Compressed Air Energy Storage (CAES) Scoping Workshop

Enabling Solar and Wind Energy Technologies on a Grand Scale

OCTOBER 21 & 22, 2008

Organized by
Vasilis Fthenakis
Center for Energy & Life Cycle Analysis
Earth and Environmental Engineering
Columbia University

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Vasilis Fthenakis*, Workshop Organizer, Columbia University,*

Workshop Objective

Over the last year solar and wind have been the fastest growing segments in major energy markets. Although deployment of solar and wind systems in the U.S. can increase ten or twenty-fold from current levels without the need for adding storage, eventually, storage will be required for these technologies to become the major constituents of our energy mixture. Furthermore, incorporating storage in the system improves the flexibility of the grid in satisfying load demands. Currently, most energy storage systems are expensive; however, compressed air energy storage (CAES) is economical for large bulk storage and can provide cycling capability, regulation and quick start for both peak and base load applications. Nevertheless, questions on the value and the full potential of this technology remain. This workshop focus on investigating potential technical, geographical and economic constraints associated with large CAES deployment and on determining R&D and field testing needs at the NY state and national levels. Participation of nationally- and internationally-renown CAES technology experts, developers and utility representatives, ensures that these issues are authoritatively addressed.

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1. OPENING SESSION

Welcome to Columbia University: Klaus Lackner, Chair, Department of Earth and Environmental Engineering and Director of Lenfest Center for Sustainable Energy, Columbia University.

NYS Energy Planning: Mark Torpey, Program Manager, NYSERDA

Abstract: The presentation will provide a high level overview of energy storage issues in NYS. NYSERDA is currently developing a comprehensive energy plan that should clearly identify the importance of energy storage in
facilitating renewable resources and improving overall grid reliability.
Dr. Torpey will discuss some of the market (NYISO) and regulatory (NYSPSC) issues that need to be addressed in order for energy storage technologies to play a more prominent role for improving the performance of the electric power
delivery system.

Meeting Objectives: Vasilis Fthenakis, Department of Earth and Environmental Engineering and Director of Center for Life Cycle Analysis, Columbia University.

2. ENABLING LARGE SCALES OF PHOTOVOLTAICS AND WIND

2.1 CAES for Enabling PV: Vasilis Fthenakis, Columbia University.

Abstract: Over the last year solar and wind have been the fastest growing segments of the U.S. and certain European energy markets. Although deployment of solar and wind in the U.S. can increase ten or twenty-fold from current levels without the need of adding storage, eventually, storage will be required for these technologies to become the major constituents of our energy mixture. Furthermore, incorporating storage in the system improves the flexibility of the grid to incorporate PV and wind generated power. Most energy storage systems are expensive, either in capital outlays or in energy losses incurred while storing and retrieving energy. For example, batteries are costly, fly wheels are suitable for short-duration storage only, pumped hydro has geographical limitations and superconducting electricity storage is experimental. However, compressed air energy storage (CAES) is a technology that is economical for large bulk storage and can provide cycling capability, regulation and quick start for both peak and base load applications. It has been recently proposed (Solar Grand Plan) that large scale PV-CAES and wind-CAES deployment can enable these technologies to provide most of our energy needs. However, questions remain on the feasibility of such a grand plan. This workshop will focus on investigating potential technical, geographical and economic constraints associated with large CAES deployment and on determining R&D and field testing needs at the NY state and national levels.

2.2 Grand Scale Wind/Transmission/CAES Systems: Alfred Cavallo

Abstract: The economic and technical issues involving a combination of large scale wind turbine arrays, long distance high voltage transmission lines and compressed air energy storage (CAES) systems have been explored, and it has been shown that power from such systems is both affordable and technically equivalent to that from alternatives such as fossil fuel and nuclear power plants. However, this integration strategy is in strong contrast to the current approach, which is to feed the intermittent power onto the existing grid and have utilities take care of transmission and provide spinning reserve. It turns out to be difficult, contentious and controversial to discuss renewable energy together with transmission and storage since these introduce additional costs and make renewable energy less competitive relative to other generators. However, leaving these additional components out of the picture relegates renewable energy to a fuel saver and an appendage to conventional generators rather than a fully competitive generator in its own right. The economic and technical issues associated with transforming wind generated electricity from an intermittent to a controllable (dispatchable) power source will be reviewed; policies necessary to insure that intermittent renewable generator systems that include transmission and storage are profitable for developers and affordable for consumers will be suggested.

2.3 Wind-CAES Integration: Samir Succar, Natural Resource Defense Council

Abstract: This talk will focus on the coupling of CAES systems to gigawatt-scale wind parks as a strategy for climate change mitigation. The correlation of high-quality wind resources and geologies suitable for CAES is analyzed, highlighting regions and geologies that will be relevant for the large-scale deployment of such systems. A cost comparison of Wind/CAES with alternative sources of low-carbon baseload power illuminates its potential to become a mainstay of baseload electricity production in a carbon-constrained world.

2.4 CAES Strategic Needs: Roy Daniel, CEO, Energy Storage and Power.

Abstract: Compressed air energy storage (“CAES”) offers range unit storage capacities from 15 MW with above ground storage for distributed generation and load management applications to the large 430 MW unit with underground storage for bulk energy storage providing significant response capability to load changes to help manage the intermittency of Photovoltaic and Wind Resources. CAES is less expensive than a traditional gas-fired combined cycle plant unit and has a substantially smaller emissions profile. So why is there a delay in building these units? New bulk transmission is being permitted to enable renewables and batteries are being piloted to defer transmission upgrades; but why is CAES not part of the grid optimization solution yet? Presentation will explore the two US technologies that underlie the current CAES landscape describing the advantages of each. Infrastructure project realities to be faced to advance CAES from concept to main stream commercial application will be detailed.

3. CURRENT AND FUTURE CAES PLANTS

3.1 Iowa CAES Plant- Challenges and Prospects: Kent Holst, Development Manager, Iowa Stored Energy Plant.

Abstract: For 6 years the Iowa Stored Energy Park (ISEP) has been gathering the evidence to show this is a viable project, both technologically and economically. With climate concerns, rising fuel prices and increased demands for alternative forms of electric generation, the need for large scale energy storage is becoming more recognized. ISEP was originally conceived by the Iowa Association of Municipal Utilities after a study was commissioned to identify the future generation resource needs of municipal utilities in Iowa. The study concluded the most unmet need would likely be for intermediate electricity. Compressed Air Energy Storage (CAES) was selected as a model to study because of its ability to support expanded wind energy development. Challenges faced included the unfamiliarity of the technology, finding suitable geologic formations, and funding to do the research. Midwest municipal utilities and Iowa's congressional delegation have provided the funding to enable continued progress. Recently the State of Iowa has announced significant support. Many highly qualified consultants have provided the expertise needed to bring the project to the current status. Soon drilling and pump testing will commence in order to qualify the selected aquifer. With that information, ISEP will be ready to solicit funding for final design, procurement, and construction of the world's first aquifer based Compressed Air Energy Storage system.

3.2 Norton Energy Storage: CAES Resiliency in Uncertain Markets: Dave Marchese, VP, Haddington Ventures.

Abstract: Norton Energy Storage has been in development since 1999 with Haddington Ventures funding all development activities through its CAES Development Company (CDC). CDC had completed the key steps of site control (surface and sub-surface), geotechnical analysis, development of local support for the project, substantial engineering of the above and below ground facilities and obtaining key permits and rights of way. However, financial and market disruption in the power industry in 2001-2 sharply set back NES' prospects. CDC continues to develop Norton and hopes to begin construction on the project in early 2009, depending on the outcome of the current turmoil in financial markets.

Haddington's experience in natural gas storage indicates that as long as commodities have volatility, there is value in developing storage of those commodities if the capital costs allow. Mr. Marchese will discuss how the project has adapted to the changes in each of the power, equipment and financial markets.

4. TECHNOLOGY STATUS

4.1 CAES Technology: Mike Nakhamkin, Director, Chief Technology Officer, Energy Storage and Power, LLC.

Abstract: Presentation will start with brief description and analysis of the first Compressed Air Energy Storage ("CAES") project – the 110 MW CAES plant for Alabama Electric Cooperative, and ESPC involvement in all stages of the project execution. It will be followed by description of the patented by Dr. M. Nakhamkin second generation of the CAES technology- it's flexibility to meet variety of load management requirements, wide range of capacities, operational, performance and economic advantages including very high reliability and availability. The presentation will be concluded by economic analysis of CAES and other competing technologies.

4.2 Dresser-Rand Compressor Technology: James Heid, VP, Dresser-Rand

Abstract: The compressor technology used in the McIntosh plant will be described and systems for future CAES plants will be discussed

4.3 Compressor Selection and Design: Michael McGill, Partner, Electricity and Air Storage Enterprises.

Abstract: Compressor selection and design offer opportunities to optimize mechanical system performance in the interest of maximizing system efficiency, receipt and injection of renewable energy and/or CAES plant economics. Market requirements and structures, availability and sources of compression energy, expander selection, and designs of reservoirs and well systems are often fixed early in the process when CAES developers contemplate cycle design. Compressor selection and design can help guide reservoir selection (size, depth) efforts. More importantly, compressor selection can offer the flexibility to create the optimal CAES system to accomplish the objectives of the CAES plant ownership and its customers. Furthermore, compressors can sometimes be added after commencement of operation to amend the operating capabilities and establish a new optimization.

5. GEOLOGY

5.1 Aspects of underground compressed air energy storage: Stephen J. Bauer, Geomechanics Research, Sandia National Laboratories.

Abstract: Underground space in the form of intergranular porosity, and mined excavations, in their natural or engineered states will be reviewed as they present a great opportunity to store compressed air. Host rock considerations and constraints including depth, containment, volume, flow rate, stress state, pressure cycling and potential detrimental conditions/circumstances, will be discussed.

5.2 Geological Potential and Considerations for Underground CAES in New York State: Langhorne "Taury" Smith, NYS Museum.

Abstract: One of the most significant hurdles to successful underground compressed air energy storage (CAES) in New York State will be finding usable pore space in the bedrock geology. The ideal underground storage would be in salt caverns. In this scenario, salt layers would be dissolved to make caverns of the exact dimensions needed. There are salt layers underground at appropriate depths (500-1500 meters) in an east-west trending zone in the southern half of western New York from the Catskills west to Lake Erie. A cavern could be constructed anywhere within this area. The major hurdle in this case would be disposing of the dissolved salt which would be in the form of brine that was many times saltier than seawater. Salt could be extracted on the surface for use on roads or other applications, it could be carried to the ocean or small amounts could possible be discharged into streams during periods of high water. But it is likely that at least some of the brine will need to be disposed of by drilling wells to deep formations and injecting it into the subsurface. This is problematic in New York because there are not many formations that have the porosity and permeability required to accept large quantities of brine. These challenges will be discussed in the talk. Another opportunity would be to use depleted oil and gas reservoirs. These would need to have high porosity and permeability so that the air could be easily pumped in and released at relatively high rates. They would also need to be relatively small and well sealed. There are many depleted reservoirs in New York, but many of them have relatively low porosity and permeability. Those with higher porosity and permeability are almost all currently being used for underground natural gas storage which is a lucrative business in New York. In other words, there is competition for the pore space. Further competition for both depleted reservoirs and potential brine injection targets will likely come from geological carbon sequestration where reservoirs or brine aquifers with similar characteristics may be needed to sequester CO2 captured from power plants. The competition from natural gas storage and carbon sequestration may lead to a higher cost environment for CAES underground storage because companies will have multiple options.

5.3 Location Independent Engineered Reservoir Systems: An Alternative to Conventional Reservoir Models: Jon Myers, CEO, SEQEnergy

SEQEnergy (SEQ) has developed a proprietary, patent-applied for solution designed to enable the construction of gas or liquids storage reservoirs in many geological settings without conventional requirements for pre-existing void spaces or aquifers or for excavation to create the reservoir space. SEQ believes that its unique reservoir technology may be of strategic importance to scaling the CAES energy storage model to help meet our nation’s future alternative energy and grid management requirements. The SEQ reservoir is constructed in solid rock utilizing natural and enhanced pore space for gas or liquids containment. Existing geological fractures and reservoir performance and safety are managed by the injection of barrier material at the reservoir perimeter. Surface systems are utilized to manage injection and reproduction. The result is a cost-effective reservoir system that can be located optimally and be engineered to application-specific scale and performance specifications.

6. GRID INTEGRATION

CAES Performance Requirements & Opportunities in NY: Jim Harvilla, Program Manager, NYSEG /Rochester Gas & Electric, Rahul Walawalkar, Customized Energy Solutions, and Lisa Hoffman, NYSEG.

Abstract: We will present the preliminary results of the CAES evaluation study being carried out by NYSEG, Customized Energy Solutions and EPRI. The study includes identification of the potential caverns and attempts to map the suitable geographical locations with the natural gas and electric grid infrastructure. The presentation will include overview of the NYISO electricity markets and the opportunities available for CAES in energy, ancillary services and capacity markets operated by NYISO. We will present the results of quantitative analysis of 3 different NYISO zones that could be potential locations for the installation of future CAES projects. We will discuss issues related to design and sizing of various components of CAES that could affect the economics of CAES operation in NYISO.

7. R&D STATUS

7.1 CAES Research, Development and Deployment Projects at EPRI: Robert Schainker, Senior Technical Executive, EPRI

Abstract: A summary of EPRI's Research, Development and Deployment activities for the Compressed Air Energy Storage (CAES) technology is presented. The summary includes past, present and future planned activities, to include the work that was used to build the first US based CAES plant (i.e., the McIntosh Alabama 110 MW – 26 hour plant) and planned work to deploy an advanced CAES plant(s) in the US. Also presented is a summary of past R&D work on the adiabatic CAES plant, which does not use any fuel during its generation cycle. The RD&D work presented will also include a "roadmap" of how CAES (as well as other technologies) can be used to enhance the use and penetration of renewable technologies (e.g., wind and solar generators).

7.2 PV-CAES Modeling and Assessments at Columbia University: Vasilis Fthenakis, Director, Center for Life Cycle Analysis, Columbia U.

WORKSHOP RECEPTION & DINNER

Terrace in the Sky, 119th street and Morningside Ave

October 22, 2008

INTERACTIVE ROUND TABLE DISCUSSIONS
Trustees Room, the Low Memorial Library

CAES Business Opportunities

CAES R&D Needs

Columbia University - CAES Workshop
Round Table on CAES Business Opportunities

Topics for discussion

1. Describe the market rules across the country that present the most significant roadblocks to integration of CAES into Regional Transmission Organization (RTO) markets

Categorization and Ownership

In the past, a utility provided generation, transmission and distribution (T&D) services. Today, many power markets have adopted the separation of generation and T&D service to introduce competition in an effort to improve services and reduce costs for rate payers. Under this unbundled scheme, compensation for generators is set by the market. Meanwhile, T&D companies receive regulated compensation for their T&D investment.

The asset classification of "storage" options becomes a contentious issue under this scheme. T&D companies can use capacitors for their transmission system design and are allowed to have a regulated rate recovery of the cost. Meanwhile, even though the underlying function is similar, CAES may be considered as a generation asset and the ownership of such an asset by T&D would be contested.

A T&D company would have no incentive to invest in a CAES asset if it could not own it and, thereby, not receive compensation for its investment. Opportunities for levering CAES' "bulk" energy storage capability to reduce or defer investment in T&D infrastructure, therefore, remains largely a non-attainable value for T&D and ultimately no savings for rate payers. Meanwhile, if a T&D were permitted to own CAES, generators would think it would be an infringement by T&D, adversely affecting the market compensation for generators.

Even though the choice was made to segregate T&D and generation, it appears that there is not a public utility commission (PUC) precedent regarding the asset classification of CAES. A clear classification for CAES or provision to allow joint ownership of a CAES asset between the T&D and CAES developer would be needed to overcome this roadblock.

- Differentiate the regulated and deregulated utility industry viewpoints

Under the current rules in NY regulated utilities probably will not be allowed to build, own and operate a CAES plant if it is deemed to be generation. The regulated utility is split further into regulated T&D and regulated integrated utilities. The T&D utilities will most likely not be able to own the CAES asset because it is a generating asset. If there are ancillary services that the utility needs for its system, it could contract for these on a long term basis and ask regulators to include the cost in the rate base. Unregulated generators and load serving entities must weigh the economic costs and benefits of CAES using projections of power prices, fuel prices and value of assets in the region.

A utility’s point of view expressed by Jim Harvilla, NYSEG (a T&D company):
Under the current rules we have to follow, we are not allowed to build, own, or operate a fossil fired generating facility. Thus, we need a Public Service Commission (PSC) ruling to determine if CAES plants are generation or transmission assets. I don’t think there should be a general rule that only unregulated companies can own CAES facilities. Each project should be evaluated on its own merit and the PSC should decide if it makes sense for a regulated utility to own and operate it based on its unique requirements. I think that that the PSC needs to become more involved in the development of CAES technology so they have sufficient information to make intelligent decisions regarding building, owning, and operating CAES plants and other energy storage plants. Regarding ownership, I do not feel that there should be any one rule about ownership. I think that anyone organization or a consortium of interested parties should be allowed to build, own and operate a CAES facility, including regulated utilities. Because of the cost and risks of building a large CAES facility and the collective benefits to both generation and transmission/distribution of operating CAES, it makes sense to have joint ownership.

A developer’s point of view expressed by Dave Marchese, Huddington Ventures:

I believe that the rules most important to CAES are those defining the ability to provide regulation service, those that ensure compression power is purchased at wholesale, and 15 minute pricing rules that do not then default back to an average hourly price (ex-ante pricing vs. ex-post).

Regarding ownership and operation, I do not see CAES as a generation asset, therefore the entity that owns it must be able to buy and sell power in the wholesale market. I think that there are contracting structures which would allow transmission companies to participate in the benefits of storage on their systems without actually owning the generation asset.

- **Differentiate the value proposition for arbitrage, ramping, frequency regulation, and enhancing the use of existing wind generators and increasing the penetration of wind generators**

Increasing the use of existing wind and penetration of new wind energy is really the same as arbitrage, ramping and frequency regulation. The three products are just the economic representations of problems related to fluctuations in generation and demand. Well structured and run ISO markets will show the value of introducing CAES. To the extent that customers are willing to pay for firm and “green" energy, there may be additional benefits by combining the characteristics of both wind and CAES plants in a single product.

There is a need for identifying synergies with industry associations like the Utility Wind Integration group (UWIG), and work together to promote mutually beneficial market rules.

Renewable Portfolio Standards (RPS) and Green Credit Rules

The rules of NY State's Renewable Portfolio Standard (RPS) categorize storage as a renewable resource as long as renewable energy sources are used in the system. However, the categorization of CAES may vary with each plant, since electricity from either the grid or directly from renewable sources can be used to run the compressors, and fuel can be from either fossil or renewable sources. Therefore:

a) RPS and Green Credit rules need to be addressed so that they explicitly include CAES.
b) CAES proposals need to clearly demonstrate how ISO market benefits.
c) Arguments for CAES before State (PSC) and Federal (FERC) regulators should emphasize that CAES is for general grid support, not only wind support, and that storage is needed to regulate and improve electricity transmission.
d) Market rules are needed for proposed CAES storage that will support the deployment of renewable energy.
e) CAES to be recognized as one of the advanced technologies that have the potential to facilitate the management of intermittent non-carbon generation resources by NYISO.

2. What technical constraints need to be considered with regards to committing and dispatching CAES resources?

There are not technical constraints as CAES is proven to have fast (e.g. 10-min) start-up times and ramp rates. There are only economic constraints related to committing resources to CAES and realizing the benefits of the investment.

3. From an economics perspective, what price differential would be needed between the electricity used in compression and that generating by CAES, to make it economic?

The prevailing opinion was to avoid comparisons between peak and off-peak electricity and to present the benefit of CAES as part of an electricity supply mixture satisfying hourly grid loads; for example, NYISO optimizes the system every 5-min for the next hour. CAES is an enabler to maximizing the use of non-carbon and domestic generation. The efficient storage of less valuable off-peak energy and delivery when the energy is more valuable will tend to reduce on-peak prices.

It was also suggested to:

- Optimize the system for satisfying monthly or even seasonal energy needs.
- Compare the supply energy mixture in various regions and investigate where the forecasted wind resources are going to come on line.

4. Have the total market cost benefits of adding CAES to a region's generation mix been modeled and studied? What about total environmental benefits?

There are some economic studies on adding CAES to a region's generation mix in progress but more are needed. An issue is the ability to model a CAES plant in the generation planning models. Pump hydro units are currently used as a proxy for a CAES plant, but specific CAES unit models need to be developed. This is important as Renewable Portfolio Standards are being investigated and upgrade to the US electric grid is studied.

At the project level, cost/benefit analysis is very important for CAES developers. Such analysis should show the benefits in energy arbitrage, ancillary services market, capacity market, unlocking stranded non-carbon generation, and reducing the electric grid interconnection cost. It is important to show that CAES plants have few constraints on bidding strategy due to their flexible design, so they can:

- Provide spinning reserve capacity with the rapid ramp-up capability,
- Operate compressor and generator simultaneously to absorb load and provide electricity management control,
- Assist in system management to maximize utilization of wind electricity

Also the environmental issues and benefits CAES deployment need to be assessed; assessments should include the following:

- Enabling more non-carbon generation on to the electric grid
- Net reduction in emissions
- Carbon credits
- Renewable credits
- Moving emissions away from non-attainment areas
- Enabling better operation of fossil-fuel plants

5. What are the components necessary to develop a successful CAES facility?

a) Suitable Storage site, either above ground or below ground.

b) Availability of transmission and fuel source

c) Understanding of Environmental and Permitting issues:

- Air permits from US EPA or NYS DEC
- Water discharge (brine) permits

- Electric and gas siting licenses and environmental permits
- Well drilling and testing permits
- Electric Interconnect application process at NY ISO
- Archaeological surveys, if applicable

6. New York is working on allowing the use of Liquefied Natural Gas (LNG) in the state. What new opportunities does that present?

It would create CAES siting options in locations that do not have gas pipelines.

7. There are several technology opportunities to design, develop, and improve CAES equipment and operation. Can the use of fuel be completely eliminated?

It could be eliminated or drastically reduced in future designs that implement a higher temperature compression stage with heat recovery (advanced adiabatic CAES).

8. What are the opportunities for using the brine for marketable products?

There is certainly potential and needs to be investigated. Potential applications include liquid road salting, products in the salt industry and perhaps use in the chemical industry.

9. Who are the key players in developing the CAES industry?

- Developer of CAES technology educating and advocating for its application
- Entities delivering the CAES unit with the necessary commercial and performance guarantees
- ISO system operators who recognize the need the value of CAES in managing non-dispatchable intermittent generation resources.
- Independent Power Producers who perceive the economic benefit from providing CAES services to the electric grid.
- Load serving entities who perceive the economic benefit from providing CAES services to their service territory in managing load and transmission upgrades
- Wind energy developers that want to capitalize on the opportunities that CAES presents to increase the profitability of wind resources
- Federal and State government entities seeking to de-carbonize the electric grid and to optimize the use of the electric transmission grid.
- Venture capitalists that are looking for financing and funding opportunities in the energy sector.

Columbia University -CAES Workshop
Round Table on CAES R&D Needs

Topics for Discussion

Policy - Economics

1. What is the CAES value proposition and how can we best quantify it?

CAES provides to a Regional Transmission Organization (RTO) more flexible generating alternatives. There is inherent value in generation that can be quickly scaled up and down. CAES has fast ramping rates and can operate between 20% (depending on the permitted emissions level and the train redundancies) and 100% of its rated capacity. If sited in areas that are transmission constrained, this added flexibility provides the RTO with means to maintain system security. A second, and just as significant, benefit of CAES to the entire system is the ability to store clean and off-peak generation until the peak hours. This has environmental and cost benefits.

