Innovative Methods to Improve Flexibility in PJM

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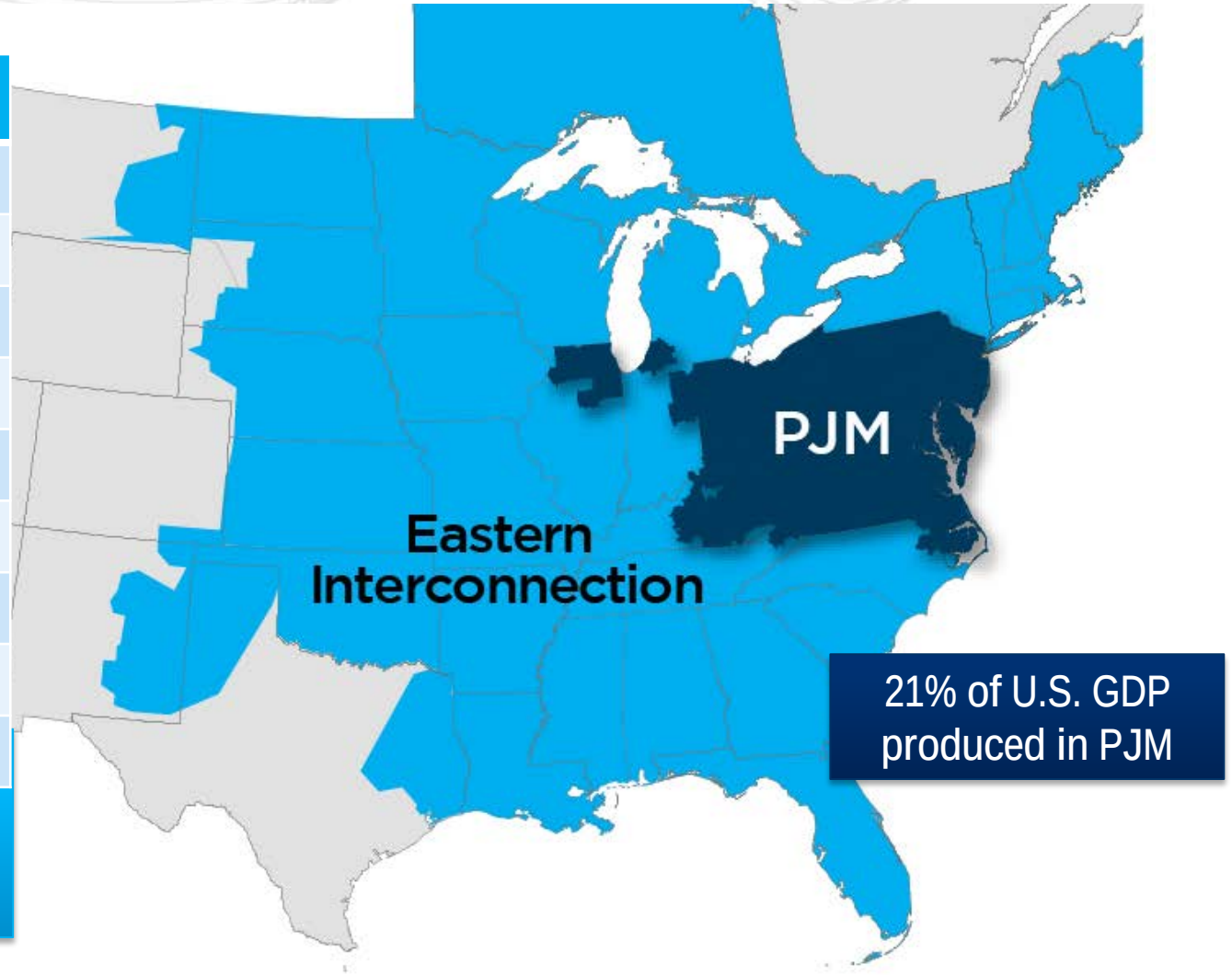
PJM as Part of the Eastern Interconnection

Key Statistics	
Member companies	1,040+
Millions of people served	65
Peak load in megawatts	165,492
MW of generating capacity	178,563
Miles of transmission lines	84,042
2017 GWh of annual energy	773,522
Generation sources	1,379
Square miles of territory	243,417
States served	13 + DC

