APL000046
10/21/11

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

Septimus van der Linden

President, BRULIN Associates, LLC.

ECOS2004
energy
economy
ecology
Guanajuato - México

17th International Conference on
Efficiency, Costs, Optimization, Simulation and Environmental Impact of Energy and Process Systems

Hotel Real de Minas – Guanajuato, México
July 7 – 9, 2004

# 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.

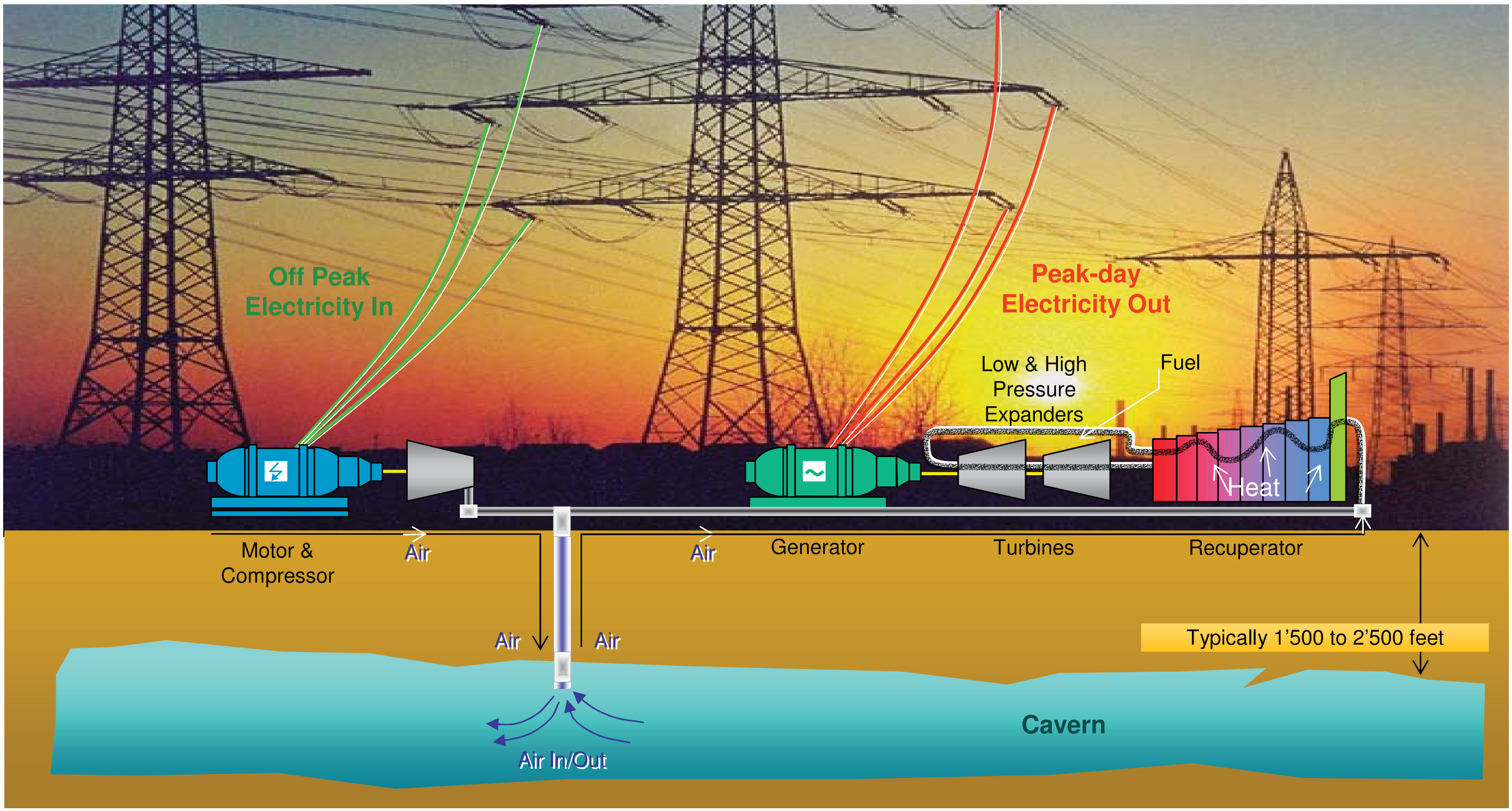
  ---installed capacity reached 6700 MW in USA