The basic CAES intrinsic value proposition stems from the ability of the system to provide energy (MWh) at a thermal efficiency equal or higher to a combined cycle gas turbine (CCGT) with less than half the fuel and emissions of the former, capacity (MW at peak hour), and ancillary services (all ancillaries with an equal or better response rate than that of a GT). The extrinsic value proposition comes from the ability to dispatch lower cost or sustainable and renewable energy resources to satisfy hourly loads on demand

To fully realize the economic benefits of CAES, one should take advantage of both the ancillary and arbitrage benefits of adding the system in the grid along with optimizing the new build requirements for transmission. In cost analysis, RTO systems must be modelled with their existing generation mix to determine total system cost, and again with strategically located CAES to determine the cost benefit to the system. A generic model will be less impactful than a model using a specific RTO's set of circumstances, since the existing load patterns and generation mix on the system can greatly affect the value of CAES. Siting of the CAES is essential in order to apply maximum CAES benefits to non-carbon emitting generation. For instance, CAES could have a direct benefit to wind resources if it is able to absorb excess wind energy that otherwise would need to be curtailed due to transmission constraints. Energy stored off-peak and delivered on-peak will tend to reduce on-peak prices is a benefit to all electric users.

2. What are the best ways to improve the capital cost and operational performance of CAES components and an integrated overall CAES plant?

<u>Near term</u>: The cost and performance of CAES equipment are well studied from the operation of the existing first generation CAES plants in Huntorf and McIntosh, and have been improved through the application of industry standard components in the second generation CAES design. The best way for improving cost and operation in the near-term would be to have several CAES plants deployed in the US based on either first generation or second generation CAES, improving the efficiency of construction and consolidating operating experience and expertise.

Mid Term: a) The industry needs an air driven turbine (derived from steam turbine design). There are currently few vendors willing to provide larger than 85 MW air turbines with guarantees for performance. Also, high pressure fired expanders need to be engineered in order to offer operational flexibility.

b) Minimize the use of fossil fuels by incorporating low emission, or renewable energy heat sources for expanding the compressed air.

b) Reduce the use of fuel by developing semi-adiabatic systems with higher compression discharge temperatures than current designs, enabling efficient heat storage and recuperation.

Long Term: Eliminate the use of fuel with advanced adiabatic systems. This requires studies of high heat production by compressors, heat capture and transfer media systems.

3. How do we get utility regulators and grid Independent System Operators familiar with the benefits of CAES?

A clear presentation of the CAES technology, its concepts, its benefits and the current operation of the two existing first Generation CAES plants would be very helpful; specific action items include:

- Publishing an industry newsletter on the subject.
- Conduct thorough studies on the various concepts and publish these in industry publications
- Present at RTO market participant workshops.
- Meet individually with RTO planners.
- Identify synergies with organizations like UWIG (Utility Wind Integration Group) and work together to promote mutually beneficial market rules.
-

Energy-Environmental-Economic Analysis

4. What are the environmental benefits of CAES?

There are several environmental benefits from the introduction of CAES in the grid:

- Strategically sited CAES could reduce the amount of wind curtailment (thus increase the amount of wind generation on the system overall) that would otherwise occur without the ability to store their excess generation.
- CAES could allow less clean technologies to operate at a somewhat higher capacity level in off-peak hours, allowing them to run in a more efficient and clean range.
- CAES would increase the percentage of power generated by clean technologies and enable it to be delivered during peak hours.

5. How can CAES be "greener" over its life cycle?

- By producing less NOx, CO, CO_2, PM10, SOx and other toxic emissions by design (e.g., 2nd generation and adiabatic CAES plants) or by choice of fuel (e.g., biofuels, waste products).

- By considering the Best Available Technology in term of low emissions and higher efficiencies.
- By control systems for better grid management.
- Using less water, perhaps with dry cooling.
- Preventing any direct environmental impact (e.g., using brine from depleted salt formations, instead of disposing it).
- Use pre-existing underground storage.

6. What are the modeling and analysis needs?

There is a need to quantify the emissions profile of 1st generation CAES plants over the operating range of spinning and synchronized reserve capacities in terms of NOx, CO, and CO_2 emissions. Also, there is a need for comprehensive life cycle analysis of 1st generation CAES systems to provide accurate emission estimates and balanced comparisons with other energy generation (or 2nd Generation CAES based on standard Gas Turbines) and storage options.

Brine disposal is important in the development of salt formations for CAES storage. Safe disposal alternatives and options of using it in marketable products need to be investigated.

Since CAES storage may compete with natural gas storage, modeling the value of the two in comparative terms, it may be instrumental.

Depleted natural gas reservoirs are suitable for CAES, and the presence of natural gas in the reservoir should not present a safety problem. This is an issue that needs detailed analysis.

Collaboration among national labs and universities in integrating CAES with on going activities on wind and solar resource modeling would be beneficial. This collaboration could as well be extended to an international basis in which the European CAES community (academic, R&D and Industrial) could bring their respective CAES experience.

The development of adiabatic CAES plants is another area requiring collaborative research on an industrial basis. While adiabatic CAES is technically possible but not currently at the efficiencies calculated theoretically, there are challenges related to the design of heat storage systems, to the compression high pressure, high end temperature design and to the selection of heat capture and storage technology.

Geological Capacities and Constraints

7. Is there a competition for locating underground storage between CAES, natural gas storage, and CO_2 storage?

There is a competition between CAES and natural gas storage, but not with CO_2 storage which requires deeper formations (higher storage pressure). However, there are also synergies since the same companies could be involved in developing underground storage of for all the gases. It appears that several natural gas storage companies are now active in identifying potential CAES underground air storage locations with a couple moving into the CAES plant project development business.

8. How good are underground reservoir indications reported by EPRI in early 90s (e.g.,suitable underground formations in 75% of the country)?

These indications are good, but testing of individual formations is required to test suitability. It is concerning that a state-wide search by the Iowa Energy Storage Association resulted to the candidacy of only three sites from a total of twenty sites investigated.

1.1 NYS Energy Planning: Mark Torpey, Program Manager, NYSERDA

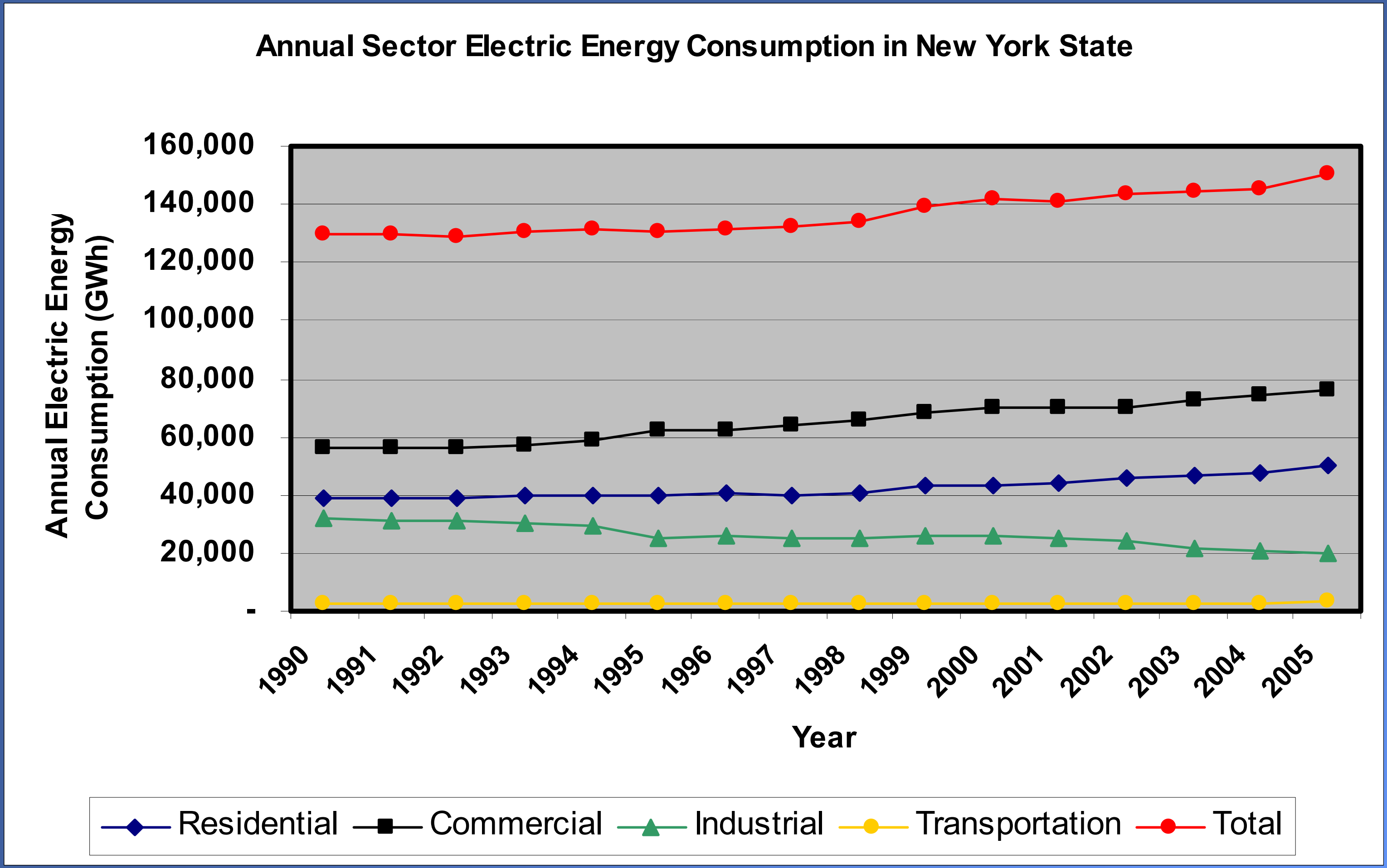
Mark Torpey - NYSERDA Program Manager T&D and Exploratory Research (7 years with NYSERDA). Served as Director of Government Relations with Plug Power (2 years) before coming to NYSERDA. Plug Power manufactures small-scale fuel cells.
Spent 15 years after college working for Foster Wheeler designing large-scale coal, oil, and natural gas power plants. The last position he held with Foster Wheeler was Director of R&D. Mr. Torpey was recently elected a Fellow of the American Society of Mechanical Engineers (ASME) and he is also an Adjunct Professor at Skidmore College teaching energy policy. He has a BSME from Brown University and a MSME from MIT.

Compressed Air Energy Storage (CAES) Scoping Workshop

Columbia University – Center for Life Cycle Analysis
Tuesday, October 21st – 2008

Mark R. Torpey
NYSERDA
Program Manager – T&D and Exploratory Research

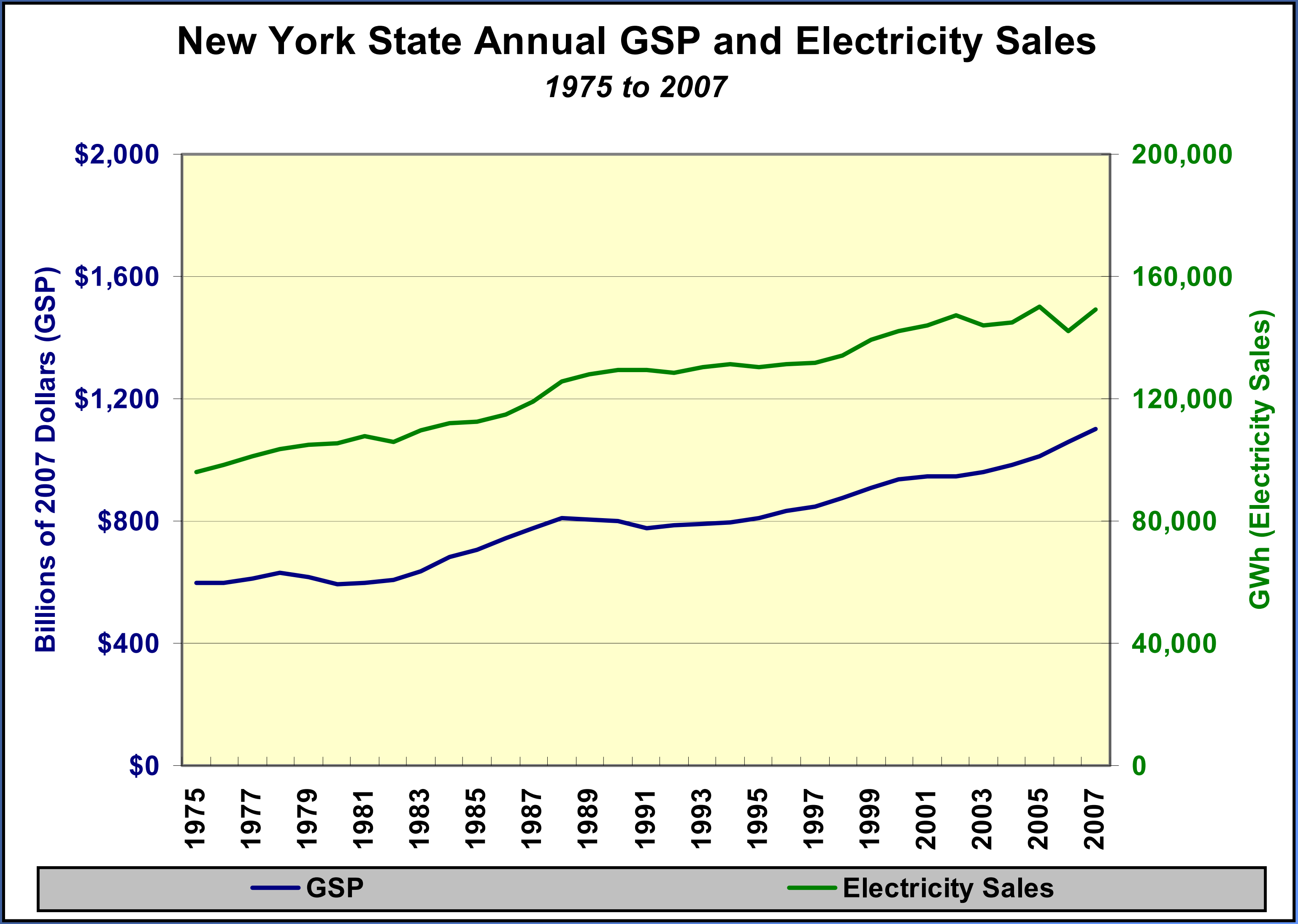
Historical Electric Energy Consumption in NYS



Sector Thermal/Electric Ratios

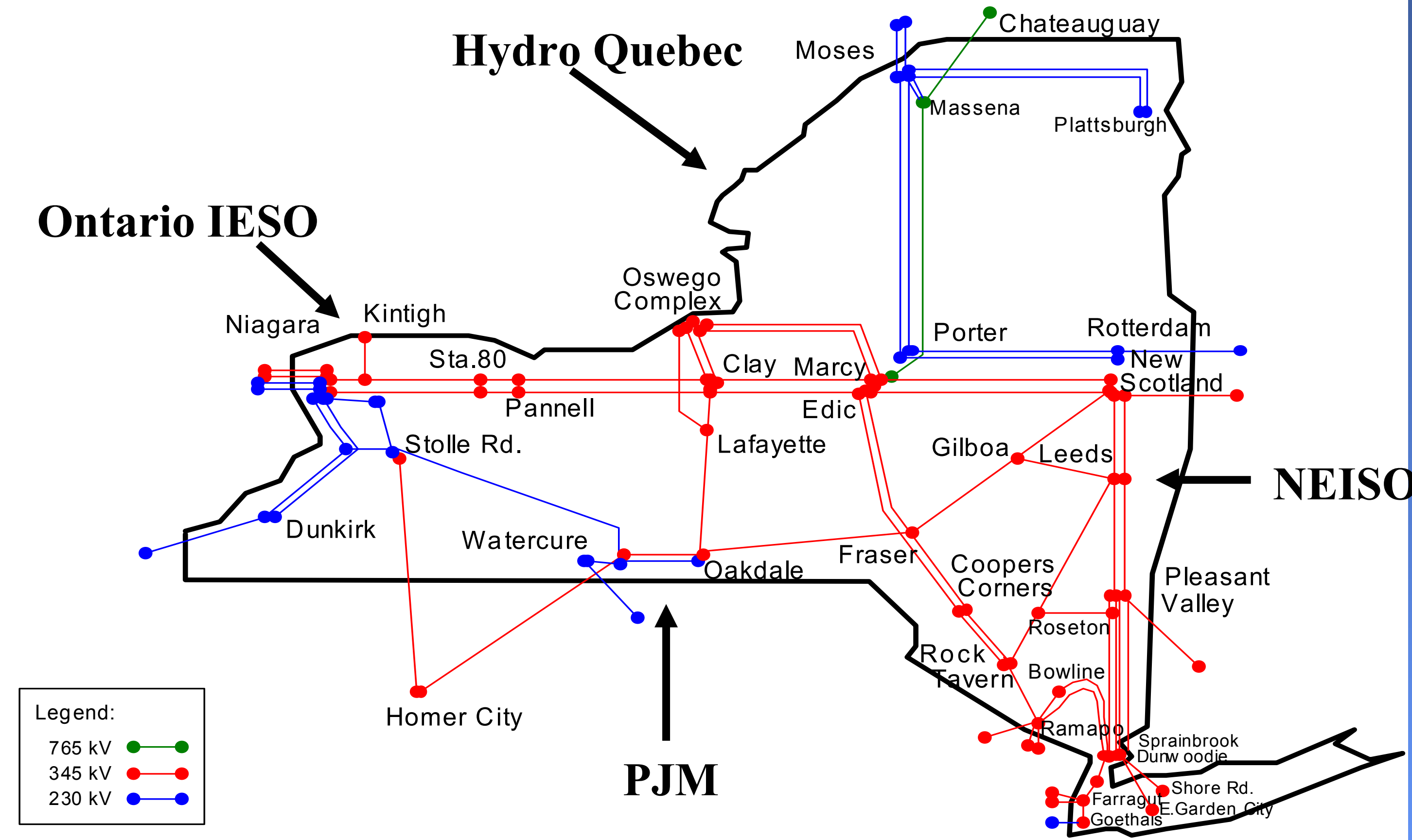
Industrial (6:1) Residential (4:1) Commercial (2:1)

Electric Load Growth and Gross State Product



Economy becoming more reliant on electric energy

NYS Electric Transmission System



Regulatory Initiatives

Deregulation: NYISO administers $11 billion market

Renewable Portfolio Standard: 25% renewable energy by 2013

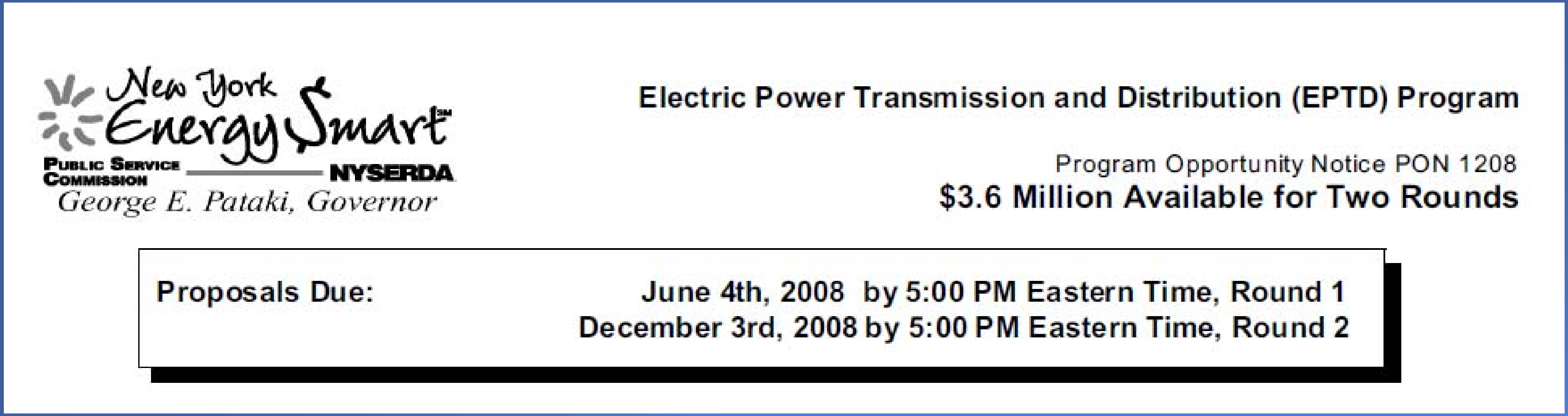
Regional Greenhouse Gas Initiative: 10% CO2 reduction by 2018

Can energy storage be used to support regulatory initiatives?

How do we coordinate effectively to address all perspectives?

NYSPSC: Should storage be considered a form of generation?
NYSDEC: What are the air quality impacts associated with storage?
Utilities: Can storage be used to delay/offset T&D expenditures?
NYISO: How should the market rules be developed?

