Emissions from Traditional & Flywheel Plants for Regulation Services

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Outline

- Introduction
- Principles of Frequency Regulation
- Goal of Emissions Model
- Emissions Comparison Approach
- Generation Mix per ISO
- KEMA Emissions Tool
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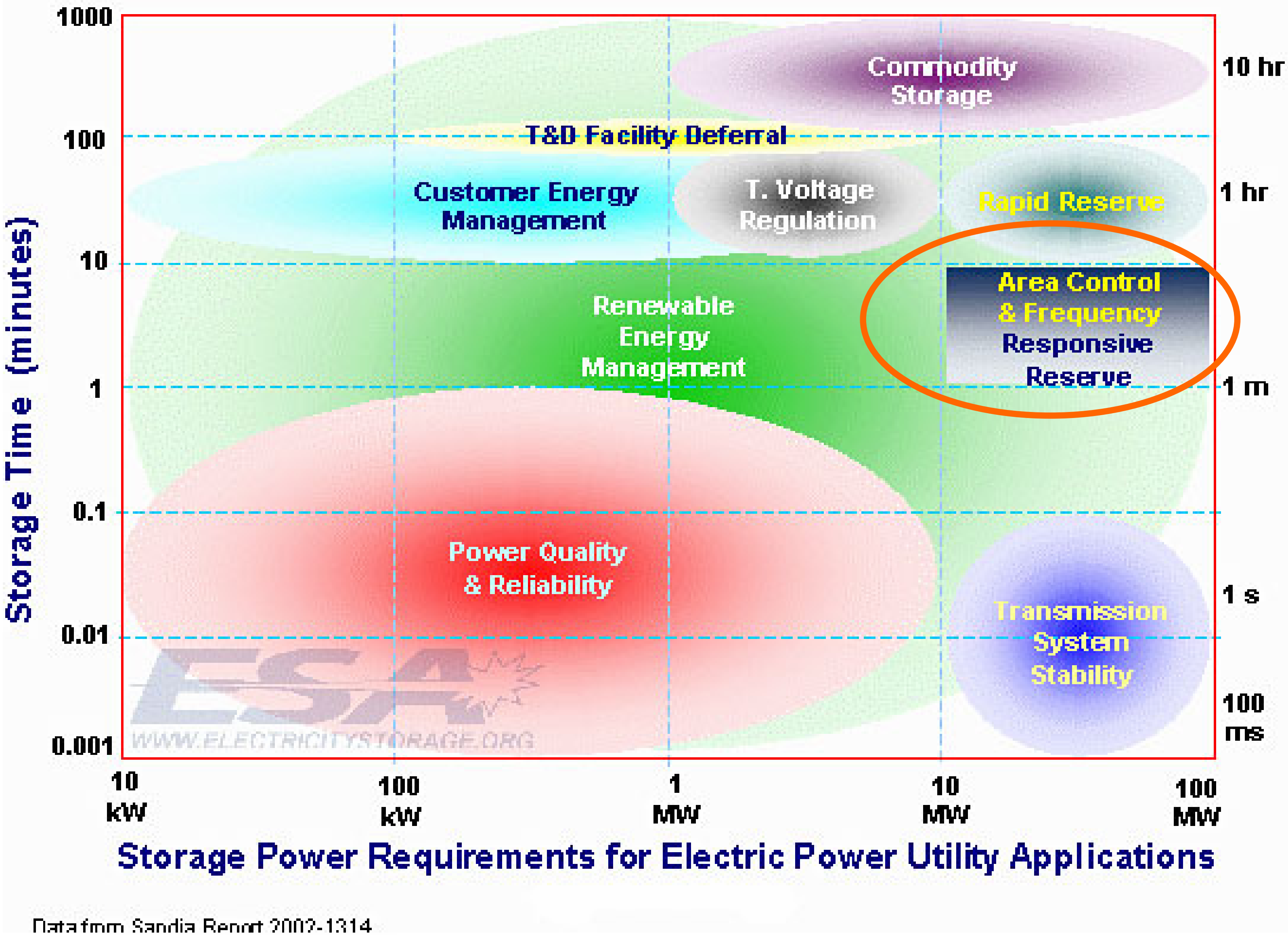
- Conclusions