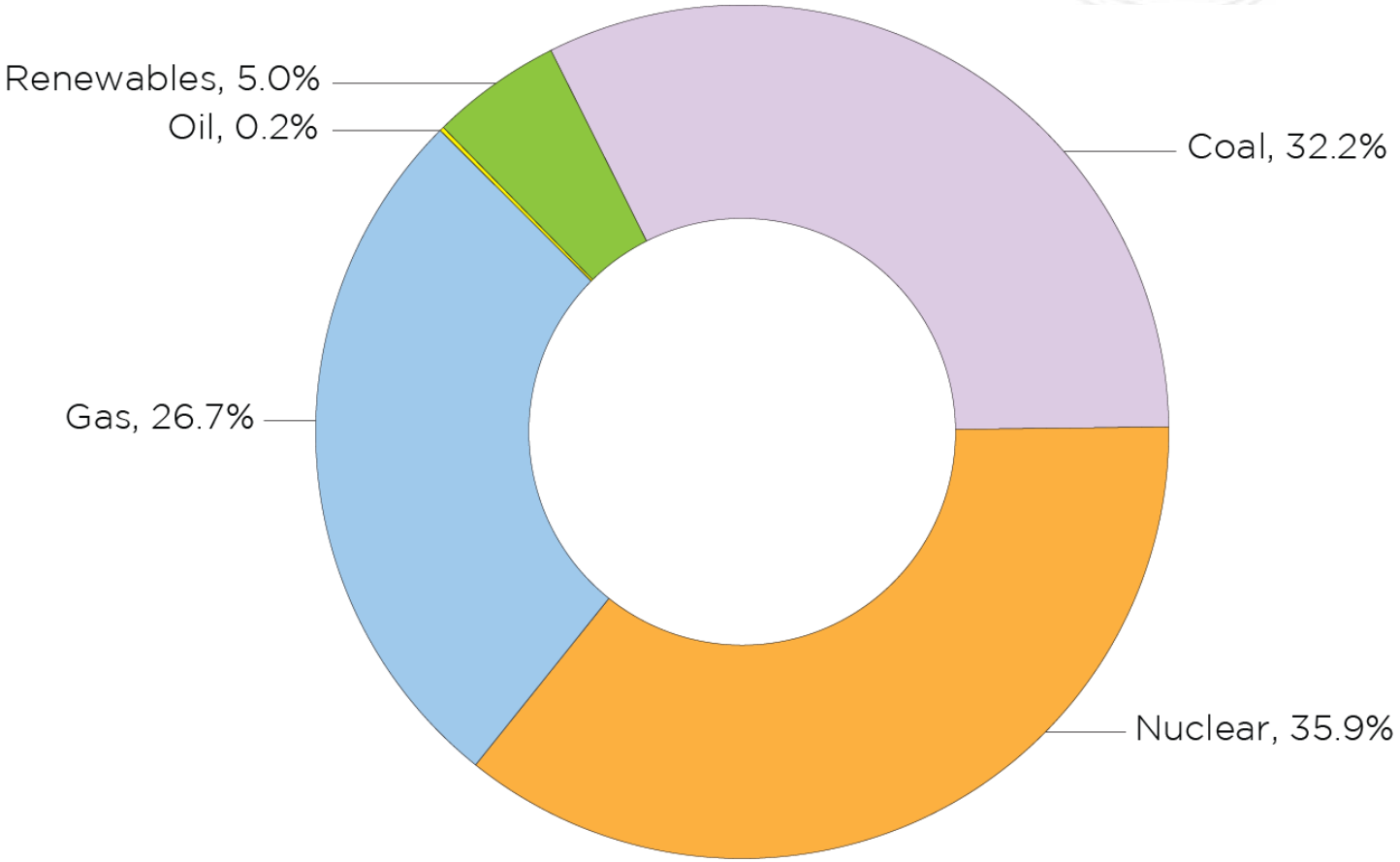
- 28% of load in Eastern Interconnection
- 20% of transmission assets in Eastern Interconnection

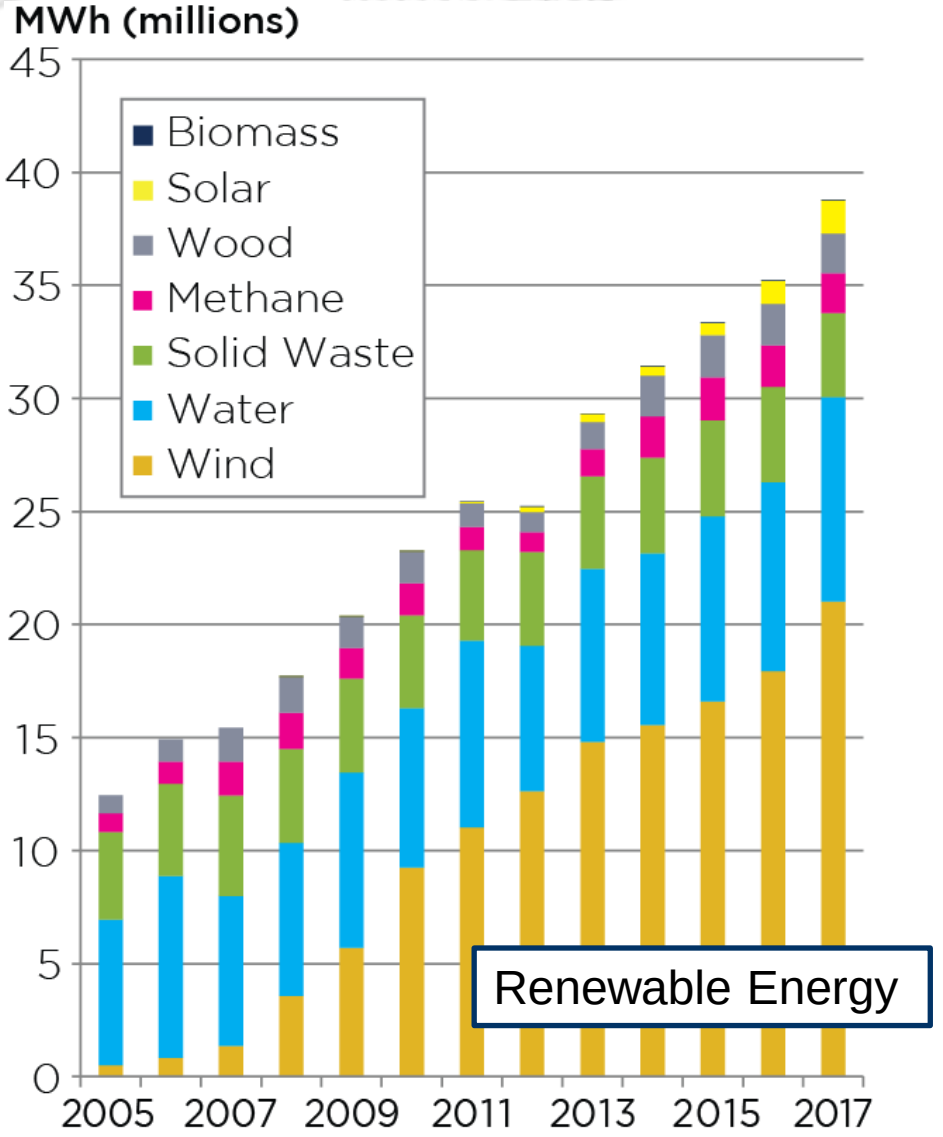


As of 2/2018

Percentage of Renewable Energy is Small but Growing

PJM Generation Mix – 2017
Annual Energy





PJM Initiatives to Address Impacts

Energy Markets / Operations

- Implemented a centralized wind power forecast service
- Solar power forecast is in progress
- Implemented changes to improve wind resource dispatch / control
- Demand Response / Price Responsive Demand improves operational flexibility
- Frequency Regulation – “pay for performance” rewards better performing resources (like storage)
- Interchange Scheduling – compliant with FERC Order 764 (15-minute intervals)

