Bulk Energy Storage Potential in the USA, Current Developments & Future Prospects

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Bulk Energy Storage :Overview

- Stored Energy can provide electricity during periods of high energy demand
- Currently demonstrated with bulk energy storage systems such as Pumped Hydro Storage (PHS)+- 2.5% of USA installed base.
- Potential beyond PHS with bulk storage systems-CAES-Flow Batteries—Flywheels.
- Current Developments—Wind Energy Integration.
- Potential & Economic Benefits of Energy Storage
- Future Prospects

Reasons for Energy Storage

Electricity Storage ?

- **Electricity! 3rd Largest Business in the USA -**
  $300 billion/per annum.
- **Demand for Electricity is seldom constant over time.**
- **Excess generation during low demand periods - can be stored.**
- **Stored Energy can provide Electricity during high demand.**
- **Help reduce power system loads.**
- **Improve Efficiency and Reliability.**
- **Make better use of efficient Baseload generation.**
- **Allow use of Renewable Energy technologies.**

Presentation Outline

- Introduction
- Bulk Energy Storage-CAES
- Projects in Development
- Applications
- Benefits from Energy Storage
- Market Potential
- Future Prospects
- Conclusions

Introduction

- Electricity Demand has considerable Daily & Seasonal variations.
- Maximum Demand require some plants to operate for short periods during the year.
- Without additional storage above the present 2.5% mainly PHS—Base-loaded plants are detrimentally cycled more frequently.
- Cycling further exacerbated by growing demand for renewable energy, such as Wind Energy.

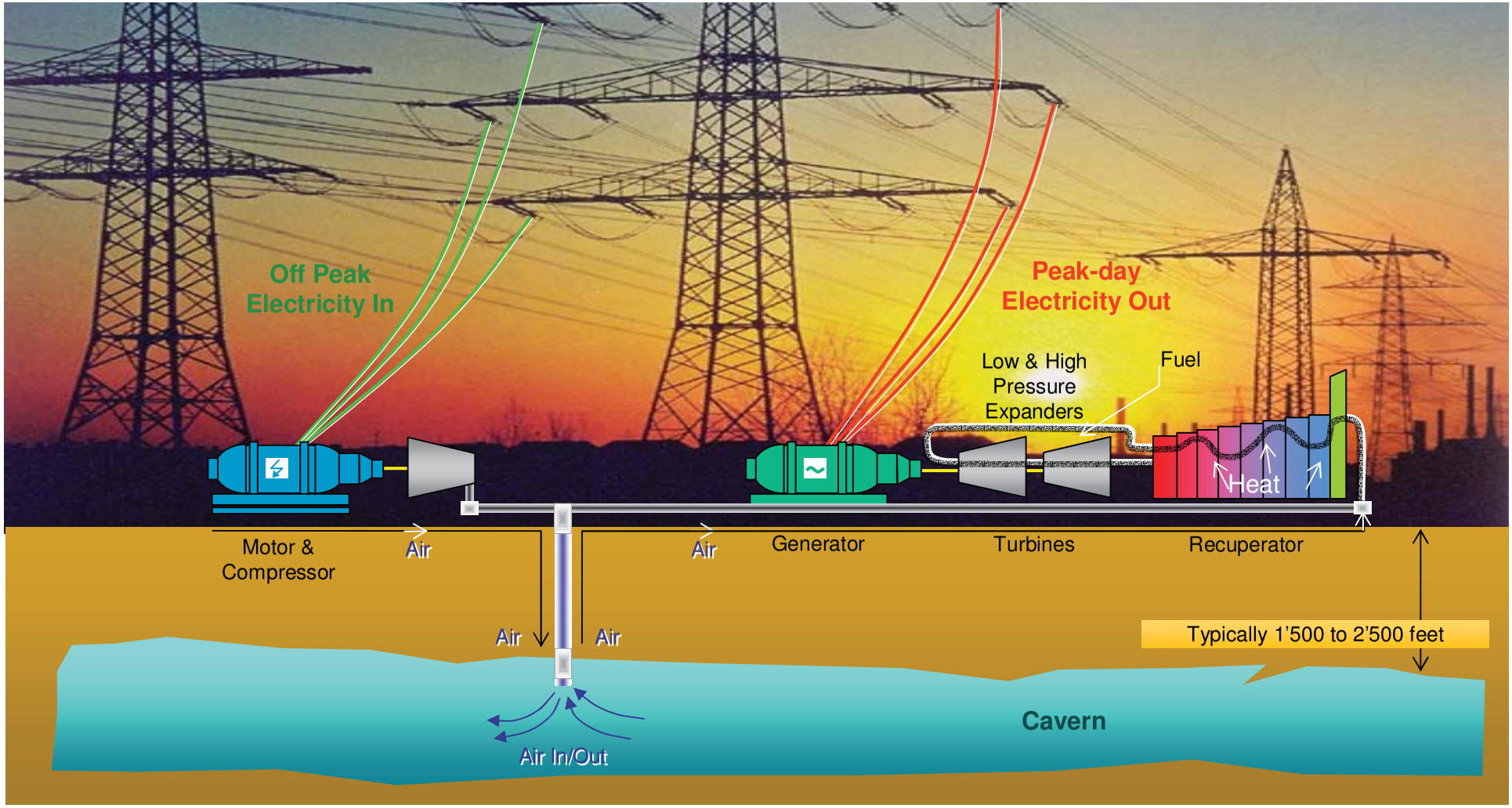
  ---installed capacity reached 6700 MW in USA

  ---projected to reach 30,000 MW by year 2020

Introduction-2

- Large Scale Storage would allow system planners to build only sufficient generating capacity to meet the average electrical demand.
- High Response systems such as Flywheels or Flow Batteries (second/millisecond) can be combined with CAES or SSCAES 60MW/hr Systems to 1000MW or more.
- Theoretically an 800MW Base-loaded plant can be scaled down to 500MW combined with 300MW Storage.
- Geologically suitable identified sites for Bulk Energy Storage-using salt domes, hard rock or aquifers can be readily exploited for 20/30 GW capability by 2020 or sooner

Compressed Air Energy Storage



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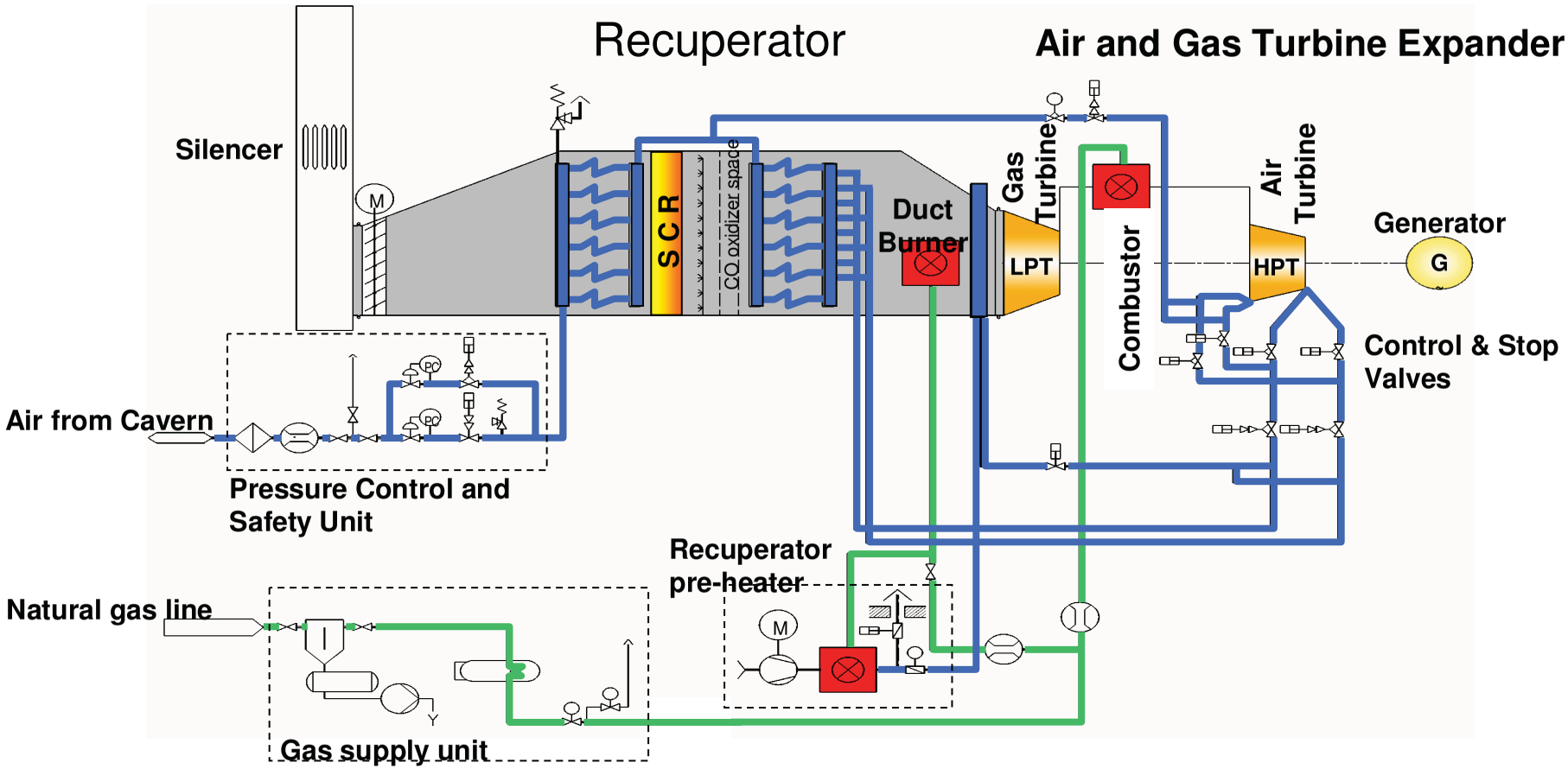
CAES –Power Train

- Integrated Cycle

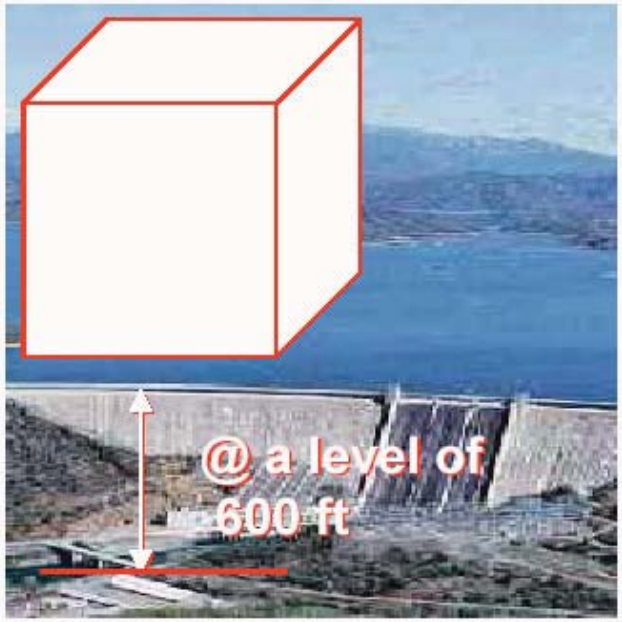


CAES vs.PHS

Required Storage Volume to Generate 300 MW (12 Hours Pumping, 12 Hours Generation)

10 million cft of Compressed Air

250 million cft of Water



Ecologically Friendly

Enviromental Constraints

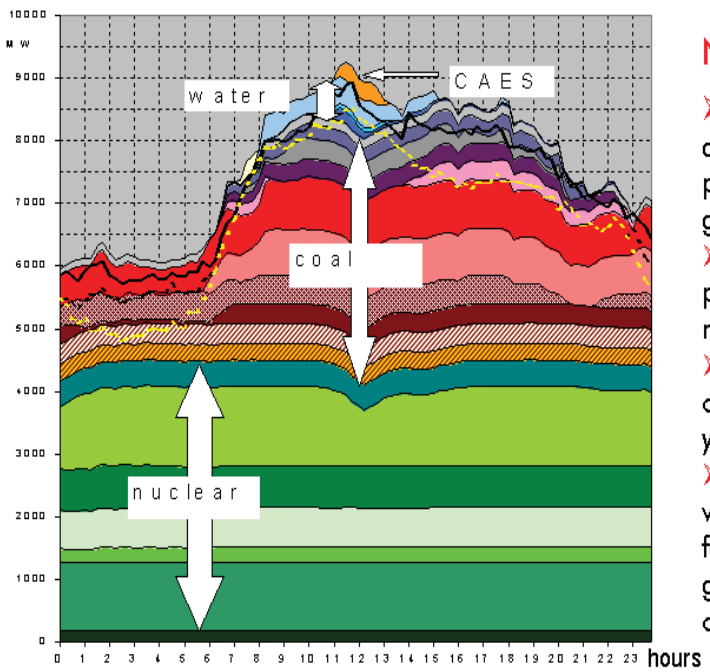
CAES – Germany - Huntorf 290MW

Bulk Energy Storage

- **First Commercial CAES Plant in the World - 1978**
- **Single Train Turbine Expander/Compression - ALSTOM (BBC)**
- **Two small Storage Caverns - Salt Strata - 10.6 million Cub/Ft**
- **Fast Response 2.5 minutes to idle - 90 MW/Min to Full Load**
- **Auto-Start for Grid Frequency Protection**
- **Phase Shift Operation/Excessive Reactive Power**
- **Black Start following Blackout - establish isolated grid**
- **Nuclear Power Plant Support**

Bulk Energy Storage Systems-CAES

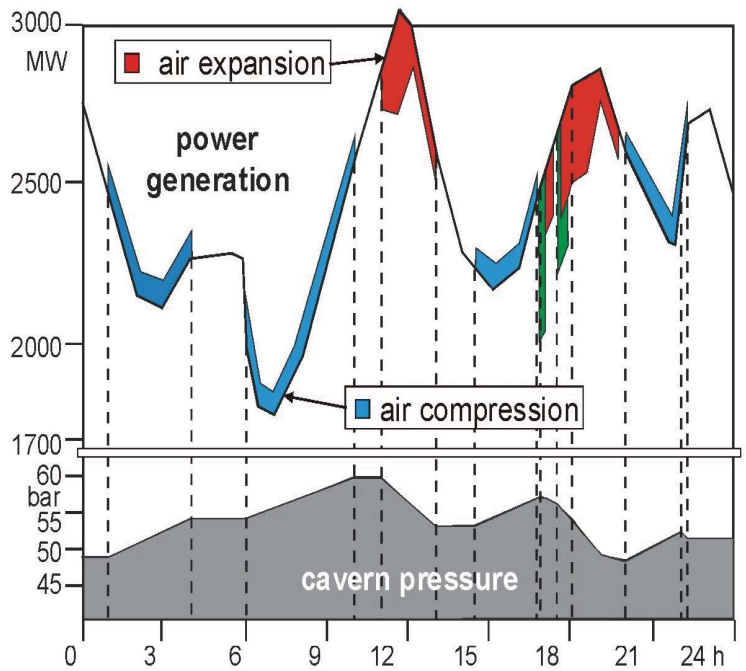
Power Production vs. Time



Notes:

- Substantial amount of hydro-power in E-on's generation mix
- With no hydro-power, CAES would run 7-8 hours daily
- results in 2000 operating hours yearly
- E-on has found a way to use Huntorf for 3 hours daily generation vs original 2 hours

24 Hour Load Profile CAES Operation



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CAES - USA Alabama Electric Co-operative 110 MW

- Bulk Energy Storage

•First Commercial CAES Plant in USA

–Operating since 1991

–Single Train Turbine Expander/Compression

Dresser Rand

–Single Storage Cavern-Salt Dome-19.8 Million cub/ft.