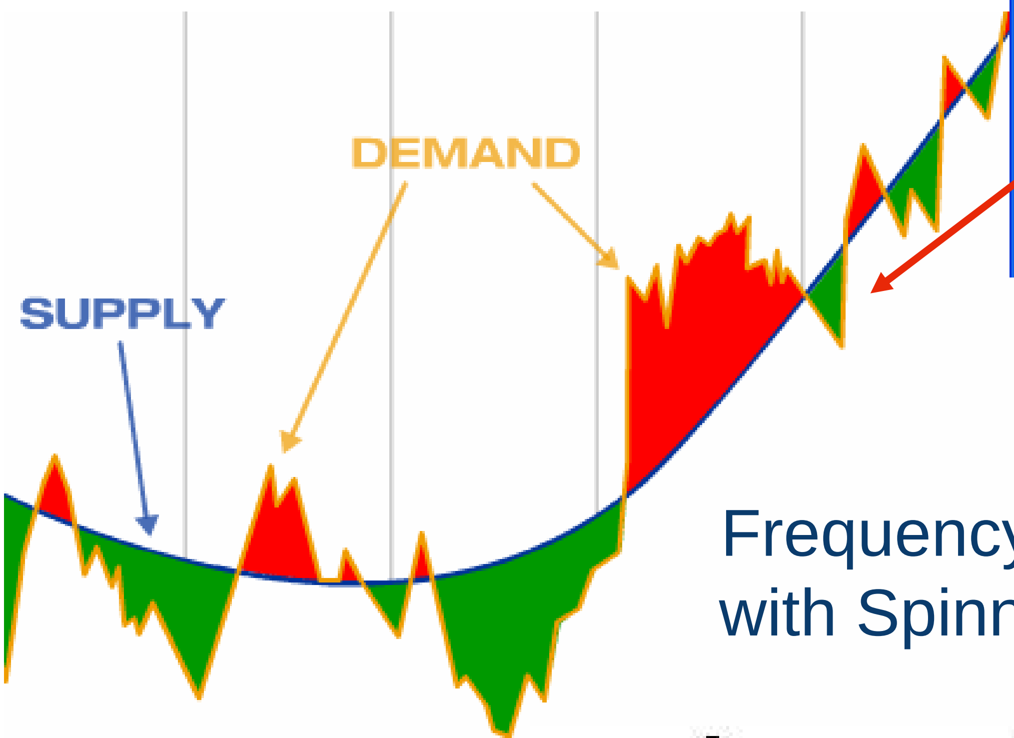
Introduction

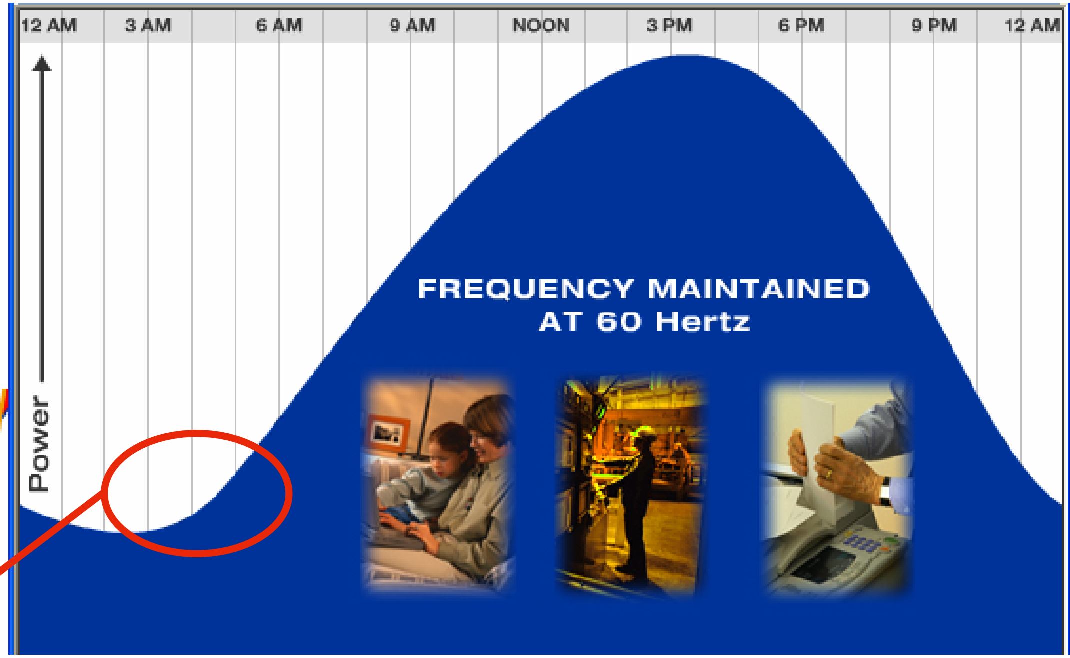


Grid Regulation Ancillary Services

Power Supply and Demand

Short-term Supply
and Demand Curve



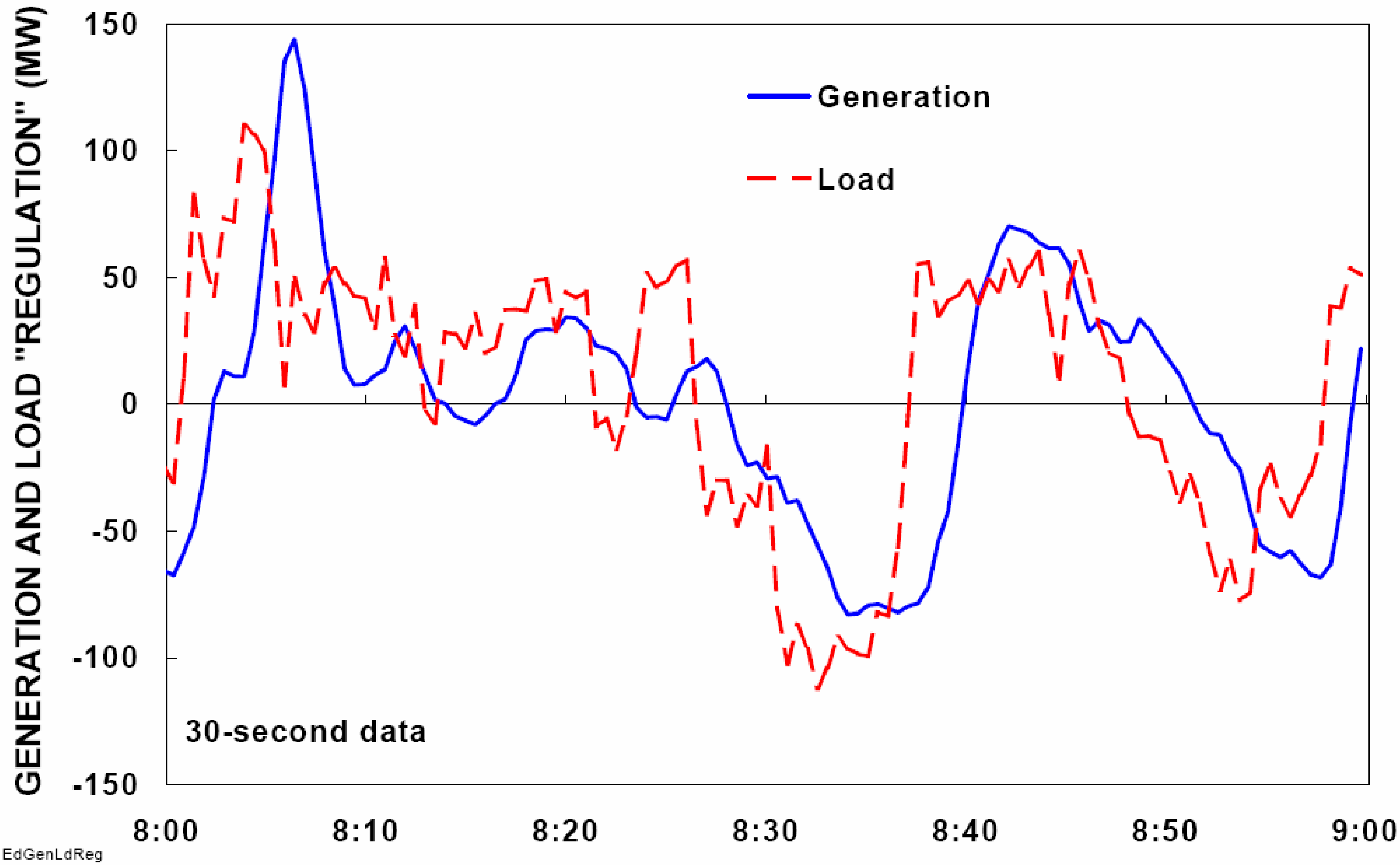


Daily Supply and
Demand Curve

Frequency Excursions