Transmission Planning

- Light load criteria implemented to improve grid reliability
- Expansion planning considers public policy impacts (i.e., RPS)
- Grid interconnection – enhanced standards for new inverter-based resources (wind and solar)

Evaluating Potential Grid Impacts

- PJM Renewable Integration Study (PRIS) - assessed grid impacts

Advanced Technology Research Program (ATRP)

- Pilot programs to evaluate new technologies and remove barriers to participation in PJM markets and operations.

Renewables and the Regulation Requirement

PJM Renewable Integration Study shows a need for regulation reserves to increase under all scenarios, especially under High Solar scenarios.

Regulation	Load Only	2% BAU	14% RPS	20% HOBO	20% LOBO	20% LODO	20% HSBO	30% HOBO	30% LOBO	30% LODO	30% HSBO
Maximum (MW)	2,003	2,018	2,351	2,507	2,721	2,591	2,984	3,044	3,552	3,191	4,111
Minimum (MW)	745	766	919	966	1,031	1,052	976	1,188	1,103	1,299	1,069
Average (MW)	1,204	1,222	1,566	1,715	1,894	1,784	1,958	2,169	2,504	2,286	2,737
% Increase Compared to Load		1.5%	30.1%	42.4%	57.3%	48.2%	62.6%	80.2%	108.0%	89.8%	127.4%

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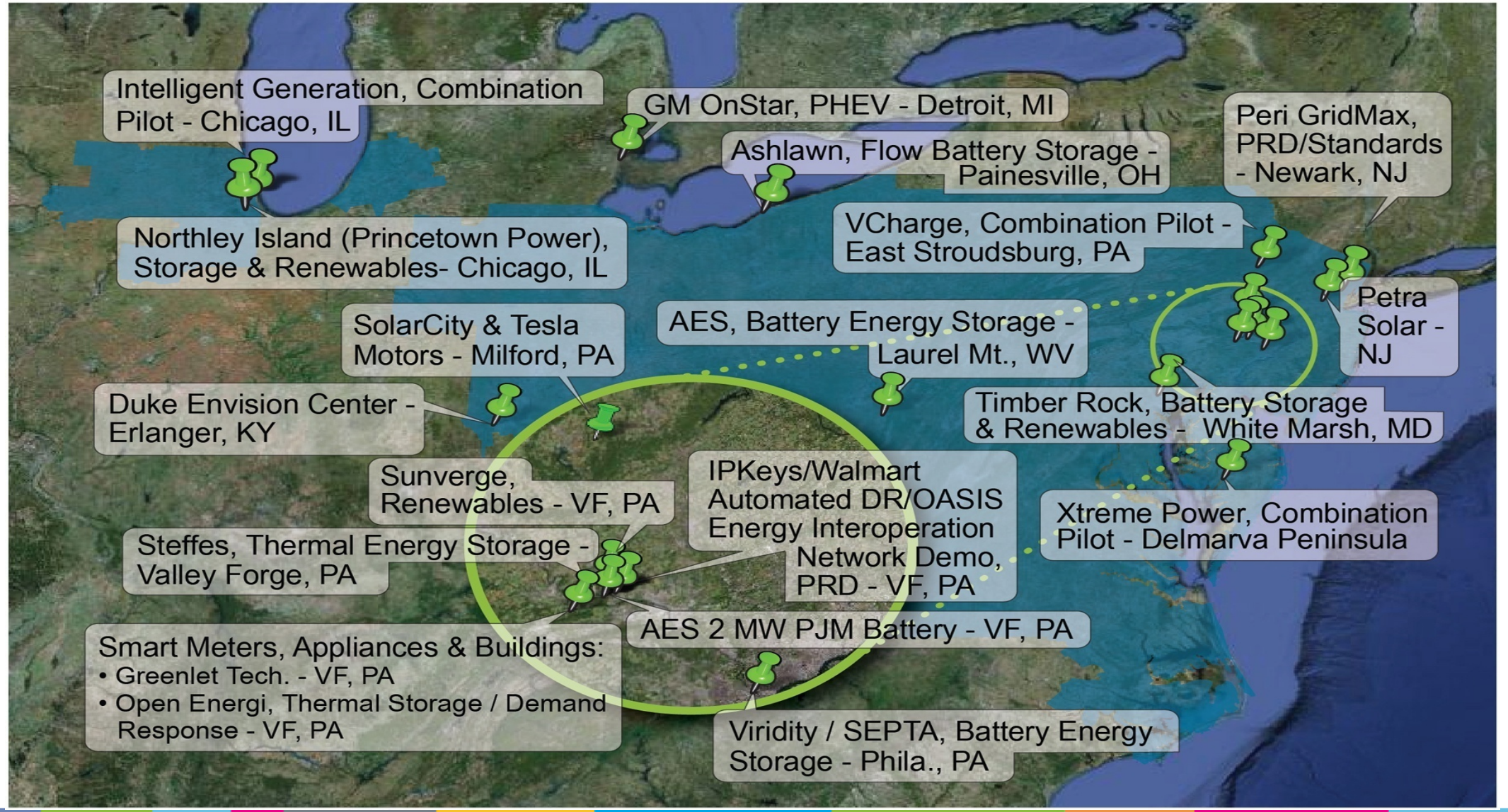
Advanced Technology Research Program