  ---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

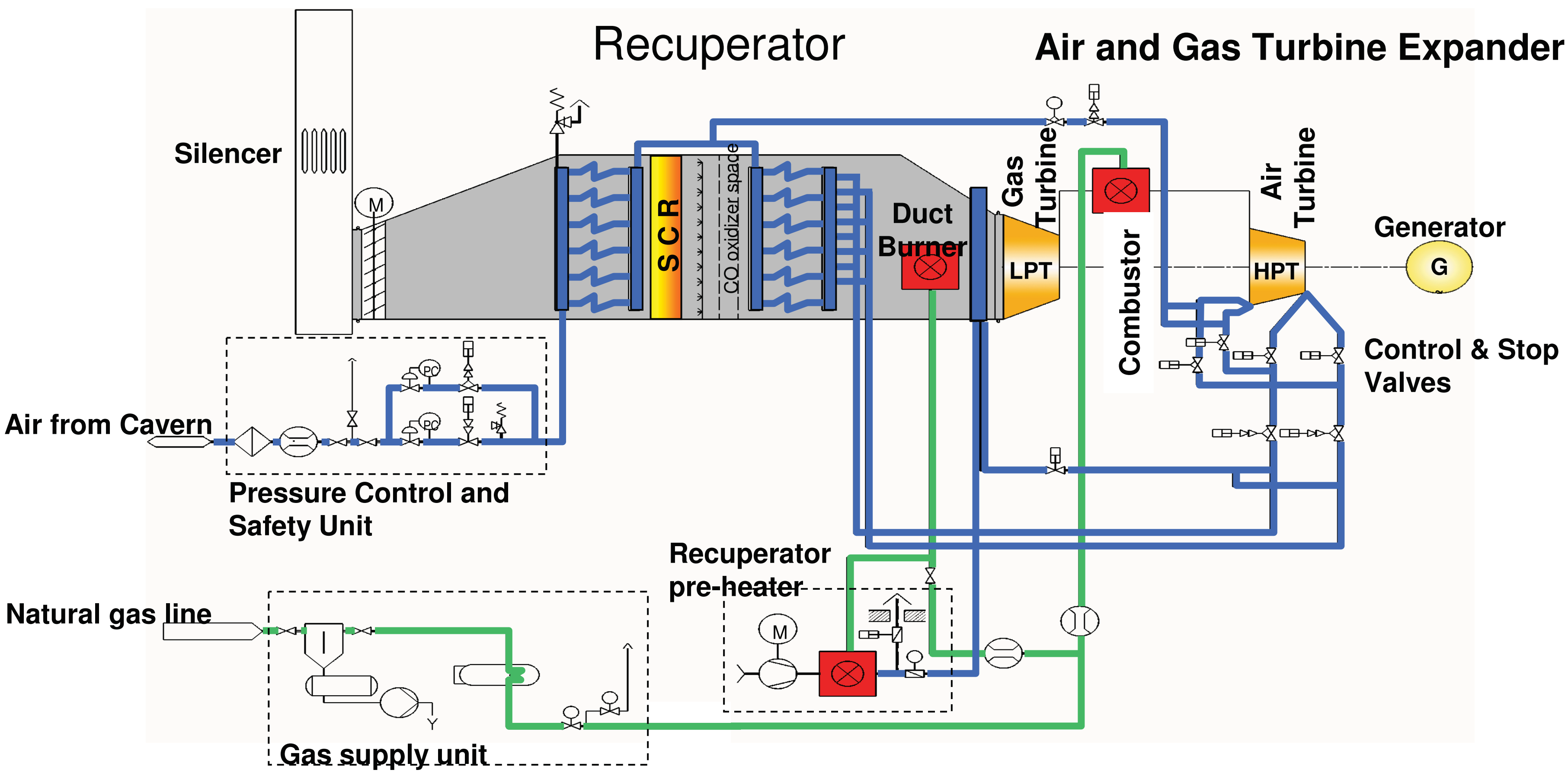
# Compressed Air Energy Storage




BRULIN

# CAES –Power Train

- Integrated Cycle



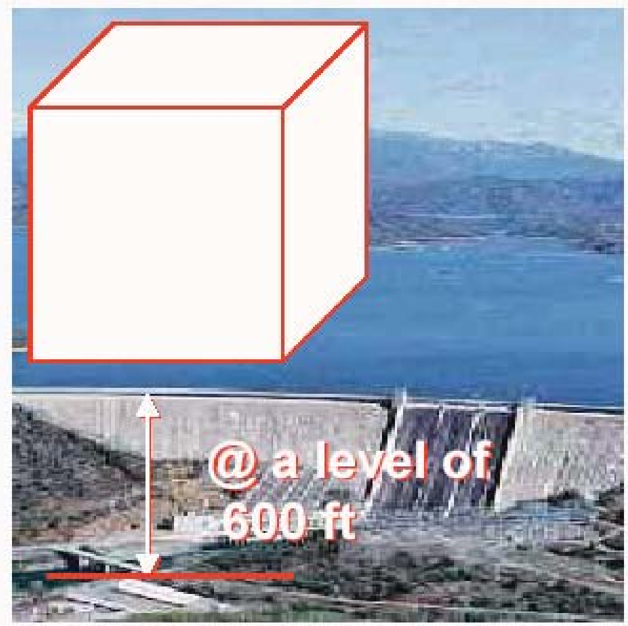

BRULIN

# 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

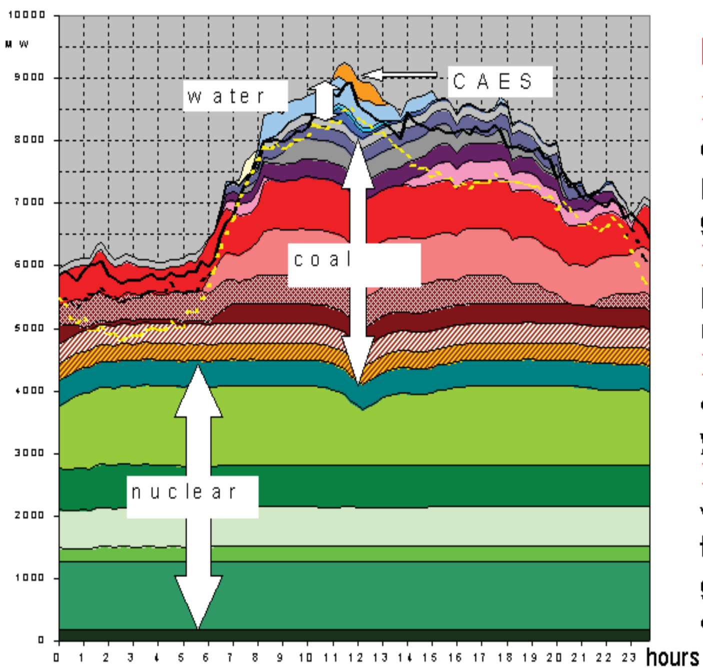
# CAES – Germany - Huntorf 290MW

## 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

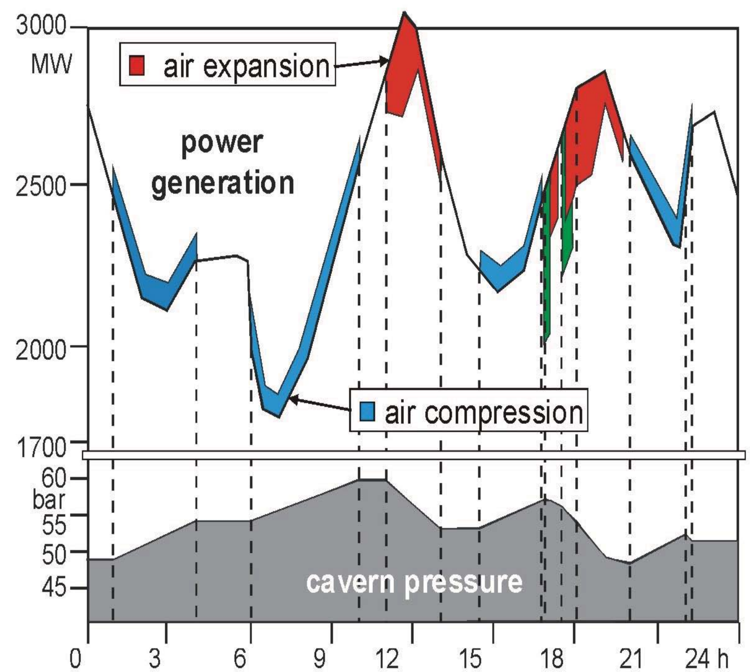
**Power Production vs. Time**




**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**




BRULIN

# 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**

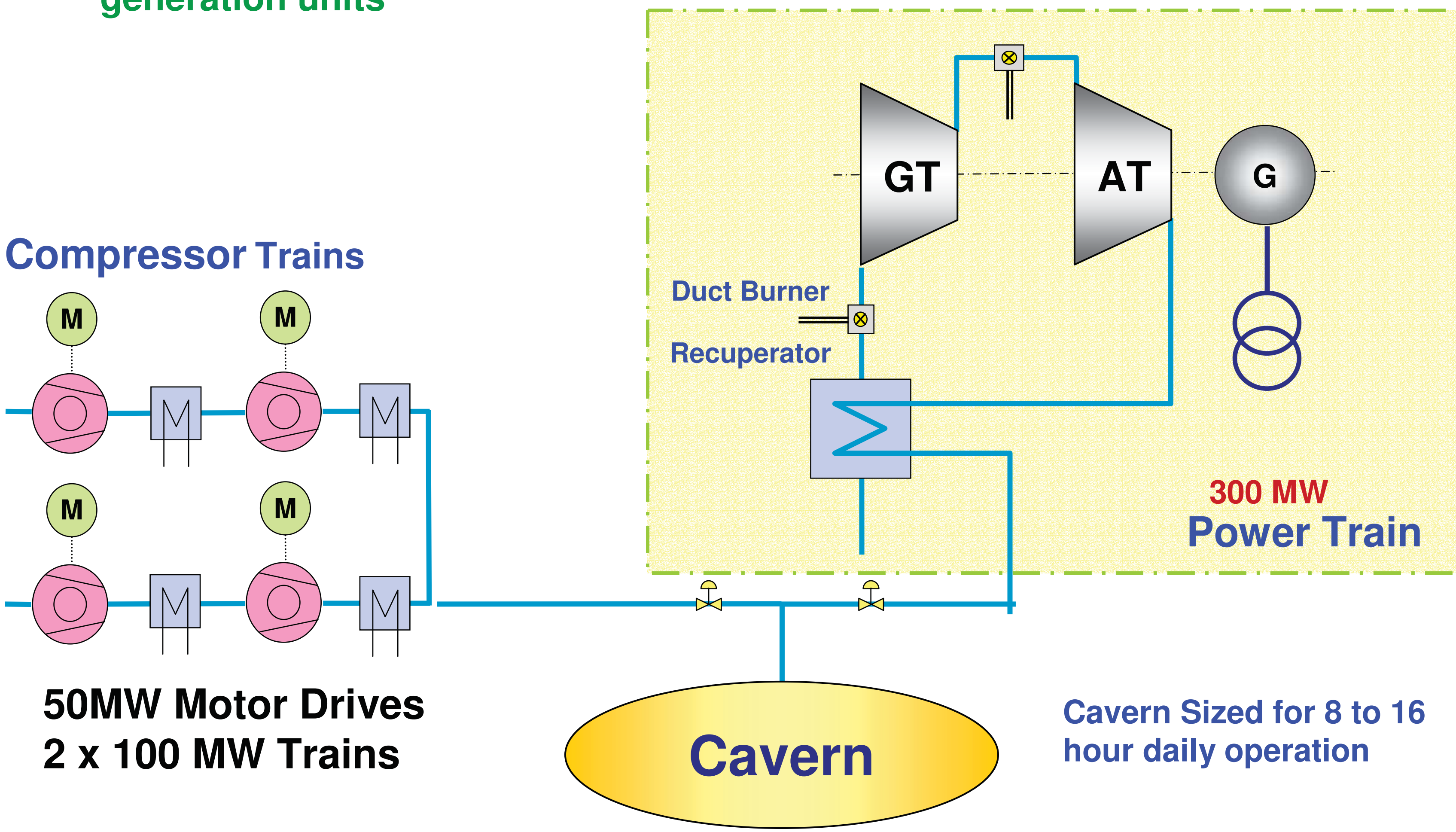
**–Start to full load - 15 minutes or less**

# 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

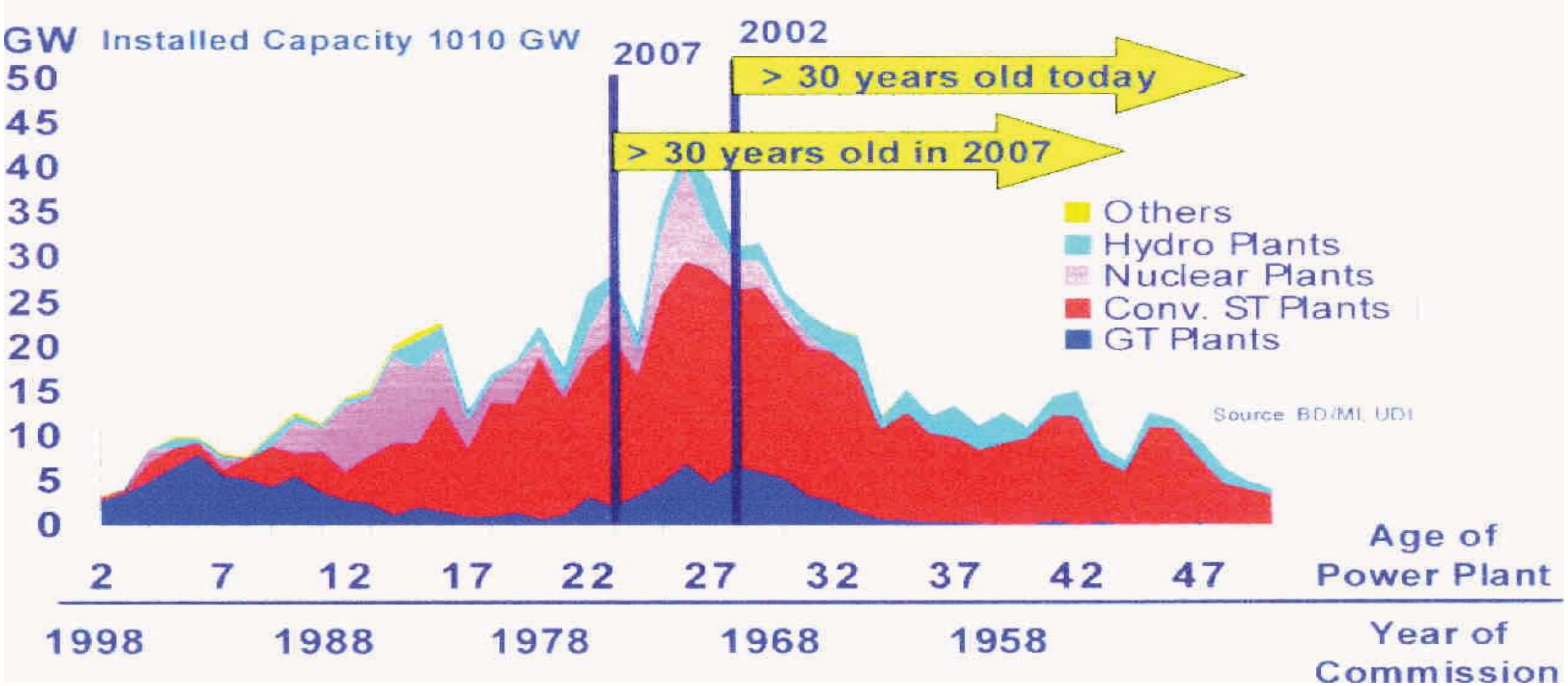
- No compressor linkage
  - Completely independent operation of compressors & generation units




- 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.*



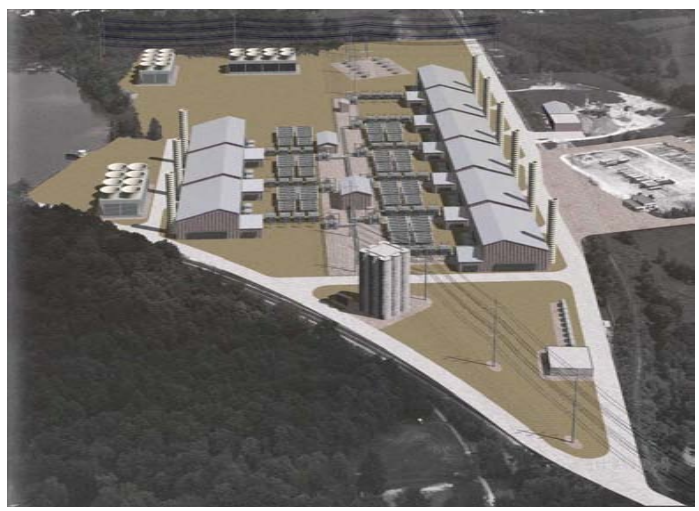

- Replacement with CAES will improve loading & efficiency of advanced coal plants, lower emissions per kW/hr
- Integrate Renewable power with more grid stability

BRULIN

# 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**



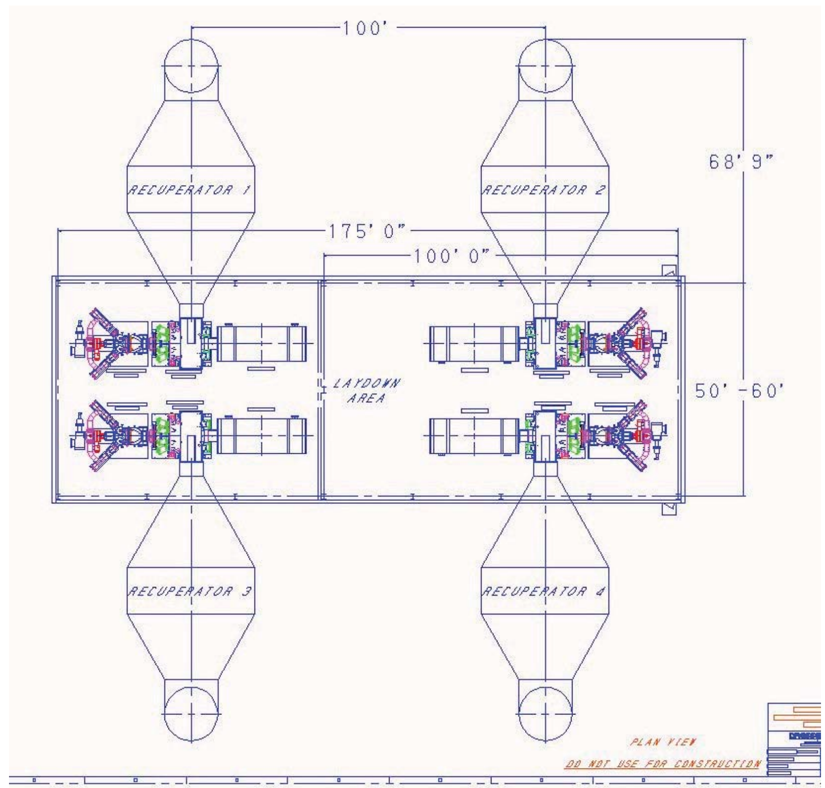
- Flexible Operation in Multi Unit Plants-

BRULIN

# Project Markham 540 MW

## *Matagorda County Texas - Ridge Energy Services*

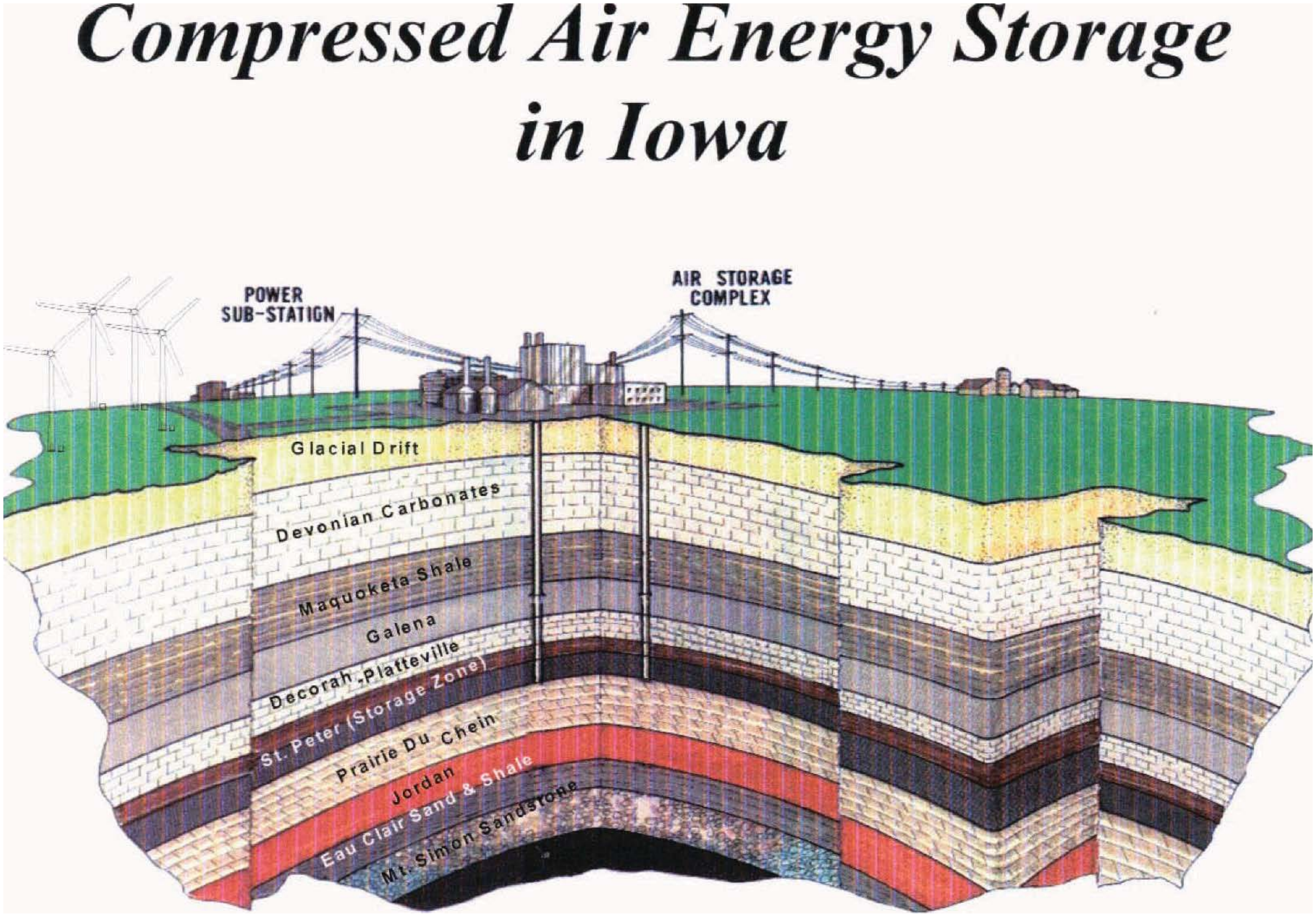
- Bulk Energy Storage
  - **Four x 135 MW**
  - **Dresser Rand Units**
    - **Wide Load Range - Min 10 MW to full Capacity 540 MW**
    - **Capacity available in less than 15 minutes**
    - **Salt Dome Caverns**
    - **Gas Storage on site**