with Spinning Reserve

$$E = (I\omega^2)/2 \quad = \quad (mr^2\omega^2)/2 \quad = \quad (m\,v^2)/2$$

Generation and Load Mismatch



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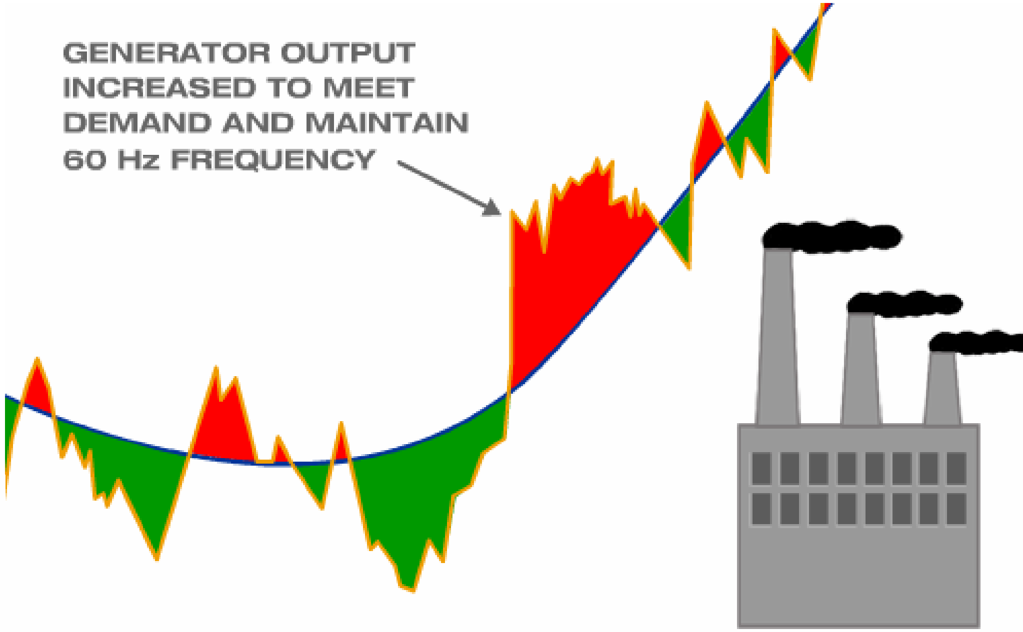
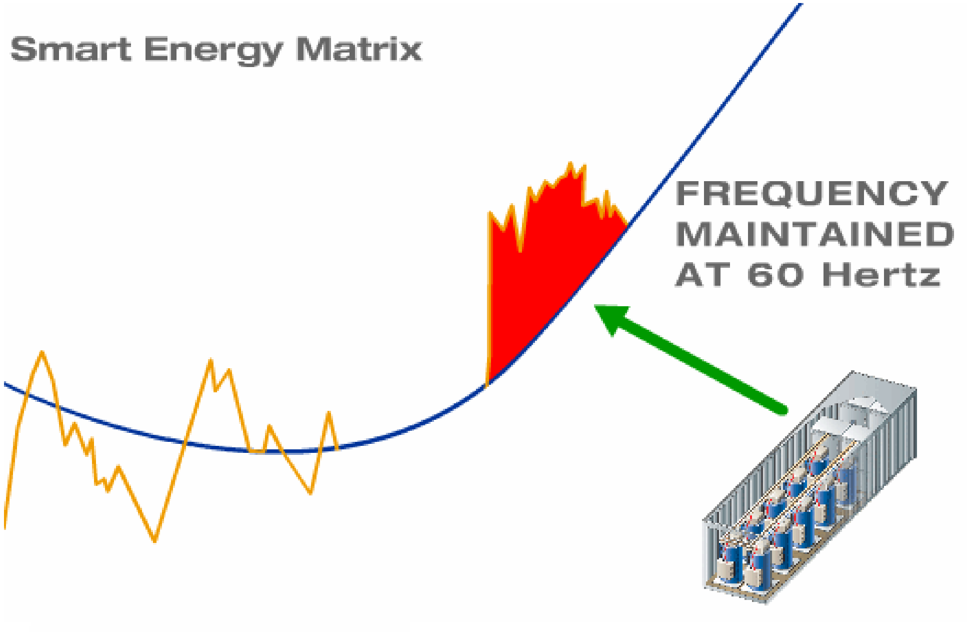
Principles of Frequency Regulation