PJM Advanced Technology Research Program



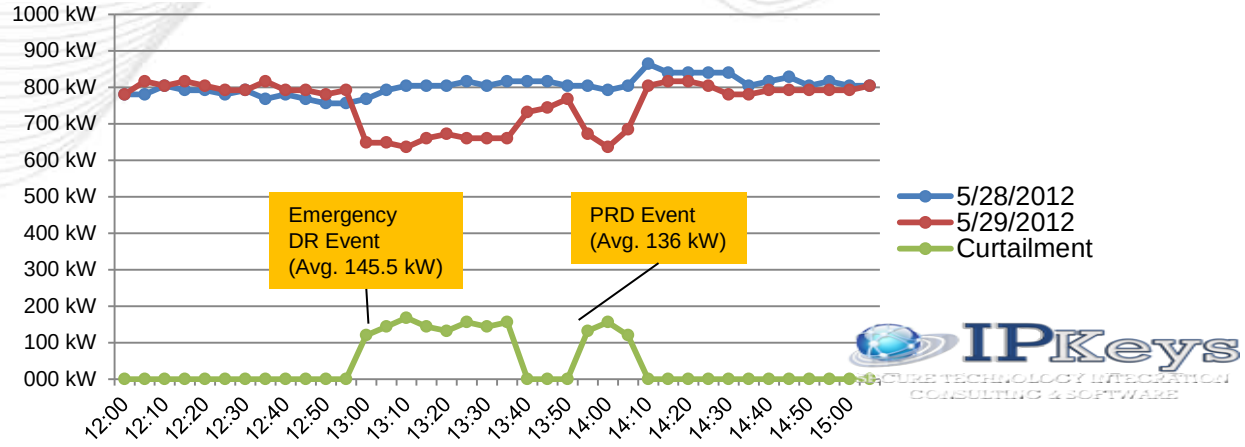
Demonstrations in Progress

BMW of North America
SMART CHARGING DEMONSTRATION PROJECT

Freude am Fahren

Walmart
Save money. Live better.

Store #3475 (Trooper Road) HVAC Response



IPKeys
SECURE TECHNOLOGY INTEGRATION CONSULTING & SOFTWARE

AES Energy Storage

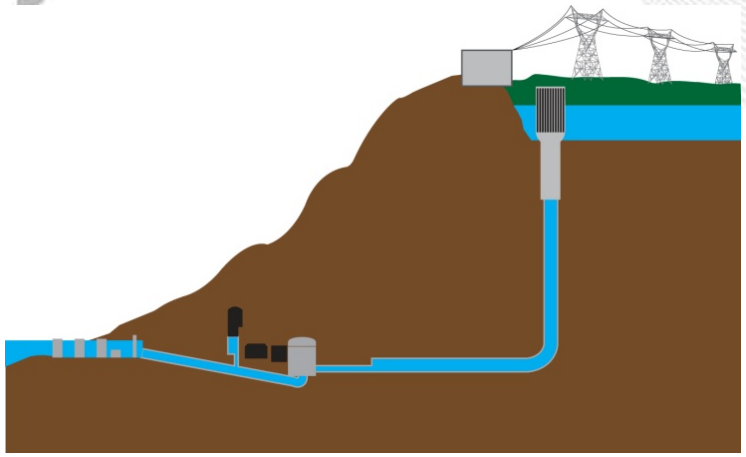
SolarCity

(example ground mount array)

