



## **Beacon Power Corporation**

# **Flywheel Technology for Grid-Based Energy Storage and Frequency Regulation**

**Matt Lazarewicz**

**MIT – NESCAUM Symposium**

**August 16-18, 2011**

**Boston, MA**



# Safe Harbor Statement



This presentation contains forward-looking statements, including the Company's beliefs about its business prospects and future results of operations. These statements involve risks and uncertainties. Among the important additional factors that could cause actual results to differ materially from those forward-looking statements are risks associated with the overall economic environment, the successful execution of the Company's plan of operation, changes in the Company's anticipated earnings, continuation of current contracts, changes in energy and other applicable regulations, and other factors detailed in the company's filings with the Securities and Exchange Commission, including its most recent Forms 10-K and 10-Q. In addition, the factors underlying Company forecasts are dynamic and subject to change and therefore those forecasts speak only as of the date they are given. The Company does not undertake to update them; however, it may choose from time to time to update them and if it should do so, it will disseminate the updates to the investing public.

# Overview



- Storage Basics
- Beacon Power
- Frequency Regulation
- Flywheel Technology
- Performance
- Market and Regulatory Reform
- Future Plans
- Economics

Energy Storage provides Energy

**when** it is needed

just as Transmission provides Energy

**where** it is needed

### Progress in Energy Storage Applications and Technology

IMRE GYUK, PROGRAM MANAGER  
ENERGY STORAGE RESEARCH, DOE

StarWeek 7-15-09

### Stored vs. Delivered Energy:

- 2.5% U.S
- 10% Europe
- 15% Japan

Which Country has most Outages?

# Storage Makes Life Easier



- Car gas tanks
- Woodpiles for fire places
- Computer RAM, Hard drives, DVDs, thumb drives
- City parking lots
- Kitchen pantries
- Warehouses
- Hotels
- .....

**What about electricity?**

# Storage Types



## Laptop Computer

- RAM
  - Millions of operations/min
- Hard Drive
  - Current work
- DVD
  - Occasional Usage

## Power Grid

- Flywheels, Capacitors
  - $> 10^5$  deep 15 min cycles
- Batteries
  - $< \text{than } 10^4$  deep 4 hour cycles
- CAES and Pumped Hydro
  - $> 1$  day cycles

**Technologies can do other functions – but not well!**

**Let's use the right tools for the job – may need all of them**



# Company Overview



- Public Company – NSDAQ: BCON
- Supplier of fast response frequency regulation using flywheel energy storage:
  - Merchant service provider
  - Seller of turnkey plants
- Operating commercially in ISO-NE since November 2008 (1-3 MW)
- 20 MW merchant plant in NY, complete April, 2011
- Second 20 MW merchant plant to break ground in 2011 in eastern PA
- Pursuing sales of turnkey plants in the US and internationally



# DOE Funding Sources



- \$43 million loan guarantee for plant #1 in New York
- \$24 million Smart Grid stimulus grant for plant #2 in Pennsylvania
- \$2.3 million ARPA-E award
- Only company to receive all 3 types of funding





# Typical “Regulation” Profile



**ISO Goal:**

**Load = Power Generated**

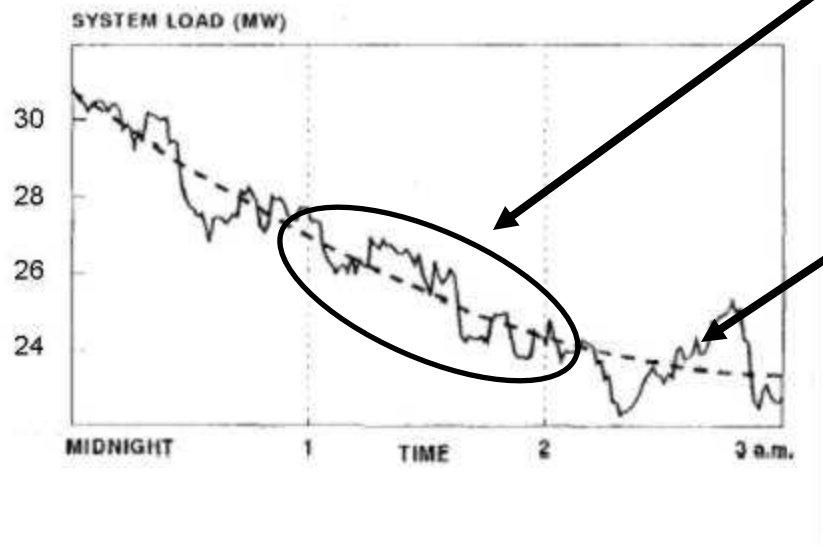
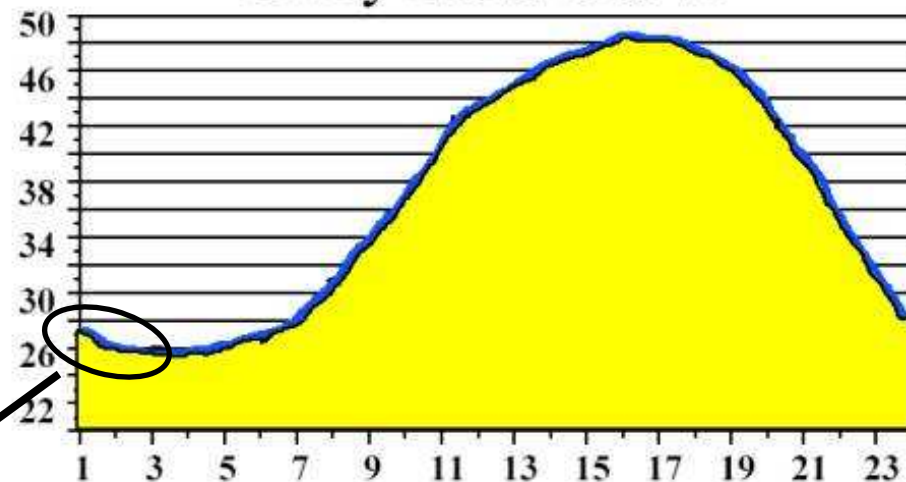
**Power < Load:**

- Frequency drops under 50/60 Hz.

**Power > Load:**

- Frequency rises over 60 Hz.

