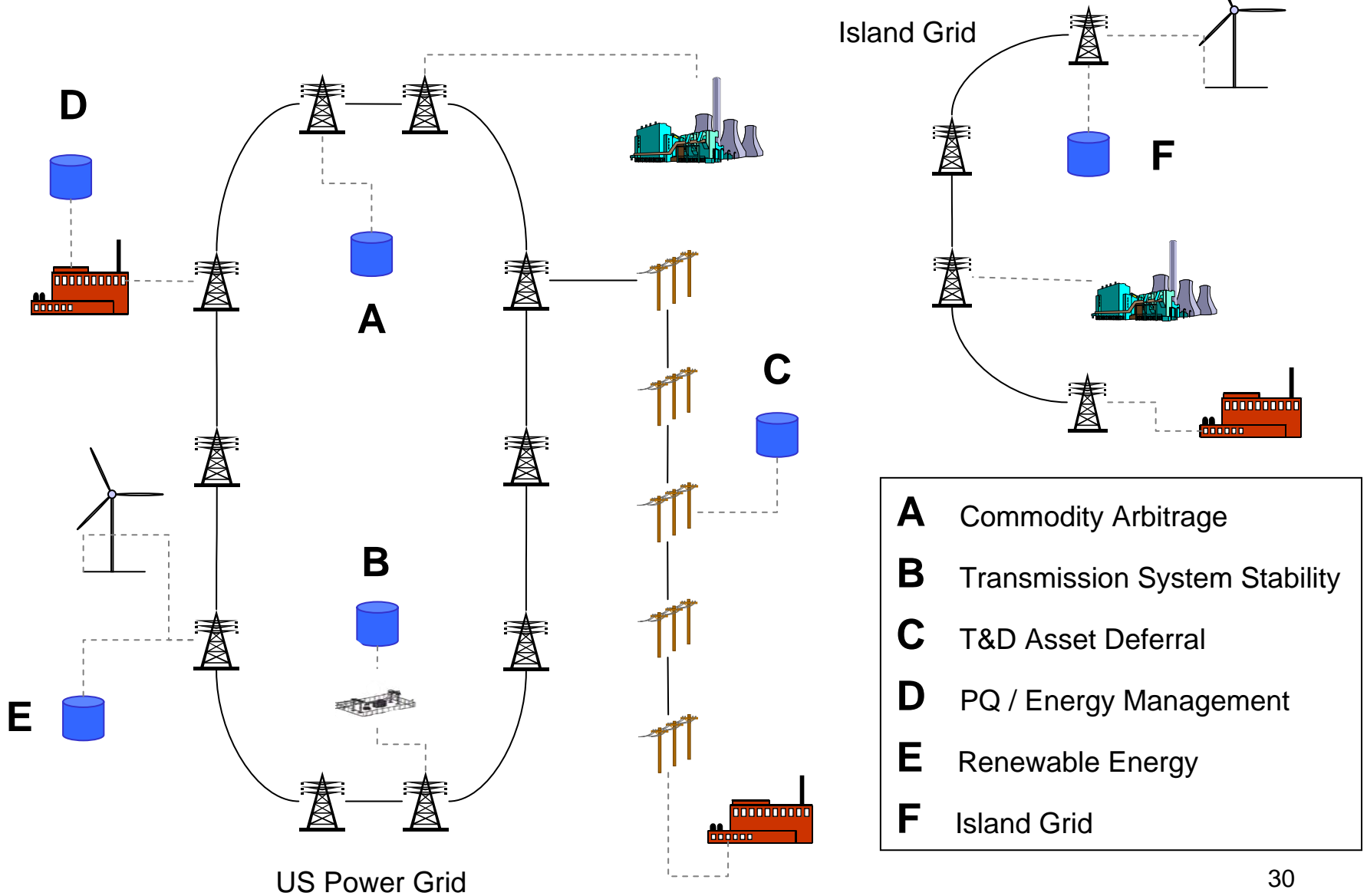


Standard Building Cooling System  
-- With TES

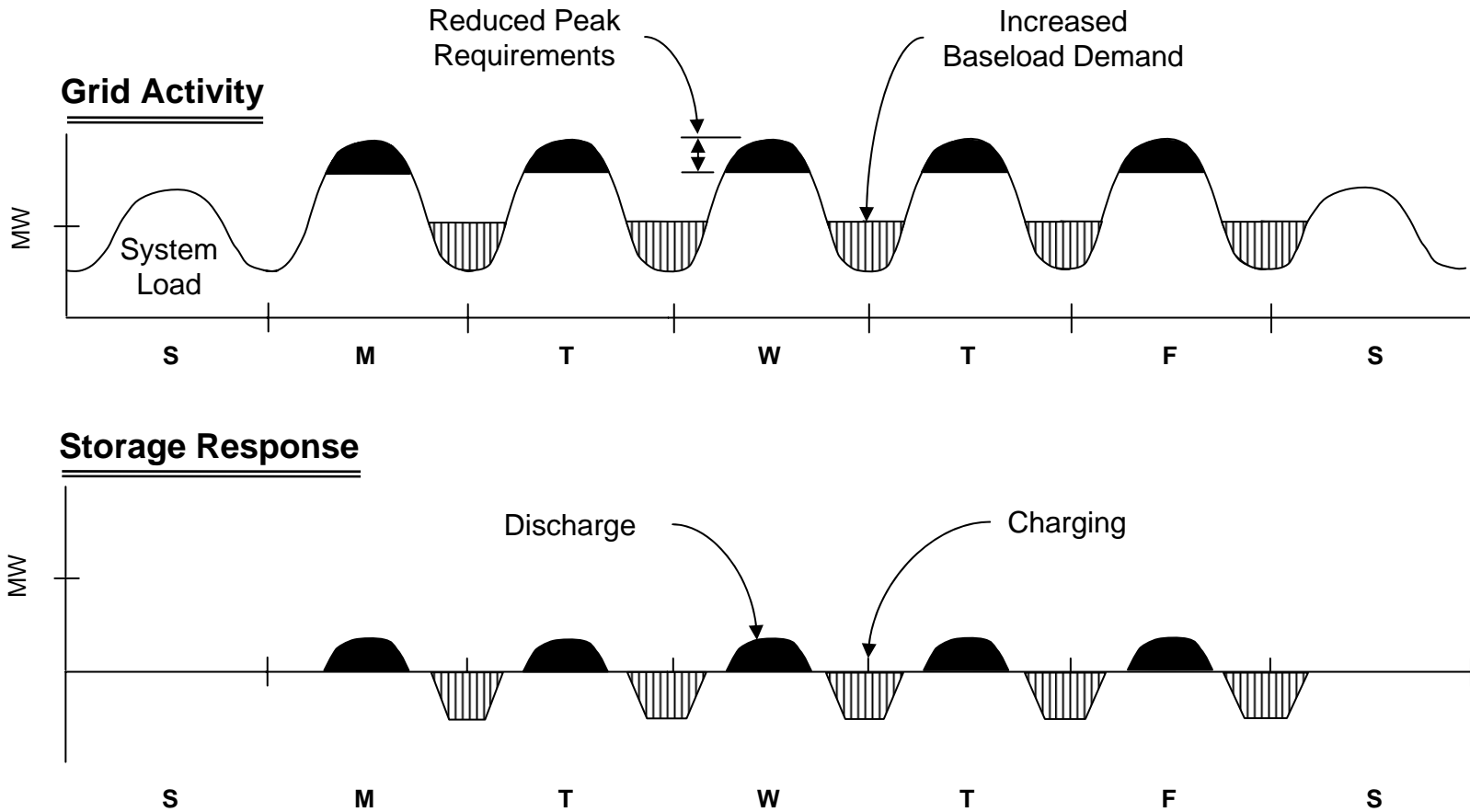


# Energy Storage: Applications

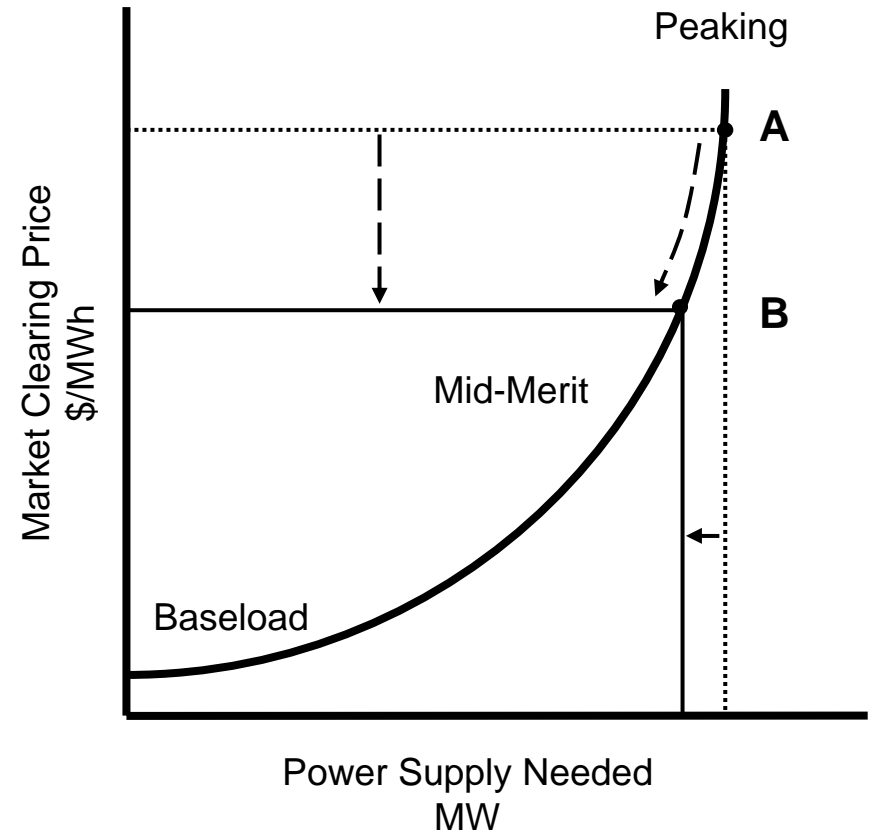
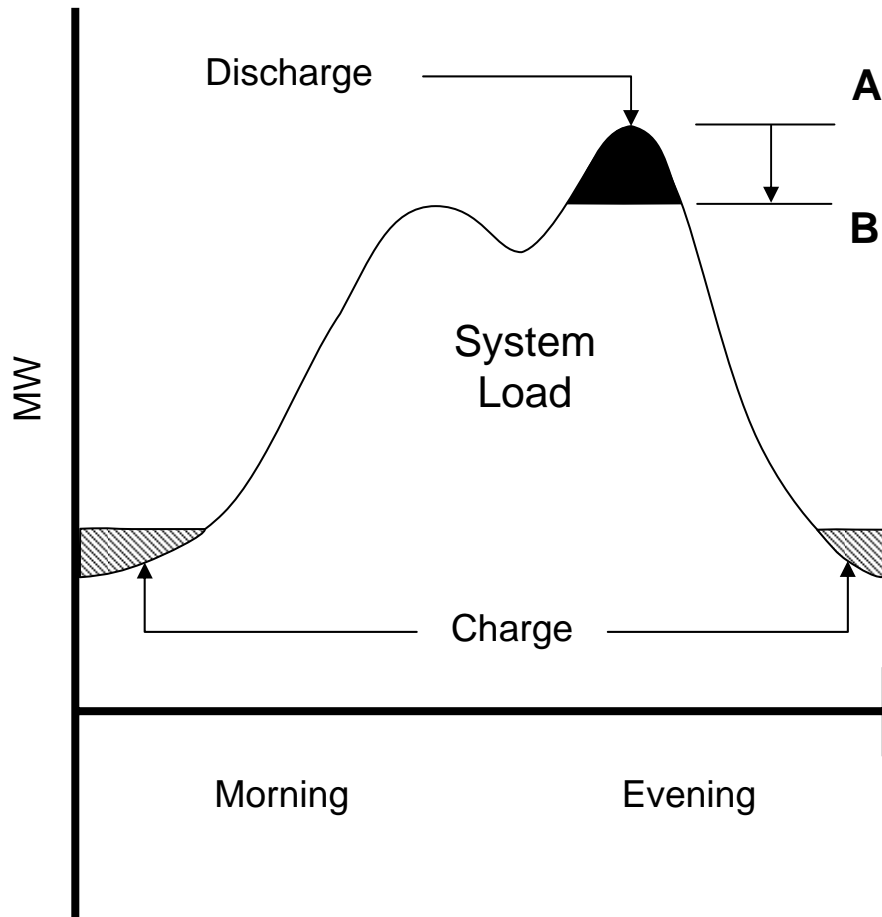
# Grid-Scale Energy Storage Applications



