Transition to Firm Renewable Power: The Importance of Timing

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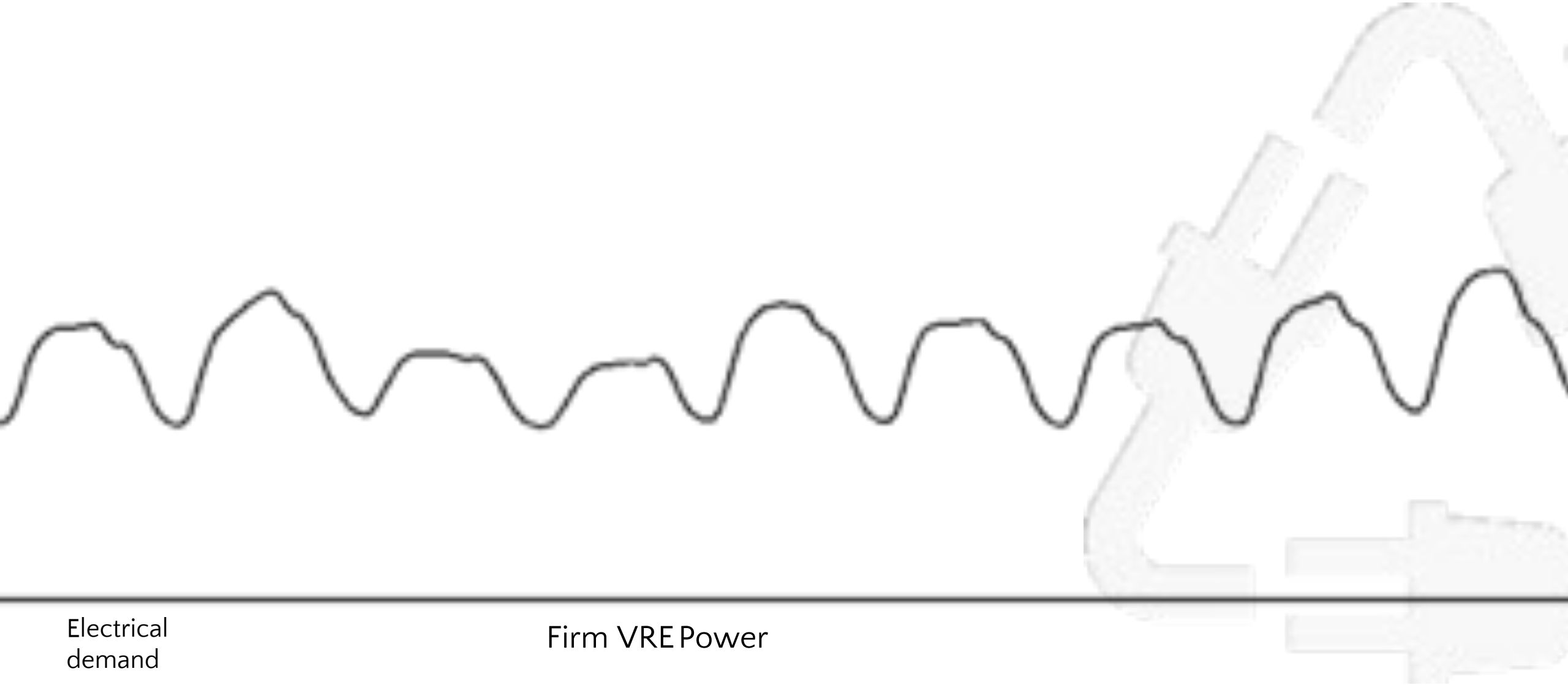
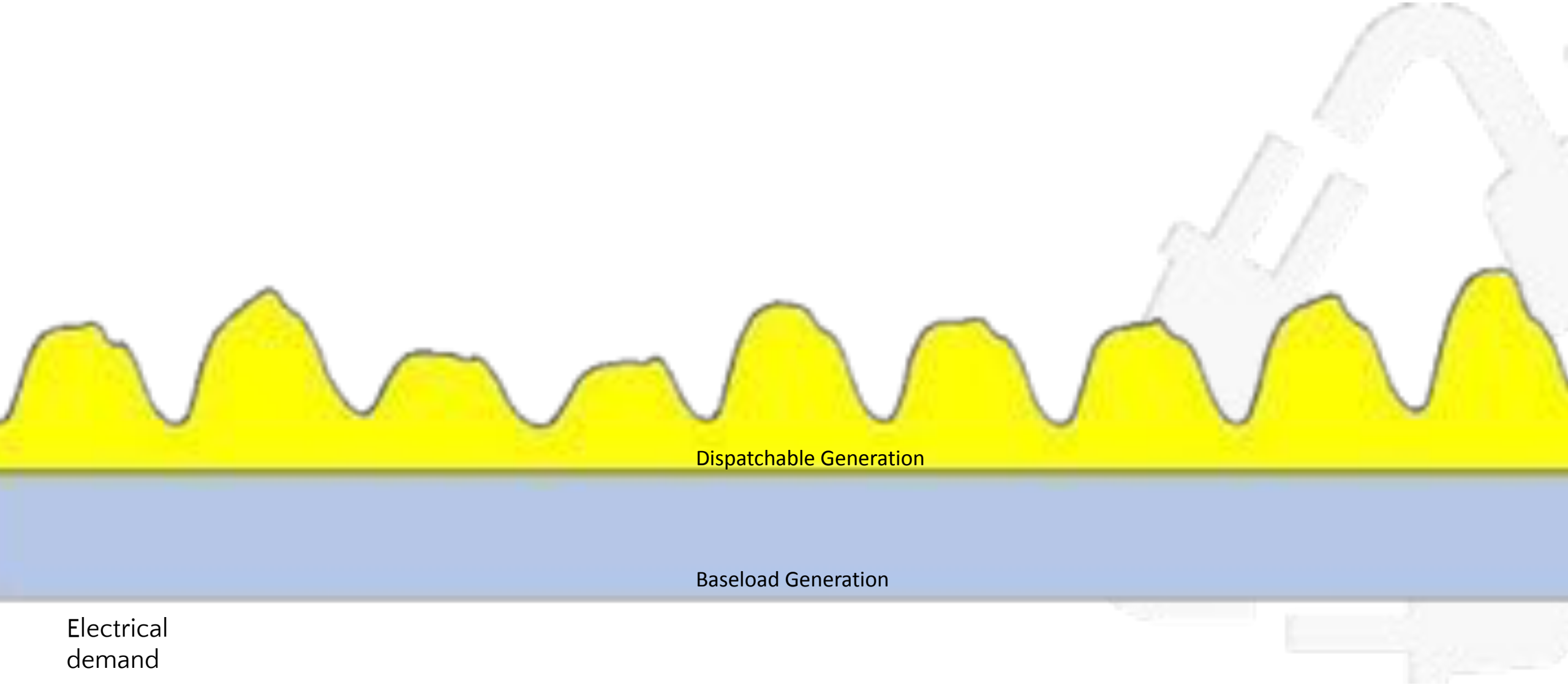
52nd Annual National Solar Conference