Daily Load Curve

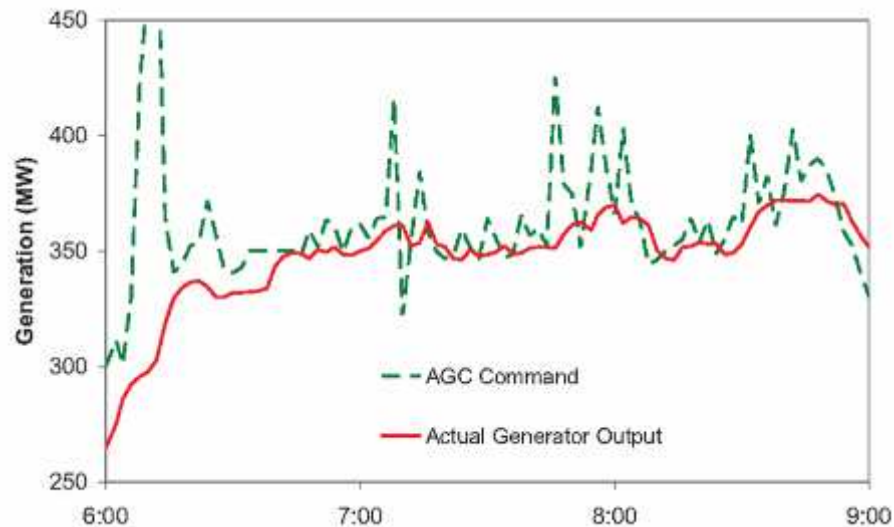


Short term variation

- ~ 1% of daily load
- Managed via regulation
- Fluctuation is net zero

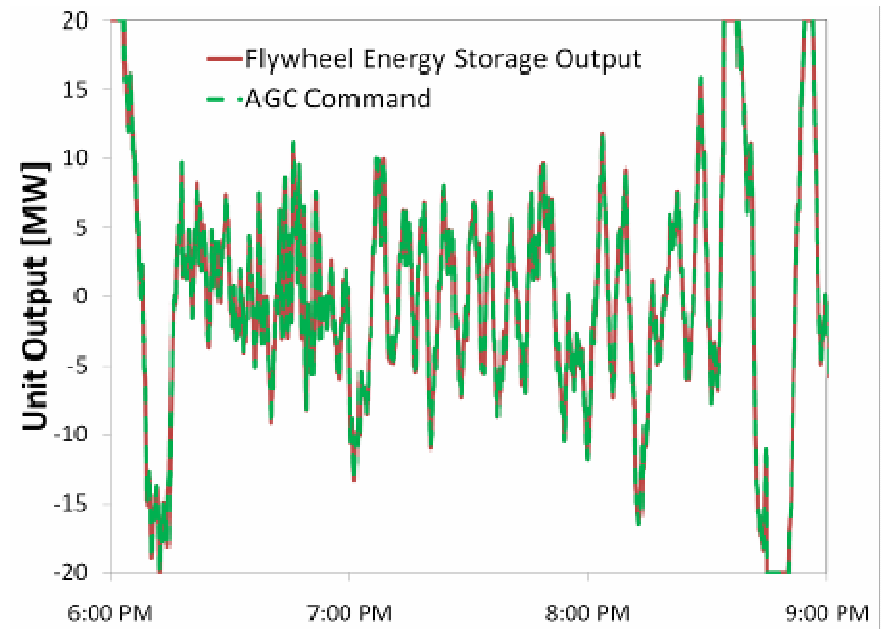
Video available [www.beaconpower.com](http://www.beaconpower.com)

# Fast Regulation: Speed Matters



A coal-fired power plant poorly following a regulation command signal

A 20 MW flywheel energy storage resource accurately following a signal



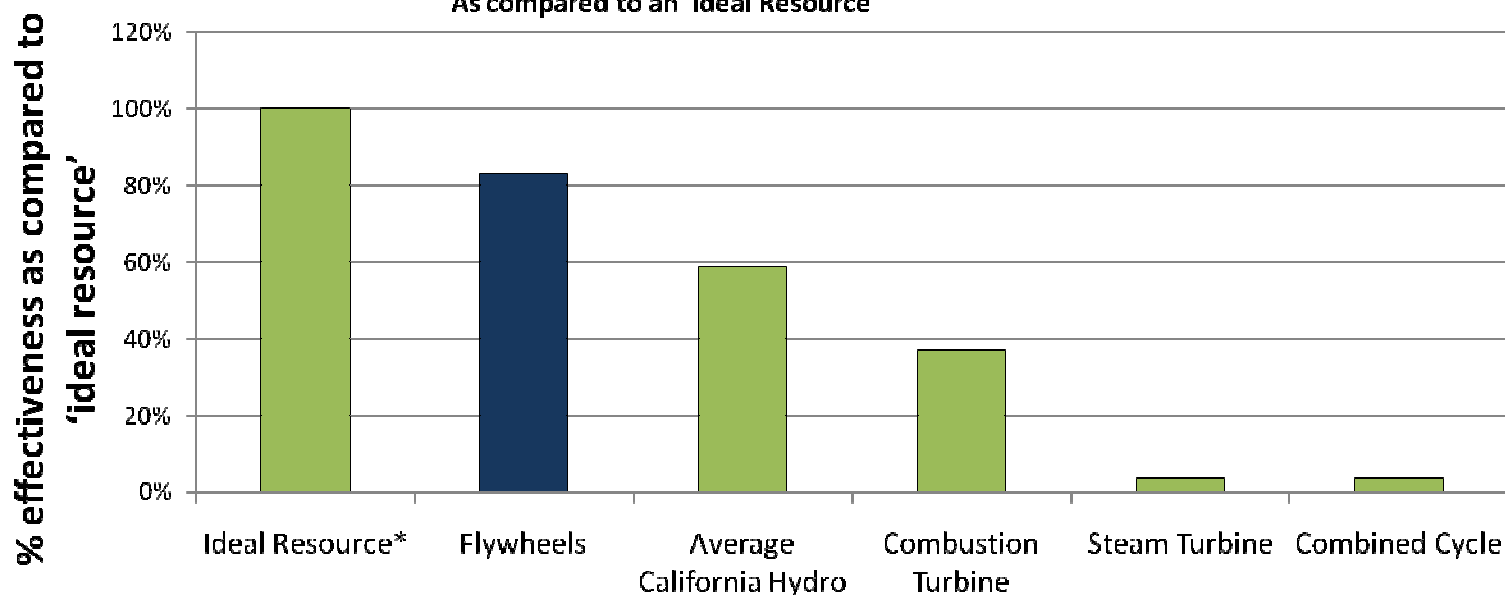
**Flywheels provide “near instantaneous” response**

# Benefits of Fast Regulation



## Regulation Effectiveness: Ability to Correct ACE

As compared to an 'Ideal Resource'



\*An Ideal Resource is defined as one that has fast, accurate sustained response and infinite energy

**PNNL: Fast response technologies can help reduce the amount of regulation procurement required → 1 MW flywheel = 2-24 MW traditional generation**

\*Source: Makarov, Y.V., et al. "Assessing the value of Regulation Resources Based on Their Time Response Characteristics." Pacific Northwest National Laboratory, PNNL – 17632, June 2008.

**KEMA: "A 30 - to - 50 MW storage device is as effective or more effective as a 100 MW combustion turbine used for regulation purposes."**

Source: "Research Evaluation of Wind Generation, Solar Generation, and Storage Impact on the California Grid," Study by KEMA, Inc., done for California Energy Commission, page 6, June, 2010.