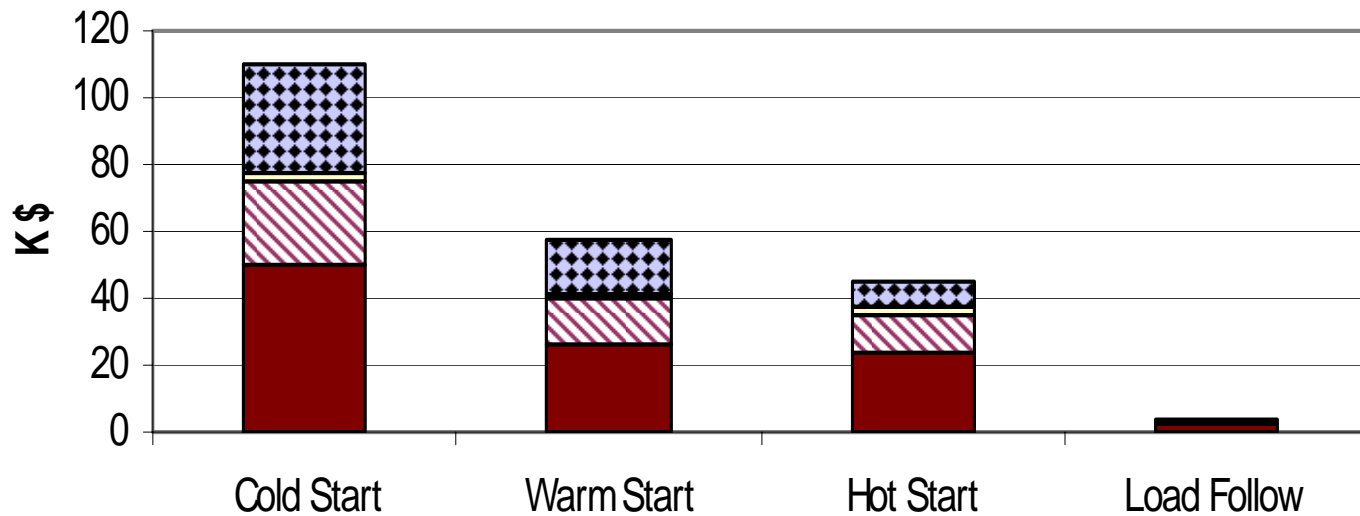
# Wholesale Power – Commodity Arbitrage



# Wholesale Power – Dispatch Order



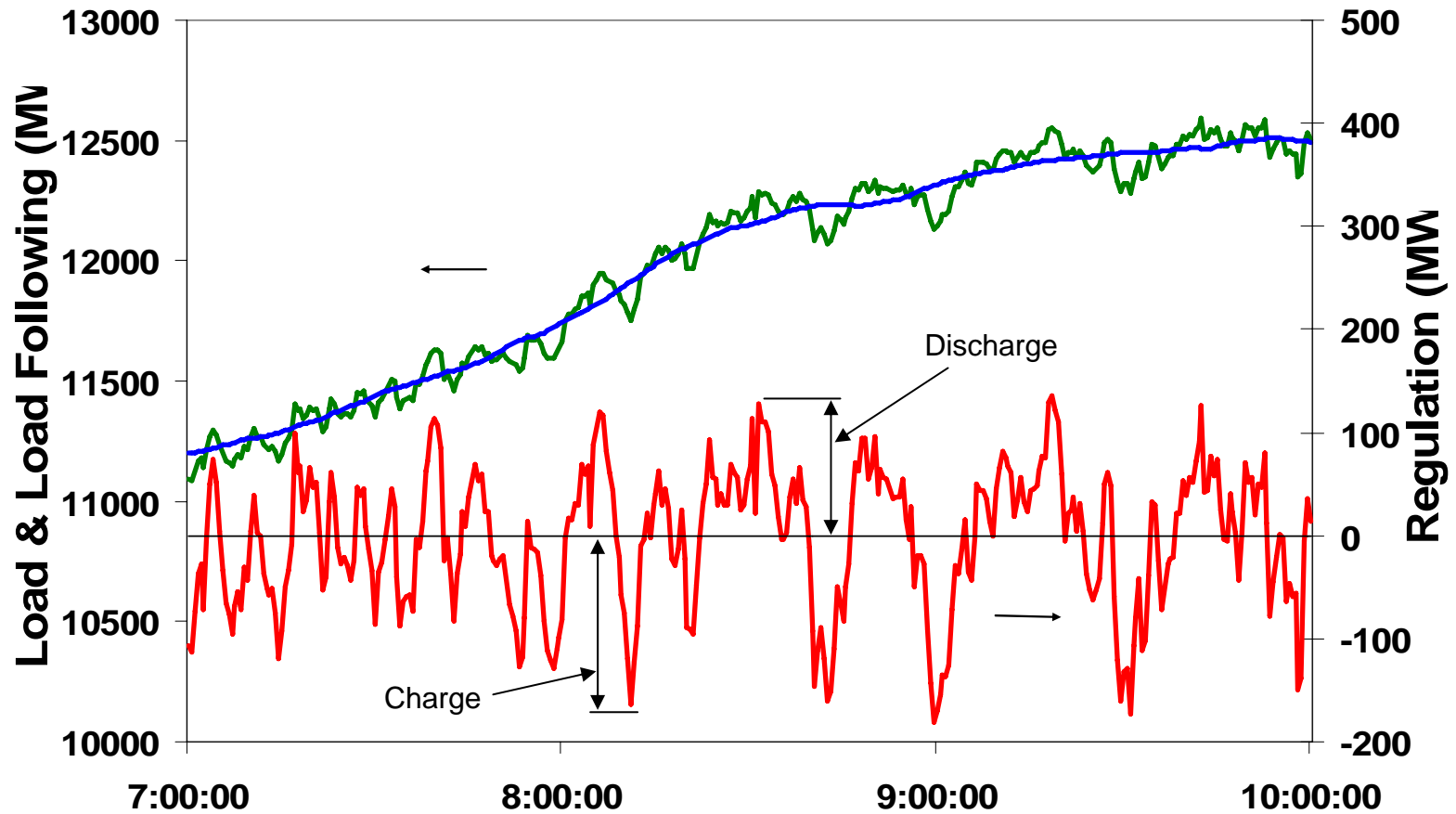
# Wholesale Power – Generator Cycling Cost



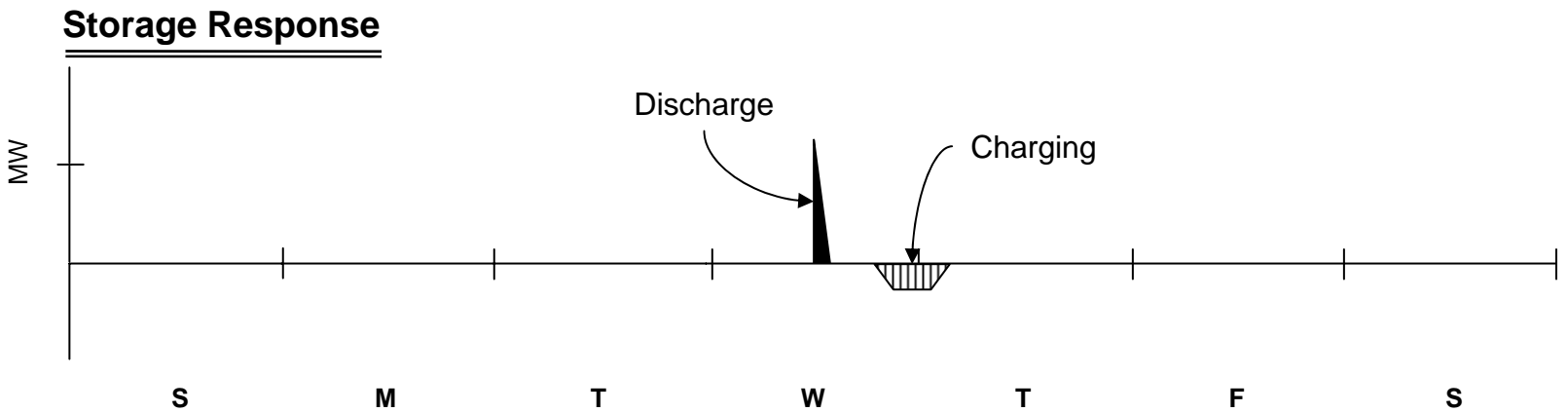
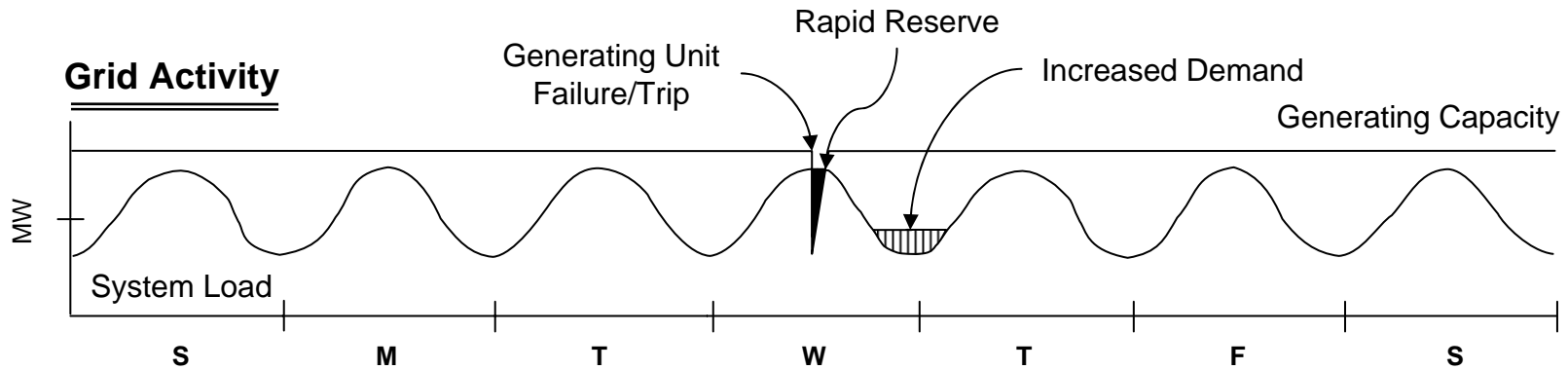