# 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



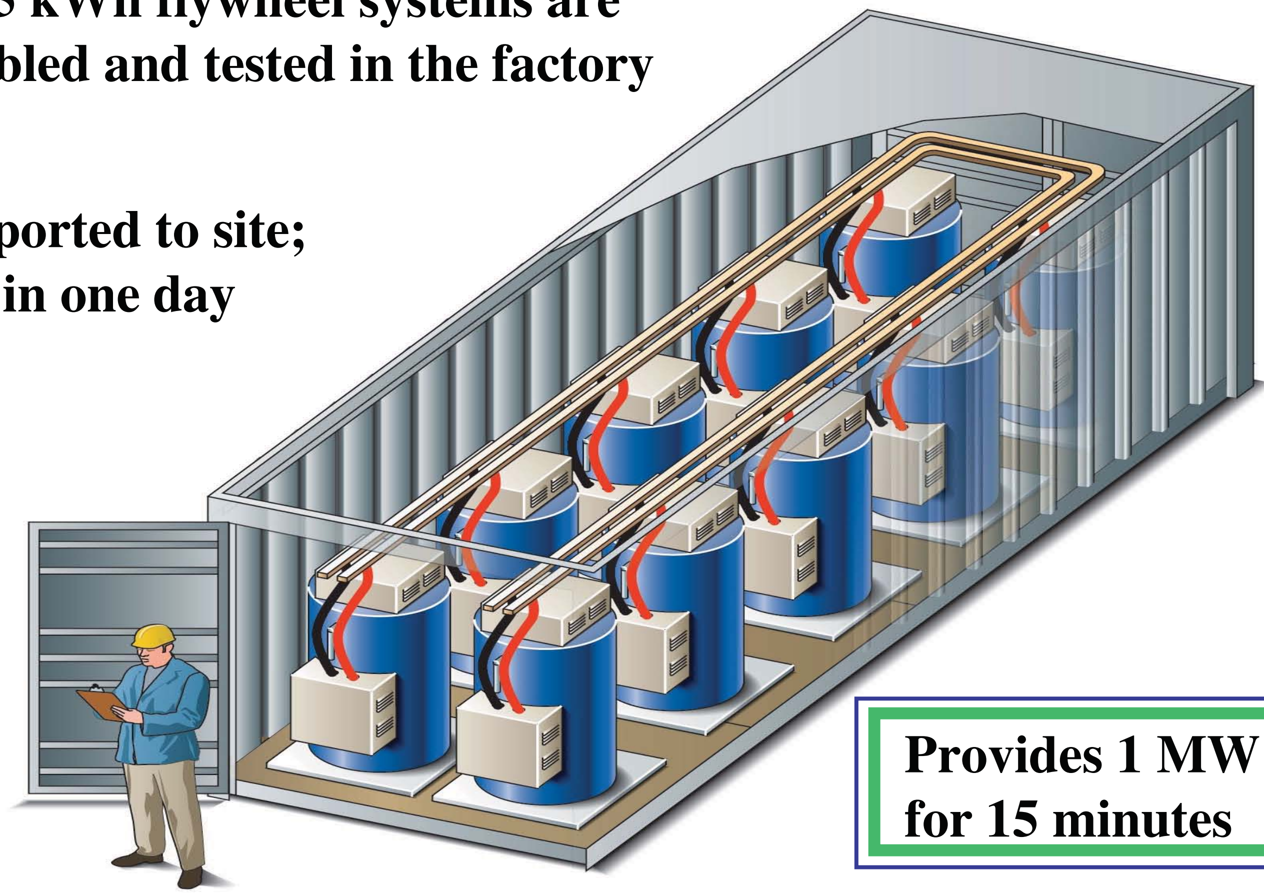
# FLYWHEELS *Beacon Energy*

## 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

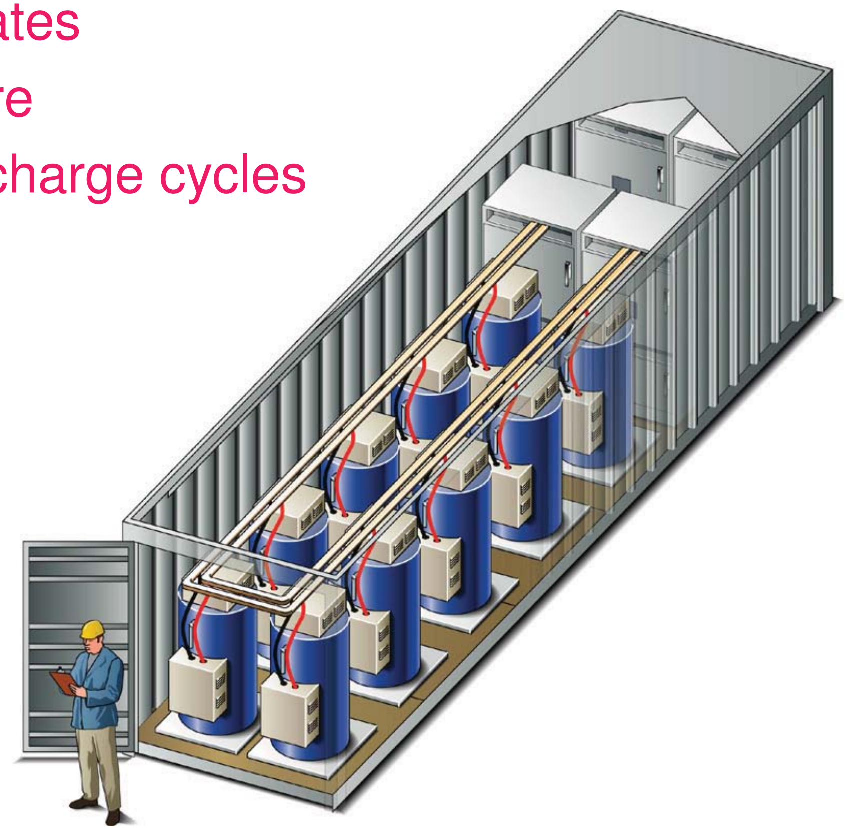


**Provides 1 MW for 15 minutes**

**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**

# Typical 40 MW Modular Layout

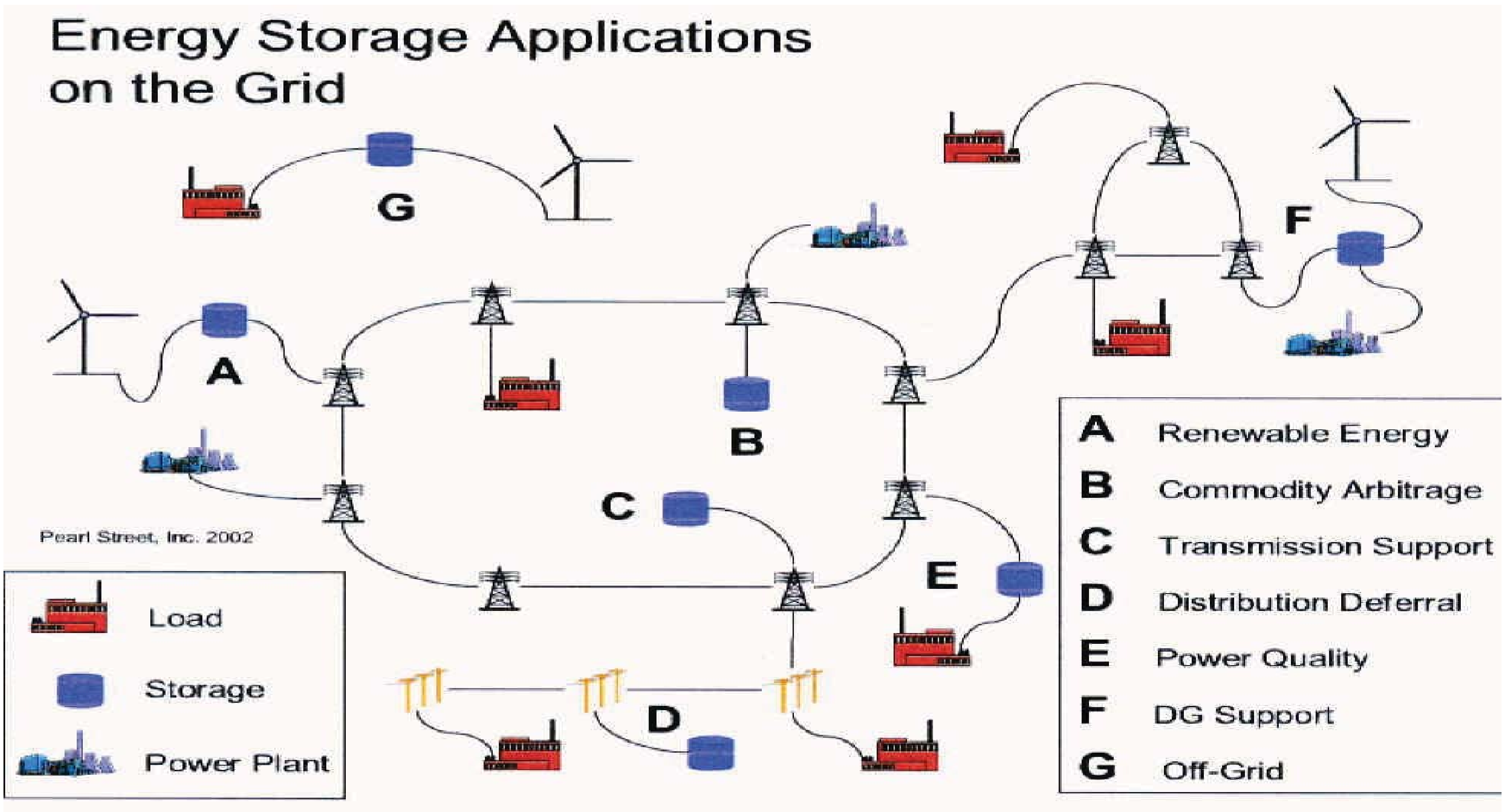
Pictures are actually of containerized 1 MW generators.  SEM installations would have similar look

**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

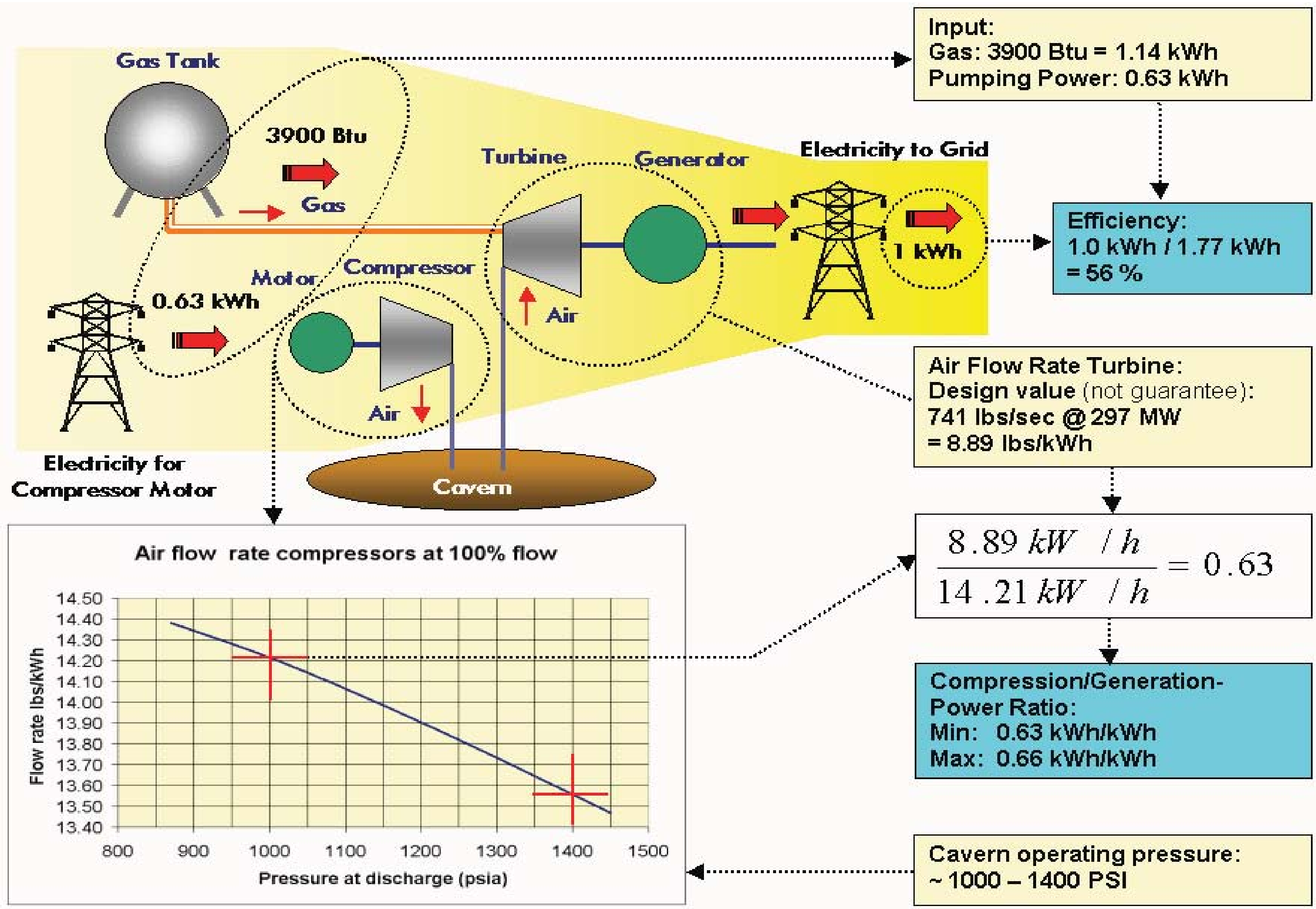
- Four Major areas of Electricity Supply Chain;
- Generation. Transmission & Distribution

