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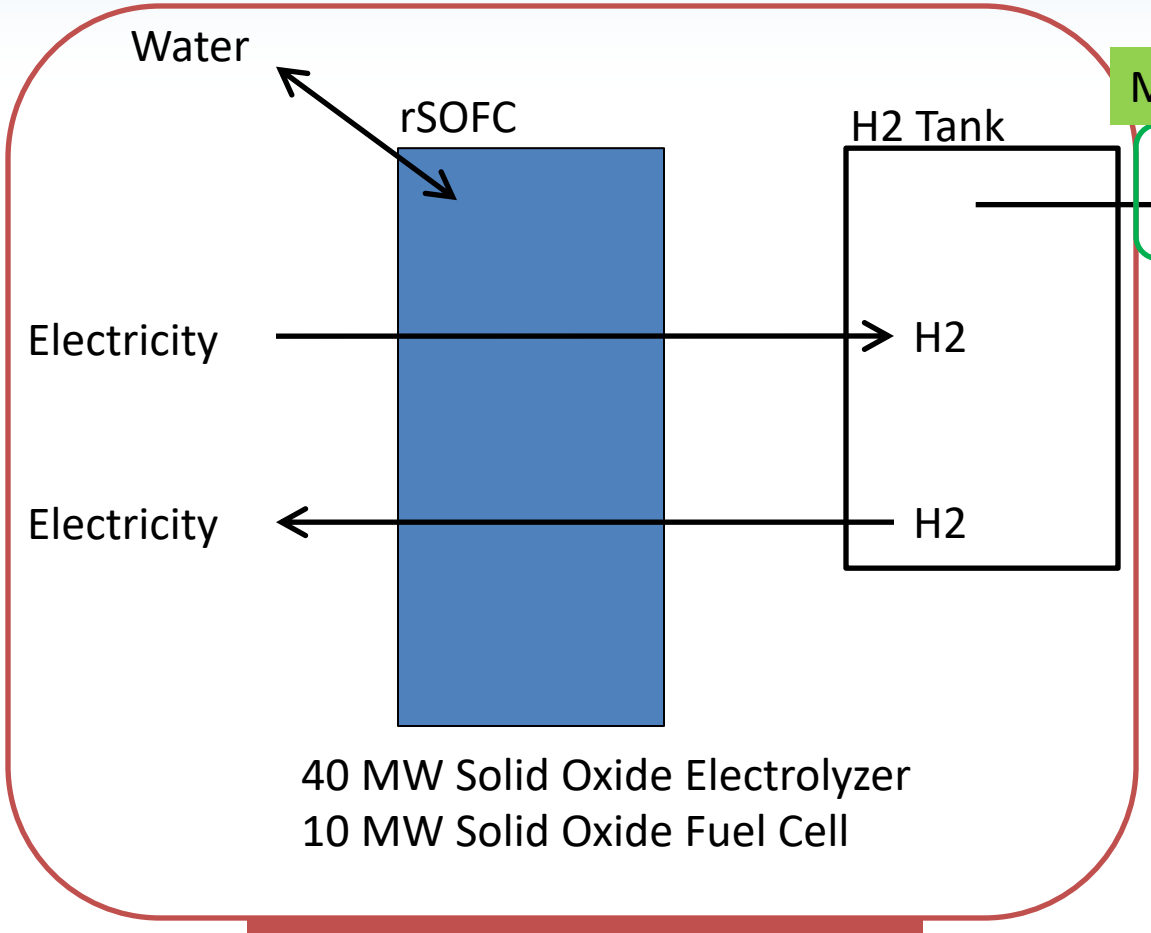
Market Integrated Ammonia

Ammonia Energy Association

Market Integrated H2 Production



Regulated Energy Storage Asset is a hydrogen flow battery. It is compensated for capacity value as a battery.

When the hydrogen flow battery tanks are full, it sells wholesale power as hydrogen for ammonia production.

ROI with $300/tonne NH3 Sales

CapEx & Volatility	$1250/kW electrolyzer	$1000/kW electrolyzer	$750/kW electrolyzer	$500/kW electrolyzer	$250/kW electrolyzer
.8x volatility	$430/tonne -ROI	$400/tonne -ROI	$370/tonne -ROI	$340/tonne -ROI	$310/tonne -ROI
.9x volatility	$400/tonne -ROI	$370/tonne -ROI	$340/tonne -ROI	$320/tonne -ROI	$290/tonne 80 yr ROI
1x volatility	$370/tonne -ROI	$340/tonne -ROI	$306/tonne -ROI	$280/tonne 60 yr ROI	$250/tonne 20 yr ROI
1.1x volatility	$310/tonne -ROI	$280/tonne 89 yr ROI	$250/tonne 33 yr ROI	$220/tonne 17 yr ROI	$190/tonne 9.8 yr ROI
1.2x volatility	$220/tonne 29 yr ROI	$190/tonne 19 yr ROI	$160/tonne 12 yr ROI	$130/tonne 8.4 yr ROI	$96/tonne 5.5 yr ROI

Why a reversible solid oxide fuel cell (rSOFC)?

fuelcellenergy

High Efficiency and High Density Electrolysis:
SOEC efficiency surpasses PEMEC with zero free steam

For a given Production rate:

- **High current density = Lower Capex**
  - 30 to 50% lower cost per kg for hydrogen depending on power cost
- **Low electrolysis voltage = Lower Opex**
  - Solid Oxide Electrolysis Cells (SOEC) can be operated at **more than 100% electrically efficiency**
  - Provides opportunities for **waste heat utilization in hydrogen production**
  - Allows high round trip energy efficiency in **energy storage systems** with thermal energy storage

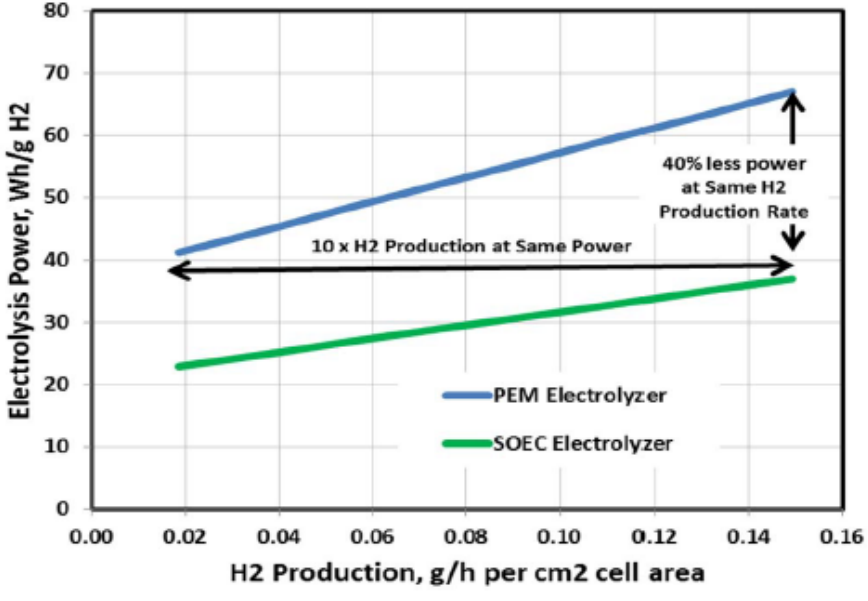
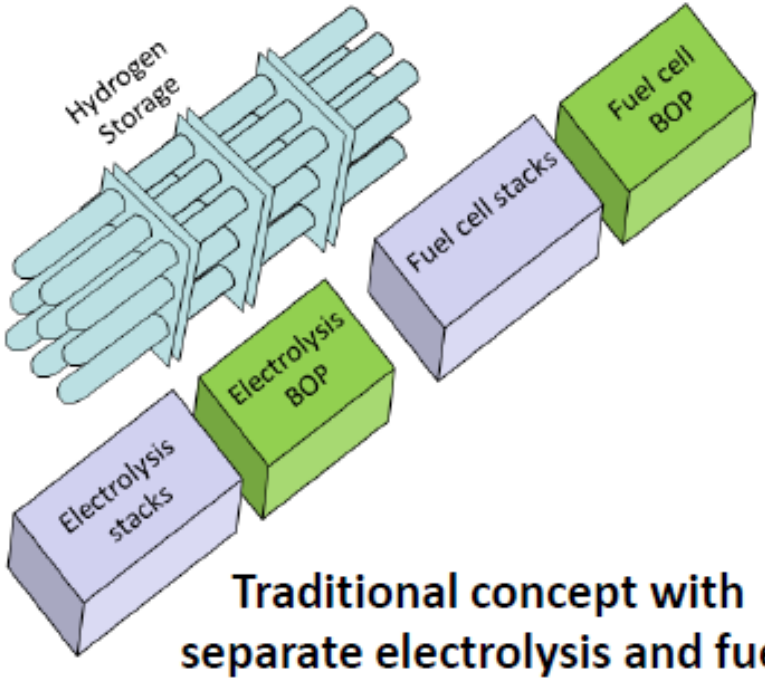
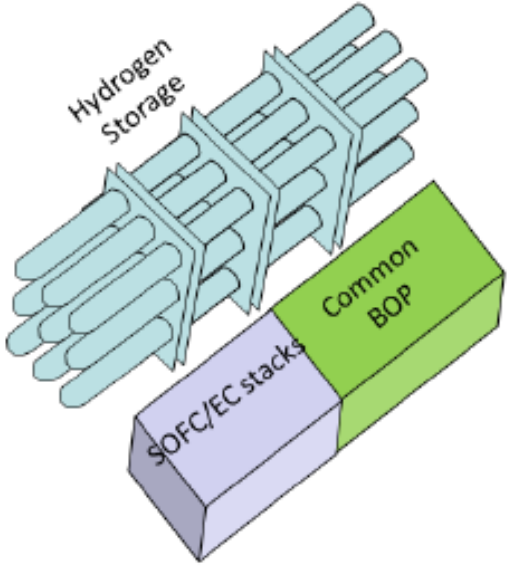


Image Courtesy of FuelCell Energy

Why a reversible solid oxide fuel cell (rSOFC)?