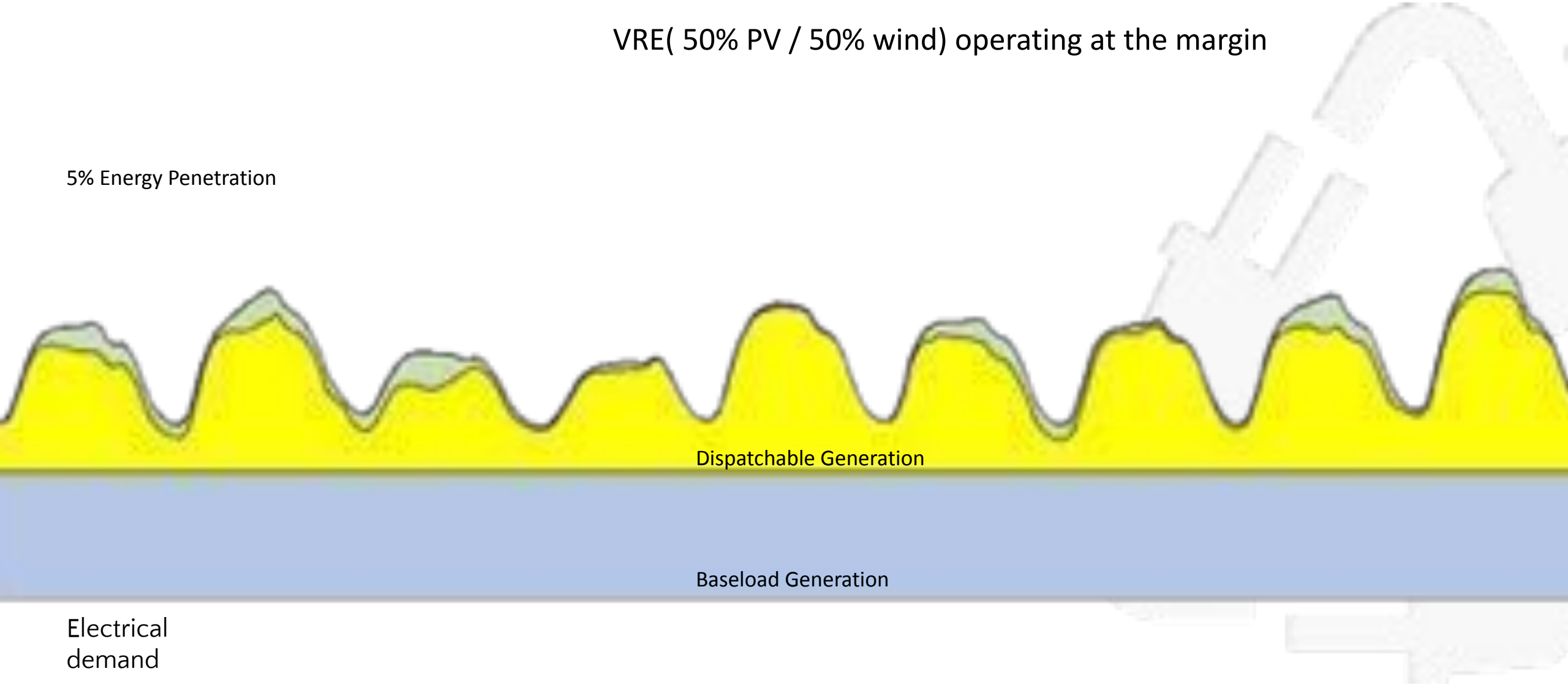
Clean Power Research





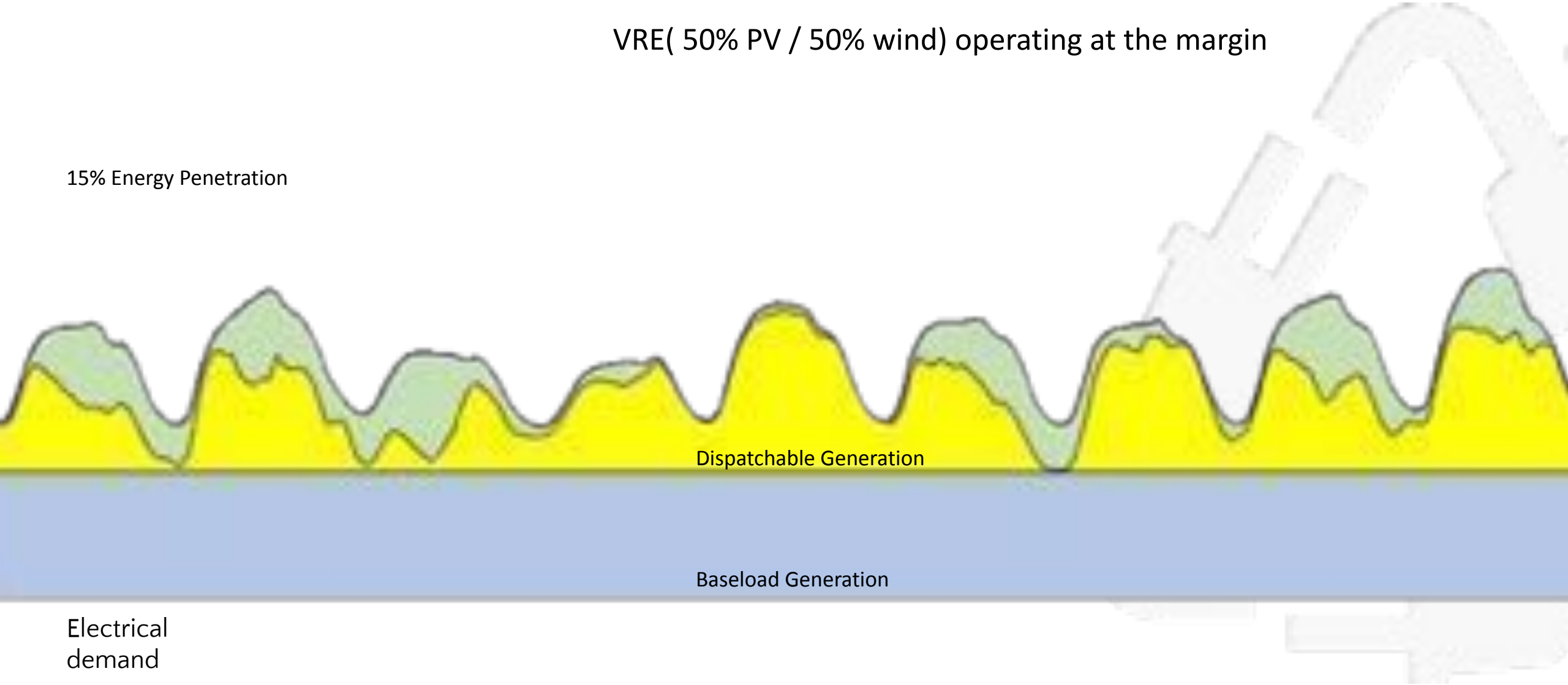
VRE(50% PV / 50% wind) operating at the margin

5% Energy Penetration



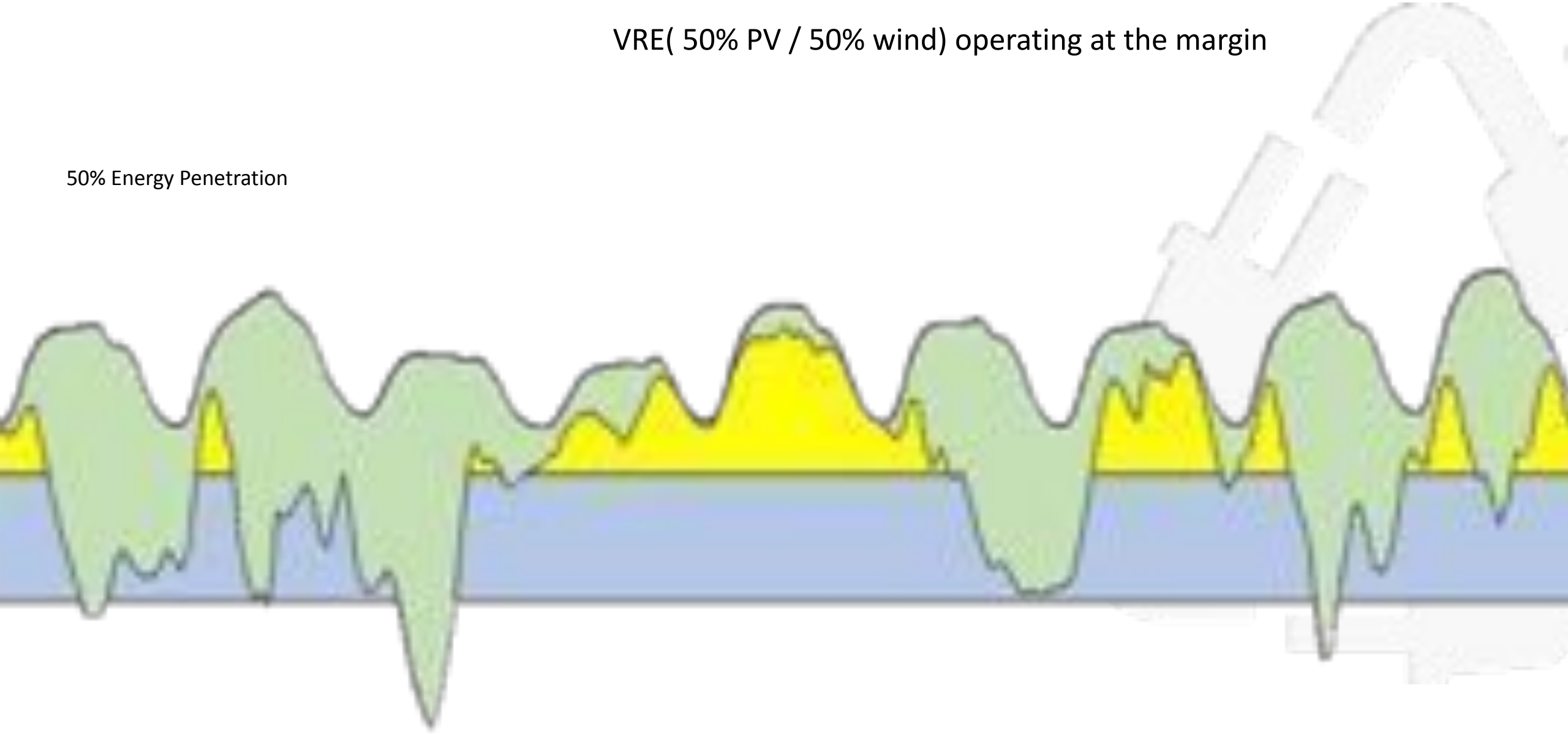
VRE(50% PV / 50% wind) operating at the margin