# CAISO Integration of Energy Storage



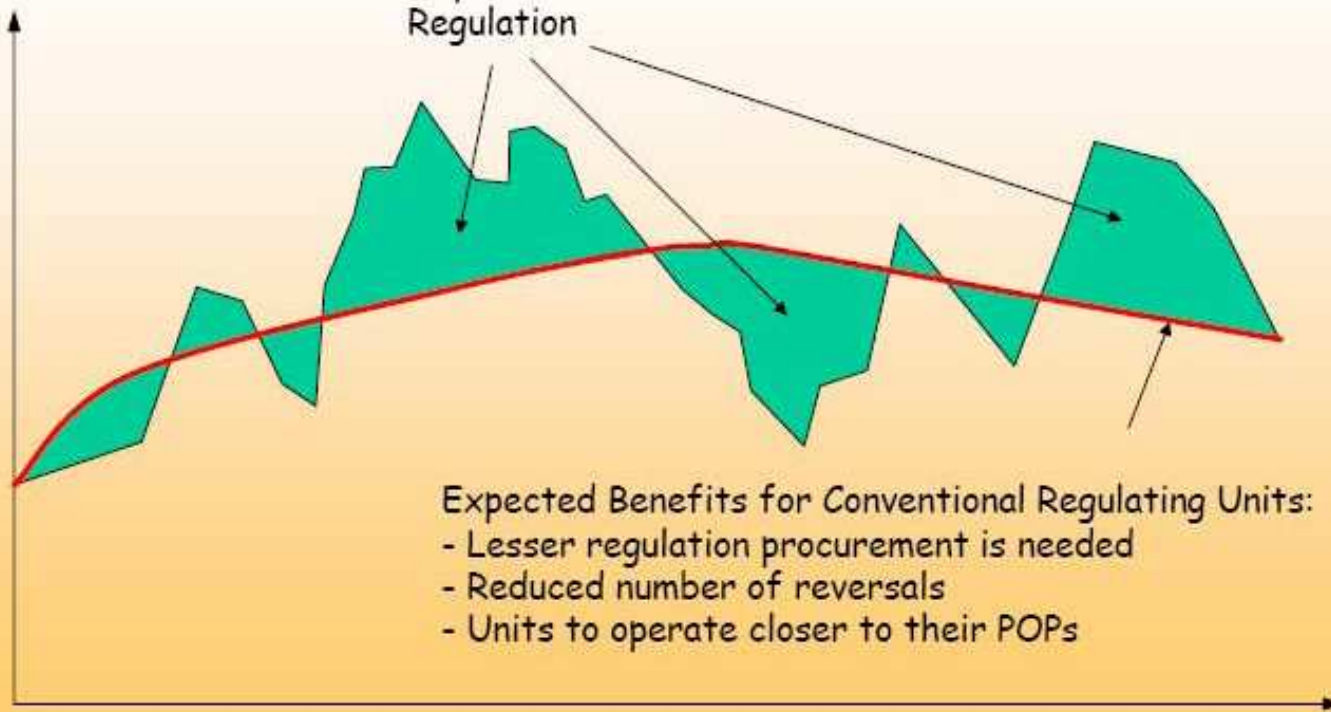
CALIFORNIA ISO

California Independent  
System Operator

## ACE “Smoothing”

Regulation  
Requirement  
MW

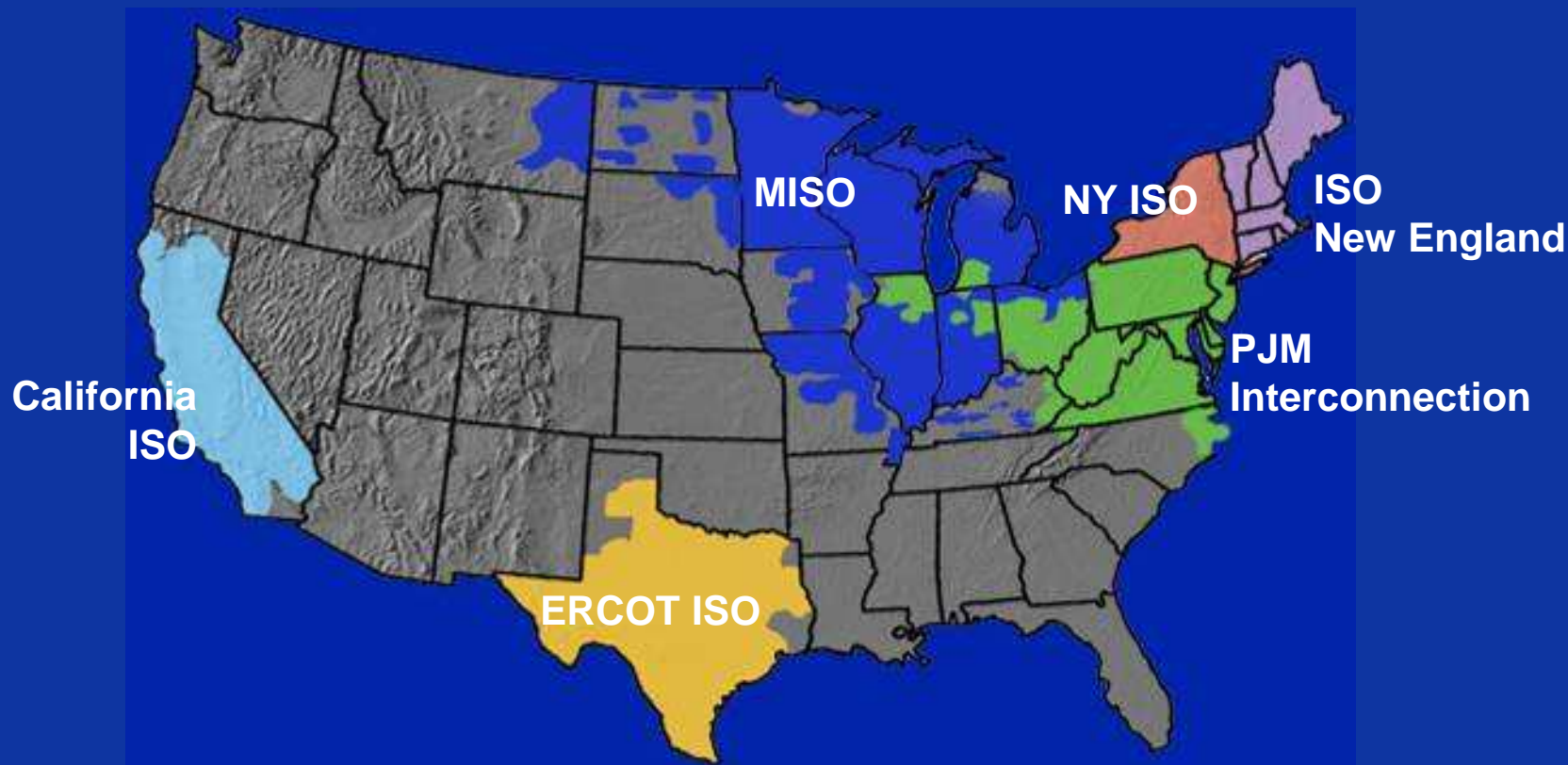
Flywheel  
Regulation



Expected Benefits for Conventional Regulating Units:

- Lesser regulation procurement is needed
- Reduced number of reversals
- Units to operate closer to their POPs

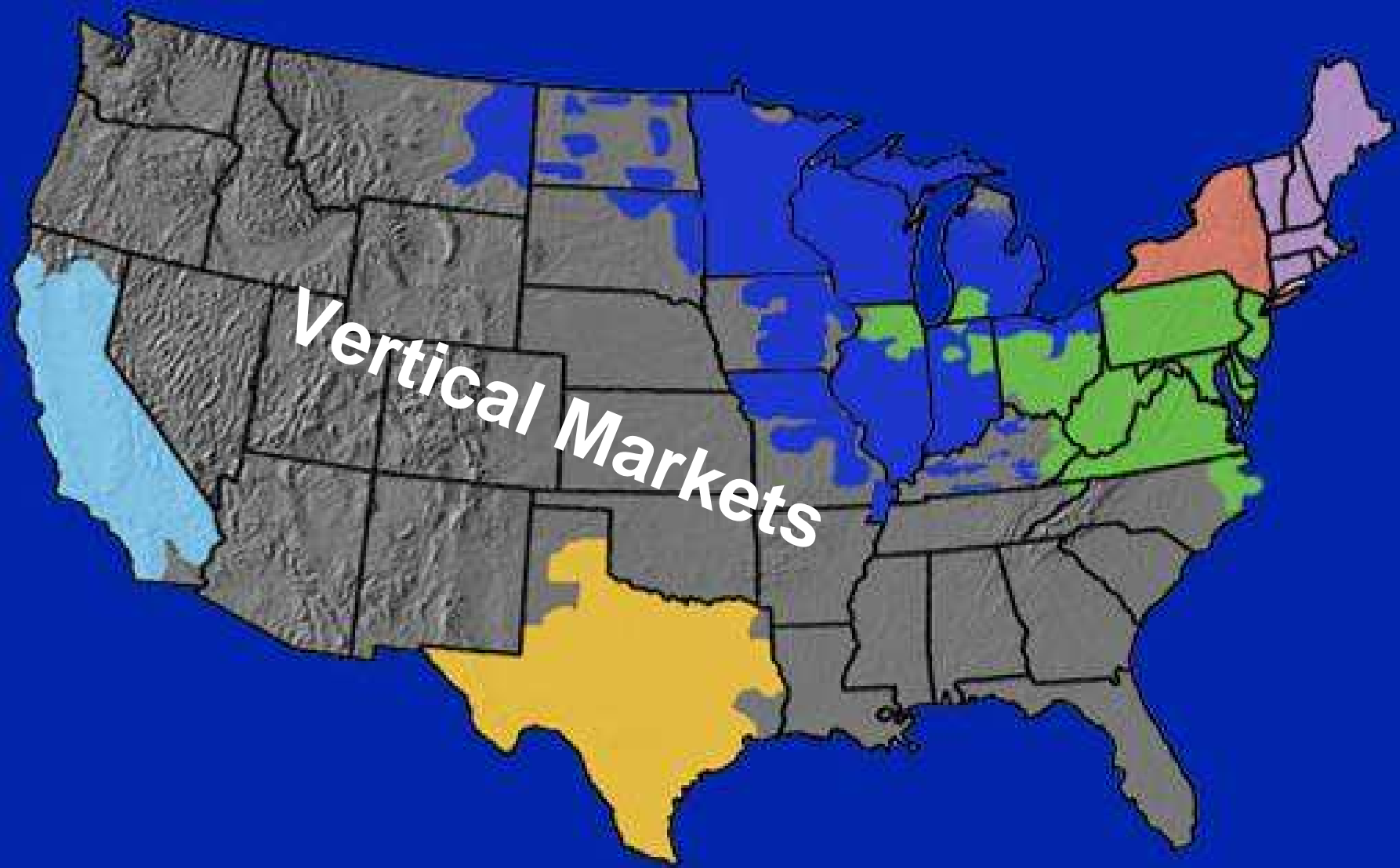
# U.S. Markets for Regulation Services



- Four open-bid markets accessible now
- California planning new tariff
- ERCOT initial steps under way