- Maintenance, Operation & Capital Cost
- ▨ Forced Outage Replacement Power Cost
- Low & Variable Load Extra Fuel Cost
- ▣ Startup Fuel, Aux Power, etc. Cost



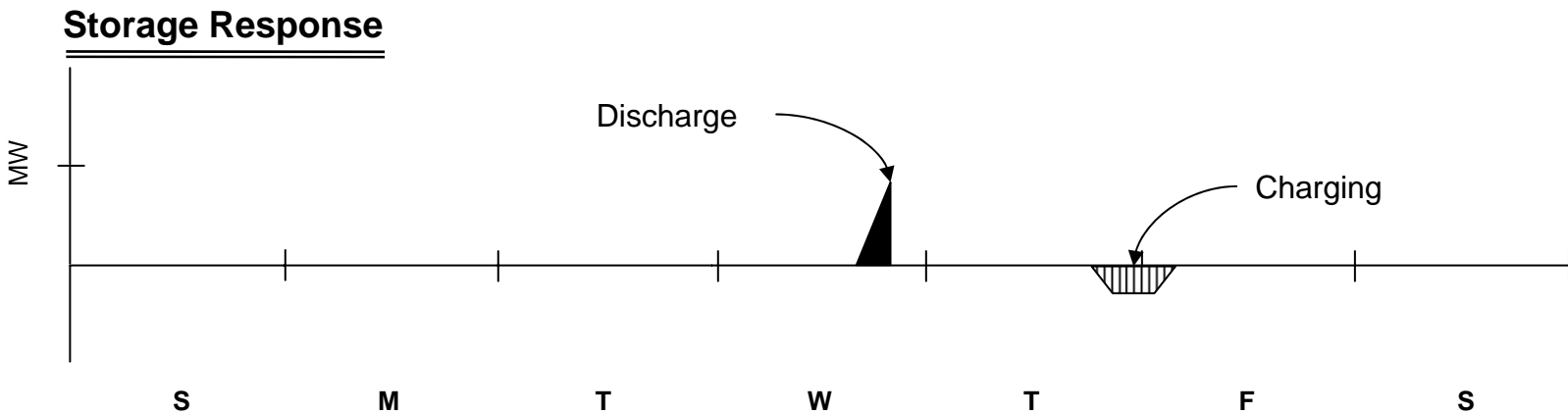
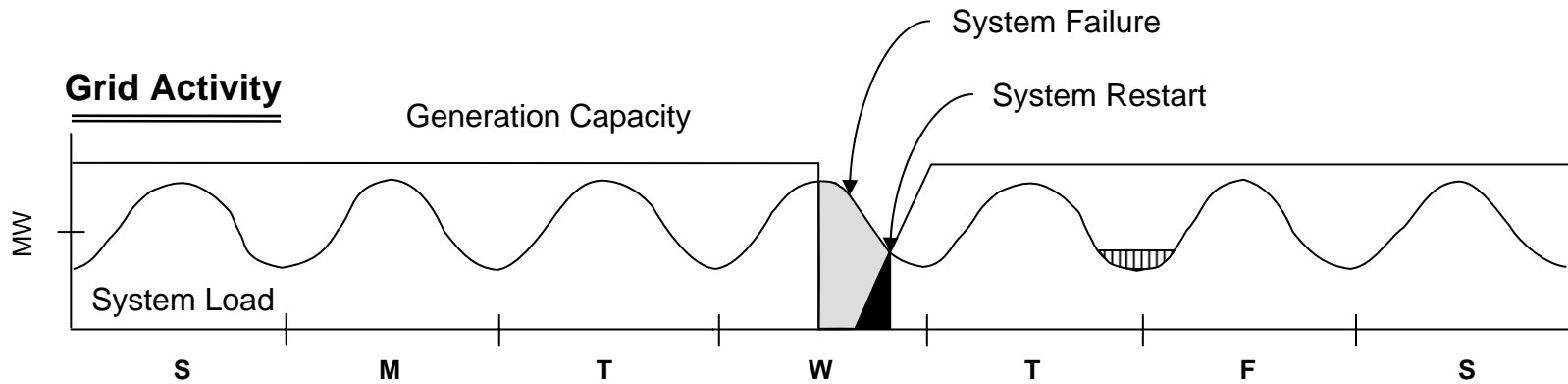
# Wholesale Power (A/S) – Frequency Regulation