15% Energy Penetration



VRE(50% PV / 50% wind) operating at the margin

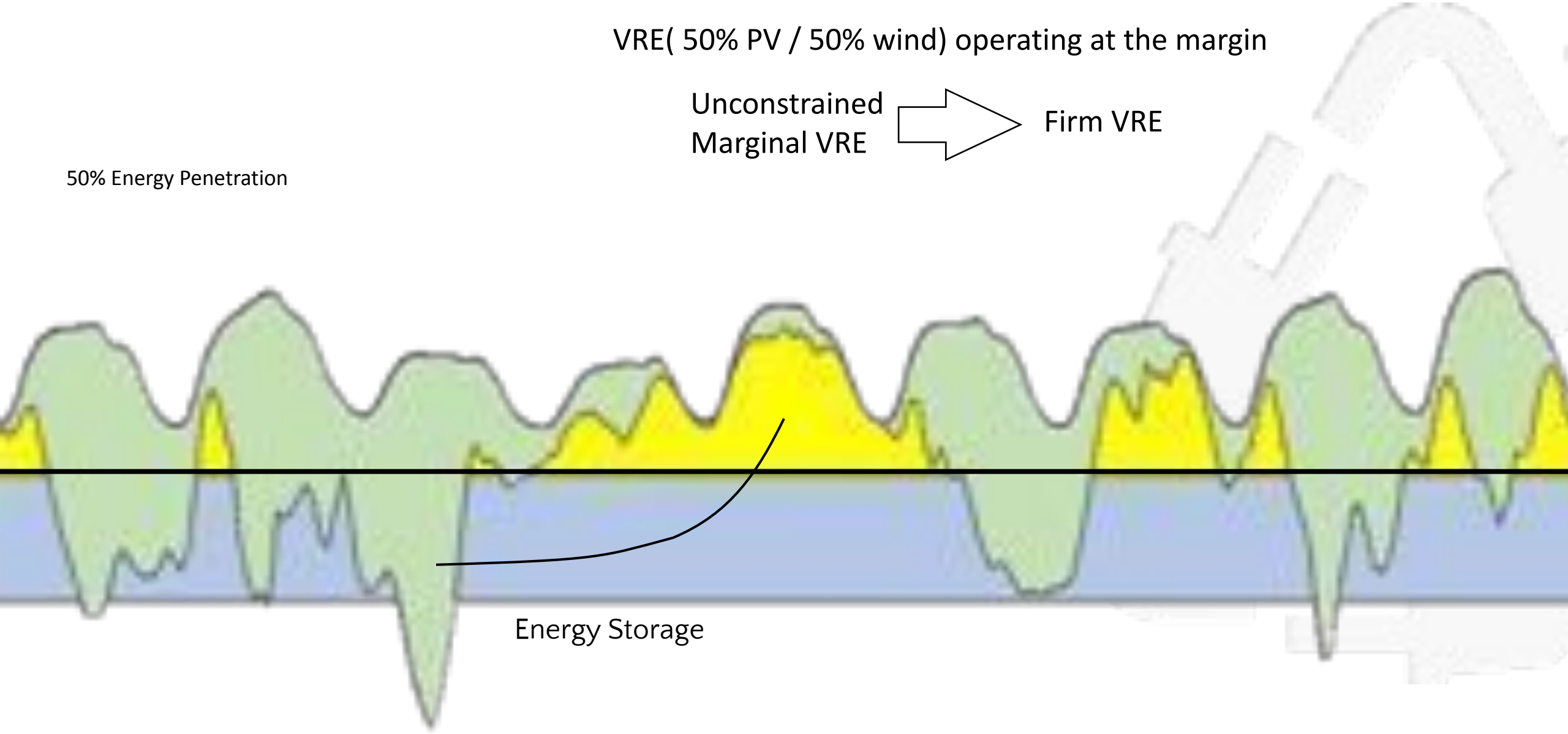
50% Energy Penetration

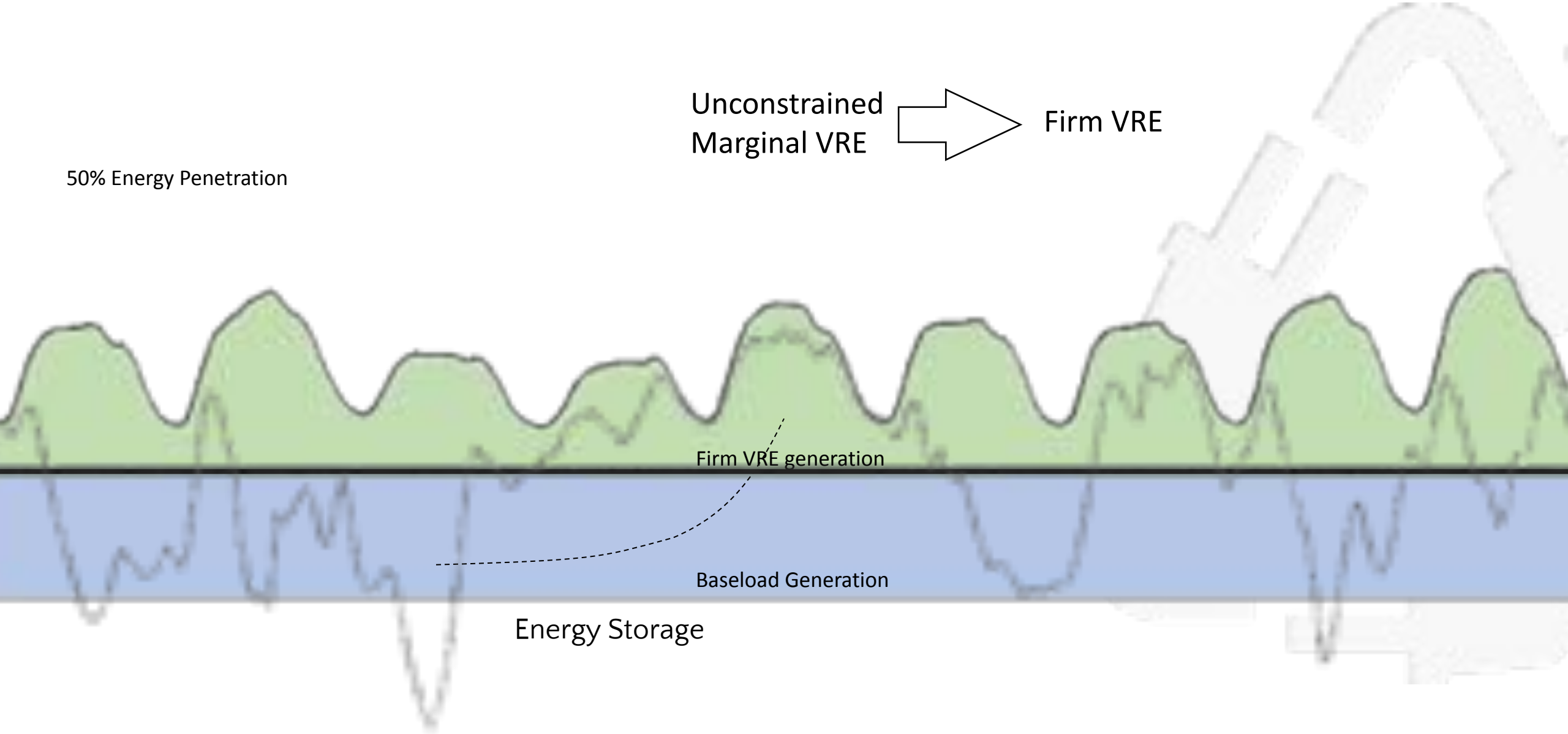


VRE(50% PV / 50% wind) operating at the margin

Unconstrained Marginal VRE → Firm VRE

50% Energy Penetration

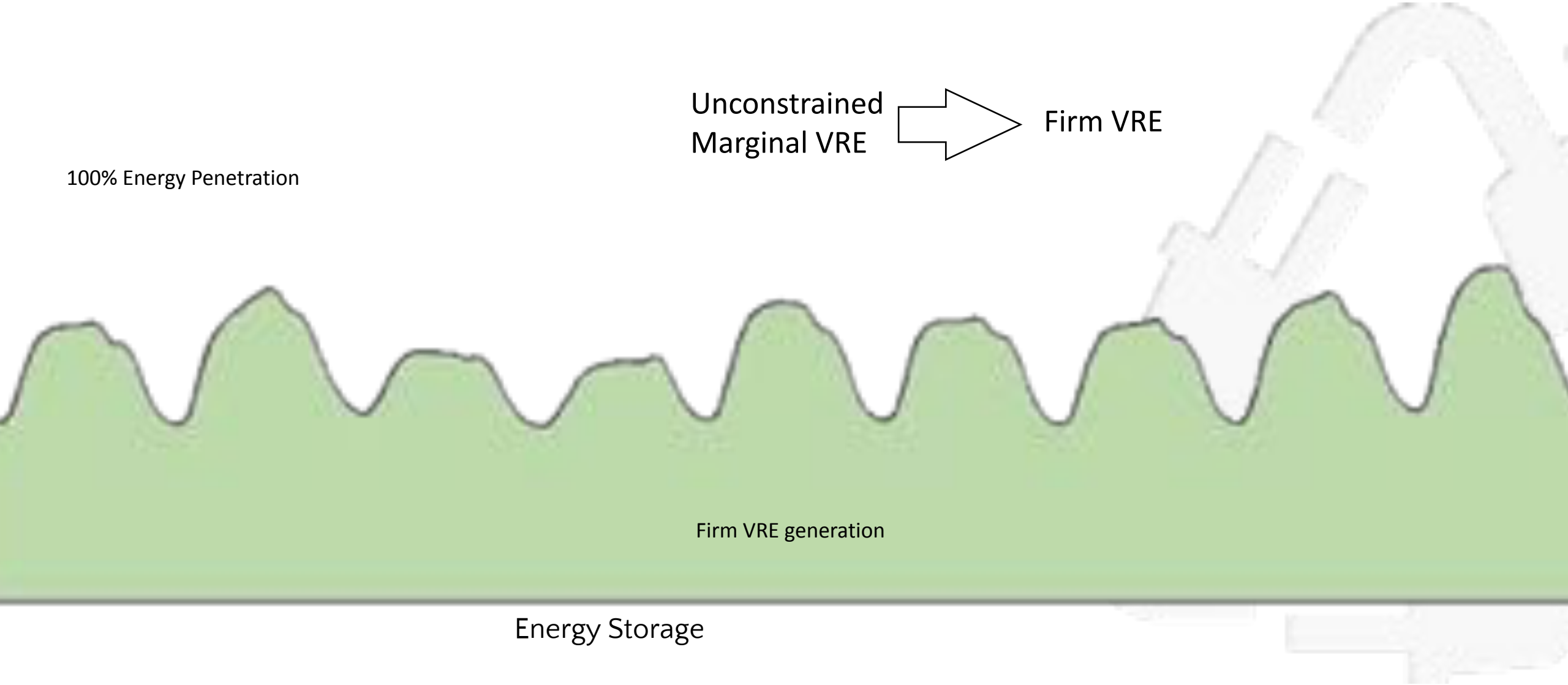


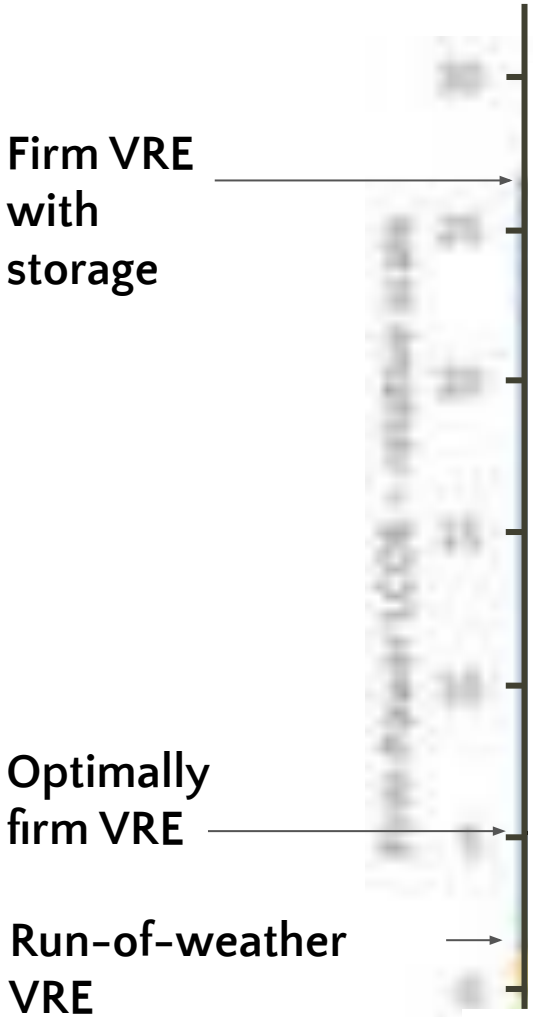


Unconstrained
Marginal VRE

Firm VRE

100% Energy Penetration