# Vertical Markets – Equipment Sales





# Renewables Need more Regulation



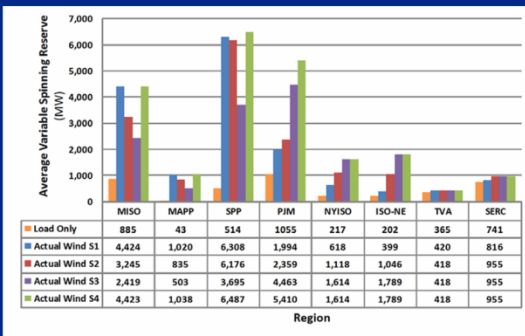
Expected increase in Regulation capacity (MW) requirements at 20% and 33% RPS (Spring\*)

	2006	2012	2020
Maximum Regulation Up Requirement (MW)	277	502	1,135
Maximum Regulation Down Requirement (MW)	-382	-569	-1,097



Requirement increases by 300% with 33% wind

## Impact of 20% Wind Penetration in Eastern U.S.



"Load Only" is today's regulation requirement

Scenarios 1,2,3 show different mixes of on-shore, off-shore and regional mixes for 20% wind penetration

Scenario 4 is 30% wind penetration

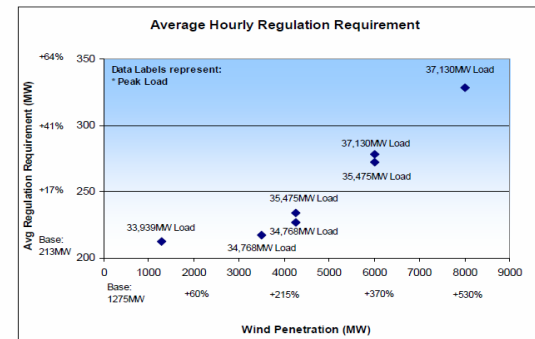
For 20% wind penetration, the **average increase** in forecasted need for regulation resources is **several hundred percent**...

EASTERN WIND INTEGRATION AND TRANSMISSION STUDY, January 2010 Prepared for NREL by: EnerNex Corporation Knoxville, Tennessee, NREL Technical Monitor: David Corbus, Prepared under Subcontract No. AAM-8-88513-01

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## Regulation Req. vs. Wind Level

- As shown in the graph below, the average regulation requirement increases approximately 9% for every 1,000MW increase between the 4,250MW and 8,000MW wind penetration level.



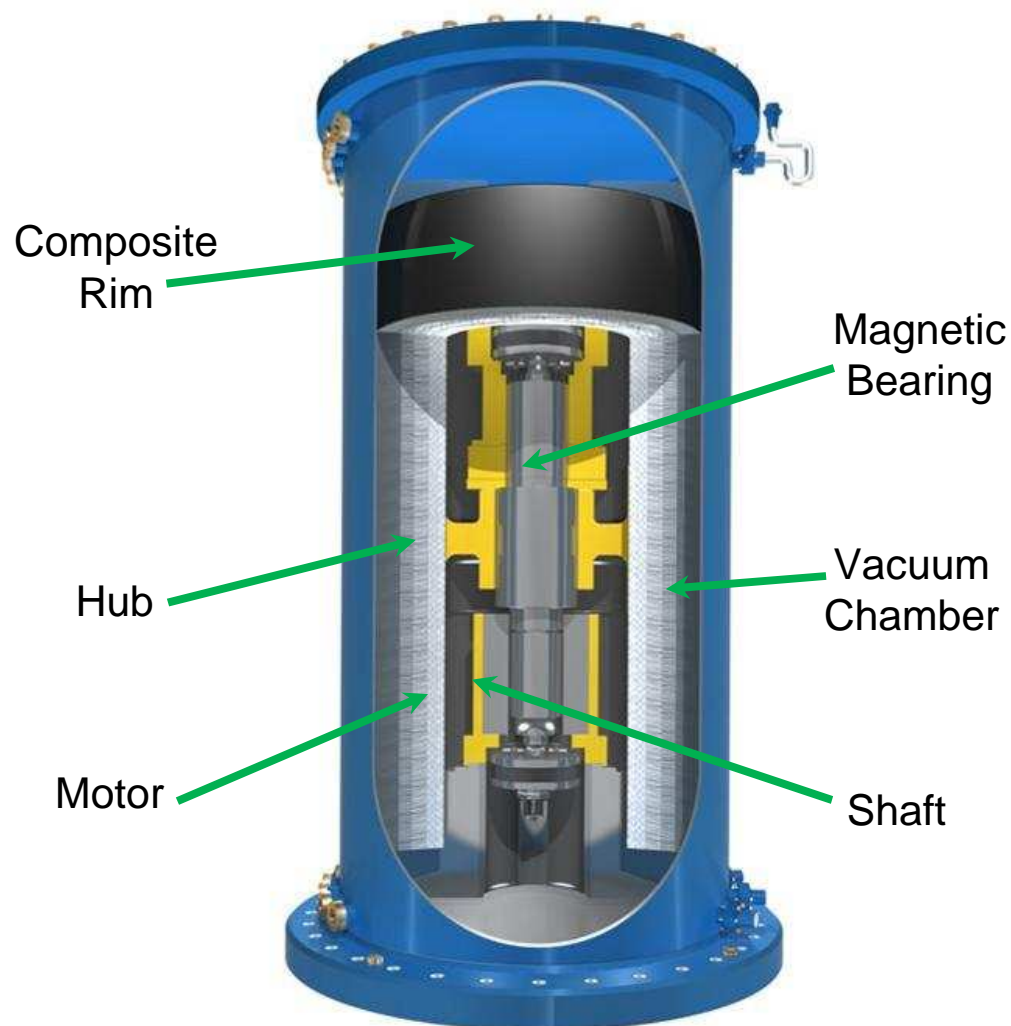
Requirement increases by 60% with 10% wind

*"PJM expects the requirement for regulation to increase from 1,000 MW today to 2,000 MW when we reach 20% wind penetration."*

– Terry Boston, CEO of PJM  
Storage Week conference, July 13, 2010

Requirement increases by 200% with 20% wind

# Validated Technology



- Many third party evaluations
  - Scale power demonstrations in CA and NY in 2006
  - Commercial operation since 2008 on ISO-NE power grid
  - DOE due diligence
  - Now operating at 14 MW in NY
- 20-year design life
- 125,000 equivalent cycles
- Low operating cost
- Zero emissions
- Earning Renewable Energy Credits in Massachusetts

# Flywheel Product Evolution



2000



**Gen 1**

**Telecom**

**2 kWh / 1 kW**

2001



**Gen 2**

**Telecom**

**5 kWh / 2 kW**

2004



**Gen 3**

**Grid**

**4 kWh / 15 kW**

2006-2007



**Gen 4**

**Grid**

**25 kWh / 100 kW**

2008



**1 MW Module**

**10 Gen 4 Flywheels**

**2010**

2005-6



(2) 100 kW demo system  
(DOE co-sponsored)



20 MW Plant Constructed in  
Stephentown NY

- Over 650,000 hours of operation in the field. Units running continuously without service 9 years
- Technology is product of 10 years of R&D and testing at a cost of \$180M