Traditional concept with separate electrolysis and fuel cell systems

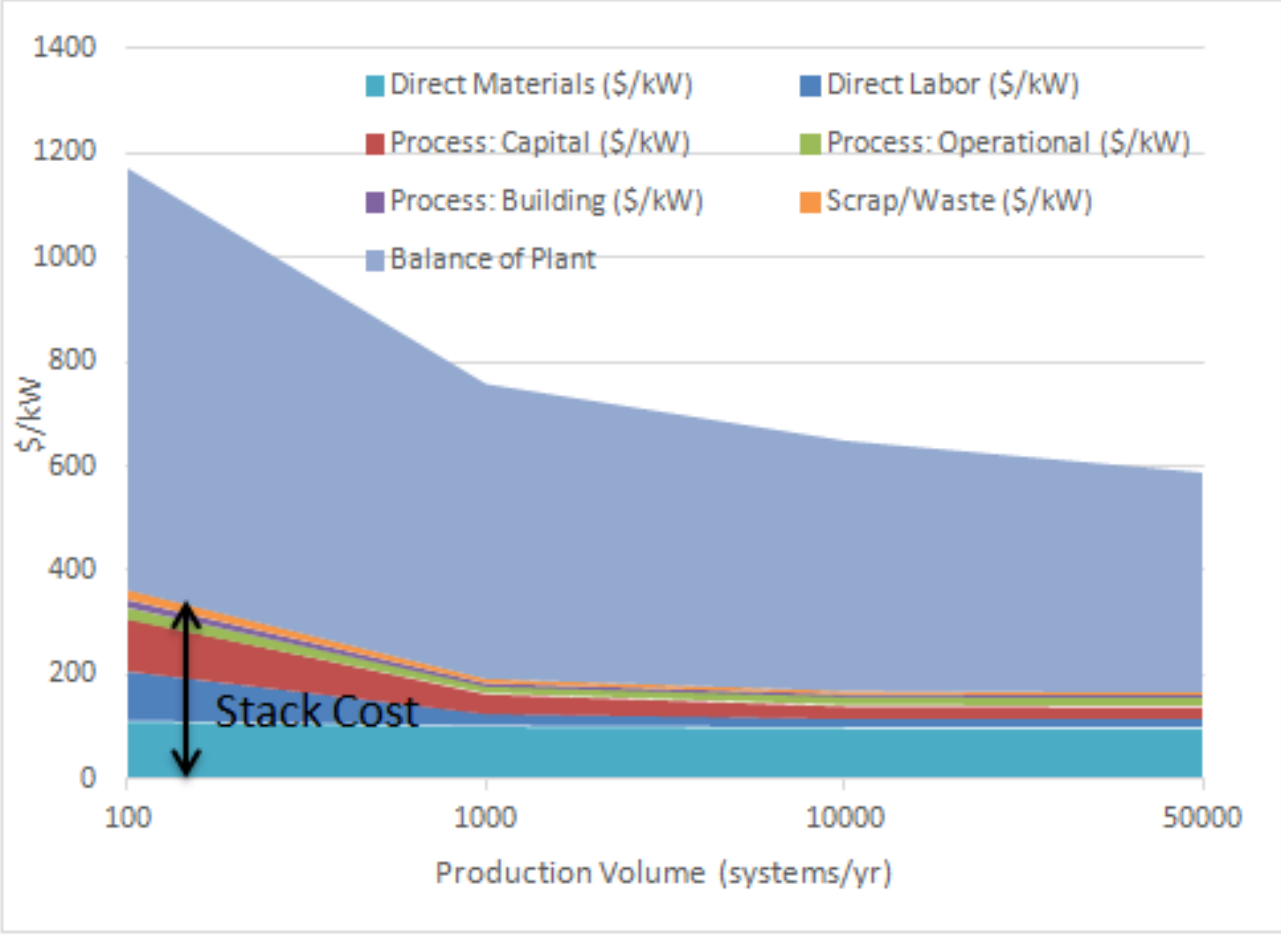


RSOFC Concept

RSOFC enables simplification of stack and BOP components.

Image Courtesy of FuelCell Energy

Electrolyzer Cost at Volume



This graphic is for 250 kW fuel cell systems installed at commercial facilities.

