MISO Energy Storage Study

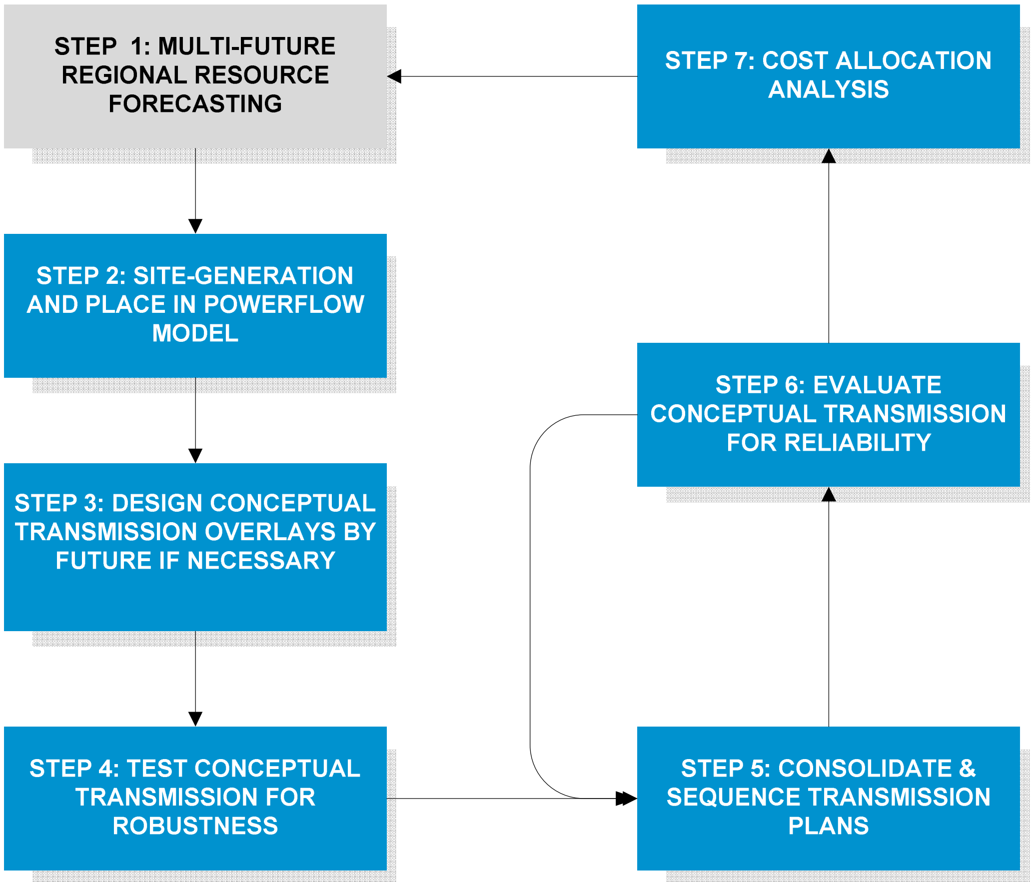
Background

- MISO initiated the Energy Storage Study to explore the benefits that pumped hydro storage, compressed air energy storage, and battery storage technologies could provide as well as their economic potential in the MISO region.

- This study is part of MISO's involvement in GO15, an initiative with the largest power grid operators in the world.

- Study findings indicate that although there is overall opportunity for long-term storage resources in certain future scenarios, the existing MISO market and tariff conditions currently do not find large-scale investment in storage to be economical based on capacity and energy benefits captured in the model.

MISO's Value-Based Planning



- **The MISO 7-Step planning process should result in a robust plan under a variety of scenarios, not the least-cost plan under a single scenario**
- **By Identifying Possible Futures…**
  - **D/E Growth, Retirements, Fuels, RPS, Environmental, DSM…**
- **We get a footprint-wide plan that can deliver value and accommodate plans and goals for all our stakeholders**