# Ramping up Manufacturing

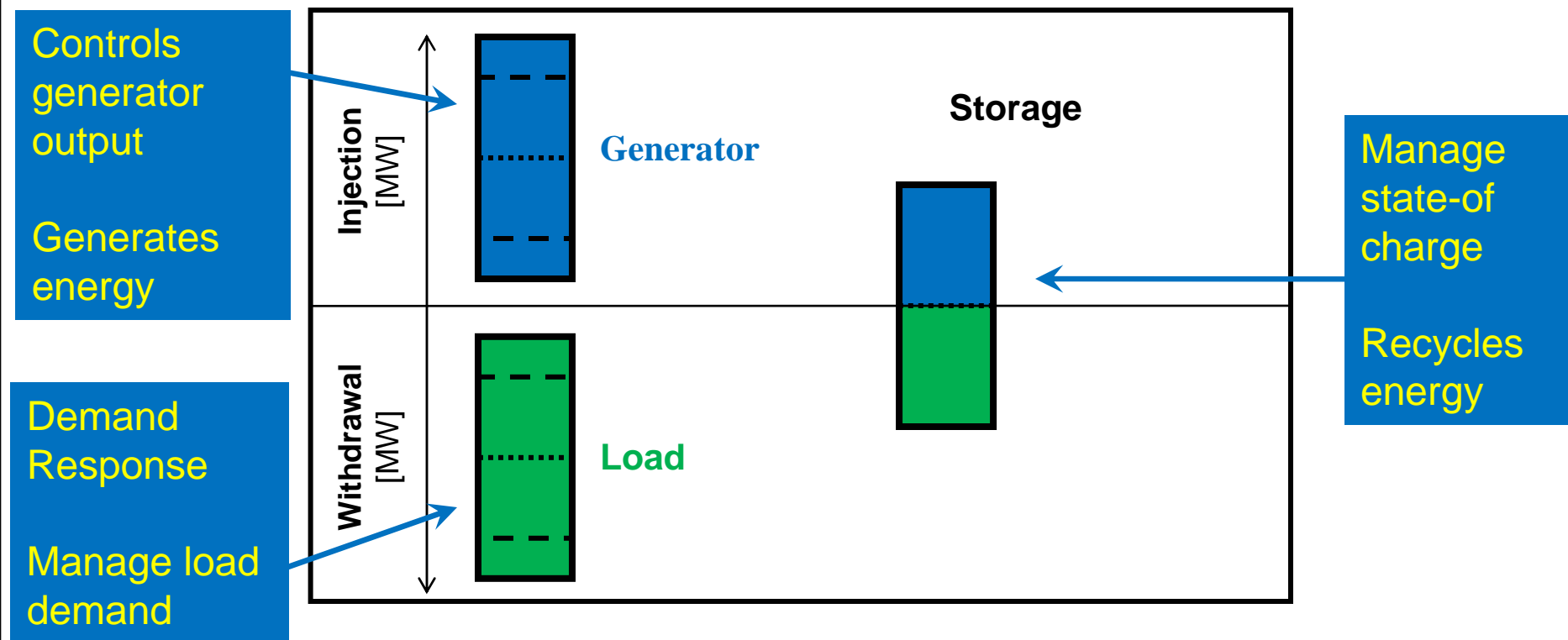


# 1 MW / 250 kWh Module



- 10 100kW / 25 kWh flywheels
- Transformers and support equipment
- Electronics and controls inside container

# Market Rule Best Practice: Create Energy Storage Category



- Storage provides regulation by recycling energy and behaving like a generator and load

***Energy Storage should be treated as a separate asset class from Generation and Load***



# Benefits of Performance Payment



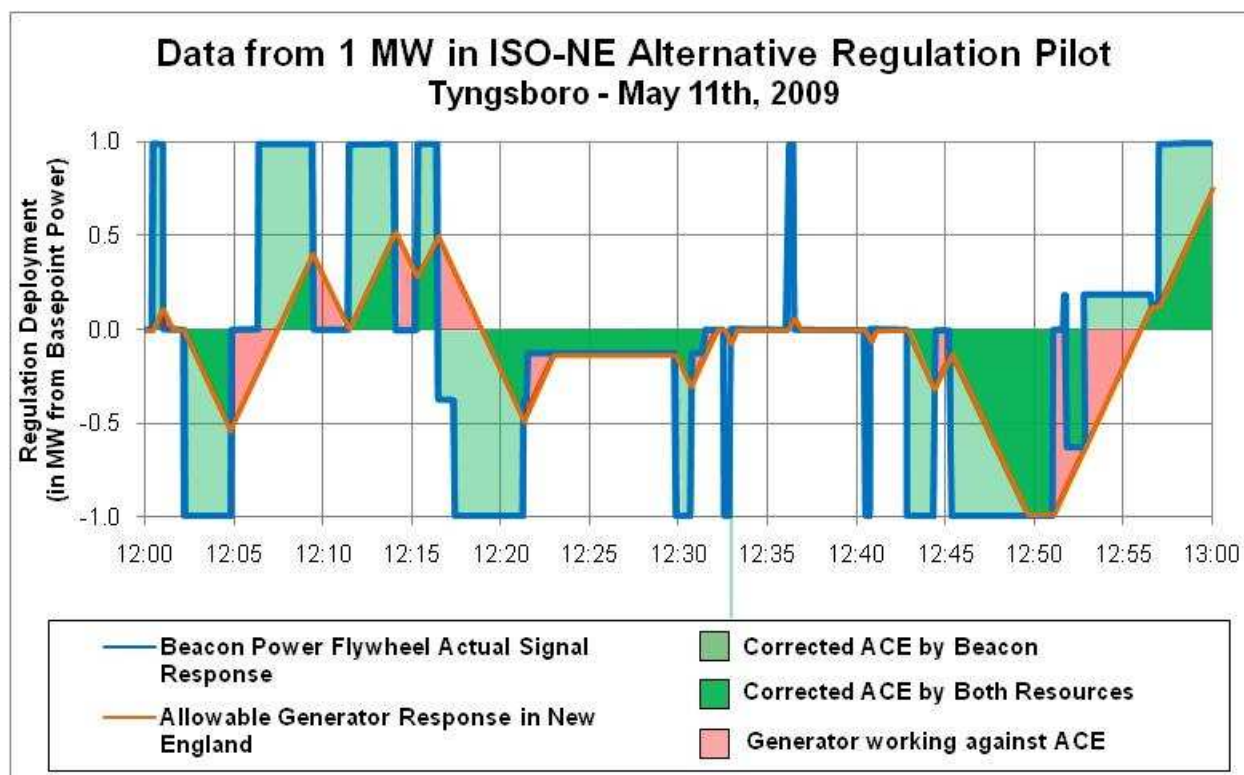
- ISO-NE demonstrates the benefits of payments based on performance
  - ISO-NE procures the least amount of regulation as a % of load
  - Regulation dispatch based on ramp rate: “Fast First”

2010 Status	ISO-NE	MISO	PJM	NYISO	CAISO	ERCOT
Dispatch signal based on resource ramp rate	✓	✓	N	N	N	N
Pay-for-Performance	✓	N	N	N	N	N
Maximum Allowable Response time	5 minutes	5 minutes	5 minutes	5 minutes	10 minutes	10 minutes
Regulation Procurement (as % of Avg. Load)	0.47%	0.58%	1.07%	1.17%	1.36%	1.88%
Regulation Procurement vs. NE	100% (baseline)	122%	225%	246%	286%	396%