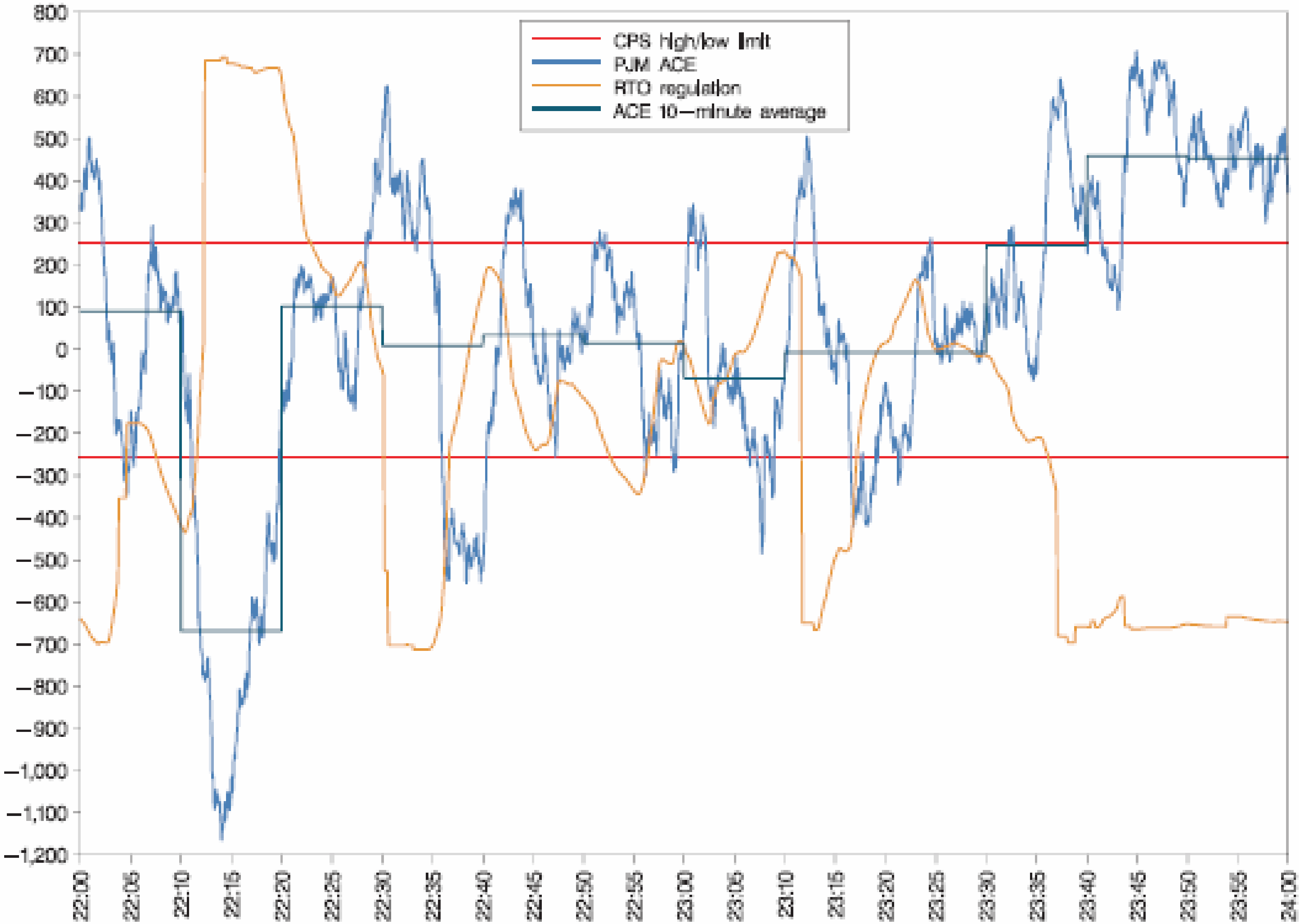


Flywheel Option



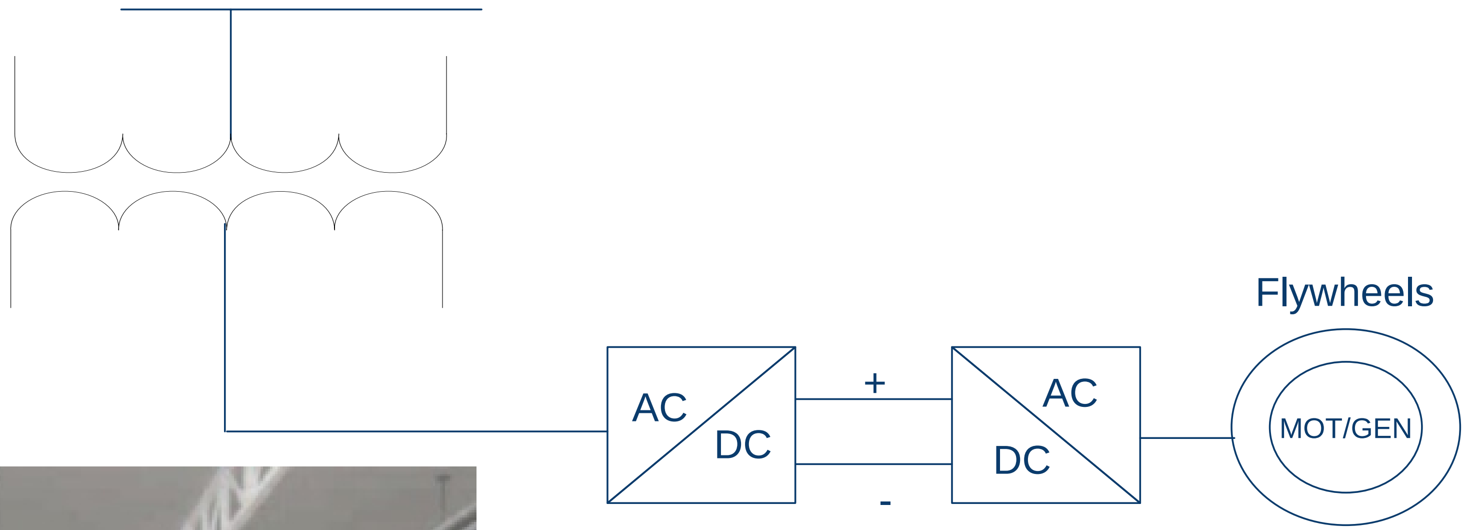
Traditional Generation Option

PJM Area Control Error and Regulation



Electrical Energy Storage Plant

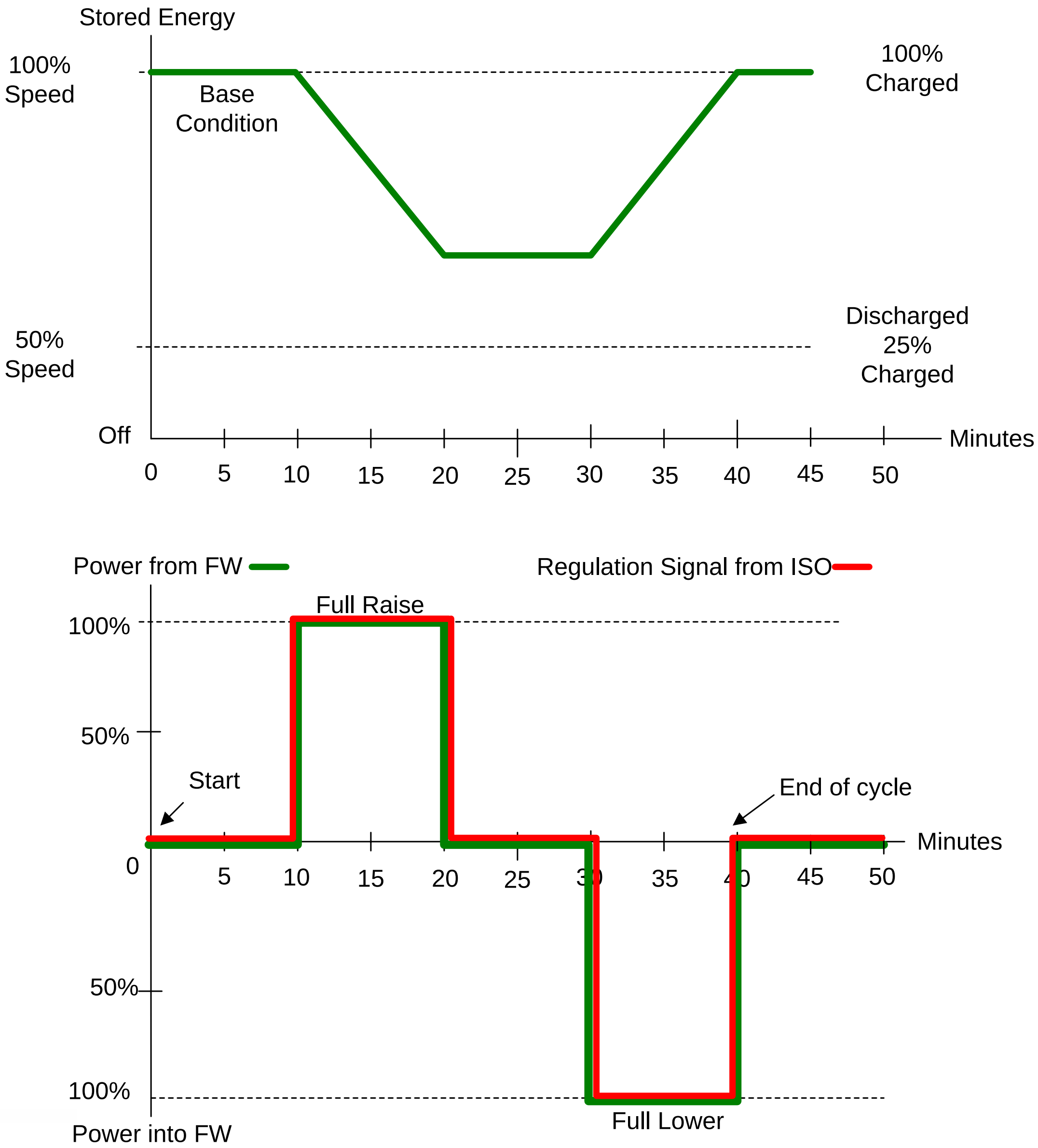
Flywheel
Energy Storage



Beacon Power

20 MW Plant

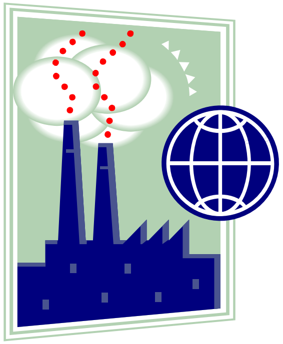
Flywheel Regulation Cycle



Goal of Emissions Model

- Compare the emissions profile for a 20 MW Flywheel vs. Traditional Technologies for Regulation

- Emissions Comparison between:
  - Coal Power Plant – Baseload and "Peaker" Mode
  - Natural Gas Plant – Baseload and "Peaker" Mode
  - Pump Hydro Storage System
  - Flywheel Energy Storage System