–Capable of 2600 MW/Hrs. without recharging

–Winter Heating/Summer Cooling periods

–Daily Cycling - one or two periods up to 10 hrs/day

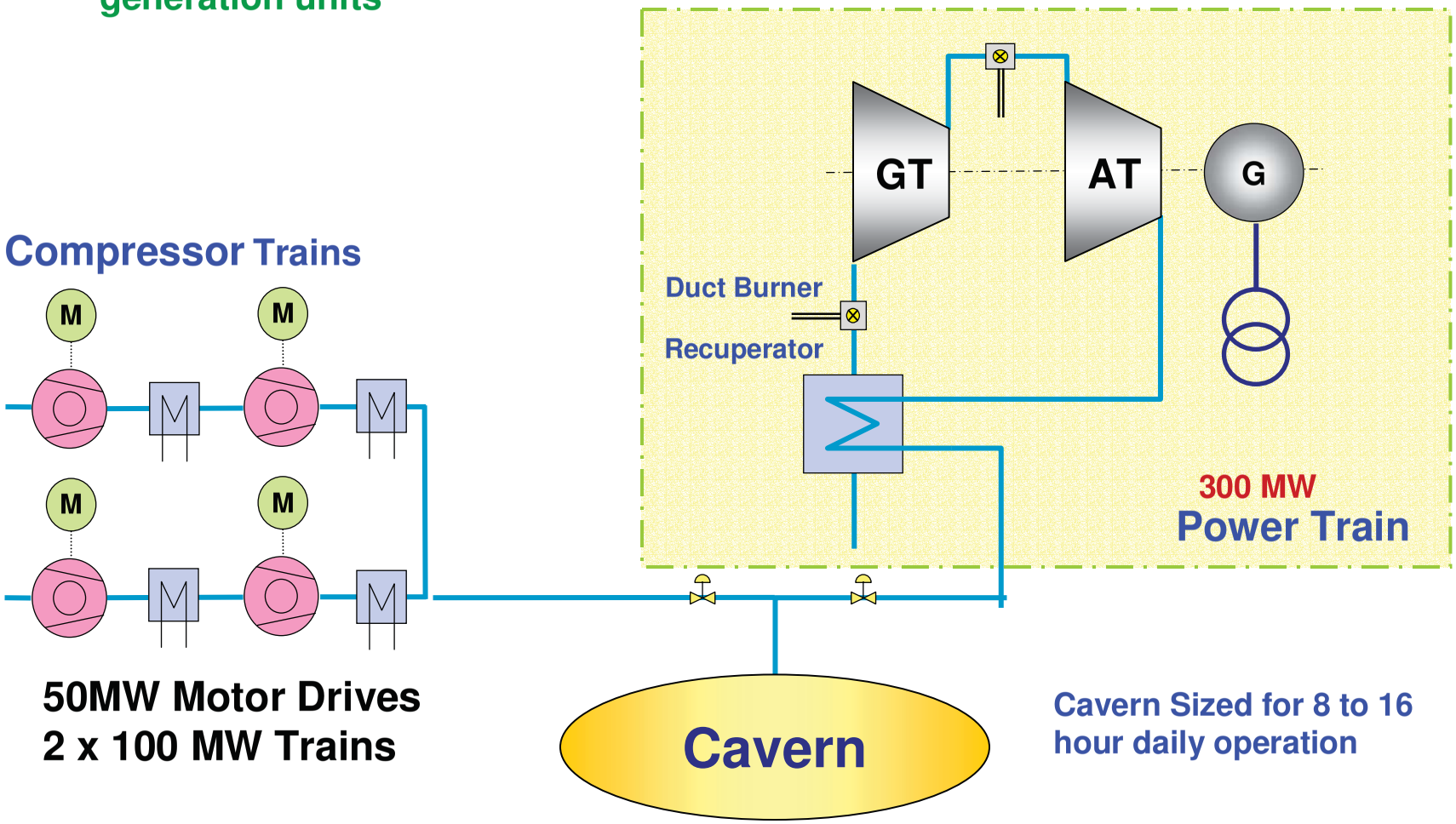
–Start to full load - 15 minutes or less

Decoupling of Compression Trains

- Flexibility in Compression optimization & utilization

- 50 MW compressor drives combined as 100/200 and 300MW systems act as load sinks—
- to avoid unnecessary cycling of base-loaded plants

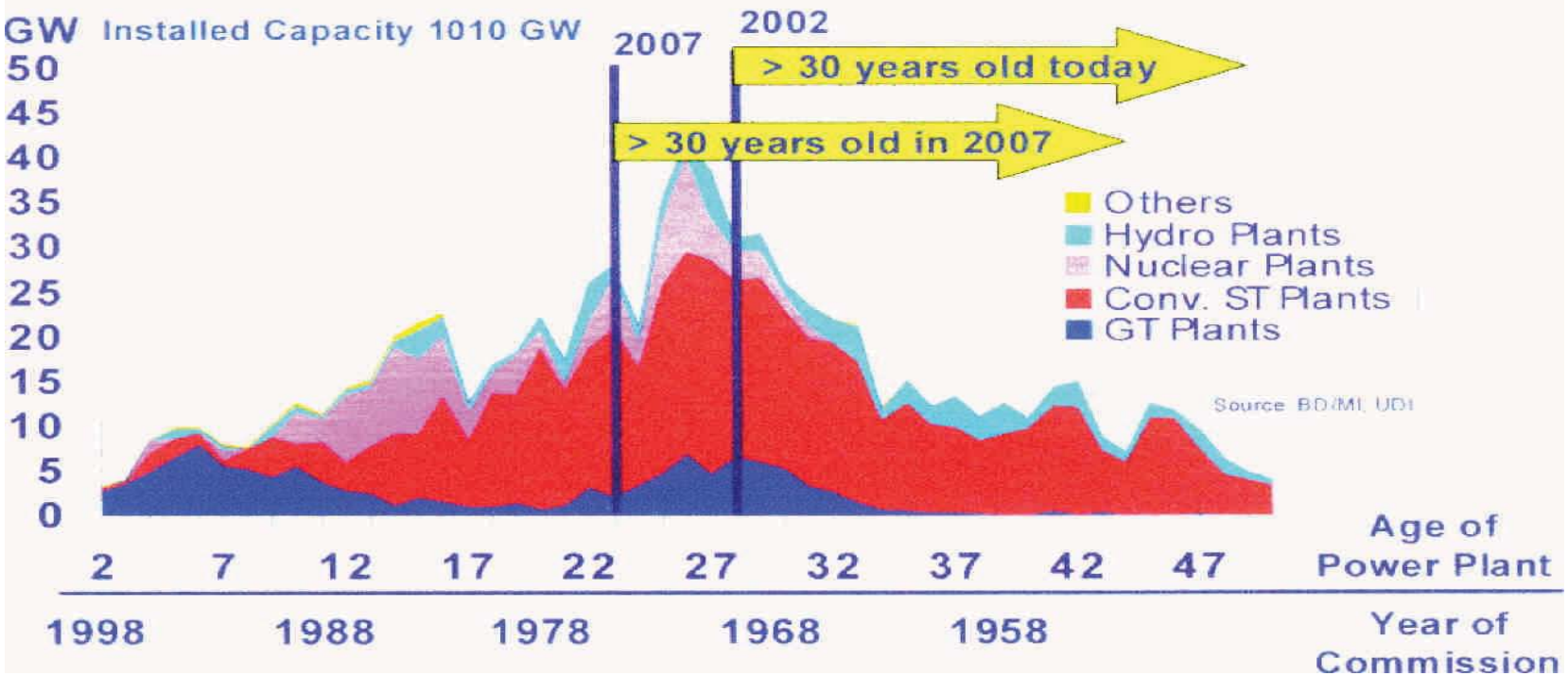
- # Decoupling of Compression Train
- No compressor linkage
  - Completely independent operation of compressors & generation units



- Flexibility in Compression Optimization & Utilization
- Compressors act as load sinks to avoid cycling of base-loaded Plant

Aging USA Generating Fleet

Figure 2: Age and year of commission of U.S. coal power plants. The red portion represents conventional steam plants.



- Replacement with CAES will improve loading & efficiency of advanced coal plants, lower emissions per kW/hr
- Integrate Renewable power with more grid stability

Norton Energy Storage, Ohio. 2700 MW

Nominal 300 MW Units

Large Limestone Mine Cavern
Suitable 1500 psia Charging Capacity
Planned for weekly 5 x 16 hour operations
Stored Energy when fully developed - 43200 MW/Hrs Daily

- Flexible Operation in Multi Unit Plants-

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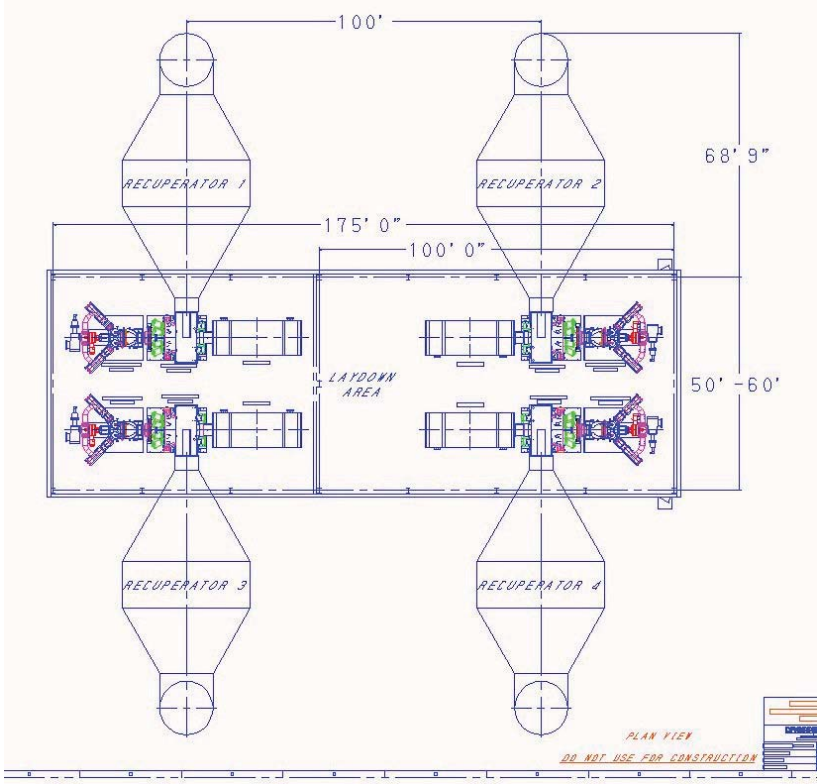
Project Markham 540 MW

Matagorda County Texas - Ridge Energy Services

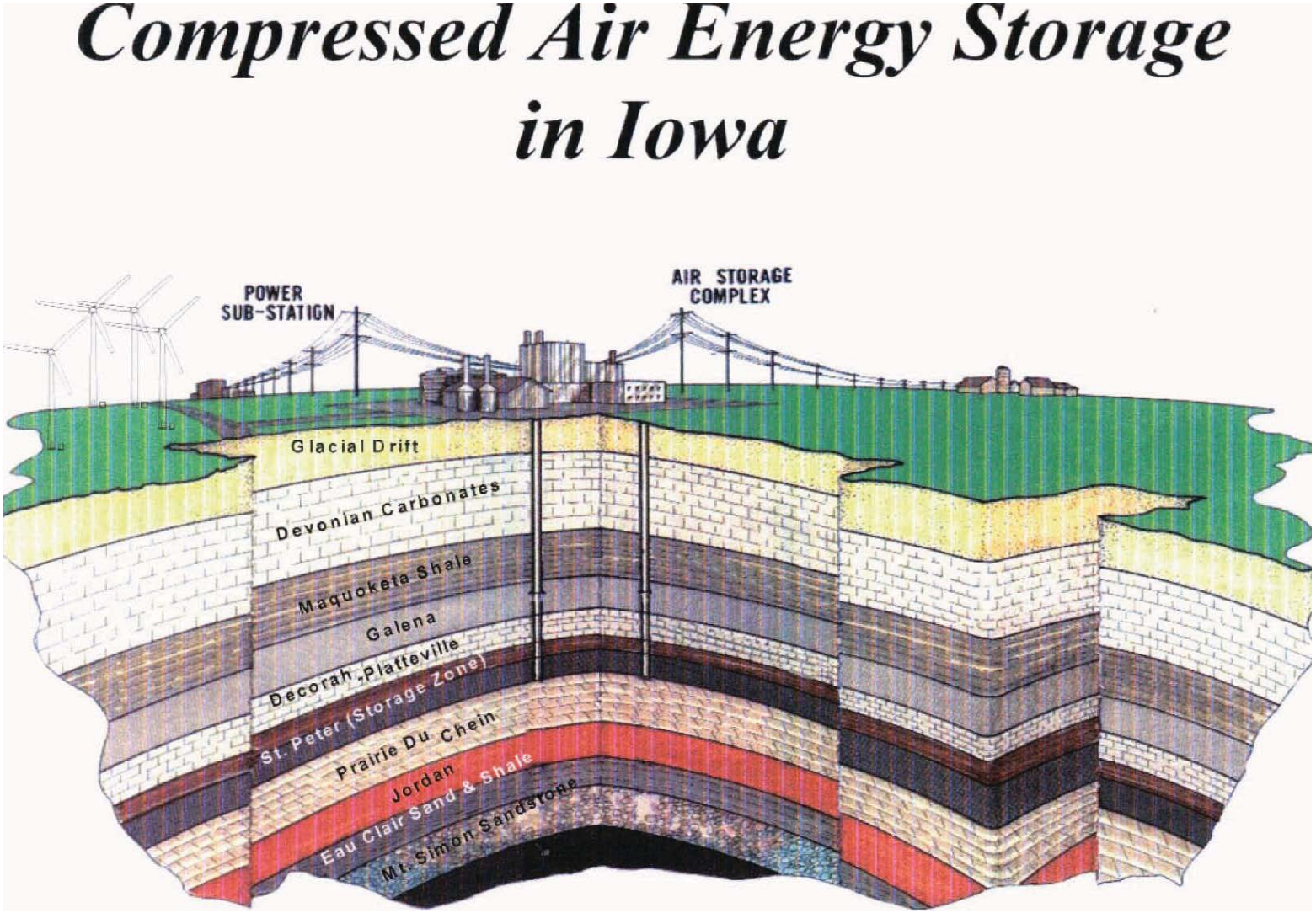
- Bulk Energy Storage
  - **Four x 135 MW**
  - **Dresser Rand Units**
    - **—Wide Load Range - Min 10 MW to full Capacity 540 MW**
    - **—Capacity available in less than 15 minutes**
    - **—Salt Dome Caverns**
    - **—Gas Storage on site**