# ISO-NE Pilot Program Empirical Data



Storage: 3X – 4X More Effective Correcting  
Area Control Error



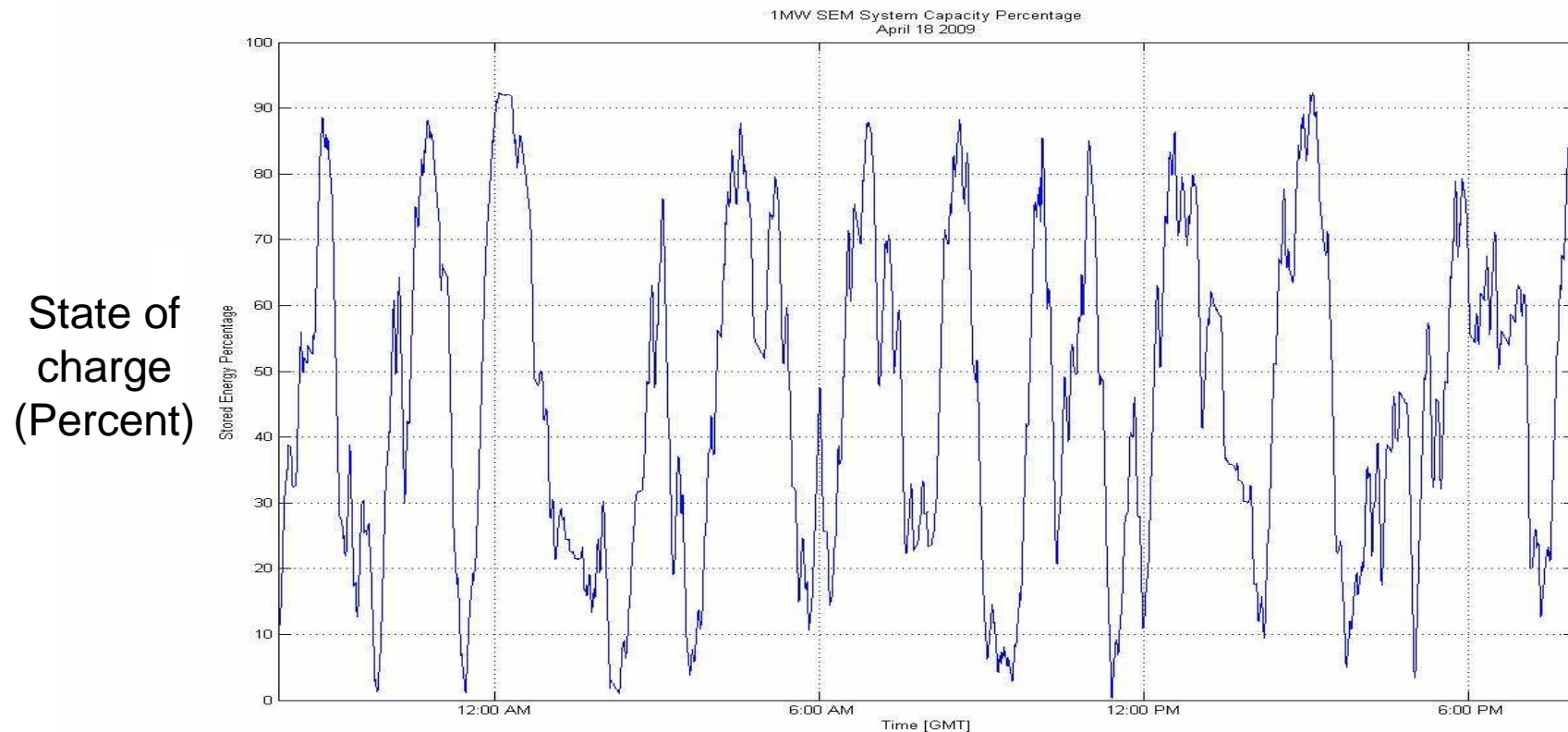
1 MW of Regulation		
	Flywheel	Generator
ACE Corrected	0.48 MWh	0.18 MWh
Against ACE	0 MWh	-0.07 MWh
Net ACE Correction	0.48 MWh	0.11 MWh
Mileage	25 MW miles	8 MW miles
Accurately followed signal?	Yes	Yes

ISO-NE's "Mileage Payment" (sum of up & down movement) recognizes and pays a premium to resources that provide more Regulation Service to the grid

# Cyclic Content: ISO-NE Pilot Program



April 18, 2009



Cyclic content for regulation is demanding:

- Equivalent to 6,300 full charge/discharge cycles per year!
- A 20 MW plant will process ~ 100MWH per day

# 1<sup>st</sup> 20 MW Flywheel Energy Storage Plant



- 200 high-speed, high-energy 25 kWh/100 kW flywheels
- +/- 20MW Regulating Range:
- Energy storage capacity: 20 MW for 15 minutes
- 4 second full range response
- Provides ~20-40% of regulation for NY State



20 MW plant in Stephentown, NY

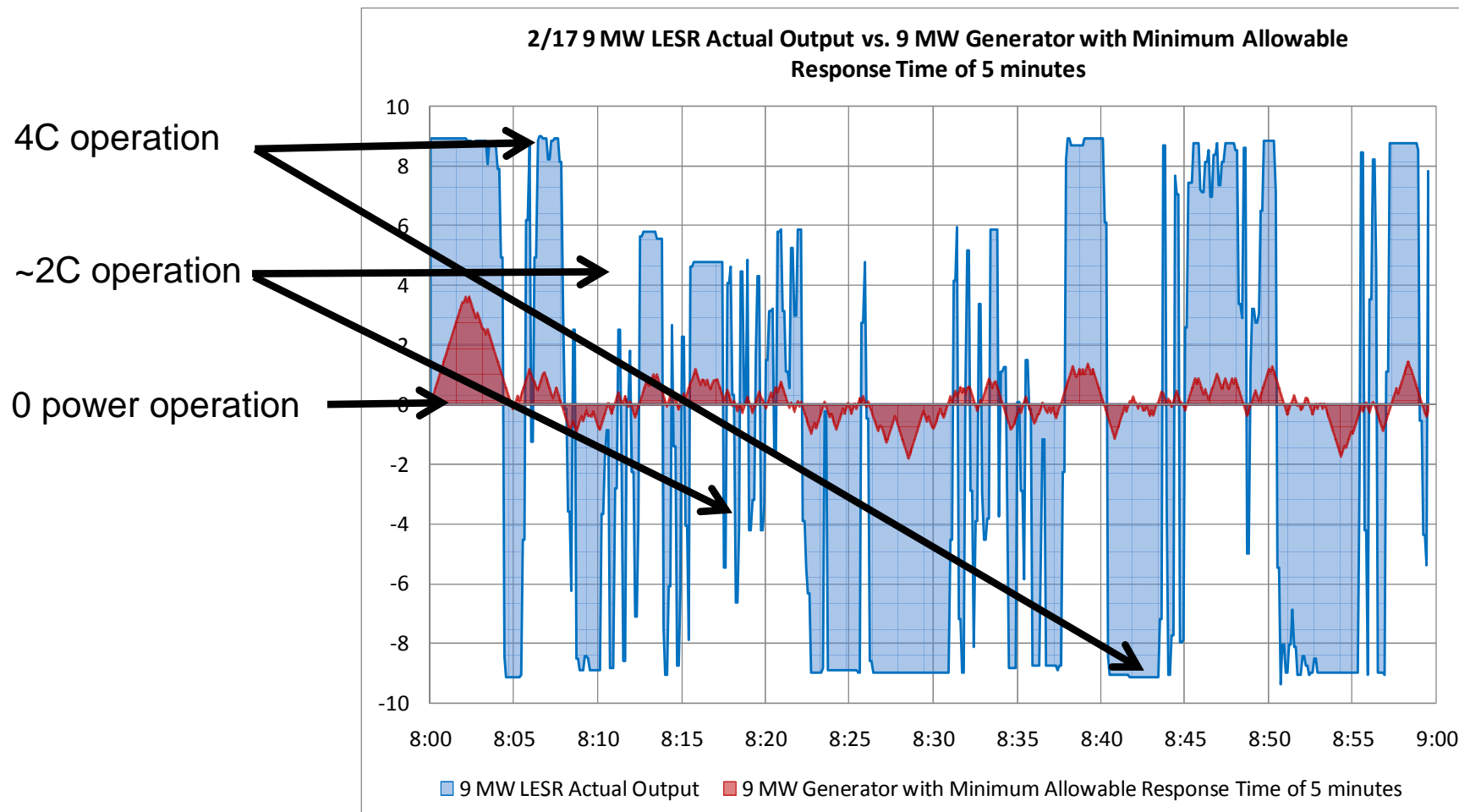
**Highlighted by the White House as being one of the  
*100 Recovery Act Projects that are Changing America***



