Storage Technologies for Renewable Energy

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AzRISE – The Arizona Research Institute for Solar Energy
University of Arizona
http://www.azrise.org

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Arizona Research Institute for Solar Energy

AzRISE - The Arizona Research Institute for Solar Energy
formed at the University of Arizona in September 2007
Funded by ABOR, University of Phoenix, TEP, APS, DOE and SFAz

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- New PV materials
  - Nanostructures for high efficiency and large area multijunction solar cells
  - Polymer and hybrid materials for low cost solar cells
  - Porous Si solar cells and temperature-tolerant solar cells
- **Storage**
  - **Short term and low cost (Batteries and supercapacitors)**
  - **Long term with high efficiency (CAES and pumped hydroelectric)**
  - **Integrated generation and storage systems**
- Smart Grid and Control Systems, Solar Desalination, Measurements, Testing
  - Smart Home systems in Solar Decathlon House
  - Solar irradiance, effects of clouds and temperature, TEP Test Yard Data
- Economics and Policy analyses
  - Economic assessments of integrated storage systems
  - Policy analysis of incentives, tariffs, regulations and renewable energy standards
  - Economic and policy drivers and comparative technical and economic assessments
- Education and Workforce Training and Outreach

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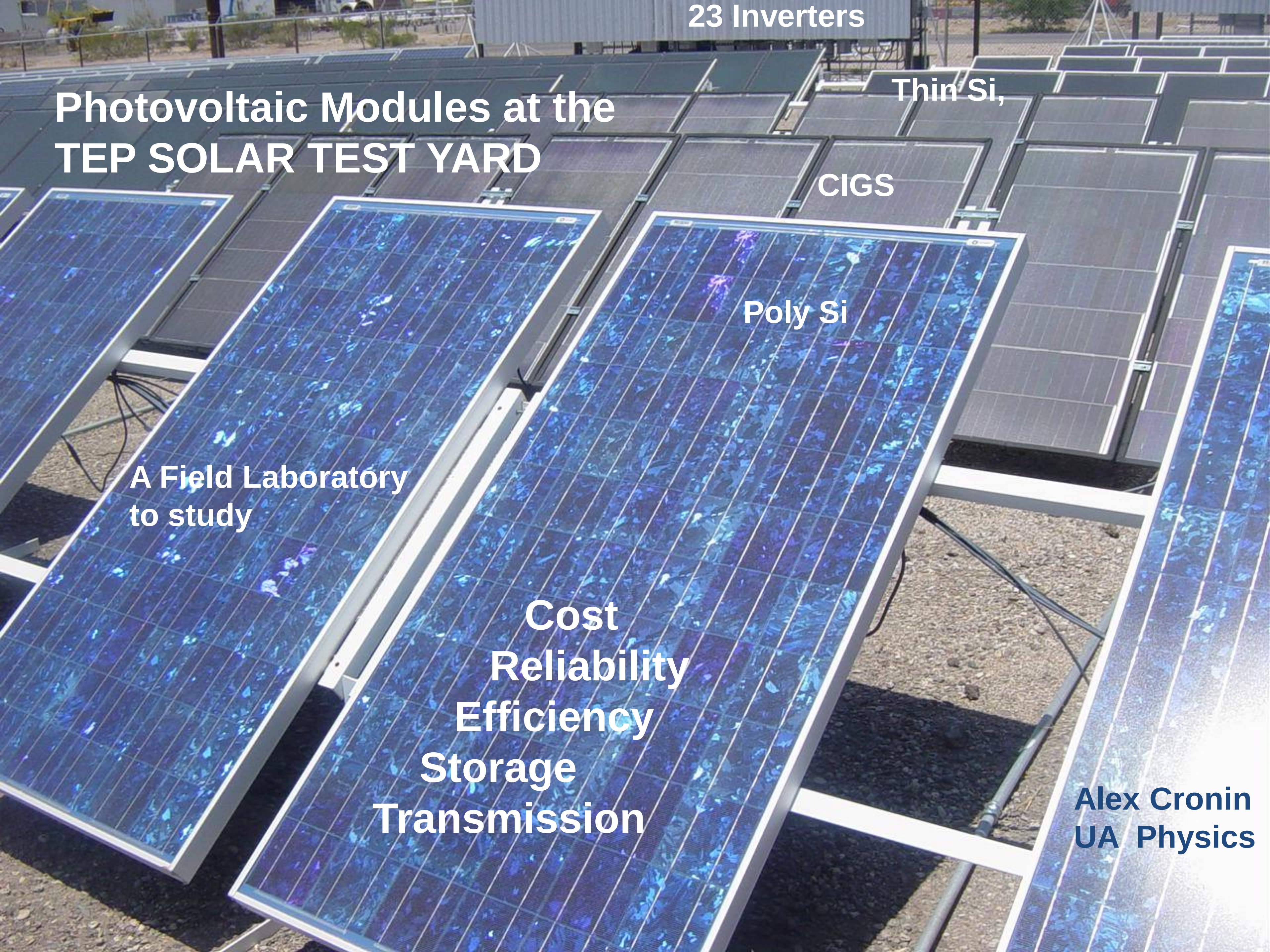
Overview

- Useful Storage Technologies
  - Batteries
  - Compressed Air Energy Storage
  - Thermal Energy Storage
  - Pumped Hydroelectric
- Opportunities in Arizona
  - Geology
- **Macro-economics of Solar/Renewable Energy (to be presented at the next session by Ardeth M. Barnhart)**