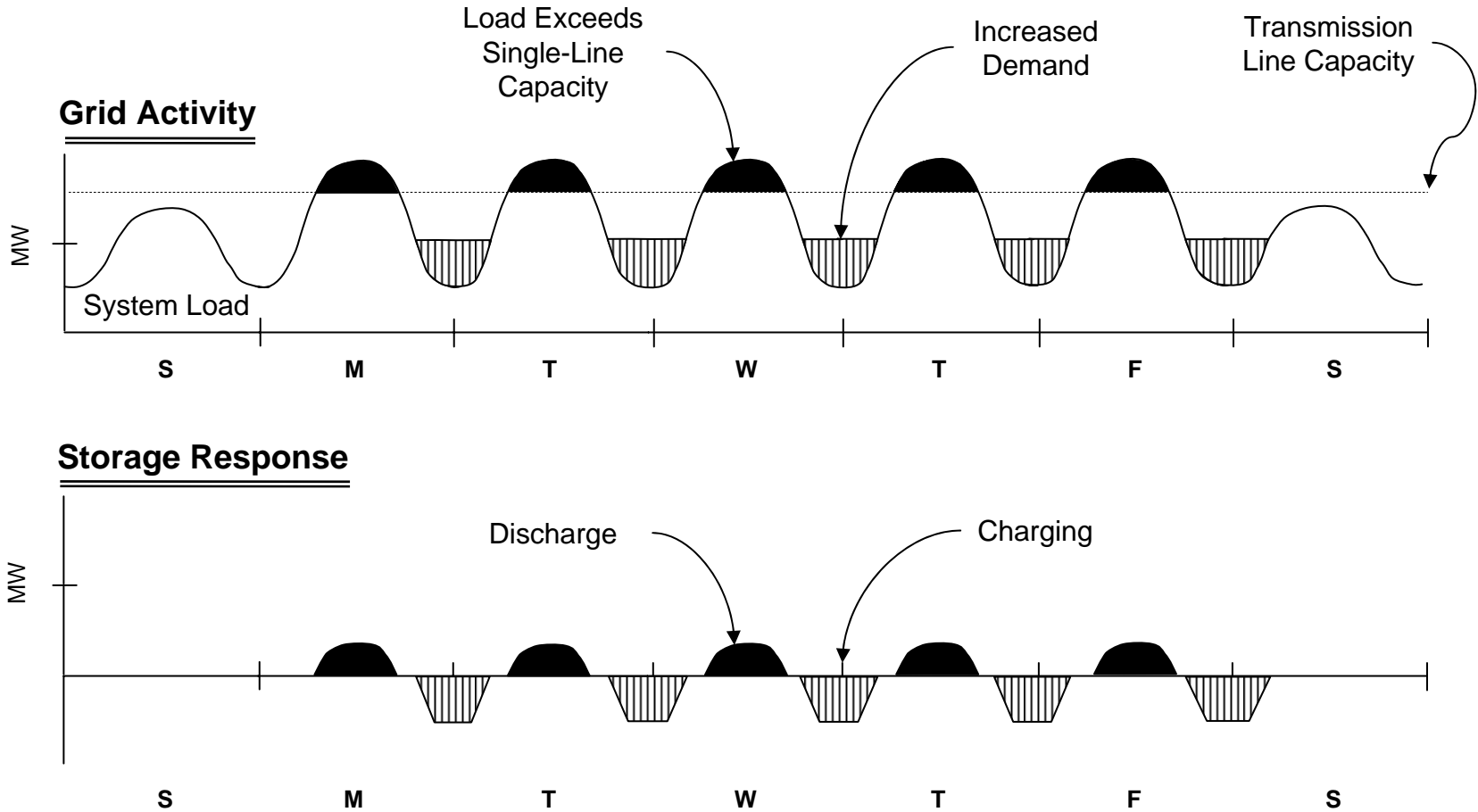
# Wholesale Power (A/S) – Contingency Reserves