Importance of Scenario Analysis

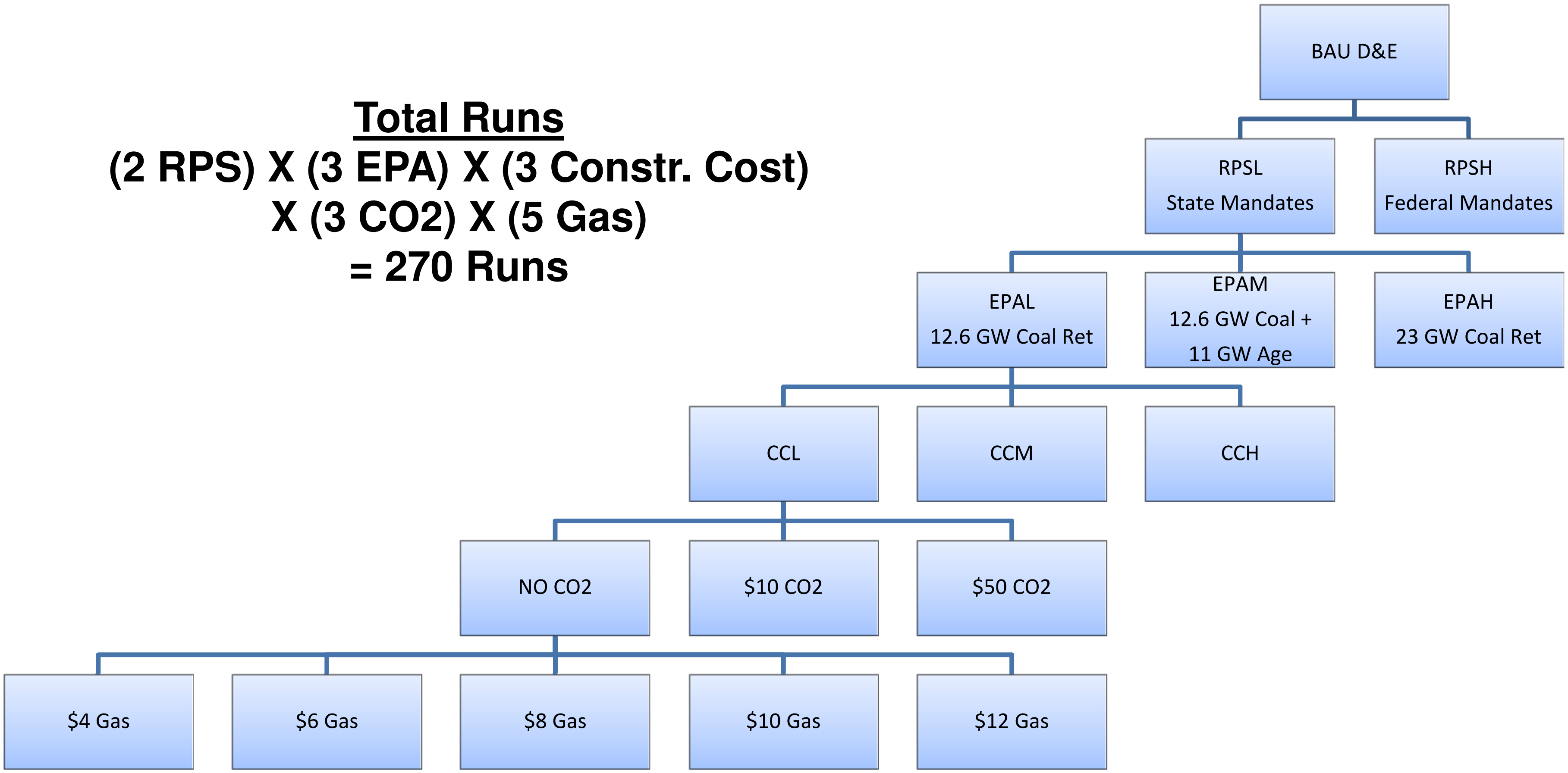
- **The scenarios should simulate likely or plausible real-life future system conditions and provide a broad range of outcomes showing potential for storage to be economic.**
- **States have already implemented goals and mandates for renewables which could carryover to energy storage as another clean technology.**
- **There are potential business development ideas for storage in MISO.**
  - System Support Resource (SSR) alternative
  - Address potential resource shortfall in summer 2016
  - Alternative to distribution transmission projects
  - Use in initiation of emergency operating procedures (EOPs)
  - Solution for market efficiency in congestion prone areas