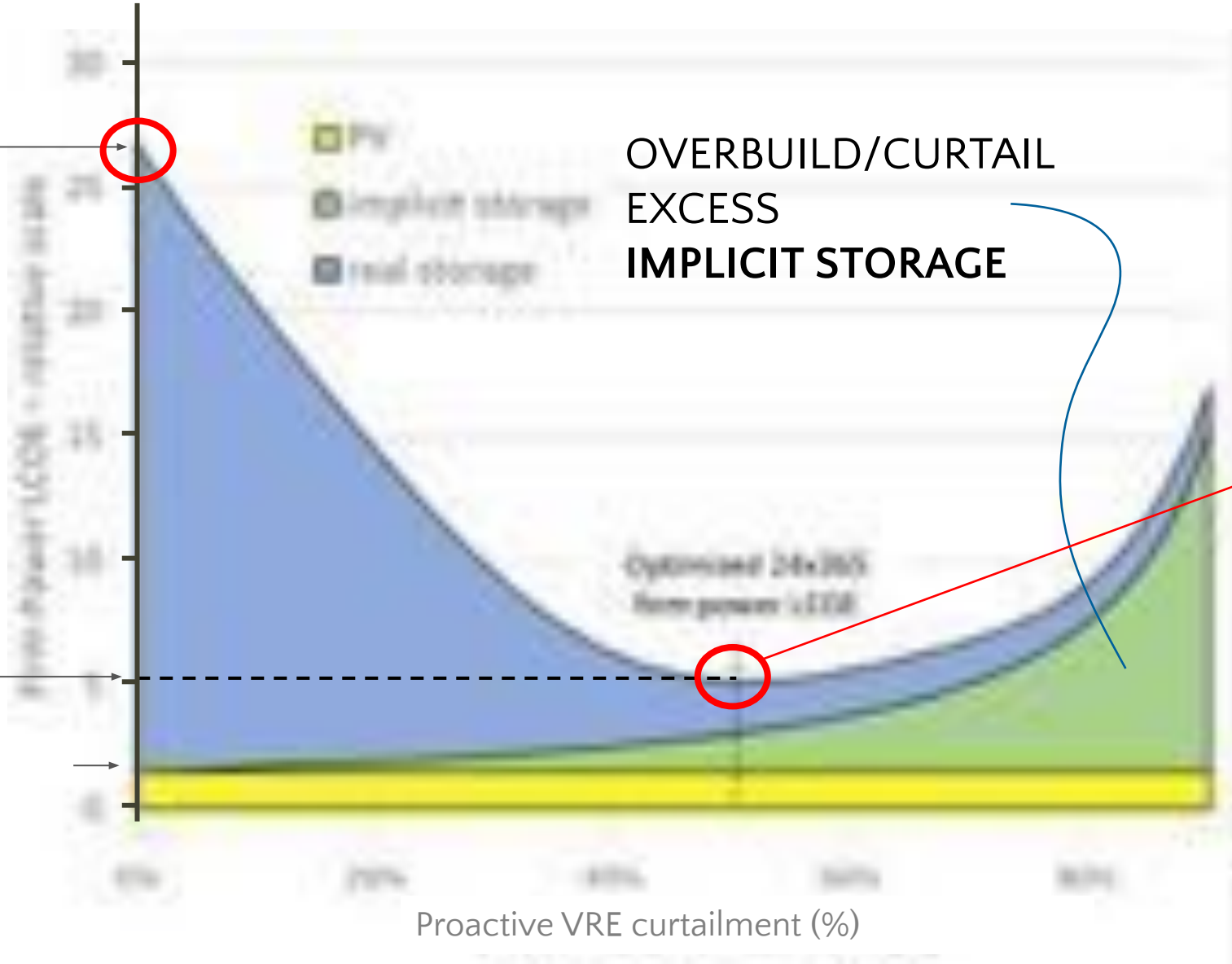




OVERBUILD/CURTAIL
EXCESS
IMPLICIT STORAGE

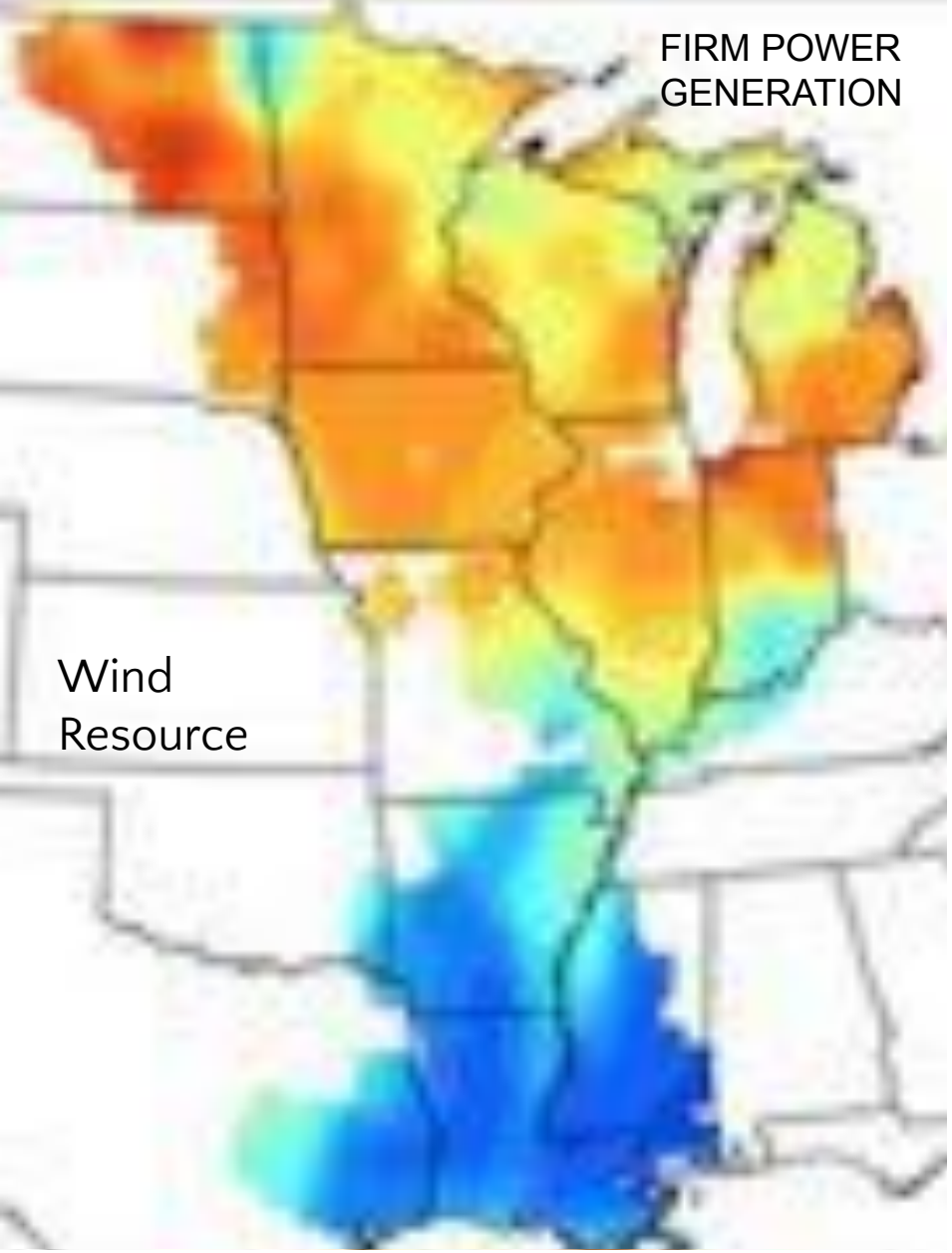
Energy Storage

Firm VRE with storage



Optimally firm VRE

Run-of-weather VRE



MN SOLAR PATHWAYS

US Dept. of Energy

- [nearly] 100% Renewables
- Solar PV + wind
- Impact of (PV/wind/storage) technology costs
  - 2025 low tech development*
  - 2050 high tech development**
- Flexibility: Keep 5% dispatchable gen