Photovoltaic Modules at the TEP SOLAR TEST YARD



23 Inverters

Thin Si,

CIGS

Poly Si

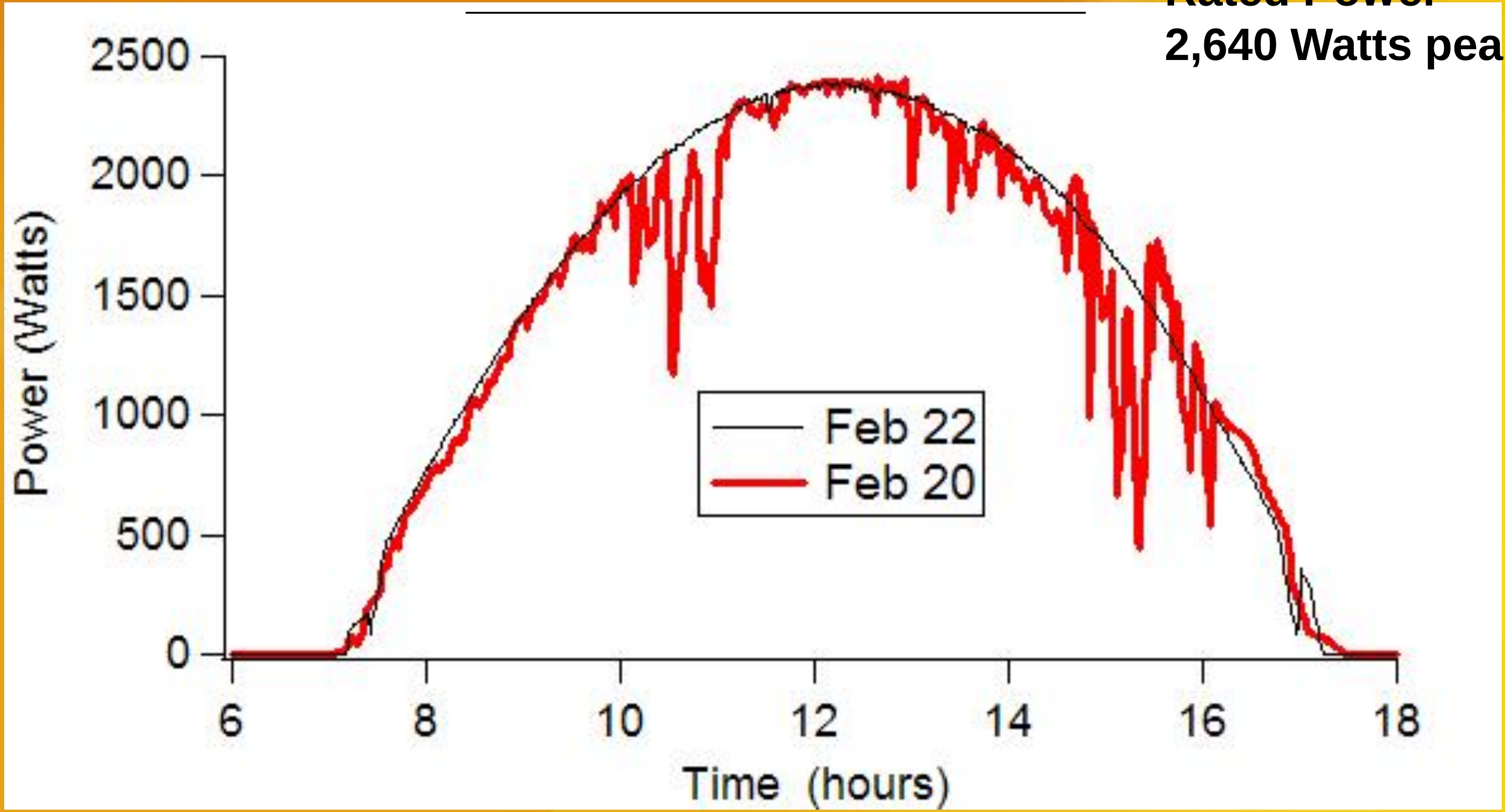
A Field Laboratory
to study

Cost
Reliability
Efficiency
Storage
Transmission

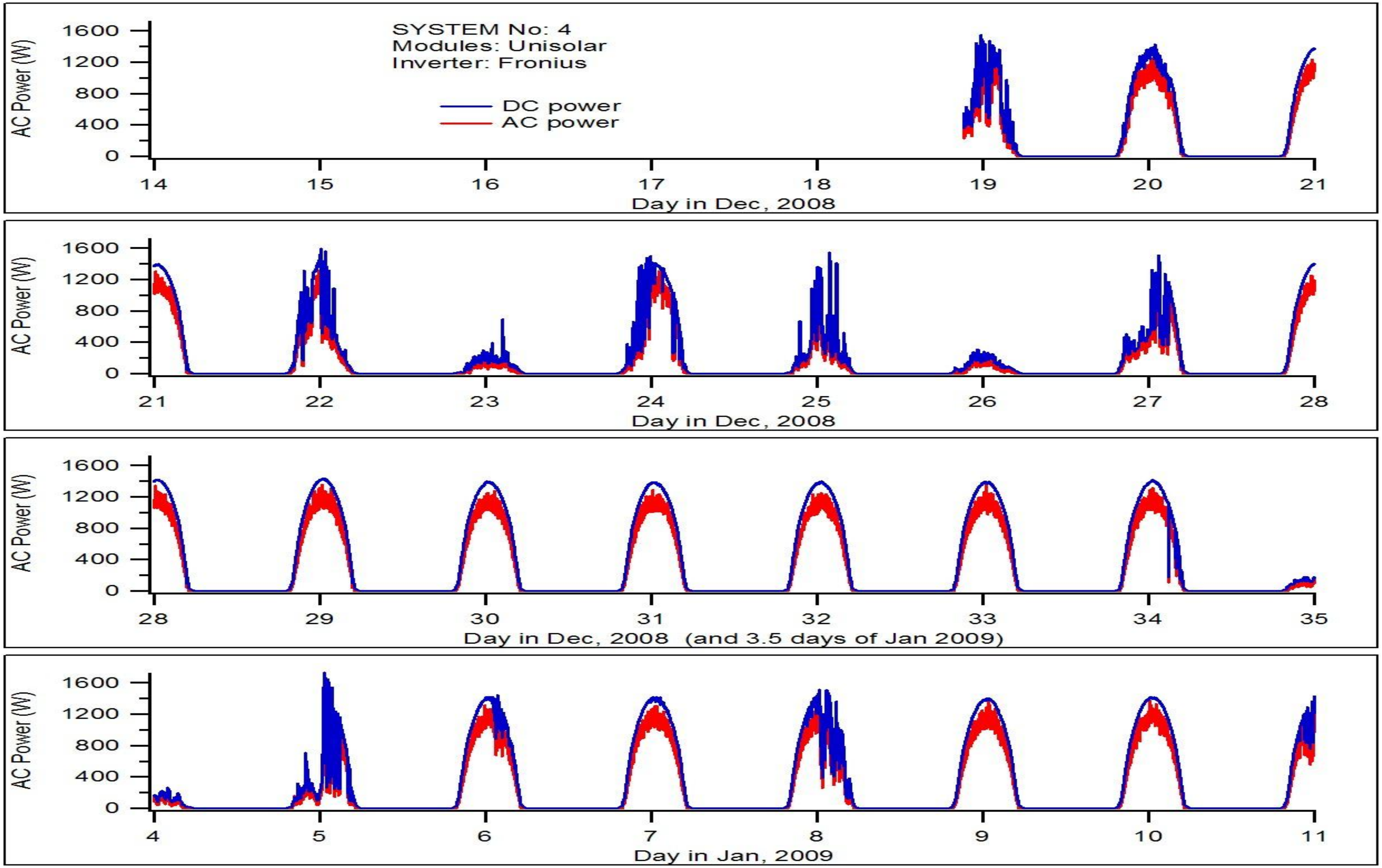
Alex Cronin
UA Physics

Short-term intermittency due to weather

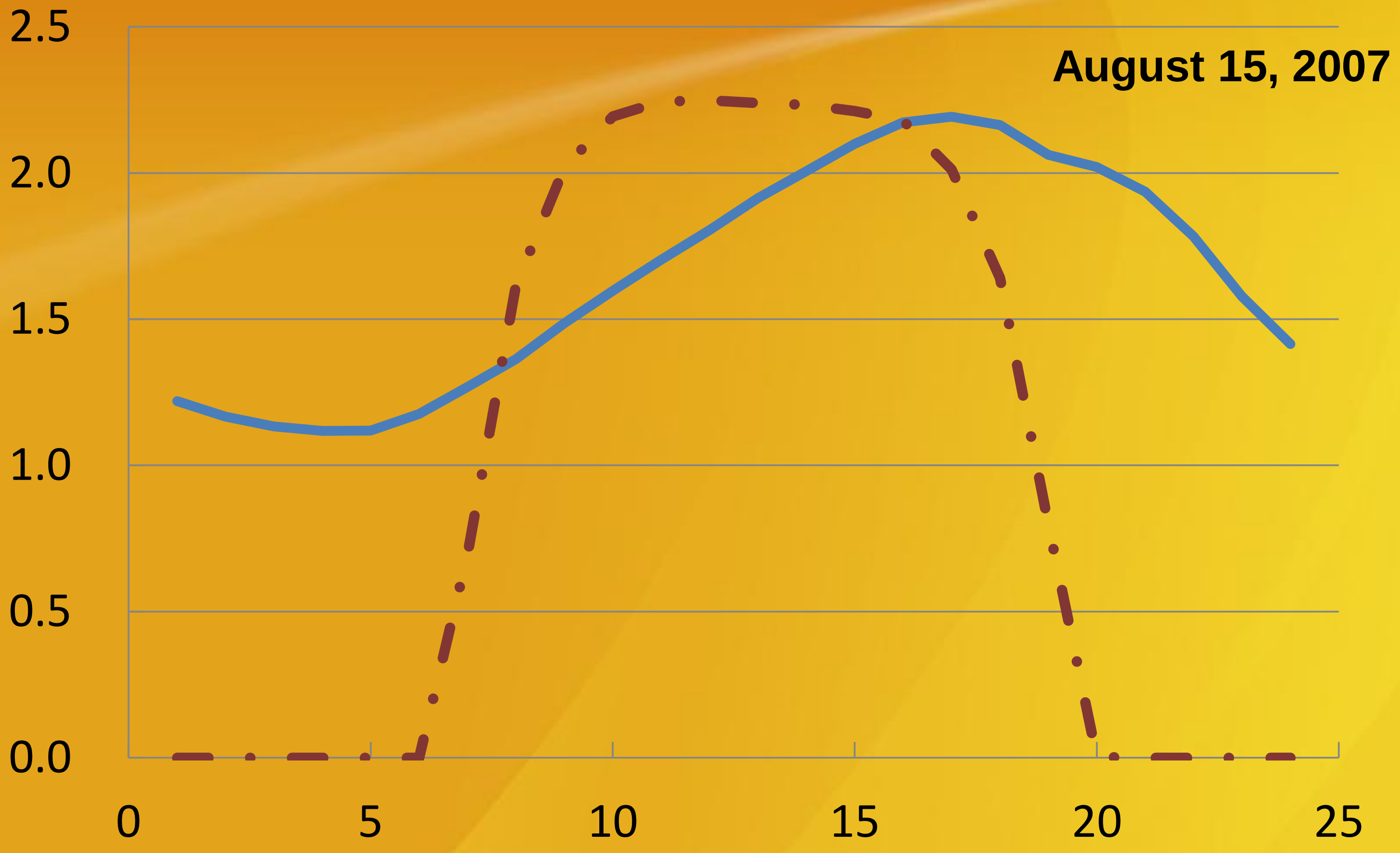
Rated Power
2,640 Watts peak



Day-to-day Production Variation



Load Mismatch with Single Axis Tracking PV



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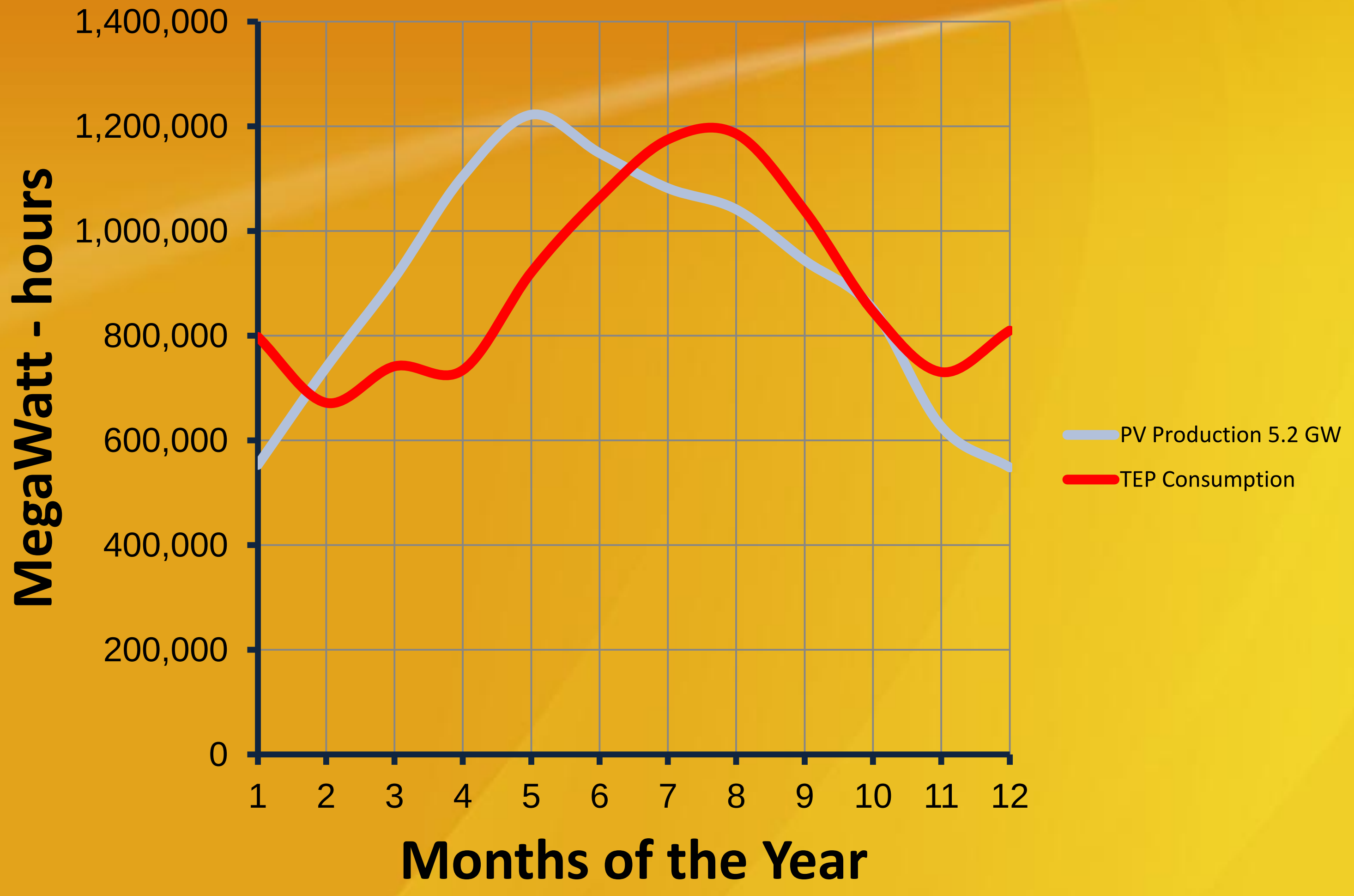
Seasonal Mismatch Between Demand and Production