  -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

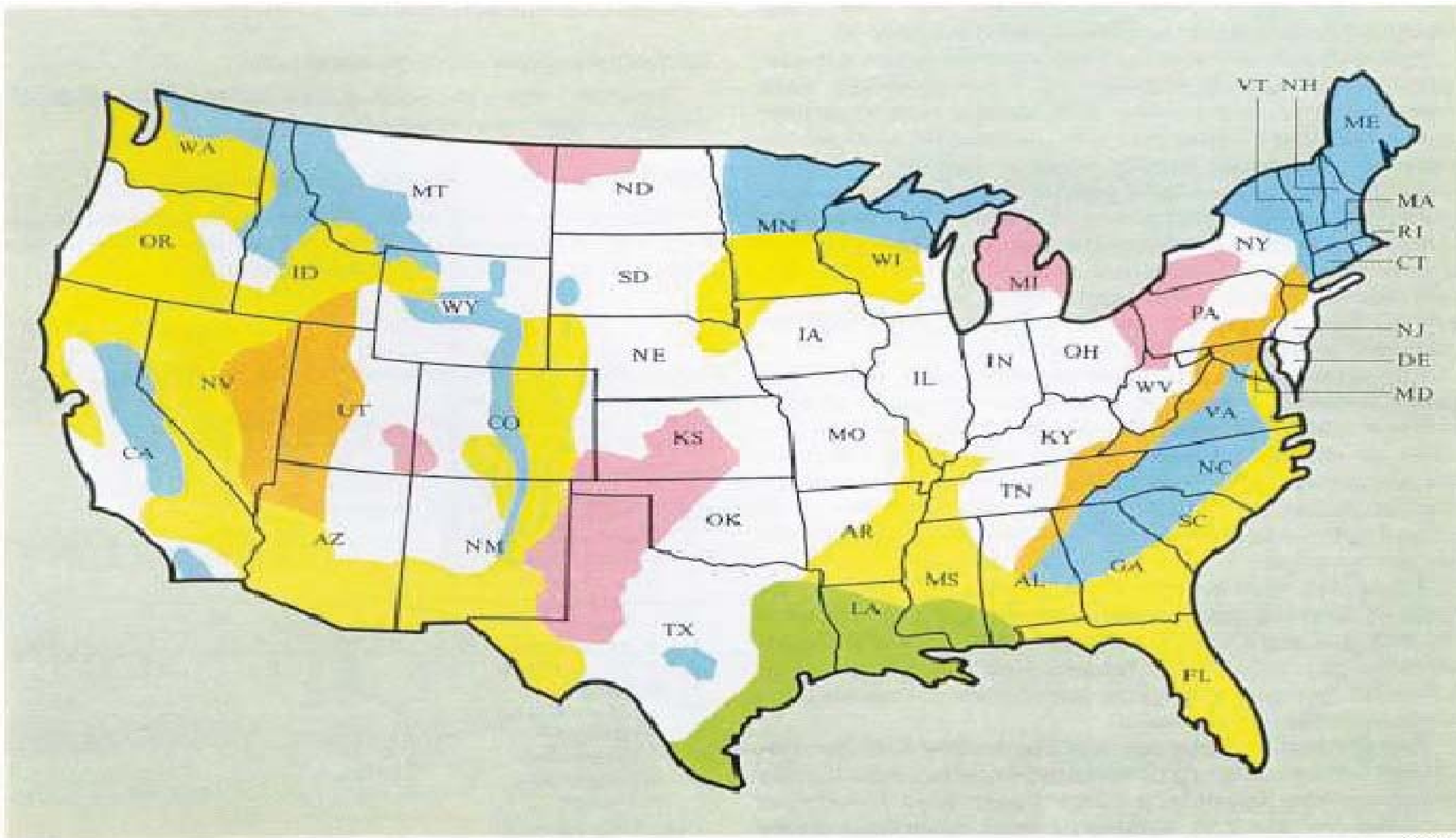
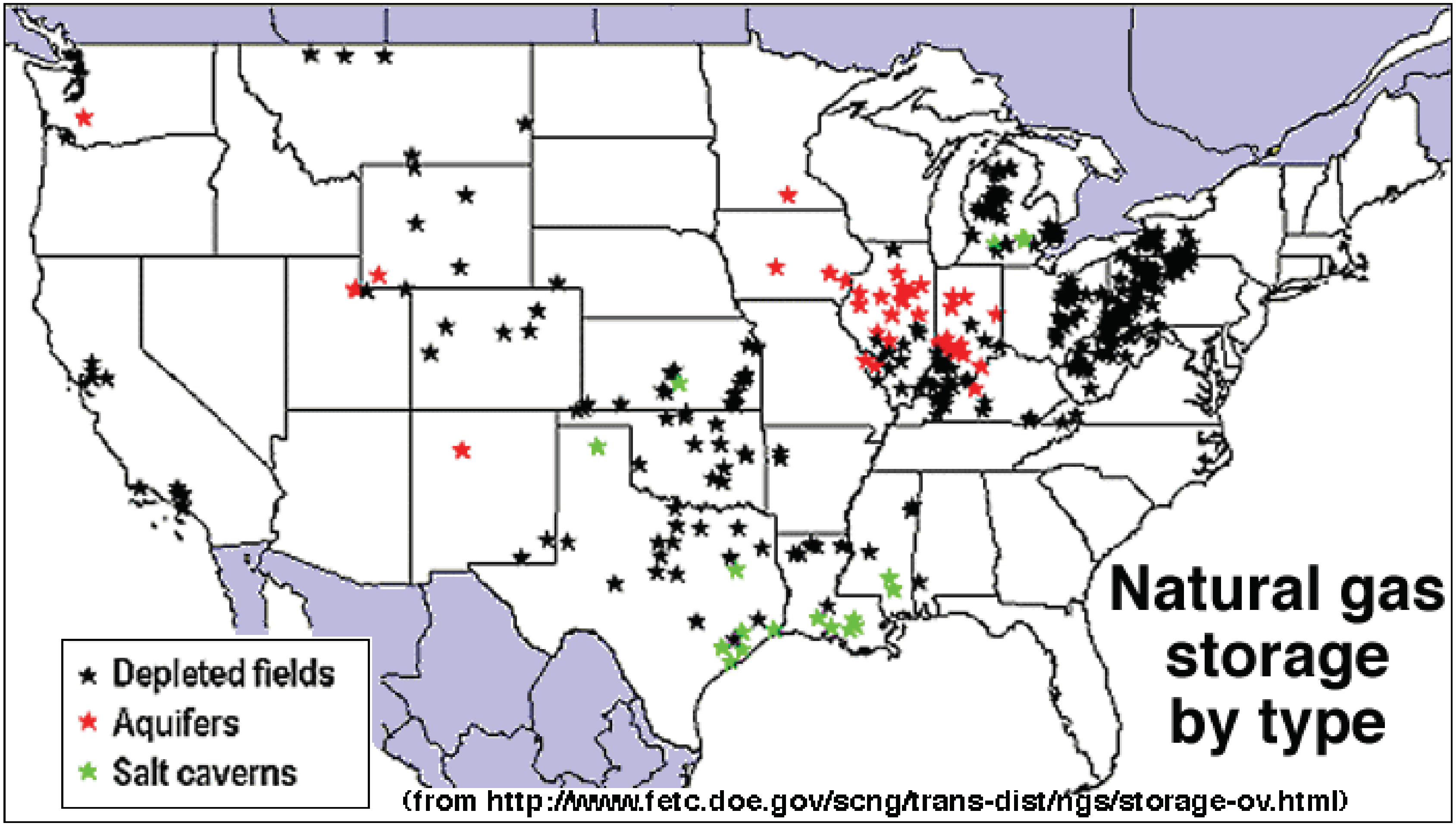



Fig. 3 – USA areas classified for subsurface storage

- 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

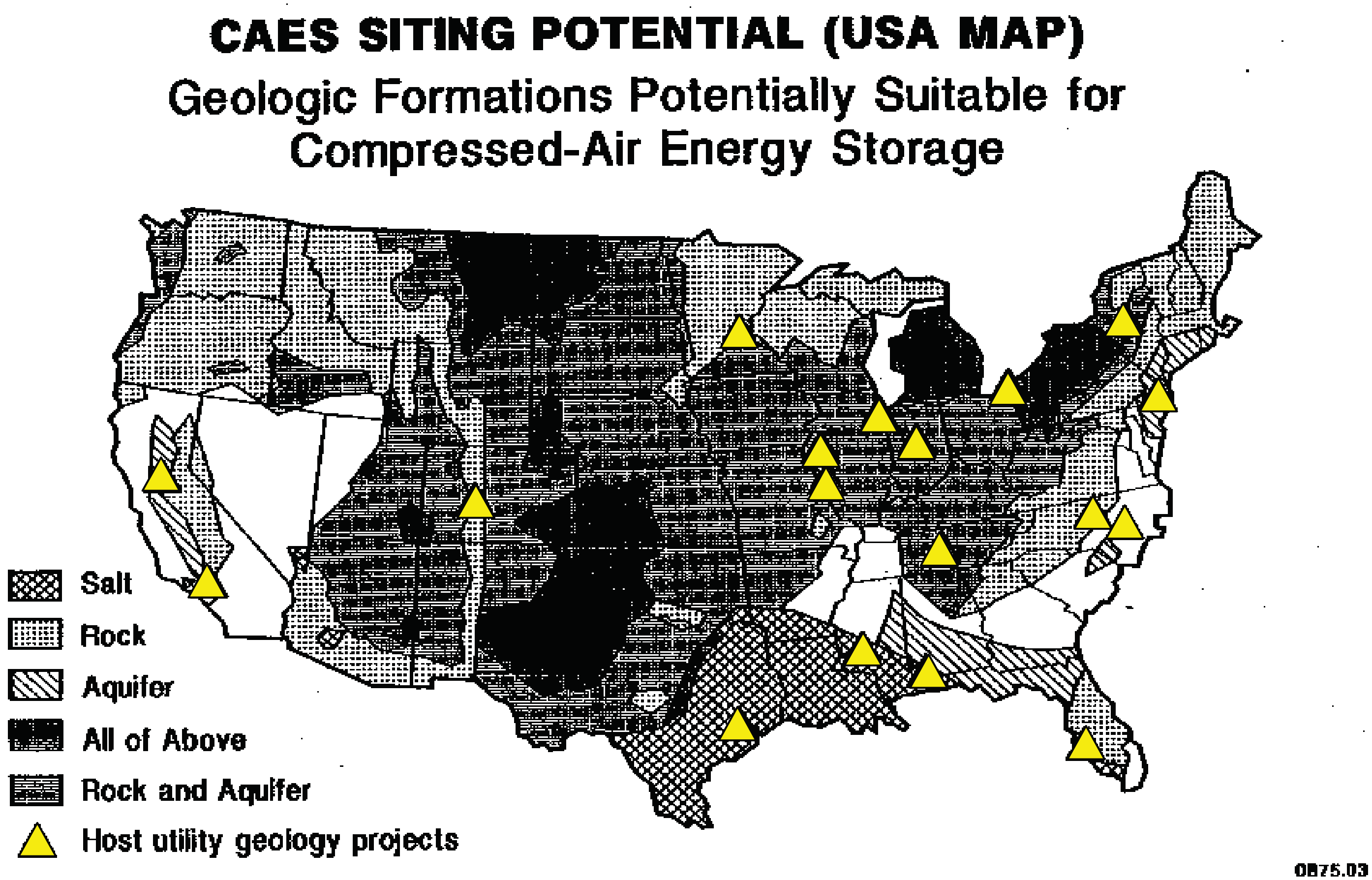
Comment on Sedimetary: **Light Brown** fromAL to NY- & straddling NV and UT into AZ