MIS
O

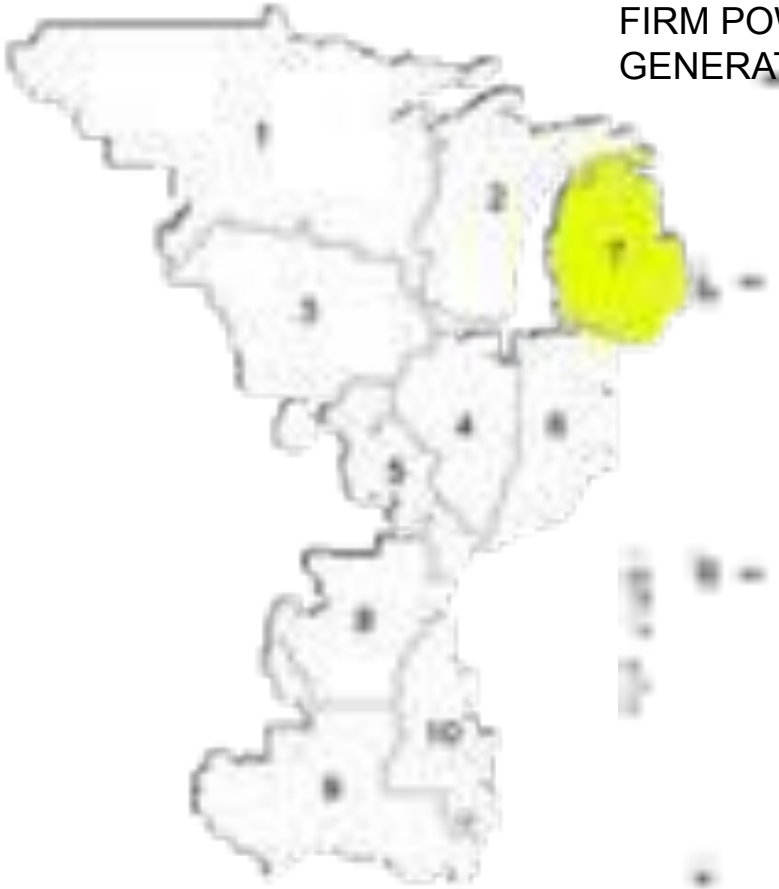
* PV: $1050/kW Wind: $1,500/kW Storage: $175/kWh