Iowa Stored Energy Project (ISEP)

- 200 MW CAES Plant Configuration
- 100 MW of Wind Energy
- Aquifer Storage 525 psig(36bar)
- CAES will expand the role of Wind
- Additional off-peak power from fossil
- CAES Plant will operate to follow loads
- Natural Gas Storage in Aquifer for back up in high demand cycle

ISEP Project-Integrated Wind Energy and Fossil Plant Low Pressure Aquifer Storage



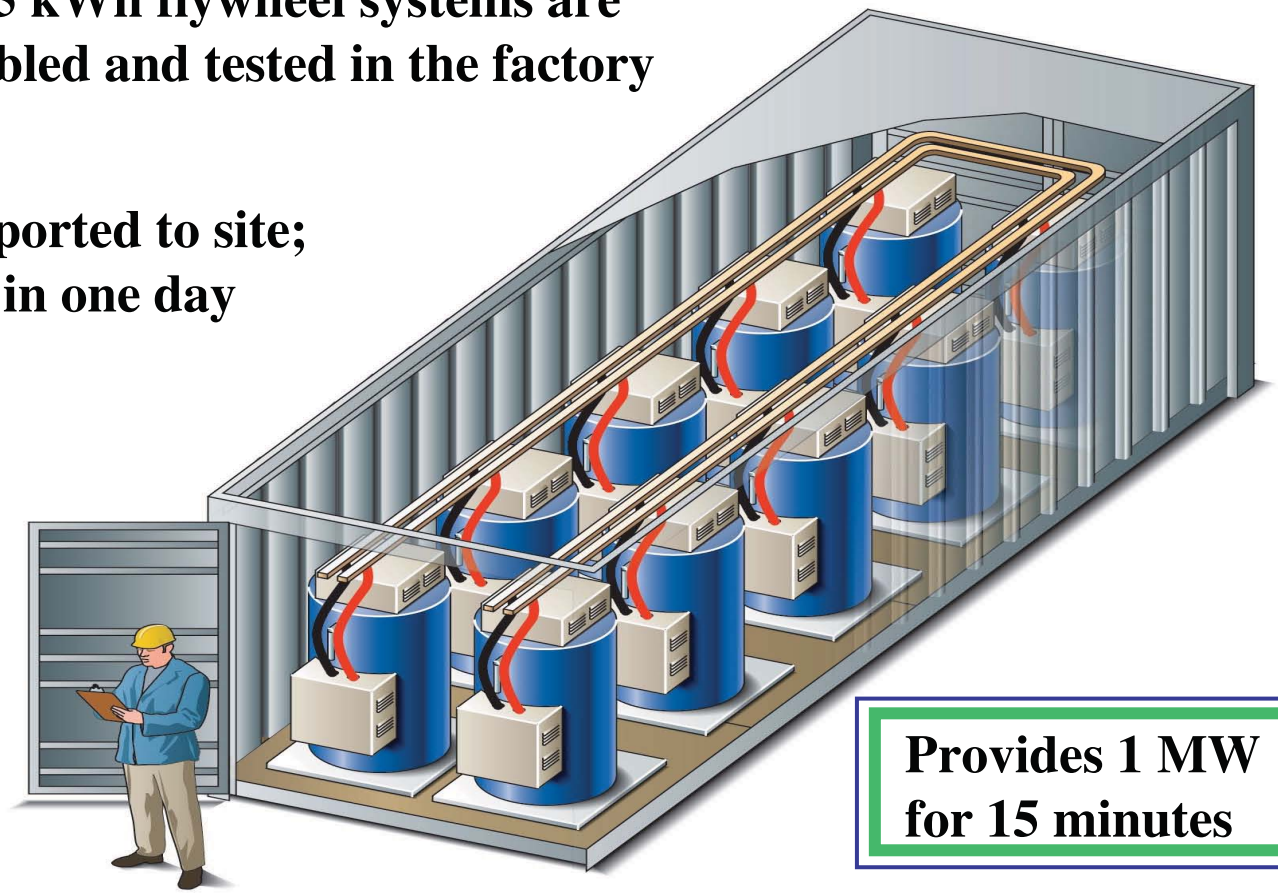
FLYWHEELS *Beacon Energy*

Combining High Energy and Power

- Multiple modular approaches possible
- Utility-grade DG and T&D applications
- Spinning Reserve, Load following
- Frequency and Voltage Regulation
- Bridge to Generator start > 3 Minutes
- Sustainable replacements for battery farms
- Optimum balance of power, Stored Energy, cyclic life, response time , and design life

Smaller Bulk Storage Systems

- **10 x 25 kWh flywheel systems are assembled and tested in the factory**
- **Transported to site; set up in one day**

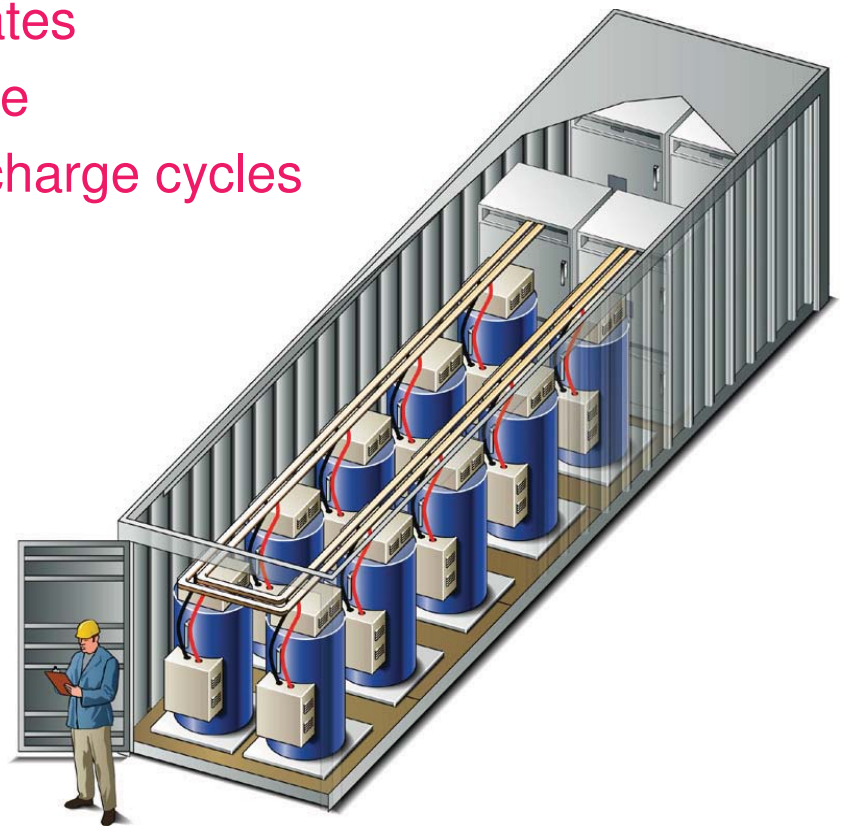


Provides 1 MW for 15 minutes

Smart Energy Matrix

Smart Energy Matrix

- Symmetrical charge and discharge rates
- No degradation with time, temperature
- Capable of millions of full charge/discharge cycles
- Uses no fuel, produces no emissions
- Sub-second response time
- Low Operating Cost
- 20 year life
- No downtime maintenance
- High round trip efficiency
- High availability (10 redundant units)
- Sustainable Green technology
- Predictable operation
- Uses commercial electronics for grid connection



Flywheels are a true "working storage" device

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Typical 40 MW Modular Layout

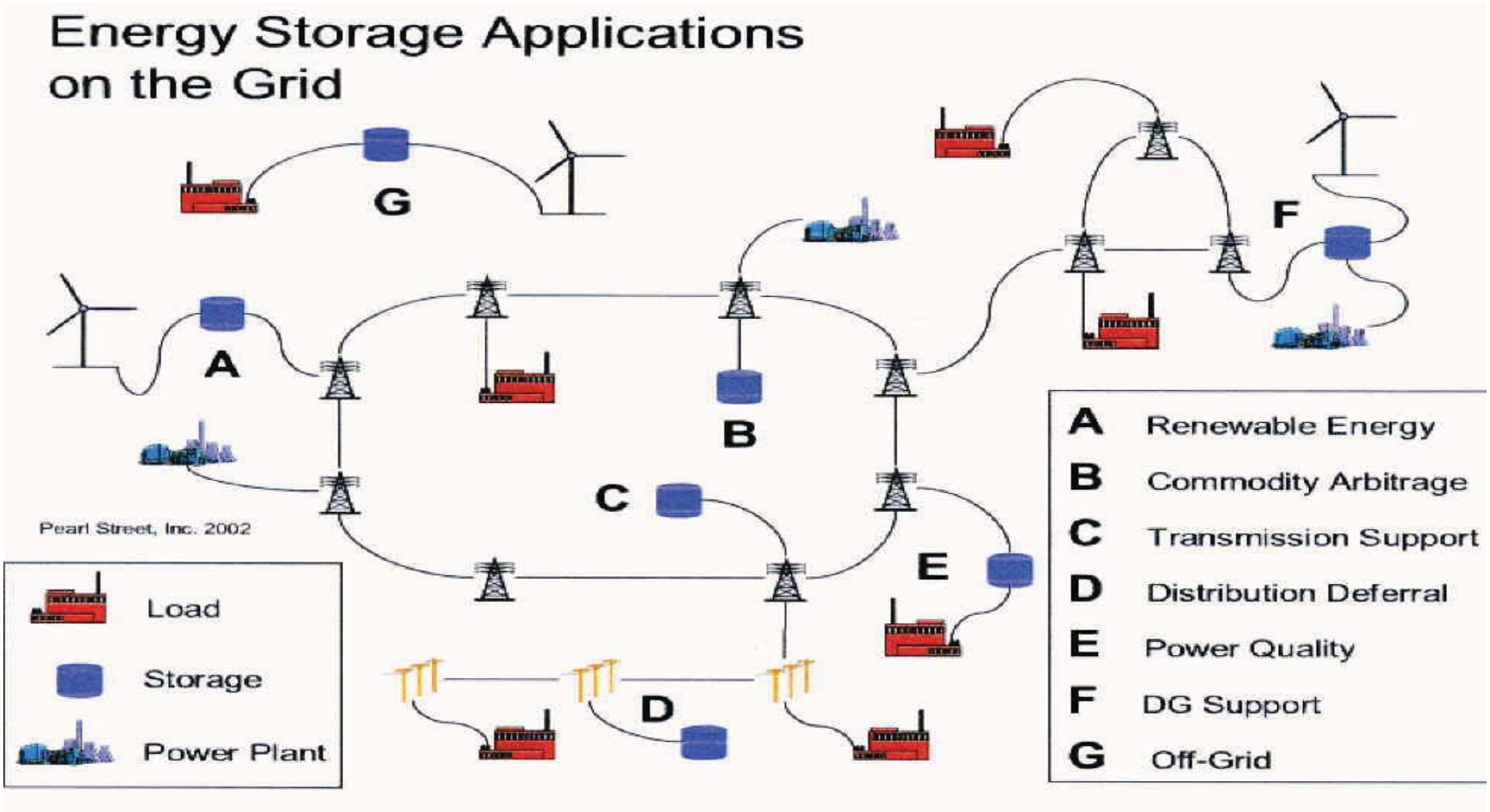
Pictures are actually of containerized 1 MW generators. SEM installations would have similar look

Flexible modular SEM are attractive, green alternatives to "battery farms"

Stored Energy Applications

- The ability of various technologies to react quickly—converting stored energy back to electricity—provides three primary functions.
- Energy Management (hours of duration) load leveling-peak periods
- Bridging Power(seconds or minutes duration)- continuity of service
- Power Quality & Reliability (milliseconds to seconds duration)-in support of manufacturing facilities voltage and frequency control