NYSERDA has initiated a new program focused on T&D issues



New York Energy Smart℠

Public Service Commission

NYSERDA

George E. Pataki, Governor

Electric Power Transmission and Distribution (EPTD) Program

Program Opportunity Notice PON 1208

$3.6 Million Available for Two Rounds

Proposals Due:	**June 4th, 2008 by 5:00 PM Eastern Time, Round 1** **December 3rd, 2008 by 5:00 PM Eastern Time, Round 2**

New York Statistics

Peak Demand: 34,000 MW

Energy Consumption: 150,000 GWh

Averaged Demand: 17,000 MW

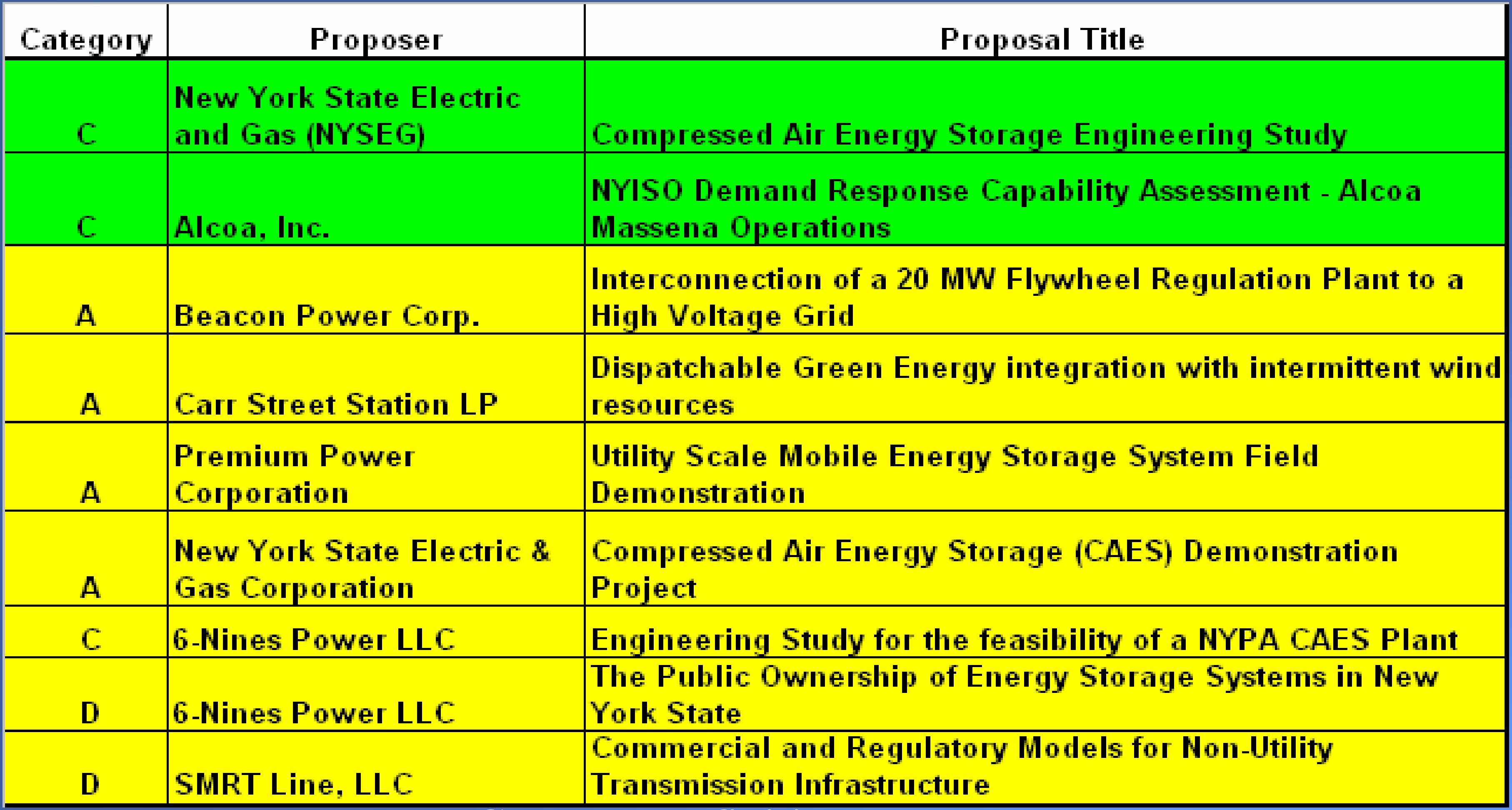
Existing Pumped Hydro: 1,000 MW

Regulation Service Market: 200 MW

Current Wind Resource: 700 MW

11 Million Vehicles: PHEV Energy Demand = 12,000 GWh

A sampling of selected and pending EPTD projects



Category	Proposer	Proposal Title
C	New York State Electric and Gas (NYSEG)	Compressed Air Energy Storage Engineering Study
C	Alcoa, Inc.	NYISO Demand Response Capability Assessment - Alcoa Massena Operations
A	Beacon Power Corp.	Interconnection of a 20 MW Flywheel Regulation Plant to a High Voltage Grid
A	Carr Street Station LP	Dispatchable Green Energy integration with intermittent wind resources
A	Premium Power Corporation	Utility Scale Mobile Energy Storage System Field Demonstration
A	New York State Electric & Gas Corporation	Compressed Air Energy Storage (CAES) Demonstration Project
C	6-Nines Power LLC	Engineering Study for the feasibility of a NYPA CAES Plant
D	6-Nines Power LLC	The Public Ownership of Energy Storage Systems in New York State
D	SMRT Line, LLC	Commercial and Regulatory Models for Non-Utility Transmission Infrastructure

Category Definitions

A: Demonstration
C: Engineering Study
D: Research Study

Please visit the website (www.nyserda.org)

NEW YORK STATE

NYSERDA New York State Energy Research and Development Authority

David A. Paterson, Governor

Click Here to View the TEXT ONLY Version of this Web Site

FIND IT SEARCH

ABOUT NYSERDA | FUNDING OPPORTUNITIES | EVENTS | CONTACT US/DIRECTIONS

- Commercial / Industrial
- Residential
- Research and Development

NEWS AND NOTES

- GOVERNOR PATERSON LAUNCHES STATEWIDE CAMPAIGN TO ASSIST VULNERABLE NEW YORKERS WITH RISING HEATING COSTS
- 9/25/2008 - New Funding Available for Innovative Products or Systems that Improve Safety, Energy, and Environmental Performance of Buildings
- 2007-08 NYSERDA Annual Report
- 8/18/2008 - PV Incentive Program Funding
- Fuel Saving Tips - Stretch Your Dollar at the Pump

WHERE CAN I FIND...?

- Heat Smart NY
- Energy Prices / Weather Data
- State Energy Planning
- Forms/Applications
- Press Releases
- Publications
- Financial and Other Reports
- Job Opportunities
- Success Stories!

INCENTIVES FOR...

- Agricultural
- Commercial / Industrial
- Commercial Real Estate
- Hospitality
- Con Edison Gas
- National Fuel Customers
- Municipalities
- Residential
- Schools

PROGRAMS

- Business Partners
- Commercial / Industrial
- Economic Development
- Energy Analysis
- Renewable Portfolio Standard
- Research & Development
- Transportation
- West Valley

OTHER NYSERDA SITES

- GetEnergySmart.org
- Low-Income Forum on Energy (LIFE)
- Renewables - Power...Naturally
- Saratoga Technology + Energy Park (STEP)
- Small Commercial Lighting Program
- Environmental Monitoring, Evaluation, &

Mark R. Torpey (518) 862-1090 ext: 3316; mrt@nyserda.org

2.1 Vasilis Fthenakis, CAES for Enabling PV and Wind

Vasilis Fthenakis, is the founding Director of the Center for Life Cycle Analysis and a Professor at the Earth and Environmental Engineering Department of Columbia University. He holds a joint appointment with Brookhaven National Laboratory, as a Senior Scientist and the Head of the National Photovoltaics Environmental Research Center. His research opened the door for commercialization of a thin film PV technology that currently has a 20 billion $ market capitalization. He was received multiple awards and commendations including a 2006 Department of Energy Certificate of Appreciation "for superior technical, management and communications skills exhibited in photovoltaic environmental research and in effective dissemination of research results". Dr. Fthenakis is a frequent invited speaker in national and international forums on energy and sustainability issues. He has participated in Expert Panels for the U.S. Department of Energy, the European Photovoltaic Industry Association, the California Energy Commission, the American Institute of Chemical Engineers, and the New York Academy of Sciences. He has also served as a safety and environmental consultant for major oil and chemical companies in the U.S. and as an expert on investigating major chemical incidents in the U.S. He is a Fellow of the American Institute of Chemical Engineers, and a Fellow of the International Energy Foundation. He leads for the DOE, an International Energy Agency Task on PV and the Environment. He serves at the Editorial Board of two journals, and frequently organizes symposia and workshops linking the industry and scientific communities. Fthenakis is the author of the book "Prevention and Control of Accidental Releases of Hazardous Gases", editor of two books on Life Cycle Analysis, and author or co-author of more than 200 papers and a patent on PV recycling. Fthenakis earned his bachelor's degree in chemistry from the University of Athens, a master's degree in chemical engineering from Columbia University, and a Ph.D. in fluid dynamics and atmospheric science from New York University.

Enabling Large Scales of PV and Wind

Vasilis Fthenakis

Columbia University
and
Brookhaven National Laboratory

PV Module Steady Growth > 40%

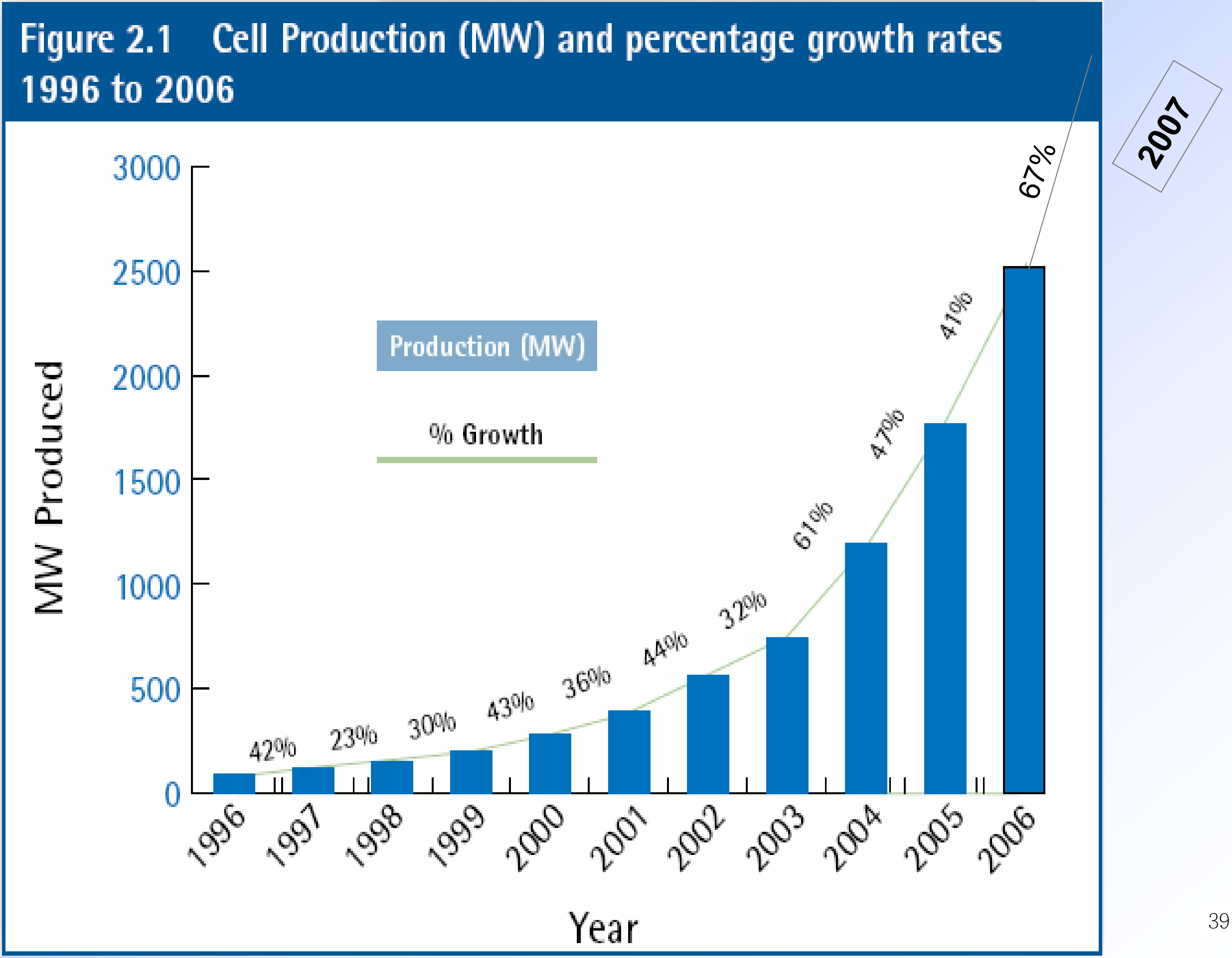


Figure 2.1 Cell Production (MW) and percentage growth rates 1996 to 2006

Fthenakis residence, Dix Hills, NY
4.8 kW

Roofs-Commercial Buildings
New York

Sinzheim, Germany, with permission from Juwi, 2006
1.4MW

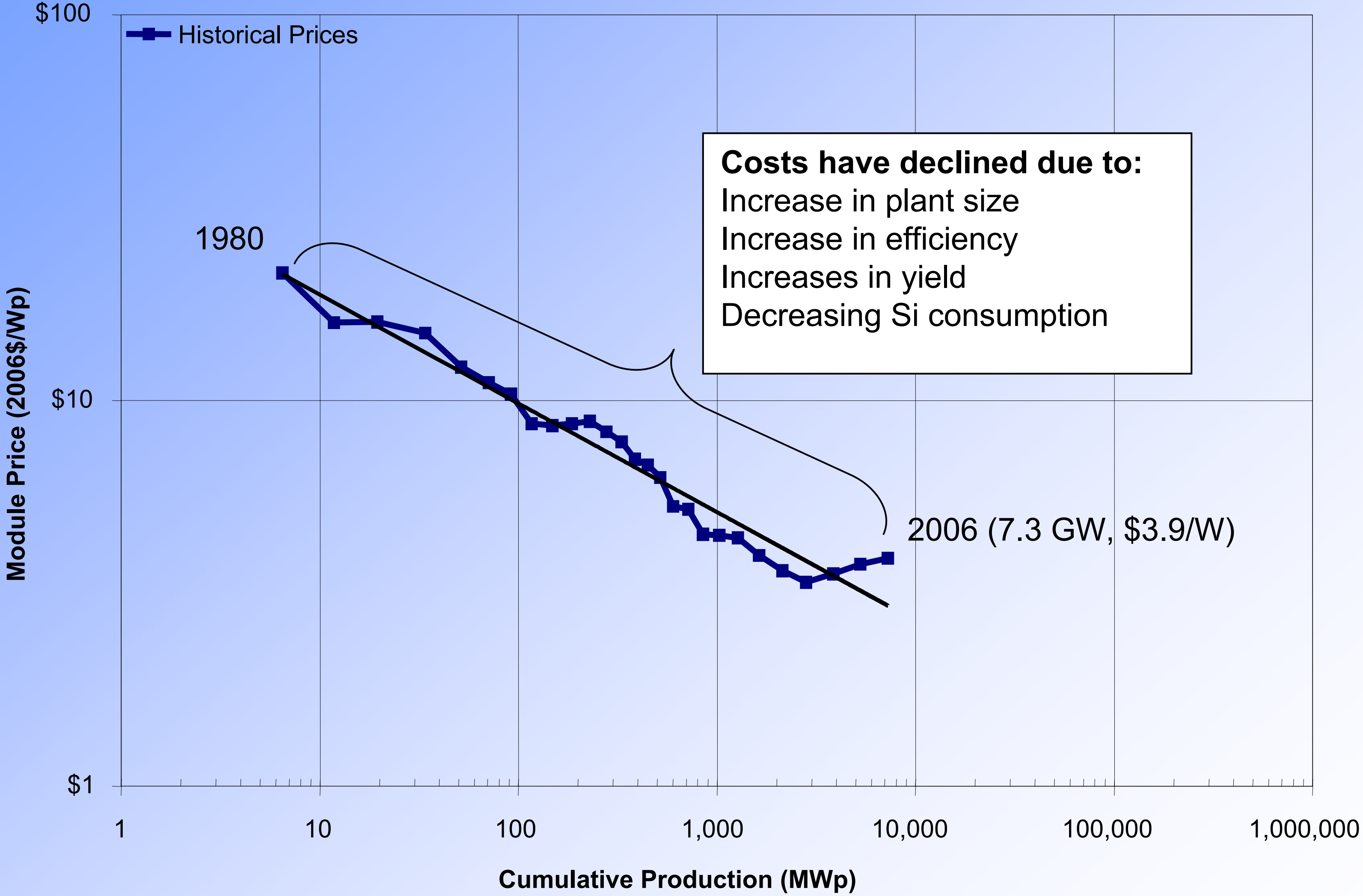
Dimbach, Germany; with permission from Blitzstrom /Beck Energy, March 2007
1.3 MW

PV Power Plants in the South West

Tucson Electric Power, Springerville, Arizona
www.greenwatts.com

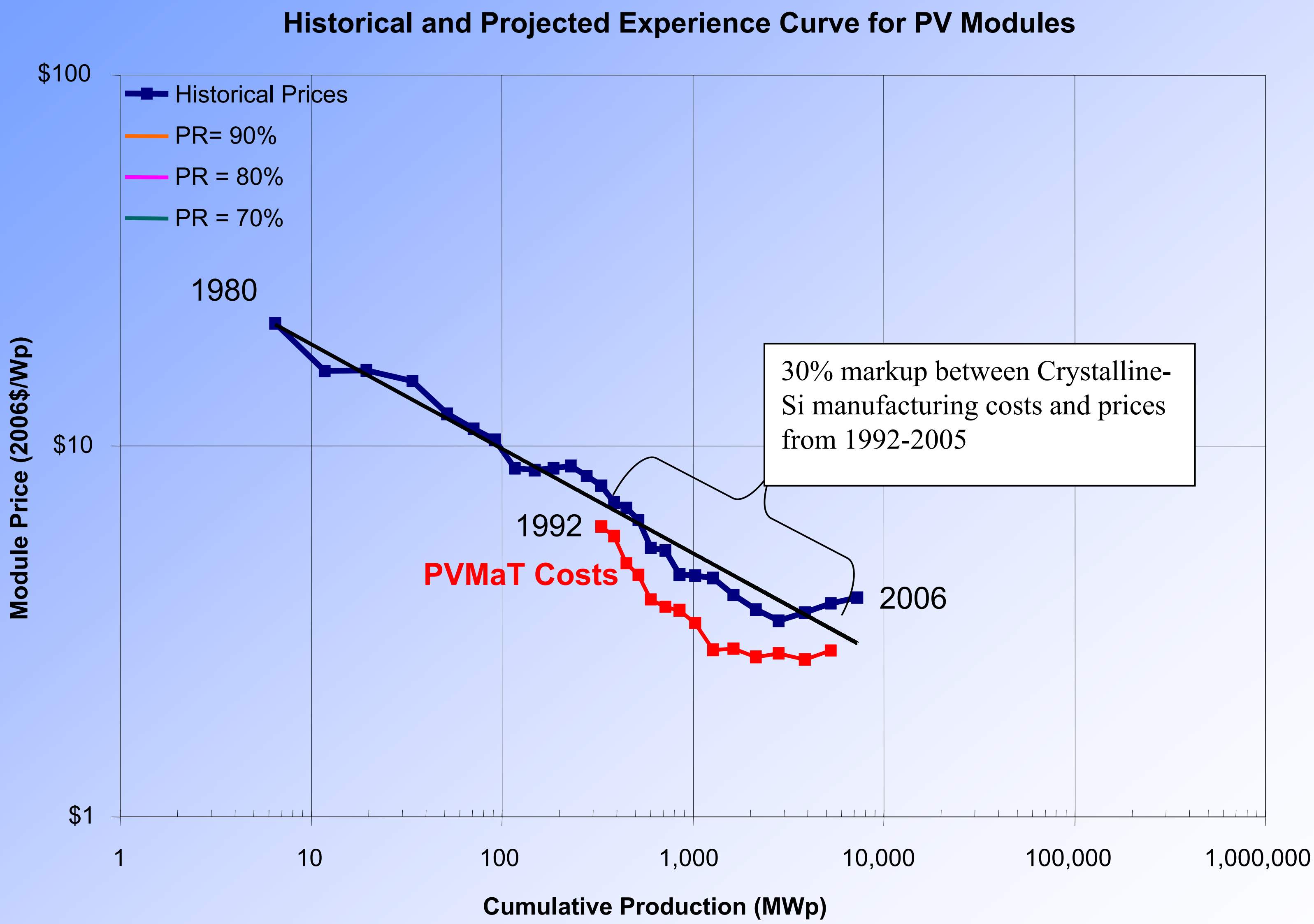
Prices of crystalline-Si PV Modules

(average Progress Ratio =80%)



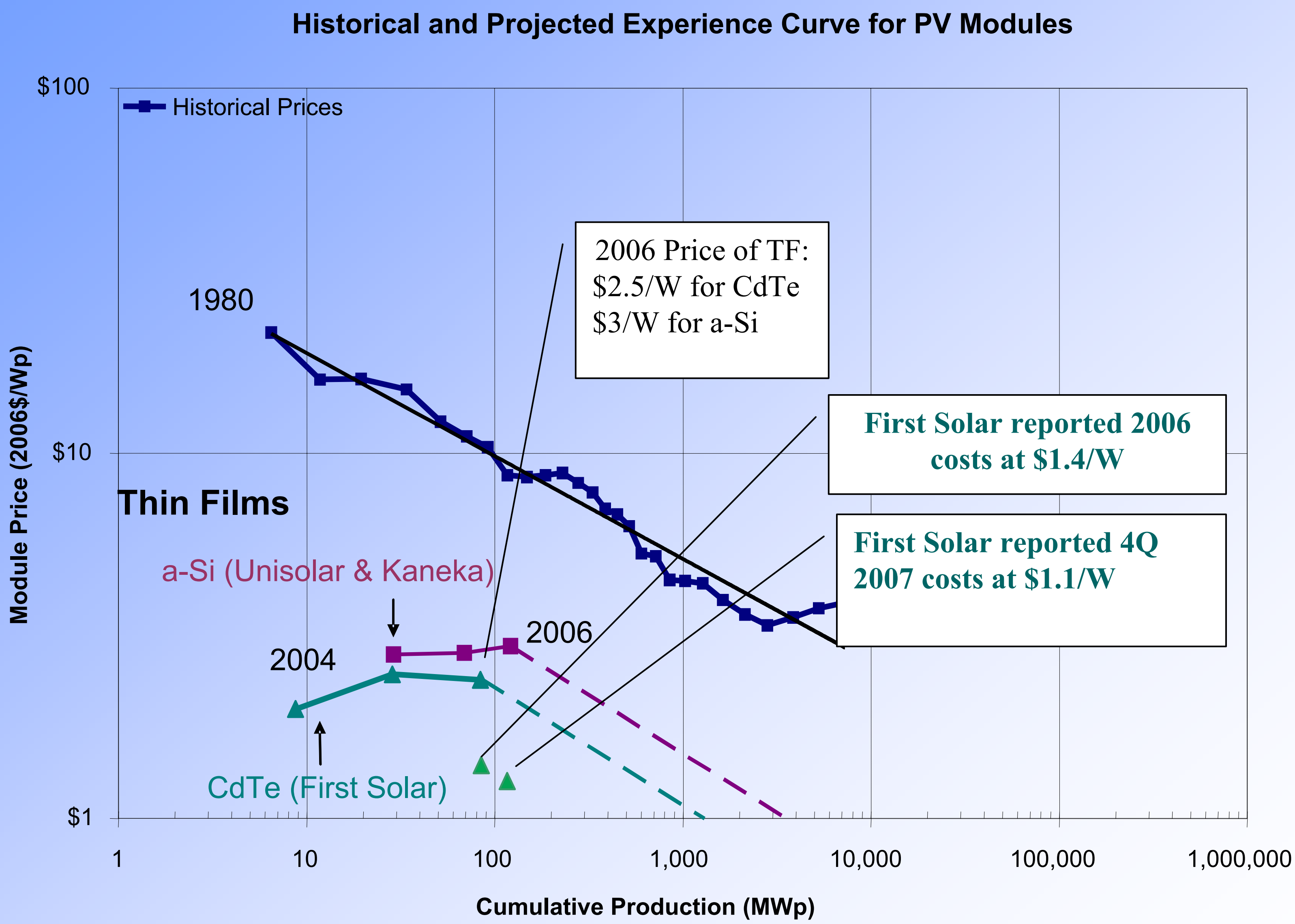
Costs have declined due to:
Increase in plant size
Increase in efficiency
Increases in yield
Decreasing Si consumption

Crystalline-Si Prices vs. Production Cost



30% markup between Crystalline-Si manufacturing costs and prices from 1992-2005

Thin-film PV Accelerating Cost Reductions

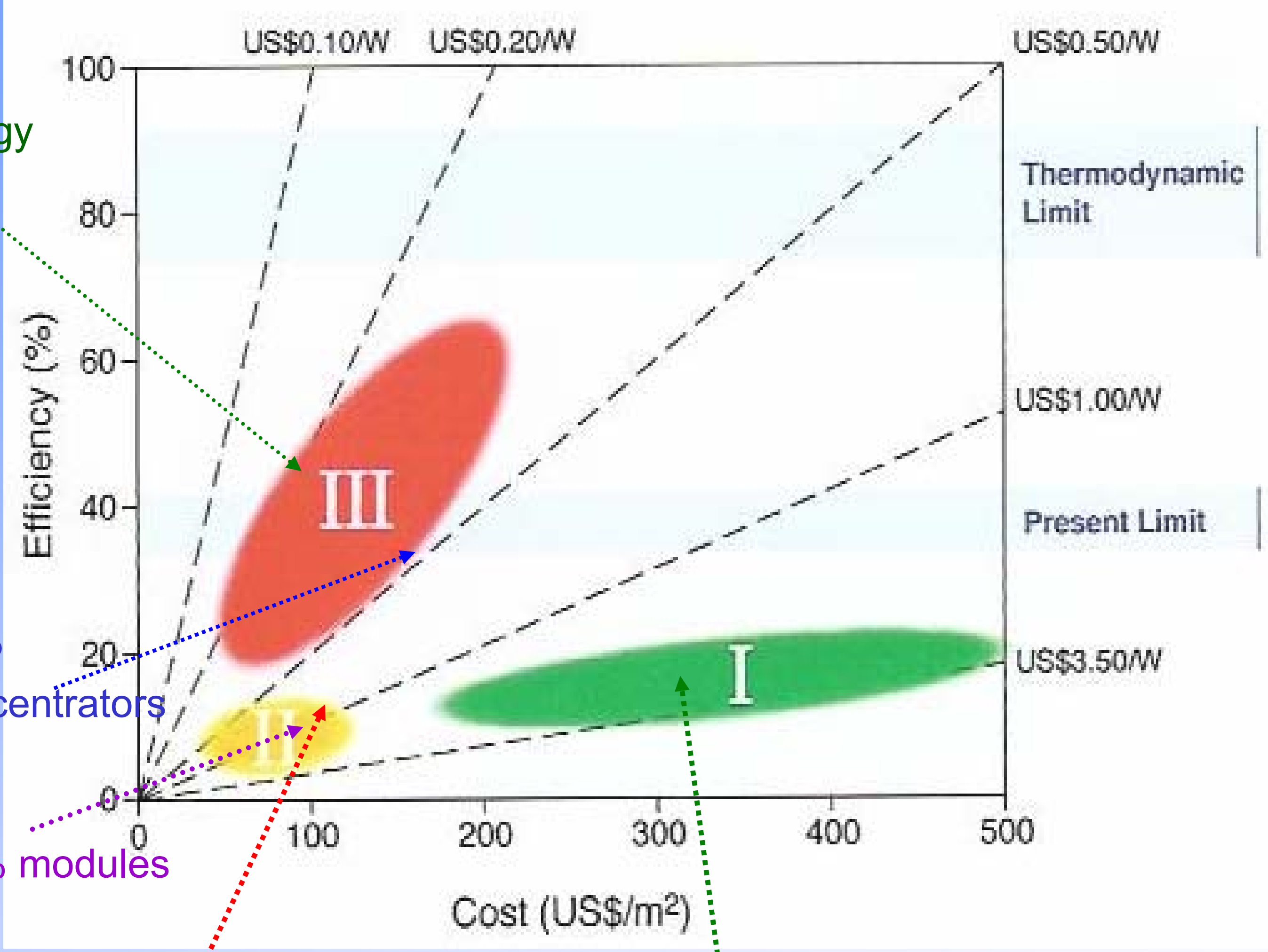

Historical and Projected Experience Curve for PV Modules

2006 Price of TF:
$2.5/W for CdTe
$3/W for a-Si

First Solar reported 2006 costs at $1.4/W

First Solar reported 4Q 2007 costs at $1.1/W

Cost-Efficiency Analysis for 1st, 2nd and 3rd Generation PV Technologies



Nanotechnology enabled PV 2030 ?