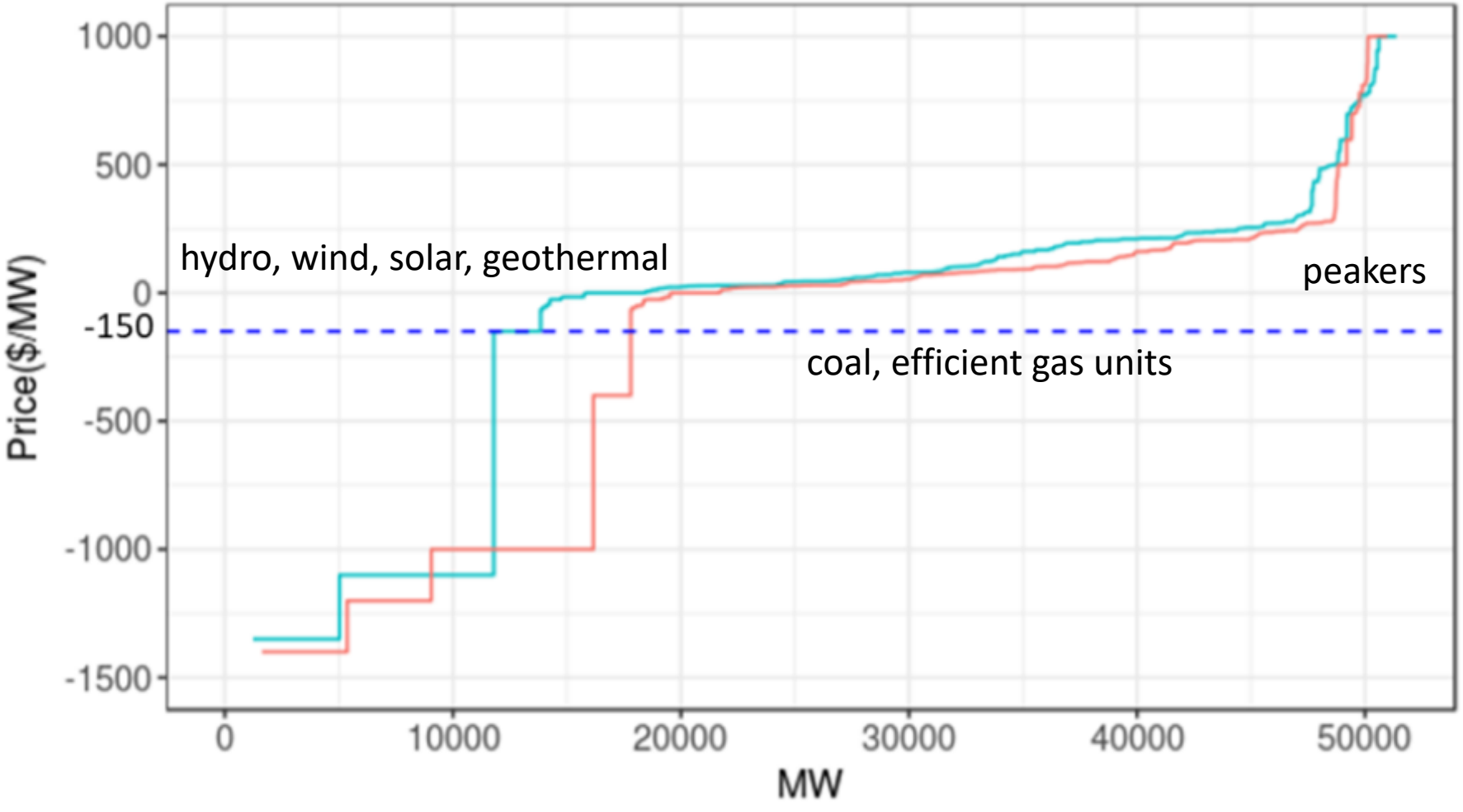
The same device used as an electrolyzer has 4x power density. Divide this fuel cell cost by 4 to get electrolyzer cost.

1000 of these systems/yr is 250 MW/yr of fuel cells or 1,000 MW/yr of electrolyzers.

Utility scale systems will have lower Balance of Plant costs.

https://www.energy.gov/eere/fuelcells/downloads/total-cost-ownership-model-solid-oxide-fuel-cells-combined-heat-and-power