Energy Storage Applications on the Grid

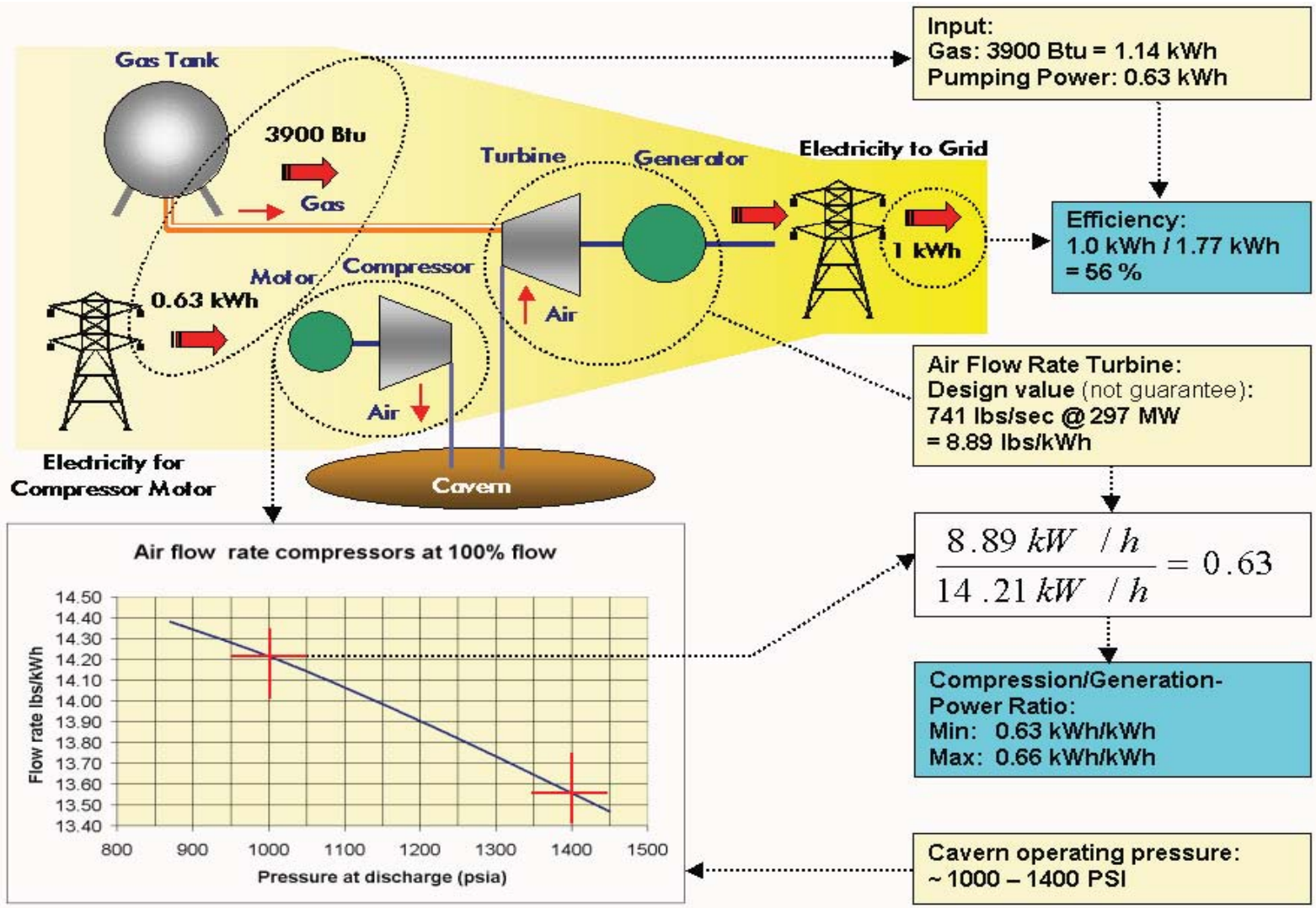


Benefits from Energy Storage

- Four Major areas of Electricity Supply Chain;
- Generation. Transmission & Distribution
  -Energy Services. Renewable Energy.

- Projected Benefits-15 year period for US Generation and T&D—could exceed $100Billion
- Fully Utilize capital assets—increase Plant CF above 58/60%--Increase Transmission above 50/52%
- Allow most efficient units to be fully-utilized
- Avoid the use of inefficient Plant
  -using premium fuels (during peak periods)

CAES-Economics Compression/Generation Power Ratio



Market Potential

- CAES Power Modules 100 to 300 MW – Competitive with CC Plant for Mid Range 4200Hrs/yr
- Coal and Nuclear Base load plants produce 72% of Electric Energy in US
- Plants are excessively cycled to meet load demand (*aptech study*)
- **Goal of 5% of 1000 GW base-50GW Potential**
- Available Storage sites readily account for 15/20GW –next 10/15 years(*Map*)

Market Potential

- CAES- Identified Sites

STATE	MW
CALIFORNIA	1200
MICHIGAN	600
WEST VIRGINIA	300/900
TEXAS	1200
TEXAS	1200
TEXAS	2400
TEXAS	600
TEXAS	900
NEW YORK	600
WYOMING	900
UTAH	600
COLORADO	300
MINNESOTA	600
ILLINOIS	200
INDIANA	600
IOWA	600/1200
OHIO	3600
ONTARIO	300

4 Known Developers

17,900 MW
Potential 5% of Installed Base
1000 GW = 50GW
50,000 MW
2020 Wind Energy= 30GW
Storage for Wind= 15GW
15,000MW
2020 Potential Total
65,000MW

US Siting Potential for CAES

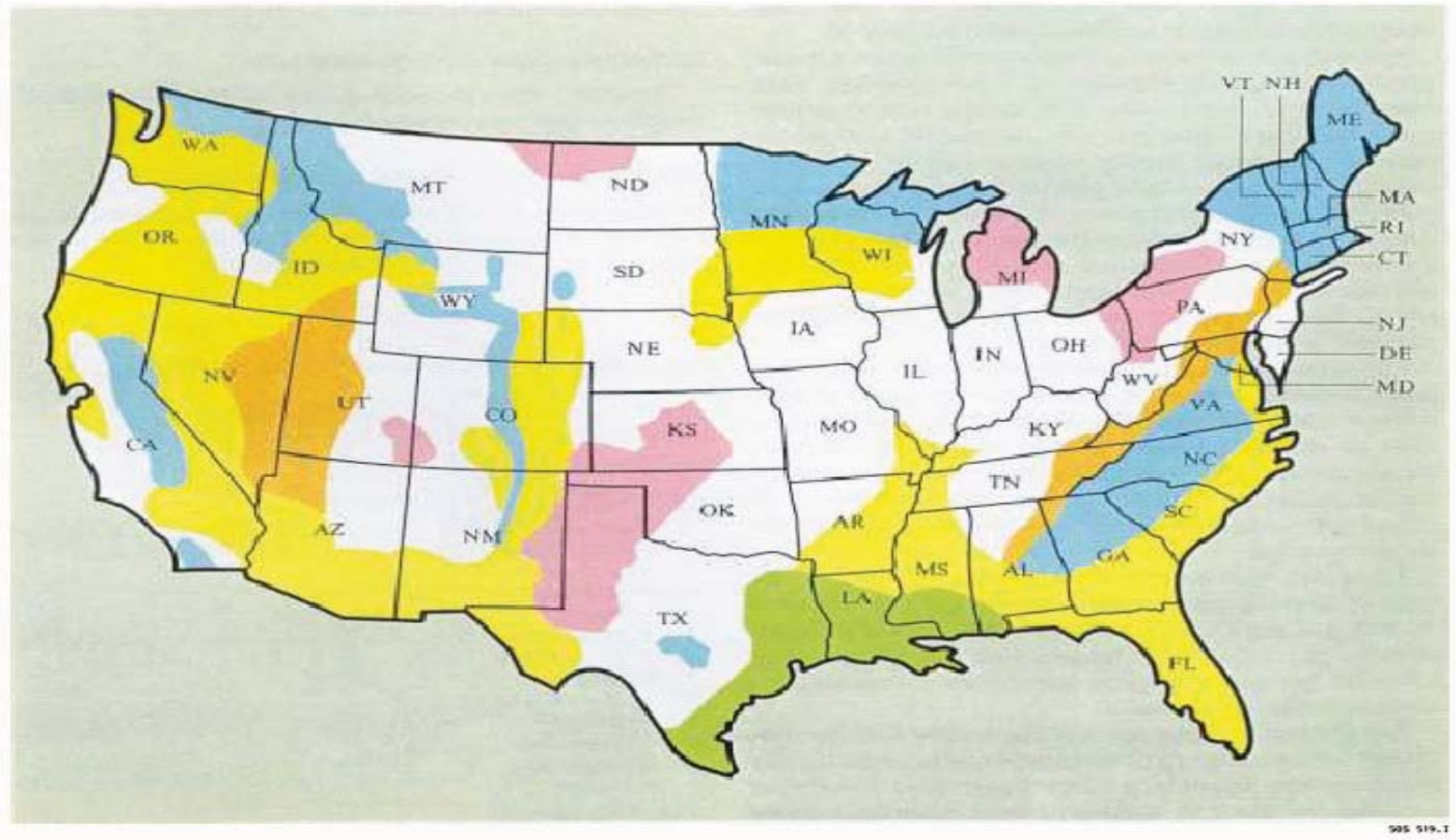
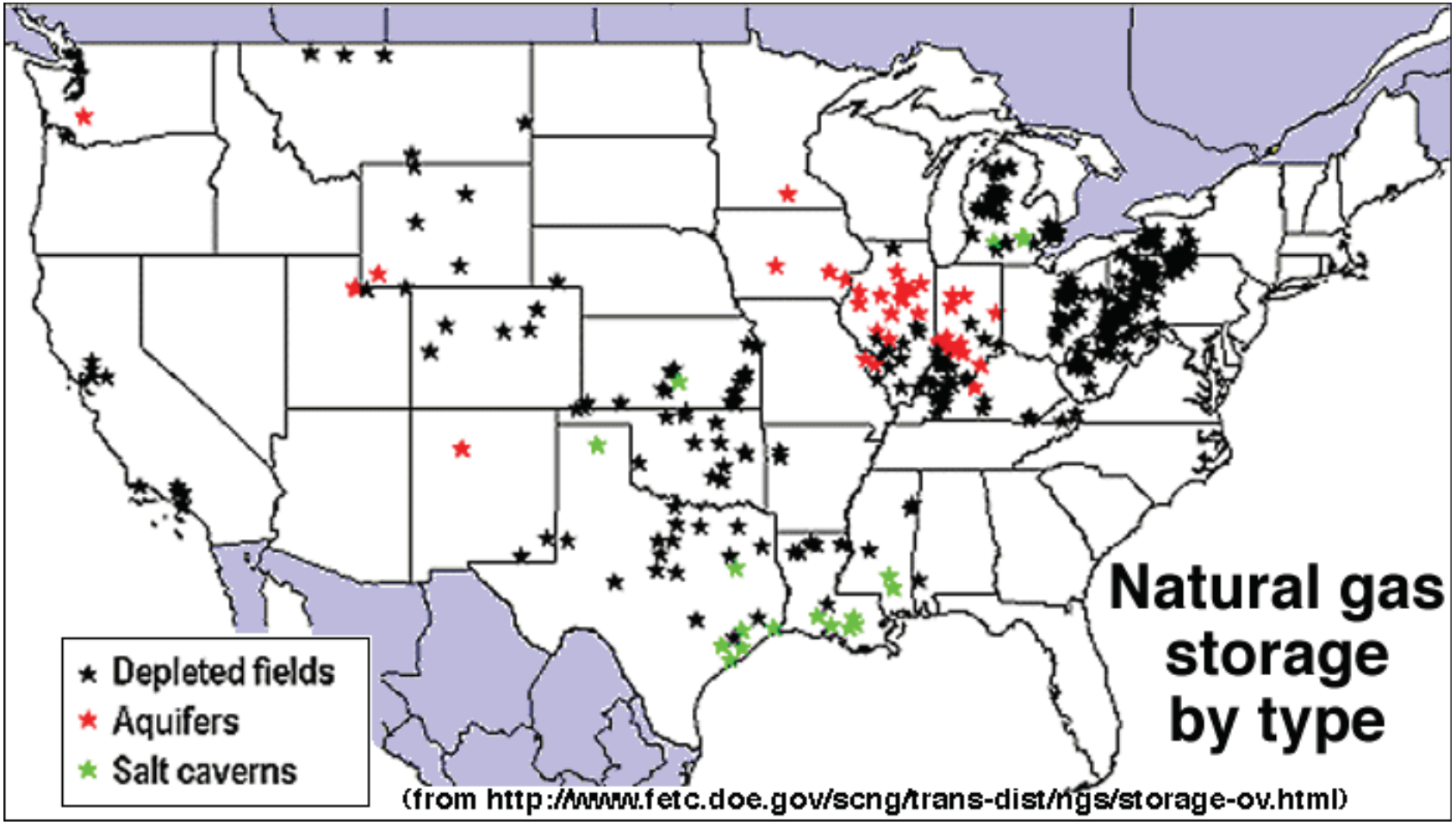


Fig. 3 – USA areas classified for subsurface storage

- Salt domes—most favourable for solution cavities
- Salt beds—favourable for solution or mined cavities
- Sedimentary—favourable for mind cavities
- Granitic, plutonic—favourable for cavities in hard rock
- Sedimentary—injection in porous rocks. Limited to favourable structure
- Volcanic and sedimentary—not favourable

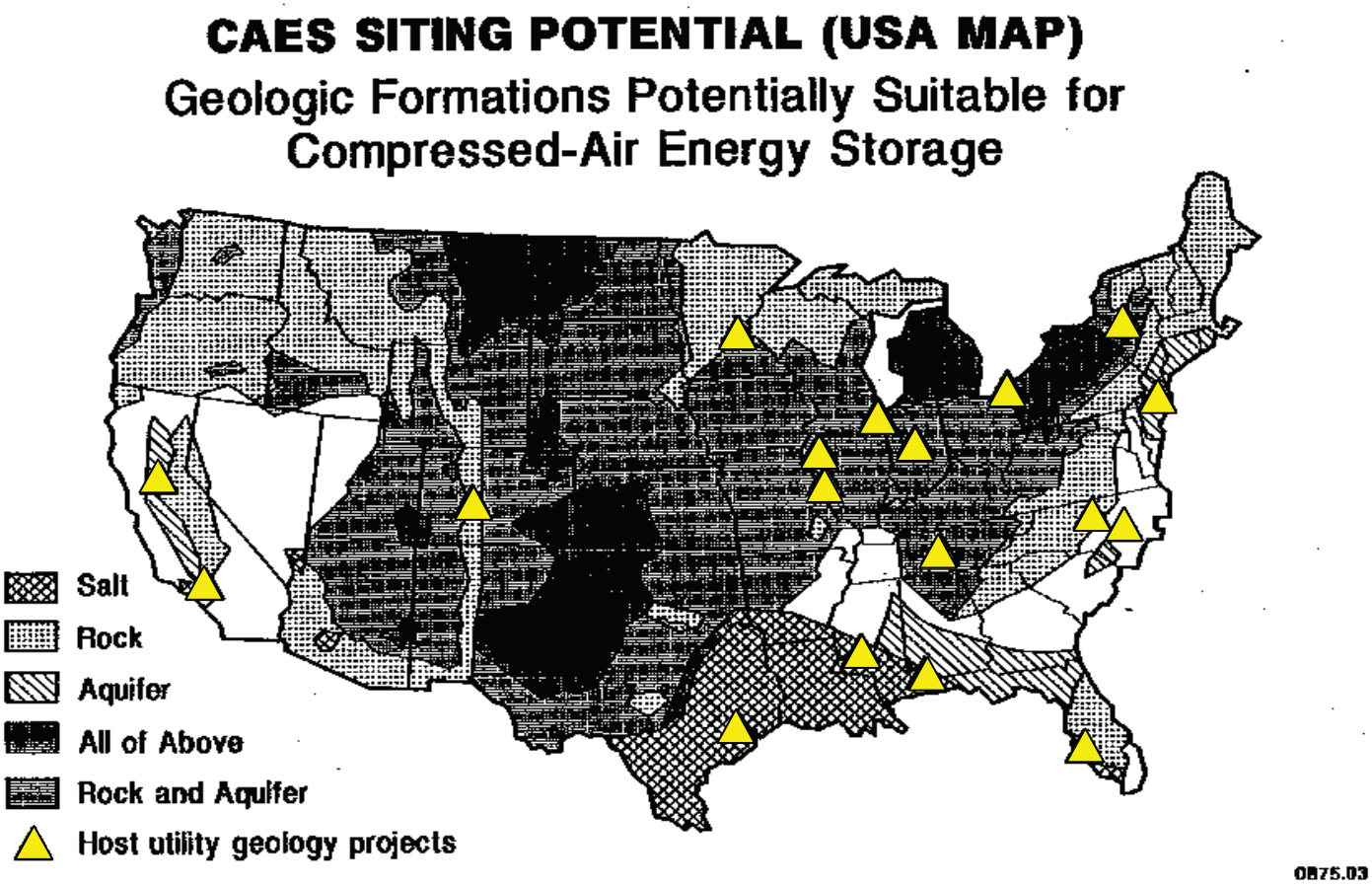
Comment on Sedimetary: **Light Brown** fromAL to NY- & straddling NV and UT into AZ