# Data from Beacon Power's Stephentown, NY Plant



- NYISO utilizing fast response storage as “first responders” to ACE



**Today NYISO compensates both resources the same**

# ACE Correction Example

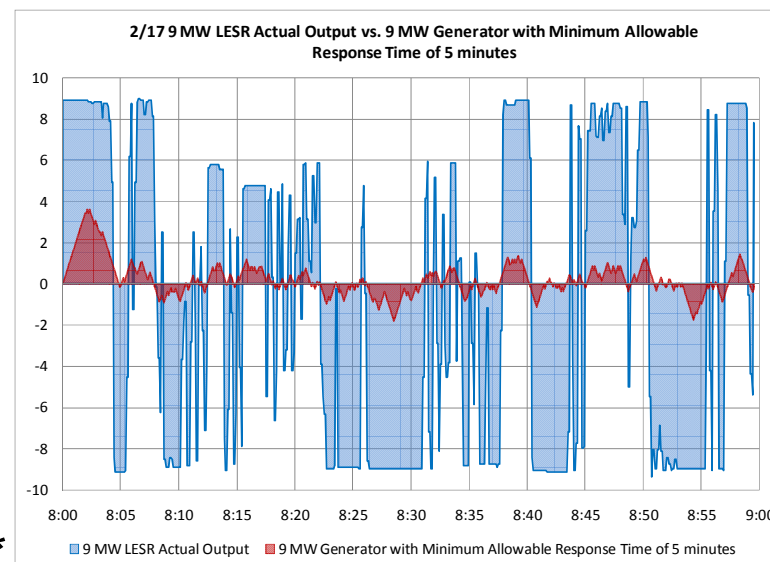


- 9MW of Flywheels dispatched
- 275 MW total contracted \*

3.3% of regulation from Flywheels

- 7.4 MWh managed by flywheels
- 31.1 MWh Total ACE energy dispatched \*\*

23.8% ACE correction from flywheels



**Max benefits come from fast first and dispatch at full power**

\* [http://www.nyiso.com/public/webdocs/market\\_data/reports\\_info/nyiso\\_regulation\\_req.pdf](http://www.nyiso.com/public/webdocs/market_data/reports_info/nyiso_regulation_req.pdf) Accessed 4/29/11.

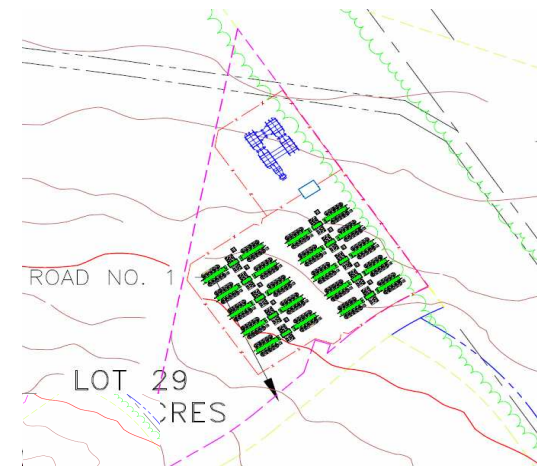
\*\* ACE data provided by NYISO Customer Relations on 3/4/2011



# 2<sup>nd</sup> 20 MW Plant — Pennsylvania



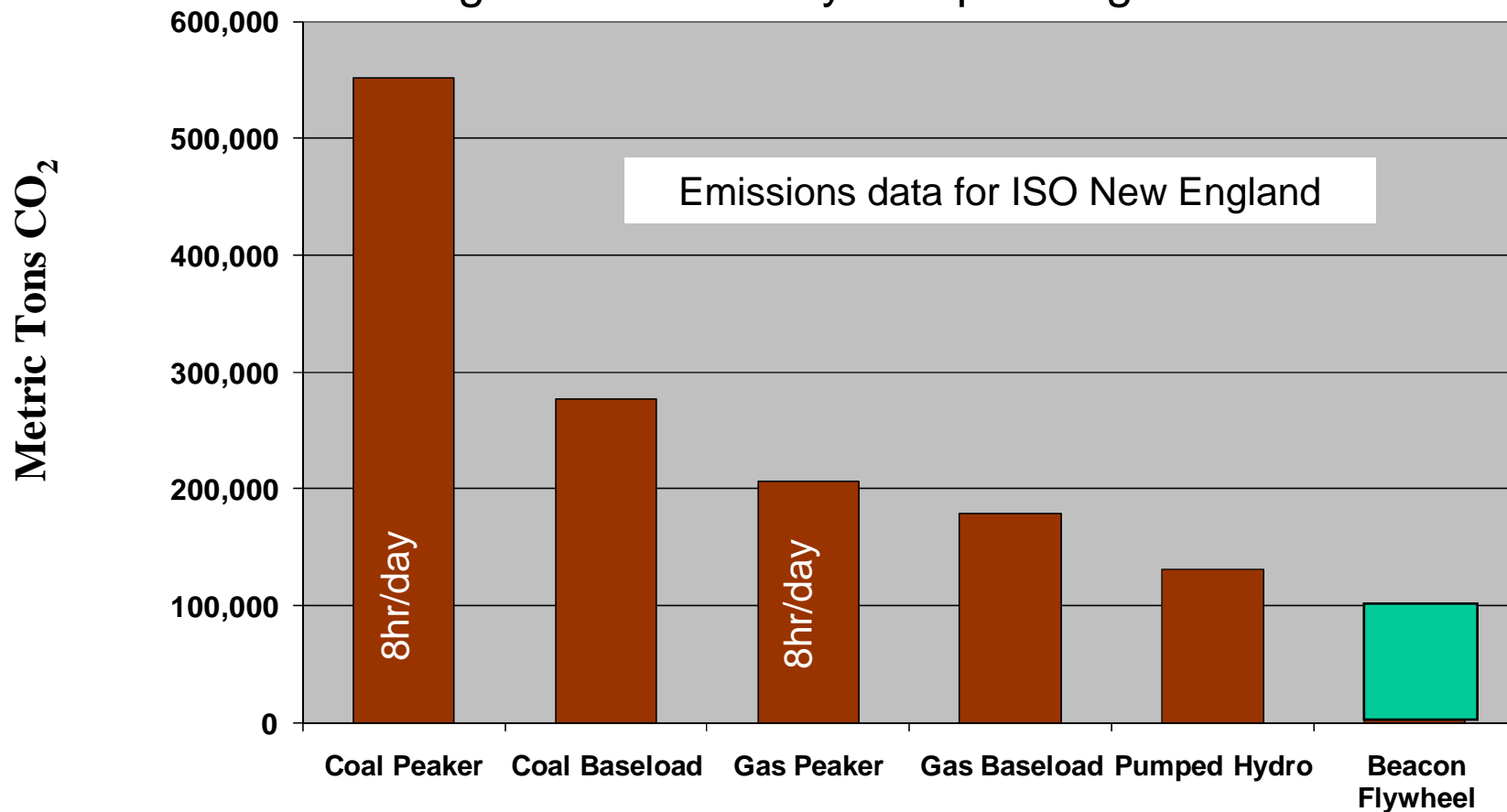
- Hazle Township, PA.
- PJM Interconnection region (largest U.S. grid operator)
- \$53 million cost (\$16 MM cost reduction vs. plant #1)
  - \$24 million DOE stimulus grant
  - \$5 million state grant
  - \$24 million additional capital requirement
- Interconnection process under way



# Lower CO<sub>2</sub> Emissions



KEMA study: CO<sub>2</sub> Reduction for 20 MW of storage-based regulation over 20-year operating life