Model Assumptions

EGEAS Decision Tree

Total Runs

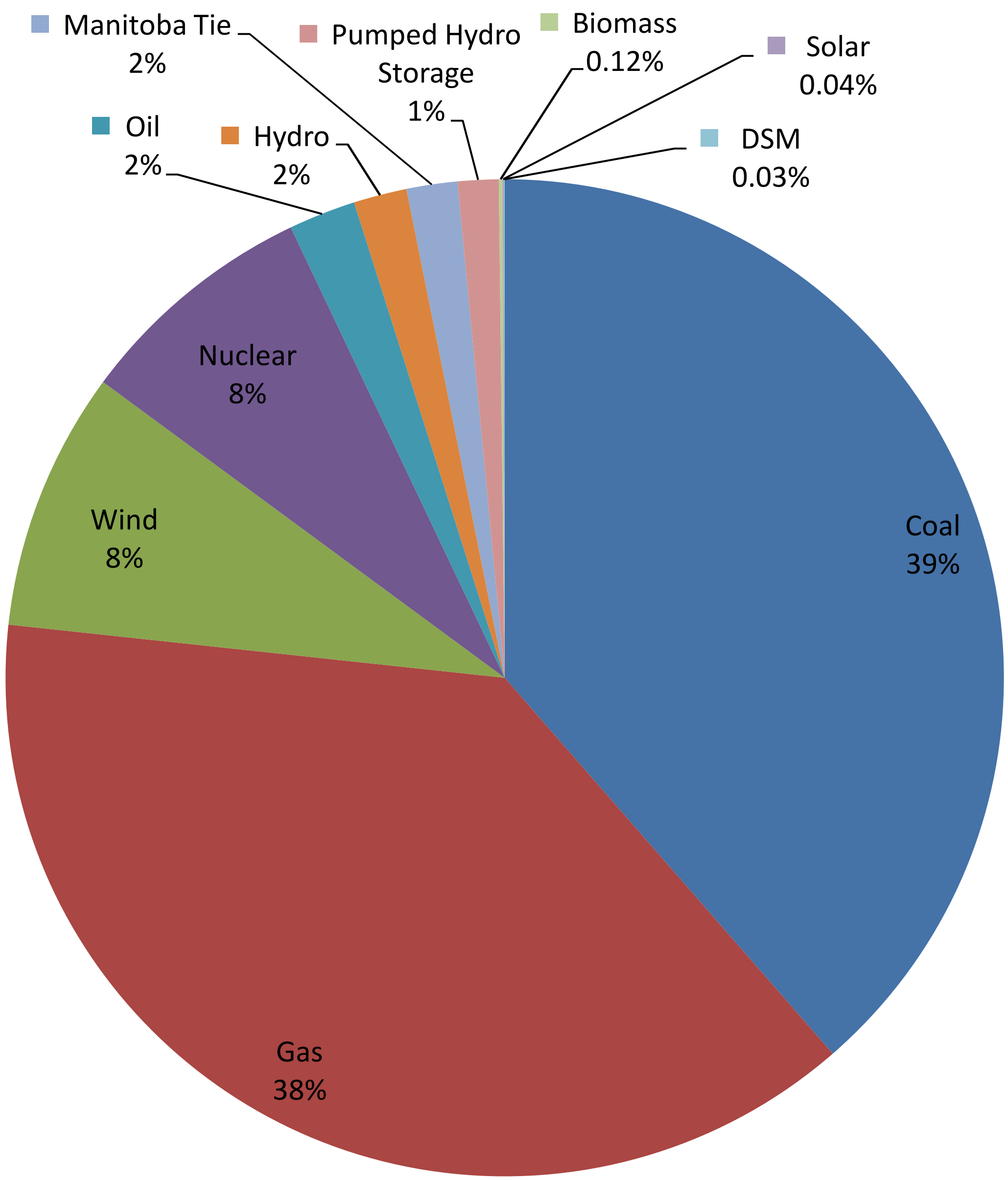
(2 RPS) X (3 EPA) X (3 Constr. Cost) X (3 CO2) X (5 Gas) = 270 Runs



Assumptions

Variable	Low (L)	Mid (M)	High (H)
Pumped Storage Hydro ($/kW)	4050	4590	5400
Compressed Air Energy Storage ($/kW)	957	1085	1276
Battery ($/kW)	1,914	2,170	2552
Demand Growth Rate		0.80%	
Energy Growth Rate		0.80%	
Natural Gas	$4,6,8,10,12		
CO_2 ($/ton)	0	10	50
Retirements	12,600 MW	12,600 MW + 11,600 MW age-related retirements = 24,200 MW	24 GW coal retirements
Renewable Portfolio Standards	State mandates only / 6100 MW		30% MISO-Wide Mandate Solar 10% of overall mandate / 58,600 MW