Natural Gas Storage



Suitable Geological Formations

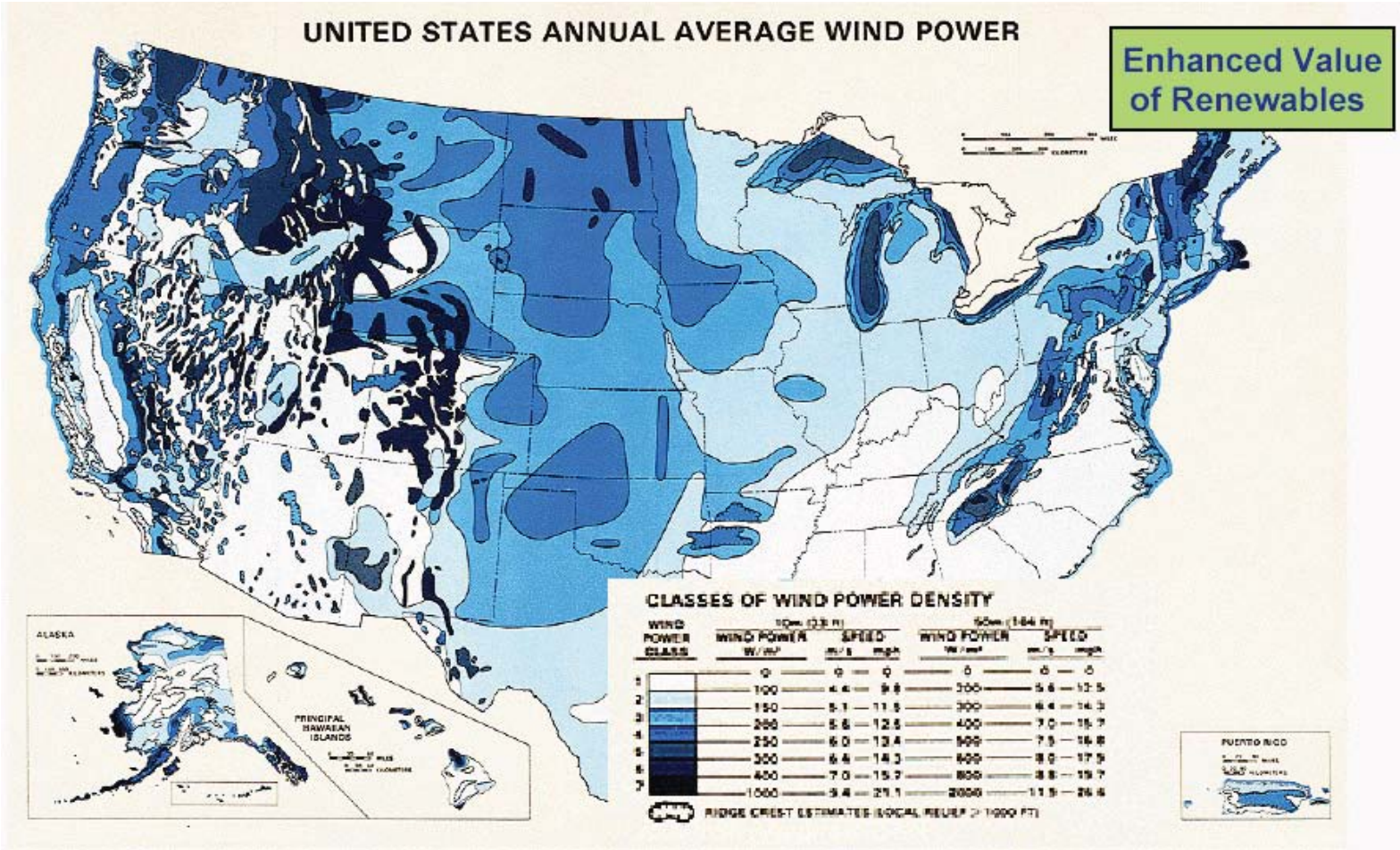
- Host Utilities *Former Studies*



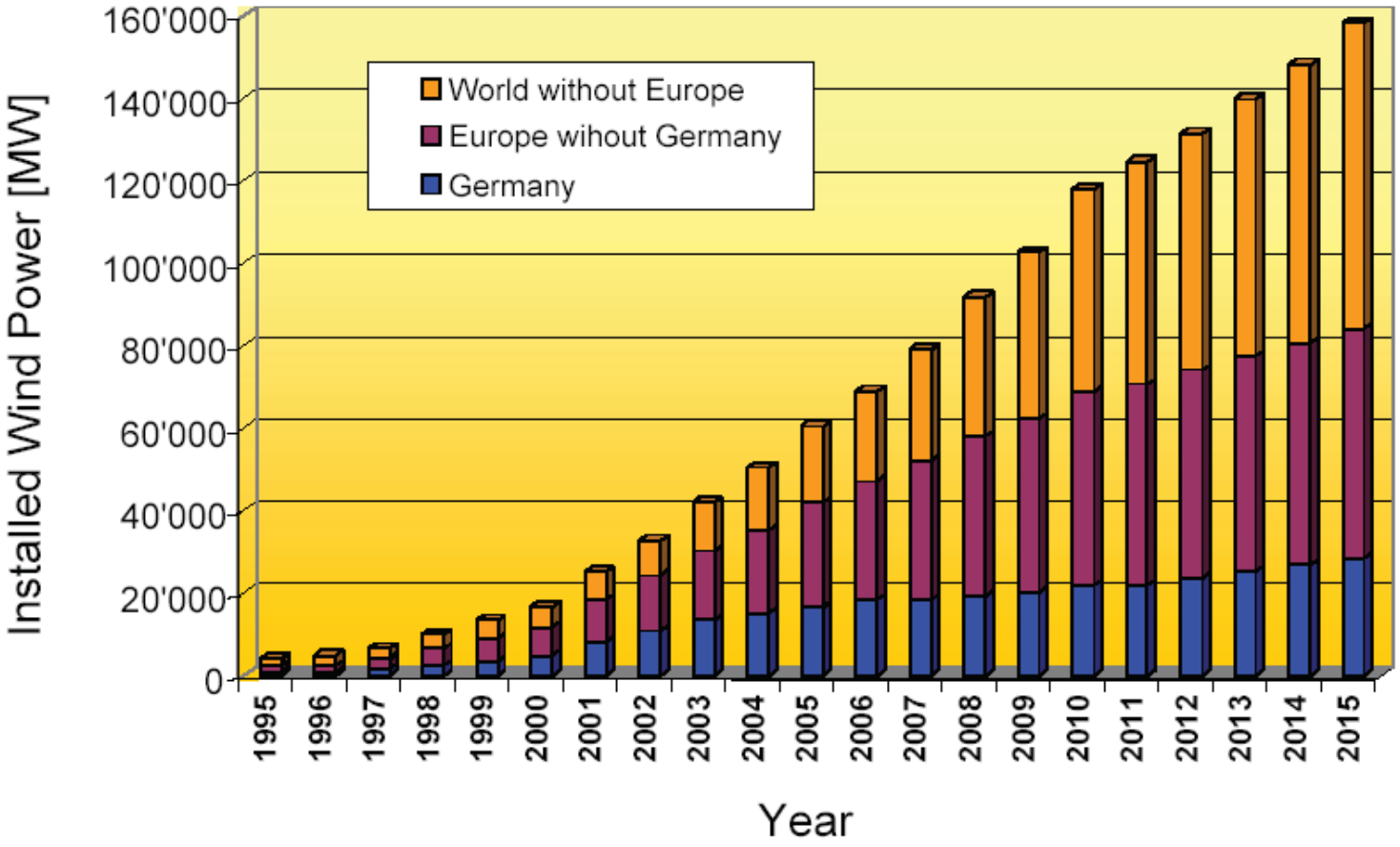
Future Prospects (Developments)

- PHS has clearly demonstrated the value of-
  Bulk Energy Storage.
- Benefits recognized-new facilities languish-projects in development show promise
- New Concepts proposed, with growing capacity of Wind Energy 6700 MW-capacity factor > 30%
- SSCAES—Pipe Storage
- Stored Air Injected in existing GT plant
- Hybrid GT/CAES concepts
- Storage Enhanced IGCC systems
- Advanced Adiabatic Compression and Expansion (TES)
- Further Developments-Flow Batteries and High Power density Flywheels
- Hydrogen Storage