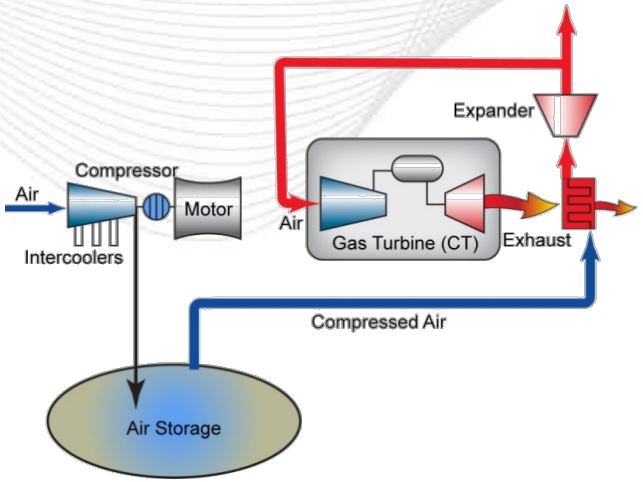
PV Array

Battery and Inverters

Grid Storage Types and Availability



Pumped Hydro



Compressed Air

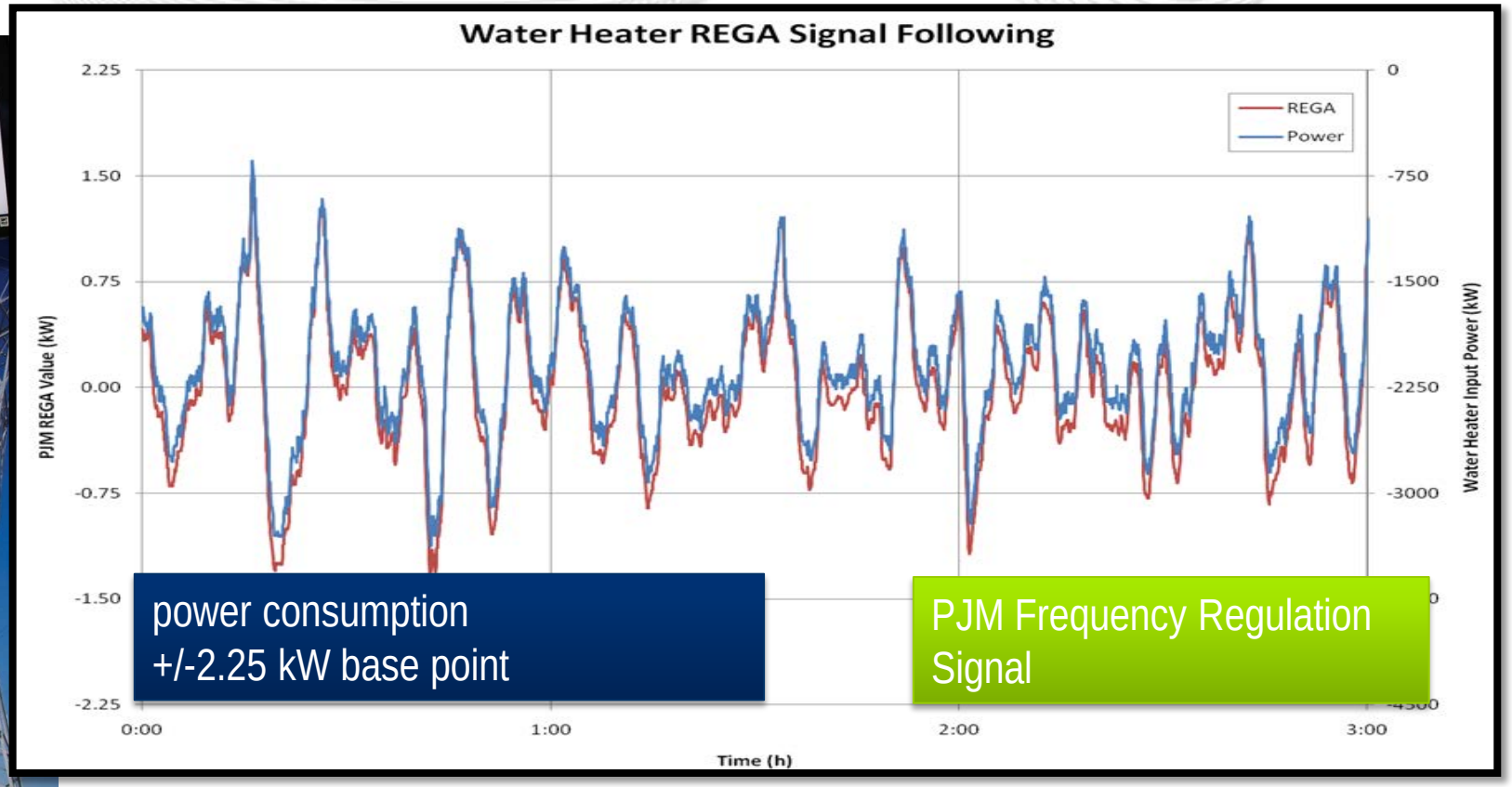
Flywheels

Stationary Battery

Mobile Batteries

Water Heaters

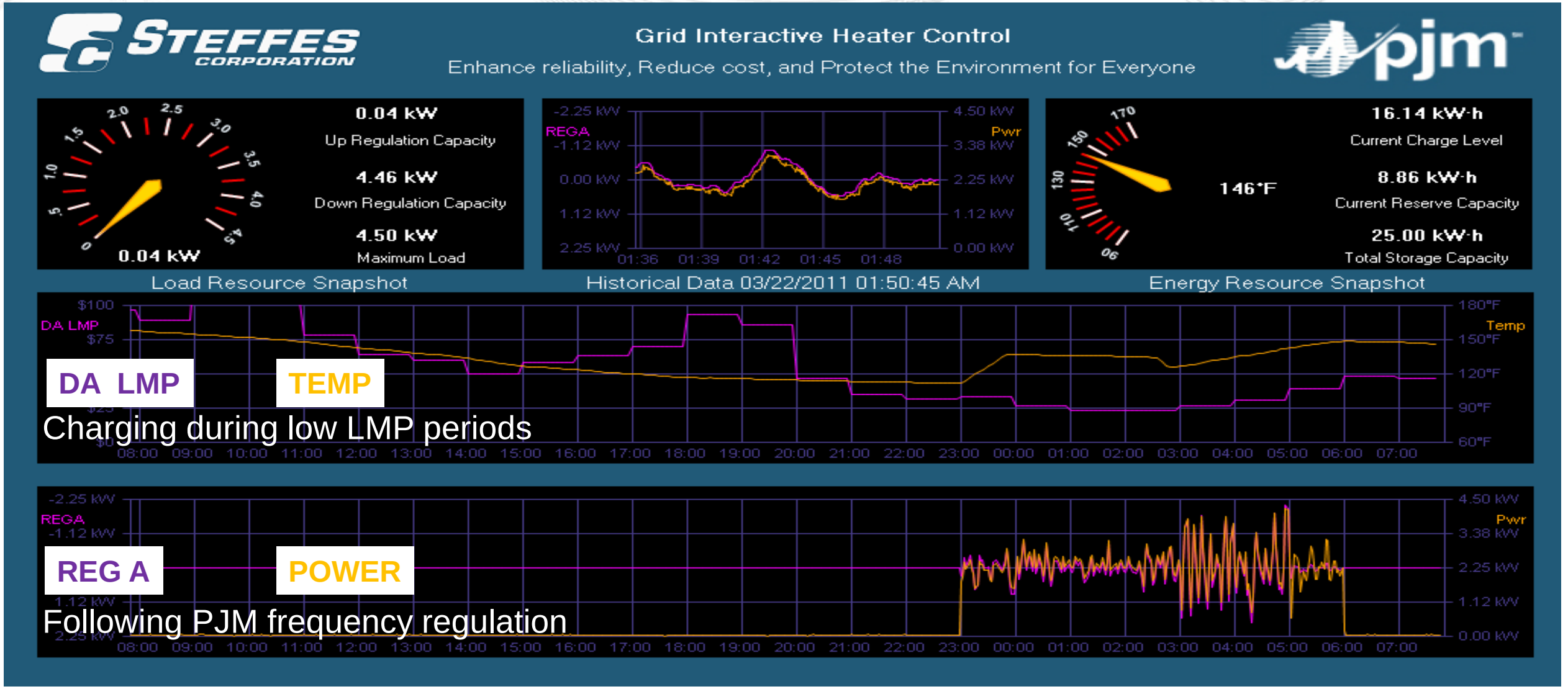
PJM Pilot Water Heater



Jan.14, 2011 Midnight to 3:00 a.m.

105-gallon electric water heater demonstrates minimization of cost while responding