A Few Words About Volatility



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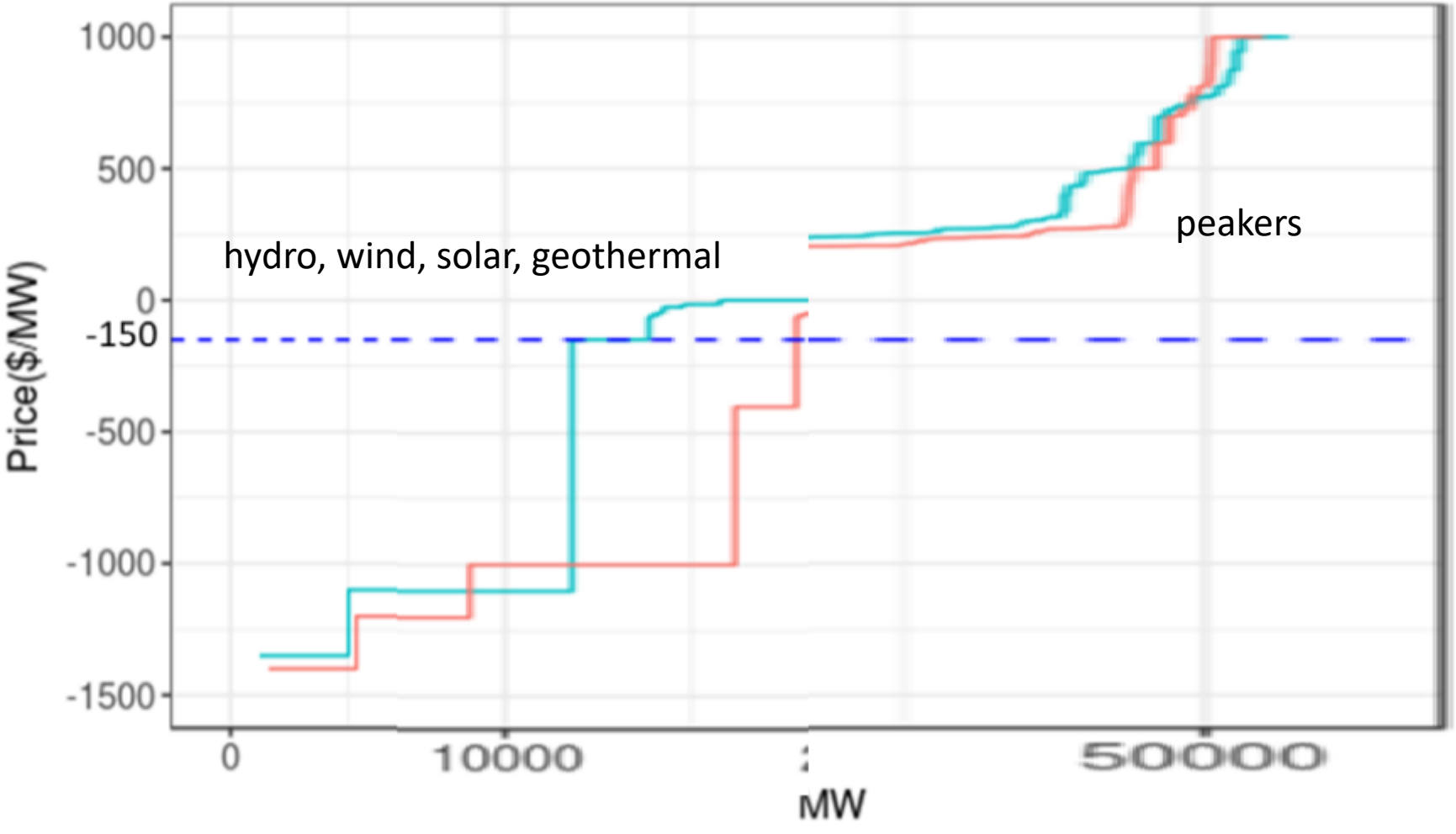
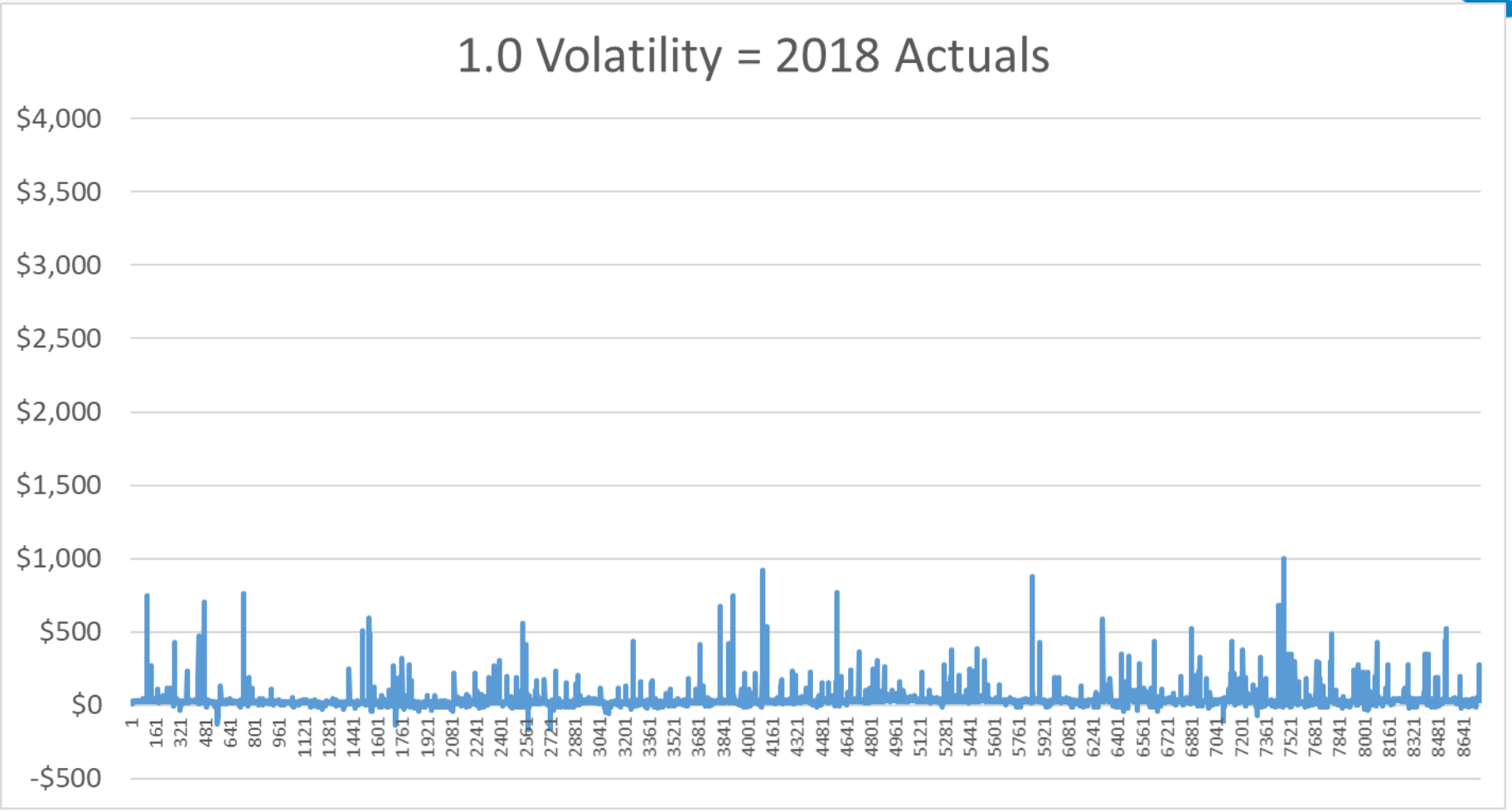
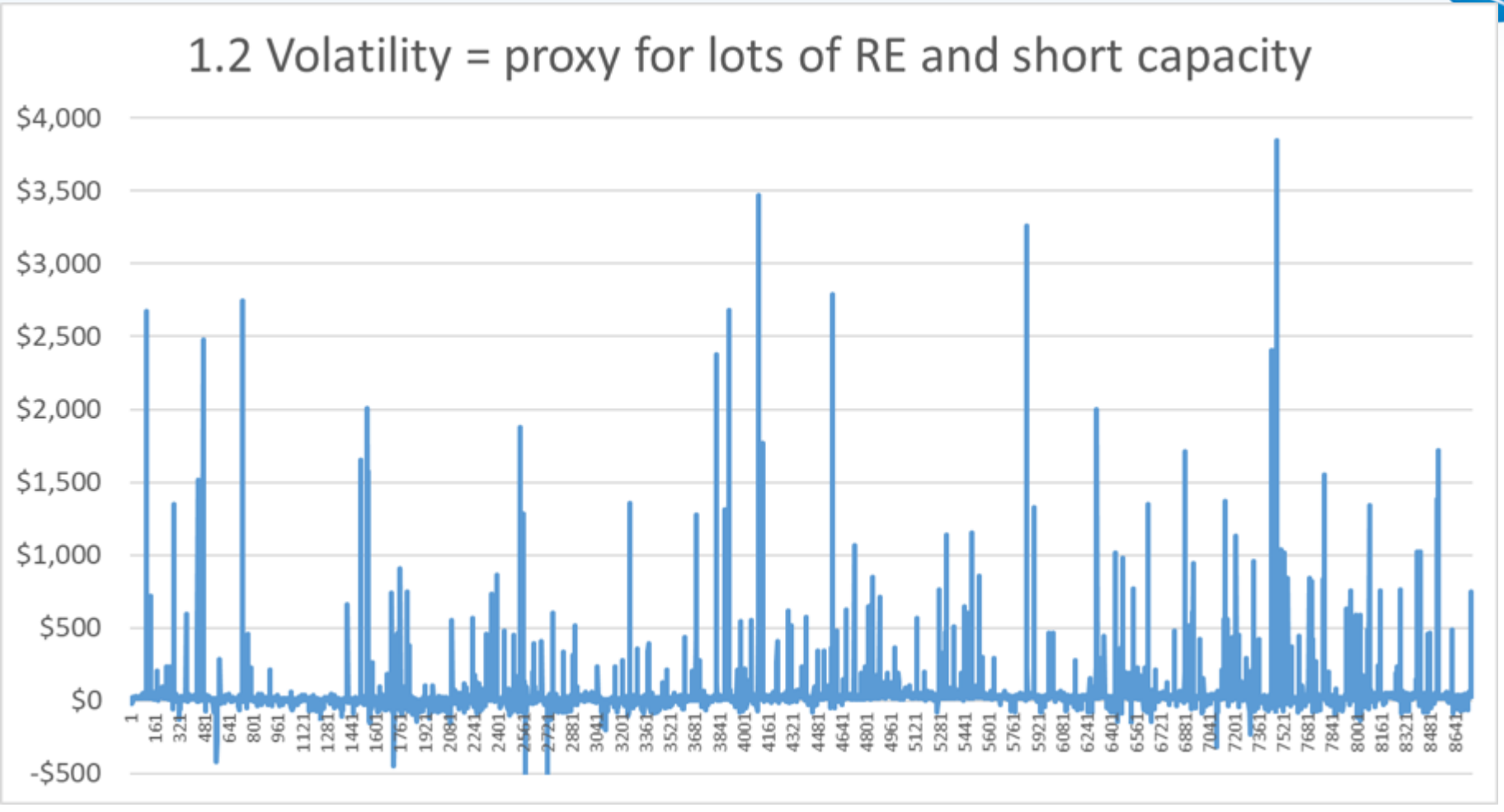