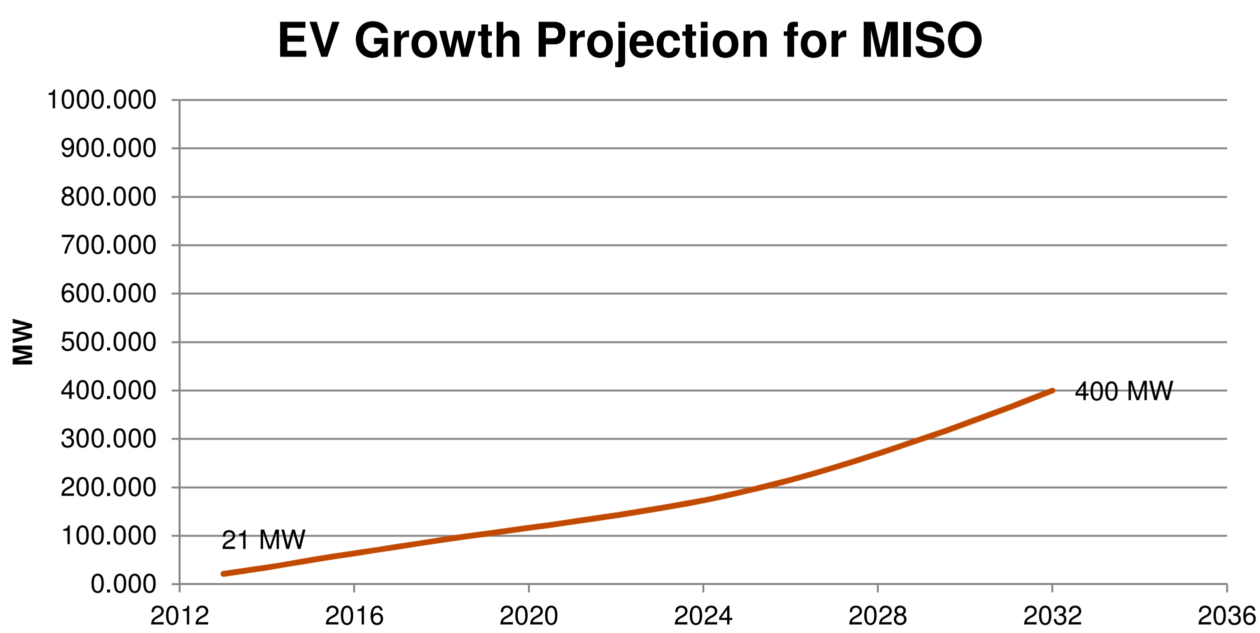
Resource Mix of MISO Footprint for 2014



Fuel Category	MW	Percentage
Coal	73,640	39%
Gas	72,724	38%
Wind	16,032	8%
Nuclear	14,953	8%
Oil	4,150	2%
Hydro	3,272	2%
Manitoba Tie	3,157	2%
Pumped Hydro Storage	2,518	1%
Biomass	224	0.12%
Solar	76	0.04%
DSM	66	0.03%
Total	190,812	