to the PJM wholesale price signal and the PJM frequency regulation signal.

Water Heater – Optimization of LMP and Frequency Regulation



Alternative Technology Providing Services to the Grid

Frequency Regulation

262.4 MW of batteries
23.6 MW of demand-side resources

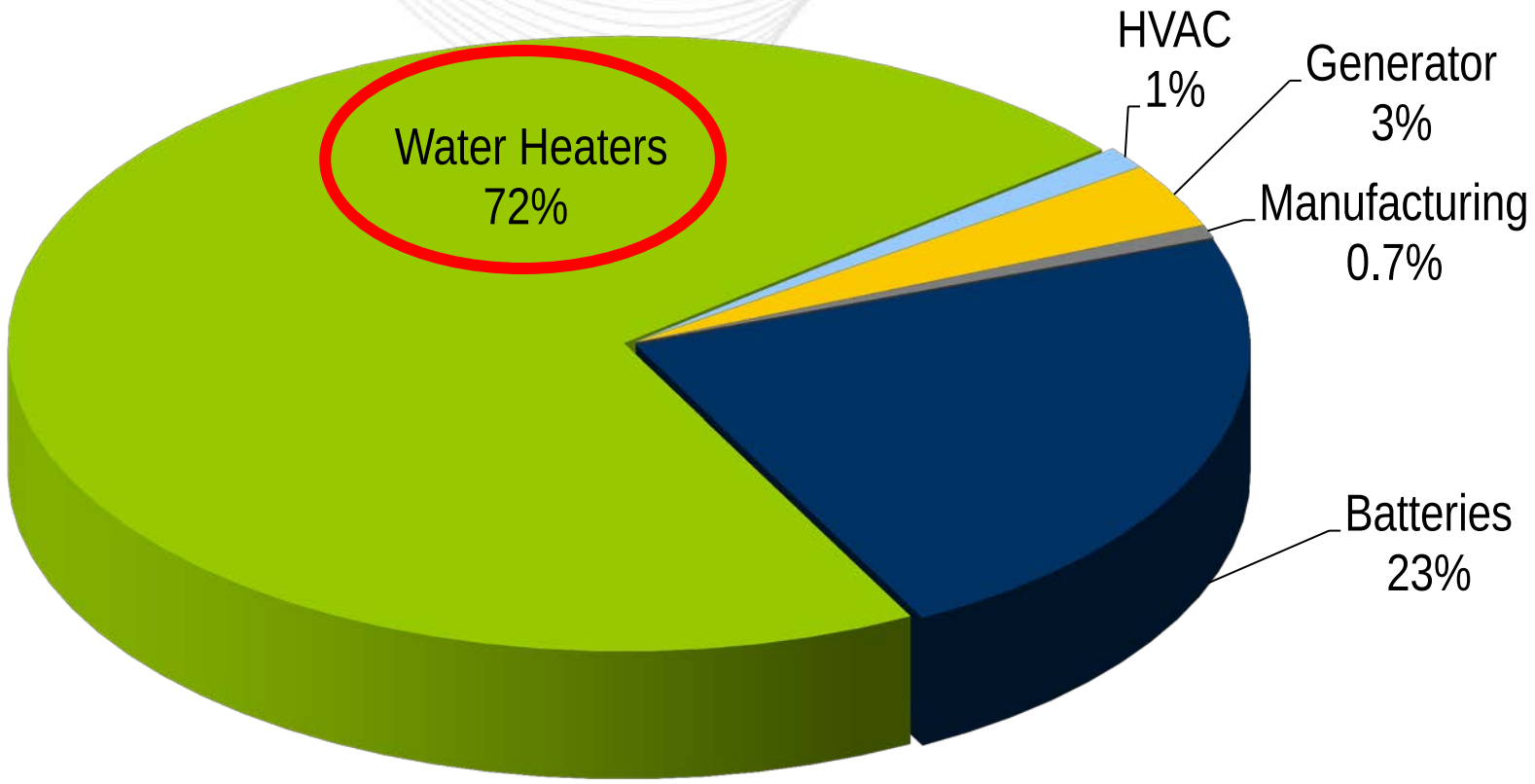
~ On average **27%.**
As high as **39%%** of our regulation requirement is provided by alternative technologies.