** PV: $360/kW Wind: $800/kW Storage: $40/kWh

FIRM POWER
GENERATION

Consider LRZ 7

- 2025 low tech $$
- Just PV
- No overbuild



FIRM POWER GENERATION

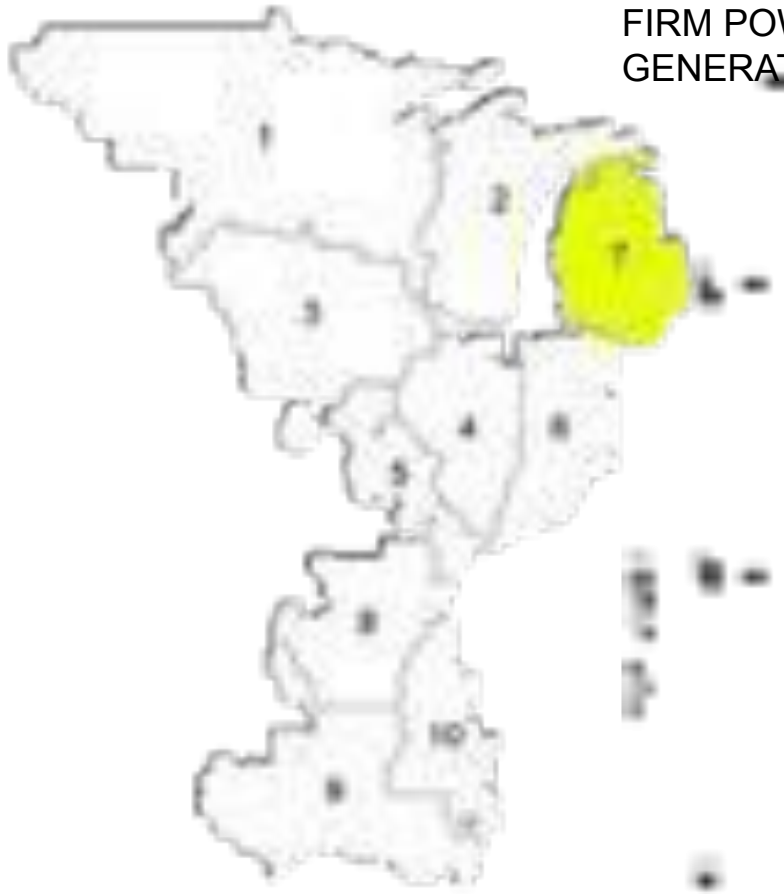
177 c/kWh

This is Exceedingly expensive…

Consider LRZ 7

- 2025 low tech $$
- Just PV
- No overbuild

FIRM POWER GENERATION



Consider LRZ 7

- **2050 lowest $$**
- Just PV
- **Optimal overbuild**

Implicit Storage is very economical

26.9 c/kWh

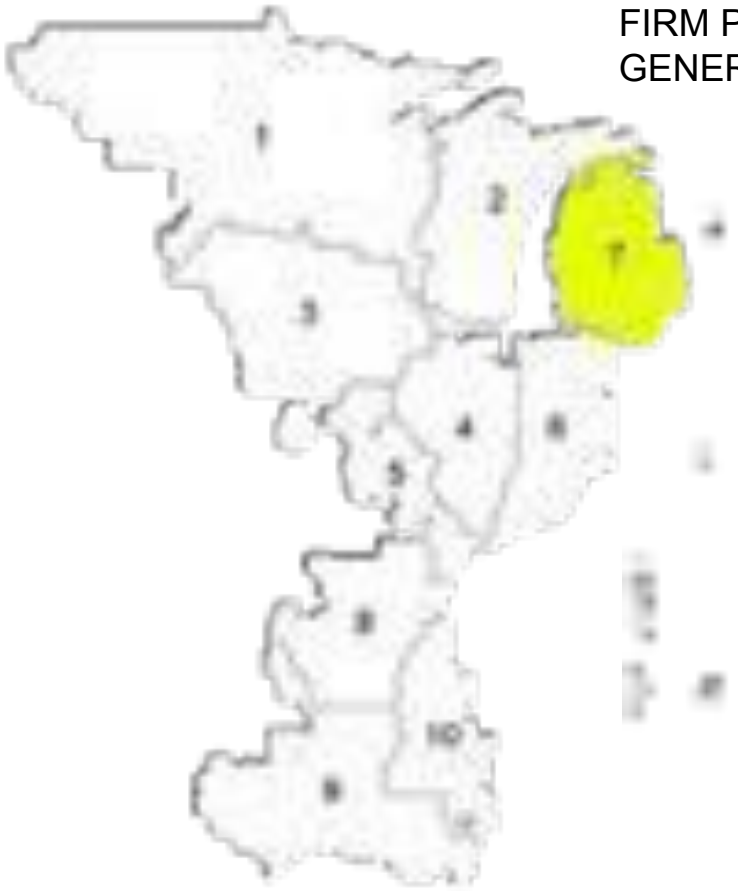
70% reduction in
LCOE in 2050

46.8 c/kWh

7.9 c/kWh

Consider LRZ 7

- **2050 Hi tech $$**
- **JUST WIND**
- **Optimal overbuild**



FIRM POWER GENERATION

44 c/kWh

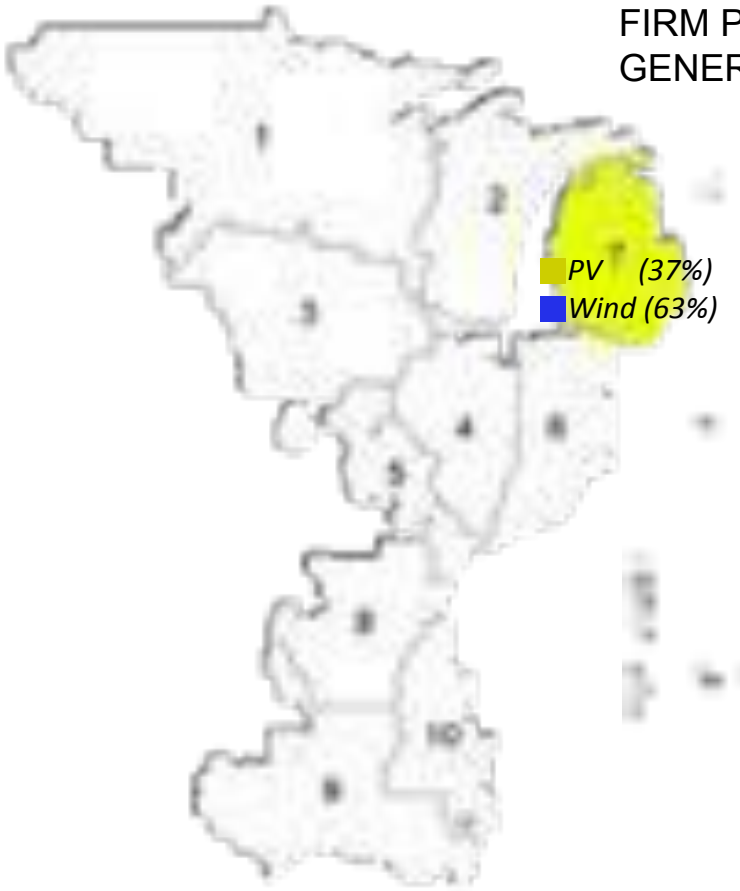
6.2 c/kWh

Implicit Storage saves 86% in LCOE

Comparable to optimal PV LCOE

Consider LRZ 7

- **2050 Hi tech $$**
- **Just WIND/PV**
- **Optimal overbuild**



FIRM POWER GENERATION

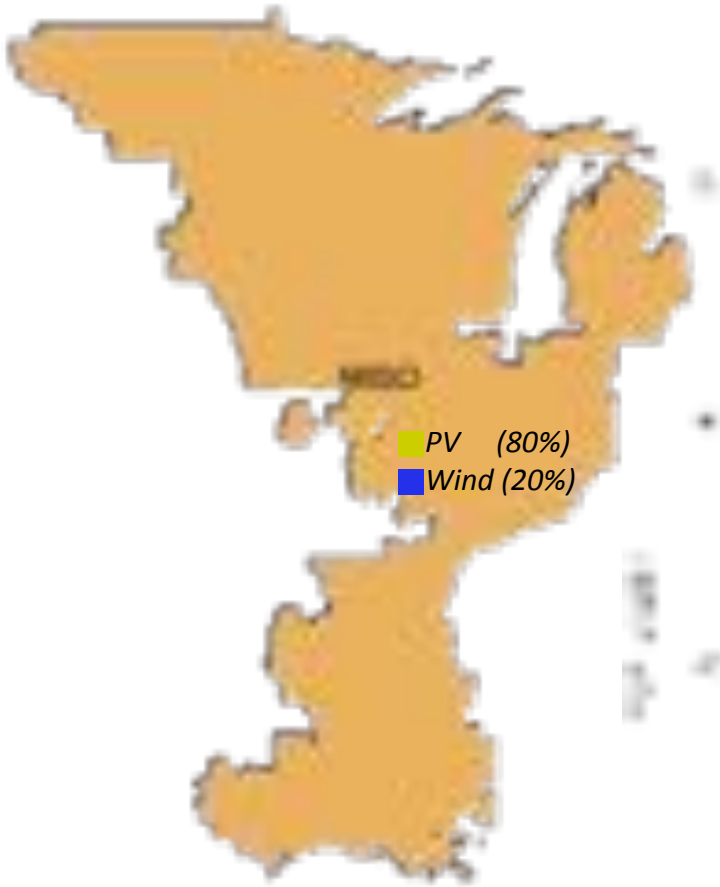
21 c/kWh

Optimal Wind/PV blend saves $

4.7 c/kWh

Consider MISO

- 2050 Hi tech $$
- Opt. WIND/PV
- Optimal overbuild



24/365 Power

21 c/kWh

MISO region marginally cheaper than LRZ 7 Region

More PV in optimum wind/solar blend

4.2 c/kWh

Consider MISO

- **2050 Hi tech $$**
- **Opt. WIND/PV**
- **Optimal overbuild**
- **5% Nat. Gas Flexibility**

FIRM POWER GENERATION

17 c/kWh

3.5 c/kWh

95% Renewables

17% cheaper than 100% across MISO

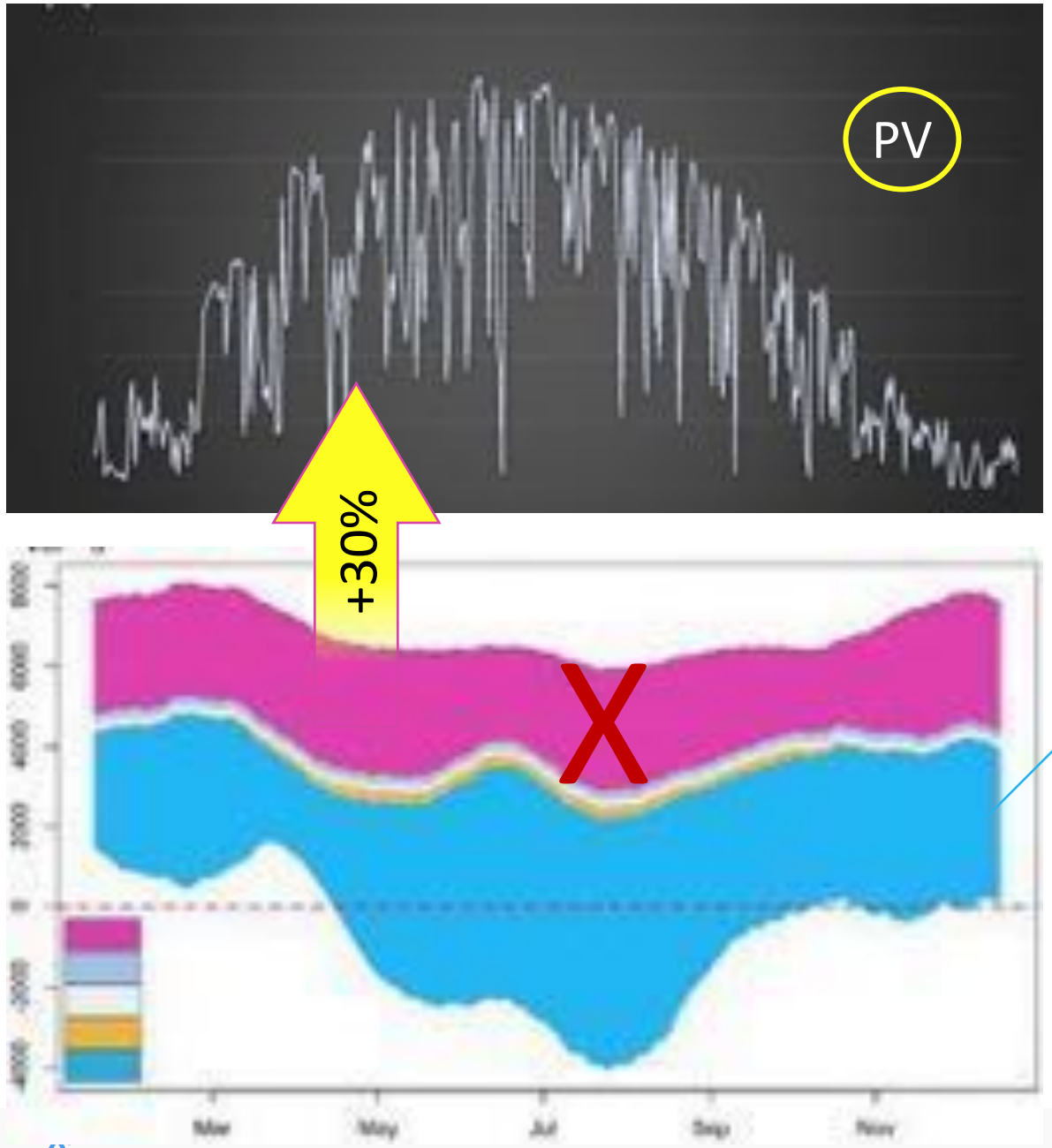
Significantly less optimal curtailment (only 17% vs 36%)

Consider MISO

- **2050 Hi tech $$**
- **Opt. WIND/PV**
- **Optimal overbuild**
- **5% Nat. Gas Flexibility**

Firm PV Power in Switzerland (FIPPS)
Swiss Federal Office of Energy

- [nearly] 100% Renewables
- Solar PV + hydro
- Impact of (PV/storage) technology costs
- Flexibility from dispatchable gen



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Swiss Federal Office of Energy