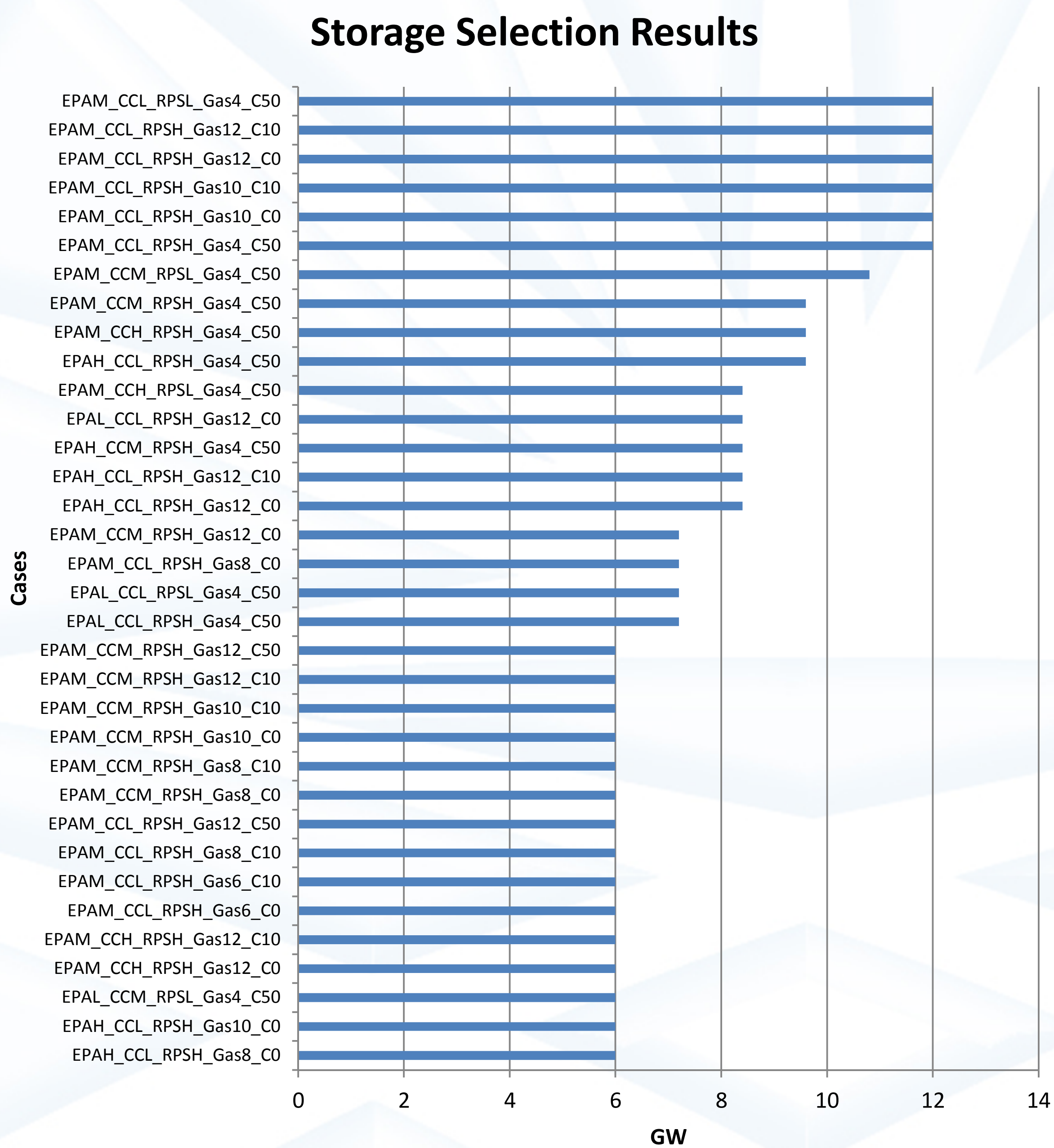
Electric Vehicle Assumptions

EV's in MISO footprint						
	2006	2007	2008	2009	2010	2011
U.S. EVs	53,507	55,706	56,856	56,407	57,451	66,614
MISO EVs	2,263	2,225	2,421	2,728	2,339	2,686
% EV's in MISO	4.23%	3.99%	4.26%	4.84%	4.07%	4.03%



The historical percentage of EVs in MISO are applied to the EIA growth projection to calculate the number of EVs in MISO over the study period.