GaAs/InP 32% concentrators 2012 ?

CIGS 9% modules 2009 ?

CdTe PV 10% efficient modules $120/m^2$ module cost (2007)

Crystalline Si based modules

A Solar Grand Plan

Components

Photovoltaics

Wind

Compressed Air Energy Storage

Concentrated Solar Power

Geothermal, Biomass

High Voltage DC Transmission

Hybrid plug-in electric cars

Hydrogen infrastructure

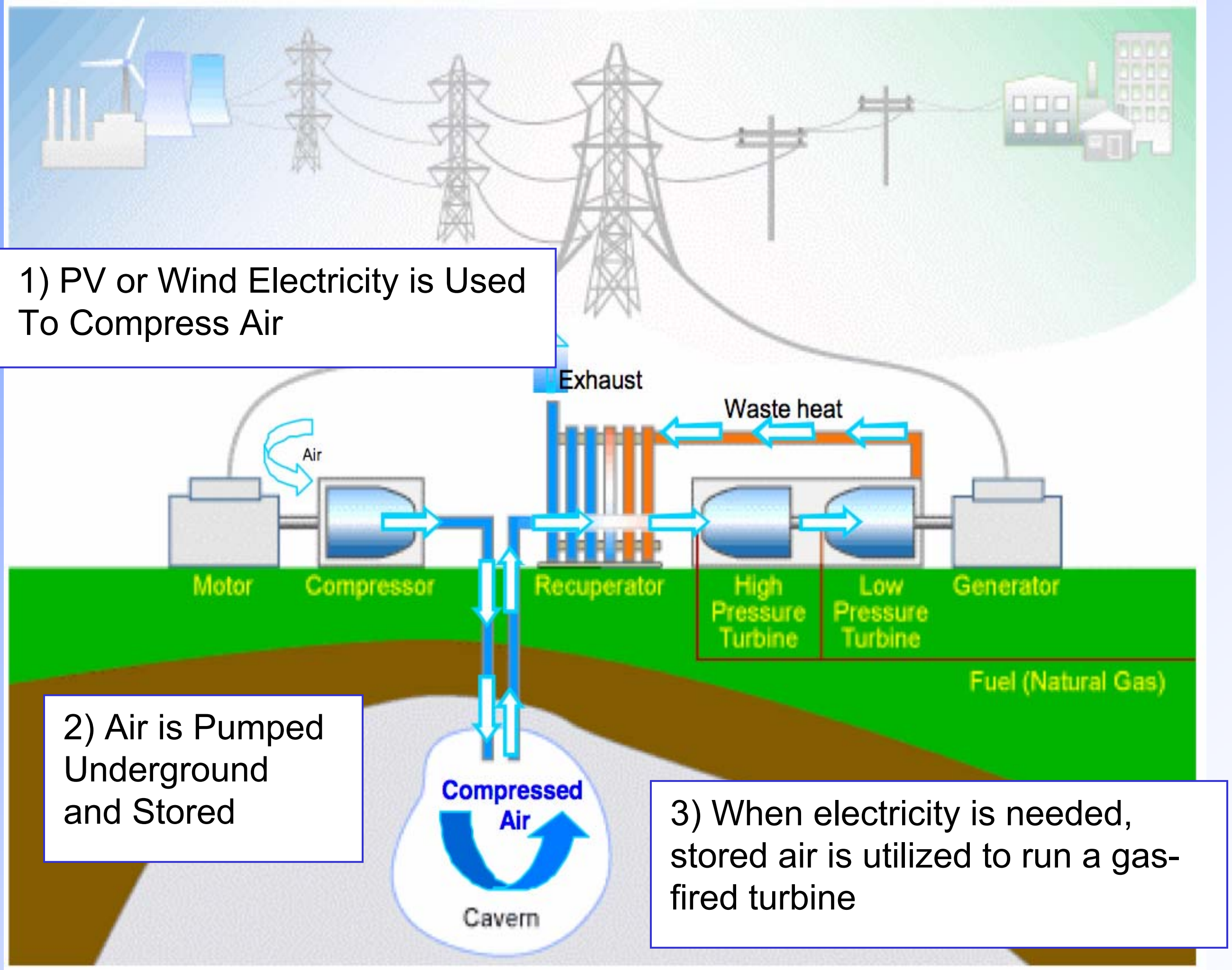
A Solar Grand Plan: By 2050 solar power could end U.S. dependence on foreign oil and slash greenhouse gas emissions

by Ken Zweibel, James Mason and Vasilis Fthenakis

PV Power Plants in the South West

Tucson Electric Power, Springerville, Arizona
www.greenwatts.com

Compressed Air Energy Storage (CAES)



1) PV or Wind Electricity is Used To Compress Air

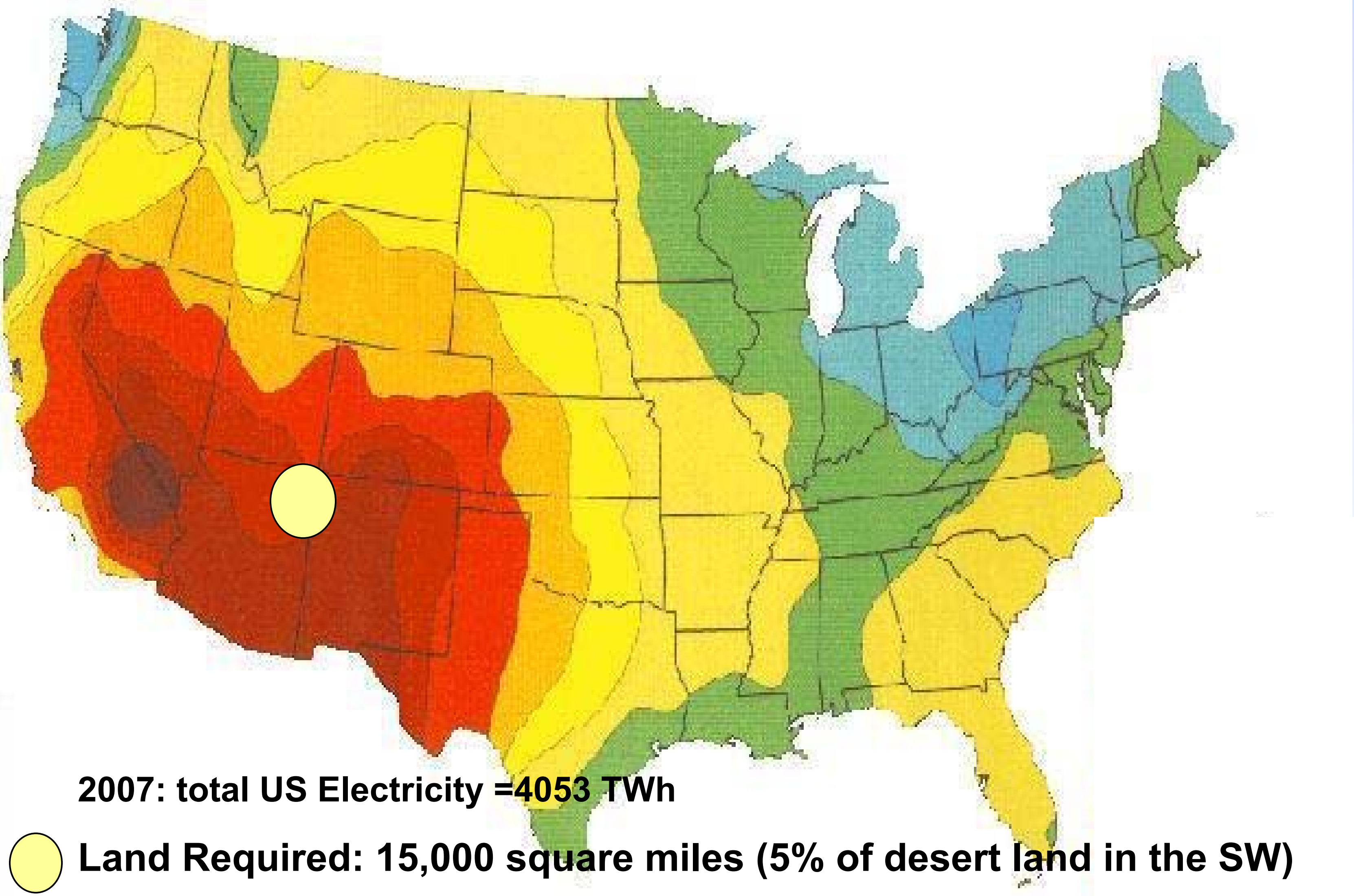
2) Air is Pumped Underground and Stored

3) When electricity is needed, stored air is utilized to run a gas-fired turbine

Operating Plants: **McIntosh, Alabama, 1991**
Huntorf, Germany, 1978

Courtesy J. Martin, NYSERDA

Geographical Feasibility



2007: total US Electricity =4053 TWh

○ **Land Required: 15,000 square miles (5% of desert land in the SW)**

(PV Efficiency=14%; performance ratio=0.8; packing ratio =2.6)

Geologic Formations Potentially Suitable for Underground Compressed-Air Energy Storage ?

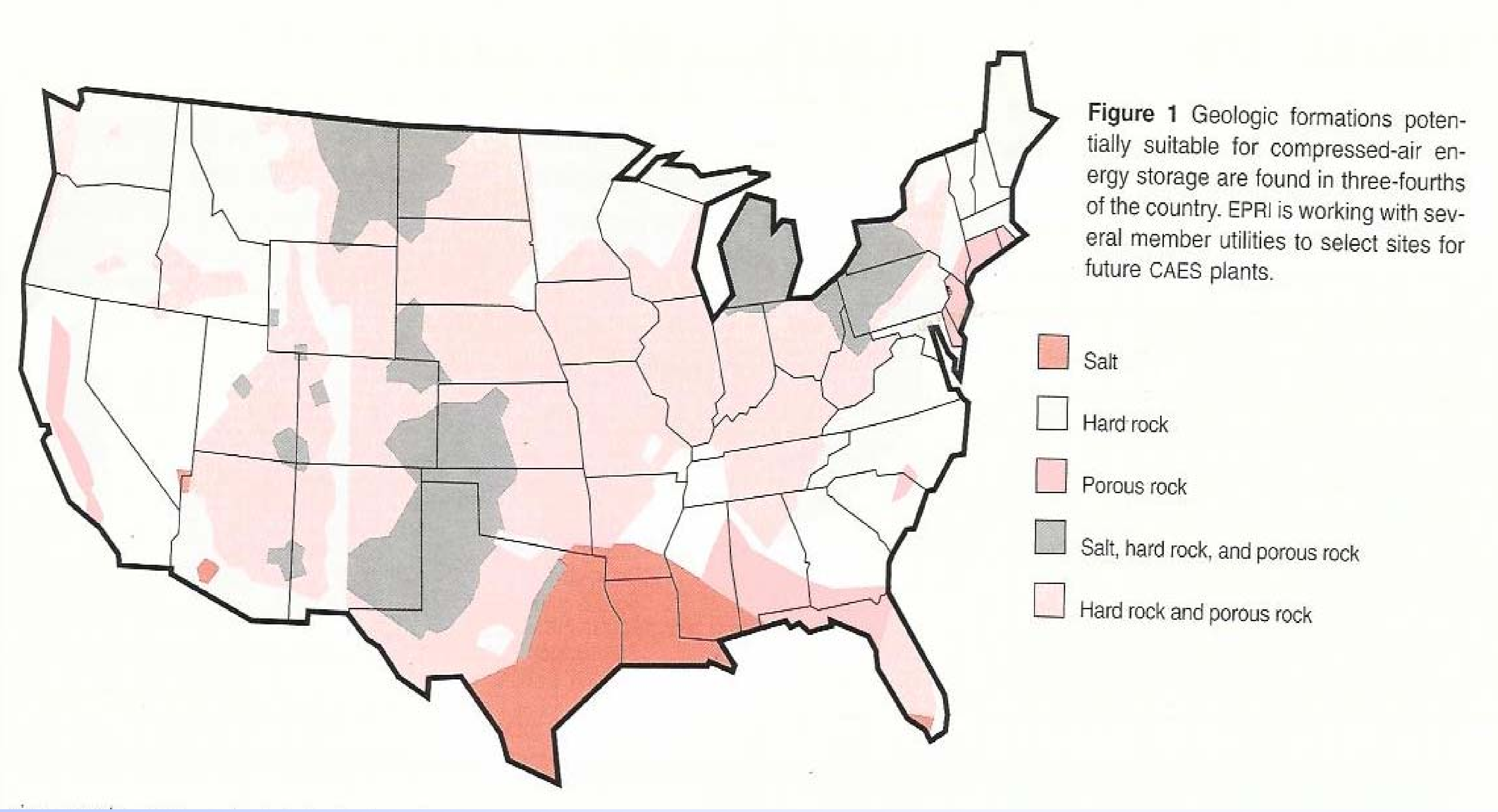
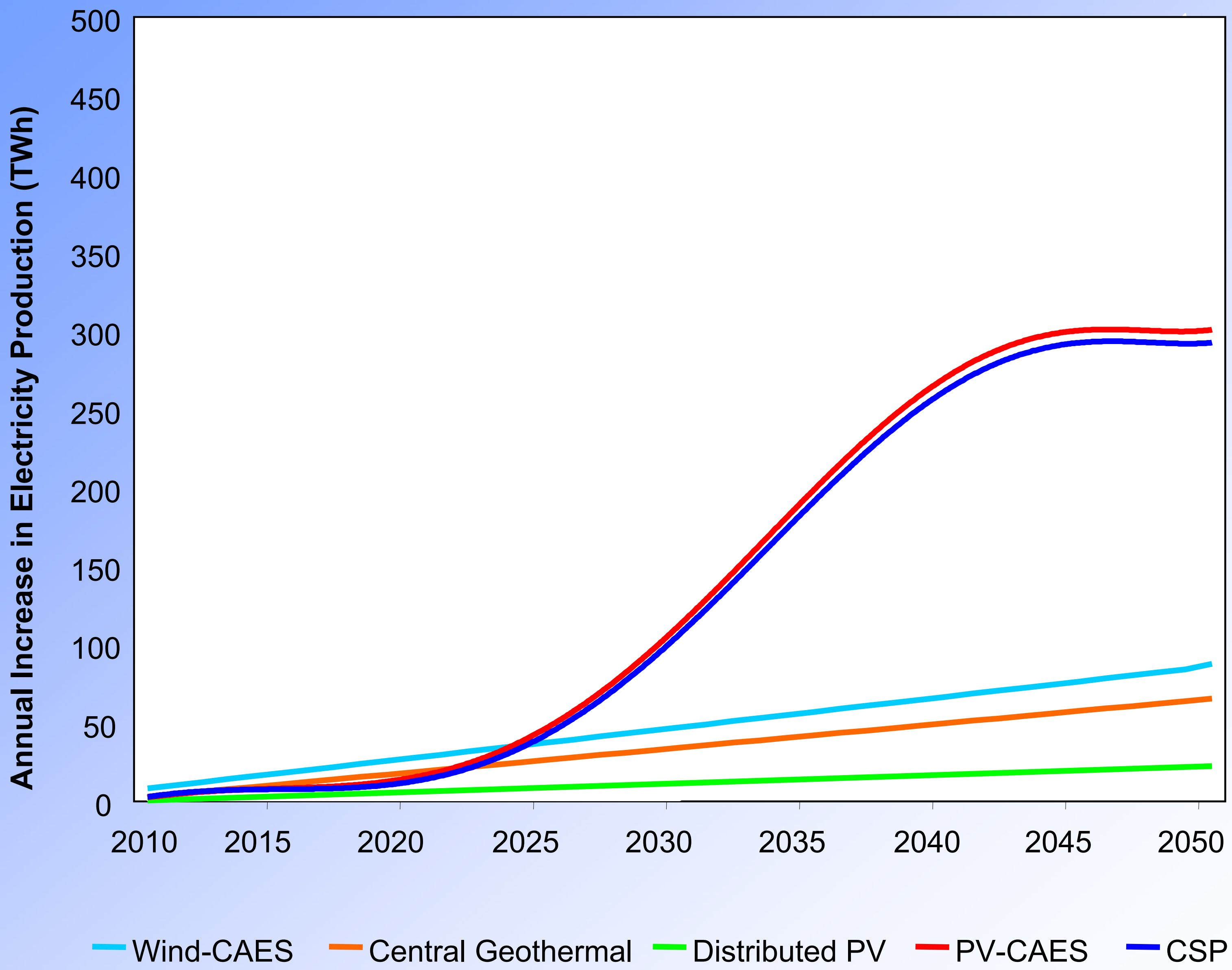


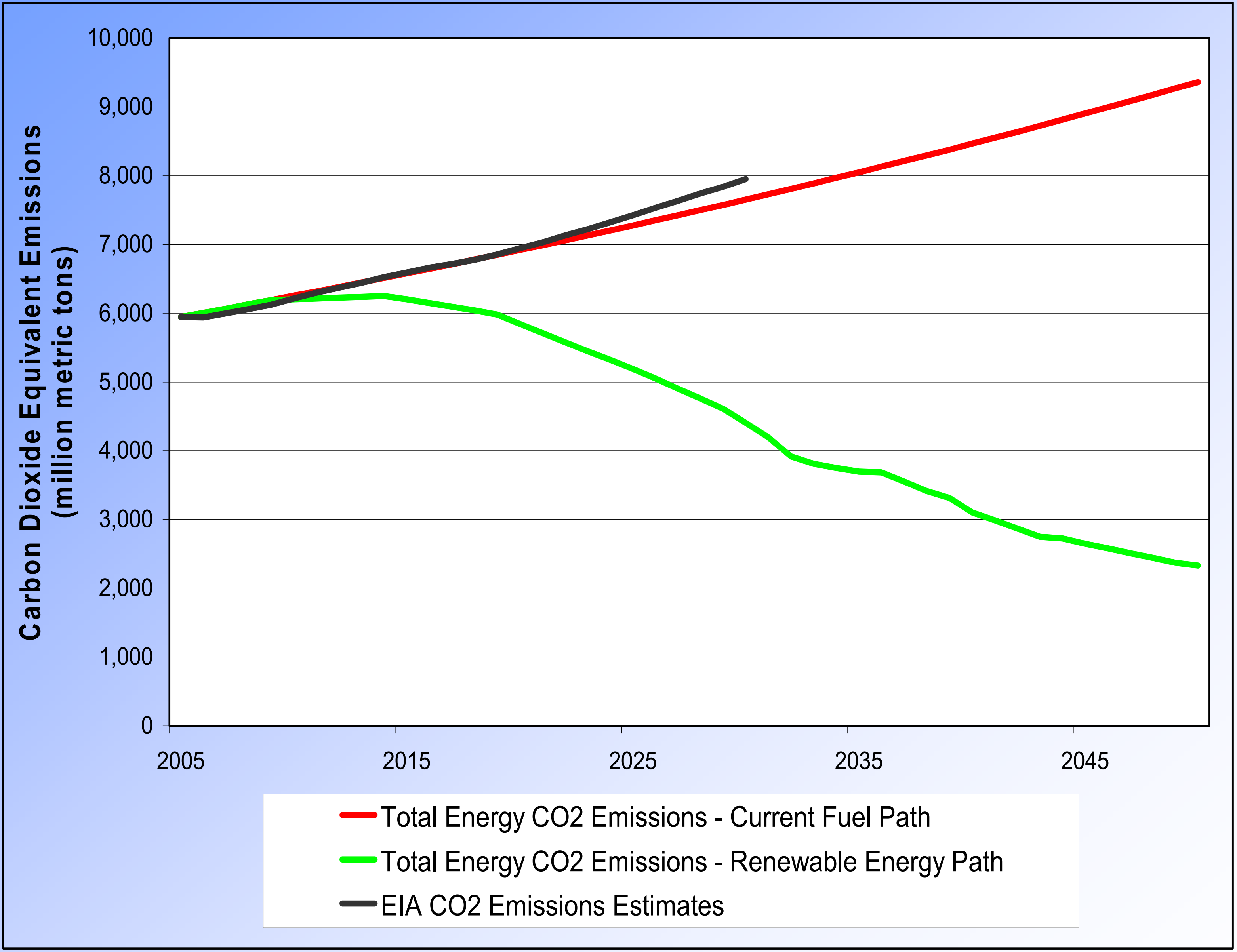
Figure 1 Geologic formations potentially suitable for compressed-air energy storage are found in three-fourths of the country. EPRI is working with several member utilities to select sites for future CAES plants.

CAES Geology, EPRI Journal, Oct/Nov 1992

Annual Electricity Growth from Renewables



U.S. Energy Related Carbon Dioxide Emission Projections



The Grand Solar Plan Additional Documentation

- The technical, geographical and economic feasibility for solar energy to supply the energy needs of the US, *Energy Policy*, in press
- Coupling PV and CAES Power Plants to transform Intermittent PV electricity into dispatchable electricity source, *Progress in Photovoltaics,* in press
- It's Doable, *Energy Biz*, March 2008
- Sun as a Solution, *Sun & Wind Energy*, April 2008

Acknowledgement

- Ken Zweibel, Director, Institute of Solar Energy Analysis, George Washington University
- James Mason, Director, Renewable Energy Research Institute

2.2 Alfred Cavallo, Grand Scale Wind/Transmission/CAES Systems

Alfred Cavallo, an energy consultant based in Princeton, NJ, graduated from the University of Wisconsin (1978), and worked for the Max Planck Institute, the French Atomic Energy Commission, and the Princeton Plasma Physics Laboratory in the experimental fusion program. He then moved to the Center for Energy and Environmental Studies at Princeton University, working on indoor air quality and on renewable energy, and developed the concept of transforming intermittent wind energy to a reliable power source that is technically and economically competitive with current generators. This approach integrates compressed air energy storage (CAES) plants with large wind turbine arrays. Dr. Cavallo has also done research on aerosols and risk assessment for the USDOE. His current interests are resource constraints and energy policy.