# Natural Gas Storage



# Suitable Geological Formations

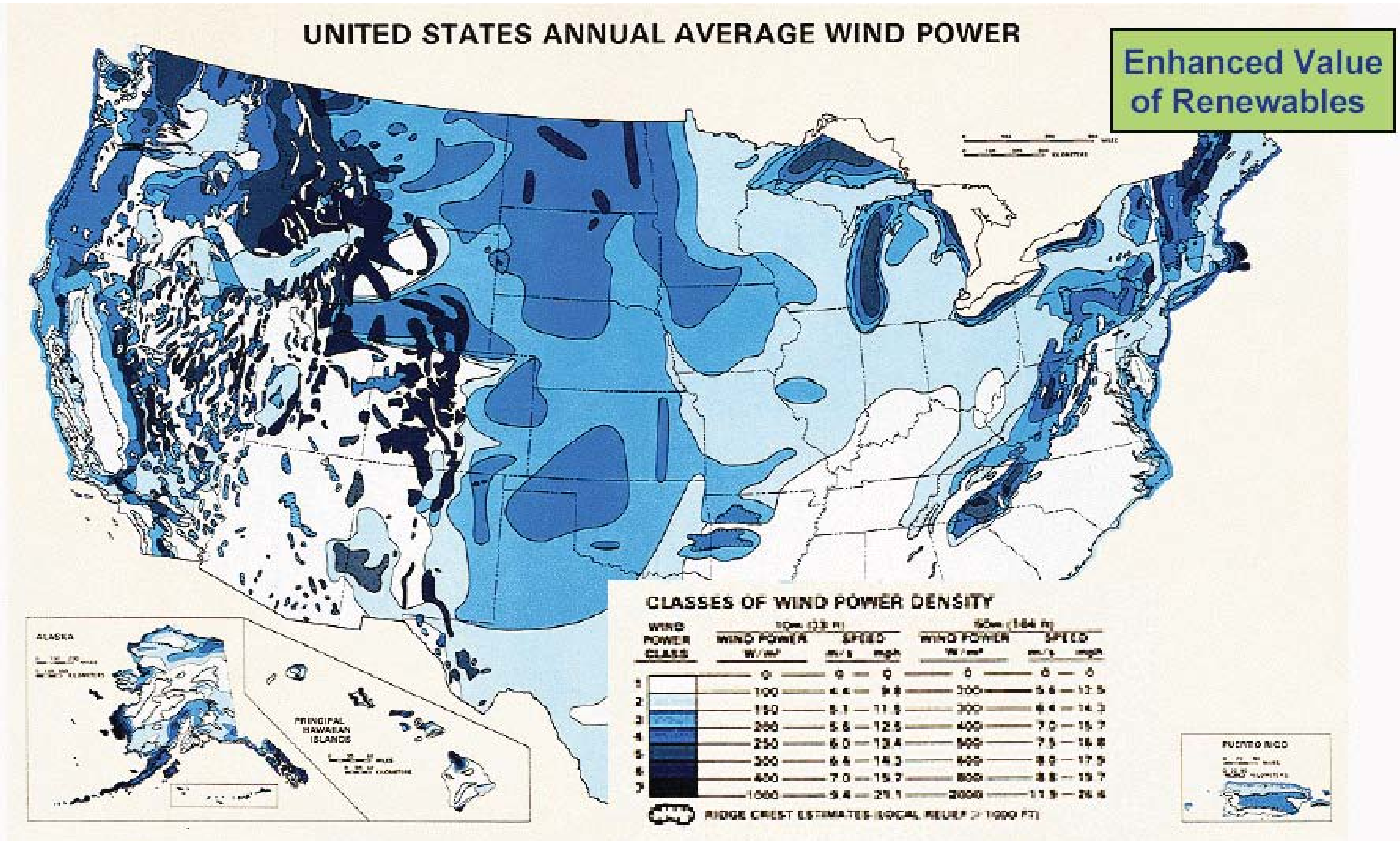
- Host Utilities *Former Studies*



# Future Prospects (Developments)

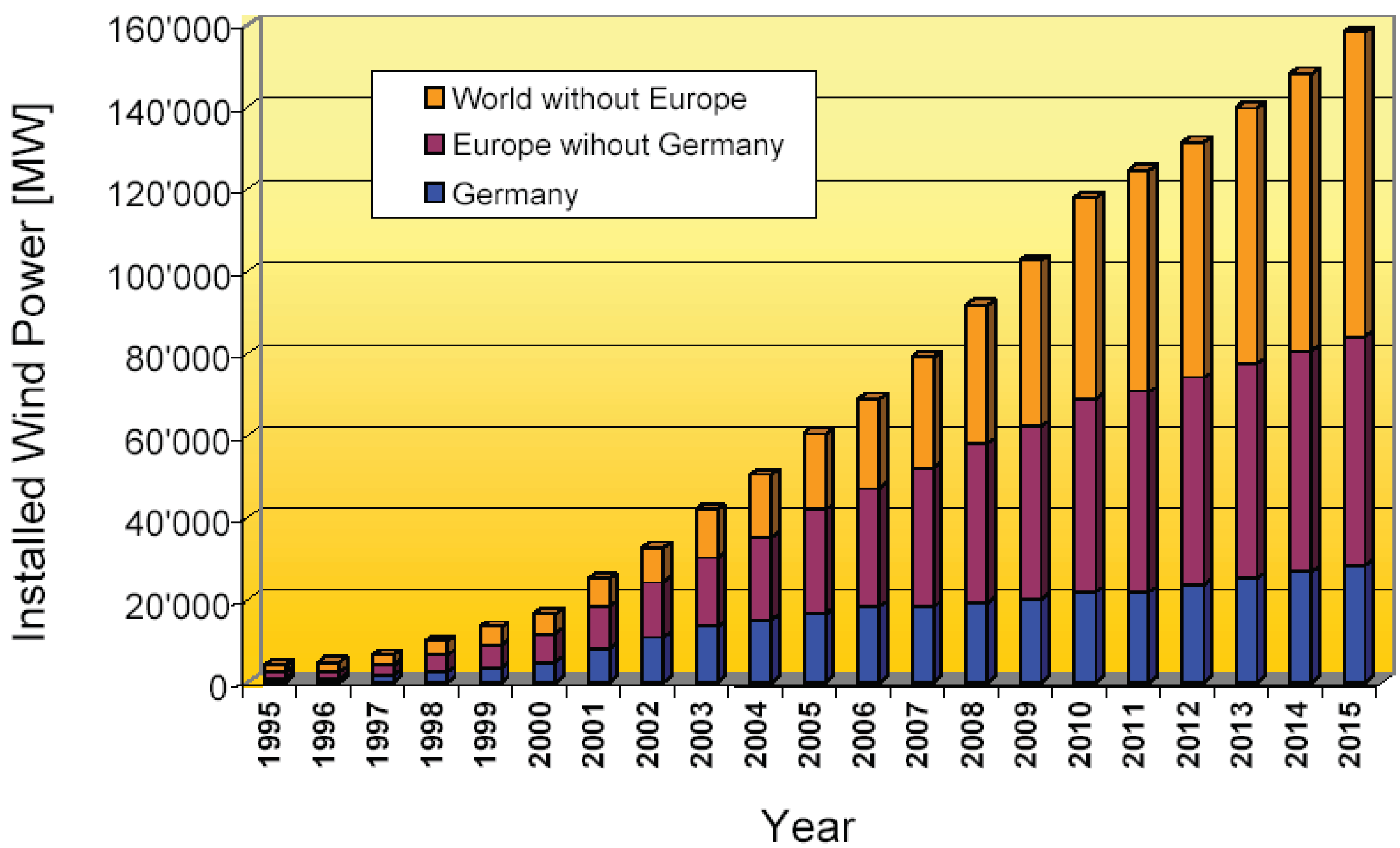
- PHS has clearly demonstrated the value of-
  Bulk Energy Storage.
- Benefits recognized-new facilities languish-projects in development show promise
- New Concepts proposed, with growing capacity of Wind Energy 6700 MW-capacity factor > 30%
- SSCAES—Pipe Storage
- Stored Air Injected in existing GT 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