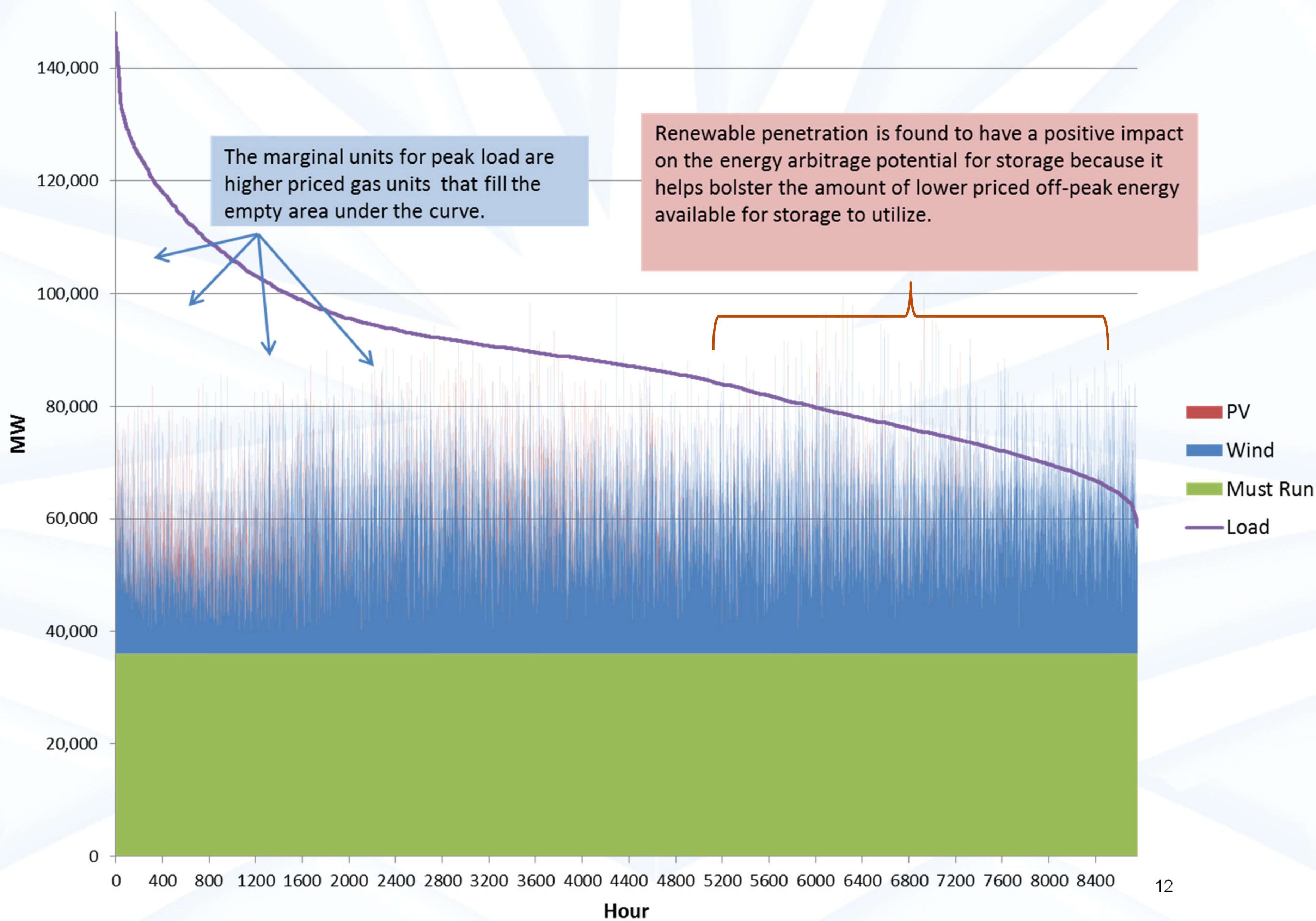
Results



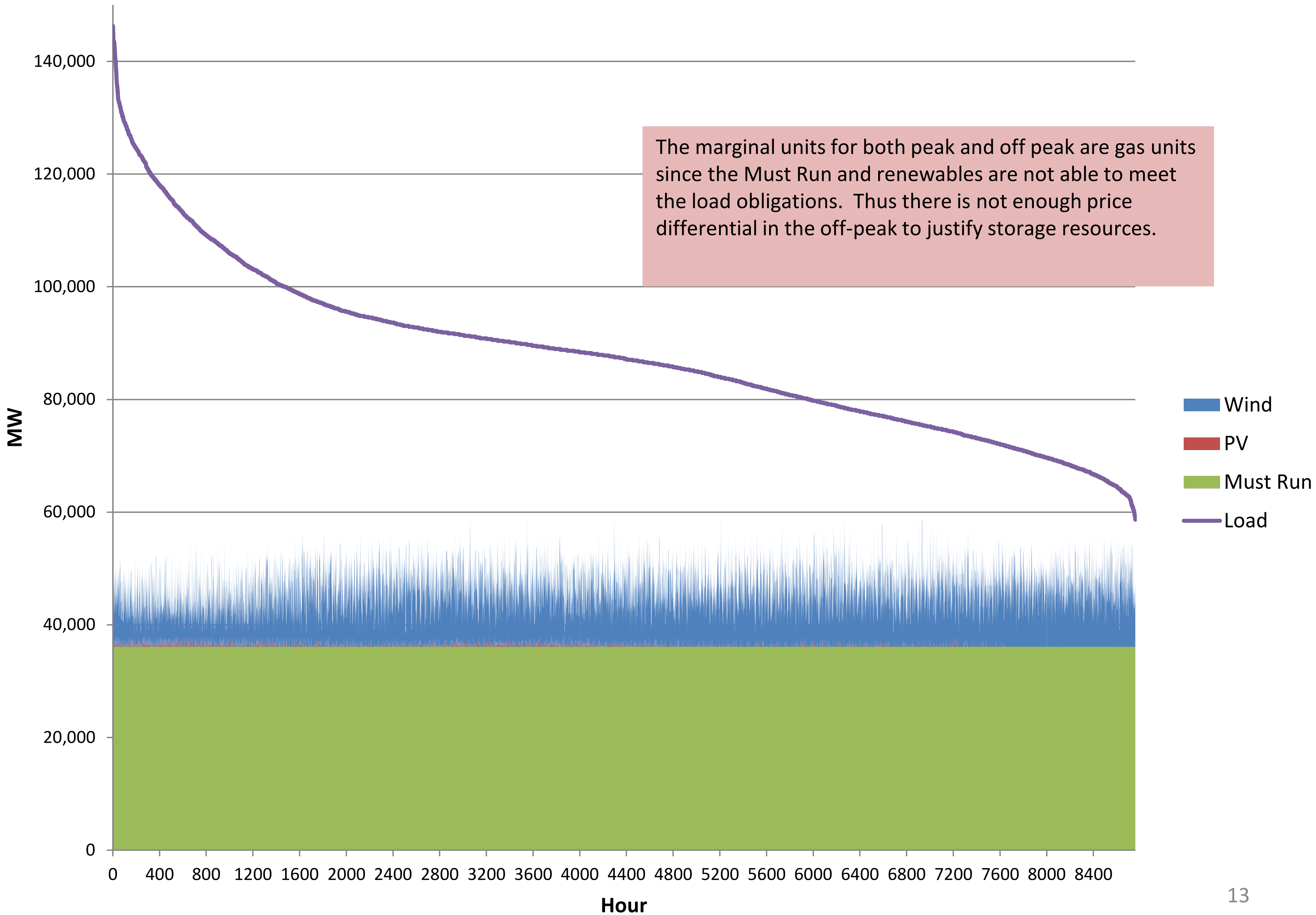
EPA = Generation Retirement (low, medium, high), CC = Construction Costs (low, medium, high), RPS = Renewable Penetration (low, high), Gas = Gas Price ($4, $6, $8, $10, $12), C = Carbon Costs ($0, $10, $50)