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Energy Storage – A Critical Component in the Development of a Solar America

- Energy storage is critical:
  - Supply side: Intermittent renewable energy sources – Solar and Wind
  - Demand side: Large variations in demand (peak-load shaving)
  - Short term weather intermittency
  - Day-to-day variations
  - Load mismatch
  - Seasonal Mismatch

- Energy storage must be:
  - Inexpensive, Efficient, Rapid reaction to loss of power
  - Available in sufficient capacity
    - Seasonal arbitrage, load shifting, regulation
    - National Energy Reserve

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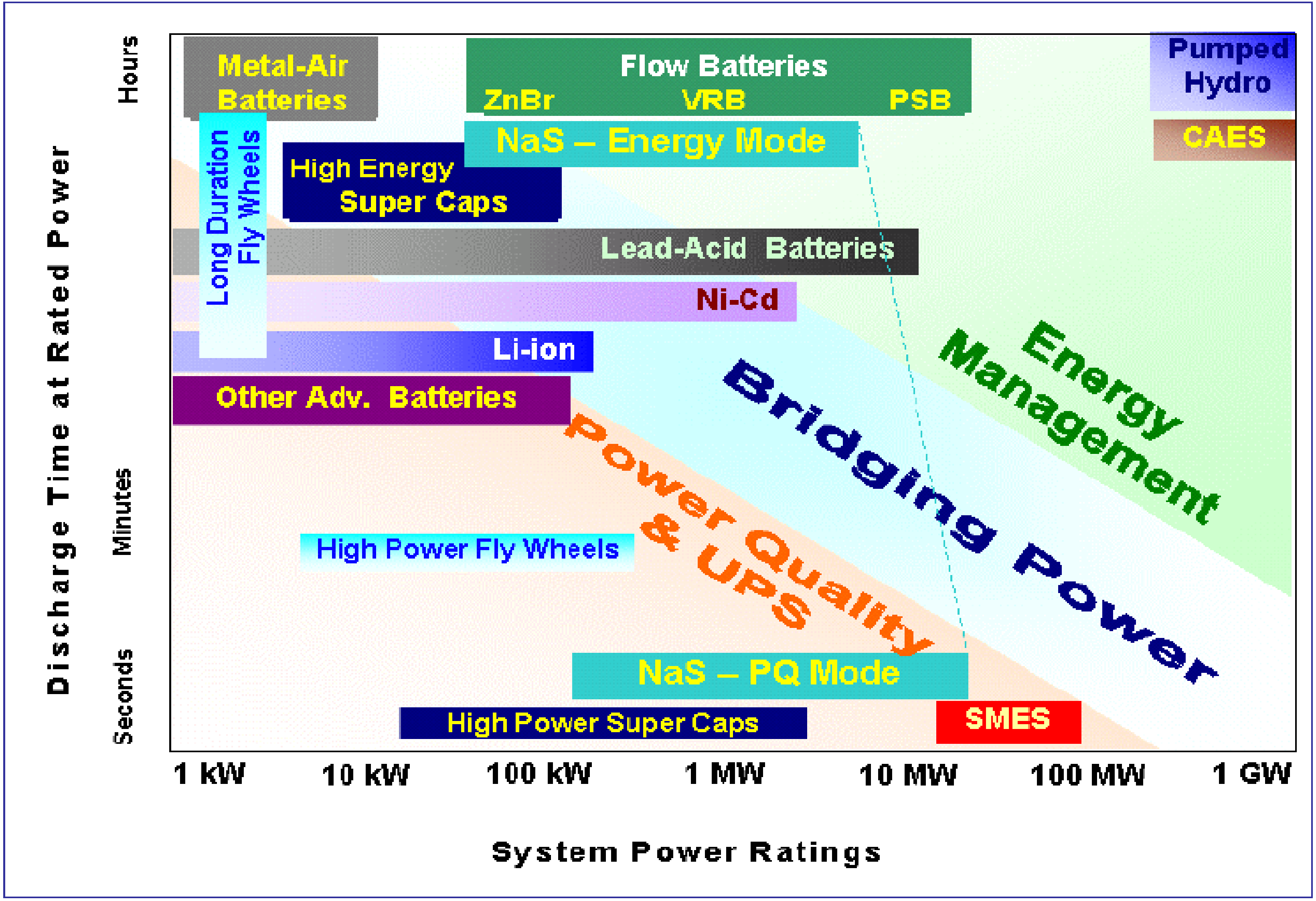
Energy Storage