# Wholesale Power (A/S) – Black Start

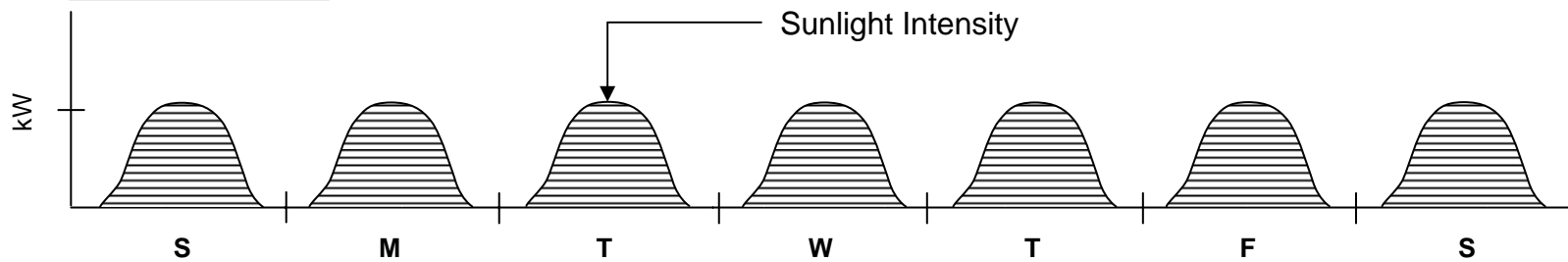


# Transmission & Distribution – Asset Deferral

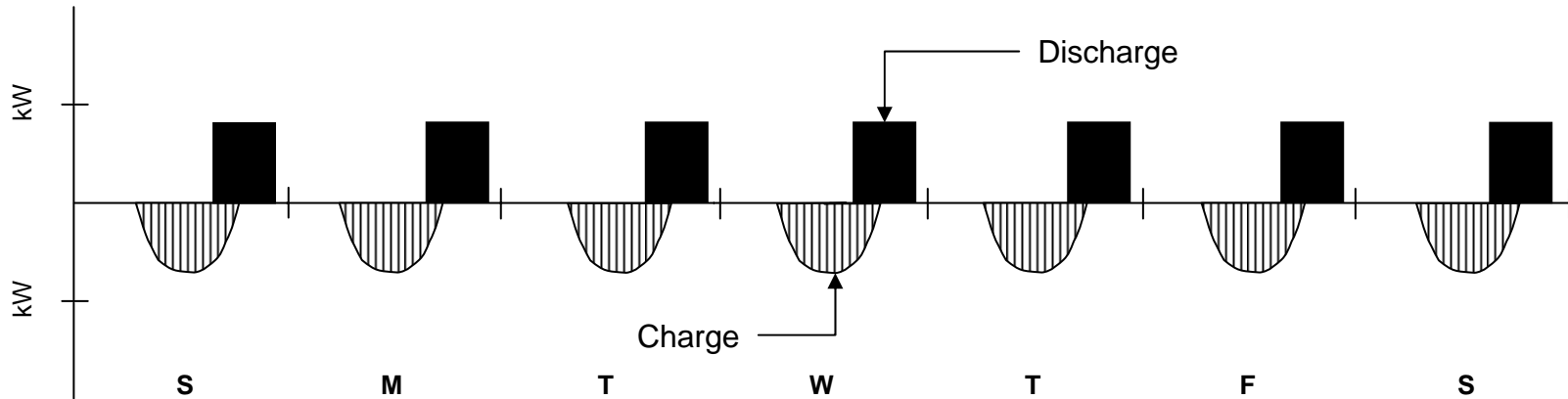


# Renewable Energy – Remote Power

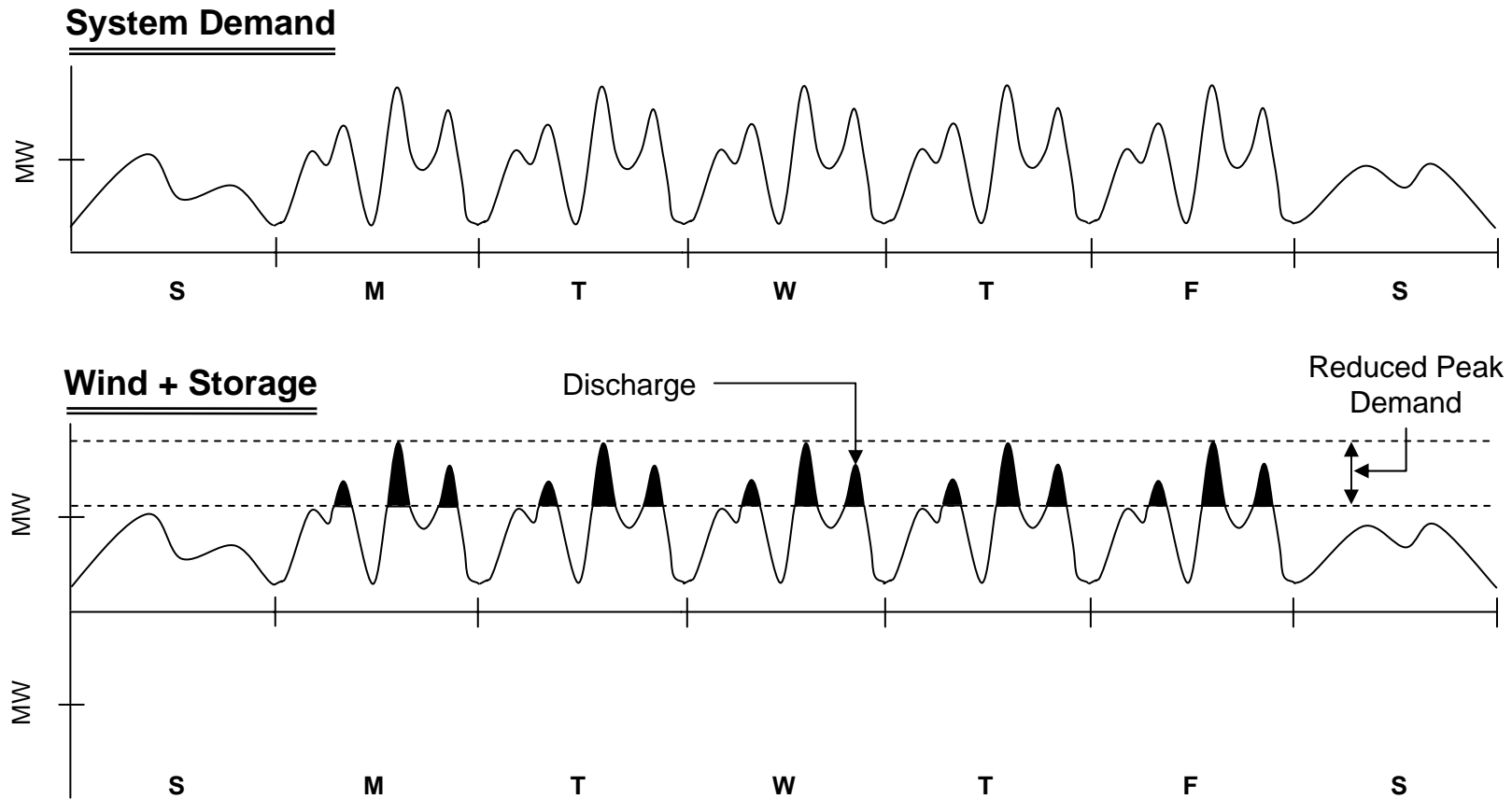
## Solar Resource



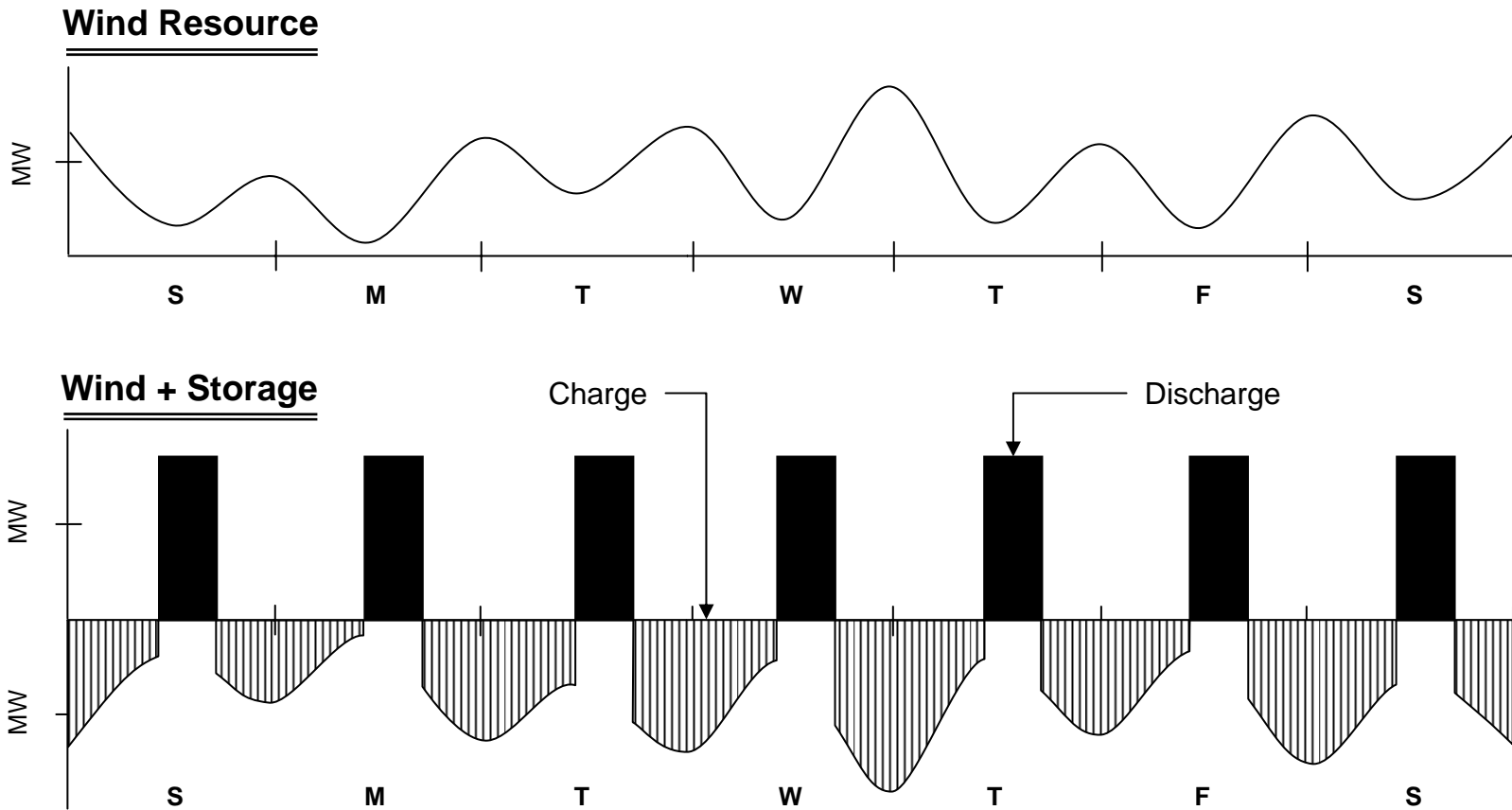
## Wind + Storage



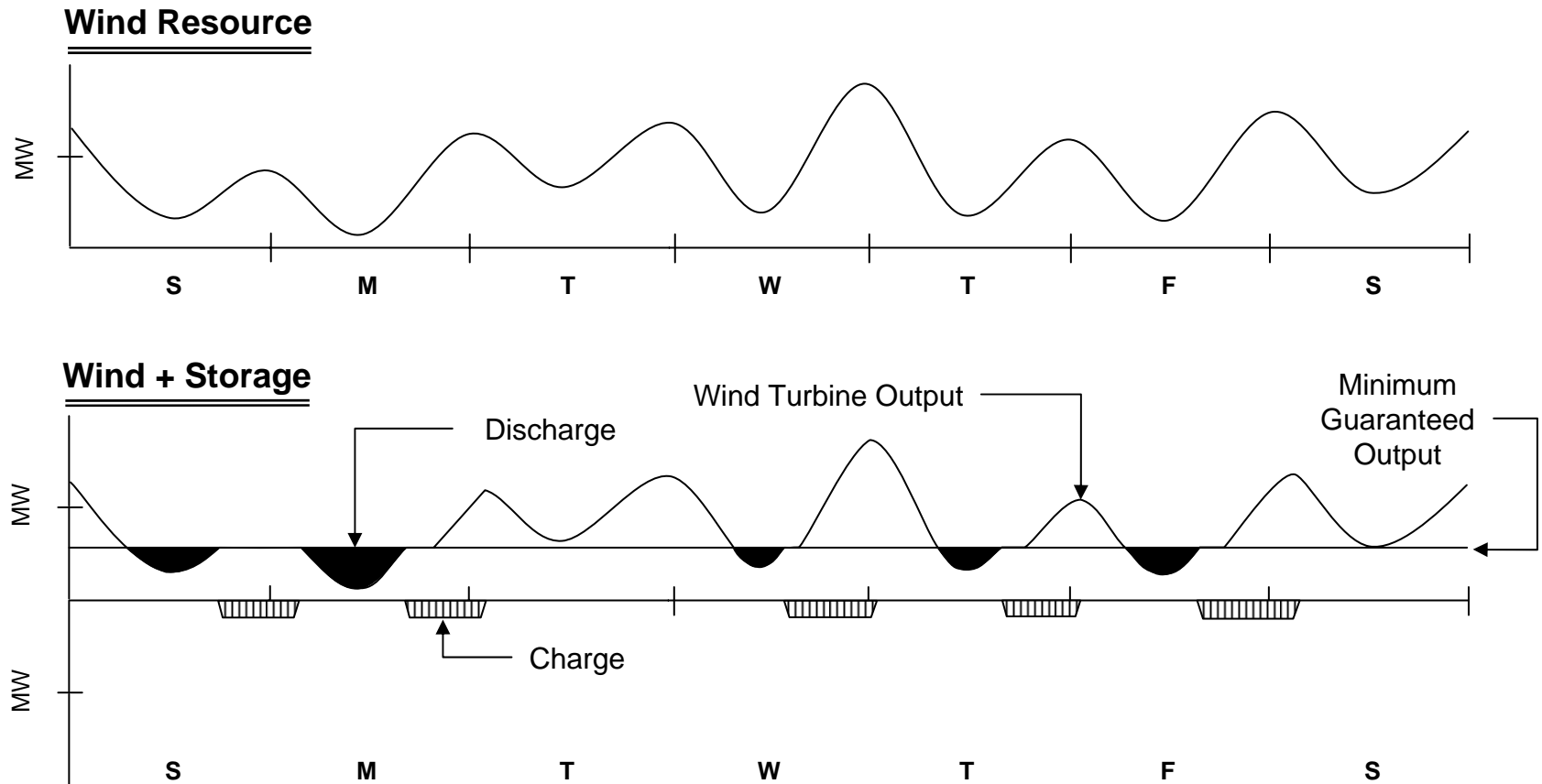
# Renewable Energy – Island Grid



# Renewable Energy – Block Power Sales

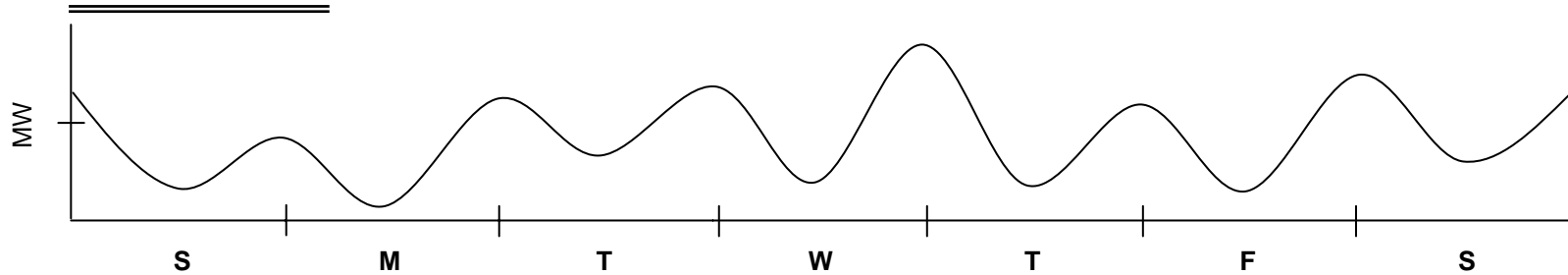


# Renewable Energy – Capacity Firming

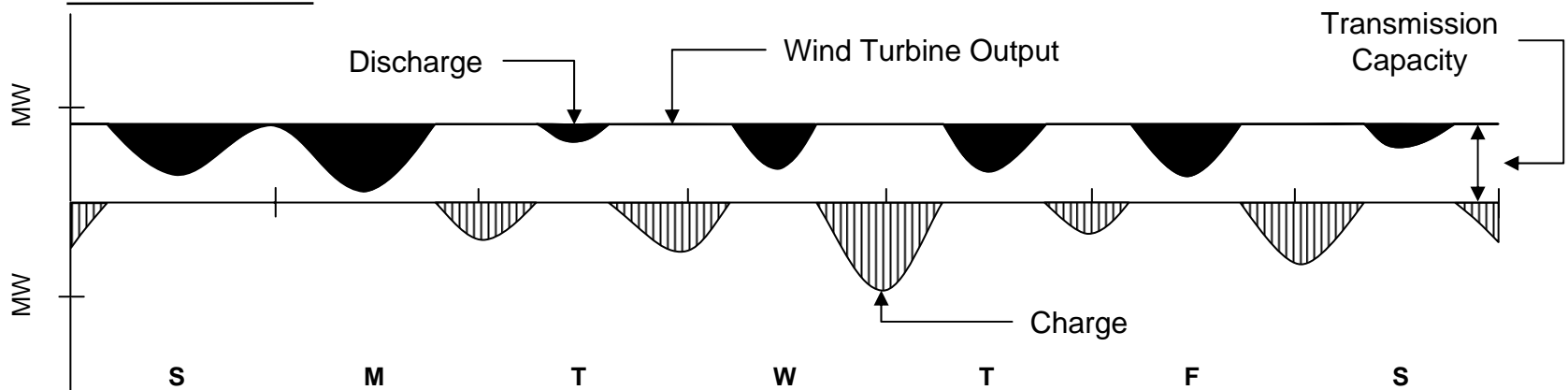


# Renewable Energy – Baseload Wind

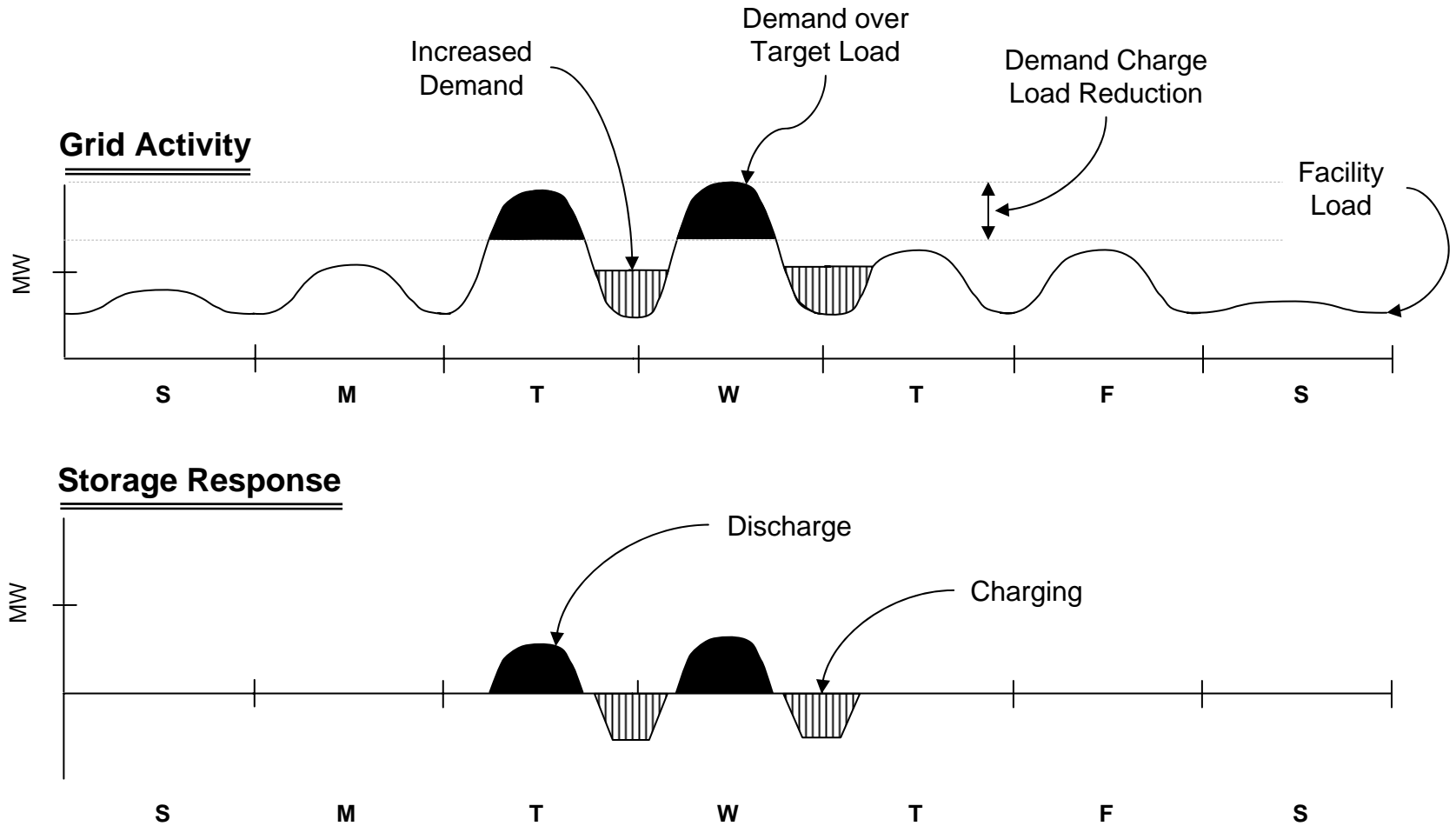
Wind Resource



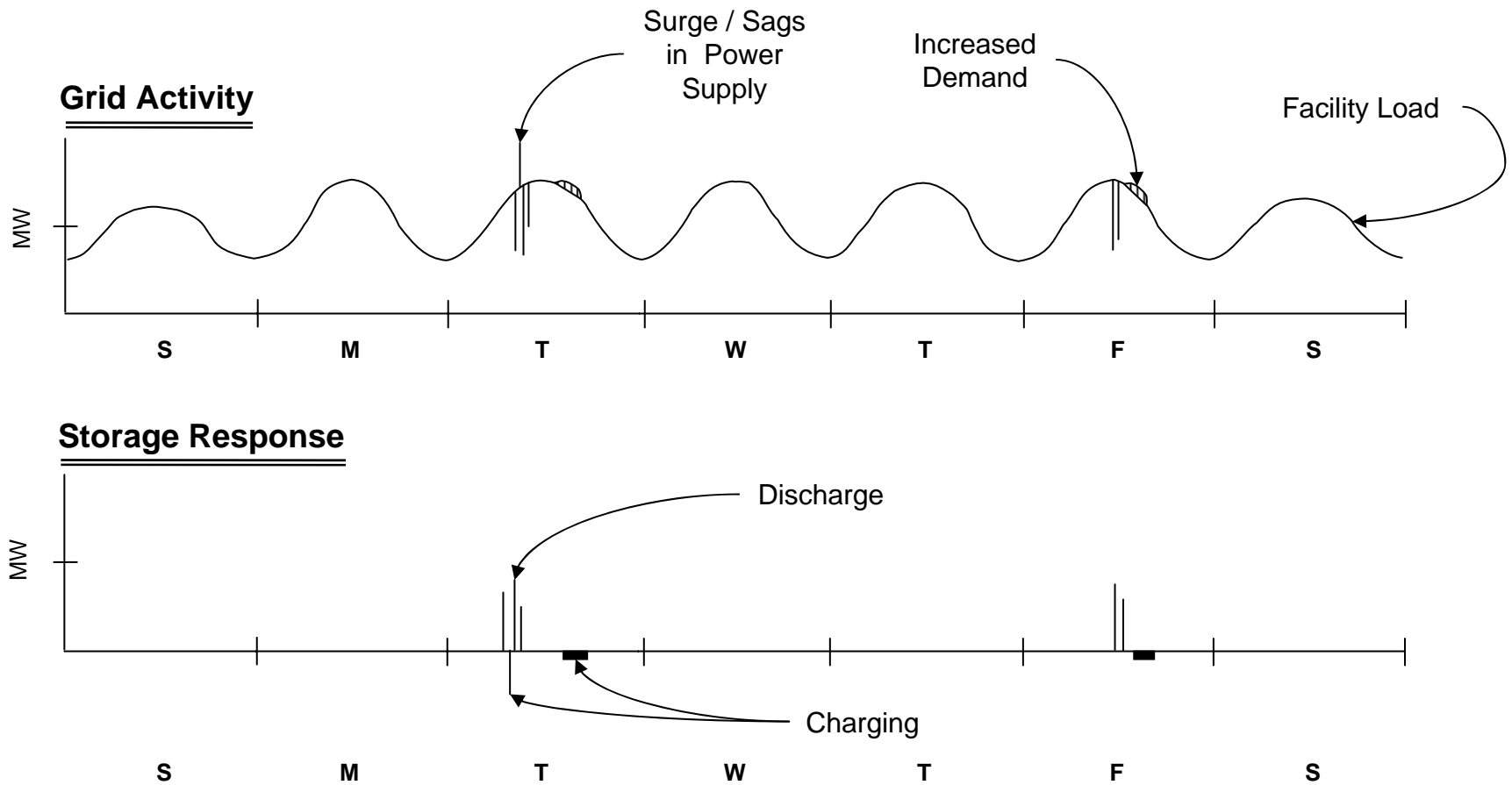
Wind + Storage



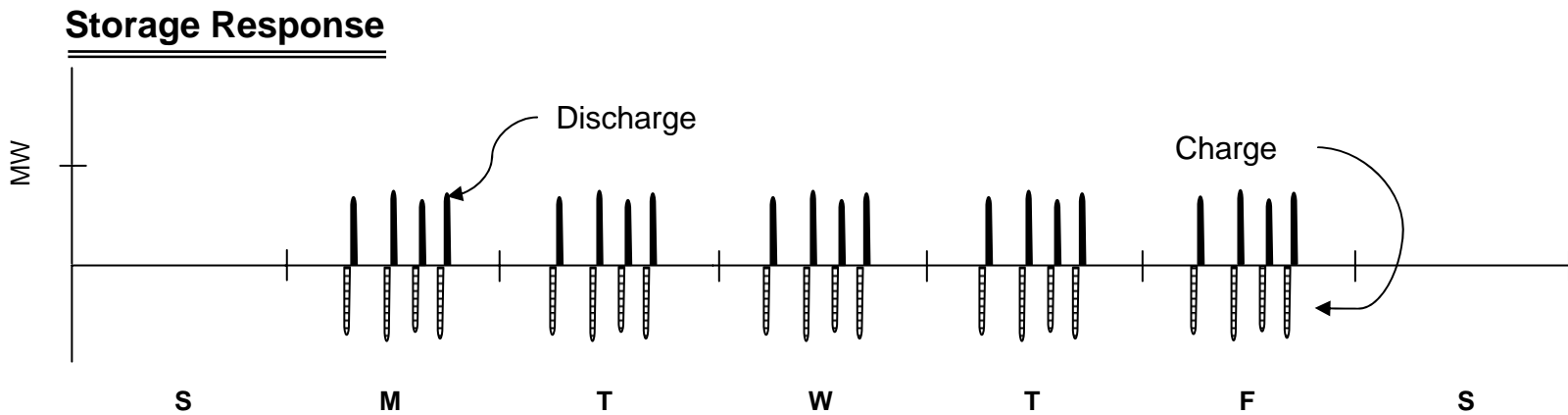
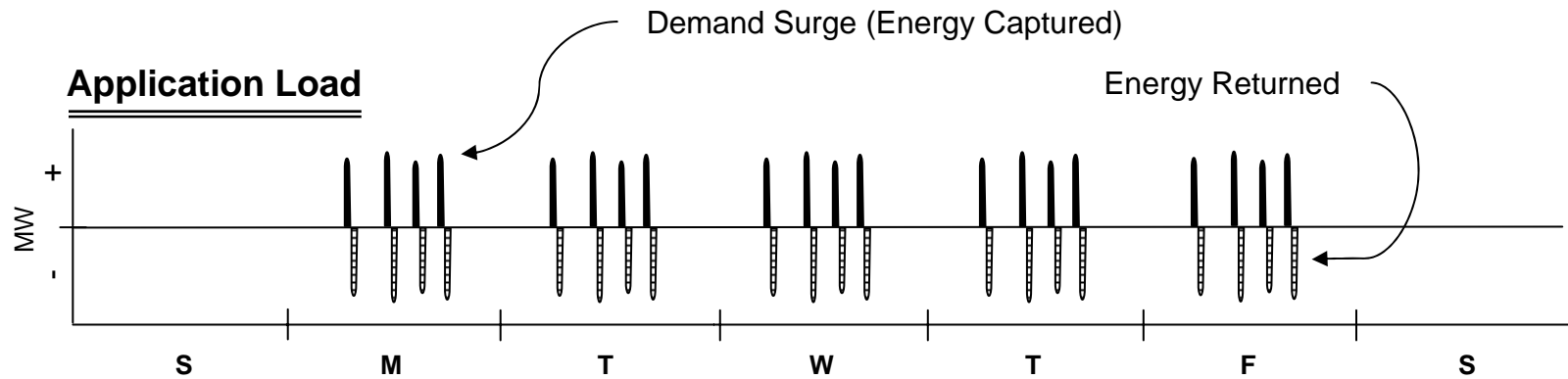
# Distributed Resources – Peak Shaving



# Distributed Resources – Power Quality



# Distributed Resources – Regenerative Energy



# Resources

Electricity Storage Association (ESA)

[www.electricitystorage.org](http://www.electricitystorage.org)

Sandia National Laboratory

[www.sandia.gov/ess/Technology/technology.html](http://www.sandia.gov/ess/Technology/technology.html)

US Department of Energy

[www.oe.energy.gov/storage.htm](http://www.oe.energy.gov/storage.htm)

# Disclaimer

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We, Walter Nasdeo, JinMing Liu, Adam Krop and Richard Baxter, hereby certify that the views expressed in this research report accurately reflect our personal views about the companies under coverage and the securities of each. We also certify that we have not been, are not, and will not be receiving direct or indirect compensation in exchange for expressing the specific recommendation(s) in this report.

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Ardour Capital uses a ratings system for research reports consisting of the following categories, BUY, ACCUMULATE, HOLD, REDUCE, and SELL. These ratings will cover the intermediate timeframe which we define as 12 months into the future.