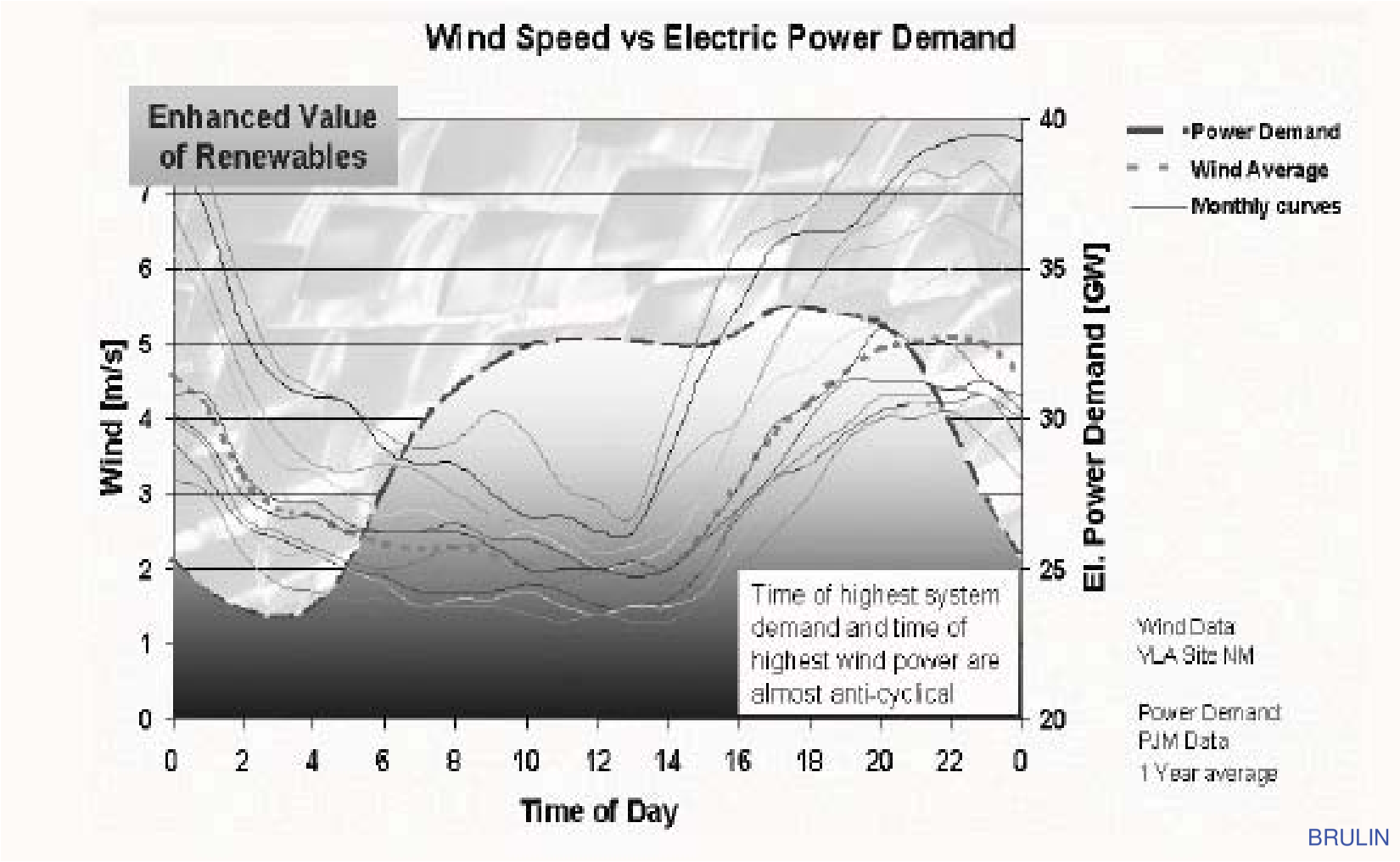
Storage-Enhanced Value of Renewables



Global Wind Power-MW

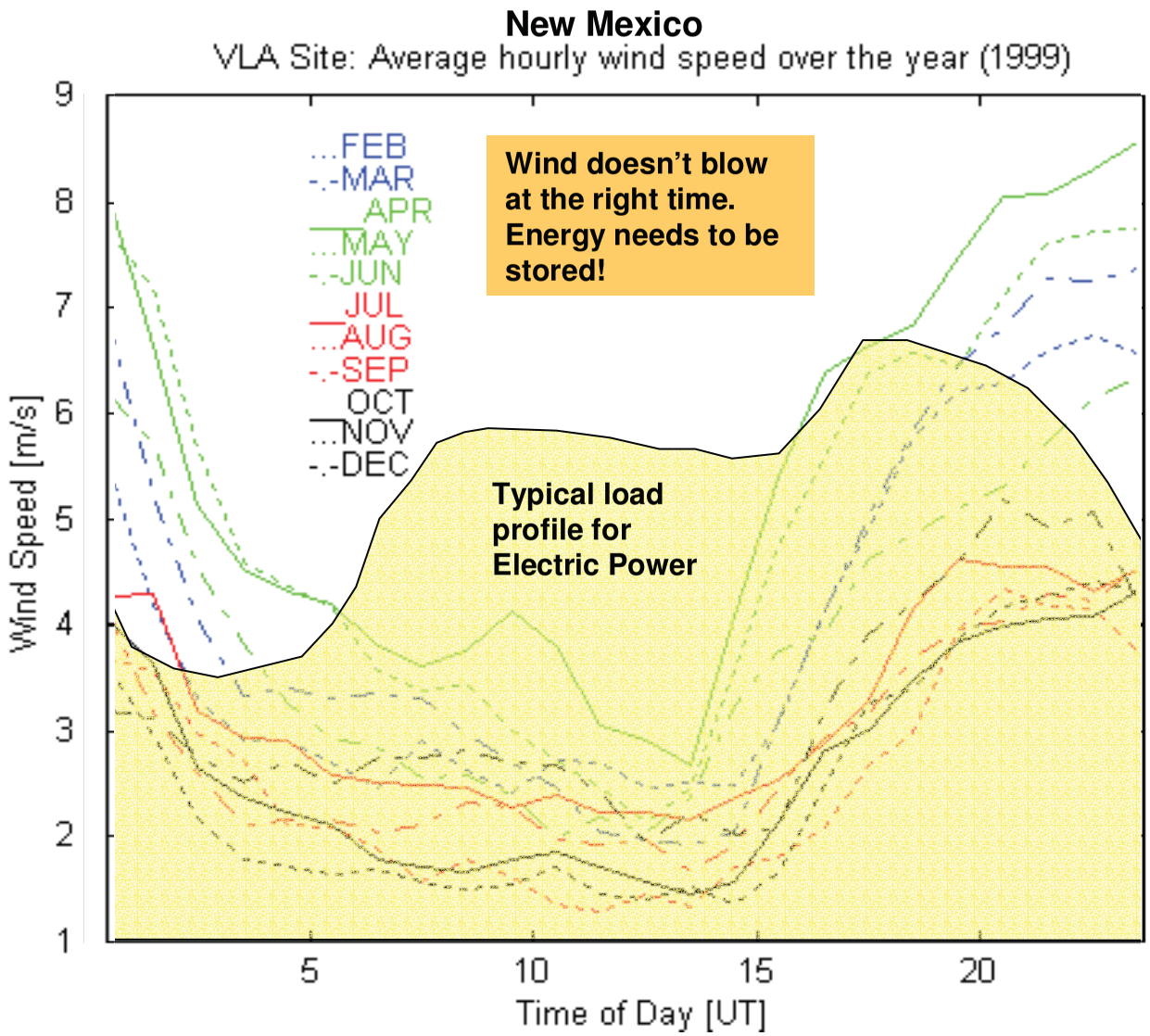


Enhanced Value of Renewables



Annual Variable Wind Power

- **Wind**



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Storage-Can Benefit Wind Energy Production

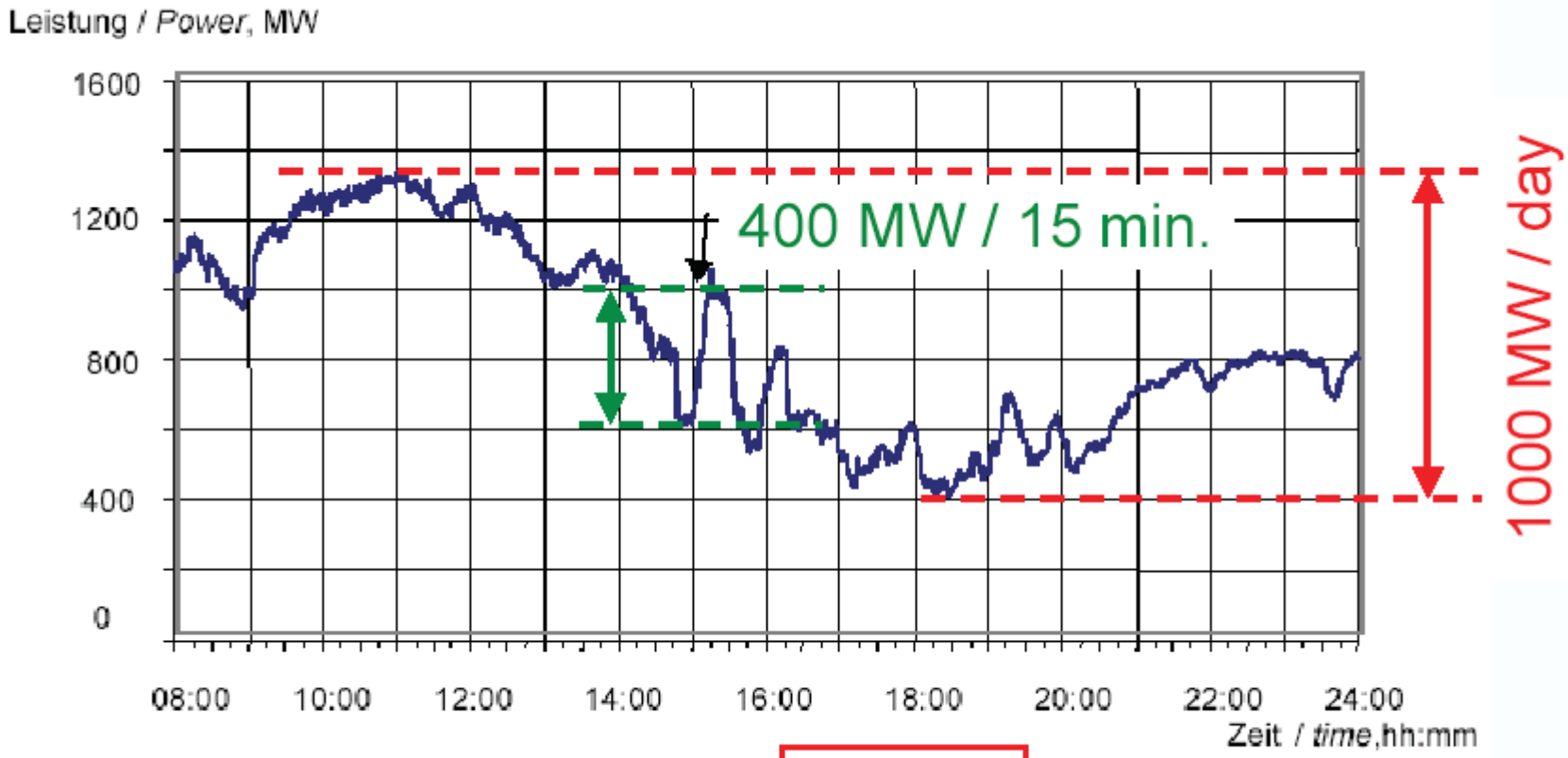


Abb. 2: Windenergieeinspeisung am 03.12.1999
Fig. 2: Wind energy production on 03.12.1999

From e-on

CAES-Reactive Power & Voltage Regulation

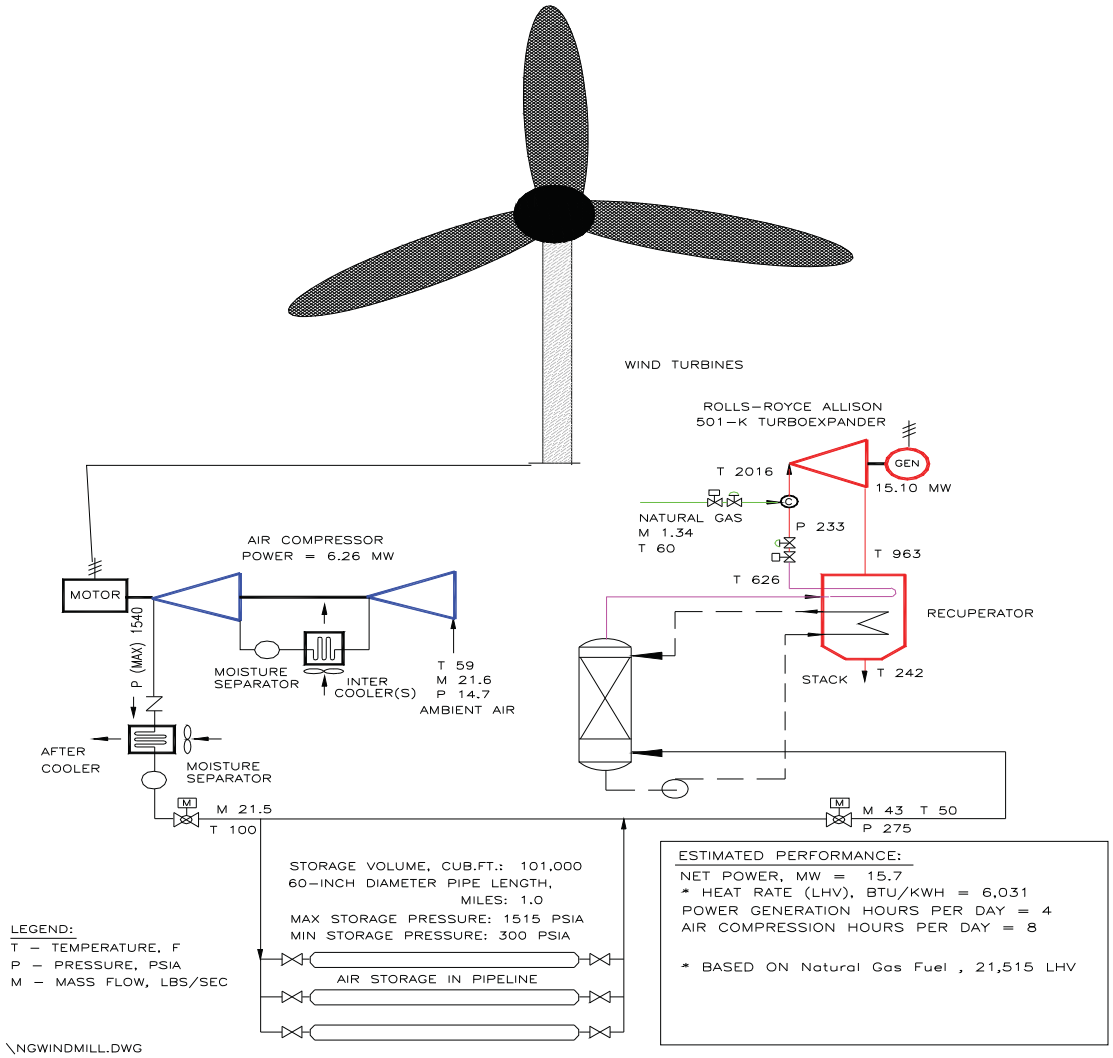
- Reactive Power & Voltage Regulation within grids with high Wind Turbine energy contribution are a challenge
- **Reactive power capability of wind turbine generators**
  - **None with asynchronous generators**
  - **limited with synchronous generators and frequency converter (cos phi ±0.975)**
- **In case of a large amounts of power delivered from wind turbines, thermal plants need to be shut down and can no longer contribute reactive power to the grid**
- **Voltage regulation becomes a challenge**
- **Offshore wind turbines with long AC connections to the grid require a high generation system supply capability for reactive power**

➔ **CAES can provide a substantial contribution to reactive power and voltage regulation**

Technologies

- SSCAES- Pipe Storage Technology
- Wind Energy Integration
- Land Fill Gas (LFG) Utilization
- Air Injection Technology-Using Storage
- Flow Batteries—Chemical Storage