Grand Scale Wind/Transmission/CAES Systems

Alfred Cavallo, Consultant
289 Western Way, Princeton, NJ

Columbia University, New York, NY

October 21, 2008

OUTLINE

- Goals
- Motivation
- Intermittent Wind/(PV/Solar Thermal)/ CAES/Transmission Systems
- Policy Issues: How to Allocate Costs?
- Proposed Solution

GOAL

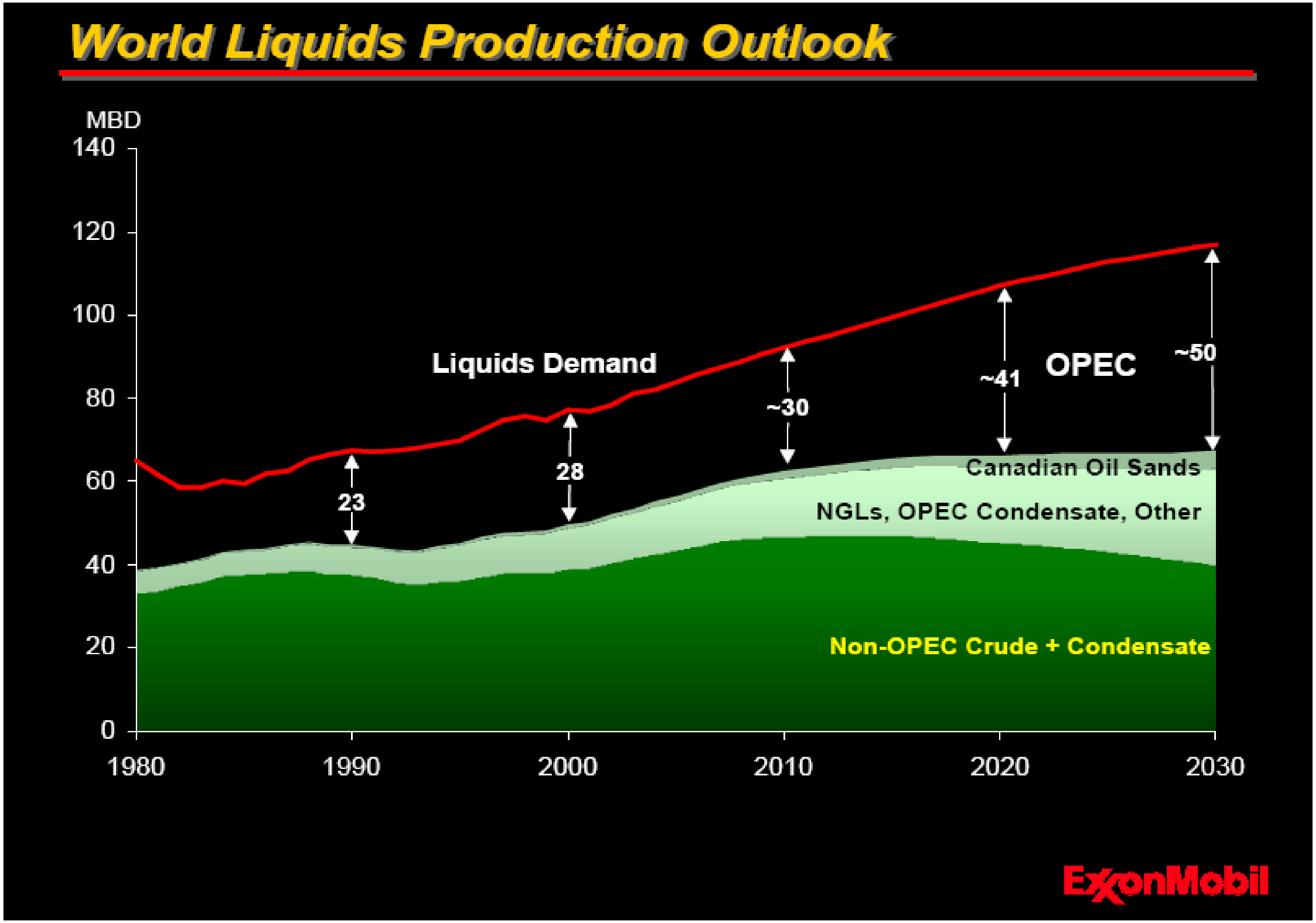
- We want to power a modern industrial economy on (mostly (80%)) renewable energy.
- (!)??

- Solution MUST Include
  - Transmission
  - Storage

Motivation

- Climate Change:
  - Voluntarily reduce consumption

- Resource Constraints
  - Fossil fuels a finite resource (as of right now)
  - If we want to have personal mobility and comfort, we MUST change our energy source/usage.



World Liquids Production Outlook

ExxonMobil

Natural Gas

- **Gazprom's gas prices rise faster than expected** *(October 1, 2008 RBC)* The price of Russia's natural gas supplies to Europe topped $500 per 1,000 cubic meters, in a statement by Gazprom CEO Alexei Miller to journalists today.
- $500/1000cm = $14/million Btu

Good News/Bad News

- Bad News: Fossil fuels much more expensive
    - Oil: $200-$400/ bbl in 2-3 years.
    - Natural gas: Price linked to oil price - $15-20/MBtu, 2-3 years.
- Good News:Fossil fuels much more expensive
    - Renewables now can compete economically!
    - Resource base excellent (solar, wind)

Reluctant Admission of Facts

- “There is going to be the need for each and every one of us to start thinking about how we use energy.”

  Senator Barack Obama, October 7, 2008, Debate w/ John McCain, regarding rising oil prices and limited supplies.

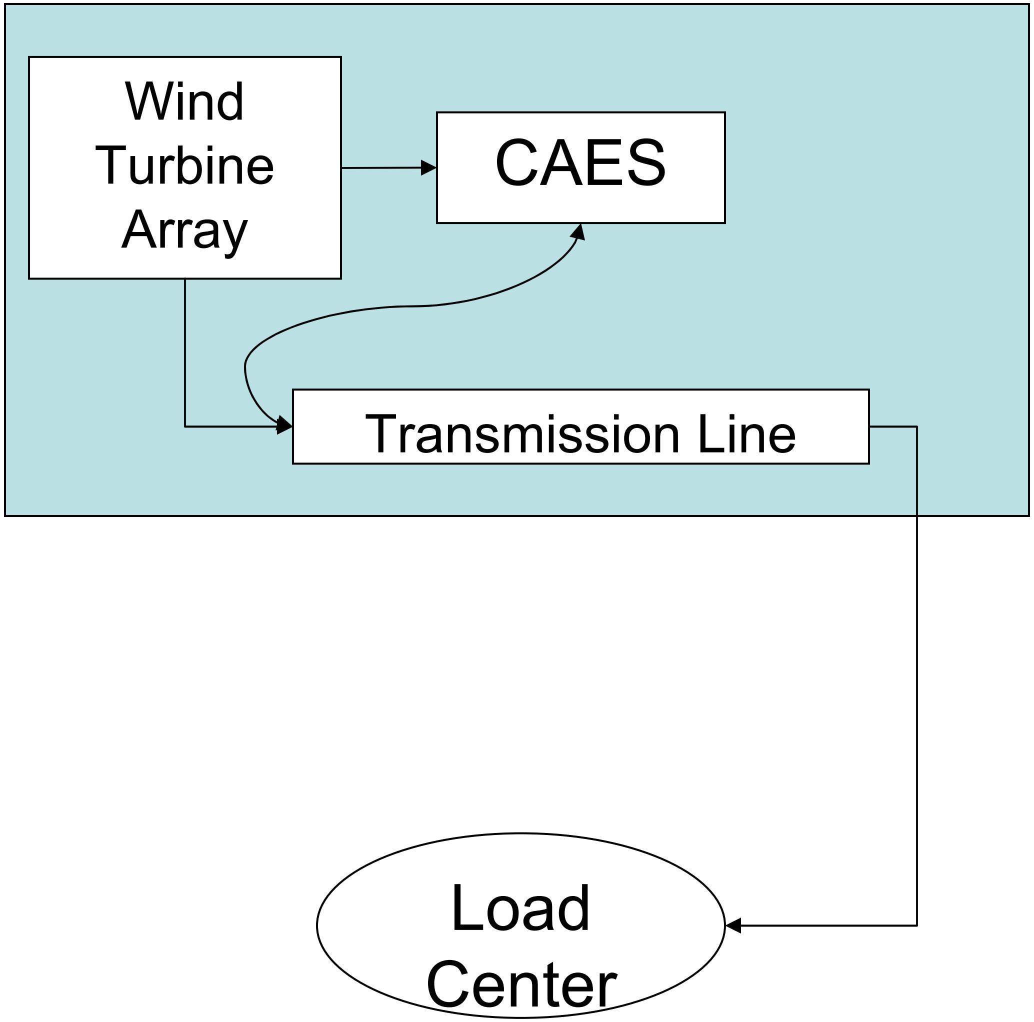
  (NYTimes, 10/8/2008, p1)

What Will New Energy Systems Look Like?

- Grand Scale Solar Thermal, PV
- Grand Scale Wind
    - Transmission, Storage ESSENTIAL for these systems
- Conservation, Efficiency, New Technology taken seriously
- Energy more expensive, **but affordable**

Grand Scale Wind

Systems Approach (Wind)



Wind Turbine Array

CAES

Transmission Line

Load Center

Systems Approach

- All costs accounted for
  - Uncover hidden synergies
- Oversized wind turbine array:

  array output >> line capacity
  - Increased array output fills transmission line, reduces cost to user
- Add storage (store spilled energy); add value

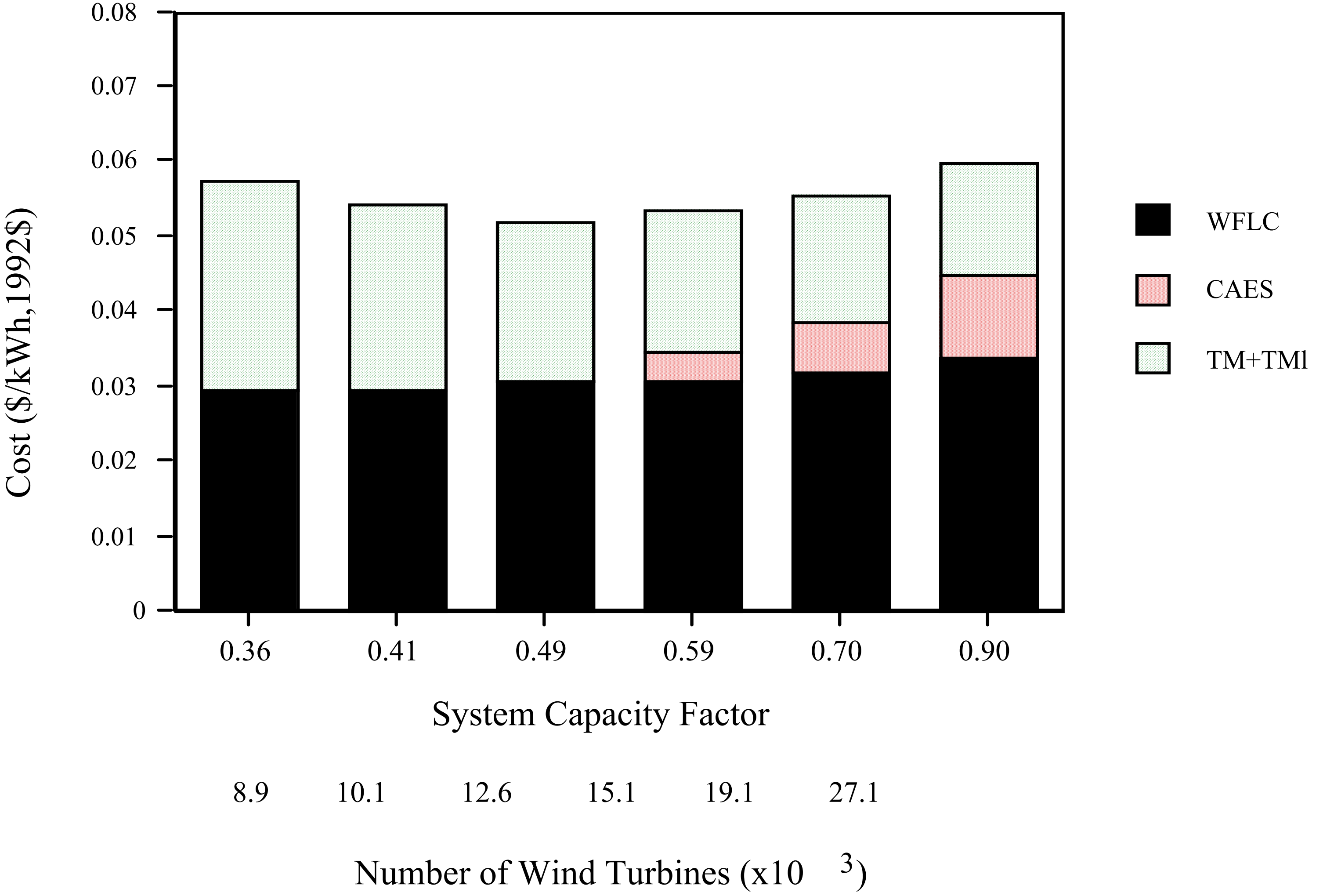
Wind/CAES/Transmission System Kansas to Los Angeles, CA

- 2000 MW HVDC Transmission Line
- Wind Class 4, P_w=440 Wm^{-2} Weibull k=3 at 50 m
- 1500 MW CAES, 50 hrs storage
- V27-225 machines (8900< N < 27,100)
    - 11x11mi < A < 31x31mi
    - 1-2% of KS wind class 4 electric potential

Cavallo, 1995, JSEE, v117, pp137-143.

Kansas-LA Transmission Line

COE vs Capacity Factor Wind/CAES/Transmission



Wind/CAES/Transmission System

- Generation, storage, transmission integrated logically, cost-effectively.
- Intermittent wind transformed to controllable power supply, high ramp rate (compression, generation).
- Power plant easily comparable with alternatives (nuclear, gas, coal)
    - Forced outage rate, scheduled outage rate

Wind/CAES/Transmission

- Seasonal Storage possible (economically, technically) (200 hrs storage vs 50 hrs for normal operation)
  - Wind speed autocorrelation time important

- See Ridge Energy Storage Report (6/2005) for more details on integration
  - 500 MW wind, 270 MW CAES, 50 hrs storage, Texas Panhandle

Current Integration Strategy

- Integration costs (transmission, spinning, ready reserve) paid for by utility
  - Cost comparison always with local, not integrated, intermittent energy
- Reasonable (technically, economically, politically) at low penetration
- Wind cannot compete with $2/million Btu gas, $1/million Btu coal, so including additional costs a disadvantage.

Flaws With Current Approach

- Renewables relegated to margins
    - “renewables inferiority complex”
        - Real men build NPPs, GTs, CCGTs, IGCCs, w/CCS
- Utilities forced to provide services without compensation: Enemies.
    - Go straight to gas, nuclear.
- There is a lack of vision.

Challenges for Grand Strategy

- Systems approach (generation, CAES, transmission) probably unachievable.
- Transmission: who will build/pay?
- Storage: makes sense only when tightly linked with generation (control compression costs)
- Current integration strategy (someone else pays, so why worry?)

Possible Solution

- Proration transmission
  - Proration = Production Rationing
  - Mandate priority access to transmission for “dispatchable (firm) renewables,” wind/solar plants closely linked to CAES plants

Conclusions

- Fossil fuels becoming much more expensive (OPEC) (US gasoline $5-$10/gal in 2-3 years, natural gas $15-$20/mmBtu)

- Intermittent Renewables can provide reliable, affordable energy to power a modern industrial economy (e.g. Solar Grand Plan, Wind/CAES)

- BUT: Current deployment strategies no longer adequate since storage, transmission are ignored

- Need **NEW RULES** to insure ***PROFITS*** for **NEW SYSTEMS**

2.3 Samir Succar, Wind-CAES Integration

Samir Succar is an Energy Analyst at the Natural Resource Defense Council (NRDC) Center for Market Innovation where he works on issues related to grid infrastructure and the large scale deployment of renewable energy. He completed his PhD in Electrical Engineering at Princeton University this past year where his doctoral research focused on the joint optimization of baseload wind-CAES systems.

Wind – CAES Integration

Samir Succar

Natural Resources Defense Council

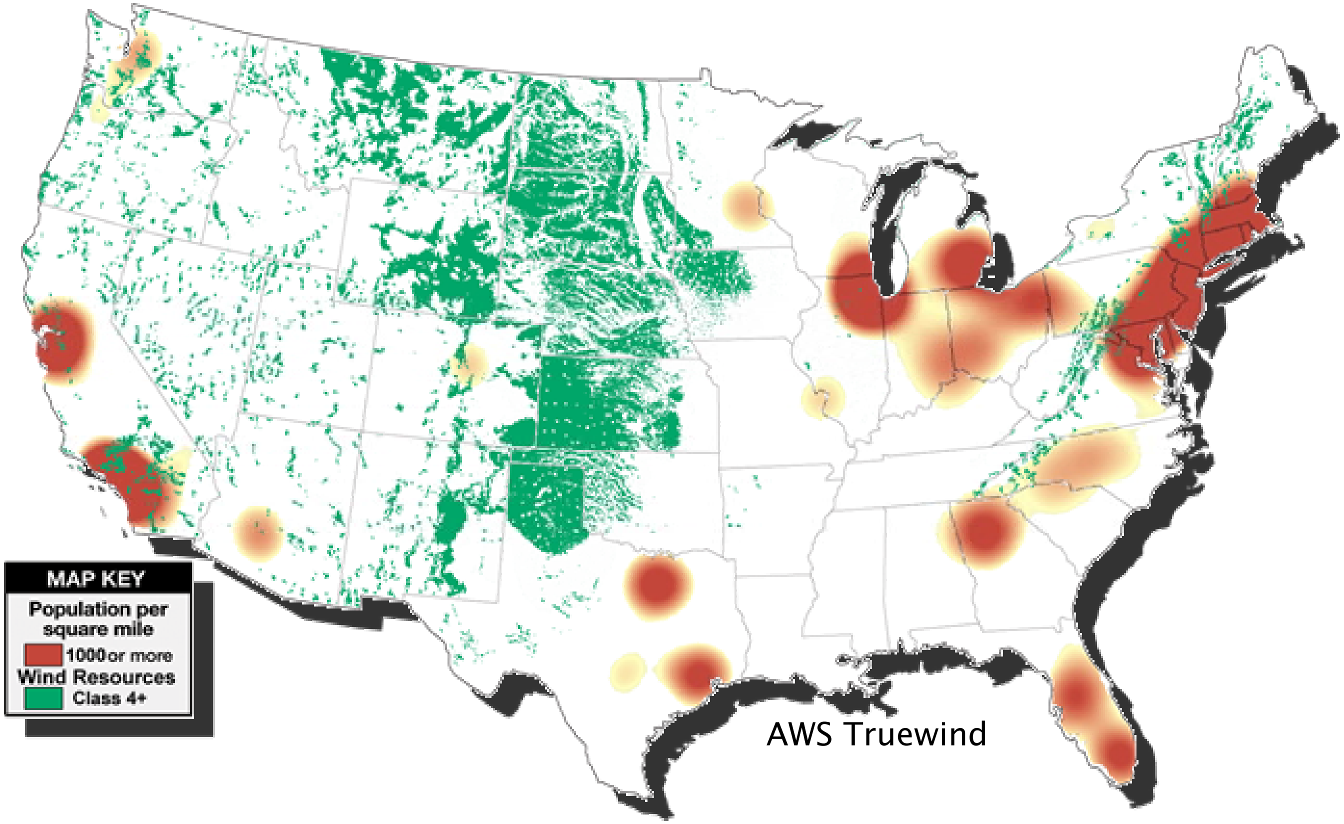
Compressed Air Energy Storage (CAES) Scoping Workshop • CLCA

October 21, 2008 • New York NY

Fundamental Motivations

- Low carbon energy sources are needed for climate change mitigation
- 40% of global fossil CO_2 from electricity
- Majority from coal (80% in the U.S.)
- Displacing coal means baseload
- Typical capacity factor for new plants: 80-90%
  - Capacity factor (CF) = Mean Power / Full Output Capacity
- Requires 10’s-100’s of hours of storage

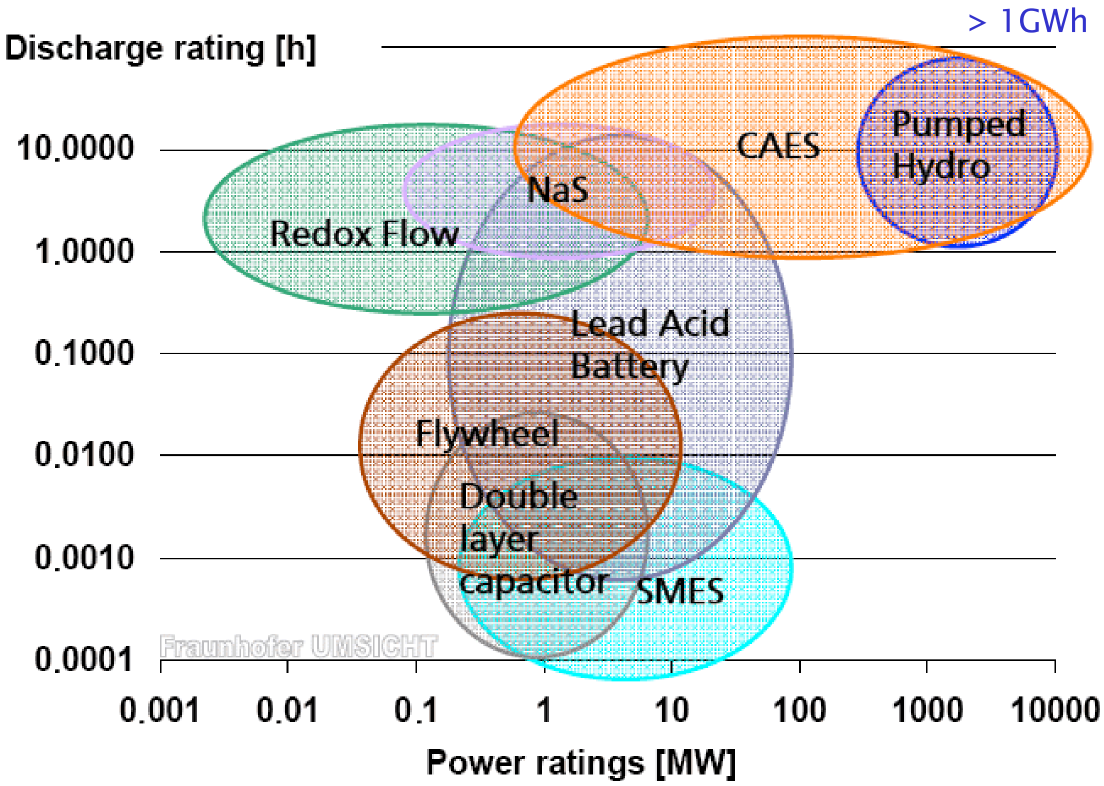
Resource Remoteness



AWS Truewind

- Location of best resources may not be proximal to demand centers
- HVDC transmission infrastructure may be required (GW Scale)
- Higher line utilizations reduce transmission component of delivered cost of power