- Batteries
- Supercapacitors
- Flywheels
- Hydrogen
- Fuel cells

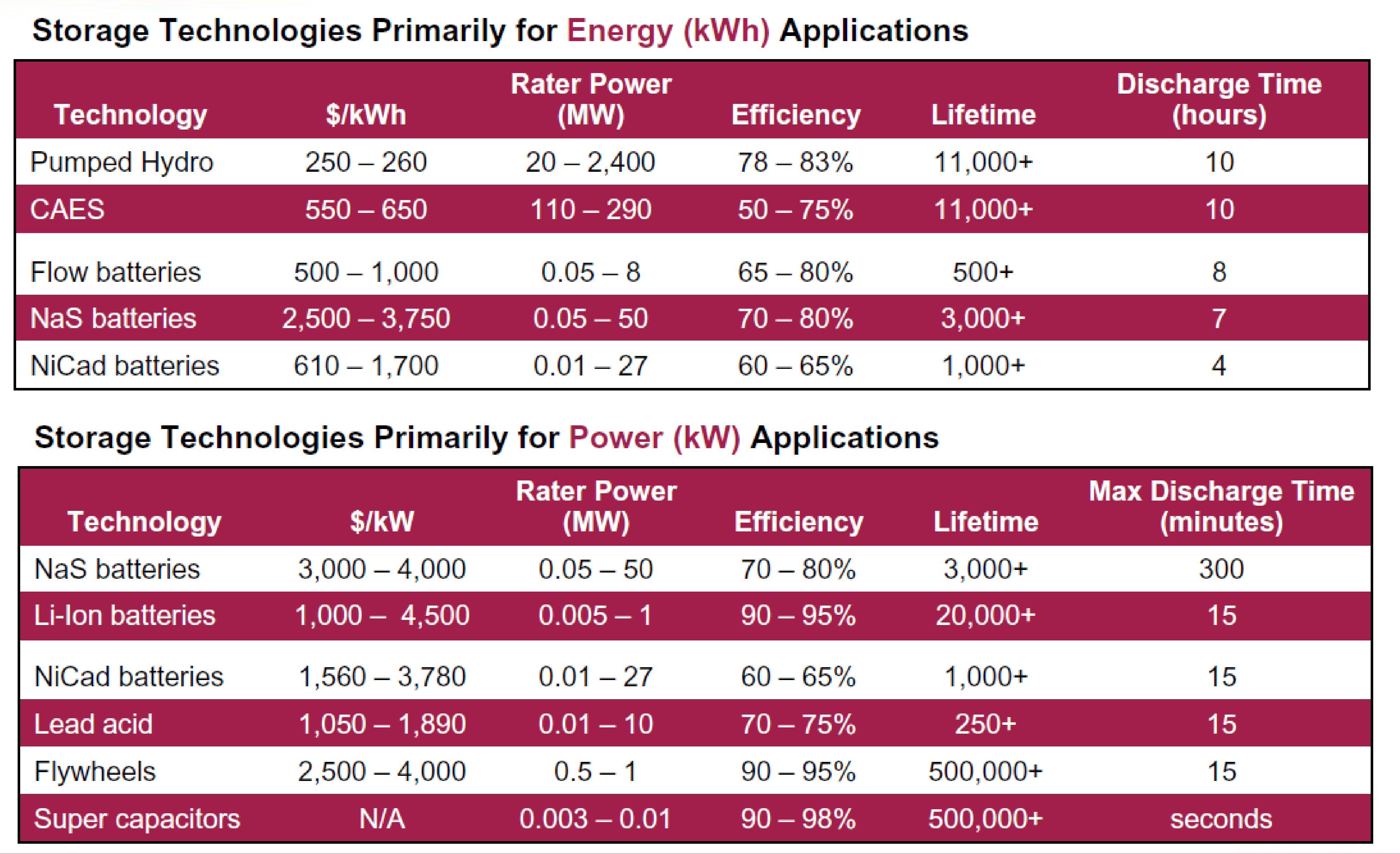
- Compressed air in vessels
- Underground compressed air
- Pumped hydroelectric
- Thermal storage
- Superconducting magnetic energy

Storage Technologies and Regimes of Application



A. Nourai

Sam Jaffe – ESA 09 (Energy Insights)
Summary of Energy Storage approaches:



Storage Technologies Primarily for Energy (kWh) Applications

Technology	$/kWh	Rater Power (MW)	Efficiency	Lifetime	Discharge Time (hours)
Pumped Hydro	250 – 260	20 – 2,400	78 – 83%	11,000+	10
CAES	550 – 650	110 – 290	50 – 75%	11,000+	10
Flow batteries	500 – 1,000	0.05 – 8	65 – 80%	500+	8
NaS batteries	2,500 – 3,750	0.05 – 50	70 – 80%	3,000+	7
NiCad batteries	610 – 1,700	0.01 – 27	60 – 65%	1,000+	4

Storage Technologies Primarily for Power (kW) Applications

Technology	$/kW	Rater Power (MW)	Efficiency	Lifetime	Max Discharge Time (minutes)
NaS batteries	3,000 – 4,000	0.05 – 50	70 – 80%	3,000+	300
Li-Ion batteries	1,000 – 4,500	0.005 – 1	90 – 95%	20,000+	15
NiCad batteries	1,560 – 3,780	0.01 – 27	60 – 65%	1,000+	15
Lead acid	1,050 – 1,890	0.01 – 10	70 – 75%	250+	15
Flywheels	2,500 – 4,000	0.5 – 1	90 – 95%	500,000+	15
Super capacitors	N/A	0.003 – 0.01	90 – 98%	500,000+	seconds

Solar Application: Wakkanai Project

NGK

1.5MW NAS Battery for 5 MW Solar

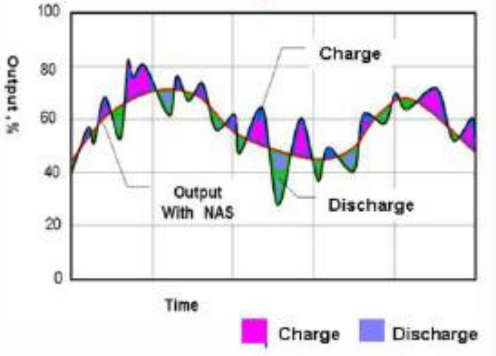
Financed by NEDO (New Energy and Industrial Technology Development Organization)

Project Size:

Solar Panel:
5MW
NAS Battery:
1.5MW

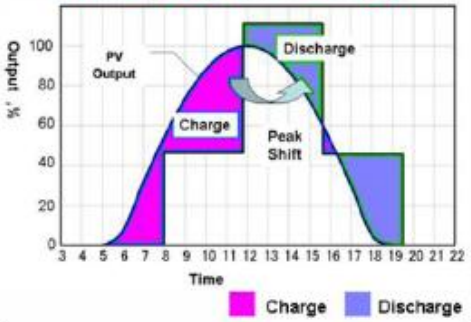
Absorb PV output fluctuation

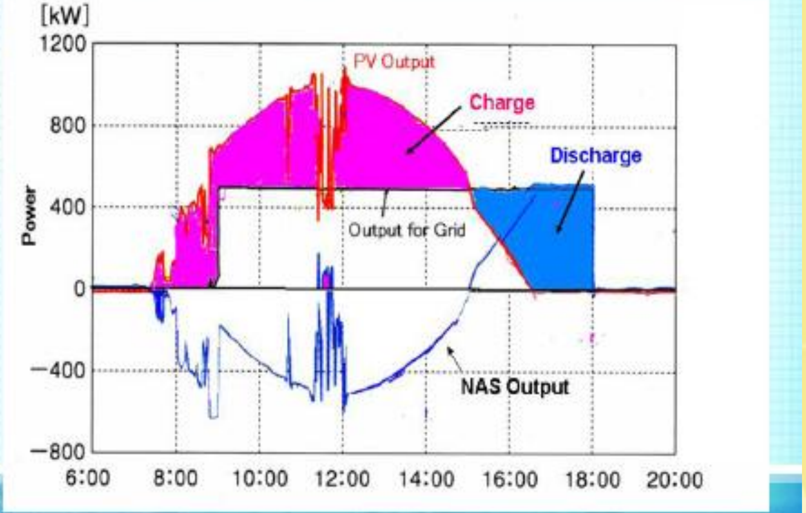
Absorption short-time fluctution of PV output



Peak Shift

Peak time discharge (Evening etc.) by Storing Day-time Energy





Case study: frequency regulation
A123Systems Li-Ion: AES Corporation

- 2-MW, 500-kWh unit assembled in trailer
- Operational and performing frequency regulation for AES-owned Huntington Beach, CA natural gas plant
- Air cooled, but plans for liquid-cooled version
- Plans to install several other units at AES facilities worldwide
- Lithium phosphate-based technology also being aimed at EV market

Caption: A123's Hybrid Ancillary Power Unit (H-APU) being placed in service

Source: A123Systems

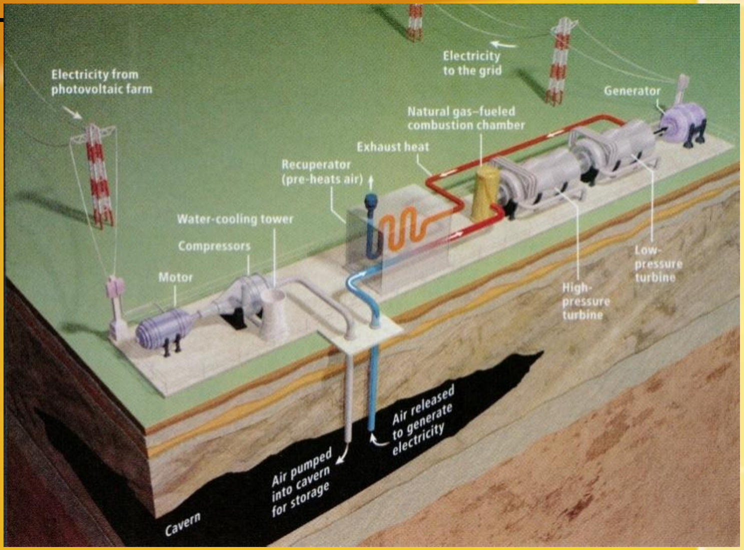
Case study: frequency regulation
Altairnano Li-Ion: PJM Interconnection