Synchronized Reserves

444 MW of demand-side resources capable of providing synch reserve in 2017 YTD.

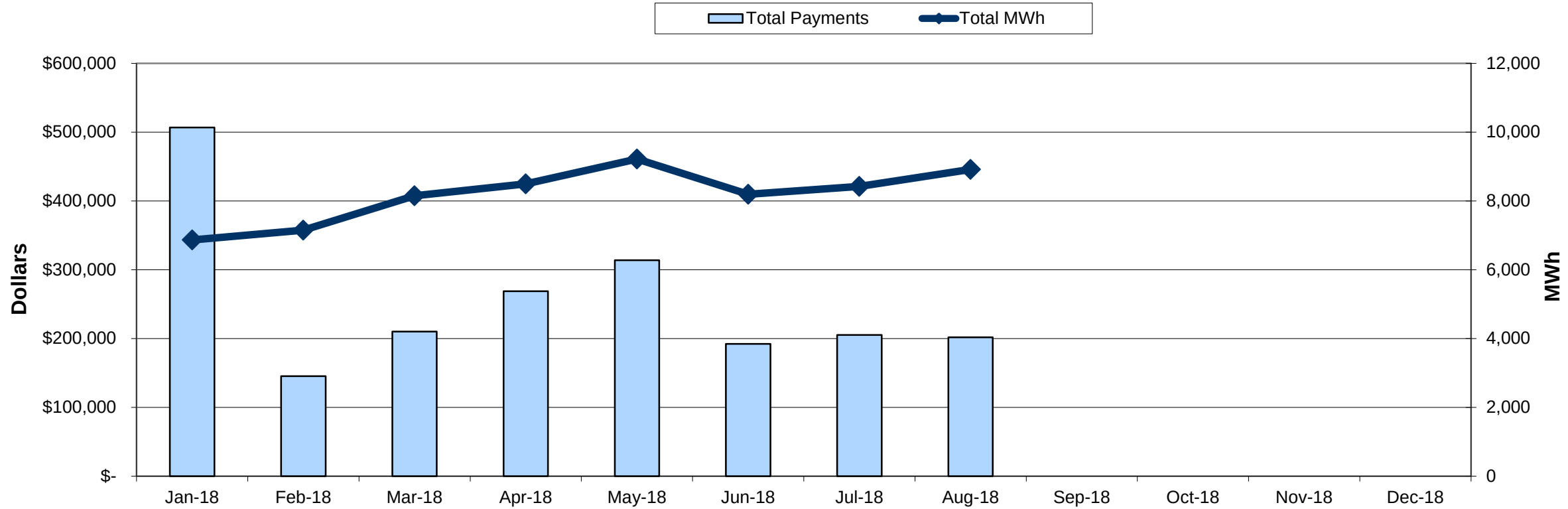
8.1% of synch reserve actually provided by Demand-Side Resources in 2017 YTD.

2018 PJM Demand Response: **Regulation Registrations**



Note: Percent of CSP Reported Load Reduction MWs

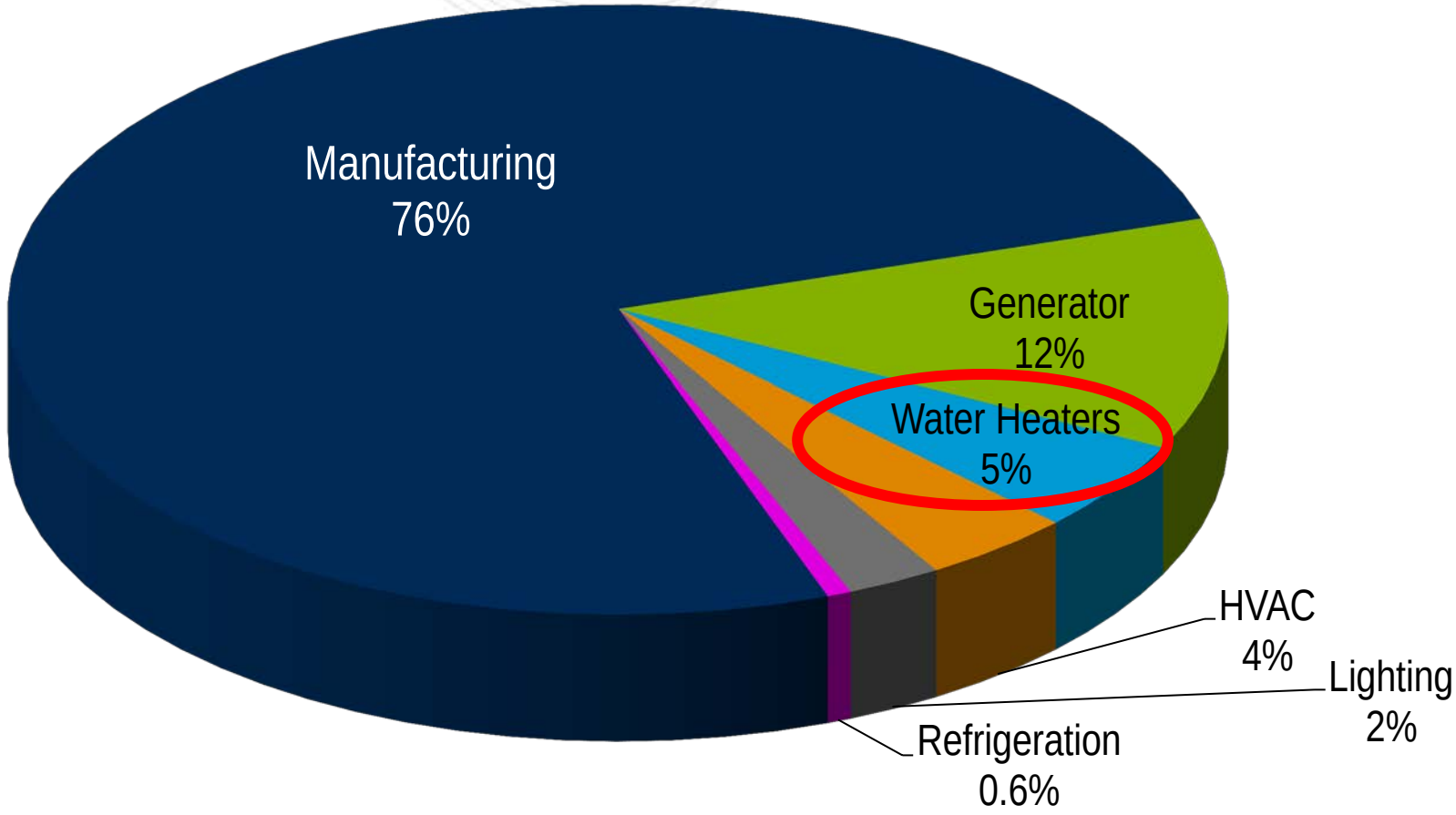
2018 Economic Demand Response **Regulation** Market Participation