- Comparisons in 3 ISO areas with generation mixes
  - California ISO
  - ISO New England
  - PJM Territory

- Emissions examined were CO_2, SO_x, NO_x

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Emissions Comparison Approach

- Premise:
  - Traditional coal and gas power plants operate *less efficiently* in ramping output in frequency regulation mode - **Increased Emissions**.
  - Flywheels and other energy storage devices use grid power at *average* emission profiles – **Decreased Emissions.**

- Flywheel Approach:
  - Examine Regulation Cycle through Charging, Discharging, Idling and Load Bank modes
  - Calculate All flywheel losses and associated emissions from operation - Charging; Discharging; Idling and Load Bank.

Emissions Comparison Approach (2)

- Traditional Power Plant Approach
  - Coal and natural gas plants consume 0.5 – 1.5% more fuel for regulation services
    - Studies can improve accuracy of estimation
  - Emissions are calculated by examining the incremental increase in fuel (0.7%) use by power plants through heat rate calculations

- Calculations
  - Calculations are made by examining one cycle, one day, extrapolating over 1 year and a 20 year plant lifetime

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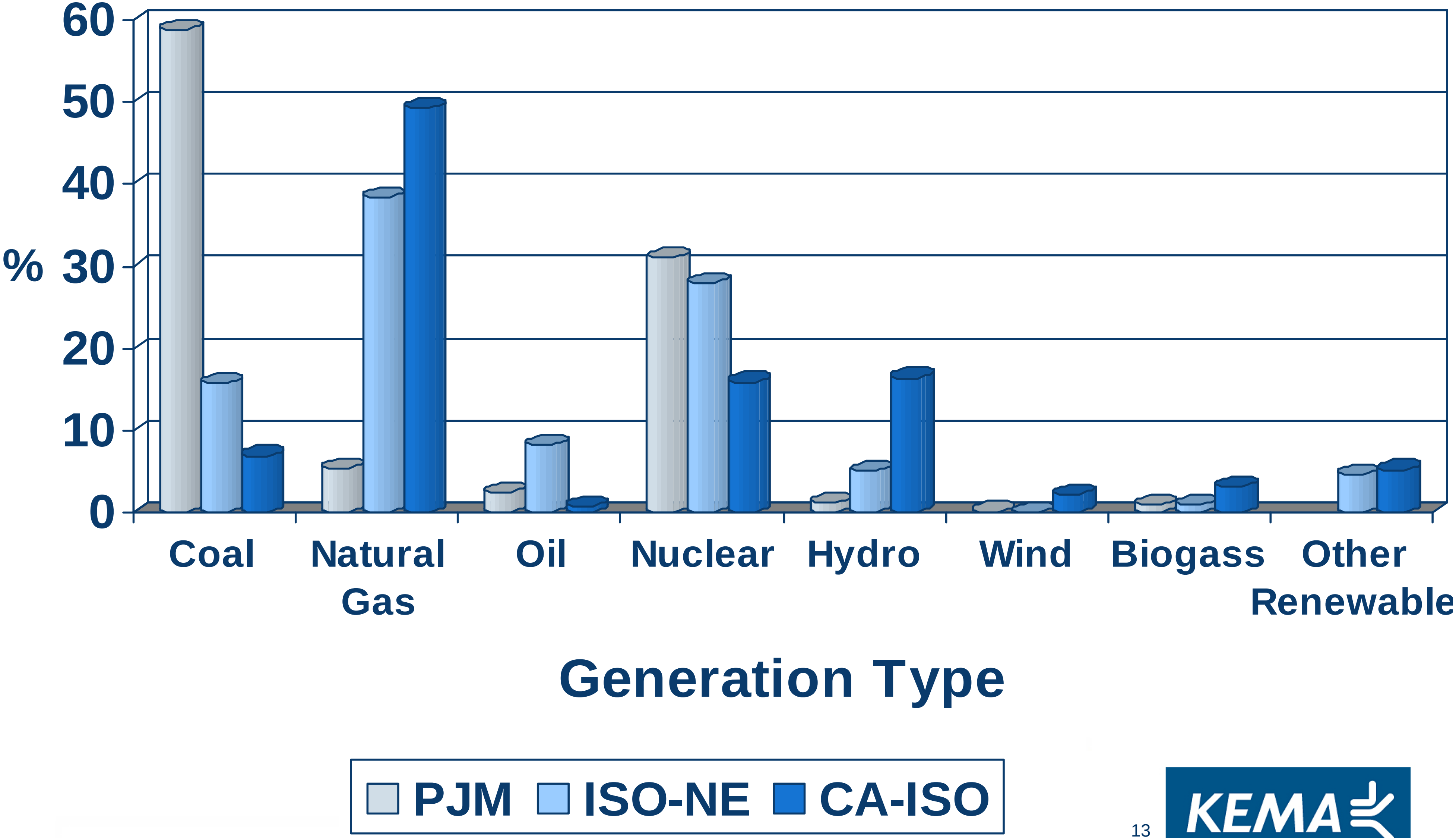
Generation Mixes in Different Regions