- 1-MW, 250-kWh system housed in 40-ft trailer
- Utilizes fast charge/discharge capability of lithium titanate oxide technology to dispatch frequency regulation services on PJM
- One unit currently in operation at PJM headquarters; Trial previously completed at IP&L
- Batteries feature extended lifetime of 25,000+ cycles, but come at a higher cost than other Li-Ion chemistries
- Courting new opportunities in frequency regulation and renewables integration

Caption: Interior view of the Altairnano battery management system

Source: Altair Nanotechnologies

Energy Storage – A Critical Component in the Development of a Solar America



- **Compressed Air Energy Storage (CAES)**
  - ❑ Above ground (vessels)
    Storage for a few hours
    Automotive applications
- **Underground Compressed Air Storage (1,100 psi, 75 atmo.)**
  - ❑ Needs salt deposits (primary)
  - ❑ High efficiency and low price (65-90%)
  - ❑ Needs additional fuel for operating the turbine (natural gas or biofuels)
  - ❑ **UA research –**
    - ► **Adiabatic pump with heat recovery using molten salt storage**
    - ► **Hydrogen heating for additional fuel**
    - ► **Salt deposits and alluvium for underground storage**
    - ► **Mining sites and mine tailing banks**
    - ► **Demonstration site (Riverpoint Solar Research Park)**

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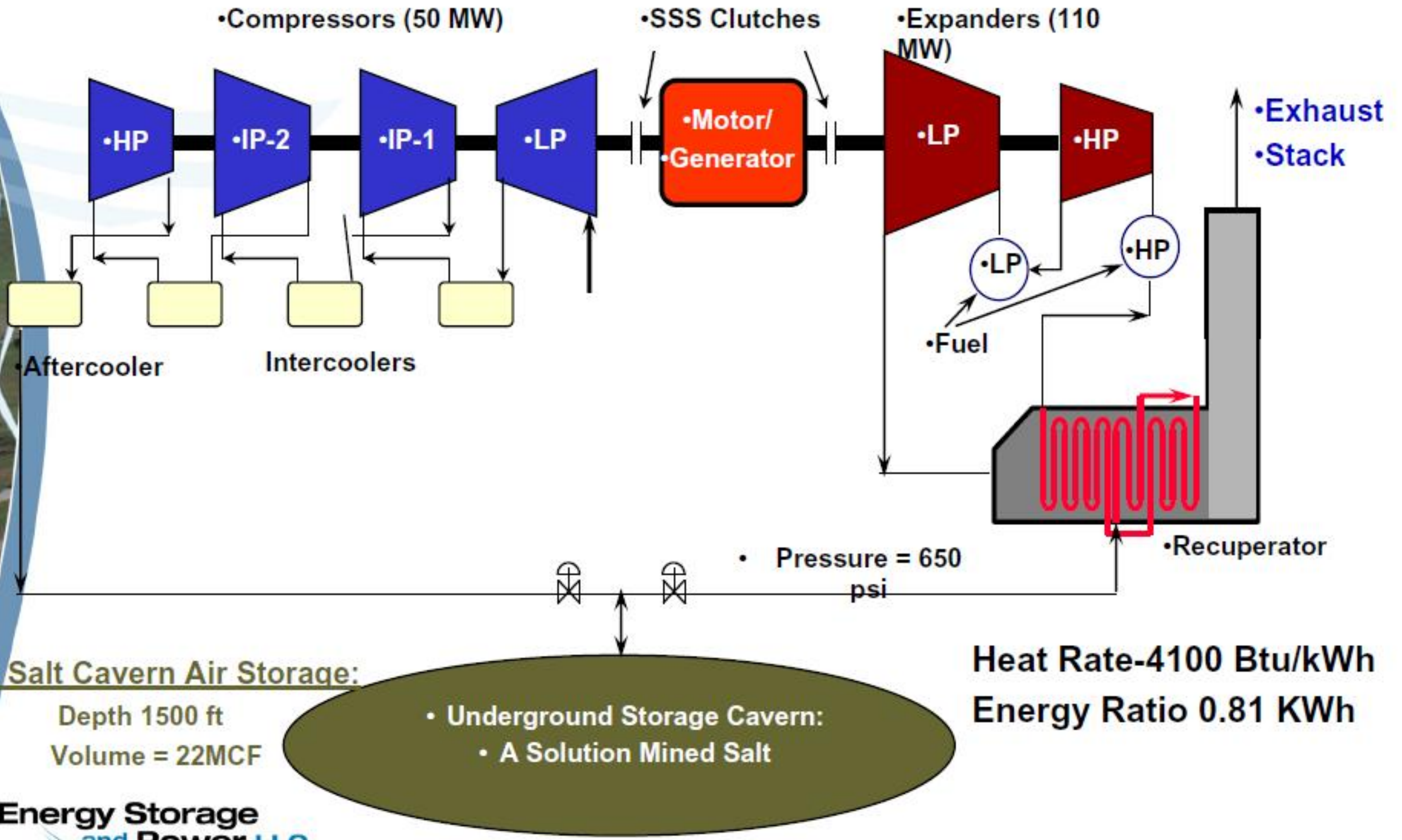
Schematic for AEC CAES Plant

ESPC: Developed and optimized the CAES Concept and Parameters

•**G&H/Herbert:** EPC Contractors
DR: Supplied Compressors &Expanders
SW: Advanced Recuperator;
AIT: HP/IP Combustors , **PB**: Underground Storage



•Compressors (50 MW)

•SSS Clutches

•Expanders (110 MW)

•HP

•IP-2

•IP-1

•LP

•Motor/ •Generator

•LP

•HP

•Exhaust
•Stack

•LP

•HP

•Fuel

Aftercooler

Intercoolers

•Recuperator

- Pressure = 650 psi

Salt Cavern Air Storage:

Depth 1500 ft

Volume = 22MCF

- Underground Storage Cavern:
- A Solution Mined Salt

Heat Rate-4100 Btu/kWh

Energy Ratio 0.81 KWh

Energy Storage and Power LLC

Energy Storage – A Critical Component in the Development of a Solar America

- **Underground Compressed Air Storage**
  - Salt reservoir – solution mined
  - Aquifer reservoir: displace water in porous rock, needs rock permeability and a suitable capping system (hardest to accomplish) but is similar to natural gas reservoirs
  - Hard rock mine: problem with fractures; Colorado rock is heavily fractured; high pressure tests are expensive
  - *Huntdorf, Ge* (1978) 290 MW, 2-3hr reservoir (salt)
  - *McIntosh, Ala* (1991) 110 MW, 26 hr = 19M ft3 reservoir (salt)
  - *Norton, OH* (2010) 2,700 MW, (abandoned limestone mine)
  - *Iowa Stored Energy Park* (future) 270 MW, 16 hr (aquifer)
  - *Briscoe, TX* (future) 1,000 MW (salt) + 3,000 MW wind = 2,000 MW continuous. 3,000 MW wind requires 120,000 acres.
    Shell + Luminant/TXU
  - ***Riverpoint Solar Research Park* (1 MW) demonstration, Phoenix, AZ**

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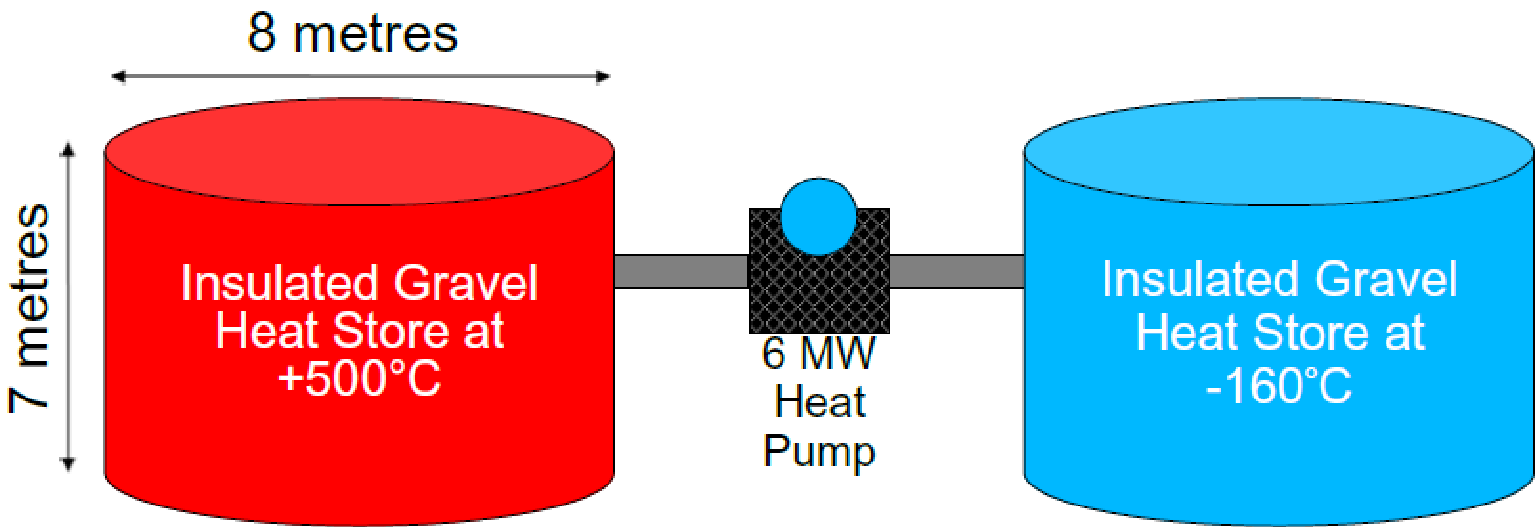
Other Technologies