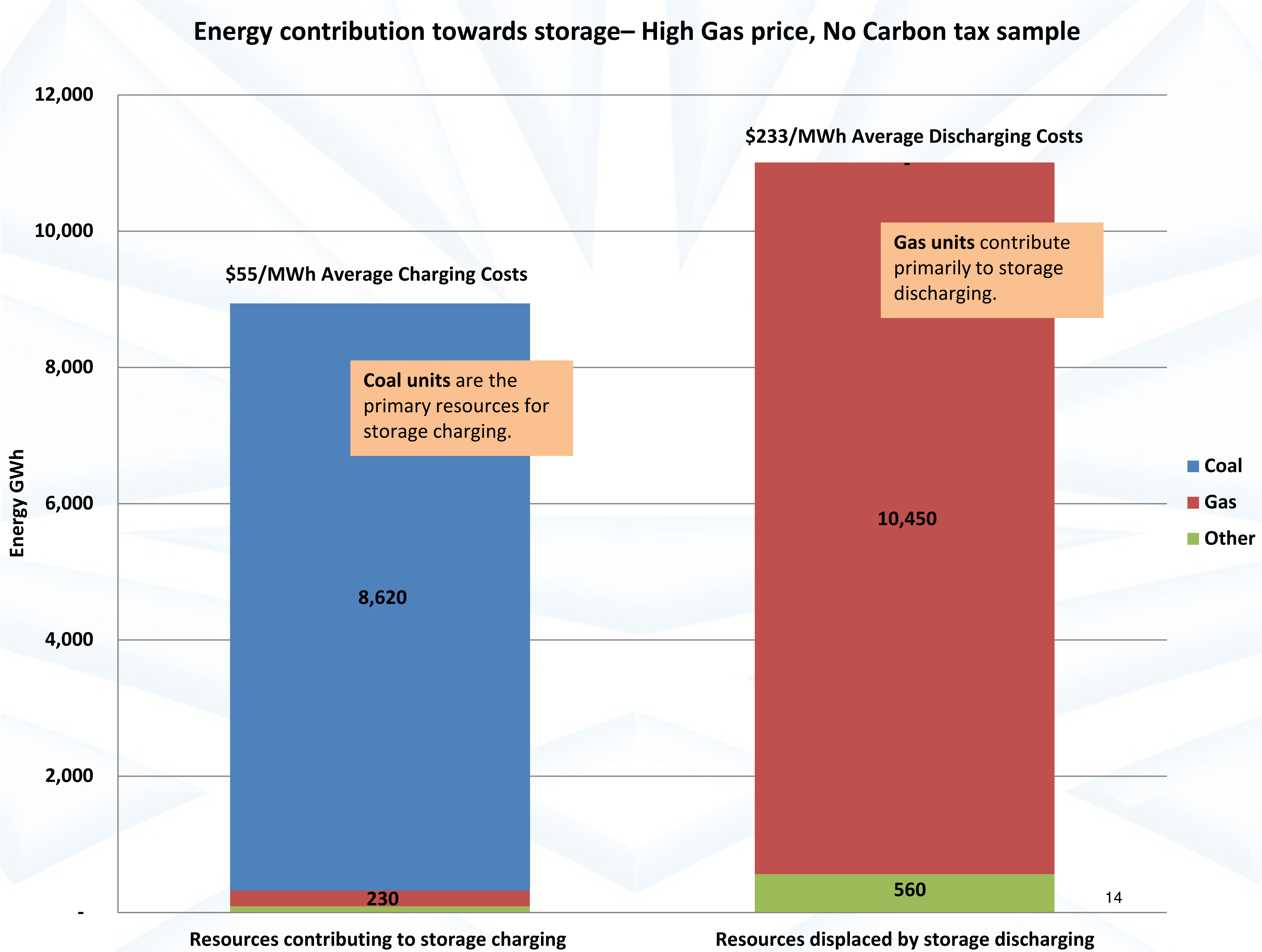
- CAES is the preferred storage resource because of its much lower construction costs and higher efficiency.
- The maximum amount of storage capacity added is 12 GW in the cases with medium retirements, low construction costs.
- High renewables, high gas prices and low carbon costs yield the most storage selection on one spectrum, while low renewables, low gas prices and high carbon costs yield just as much storage selection.