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KEMA Emissions Tool

Variables

Max Cycles per day	24	cycles
Size	20,000	kW
Heat Rate(PJM)	10,128	btu/kWh
Charge/Discharge Time	0.25	hr
Total System Losses	14%	Percentage
Percentage Regulation Compliance	98.3%	Percentage
Cycle Time with No Load	0.5	hr
Solar System Providing No Load Power Toggle	No	

Load bank energy can be used in other processes

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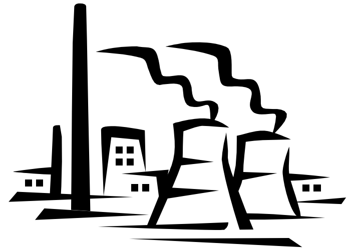
Results of Emission Analyses

Flywheel Regulation Compared to



- Coal Power Plants
  - Large reductions in the CO_2, SO_x, and NO_x emissions for all ISOs.
  - Flywheel emission from losses in ISO generation mix.
  - Average generation mix include renewable generation
  - Generators use more fuel in ramping regulation mode
- Natural Gas Fired Power Plants
  - Mainly CO_2 emission reduction
  - Average emission rates still lower than natural gas plants
- Pumped Hydro Storage Systems
  - Emission savings occur in CO_2, SO_x, NO_x
  - Flywheel efficiency higher than the pump hydro storage
  - Both storage systems

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Comparison of CO_2 Emissions

Flywheel Emission Savings Over 20-year Life: PJM					
	Coal		Natural Gas		Pumped Hydro
	Baseload	Peaker	Baseload	Peaker	
CO2					
Flywheel	149,246	149,246	149,246	149,246	149,246
Alternate Gen.	308,845	616,509	194,918	224,439	202,497
Savings (Flywheel)	159,599	467,263	45,672	75,193	53,252
Percent Savings	52%	76%	23%	34%	26%

Flywheel Emission Savings Over 20-year Life: ISO-NE					
	Coal		Natural Gas		Pumped Hydro
	Baseload	Peaker	Baseload	Peaker	
CO2					
Flywheel	106,697	106,697	106,697	106,697	106,697
Alternate Gen.	304,759	608,354	197,359	227,249	144,766
Savings (Flywheel)	198,062	501,657	90,662	120,552	38,070
Percent Savings	65%	82%	46%	53%	26%

Flywheel Emission Savings Over 20-year Life: CA-ISO					
	Coal		Natural Gas		Pumped Hydro
	Baseload	Peaker	Baseload	Peaker	
CO2					
Flywheel	91,079	91,079	91,079	91,079	91,079
Alternate Gen.	322,009	608,354	194,534	223,997	123,577
Savings (Flywheel)	230,930	517,274	103,455	132,917	32,498
Percent Savings	72%	85%	53%	59%	26%

Emissions in tons

Emission Results for PJM

Flywheel Emission Savings Over 20-year Life: PJM					
	Coal		Natural Gas		Pumped Hydro
	Baseload	Peaker	Baseload	Peaker	
CO_2					
Flywheel	149,246	149,246	149,246	149,246	149,246
Alternate Gen.	308,845	616,509	194,918	224,439	202,497
Savings (Flywheel)	159,599	467,263	45,672	75,193	53,252
Percent Savings	52%	76%	23%	34%	26%
SO_2					
Flywheel	962	962	962	962	962
Alternate Gen.	2,088	5,307	0	0	1,305
Savings (Flywheel)	1,127	4,345	-962	-962	343
Percent Savings	54%	82%	n/a	n/a	26%
NO_x					
Flywheel	259	259	259	259	259
Alternate Gen.	543	1,381	105	154	351
Savings (Flywheel)	284	1,122	-154	-105	92
Percent Savings	52%	81%	-148%	-68%	26%

Emissions in tons

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Emission Results for ISO-NE

Flywheel Emission Savings Over 20-year Life: ISO-NE					
	Coal		Natural Gas		Pumped Hydro
	Baseload	Peaker	Baseload	Peaker	
CO2					
Flywheel	106,697	106,697	106,697	106,697	106,697
Alternate Gen.	304,759	608,354	197,359	227,249	144,766
Savings (Flywheel)	198,062	501,657	90,662	120,552	38,070
Percent Savings	65%	82%	46%	53%	26%
SO2					
Flywheel	270	270	270	270	270
Alternate Gen.	1,300	3,303	0	0	367
Savings (Flywheel)	1,030	3,033	-270	-270	96
Percent Savings	79%	92%	n/a	n/a	26%
NOx					
Flywheel	115	115	115	115	115
Alternate Gen.	416	990	58	85	157
Savings (Flywheel)	301	875	-58	-31	41
Percent Savings	72%	88%	-101%	-36%	26%