- Liquid Air
- Thermal systems
- Pumped hydroelectric
- Flywheels
- Supercapacitors
- Other batteries:
  - ❑ Deep discharge, graphite enhanced lead acid batteries
  - ❑ Vanadium redox flow batteries

The Isentropic Heat Pump

- The Isentropic heat pump converts electrical energy in super-heated and super-cooled argon to store in gravel. To recover the electricity, the process is simply reversed using the same equipment.



8 metres

7 metres

Insulated Gravel Heat Store at +500°C

6 MW Heat Pump

Insulated Gravel Heat Store at -160°C

Recoverable Electrical Energy 30 MWh

Comparison of Energy Storage Technologies

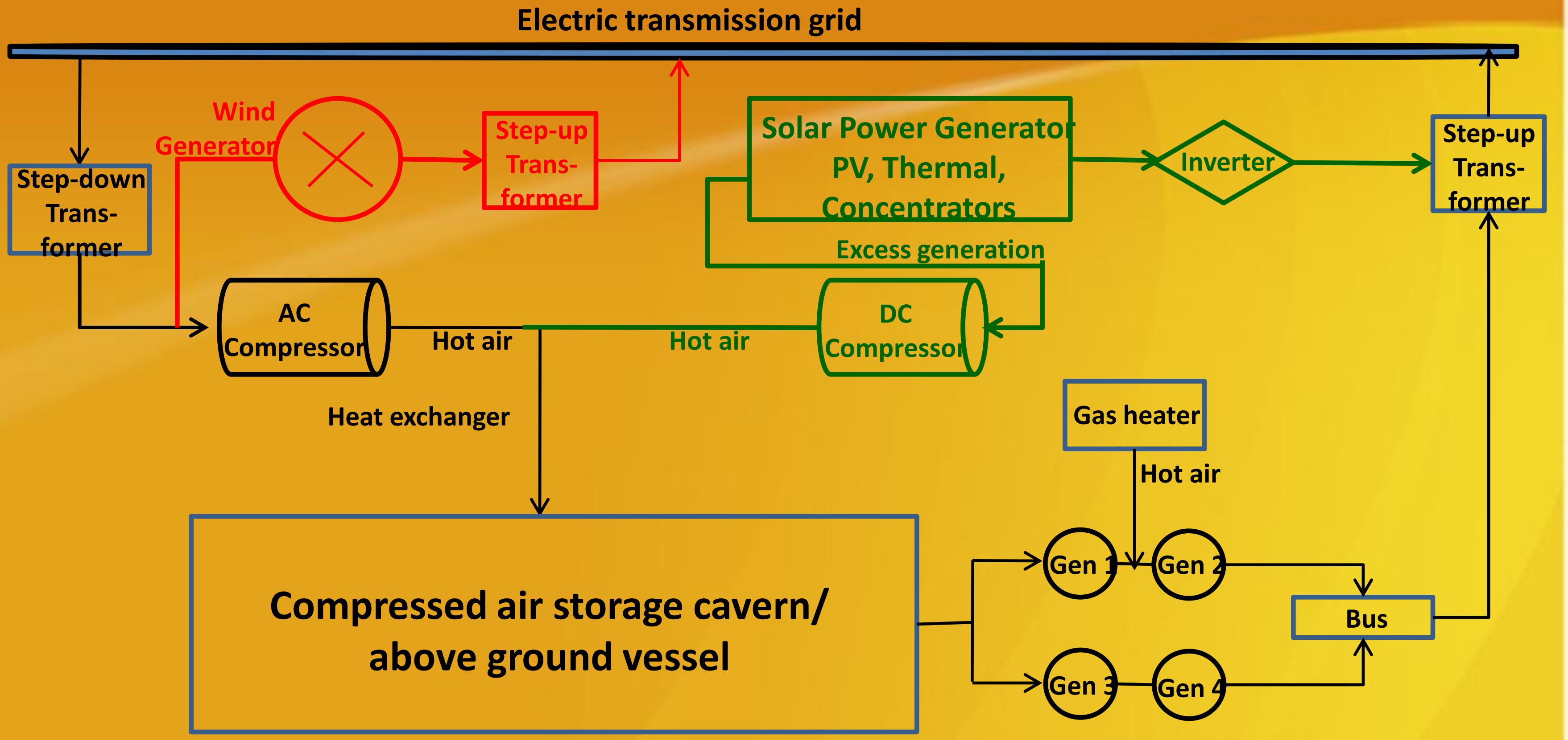
Method	**Cycles, Lifetime**	**Typical Efficiency**	**$/KW-Capacity**	**$/KWh Energy**
Niagara PS	75 + yrs	70%	~1500 - 2500	11.50-19.25
Pumped Hydro (typical)	50 + yrs	75-82%	850 - 2300	85-300
Compressed Air (CAES)	~30-50 yrs	73-89%	~200	~20
Sodium-sulfur batteries	-	89-92%	t.b.d.	-
Lead-acid batteries	1.2-1.8 kilo-cycles <10 yr	85-90%	100	2,000
Lithium-ion	1500 +	90-98%	900 - 1300	>10,000
Electrochemical Supercapacitor	500,000 + / ~12 yrs	85-98%	100	20,000
Flywheel	10^5-10^7 Cycles ~20 yr	85-90%	1500	6,000

CAES is a mixed technology that requires burning gas as part of the cycle, so not a pure storage method; CAES improves yield of gas turbines.

CAES Characteristics

- Typical range of operating pressures: 1150 psi – 750 psi
- Energy output per cavern size: 7.3 kWh/m^3
- Energy balance: 1 kWh CAES production comes from:
  - Compression energy: 0.75 kWh
  - Heating energy: 4,300 BTU (1.25 kWh/0.39 kWh NG)
- Typical round-trip efficiency: 65%
- Potential round-trip efficiency with heat recovery: 85%
- Storage vessels:
  - Underground salt cavern, abandoned mine
  - Depleted natural gas well, capped aquifer storage
  - Alluvium holes
  - Above-ground steel vessels