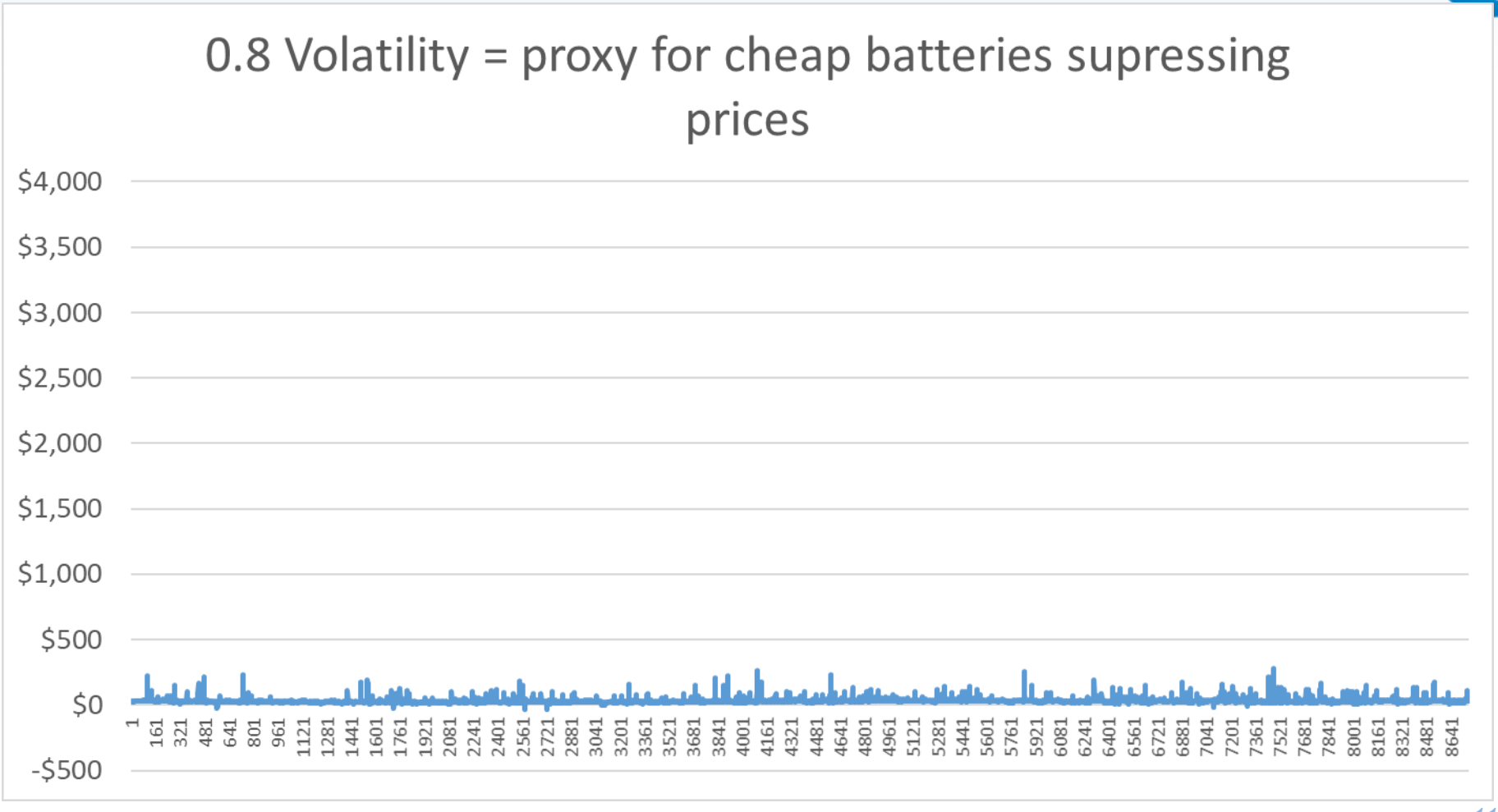
2018 Actual Prices



2018^Volatility = 2030?



2018^-Volatility = Batteries Dominate?



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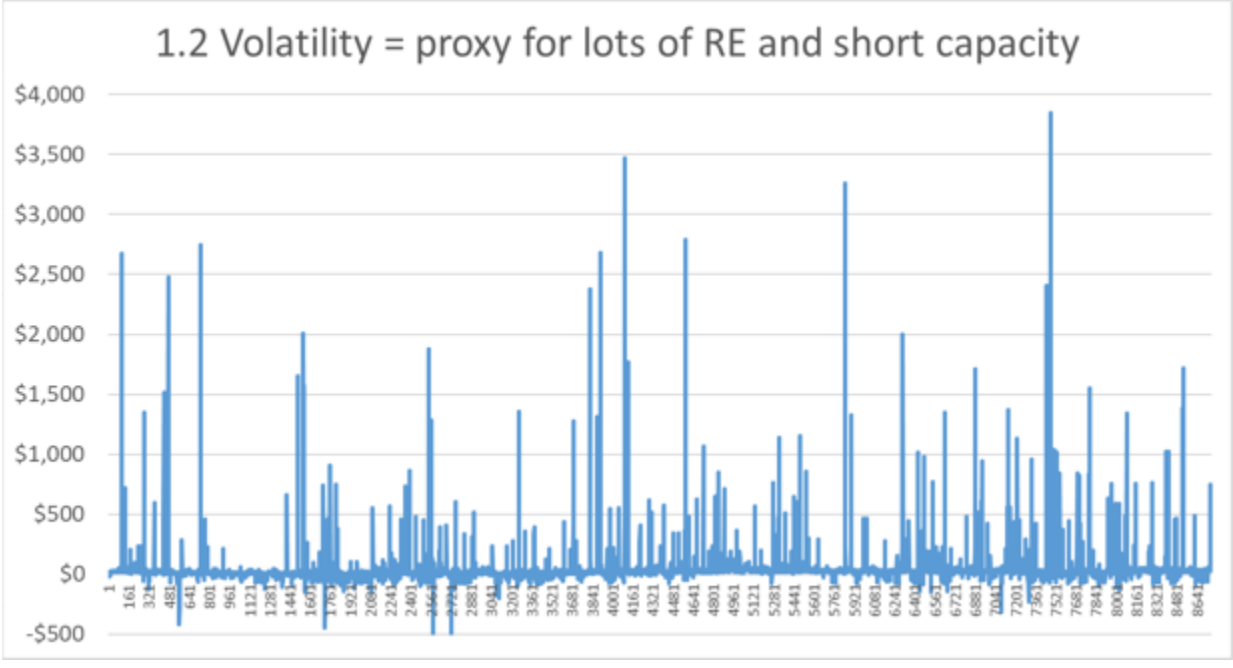
$96/tonne Loaded Cost? Really?