Heat & Mass Balance—Integrated Wind/CAES with Air Humidification



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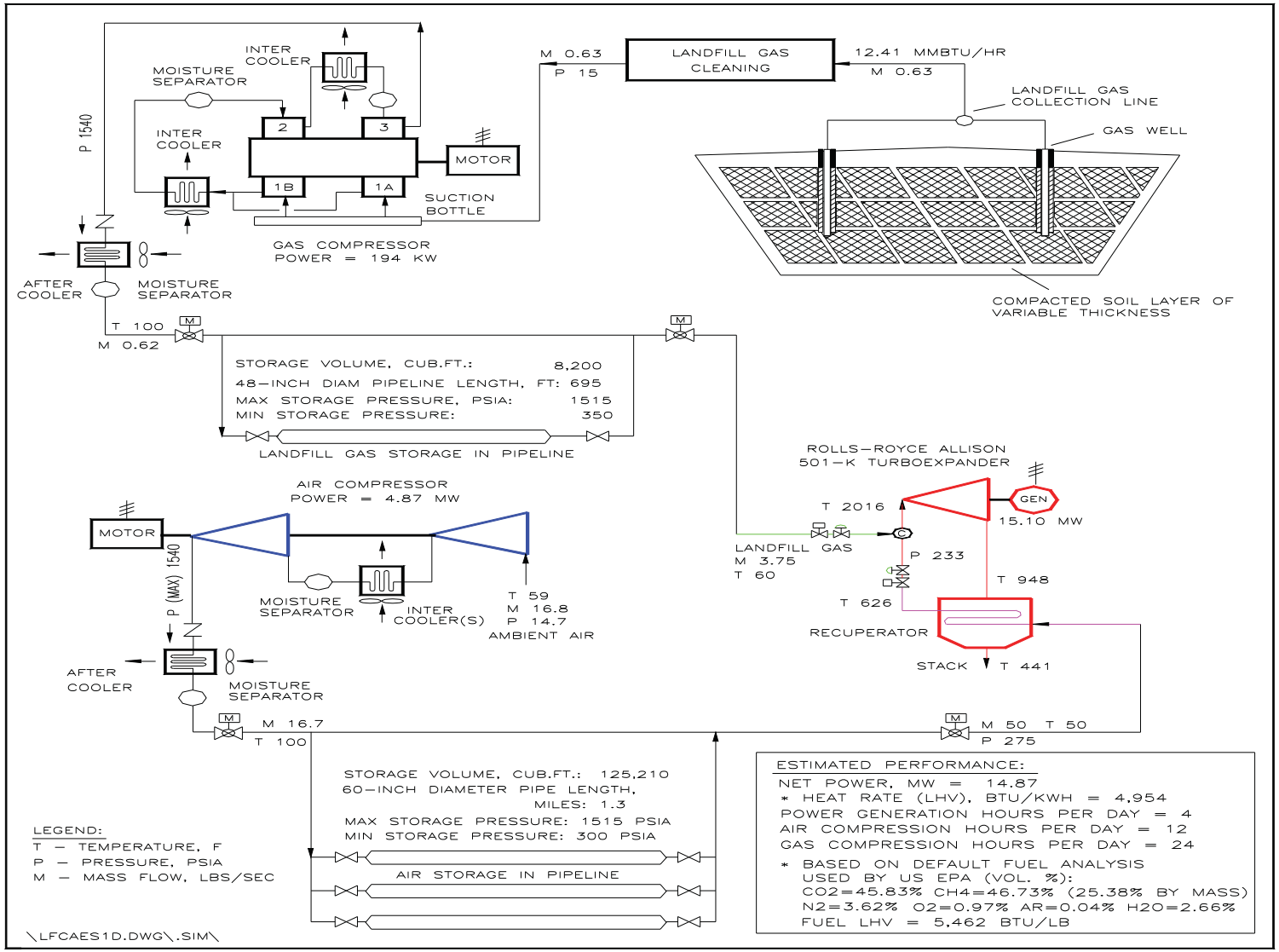
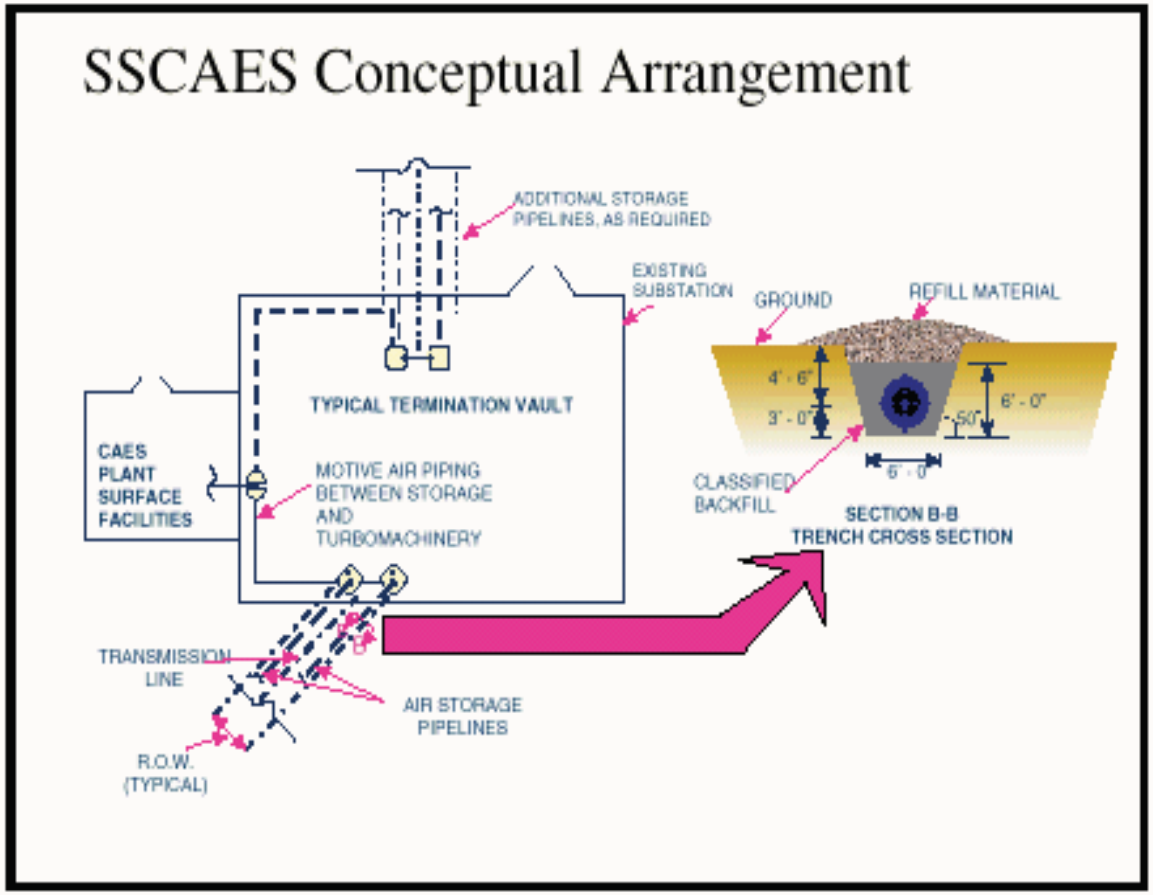
Heat & Mass Balance-SSCAES-LFG Capacity 13MM BTU/hr



Sub Surface Pipe Srorage

Figure 7.

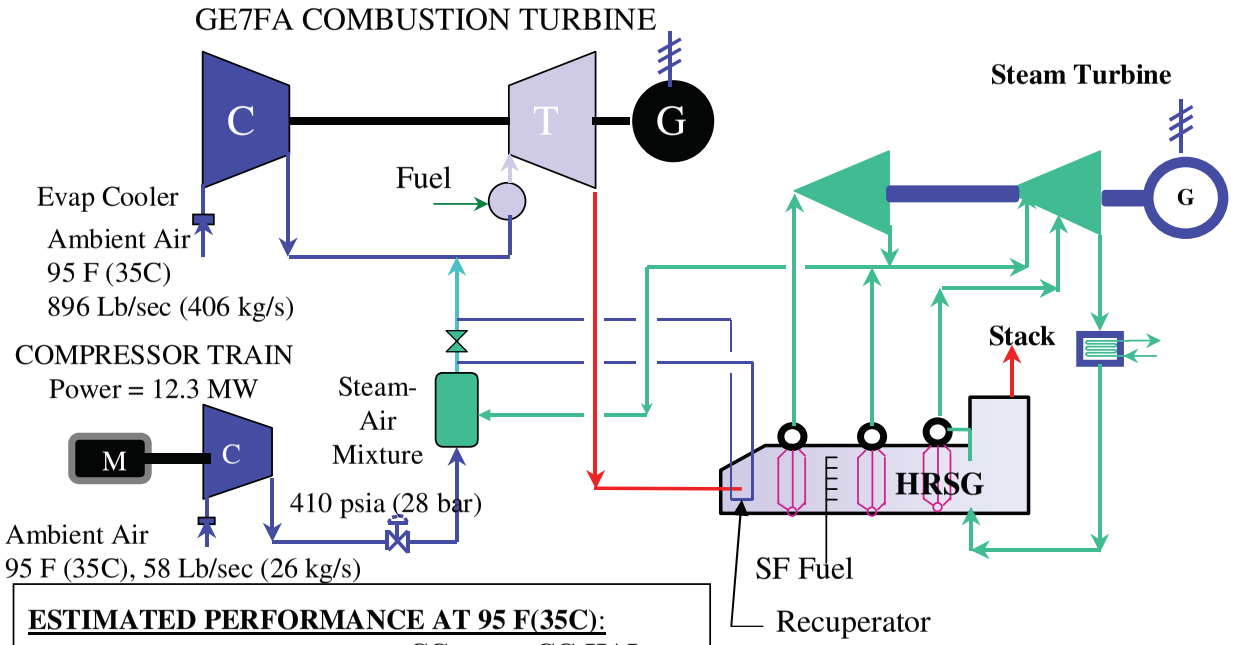


Pipe Storage Technology

Existing storage technology
Burried gas storage near Zurich, Switzerland
Operating pressure 1000 PSI

Humid air Injection Technology

CC-HAI at Sea Level

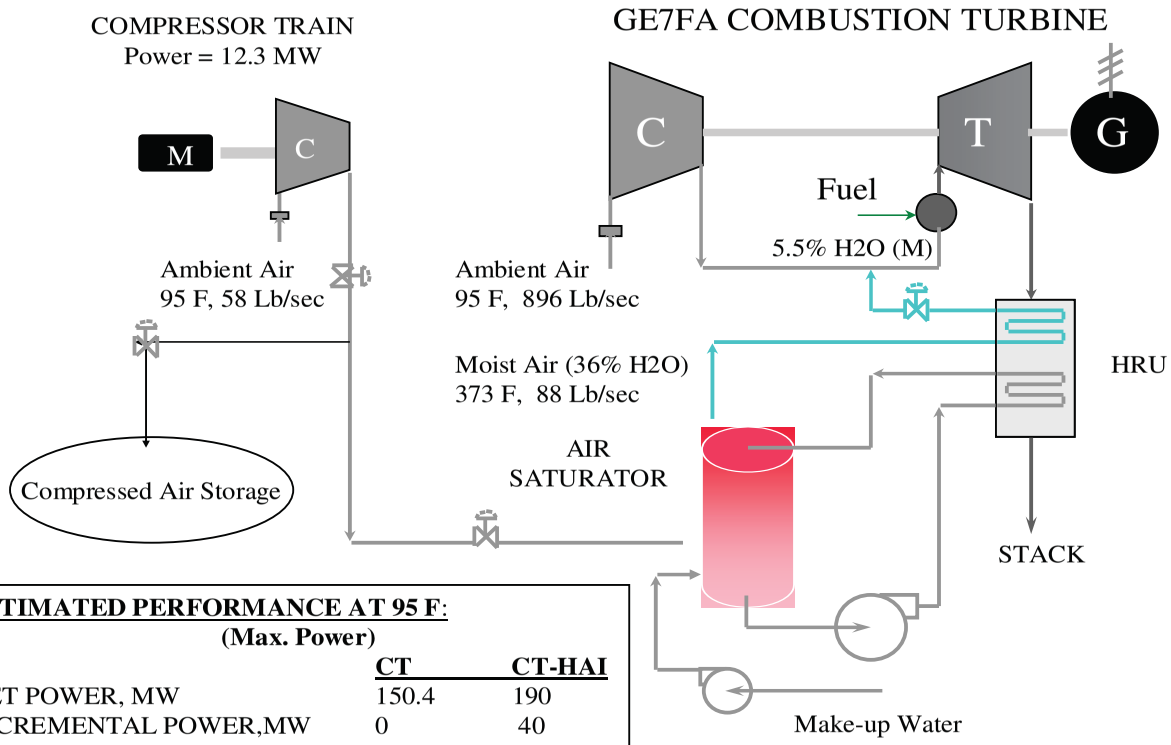


ESTIMATED PERFORMANCE AT 95 F(35C):

	CC	CC-HAI
NET POWER, MW	221	250.3
INCREMENTAL POWER,MW	0	29.3
NET HEAT RATE, Btu/kWh	6,508	6,.690
kcal/kWh (LHV)	1,640	1,686

Humid Air Injection using Air Energy Storage

CAES-CT Concept with Humidification based on GE 7FA CT

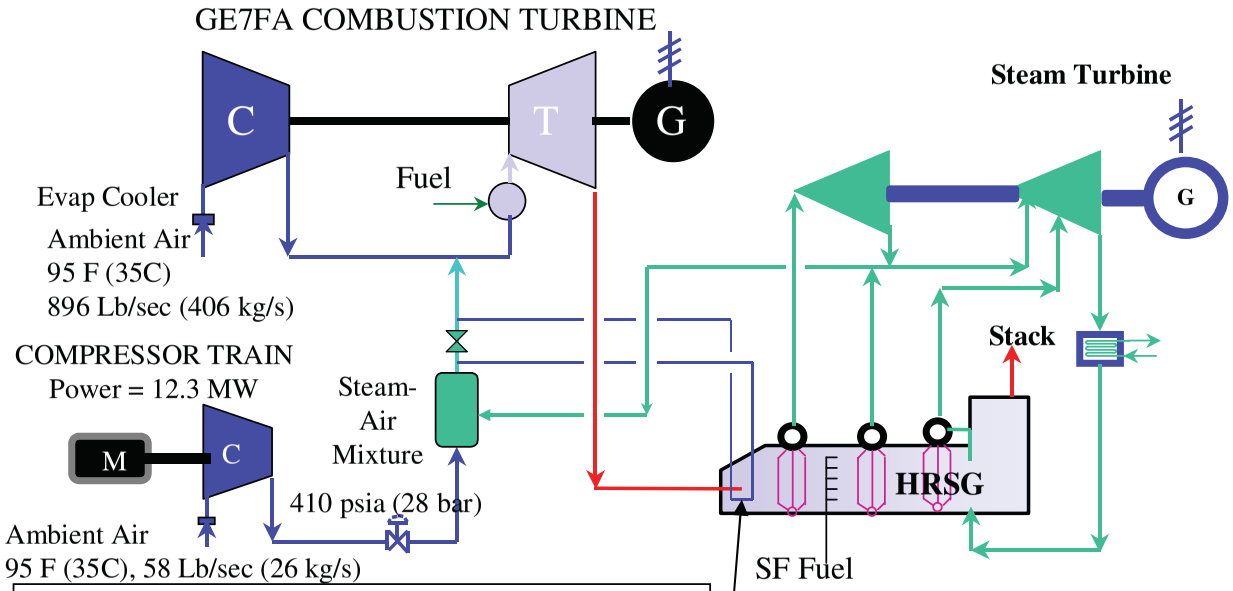


ESTIMATED PERFORMANCE AT 95 F:
(Max. Power)

	CT	CT-HAI
NET POWER, MW	150.4	190
INCREMENTAL POWER,MW	0	40
NET HEAT RATE, Btu/kWh (LHV)	9,760	6200

Air Injection Technology applied to CC

CC-HAI at Sea Level



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With Air Storage the CC output increases by another 12 MW

Conclusions

- The current storage concepts are ready for deployment
- Storage needs to be implemented World Wide
- The Trend of increased Wind Harvesting will put further stress on grid Reliability
- Bulk Energy Storage-most importantly will “buffer” Utilities from lack of spinning Reserve and load following capability
- Energy Storage provides:

Conclusions

Energy Storage provides :

- Security
- Reduces Transmission constraints
- Extends the capabilities of efficient Plant
- Reduces Emissions
- Enhances Renewable Energy
- Load management-(rapid response)-Frequency & Voltage Control-Spinning Reserve-Black start & supports Distributed Generation.