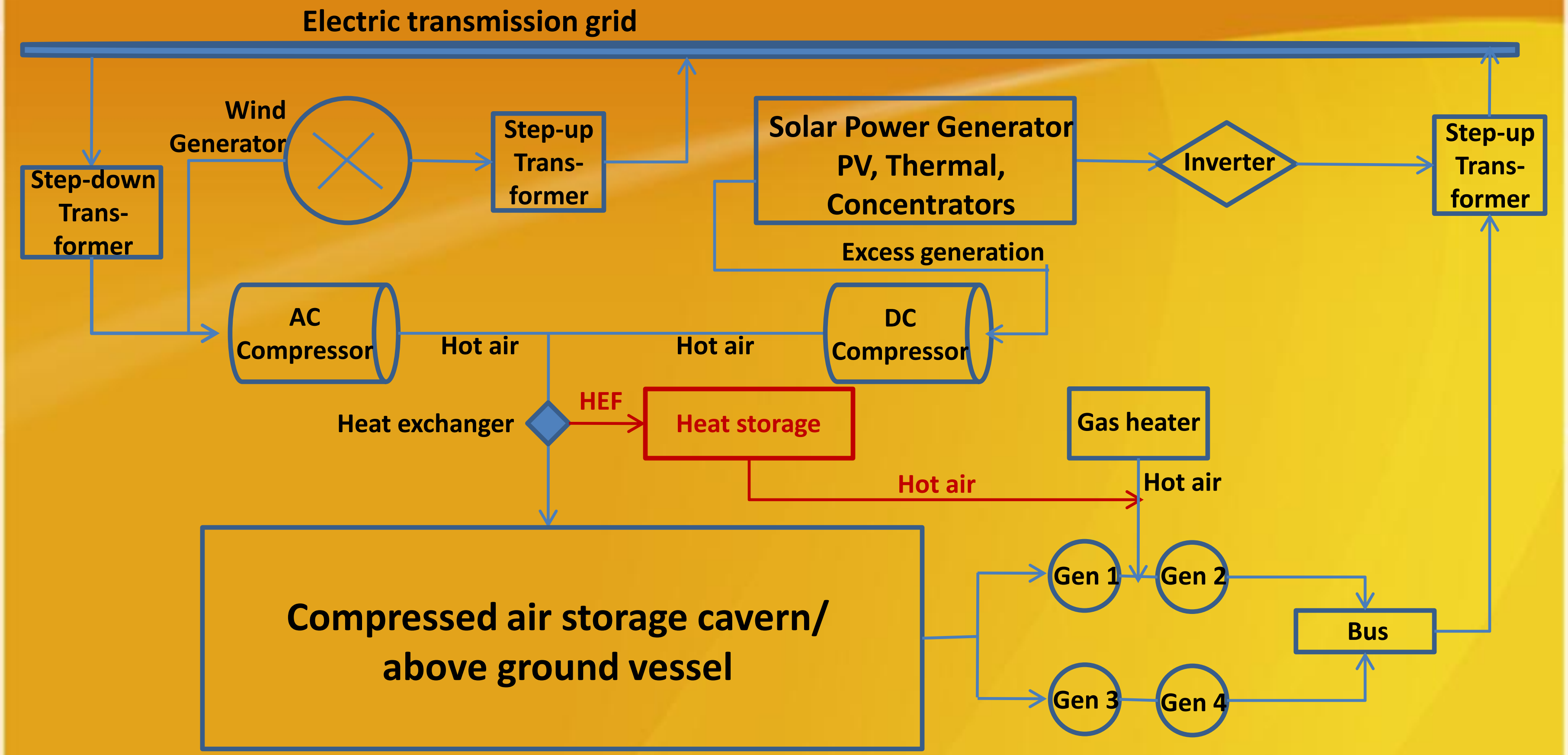
Compressed Air Energy Storage



- Generation/storage systems integration
- Efficiency w/o heat recovery: 65%, with: 85%
- Isothermal vs adiabatic pumping
- Turbine vs vessel size
- Costs and economics

- **Air Storage:**
- **Subsurface imaging to greater than 2,000 feet**
- **Solution mined salt, drilled alluvium**
- **Depleted natural gas wells, abandoned mines**
- **Above-ground tanks, underwater tanks**

Compressed Air Energy Storage



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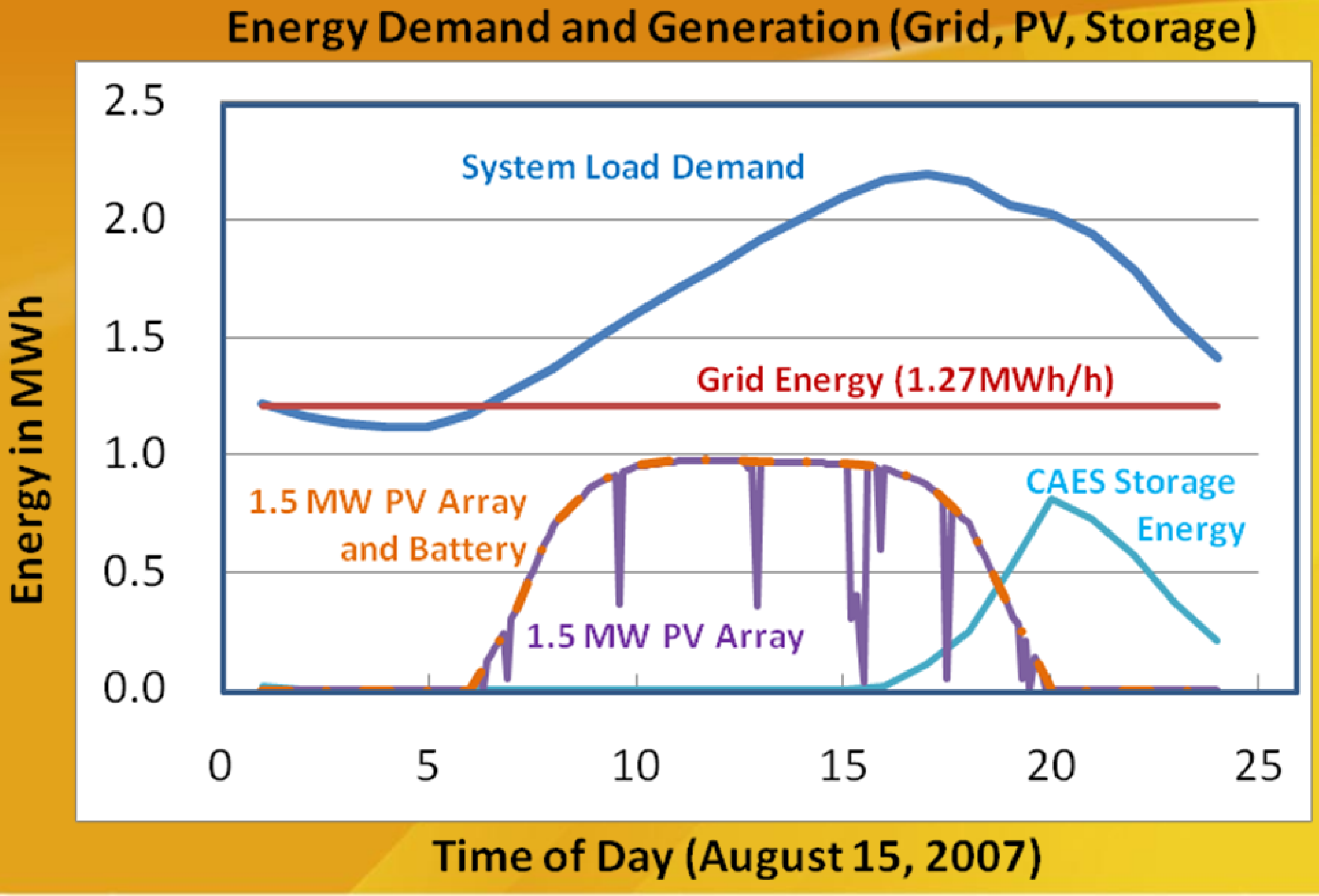
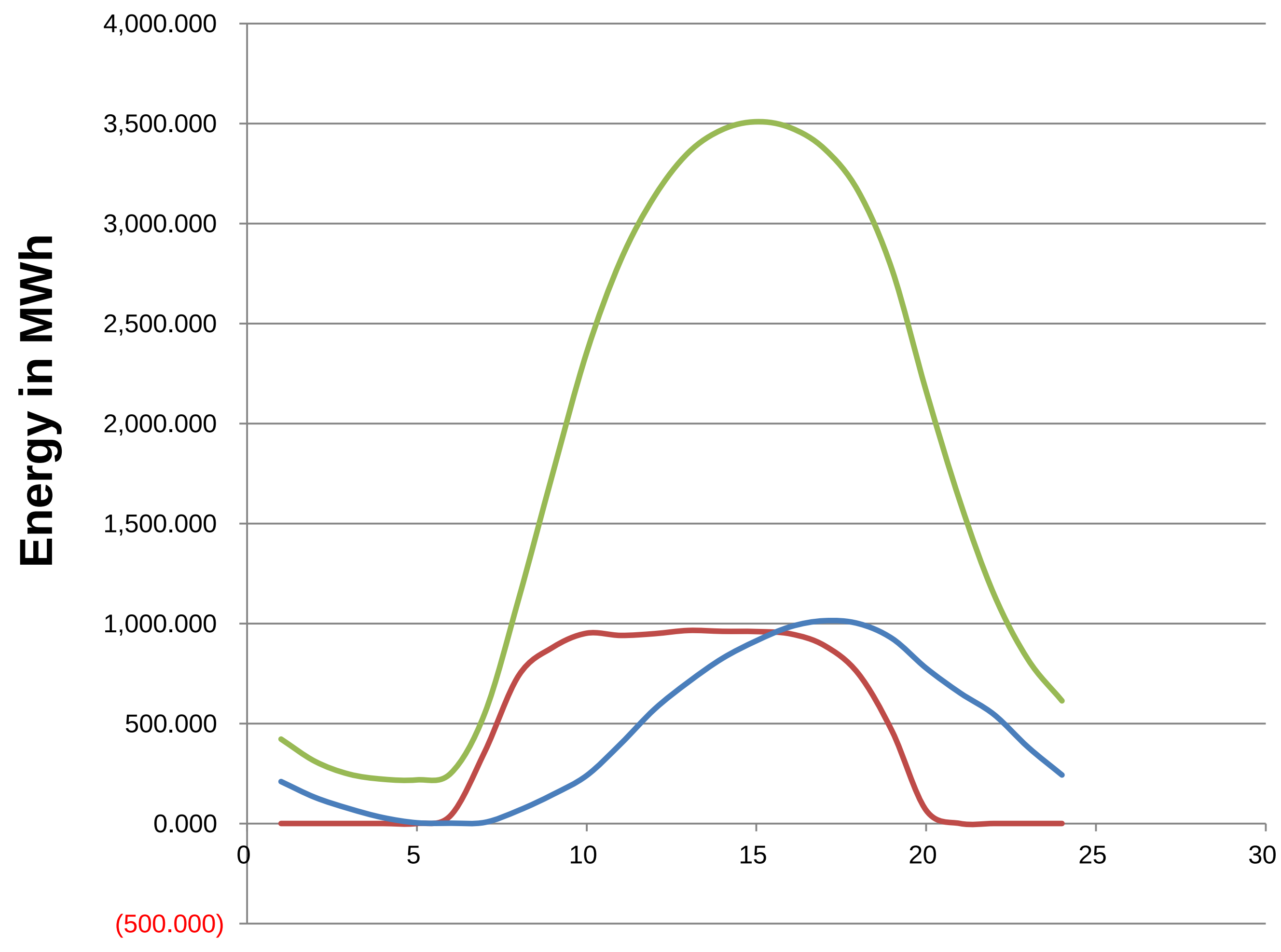
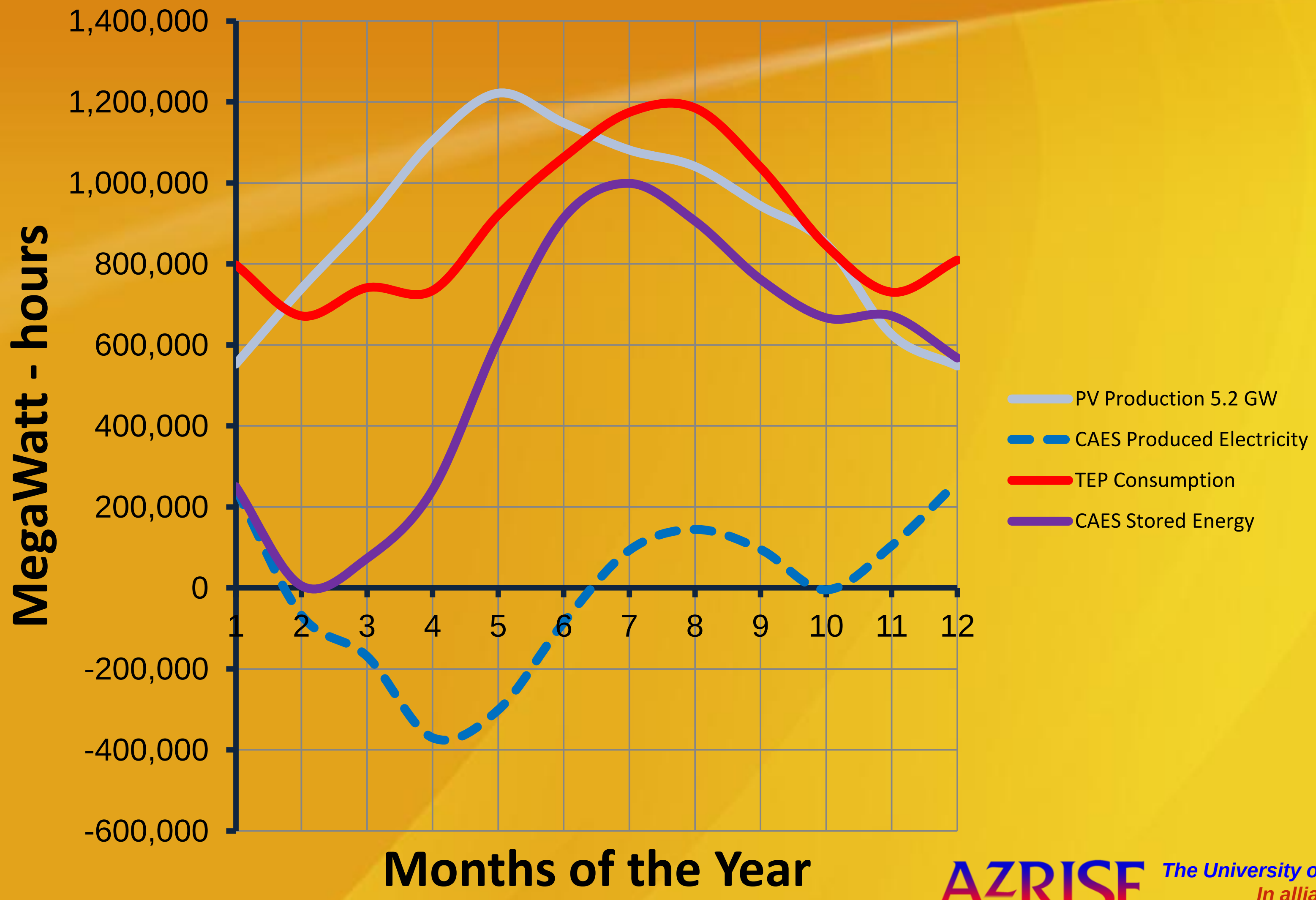
Load Shifting Function