Energy Storage Technologies and Applications



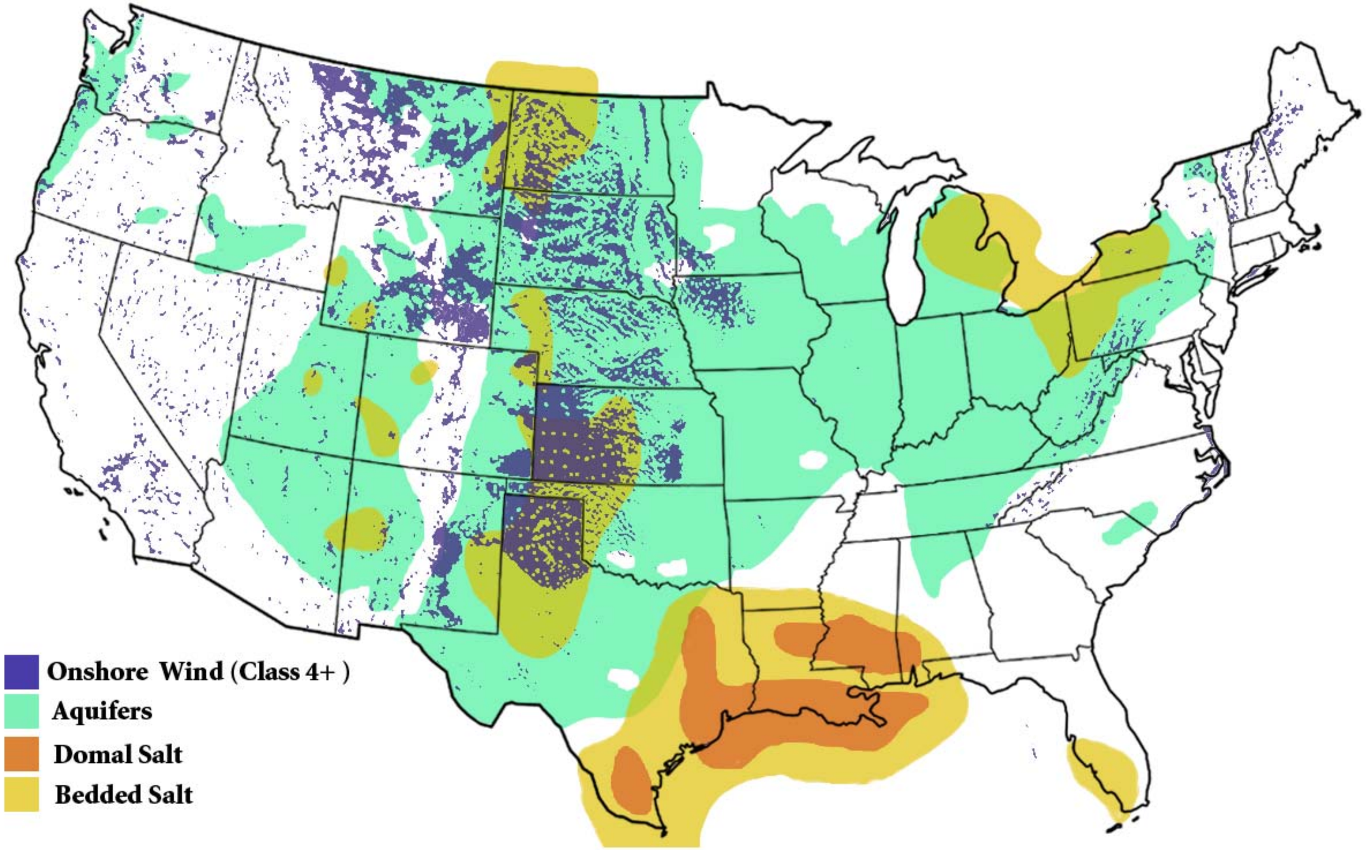
- Peak shaving
- Load levelling
- Bulk Energy Trading
- Integration of intermittent renewable
- island grid

- Spinning reserve
- Blackstart capability
- Uninterruptible power supply

- Flicker compensation
- Voltage sag correction

C. Doetsch, 2007.

Geology Suitable for CAES & Class 4+ Wind Resources

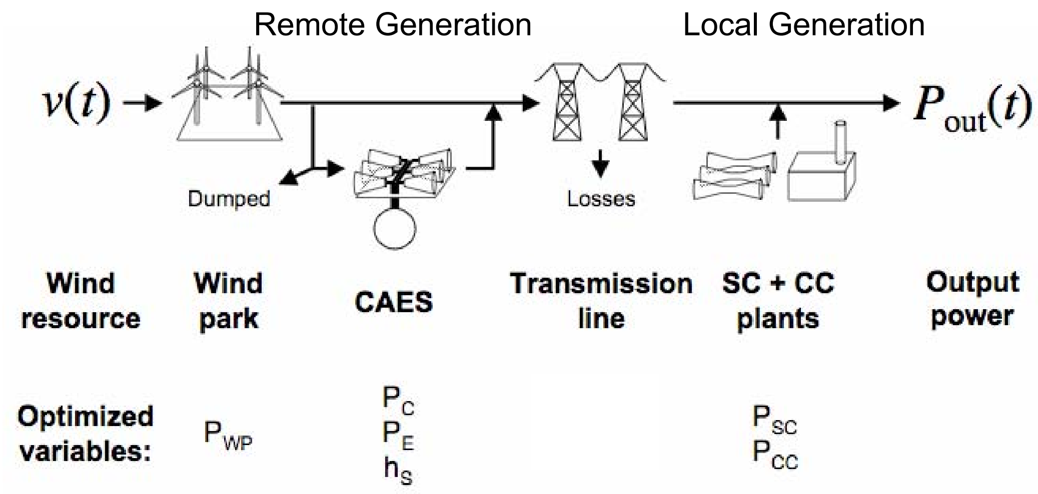


- Deploying CAES in a large scale for wind balancing implies a substantial role for aquifers
- Natural gas storage experience provides relevant tools for analyzing site suitability
- Care must be taken to address impacts of mineralogical reactions resulting from introduction of air into reservoir by methods such as dehydration of injected air
- Impact of rapid and frequent compression/expansion mode switching on reservoir and turbomachinery is critical
- Footprint of aquifer needed to “baseload” wind is ~15% of wind farm land area

Methodology

- Optimal system configuration derived through levelized cost of energy (COE) minimization
- Cost optimization based on flexible Wind/Gas/CAES framework
- Impact of alternate assumptions analyzed on the basis of optimized system configuration

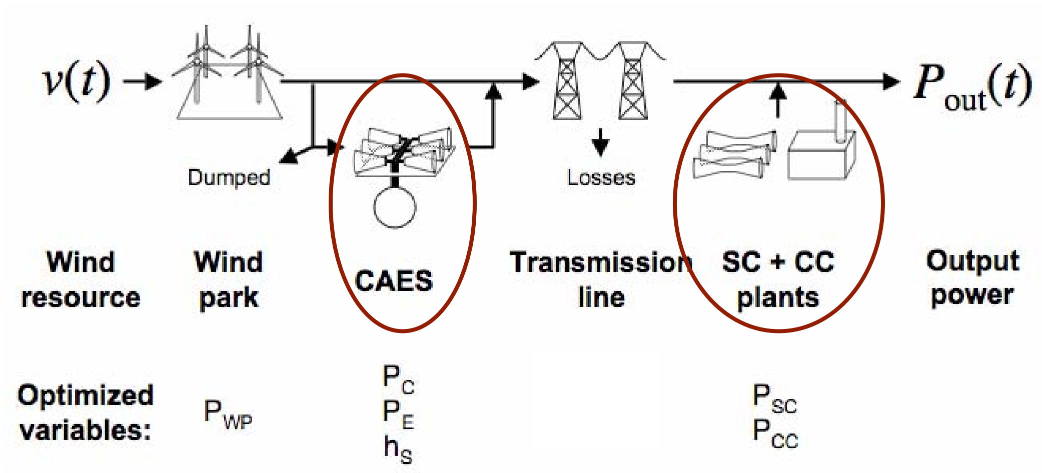
Wind/CAES Cost Model



$$COE = \frac{1}{CF * P_L * h_y} \sum_n A_n$$

- Objective Function: Levelized Cost of Energy ($/MWh)
  - CF = System capacity factor
  - h_y = 8766 hours per year
  - P_L= Load level (2000MW)
  - A_n=Plant Annual Costs
- $A_n = C_n*L+ M_n + F_n$
  - C_n = Capital Costs
  - L = Levelized Capital Charge Rate
  - M_n= Operations and Maintenance (O&M)
  - F_n= Fuel
- Constraints
  - Capacity Factor ($P_{out,avg}/P_{out,max}$) = 0.85
  - Gas Capacity ($P_{SC}+P_{CC}$) = P_{TL} - Wind/CAES 85% Firm Capacity
- Independent Quantity: Greenhouse Gas Emissions Price ($ per tonne CO_2 equivalent)

Basic Assumptions



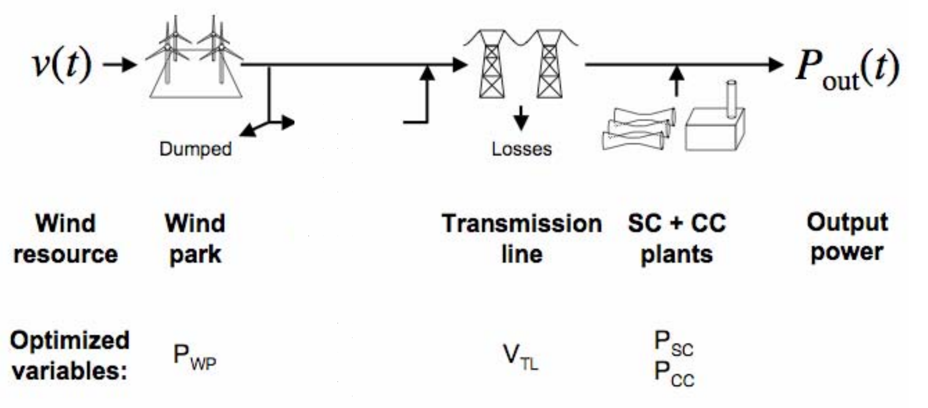
- 13.3%/year Levelized Capital Charge Rate (NETL 2007)
- 750 km High Voltage DC Transmission
- Load Level/TL Capacity = 2000 MW
- Class 4 Winds
- Wind/CAES Costs
  - $1240/kW Wind (Wiser 2007)
  - $610/kW and $2.0/kWh CAES (EPRI-DOE 2003)
- Gas Turbine Costs
  - $410/kW SC, $611/kW CC (EIA 2007)
- Fuel Costs
  - Natural Gas $6.0/GJ HHV (EIA 2007)

Wind/CAES Cost Model

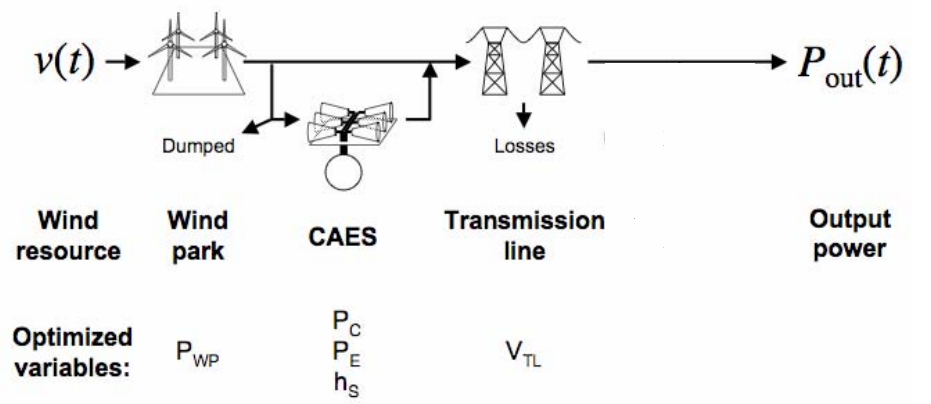
Remote Generation

Local Generation

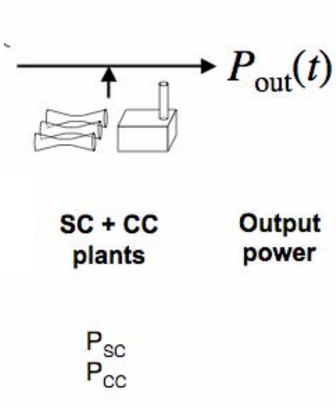
“Wind/Gas”



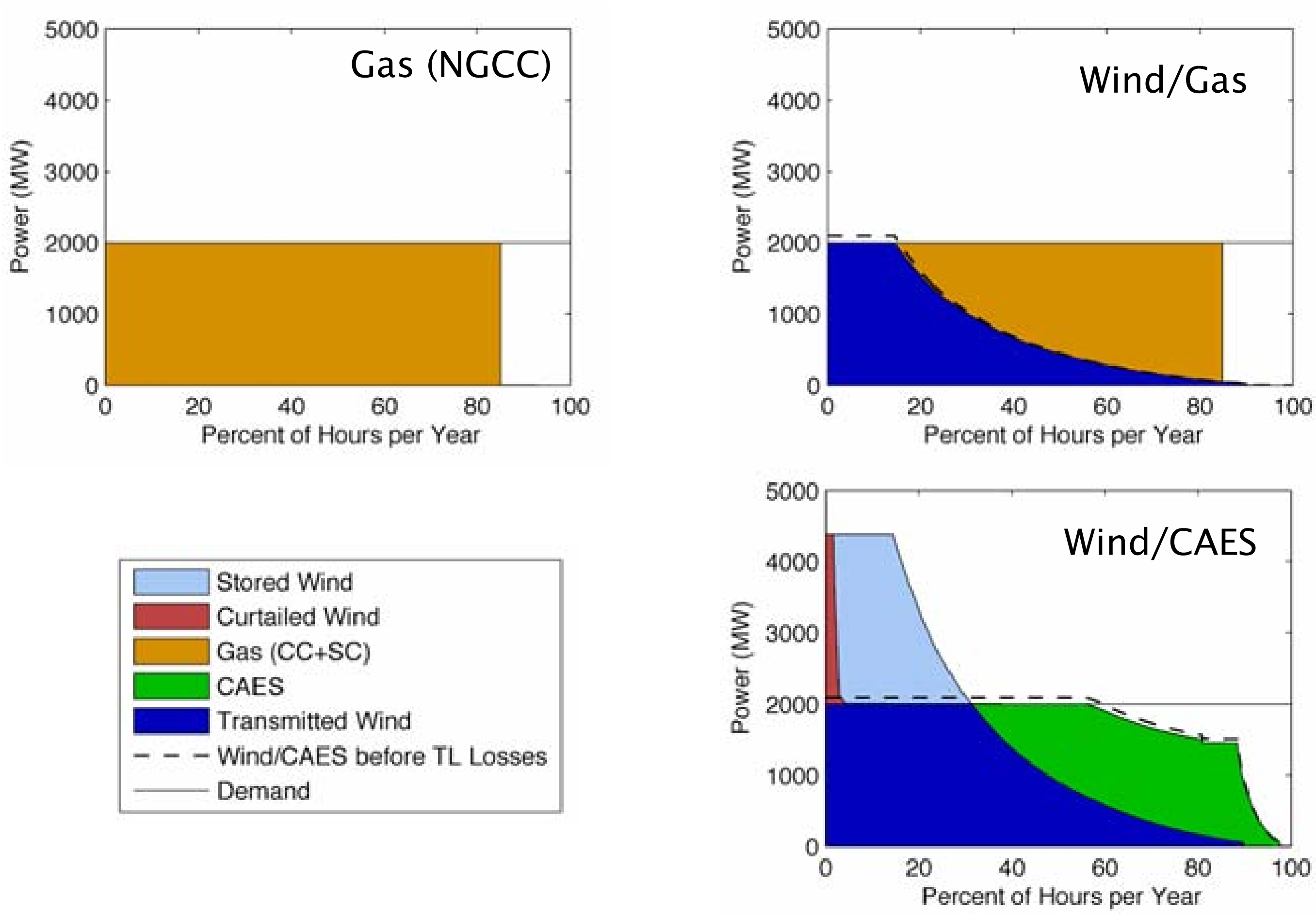
“Wind/CAES”



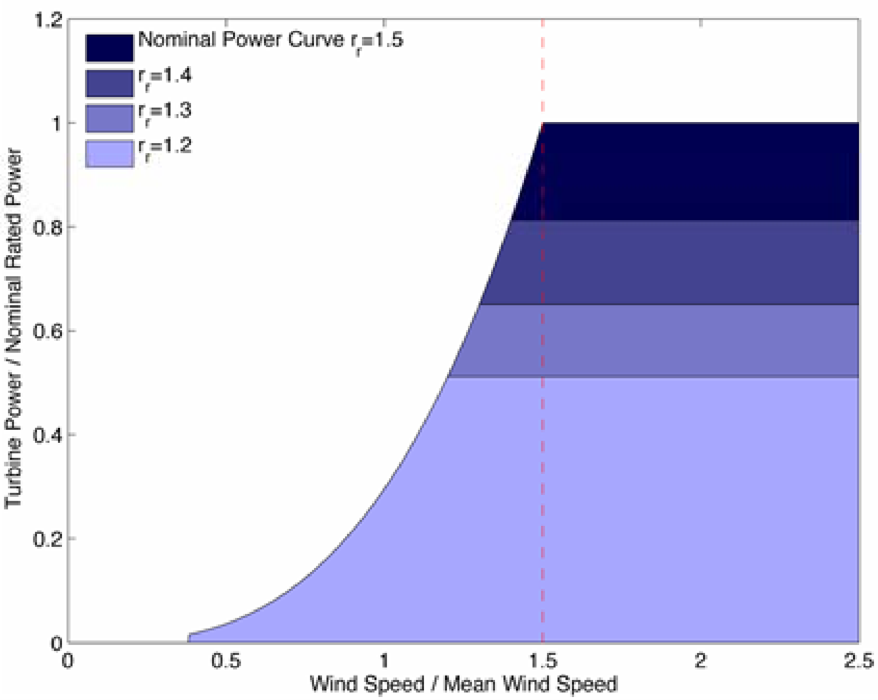
“Gas”
(NGCC)



Power Duration Curves



Wind Turbine Power Rating

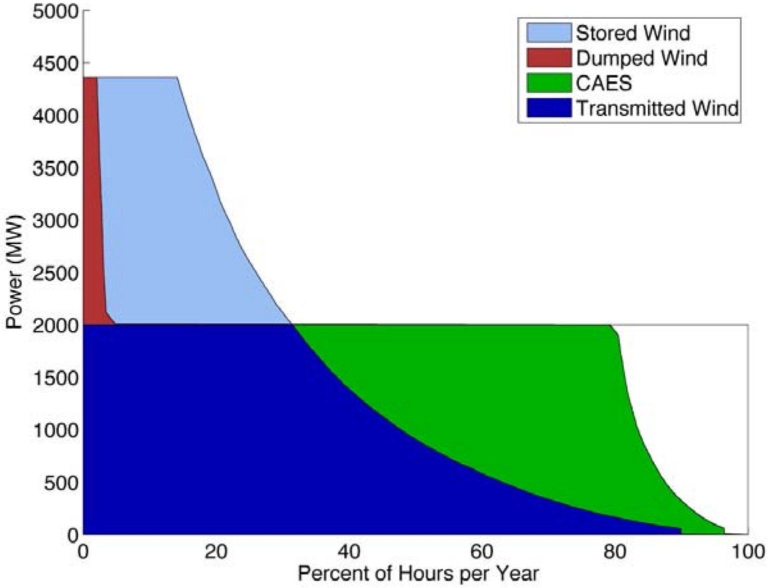


Capital Cost Blocks vs Rating

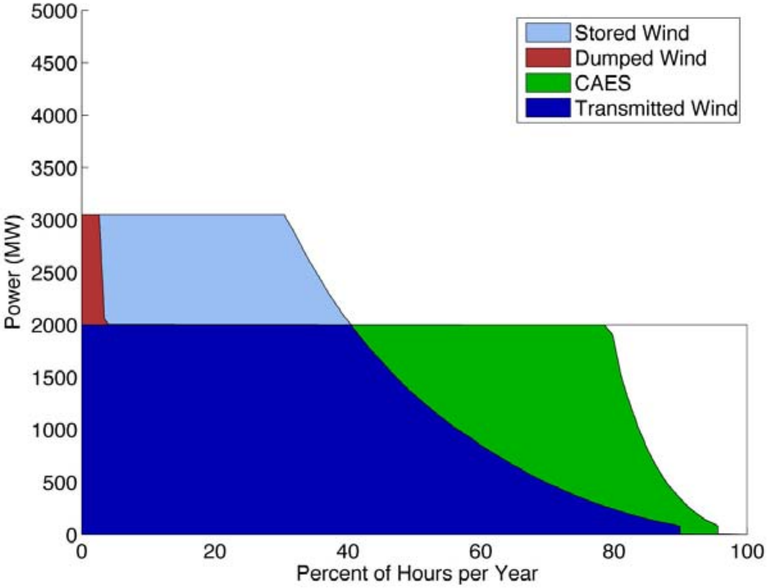
Block	Representative components	Scales with	v_{rate} exponent	Initial cost fraction
Power	Generator	Turbine rated power	3	0.30
Torque	Gearbox	Rated torque on the drivetrain	1.4	0.09
Thrust	Blades, tower, and foundation	Load fluctuations	0.7	0.32
Fixed	Roads, installation, permits	Independent of rating	0	0.29

D. J. Malcolm and A. C. Hansen, "WindPACT turbine rotor design study," National Renewable Energy Laboratory, Golden, CO 2002.