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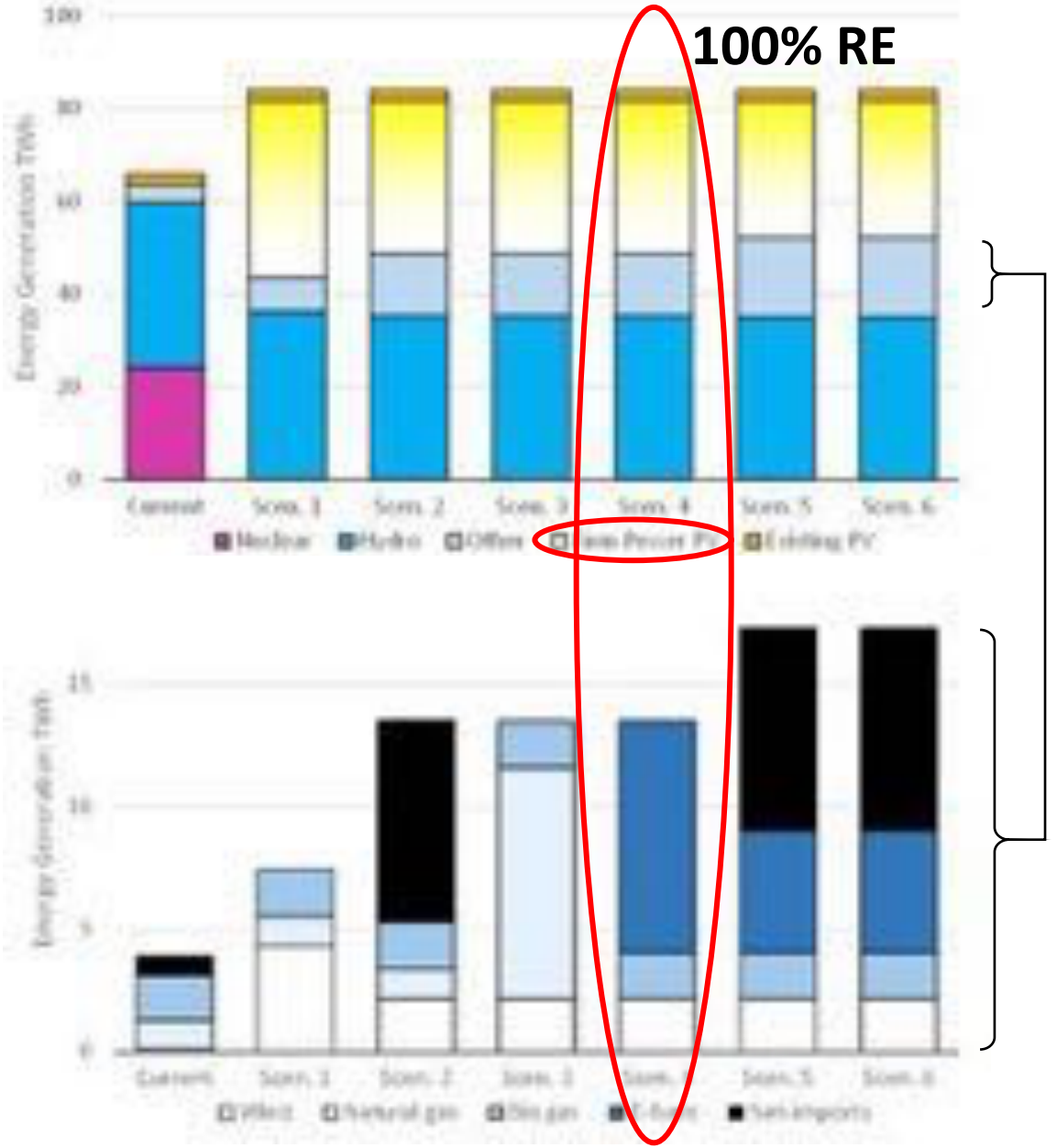
18 TWh Run of river hydro
50 GWh Two-way Pumped Hydro
10 TWh One-way Long-term Buffer Storage

OBJECTIVE 2050
30% LOAD GROWTH
100% NUCLEAR PHASE OUT
VERY LIMITED WIND POWER DEVELOPMENT
LIMITED HYDRO GROWTH POTENTIAL



Firm PV Power in Switzerland (FIPPS)
Swiss Federal Office of Energy

6 SCENARIOS

e-fuel @ 20cts/kWh bio gas @ 11 cts, wind @ 12 cts

2 PV/STORAGE COST ASSUMPTIONS

- Small scale systems
  - PV @ CHF 860/kW, storage @ CHF 330/kWh
- Utility-scale systems
  - PV @ CHF 310/kW, storage @ CHF 45/kWh

2 INTERCONNECTION CONFIGURATIONS

- Interconnected Grid with net-0 import/exports
- Autonomous Grid

OBJECTIVE 2050

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VERY LIMITED WIND POWER DEVELOPMENT

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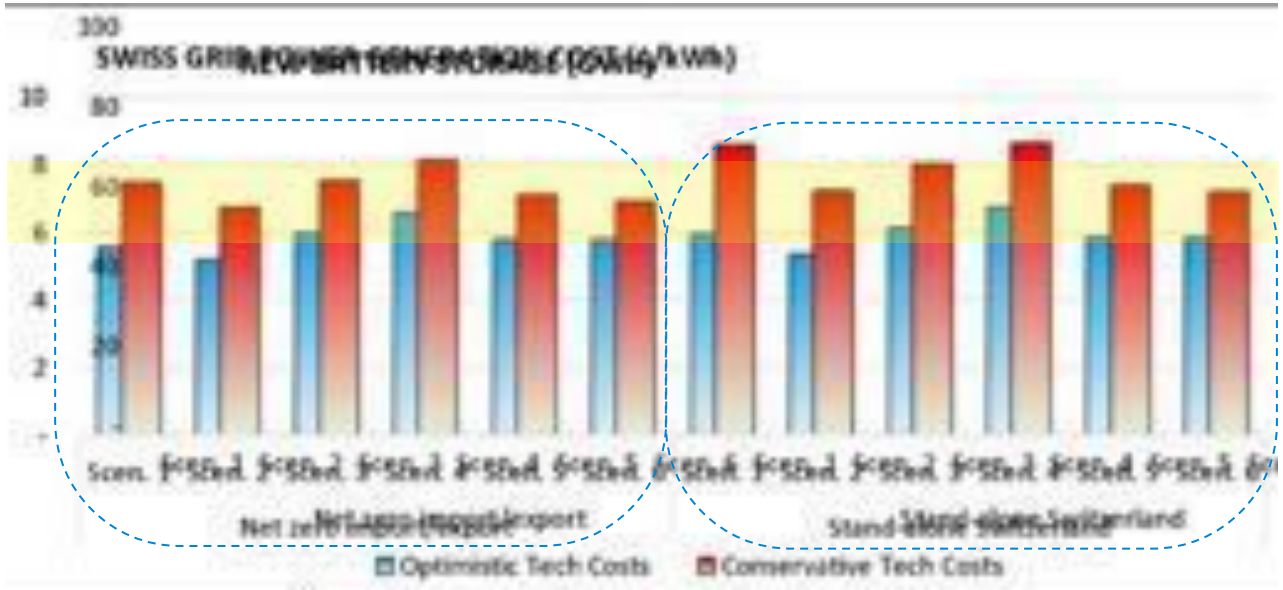

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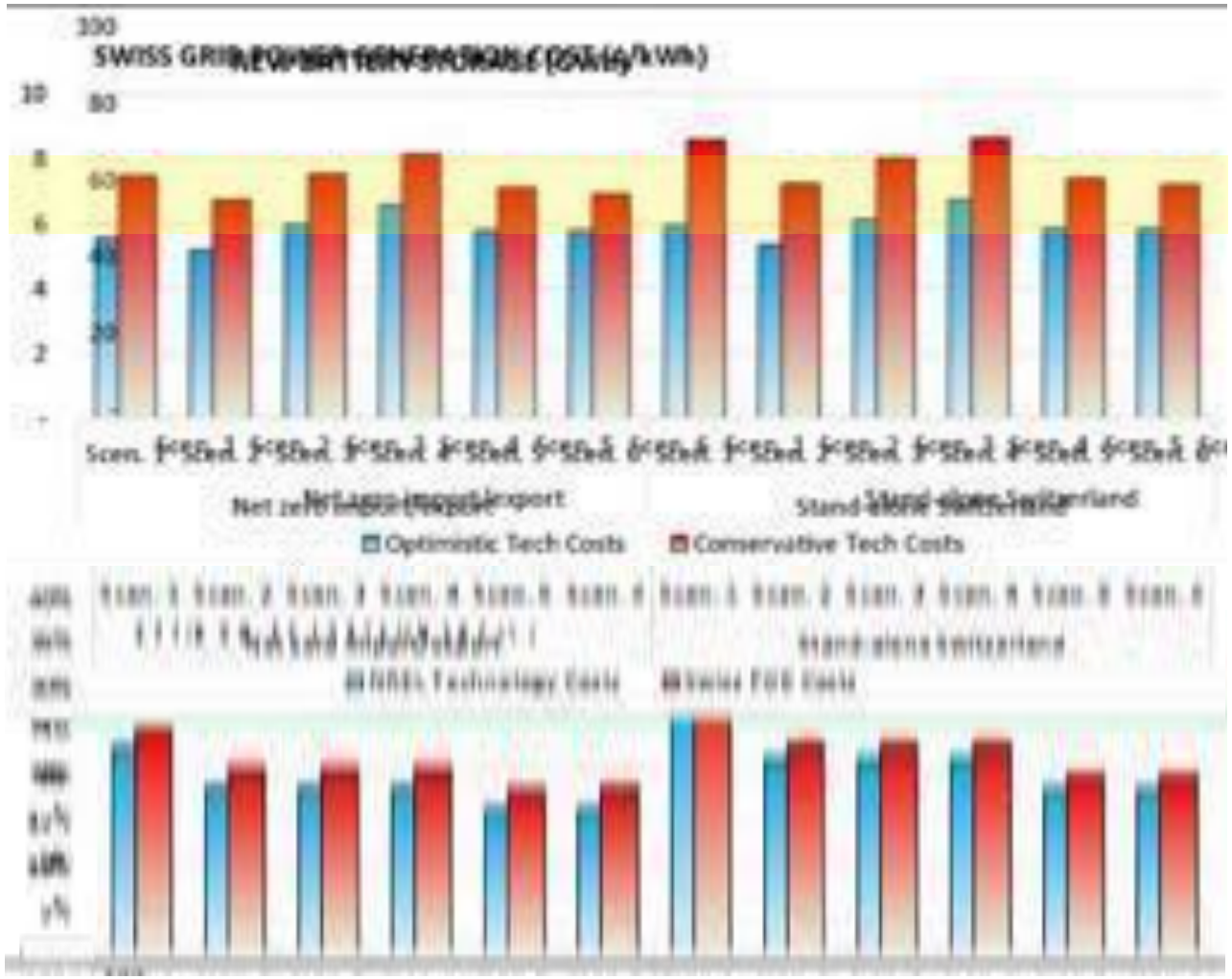