Load duration curve – High Renewables sample

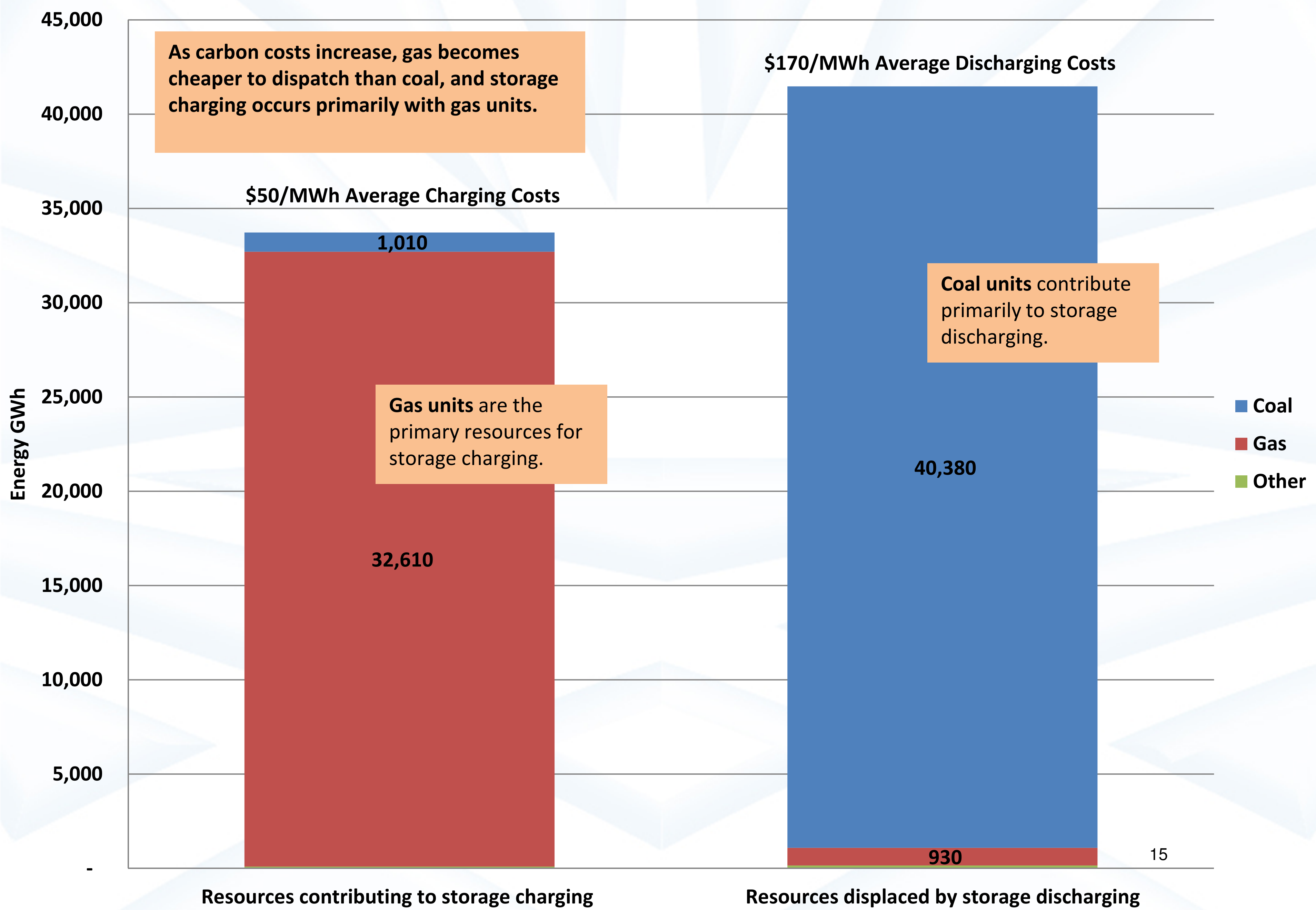


Load duration curve – Low Renewables sample




Energy contribution towards storage– High Gas price, No Carbon tax sample
12,000
10,000
8,000
6,000
4,000
2,000
-
Energy GWh
$55/MWh Average Charging Costs
$233/MWh Average Discharging Costs
Coal units are the primary resources for storage charging.
Gas units contribute primarily to storage discharging.
8,620
230
10,450
560
Coal
Gas
Other
Resources contributing to storage charging
Resources displaced by storage discharging

Energy contribution towards storage – Low gas price, High Carbon tax sample



Summary

- Low capital costs for storage resources allow the most storage selection to occur.

- Renewable penetration is found to have a positive impact on the energy arbitrage potential for storage because it helps bolster the amount of lower priced off-peak energy available for storage to utilize.

- Retirement of existing resources benefits storage up to a certain extent. When 23 GW of retirement comes solely from coal however, it negatively impacts the energy arbitrage potential because gas units become the marginal unit in the off-peak more frequently due to the lack of baseload generation.

- Carbon costs impact the system by reducing the storage potential when coal is the baseload resource and gas is the peaking resource. Under scenarios where gas prices remain low, high carbon costs make gas units ideal as baseload generation.

- This study only considers the energy arbitrage incentives along with planning reserve margin contributions. Further analysis is needed to explore the other financial opportunities available for storage, such as the Ancillary Services Market that could provide key incentives for battery and other fast-response, shorter term technologies in the intra-hour periods.

Additional questions? Please contact:

- Rao Konidena
  - rkonidena@misoenergy.org
- Clarence Bell
  - cbell@misoenergy.org

Follow Us!
@MISO_Energy