Characteristic	Metric
Electricity	$7.7/MWh (0.77c/kWh)
Capital Cost	$35M
Nameplate	113 tpd, 40 MW
Load Factor	78%, 7%
Energy Eff.	8.5 MWh/tonne
NH3 Revenue	$9.2M/yr
Elec. Revenue	$2.4M/yr



In Summary

- A market integrated ammonia plant economic model is developed
- Market price volatility and technology cost assumptions are tested
- Attractive scenario spaces are identified

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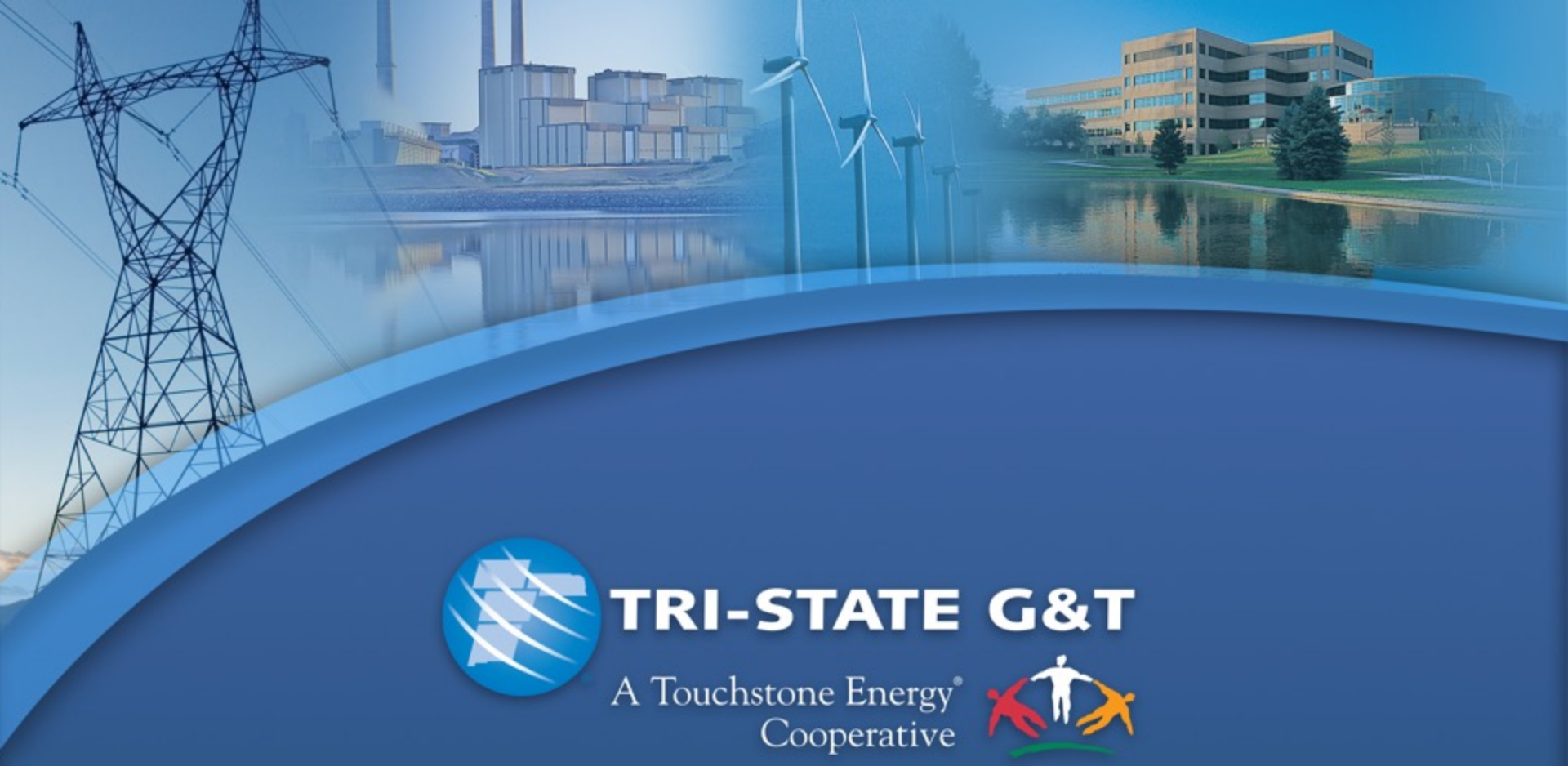

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