	Jan-18	Feb-18	Mar-18	Apr-18	May-18	Jun-18	Jul-18	Aug-18	Sep-18	Oct-18	Nov-18	Dec-18	Total
Total MWh	6,866	7,152	8,150	8,495	9,215	8,194	8,420	8,913					65,404
Total Payments	$506,727	$145,434	$209,971	$268,765	$313,882	$192,179	$205,221	$201,675					$2,043,855
$ / MWh	$73.81	$20.34	$25.76	$31.64	$34.06	$23.45	$24.37	$22.63					$31.25

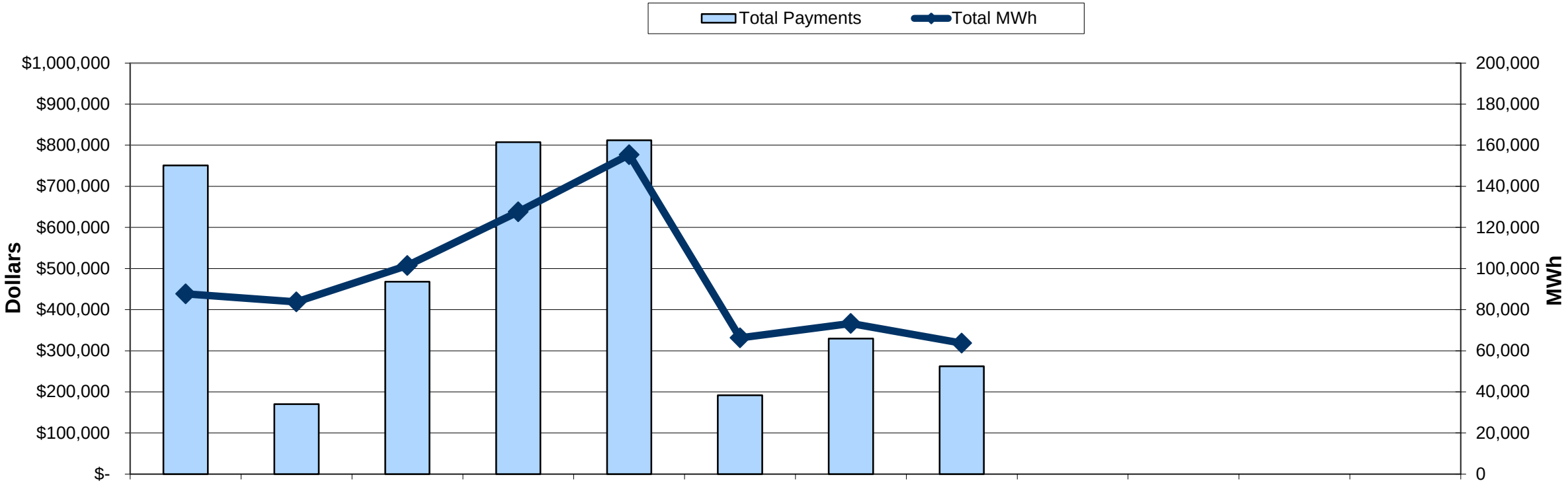
Note: MWh=sum of the settled MW. Example: 1 MW load available for 12 hours = 12 MWh.

2018 PJM Demand Response: **Synch Reserve Registrations**



Note: Percent of CSP Reported Load Reduction MWs

2018 Economic Demand Response **Synchronous Reserve** Market Participation



	Jan-18	Feb-18	Mar-18	Apr-18	May-18	Jun-18	Jul-18	Aug-18	Sep-18	Oct-18	Nov-18	Dec-18	Total
Total MWh	87,697	83,800	101,430	127,629	155,335	66,312	73,250	63,658					759,112
Total Payments	$750,921	$170,305	$467,817	$807,610	$811,970	$191,947	$329,362	$262,021					$3,791,954
$ / MWh	$8.56	$2.03	$4.61	$6.33	$5.23	$2.89	$4.50	$4.12					$5.00

Note: MWh=sum of the settled MW. Example: 1 MW load available for 12 hours = 12 MWh.

Looking to the Future

- Flexible resources will be needed to offset the impacts of variable generating resources
- New market players:
  - Distributed Energy Resources
  - Smart Grid Technologies
  - Energy Storage Resources
- Potential market changes:
  - New tools to improve forecasting and scheduling capabilities
  - New market mechanisms to incent flexible resources
    - Synchronized and Operating Reserve Market Enhancements
    - Shortage Pricing
    - Fast Start Pricing

Additional Information

- PJM Initiatives:
  - PJM Learning Center: Alternative & Renewable Generation
    - » http://learn.pjm.com/energy-innovations/alternative-renewable-gen.aspx
  - PJM Renewable Integration Study (PRIS) Reports
    - » http://www.pjm.com/committees-and-groups/subcommittees/irs/pris.aspx
- Other Publications:
  - Energy Systems Integration Group (EVIG)
    - » https://www.esig.energy/resources/
  - National Renewable Energy Laboratory (NREL) Renewable Electricity Futures
    - » https://www.nrel.gov/analysis/re_futures/index.html

PJM Now App Available