Load Shifting Function – CAES Capacity



Addition of CAES to Meet Seasonal Differences



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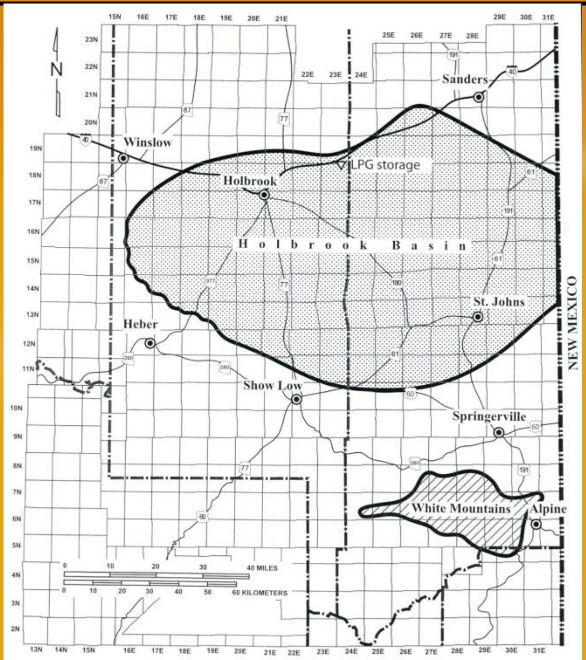
Underground Compressed Air Storage in Salt Caverns



- Holbrook salt basin covers 3,500 square miles and is 300 feet thick.
- Holbrook basin has the capacity to store 30TW of electrical production – more that the US total energy demand (3.3 TW) or 30 times the electrical demand (1 TW).

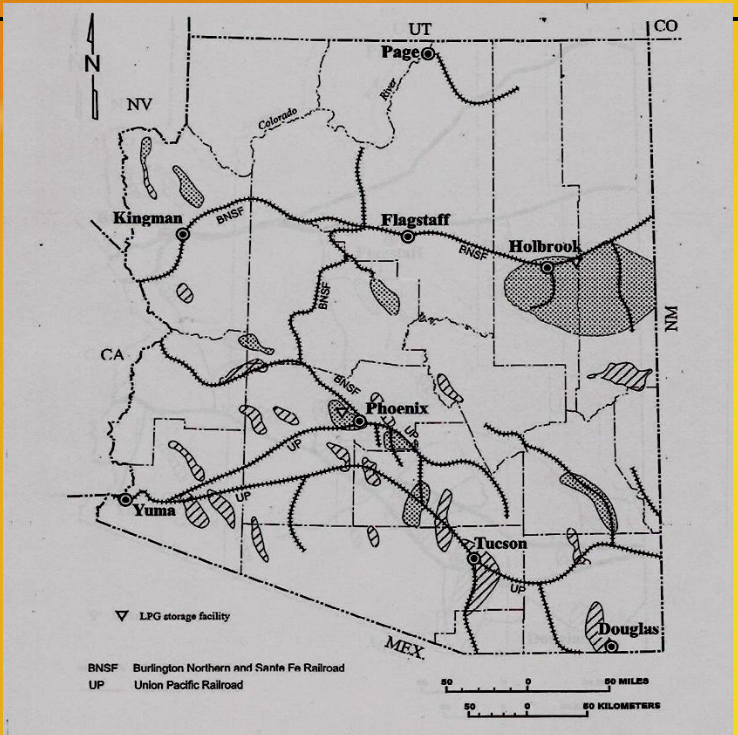


Figure 2. Railroads in Arizona superimposed on known and potential salt basins. Salt basins are identified on Figure 1.

- Many salt basins are distributed throughout Arizona
- Luke, Picacho and Holbrook are currently used to store natural gas or propane