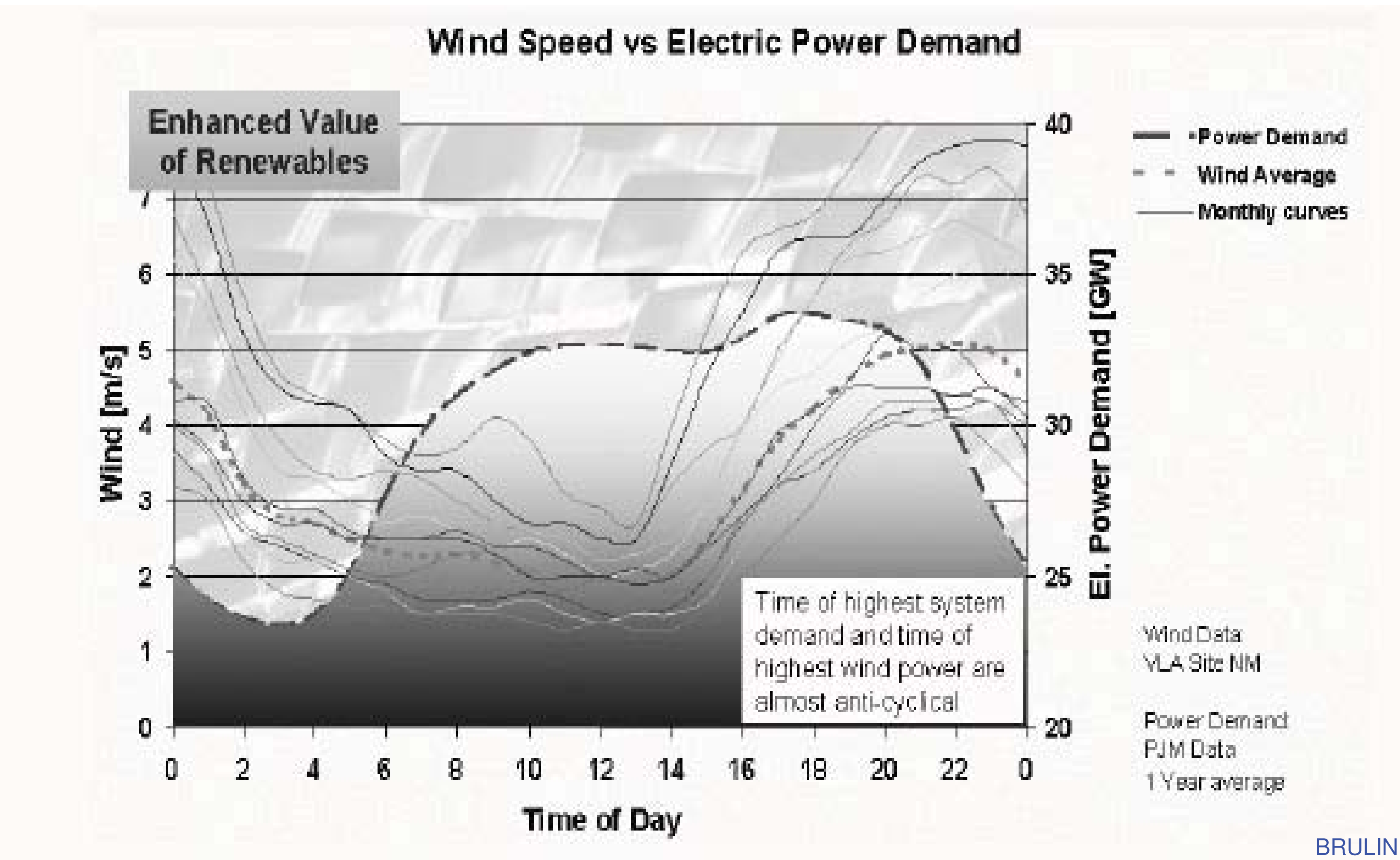

BRULIN

# Global Wind Power-MW



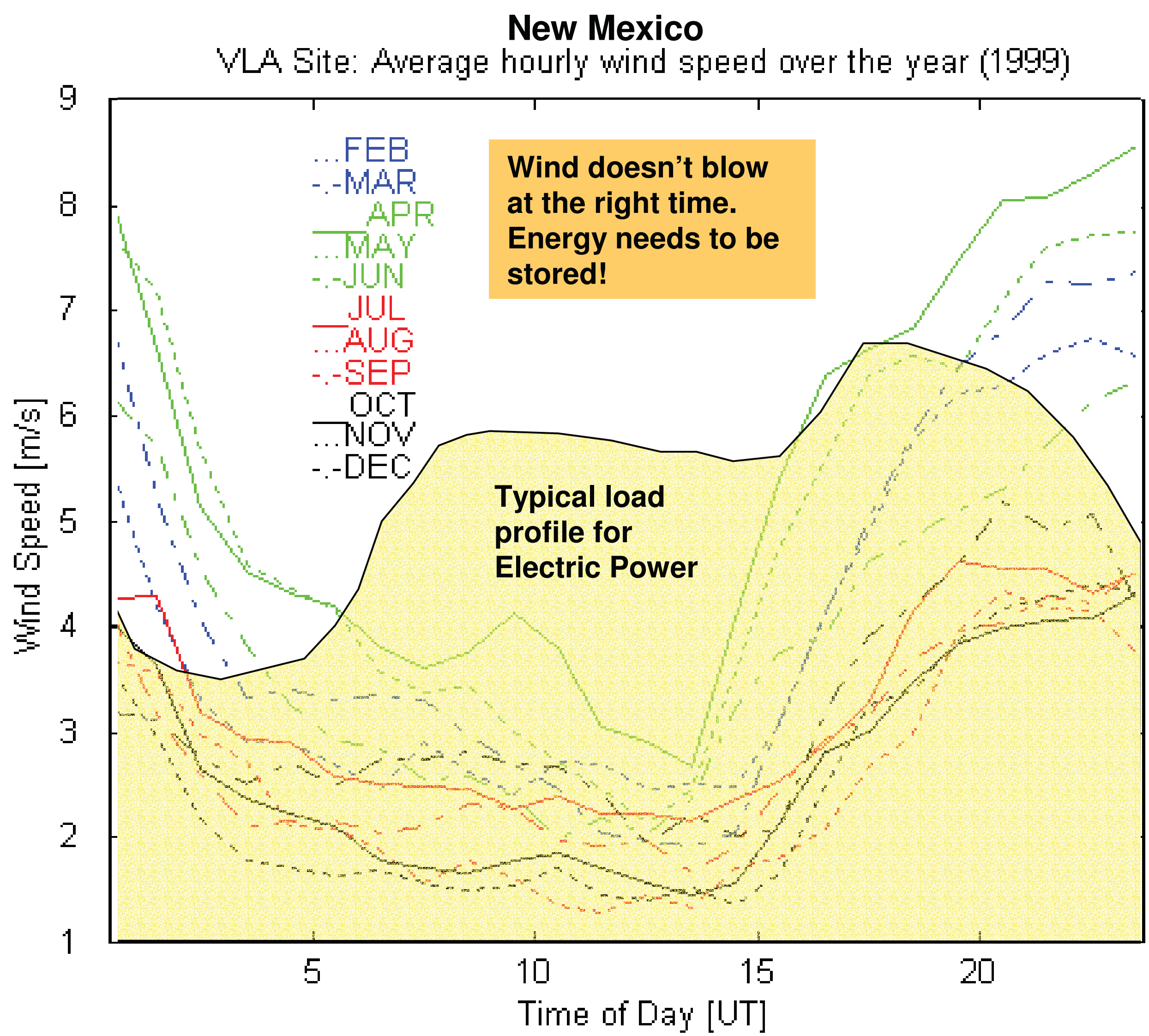

BRULIN

# Enhanced Value of Renewables



# Annual Variable Wind Power

- **Wind**




BRULIN

# Storage-Can Benefit Wind Energy Production

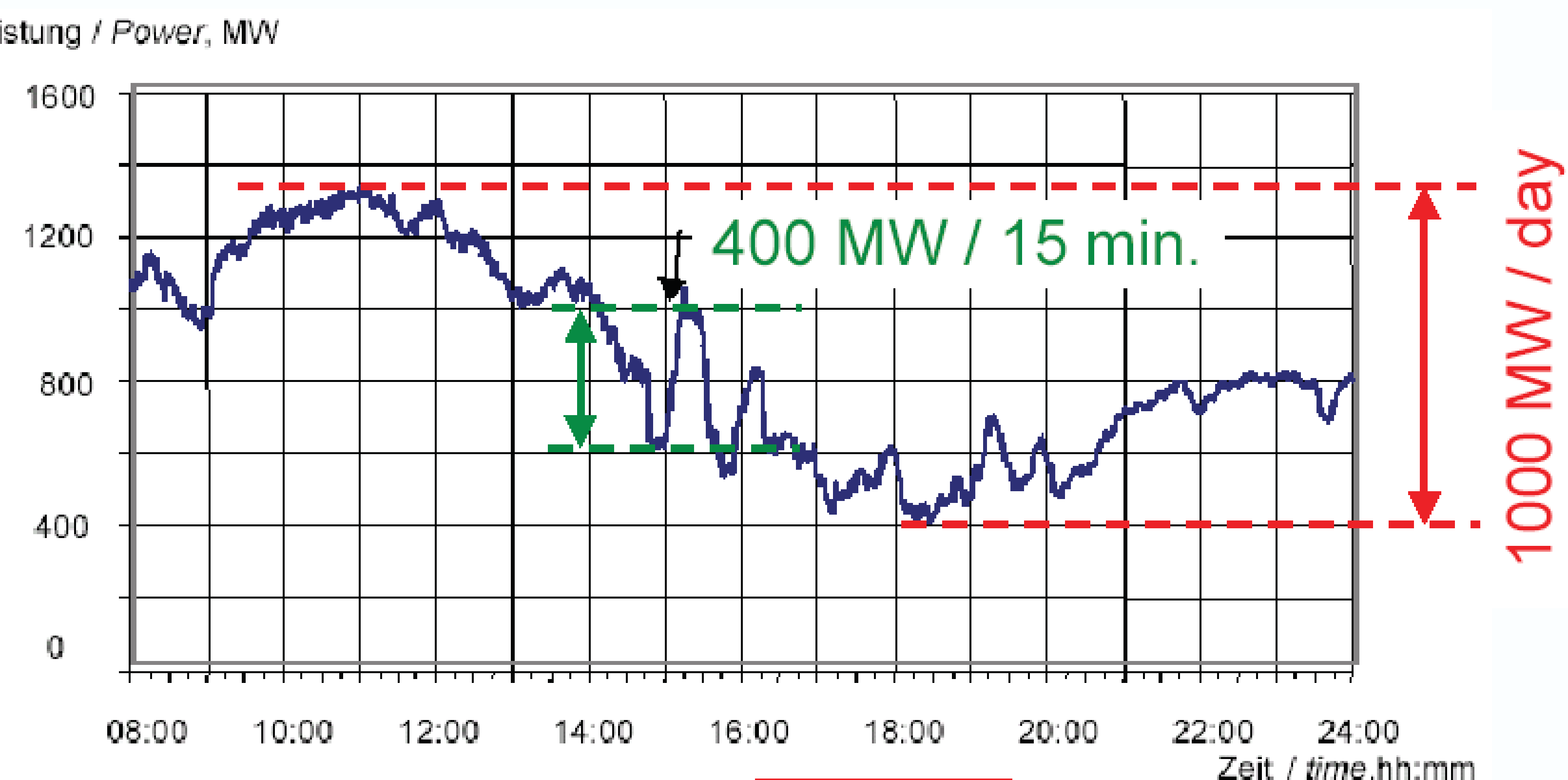



Abb. 2: Windenergieeinspeisung am 03.12.1999
*Fig. 2: Wind energy production on 03.12.1999*

**From e-on**

BRULIN

# CAES-Reactive Power & Voltage Regulation

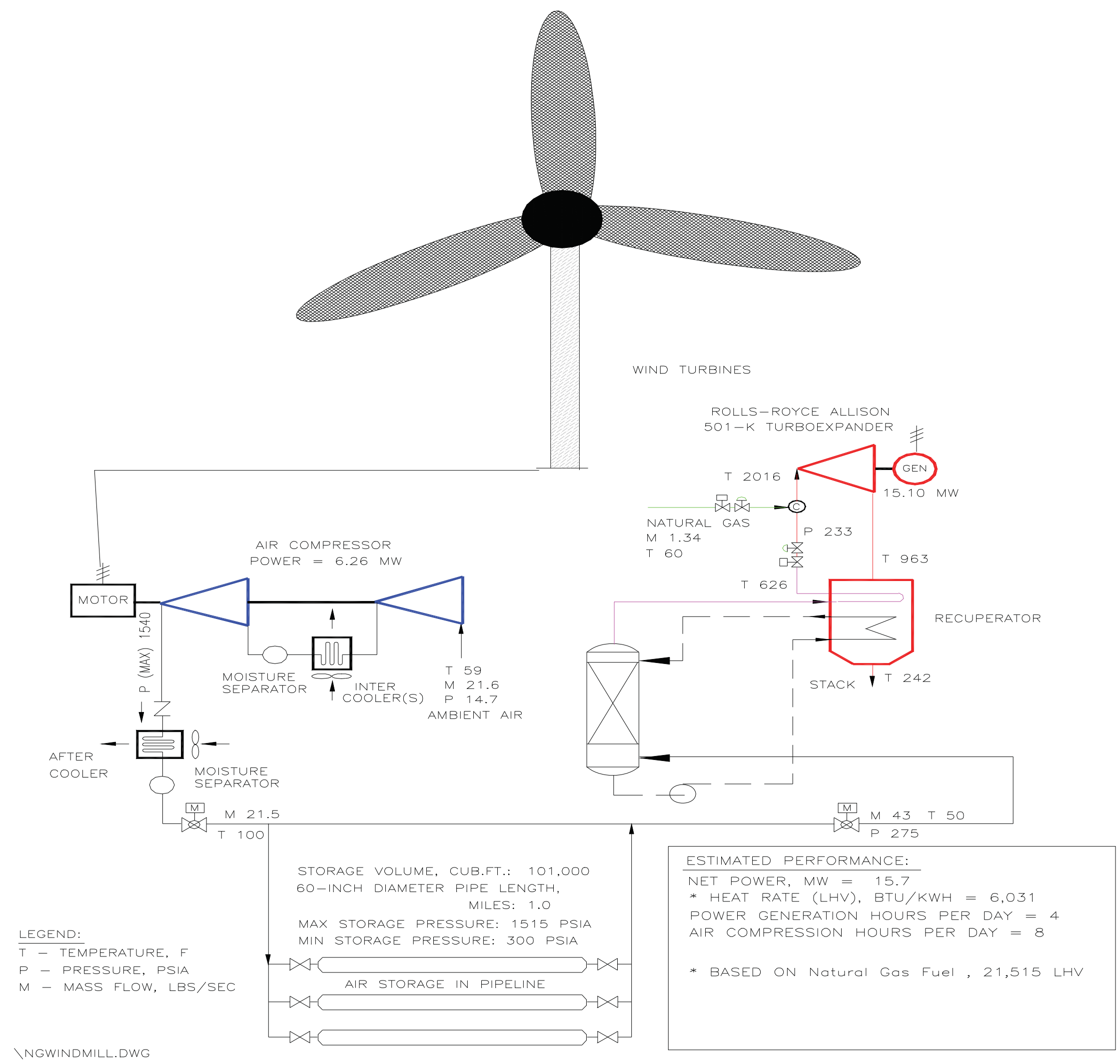
- Reactive Power & Voltage Regulation within grids with high Wind Turbine energy contribution are a challenge
- **Reactive power capability of wind turbine generators**
  - **None with asynchronous generators**
  - **limited with synchronous generators and frequency converter (cos phi ±0.975)**
- **In 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

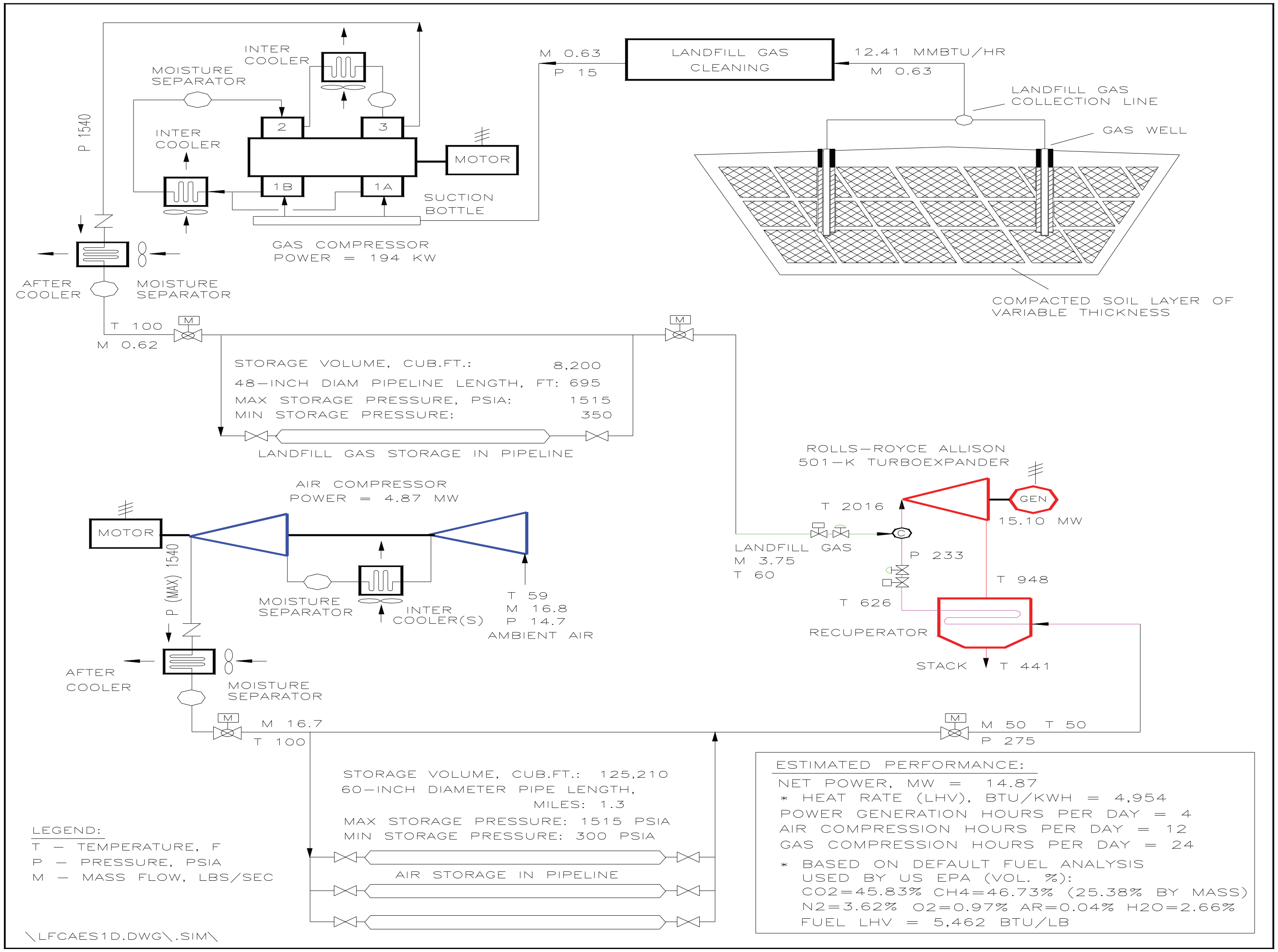
- SSCAES- Pipe Storage Technology
- Wind Energy Integration
- Land Fill Gas (LFG) Utilization
- Air Injection Technology-Using Storage
- Flow Batteries—Chemical Storage