Potential in US is under estimated –

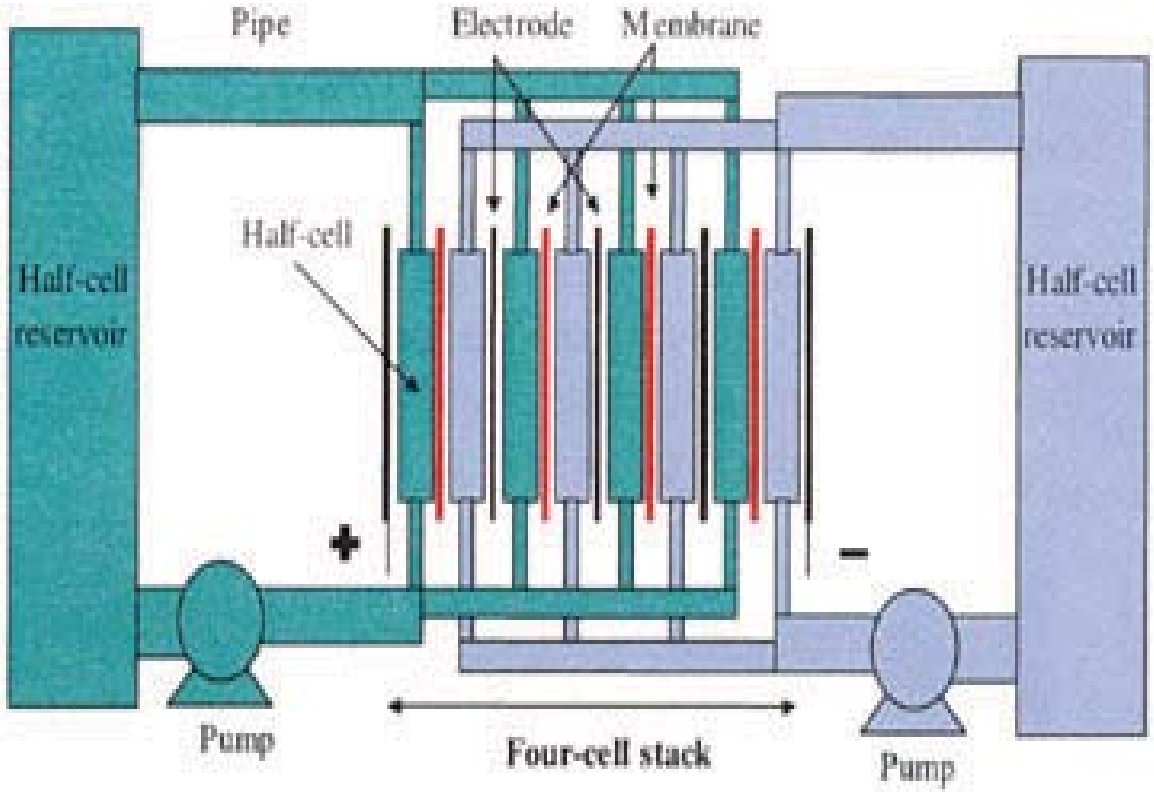
100 GW can be achieved—especially as PHS is limited.

APPENDIX

- Vandium Redox Flow Battery
- MW in a Box –Flywheel
- Cycling Costs
- CAES Start Stop Cycles

Vanadium Redox Flow Battery -VRB

120 MW/HRS



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Regenesys Flow Battery-*Columbus TVA*

- **Reinforce Transmission Grid**
- **120 MW/HR Capacity**
- **Electrolyte Storage 2 x 70,620 Cub/.Ft Tanks**
- **High Power Quality to US Air Force Base**
- **On-line 0.02 sec. response**

Project Stopped

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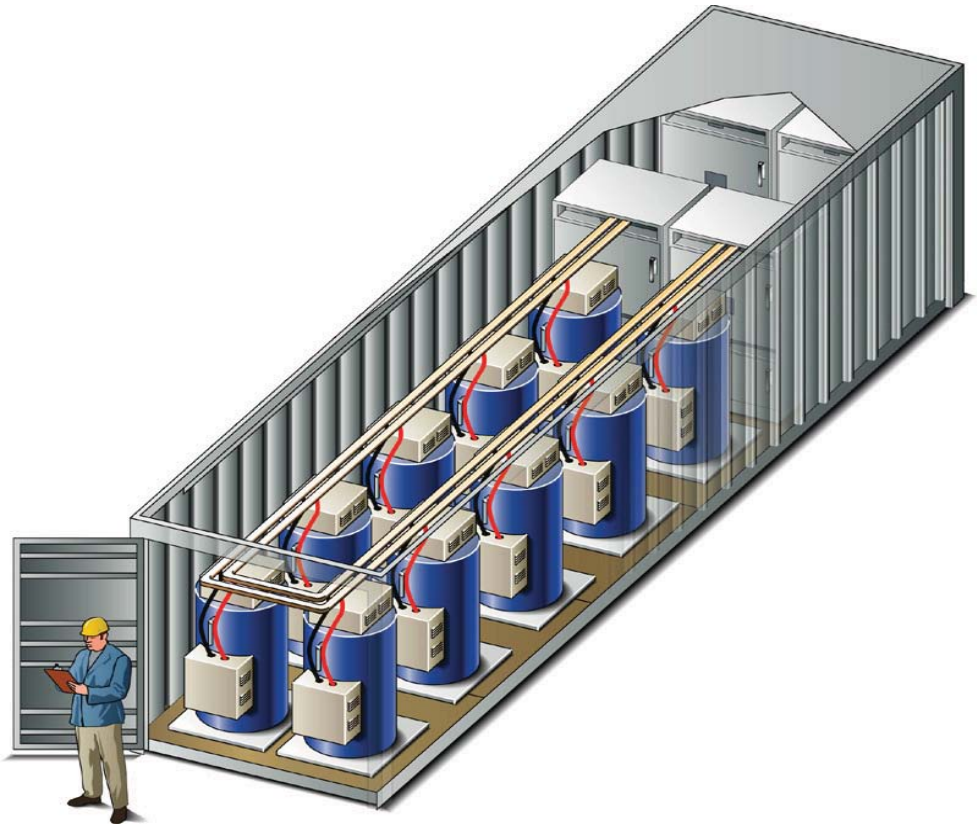
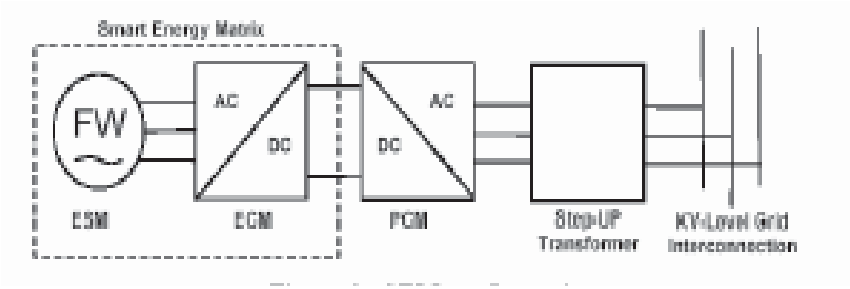
Megawatt in a Box- Flywheels

- "Megawatt in a Box"
  - 10 (25-kWh) Smart Energy flywheels
  - 1 MW for 15 minutes
  - Excellent deep discharge and high cyclic characteristics
  - Quick connection, highly mobile
  - Uses Beacon's core technology
  - 20 year life
  - Delivers both Real and Reactive Power





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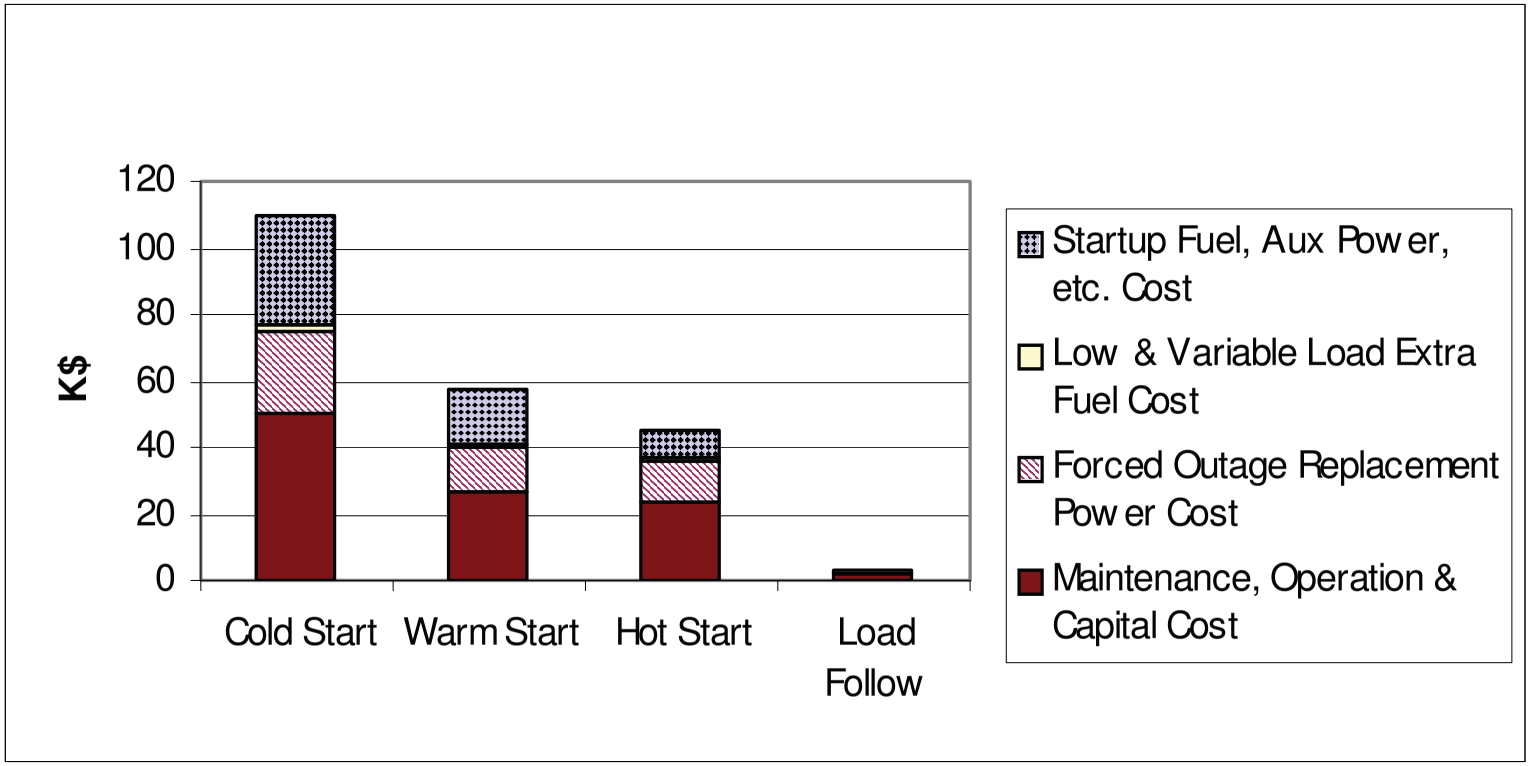
Cycling Costs--APTECH

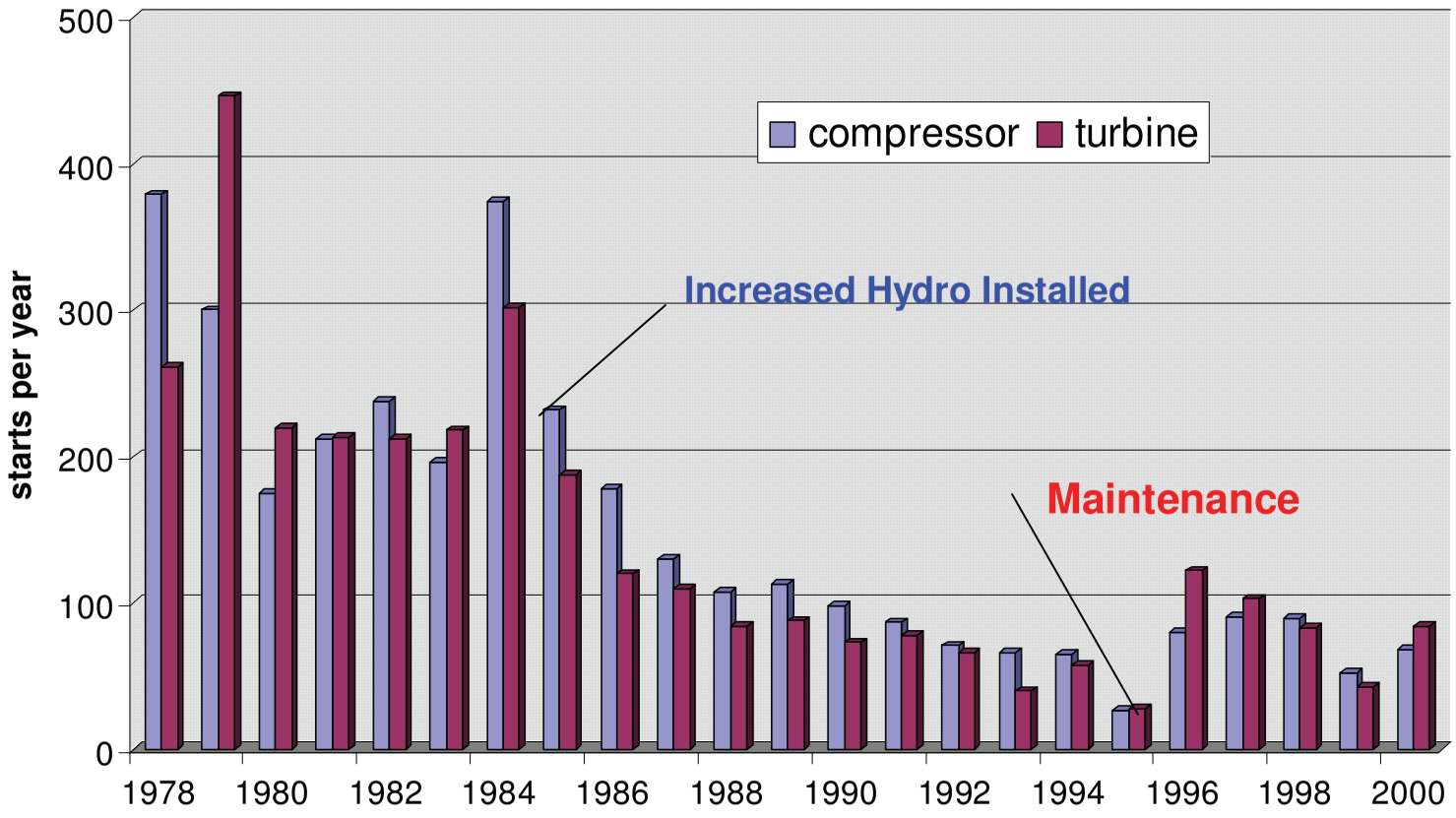
Unit Type	Typical Cycling Cost Now Used*	Range to True Cost
Small Drum	$5,000	$15,000 — $100,000
Large Supercritical	$10,000	$50,000 — $300,000
Gas Turbine	$100	$300 — $10,000

Cycling Costs

- **Aptech Research**



Huntorf Power/Compression Start Cycles



Start Cycles from 2000 to 2004 remain low—Plant gets Capacity Credit