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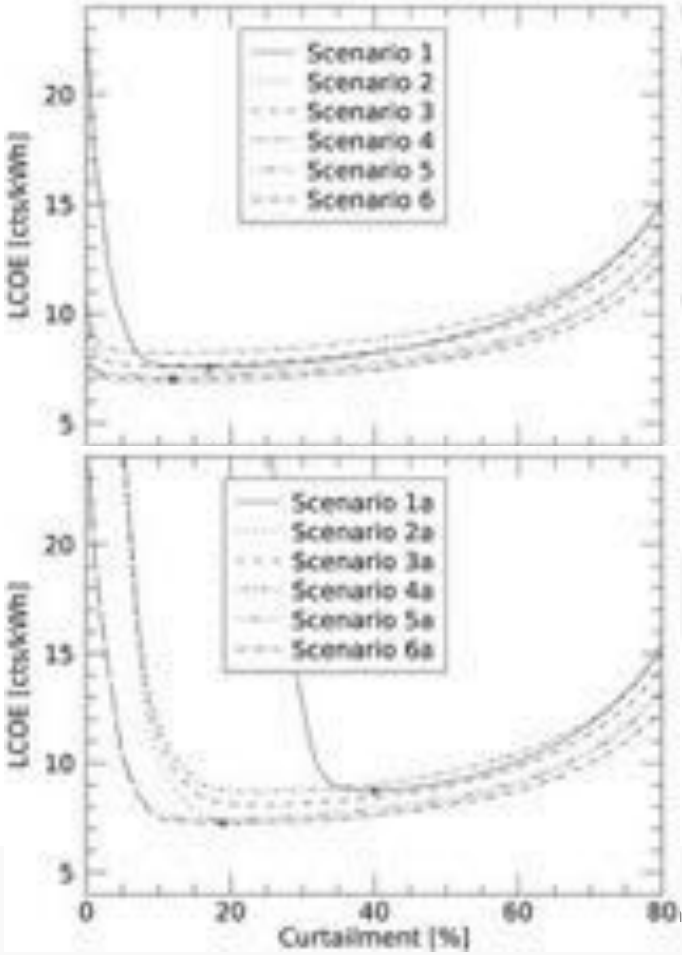
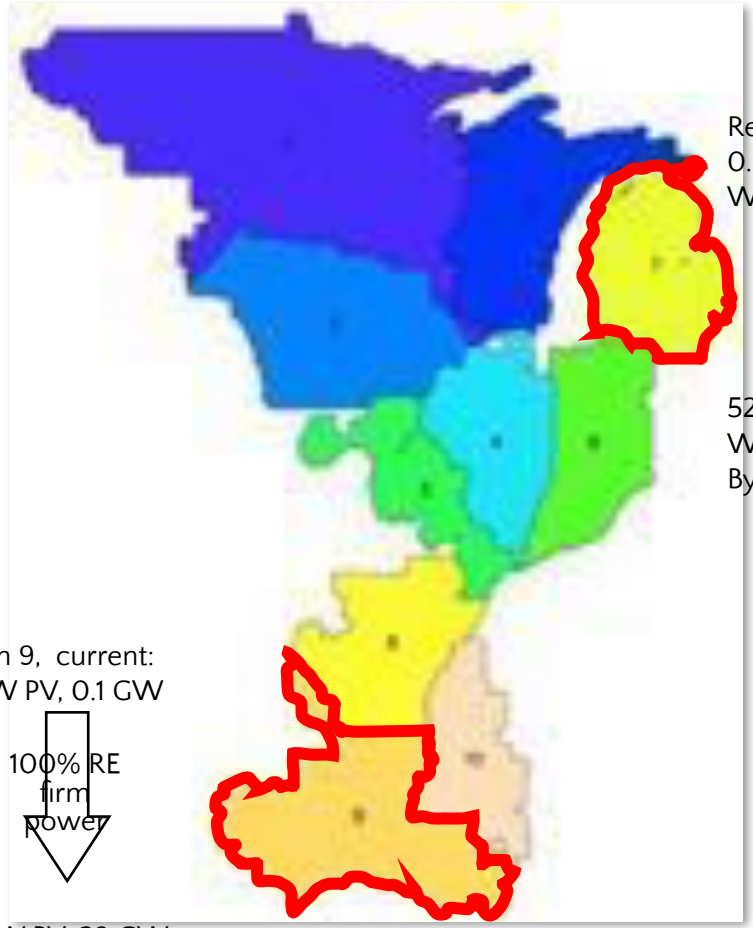
2022 SWISS TSO WHOLESALE AVERAGE DAY AHEAD/SPOT PRICE:
<u>23 Cts / kWh</u>



Grid-connected Switzerland

Stand alone S Switzerland



Region 7, current:
0.5 GW PV, 3.5 GW Wind

100% RE firm power

52 GW PV, 37 GW Wind
By 2040

Region 9, current:
0.1 GW PV, 0.1 GW Wind

100% RE firm power

107 GW PV, 29 GW Wind
By 2040

MISO (US) Regions 7 and 9

Timing is critical

Switzerland current:
2.4 GW PV

100% RE firm power

44 GW PV
By 2040

SWITZERLAND
PV (40%), hydro and RE thermal

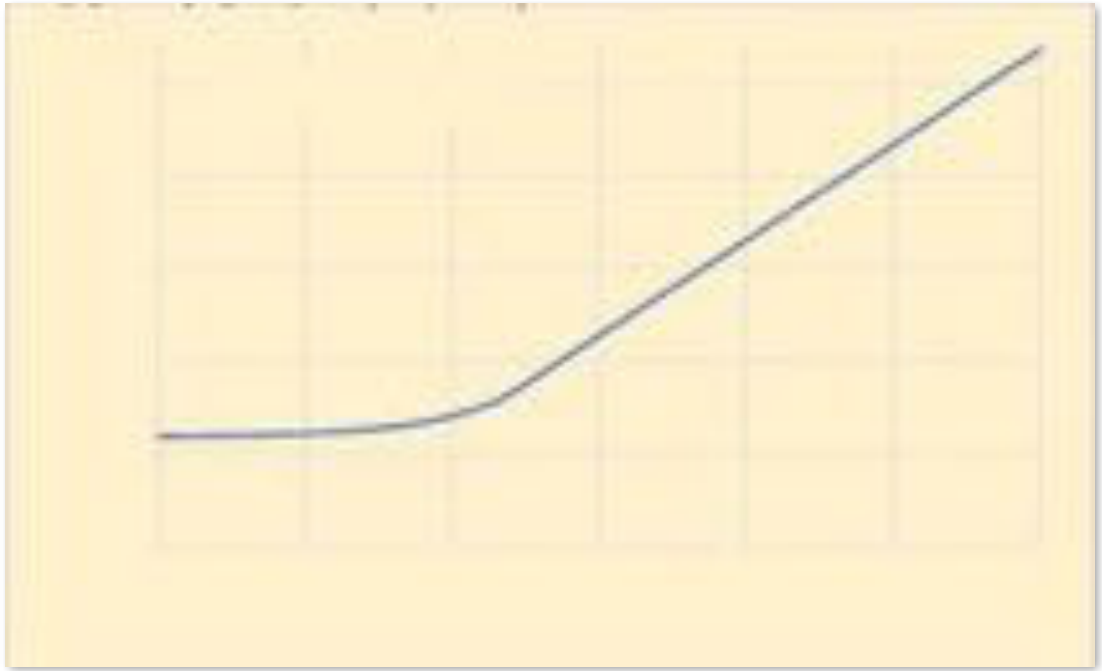
Pure PV & Wind

Assume transition to 100% VRE by 2040

Growth model: exponential to 2030, linear thereafter

Assume 2040 utility scale levelized costs (i.e., decreasing subsidies (business plan model) between now and then)

Timing is critical



TAKEWAYS

- Two projects with very different resources and environments indicate that 100% RE grids are not only possible, but would also be economically reasonable.
- Implicit storage is central to achieving economically acceptable 24x365 solutions
- Long duration storage and large-scale interconnection are not indispensable.
- These optimum 100% RE configurations should be enabled with appropriate market rules (currently they are not).
- The sooner effective RE configurations are deployed the better, because achieving firm power generation will become harder and harder if unconstrained systems continue to grow. Up to 5x reduction in cost if we act now

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