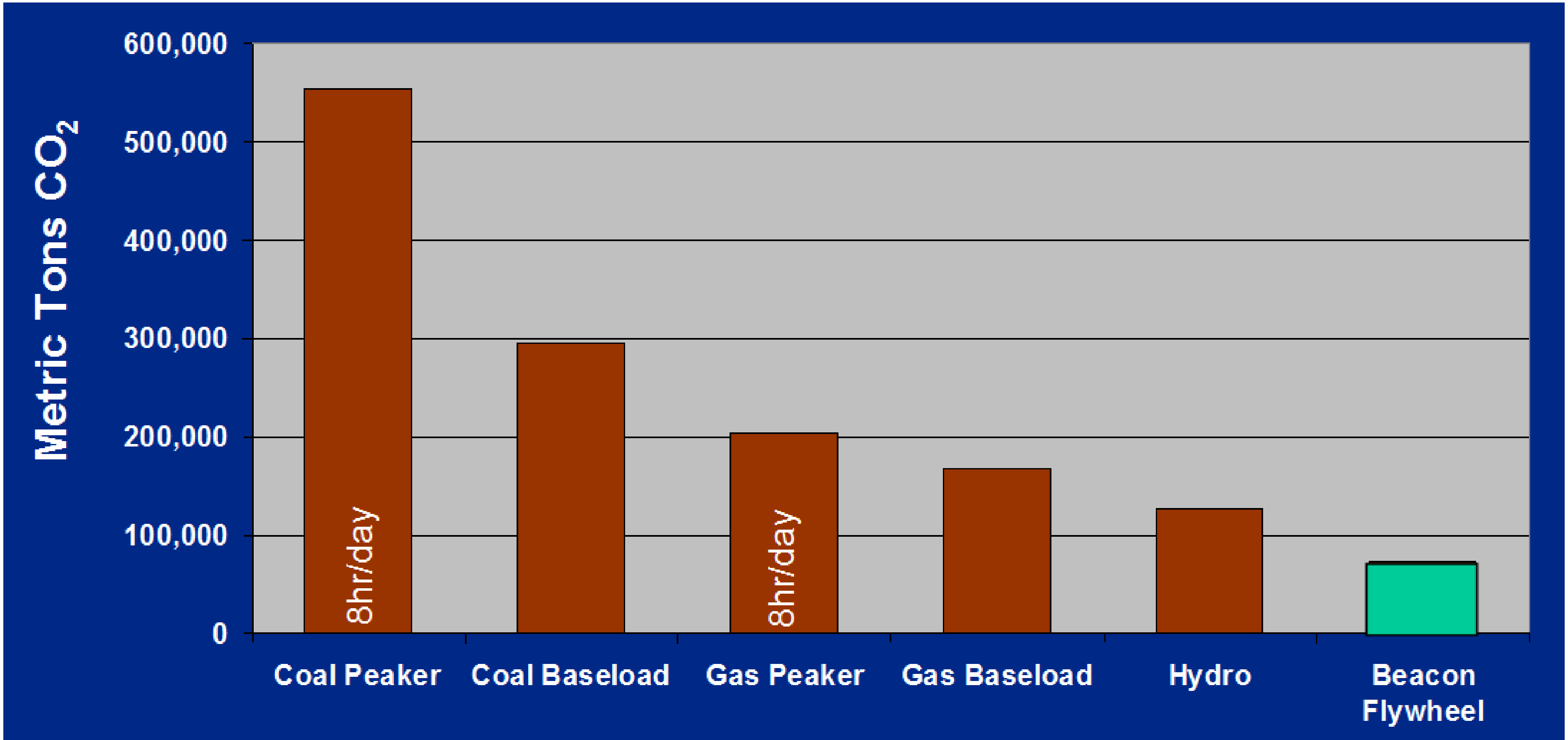
Emissions in tons

Emission Results for CA-ISO

Flywheel Emission Savings Over 20-year Life: CA-ISO					
	Coal		Natural Gas		Pumped Hydro
	Baseload	Peaker	Baseload	Peaker	
CO2					
Flywheel	91,079	91,079	91,079	91,079	91,079
Alternate Gen.	322,009	608,354	194,534	223,997	123,577
Savings (Flywheel)	230,930	517,274	103,455	132,917	32,498
Percent Savings	72%	85%	53%	59%	26%
SO2					
Flywheel	63	63	63	63	63
Alternate Gen.	1,103	2,803	0	0	85
Savings (Flywheel)	1,041	2,741	-63	-63	23
Percent Savings	94%	98%	n/a	n/a	27%
NOx					
Flywheel	64	64	64	64	64
Alternate Gen.	499	1,269	80	118	87
Savings (Flywheel)	435	1,205	16	54	23
Percent Savings	87%	95%	20%	46%	26%

Emissions in tons

CO_2 Emissions Summary



Over 80% reduction in CO_2 emissions vs. present methods

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Conclusions

- A detailed emissions comparison model was developed by KEMA to evaluate the emissions from regulation technologies in different regions
- The emissions comparison estimates show highly favorable results for the flywheel for CO_2 emissions in all regions
- KEMA's model analysis showed that flywheel-based frequency regulation can be expected to create significantly less NO_x and SO_2 emissions for CA-ISO

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