Wind/CAES with Lower Rated Wind Turbines



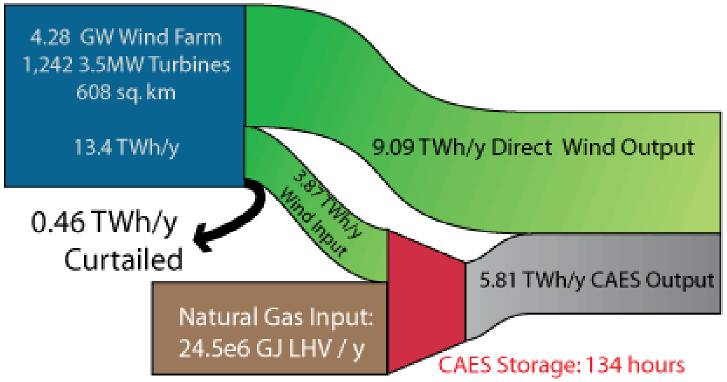
Nominal Rating (r_r=1.5)



Re-optimized Rating (r_r=1.2)

Wind/CAES Energy Flow

Wind/CAES with Nominal Rating
(rated speed = 1.50 * avg wind speed)

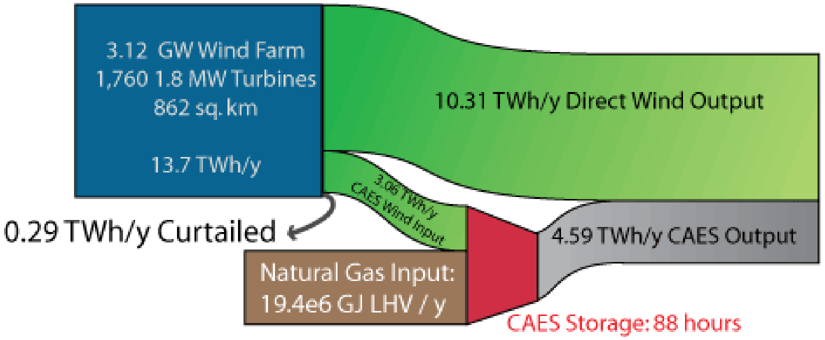


CAES Storage: 134 hours
CAES Compressor: 2.28 GW

System Output: 14.9 TWh/y
61% Wind, 39% CAES

GHG Emission Rate: 108 kgCO2/MWh
Net Heat Rate: 1640 MJ/MWh (LHV)

Wind/CAES with Optimized Tubine
(rated speed = 1.20 * avg wind speed)

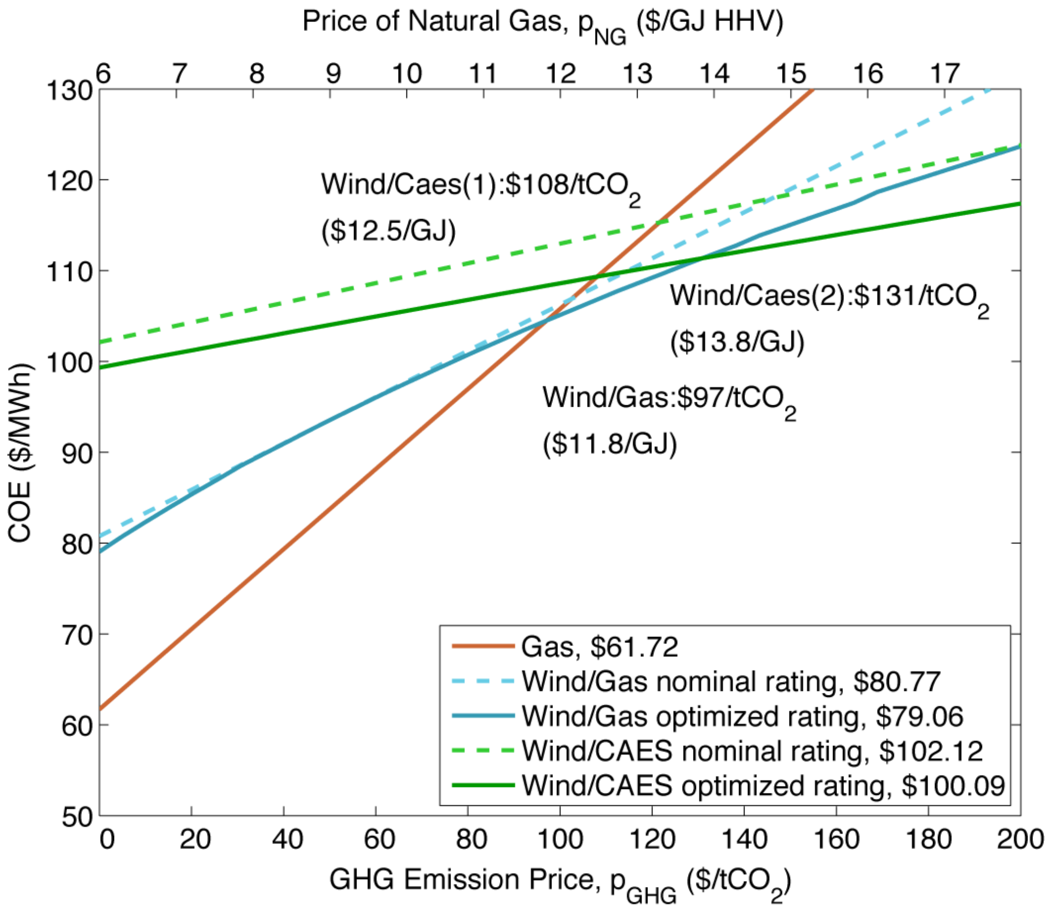


CAES Storage: 88 hours
CAES Compressor: 1.12 GW

System Output: 14.9 TWh/y
69% Wind, 31% CAES

GHG Emission Rate: 86.5 kgCO2/MWh
Net Heat Rate: 1310 MJ/MWh (LHV)

Cost of Energy and Entry Price Revisited: Impact of Derating



Base Fuel Cost (NG):
$6/GJ HHV

GHG Emission Intensity NG (Upstream + Downstream):
66.0 kg CO_2 / GJ LHV

GHG Emission Rates

NGCC:

441 $kgCO_2$/MWh,

Wind/Gas:

224 $kgCO_2$/MWh

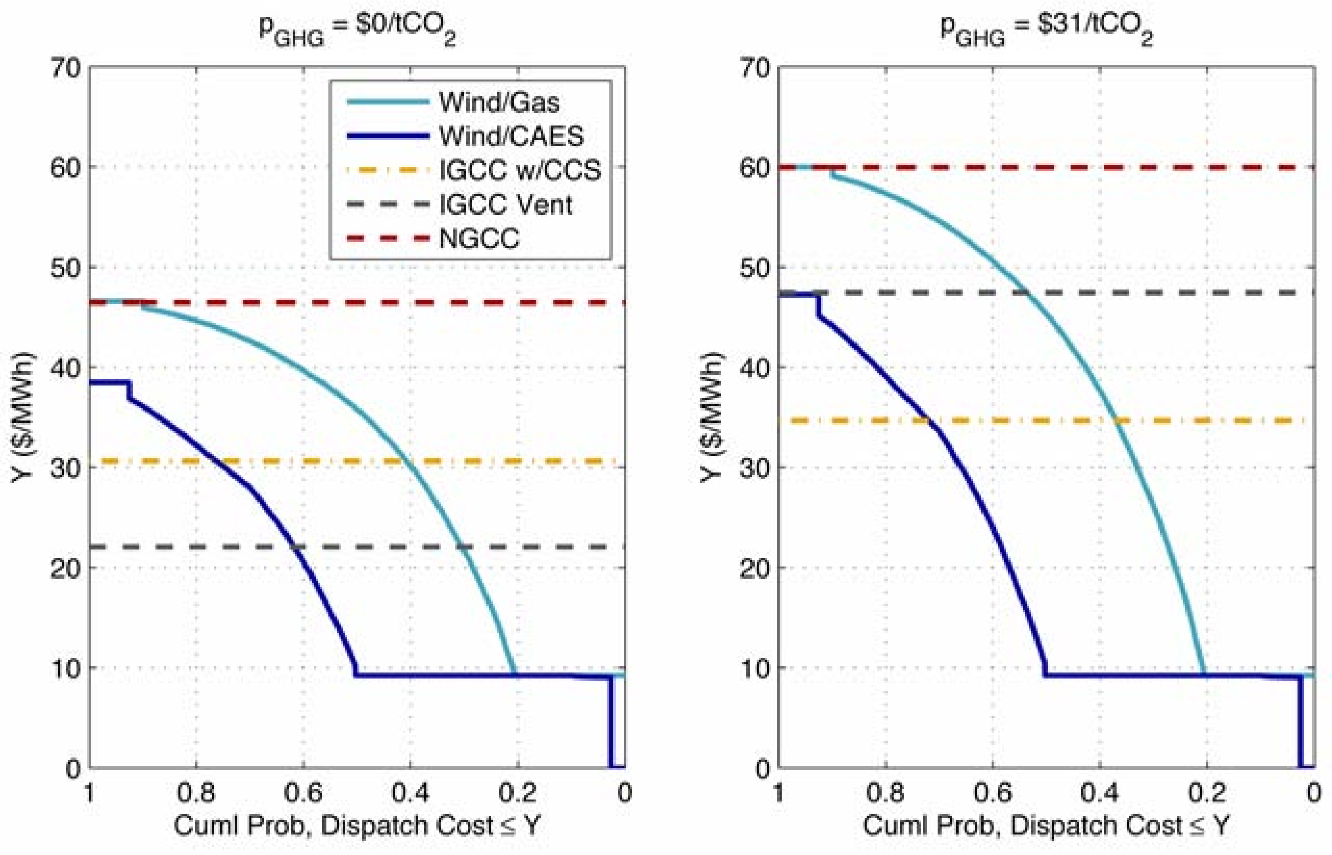
Wind/CAES:

86.5 $kgCO_2$/MWh

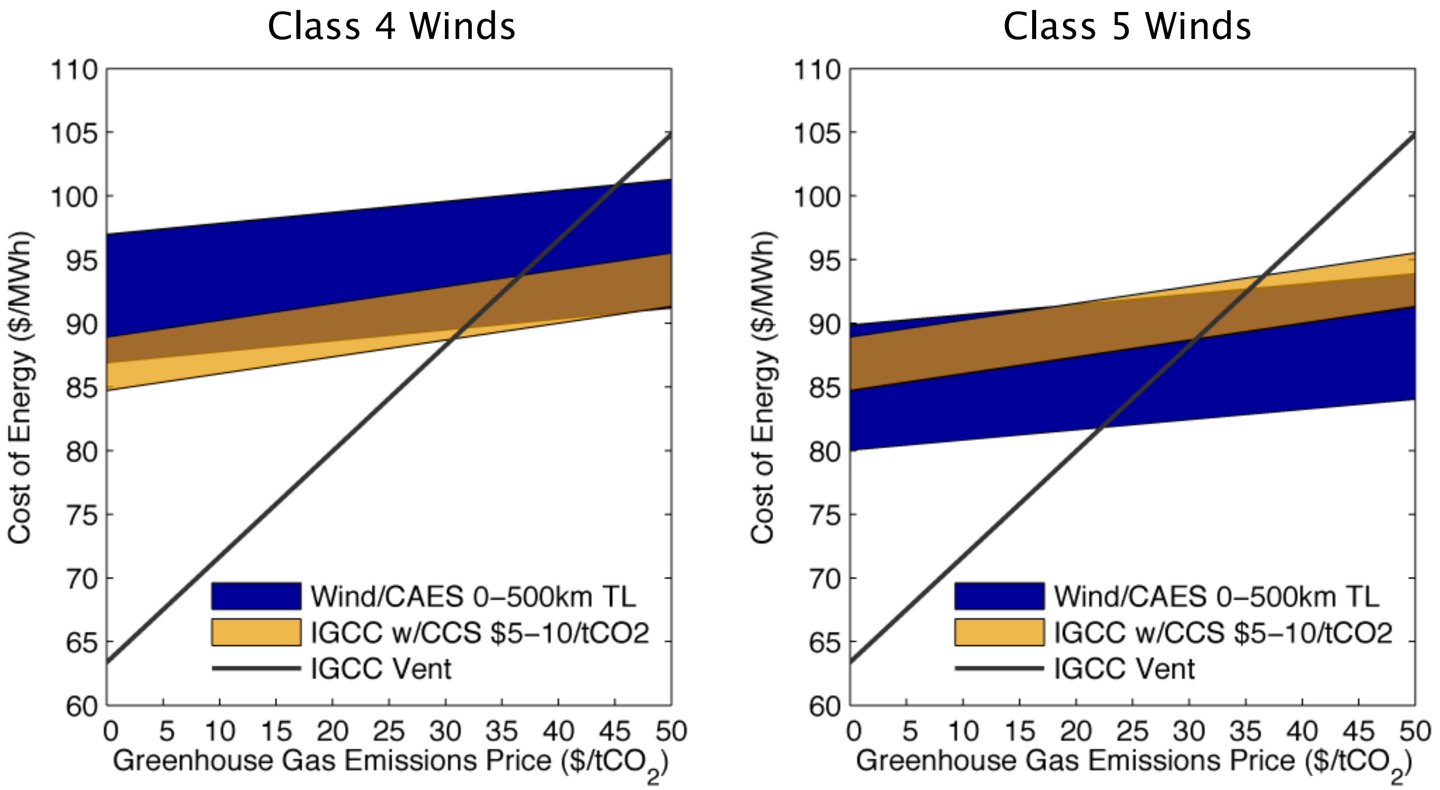
Coal IGCC: Economic Assumptions

- IGCC Costs, GE Entrained Flow Quench Gasifier (NETL 2007)
  - 80% Capacity Factor
  - IGCC with CO_2 Vented: OCC $1782/kW, LHV Eff 38%
  - IGCC with CCS: OCC $2350/kW, LHV Eff 31.5%
- Carbon Capture and Storage
  - CO_2 Transport and storage: $5/t$CO_2$
- Fuel Costs (EIA AEO2007)
  - Coal $1.65/MMBtu HHV

Dispatch Duration Curve



Cost of Energy: Wind/CAES vs Coal IGCC



Wind Class Designations (120m Hub Height)
Class 4: 8.23 m/s, Class 5: 8.8 m/s

Conclusions

- CAES is well suited for wind balancing applications
- Porous rock storage will be especially important
- Optimization of wind turbine rating reduces storage size, GHG emissions and cost
- NGCC and Wind/Gas unviable where coal IGCC or Wind/CAES is available due to high dispatch cost
- Wind/CAES has the potential to compete in dispatch and produce electricity at rates comparable to IGCC with CCS
- Wind resource strength and distance to load will determine the viability of Wind/CAES for a specific application

Acknowledgements

This research was developed in collaboration with several mentors colleagues and contributors past and present:

- Al Cavallo
- David Denkenberger
- Jeffery Greenblatt
- Robert Socolow
- Robert Williams

2.4 Roy Daniel, CAES Strategic Needs

Roy Daniel is the Chief Technology Officer at Energy Storage and Power a joint venture of Public Service Enterprise Group (PSEG) and Dr. Nakhamkin's group. Roy has more than two decades of experience in energy project development and power asset operations. He has been with PSEG since 1994 where he developed and oversaw operations of generation in Asia and the U.S.

He structured over $1 billion worth of international transactions for PSEG Global. Roy was Chief Operating Officer of Sri U-Tong, a 200 employee design and build firm for electric transmission based in Thailand. He holds a Bachelors in Nuclear Engineering and a Masters in Industrial Engineering from North Carolina State University, and a JD from Suffolk University Law School.

Energy Storage and Power LLC

CAES Strategic Needs

Roy Daniel, Chief Executive Officer

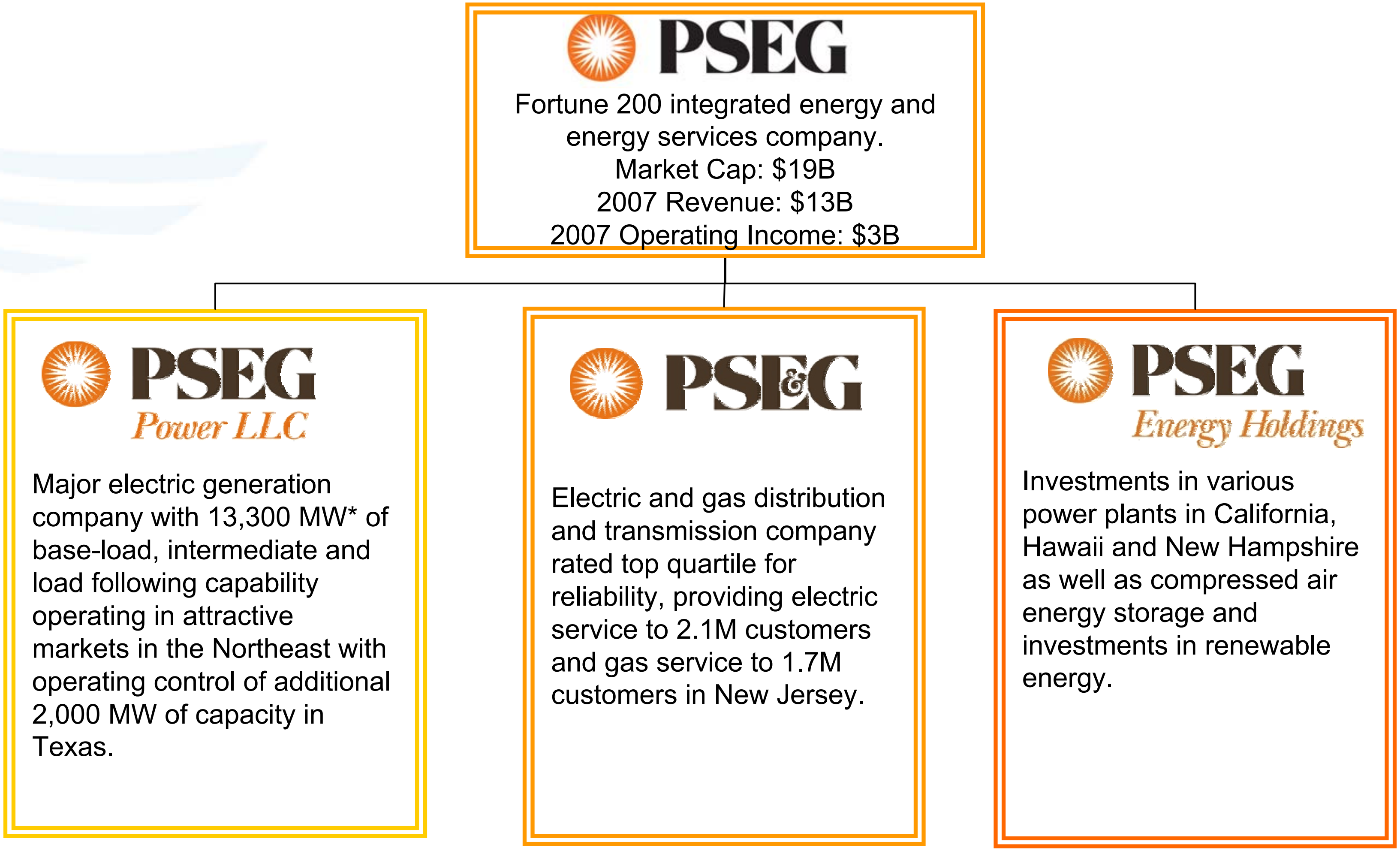
Columbia University
Center for Life Cycle Analysis
Compressed Air Energy Storage Scoping Workshop

October 21st, 2008

Company Background

- Energy Storage and Power, LLC was formed in August 2008 to market and deliver patented second generation CAES power plants including:
  - technology licensing, and
  - participation in all stages of CAES projects execution from conceptual engineering to delivery on EPC basis with business partners.
- It is a joint venture between:
  - Energy industry leader, Public Service Enterprise Group, a Fortune 200 company with over 100 year history in the electric energy industry
  - Dr. Michael Nakhamkin (ESPC) which has been a leader in the Compressed Air Energy Storage field for nearly two decades and technically supervised all stages of project execution for the 110 MW McIntosh, Alabama CAES plant

PSEG



PSEG

Fortune 200 integrated energy and energy services company.
Market Cap: $19B
2007 Revenue: $13B
2007 Operating Income: $3B

PSEG Power LLC

Major electric generation company with 13,300 MW* of base-load, intermediate and load following capability operating in attractive markets in the Northeast with operating control of additional 2,000 MW of capacity in Texas.

PSE&G

Electric and gas distribution and transmission company rated top quartile for reliability, providing electric service to 2.1M customers and gas service to 1.7M customers in New Jersey.

PSEG Energy Holdings

Investments in various power plants in California, Hawaii and New Hampshire as well as compressed air energy storage and investments in renewable energy.

Management Team – Chief Executive Officer

- Roy Daniel has more than two decades of experience in energy project development and power asset operations
  - He has been with PSEG since 1994 where he developed and oversaw operations of generation in Asia and the U.S.
  - He structured over $1 billion worth of international transactions for PSEG Global
  - He was Chief Operating Officer of Sri U-Tong, a 200 employee design and build firm for electric transmission based in Thailand
  - He holds a Bachelor of Science degree in Nuclear Engineering and a Master of Science degree in Industrial Engineering from North Carolina State University
  - He also holds a JD from Suffolk University Law School and completed the Advanced Management Program at the Wharton School of Business

Management Team – Management Board Member Chief Technology Officer

- Dr. Michael Nakhamkin, PE is a recognized leader in compressed air energy storage for over two decades
  - He invented 16 U.S. patents, 7 of them patents on the various concepts of the CAES technology
  - He is the author of 4 books and over 80 publications in industry trade journals including Combined Cycle Journal, Power Engineering and Gas Turbine World and presentations at many conferences including POWER-GEN International, EESAT, ASME Turbo-Expo and Electric Power 2007
  - He and ESPC developed and optimized the 110 MW CAES plant for Alabama Electric Cooperative, and technically supervised all stages of the project execution from conceptual engineering through the project commercialization

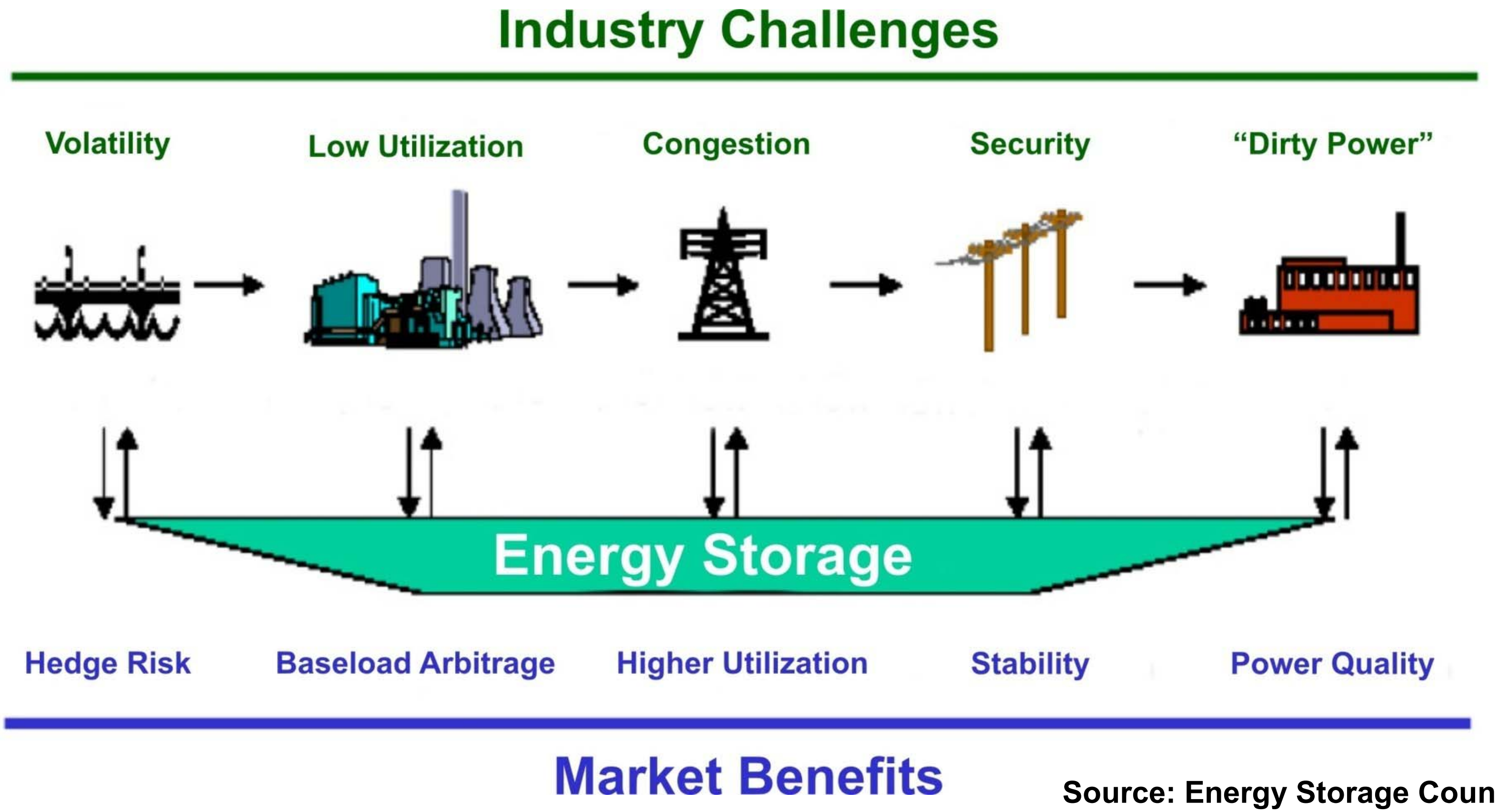
Why is Energy Storage Critical Now?