A buy rating will be assigned to a company considered to possess outstanding growth prospects by the covering analyst. Metrics will include an expected common stock appreciation of at least 20% for the intermediate future. This expected appreciation will be substantiated by a clearly defined and prominently displayed valuation methodology.

An accumulate rating will be assigned to a company considered to have positive upside stock appreciation potential between 10% and 20%. However, in some cases quantitative analysis will forecast stock price appreciation of greater than 20% but extenuating circumstances lead the analyst to assign an accumulate as opposed to a more aggressive buy rating. The analyst's reasoning will be clearly stated in the investment summary section of the report.

A hold rating will be assigned to a company that is expected to experience flat to moderate growth in the intermediate future. As with accumulate ratings, quantitative measures may point to a more aggressive rating, however, the covering analyst may have near-term concerns that will be prominently spelled out in the investment summary section of the report. This growth may be deemed attributable to purely industry dynamics and not necessarily fundamental issues.

A reduce rating will be assigned to a company that the analyst believes is nearing the target price or is overvalued due to an unexplained run up in the stock price. The analyst now recommends that investors should take some profit.

A sell rating will be assigned to a company that is either experiencing fundamental difficulties or the stock price has exceeded the analyst's target price.

As of January 1, 2009, the breakdown of ratings of all companies Ardour Capital follows is, by percentage, Buy/Accumulate = 64% Hold/Suspend = 34%, Reduce/Sell = 2%.

As of January 1, 2009, the breakdown of ratings of all companies Ardour Capital follows and receives or has received investment banking compensation in the previous year is, by percentage, Buy/Accumulate = 0%, Hold = 0%, Reduce/Sell = 0%, Suspend = 0%.