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



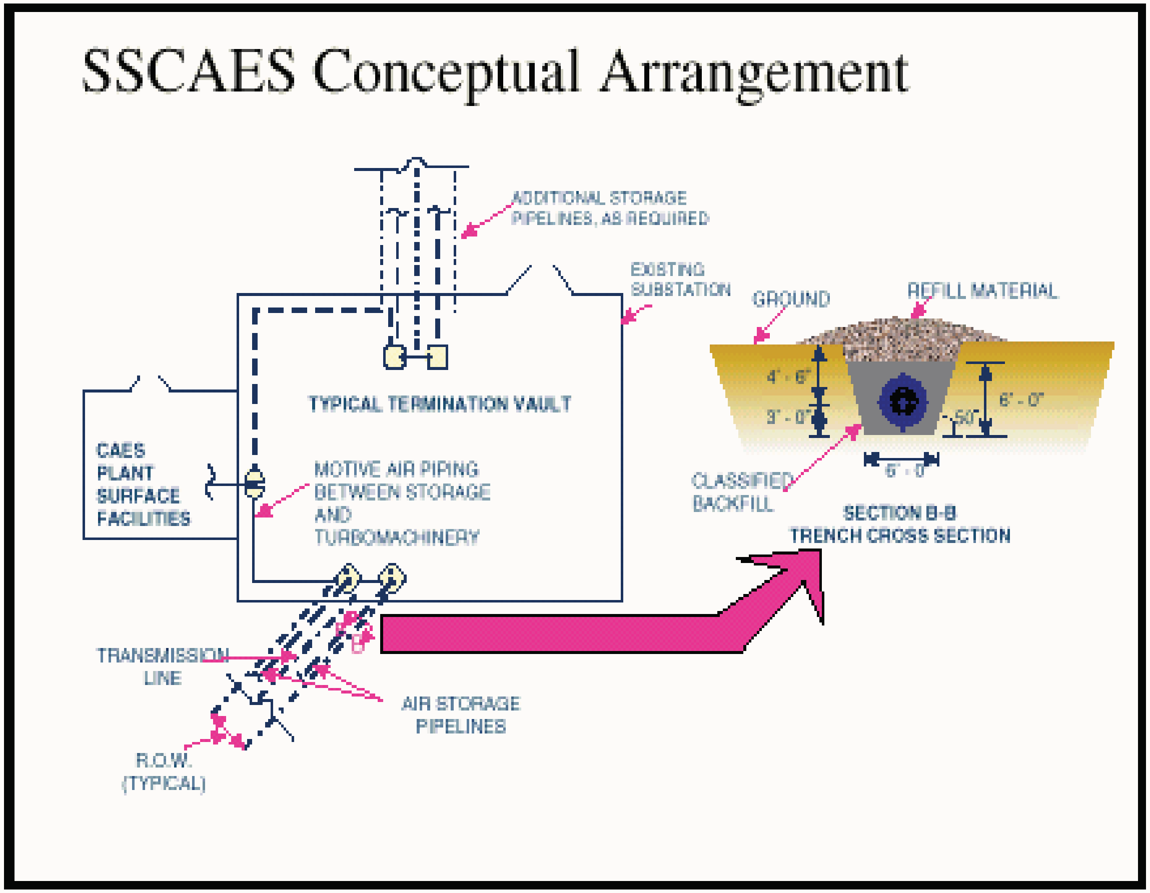

BRULIN

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



# Sub Surface Pipe Srorage

Figure 7.



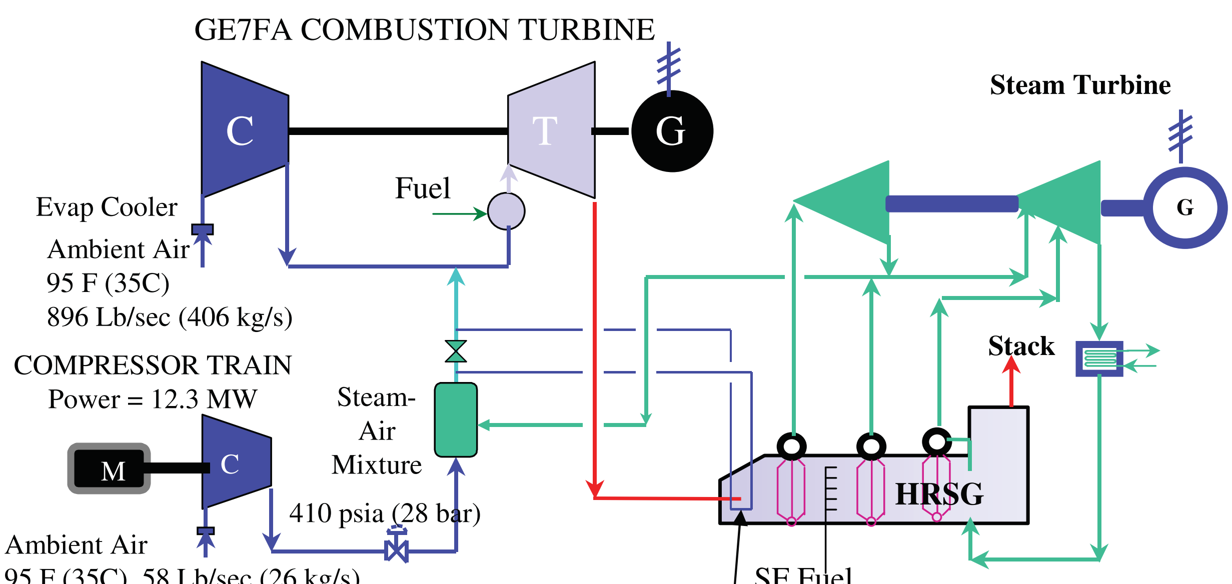
# Pipe Storage Technology

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

BRULIN

# Humid air Injection Technology

## CC-HAI at Sea Level

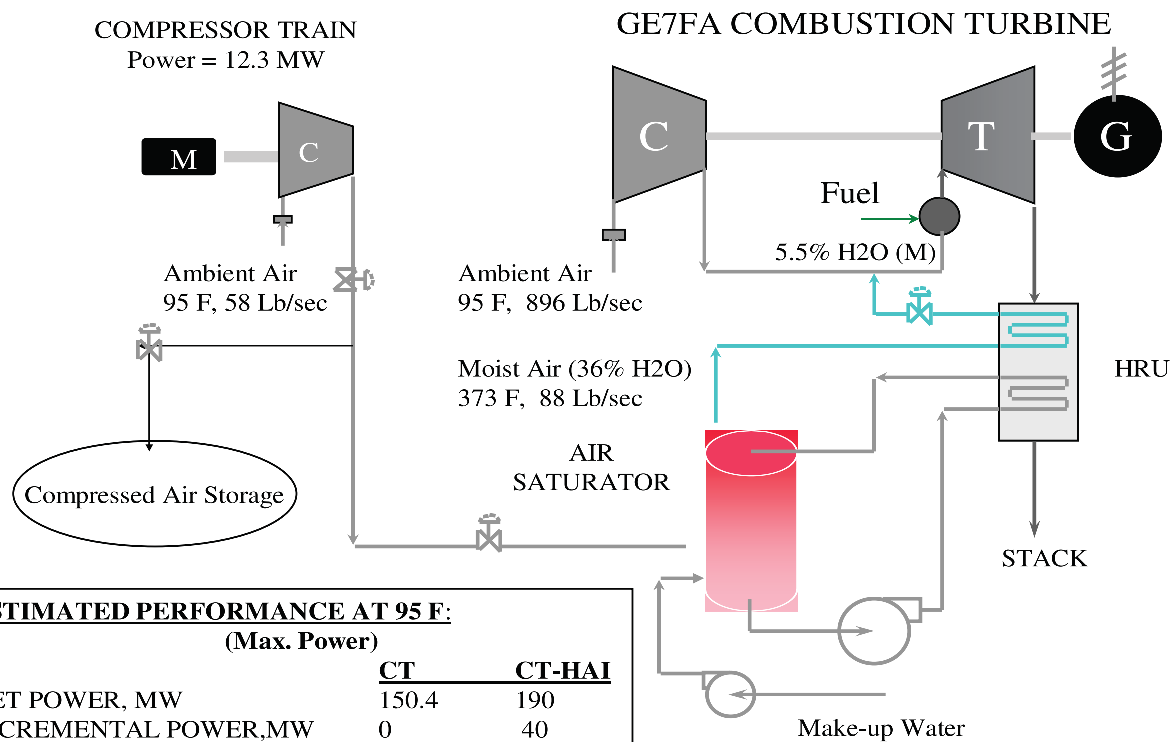



**ESTIMATED PERFORMANCE AT 95 F(35C):**

| | 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



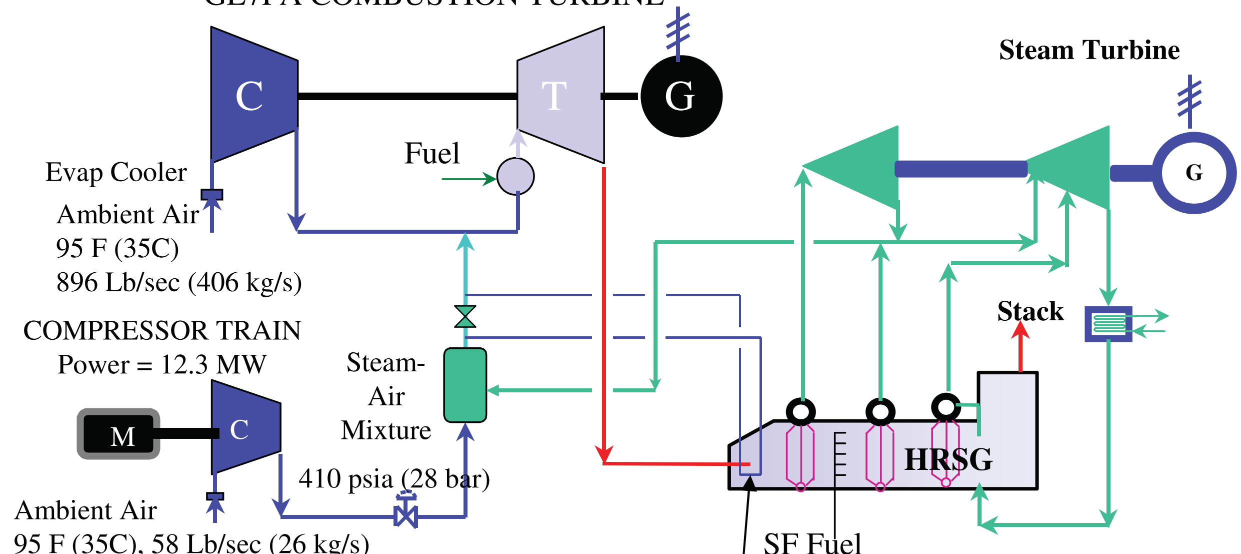

**ESTIMATED PERFORMANCE AT 95 F:**
**(Max. Power)**

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

BRULIN

# Air Injection Technology applied to CC

## 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 |

**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 –**

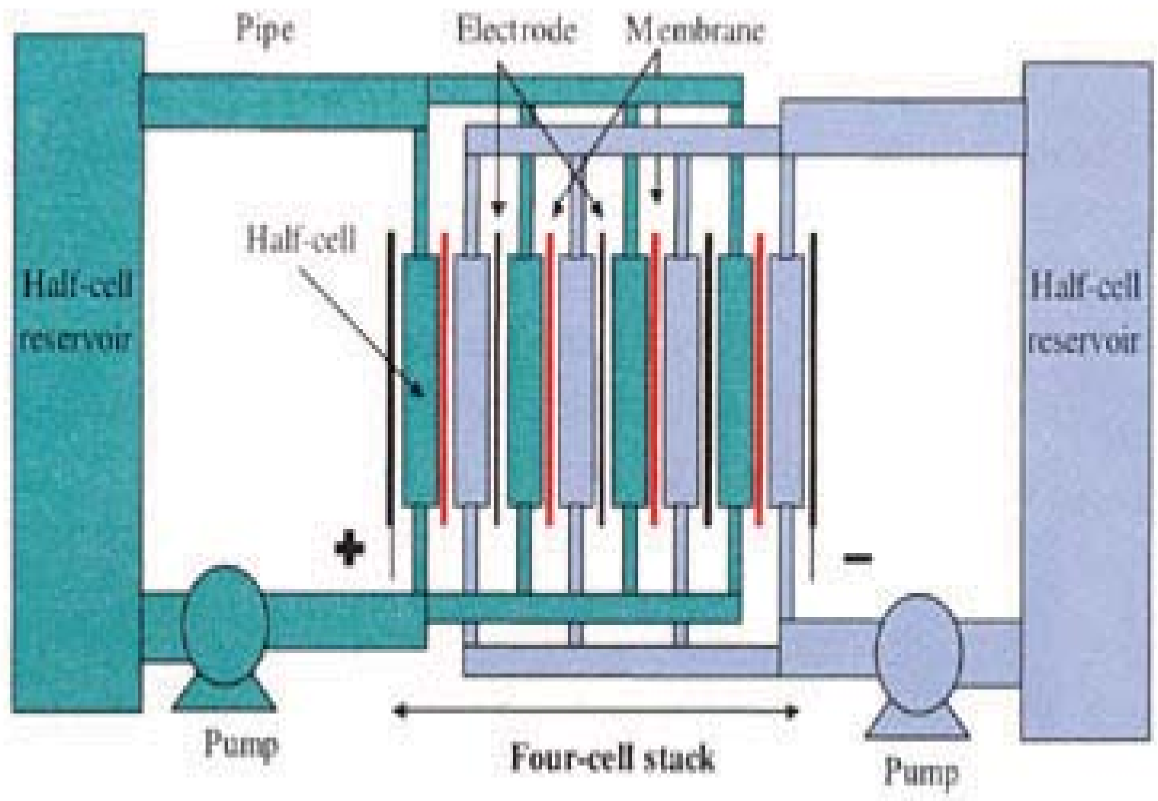
**100 GW can be achieved—especially as PHS is limited.**