*Flywheel regulation has zero direct CO<sub>2</sub> emissions*

# Example of how deploying and paying for speed can lower overall costs to ratepayers



Traditional Regulation method <i>Same signal all resources</i>						“Fast first” method <i>Dispatch and Pay based on Response Speed</i>							
Ramp Rate	RCP	Awarded Reg	Reg Service	Total Payment	\$/MW	Ramp Rate	RCP	Awarded Reg	Reg Service	Reg Payment	Service Payment	Total Payment	\$/MW
Average	\$36	20 MW	200 MW	\$720	\$36	Average	\$18	20 MW	<b>200 MW</b>	\$360	\$360	\$720	\$36
Average	\$36	20 MW	200 MW	\$720	\$36	Average	\$18	20 MW	<b>200 MW</b>	\$360	\$360	\$720	\$36
Fast	\$36	20 MW	200 MW	\$720	\$36	Fast	\$18	20 MW	<b>600 MW</b>	\$360	\$1,080	\$1,440	\$72
Slow	\$36	20 MW	200 MW	\$720	\$36	<del>Slow</del>	<del>\$18</del>	<del>20 MW</del>	<del><b>0 MW</b></del>	<del>\$360</del>	<del>\$0</del>	<del>\$360</del>	<del>\$18</del>
Slow	\$36	20 MW	200 MW	\$720	\$36	<del>Slow</del>	<del>\$18</del>	<del>20 MW</del>	<del><b>0 MW</b></del>	<del>\$360</del>	<del>\$0</del>	<del>\$360</del>	<del>\$18</del>
<b>Total Market</b>	<b>\$36</b>	<b>100 MW</b>	<b>1,000 MW</b>	<b>\$3,600</b>	<b>\$36</b>	<b>Total Market</b>	<b>\$18</b>	<b>60 MW</b>	<b>1,000 MW</b>	<b>\$1,080</b>	<b>\$1,800</b>	<b>\$2,880</b>	<b>\$48</b>
												<b>20% savings</b>	

1. Pay more for better performance
2. Drop poor performers
3. Buy less total capacity
4. Spend less on total cost for same service

# Optimum Regulation Tariff Structure



- ✓ FERC issued Order 890 directing ISOs to open regulation markets to non-generation assets
- ✓ Asset Class – Energy storage-based regulation, separate from generation and demand response
- ✓ Energy Settlement – Net at wholesale price
- ✓ Energy Management – Grid operator controls state of charge
- ✓ Optimized Dispatch – Fastest resources are dispatched first
- ✓ Pay for Performance – Payment in proportion to regulation effect actually provided, not just the capacity offered

# FERC Notice of Proposed Rule Making



FEDERAL ENERGY REGULATORY COMMISSION

NEWS

February 17, 2011

## **FERC Proposes New Compensation Method for Regulation Service**

The Federal Energy Regulatory Commission (FERC) today proposed to ensure just and reasonable rates and eliminate undue discrimination in the procurement of regulation service in organized wholesale electric markets by requiring market operators to appropriately compensate providers for their services.

# Flywheels in Grid Applications



- First Application is Frequency Regulation

- Coming up:

- Frequency Response
- Renewable energy ramp mitigation
- Mini-grid load following stability
- Light Rail Applications
- Pulse power
- Ship Power
- UPS
- Angular stability
- Voltage support

High power,  
High cyclic content



# Flywheel Product Development



2006-2007



**Gen 4  
Grid**

**25 kWh / 100 kW**

2008



**1 MW Module  
10 Gen 4 Flywheels**

2011



**20 MW Plant Constructed in  
Stephentown NY**

2009-2012



**Gen 5  
Grid**

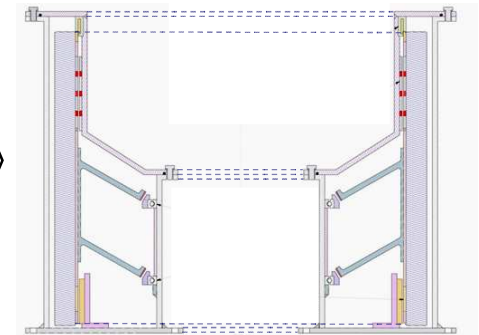
**30 kWh / 120 kW**

**Gen 5A  
Grid**

**12.5 kWh / 500 kW**

**Frequency Response  
Rail  
UPS**

2010-2013



**Gen 6  
Grid**

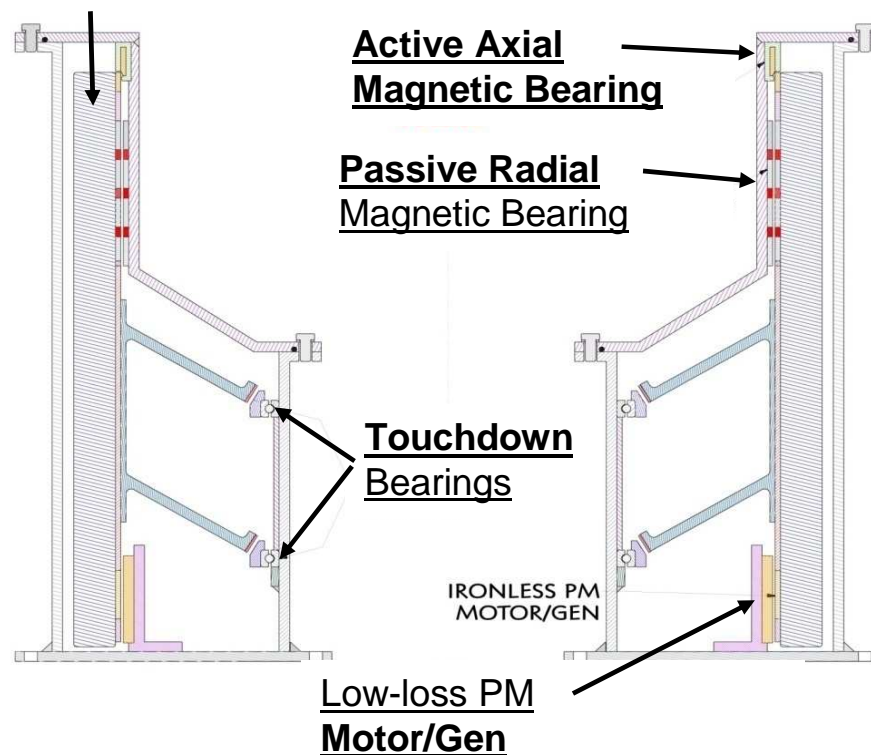
**100 kWh / 100 kW  
Sponsored by ARPA-E  
>80% cost reduction**

**Ramping  
Regulation  
Spin**

# ARPA-E “Flying Ring” Flywheel



## New Manu Process



- 100 kW/ 100 kWh
- 4X energy at ½ cost
- High cyclic life
- Excellent for ramping
- Growth capability for more cost reduction

# Future Flywheel Models



Power/Energy	Time	C-rate	Primary application	Comment
100kW/25kWh	15 min	4C	<ul style="list-style-type: none"> <li>•Frequency Regulation</li> <li>•Micro grid load following</li> <li>•Ship power</li> </ul>	In production
500kW/12 kWh	+/- 45 sec	50C	<ul style="list-style-type: none"> <li>•Frequency Response</li> <li>•Rail</li> <li>•UPS</li> <li>•Pulse power</li> </ul>	Current model modified with big motor, half-rim
100kW/100kWh	1 hour	1C	<ul style="list-style-type: none"> <li>•Renewable ramp mitigation</li> <li>•UPS</li> <li>•Fast reserve</li> <li>•Peak shaving</li> </ul>	ARPA-E funding 85-90% cost reduction / kWh

# The Cost Paradigm



What's more important given a 20 year life?

- Initial cost
- Operating cost
- Maintenance cost
- Refreshment cost
- Total cost
- \$/kW (nameplate)
- \$/kWh (nameplate)
- \$/kWh (energy processed in a single lifetime)
- \$/kWh (energy processed over the 20 year period)

**Correct answer: All of the above – use project IRR**



# Frequency Regulation of the Future



*Zero-emissions flywheel energy storage ... is a better performing, more cost-effective regulation asset... a much better match for clean renewable energy...*



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