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# Questions?

# Ardour Capital Grid Scale Energy Storage Overview

**Grid Scale energy storage technologies can help the power grid operate more efficiently, and effectively.** The power grid is based on a vast investment of generation and transmission infrastructure. Energy storage technologies leverage the existing assets to improve power quality, and reduce the need for overinvestment in additional infrastructure.

## Technologies

- CAES – Compressed Air Energy Storage
- PHS – Pumped Hydro Storage
- Solar Thermal Storage (Hot Salt)
- NAS – Sodium Sulfur
- Flow Batteries
- SMES – Superconducting Magnetic Energy Storage
- Flywheels
- Thermal Energy Storage (Ice)
- Advanced Batteries (Modules)

## Applications

- Wholesale Power
- Transmission & Distribution
- Renewable Energy
- Distributed Resources

## Emerging Market Opportunities

- Improving Power Grid Operations
- Reducing/Delaying Required Investments
- Stand-by Power Replacement for Legacy Batteries
- Improving the Value of Renewable Power
- Enhanced Power Quality

# Ardour Capital Advanced Batteries Overview

**Battery technology is advancing rapidly, promising improvements in their ability to power larger devices, and for a longer period of time.** Much of the recent advancement has centered on the ability of these devices to broaden their range of applications, including more strenuous operation requirement, and harsher environments.

## Technologies

- Nickel Metal Hydride (NiMH)
- Nickel Zinc
- Lithium Ion
  - Cathode:  $\text{LiCoO}_2$
  - Cathode:  $\text{LiFePO}_4$
  - Cathode:  $\text{LiMn}_2\text{O}_4$
  - Cathode: Nickel Cobalt Aluminum
  - Anode: Carbon, Lithium Titanates
- Lithium Polymer
- Silver Zinc
- Metal – Air
- Lead – Carbon (PbC)

## Key Design / Usage Issues

- Power
- Energy
- Cost
- Safety
- Cycle-Life

## Emerging Market Opportunities

- Mobile Devices
- Electric Drive Vehicles
- Renewable Energy
- Distributed Resources