# APPENDIX

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

# Vanadium Redox Flow Battery -VRB

**120 MW/HRS**




BRULIN

# Regenesys Flow Battery-*Columbus TVA*

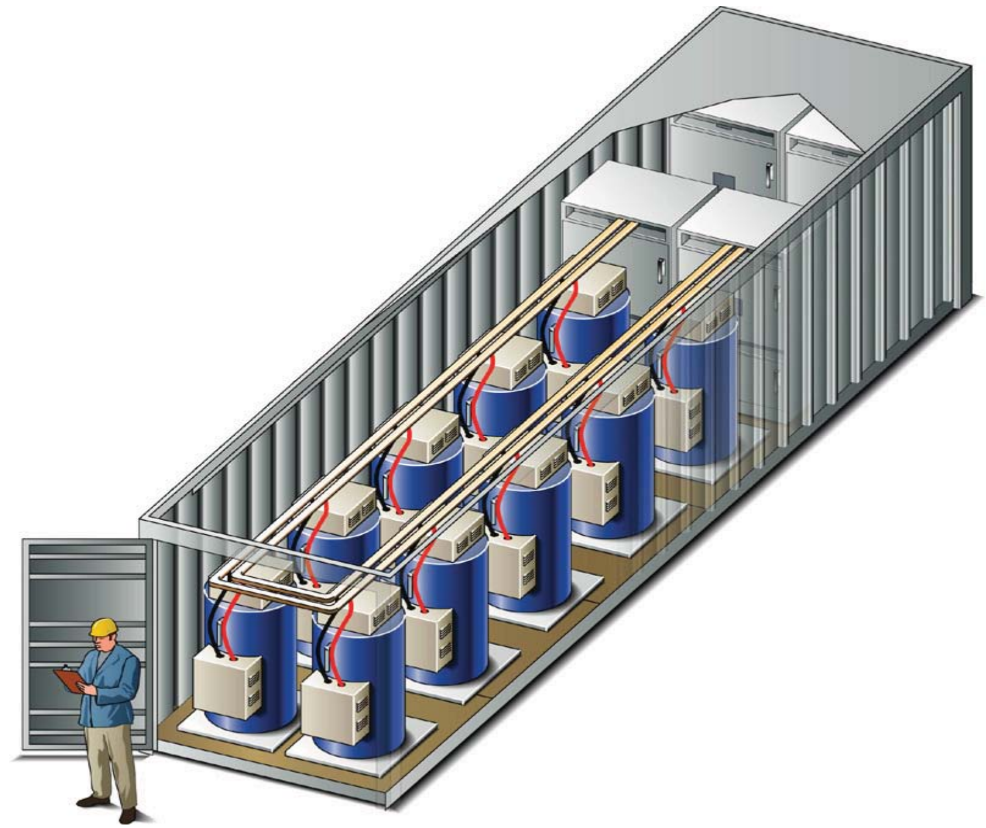
- Reinforce Transmission Grid
- 120 MW/HR Capacity
- Electrolyte Storage 2 x 70,620 Cub/.Ft Tanks
- High Power Quality to US Air Force Base
- On-line 0.02 sec. response

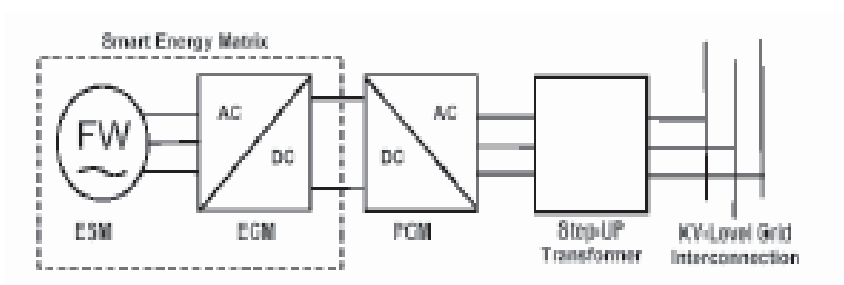
Project Stopped

BRULIN

# 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






BRULIN

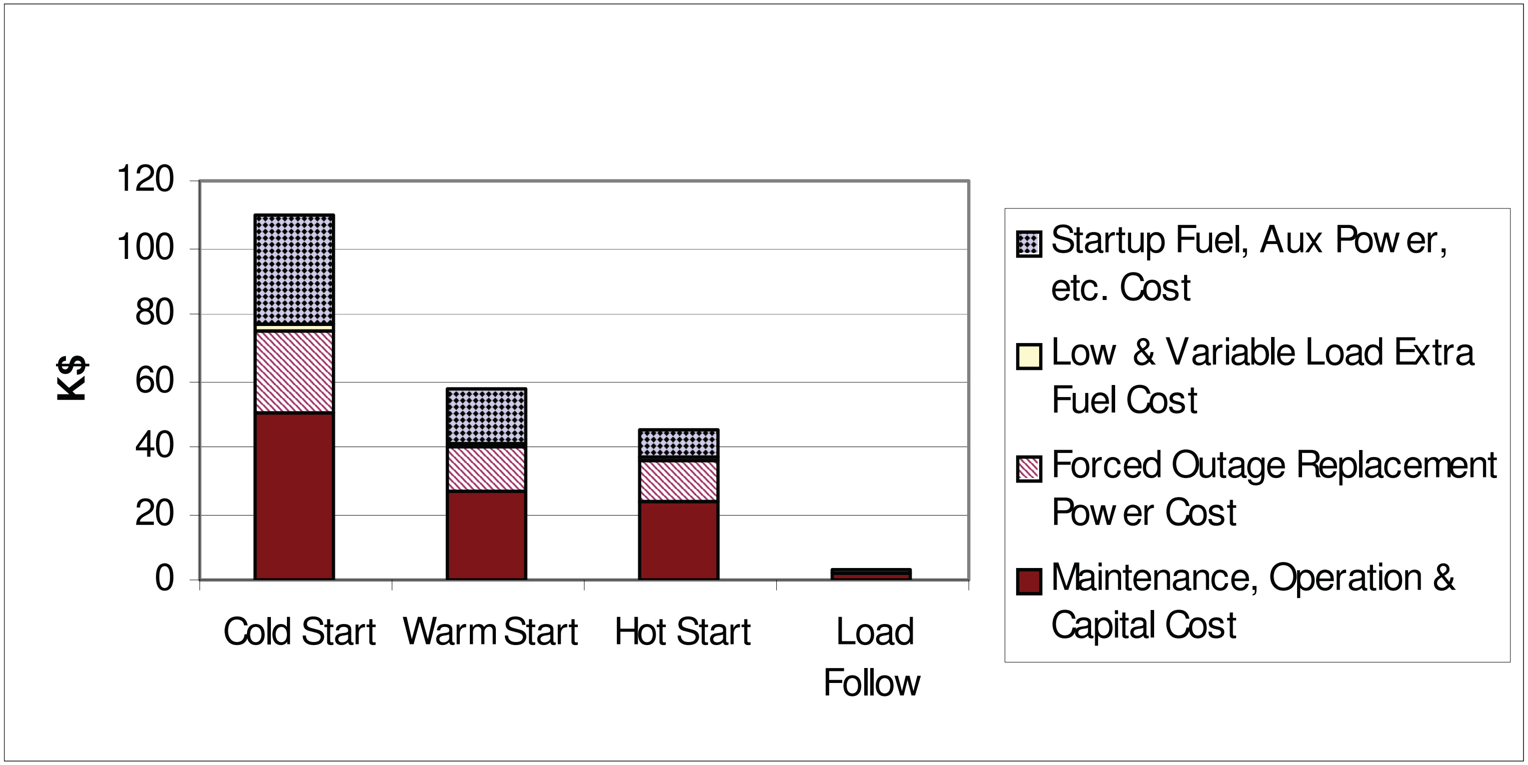
# Cycling Costs--APTECH

| 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 |

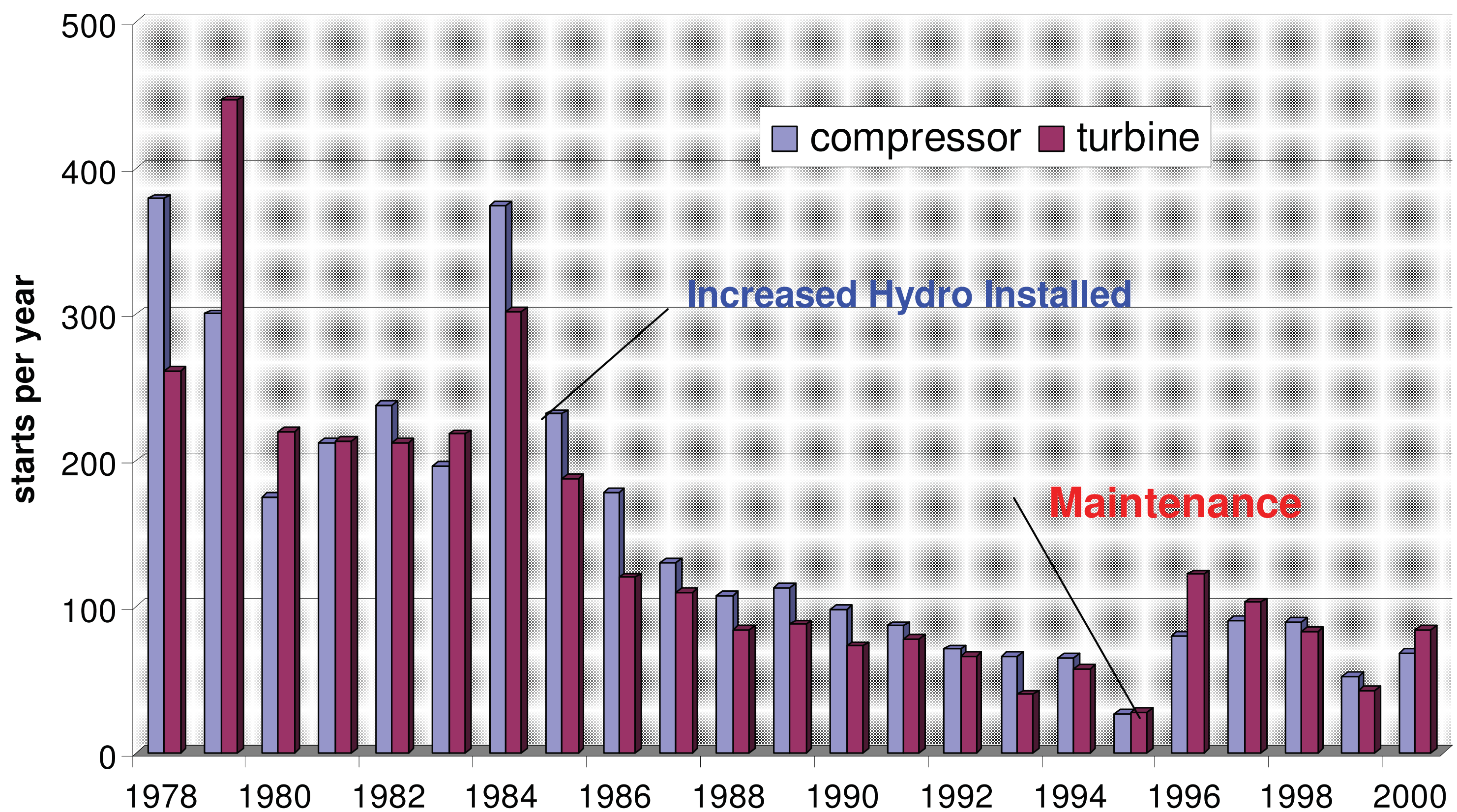
BRULIN

# Cycling Costs

- **Aptech Research**



# Huntorf Power/Compression Start Cycles




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