# Ardour Capital Smart Grid Overview

**The Smart Grid is not simply a new layer of technology for the power grid, it is a new architecture—of technology and operation—which promotes a better, more capable power industry.**

## Goals

- Reliability
- Efficiency
- Customer Choice
- Distributed Resources
- Environmental Impact

## Technologies

- Home Area Network
- Advanced Metering Infrastructure
- Demand Response
- Energy Storage
- Distribution Automation
- Transmission Expansion

## Visibility & Control

- Measure
- Monitor
- Manage

## Issues

- Architecture vs. Technology
- Pricing (RTP for Everyone?)
- Centralized vs. Distributed
  - *Power Generation*
  - *Control/Management*
- Standards
- Who owns the Data

# Ardour Capital Advanced Metering Infrastructure Overview

Advanced metering infrastructure (AMI) is key to introduce the Smart Grid. By leveraging available information, decisions can be made to better use and operate existing power grid assets.

AMI technology links smart meters at customer sites through a two-way communication network to a utility's data and operations center. Although AMI signals a change in how utilities gather and manage customer data, the technology remains a work in progress, with notable advancements and successful deployments accruing on a steady basis.

There are more than 2.5 billion electricity, natural gas, and water meters in the world. Overall, there is potentially over a \$40 billion opportunity to upgrade meters in all three utility markets (electric, natural gas, and water). The 2007 the North American electric utility AMR/AMI market was roughly \$1.2 billion, growing at 17% annually.

## System Components

- Advanced Meter
- Communication Network
- Meter Data Management System

## Primary Drivers

- Advanced Meter
- Communication Network
- Meter Data Management System

## System Benefits

- Remote Meter Reading
- Demand Response
- Home Area Network Gateway
- Remote Connect/Disconnect
- Outage Management
- Load Forecasting
- Line-Loss Reduction
- Tamper/Theft Detection