- *Renewable power sources are critical for addressing climate change and reducing North American dependency on foreign fuels*
- Energy storage greatly enhances these two missions by:
  - *Increasing load factors of renewable power sources* by storing energy produced by renewables when demand and energy prices are low and releasing it when demand and energy prices are high
  - *By more fully utilizing off-peak power plants* (nuclear, wind and coal plants) and reducing load factors of peaking power plants that are based on the fuel oil and natural gas.
- Energy storage significantly *improves operations and reliability of power grids* providing arbitration and regulation and synchronous reserve services via rapidly providing power when suddenly needed.

As renewable generation becomes a larger part of the North American energy supply picture, energy storage will be an important mechanism to fully realize its value

Energy Storage and Power LLC

Benefits of Energy Storage Along the Electricity Value Chain

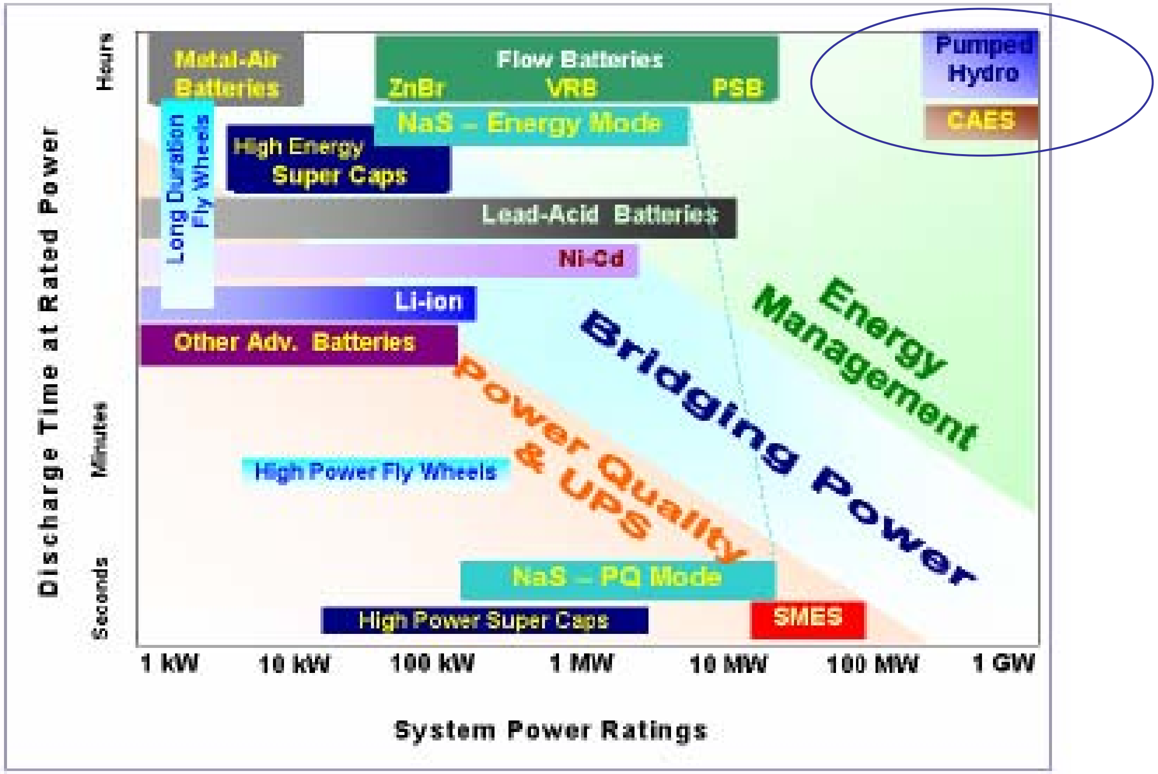


Source: Energy Storage Council

Energy Storage and Power LLC

Comparison of Energy Storage Technologies

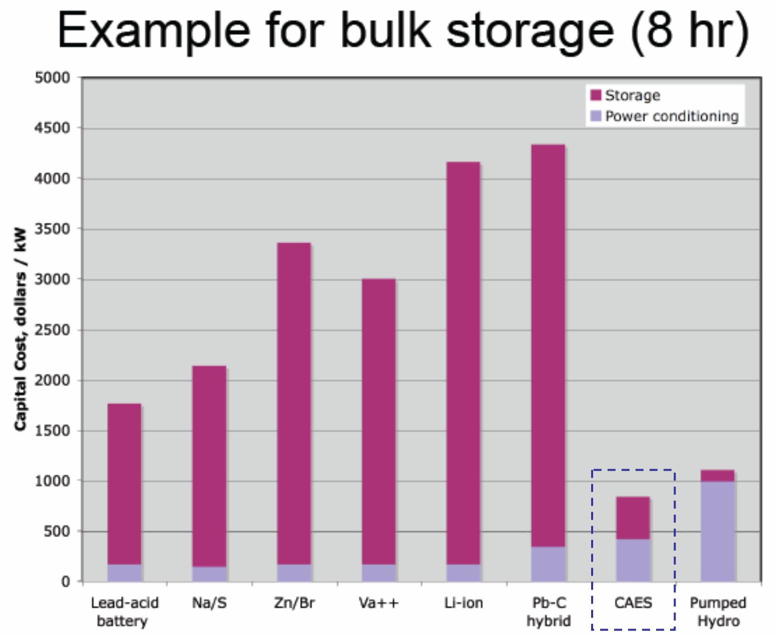
- CAES can provide large scale power storage for many hours at a time, something few other technologies can provide



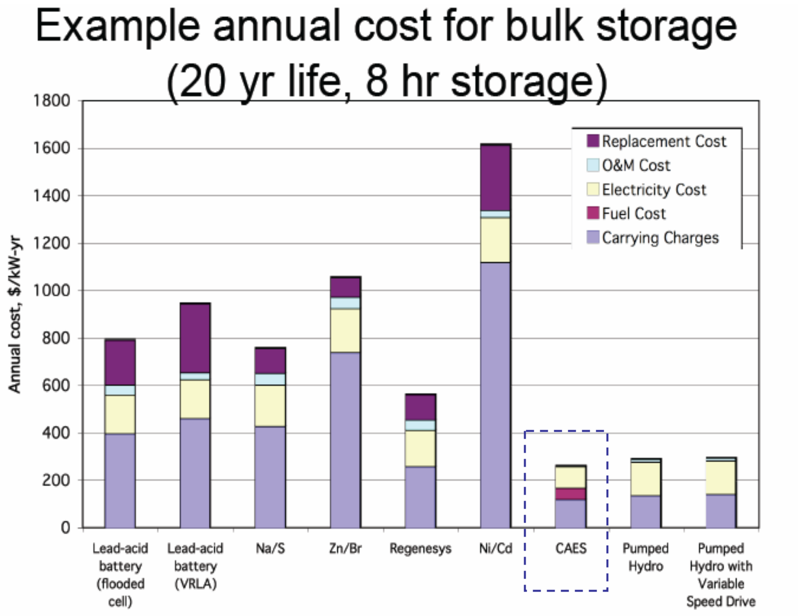
Source: Energy Storage Association

Bulk Storage Options

- CAES is significantly cheaper up front on a $/kW basis than other developed bulk storage solutions, and saves money on replacement costs due to its longer expected life than batteries



Example for bulk storage (8 hr)



Example annual cost for bulk storage (20 yr life, 8 hr storage)

Source: Longitude 122 West for DOE

How Does CAES Work?

- Energy Storage and Power's patented CAES technology uses low cost, off-peak energy to run a compressor train to create compressed air, which it stores, usually in an underground cavern
- The air is then released during peak load hours and heated with the exhaust heat of a standard combustion turbine in an air bottoming cycle
- This heated air is converted to energy through expansion turbines to produce electricity
- Various power augmentation procedures can be added at this point (including air injection and inlet chilling), taking advantage of the cooled air, creating "free" megawatts

Energy Storage and Power LLC

Electric Generators and CAES

- It is less complex and cheaper to construct and operate than a combined cycle
- Energy arbitrage is a large value driver of a CAES plant, as it uses cheaper off-peak power combined with minimal fuel, to provide on-peak power, usually at a significant spark margin to the market clearing on-peak price
- CAES provides exceptional ancillary service value, as its speed and flexibility allow for area regulation, synchronized spinning, non-synchronized reserve and other ancillary services

Non-controllable Intermittent Generators (Wind) and CAES

- Combined, it can provide a clean, firm product that is cheaper to build than a new nuclear plant and ready for commercial scale production unlike coal with carbon capture and sequestration
- CAES can manage the congestion on the transmission and convert less valuable off-peak energy to more valuable on-peak.
- CAES can help secure PPAs and debt financing in regions were this is currently difficult such as Texas west zone
- Projected installed wind generation is ~150 GW by 2020. If only 10% was linked to CAES, this would be 15,000 MW or 50 CAES units
- Some project that the grid requires 25%-30% of energy storage for wind to maintain a stable grid, making CAES a huge market opportunity

Energy Storage and Power LLC

Utilities and CAES w/ Above Ground Storage

- CAES is significantly cheaper, larger and more flexible than batteries and flywheels for load management
- It can relieve stress on distribution lines, delaying costly upgrades
- It can take advantage of existing distributed super peaker generators reducing capital cost and accelerating installation.
- Using an above ground storage reservoir frees it from geological siting concerns

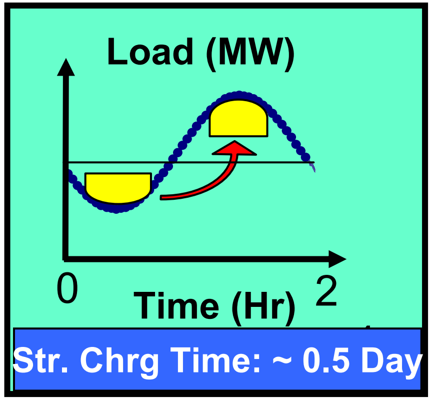
Grid System Operator and CAES

- CAES provides exceptional ancillary service value, as its speed and flexibility allow for area regulation, synchronized spinning, non-synchronized reserve and other ancillary services
- CAES can optimize use of transmission system through storing power for better line loading.
- CAES can defer upgrade of transmission and manage super peaks
- CAES is very reliable generation resource. Two thirds of the generation is from the release of compressed air

Energy Storage and Power LLC

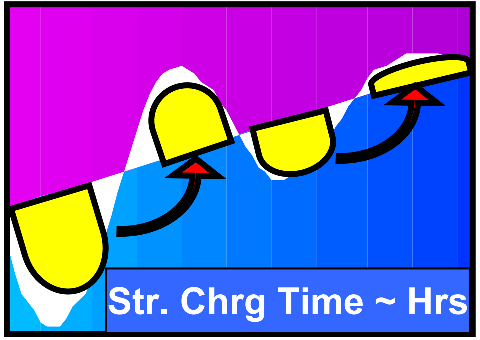
2nd Generation CAES is a System Operator's Dream Come True

Load Leveling



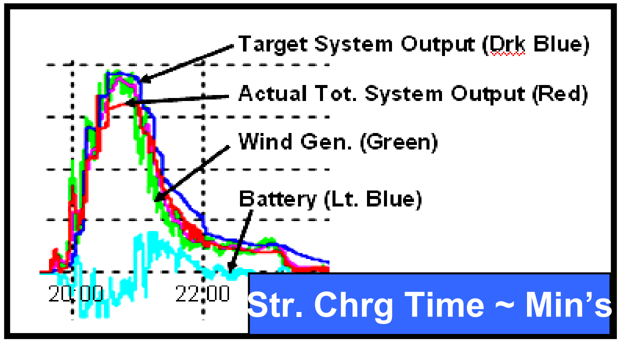
- CAES
- Pumped Hydro

Ramping:



- CAES
- Pumped Hydro
- Battery, Flow type

Frequency Regulation:



- CAES
- Battery, Regular or Flow Type
- SuperCap
- Flywheel
- SMES

EPRI ELECTRIC POWER RESEARCH INSTITUTE

Overview of ES&P's 2nd Generation CAES Technology

Energy Storage and Power's patented CAES technology is the most reliable, cost effective and practical, bulk energy storage technology:

- 2nd generation CAES unit capacities could range from as small as 15 MW to over 400 MW
- They have lowest capital costs and in many cases the best economics of storage technologies
- CAES plant power consists of:
  - ~70% of potentially green power generated by Air Expanders utilizing the stored air (utilizing the CT exhaust gas heat as am air bottoming cycle, similar to steam bottoming cycle for CC plants)
  - ~30% of power generated by a Combustion Turbine
- The variable power generation costs are based on the overall heat rate of approximately 4000 Btu/kWh (vs. 10,000-11,000 by CTs) plus ~0.75 kWh of off-peak power for every 1 kWh of on-peak power generated

Compressed Air Energy Storage in the US – 1990’s

- First load management using CAES technology
  - Alabama 110 MW unit COD 1991
  - On budget and within schedule construction project
  - Operated 16 years before first major outage
- Alabama proves the concepts of compressed air storage
- No follow-on units
  - Small difference between on-peak and off-peak prices
    - $2/MMBtu natural gas and $1.50/MMBtu coal
  - Limited minimum must run and non-controllable units in the US Grid as compared to load

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Compressed Air Energy Storage in the US – 2000 to present

- US Grid and generation stack changing
  - Non-controllable off-peak generating units with focus on renewables – Wind comes of age as a on-shore generating source
  - State mandated Renewable Energy Standards (26 states) and desire to limit emissions
  - High natural gas price on-peak creating arbitrage
  - Domestic energy sources sought
- Second Generation CAES
  - Applies lessons learned from Alabama to apply standard components in a patented novel manner to reduce capital cost, improve operations, reduce environmental footprint, and create greater flexibility in sizing for market.
- Second Generation CAES
  - Can provides both bulk storage and ancillary service important to optimizing and managing the electric grid.

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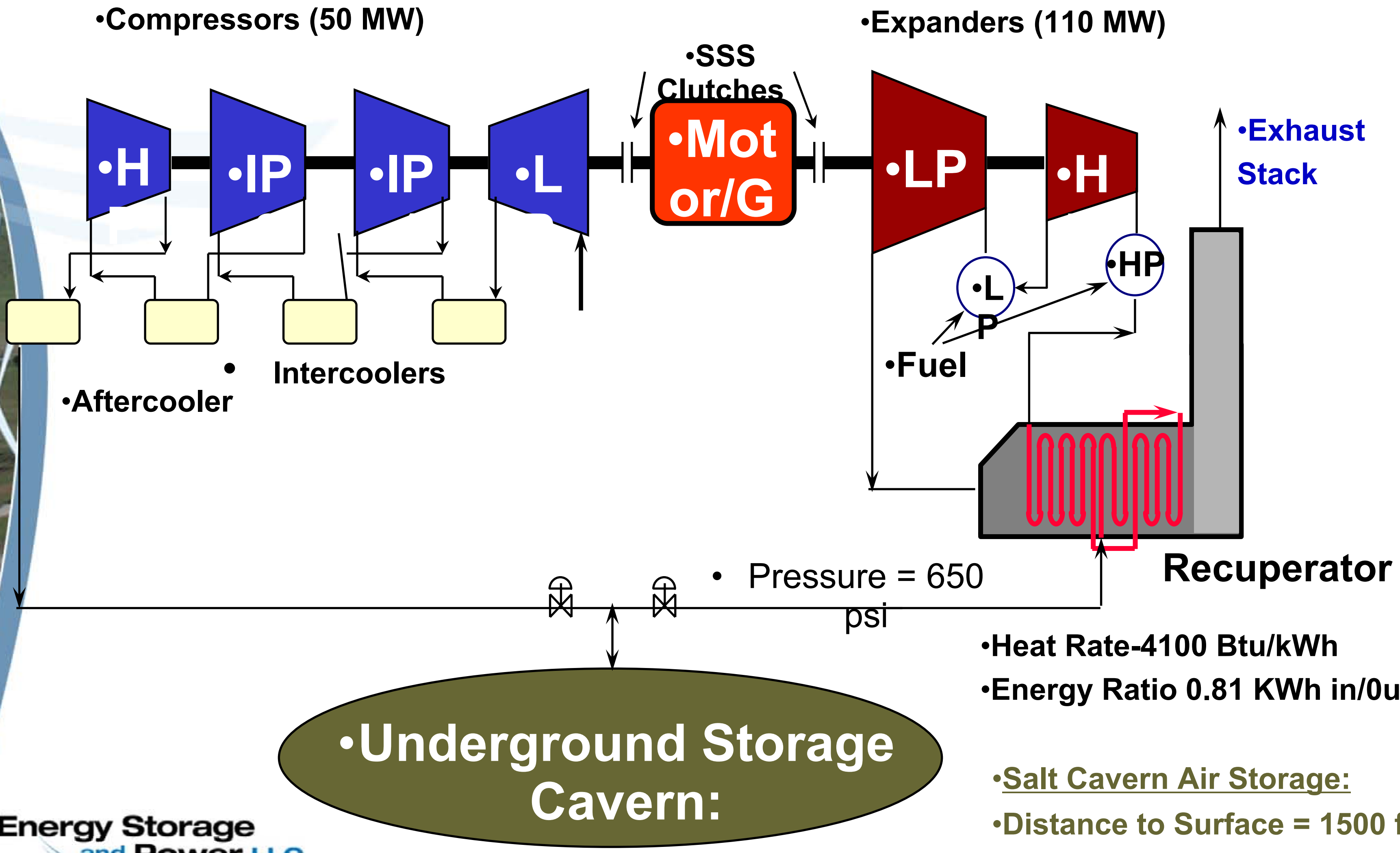
Alabama Compressed Air Energy Storage Plant
Peak Power 110 MW; 26 hrs of continuous Power Generation;
Heat rate is 4000 Btu/kWh; Off-Peak Power 51MW, Capital Cost $600/kW, 1991

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



- Heat Rate-4100 Btu/kWh
- Energy Ratio 0.81 KWh in/0ut

- <u>Salt Cavern Air Storage:</u>
- Distance to Surface = 1500 ft
- Volume = 22MCF

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Second Generation CAES Plants is Capitalizing on AEC Project Experience and Lessons Learned

- **Power is generated by:**
  - **a stand alone combustion turbine and**
  - **stand-alone Expanders operating w/o combustors and utilizing the CT exhaust gas heat - the air bottoming cycle (similar to steam bottoming cycle for CC plants)**

- **The fuel is burned only in CT's DLN combustors (there is no additional fuel burners/combustors)**

- **The storage is pressurized by multiple stand-alone off-shelf motor driven compressors**

- **Every components is operating within a typical range**

- **Flexibility to optimize the CAES plant for specific grid conditions, power requirements economics and underground storage specifics**

- **Significantly lower capital costs due to:**
  - **Use of standard components**
  - **Simple construction & tuning up**
  - **Schedule time is within two years**

CAES 2^{nd} Generation Improvements

- **Lowest capital cost** per kilowatt-hour of output of all power storage technologies (including first generation CAES)
- **Lower maintenance cost** by using standard equipment (combustion turbines and independent motor driven compressors) with established operating and maintenance procedures
- **Exceptional operating flexibility** from the combination of incorporating a combustion turbine with compressed air expansion provides fast start times and wide range of spinning reserves which are important ancillary services for grid stability that will become ever increasingly important as renewables (the output of which is inherently unpredictable and intermittent) become a bigger part of the US energy power supply
- **Scalability** of second generation from 15 MW to 430 MW to meet the specific requirements of the application. 15 MW coupled with above ground air storage can be an alternative to batteries to 430 MW for the large-scale needs of the wholesale power industry
- **Low emissions** by incorporating the dry low NOx burners of combustion turbine instead of a using custom designed high and low pressure burners. Permitting of a standard combustion turbine as the air emission source should reduce the uncertainty in permitting process
- **Exceptional equipment sourcing flexibility** as the plant can be designed around basically any combustion turbine which is available including under utilized existing peaking units. In addition, the motor driven air compressors can be grouped into trains so there is flexibility of suppliers

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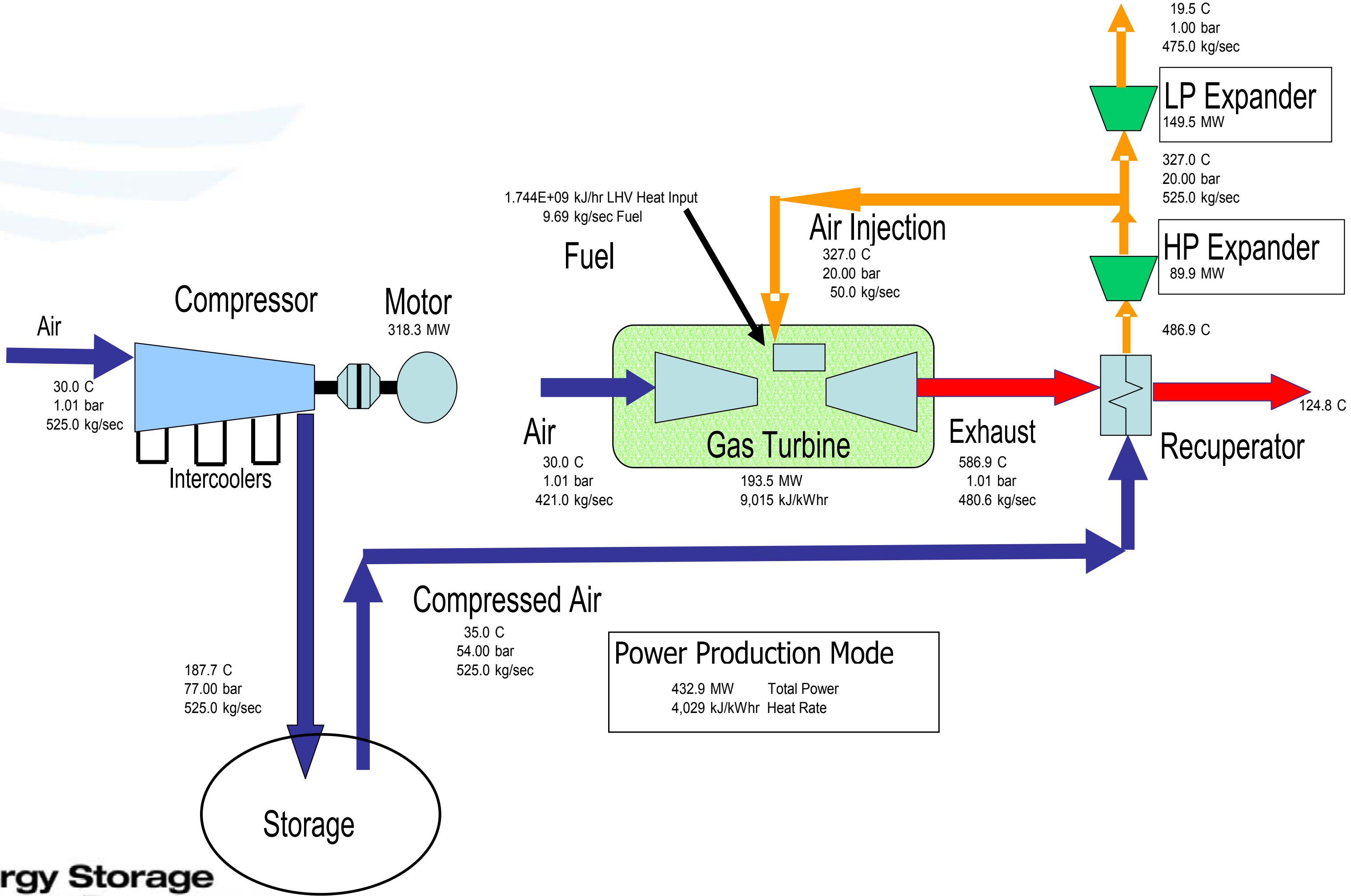
CAES w/ Bottoming Cycle and Air Injection (GE 7FA, ~400MW)



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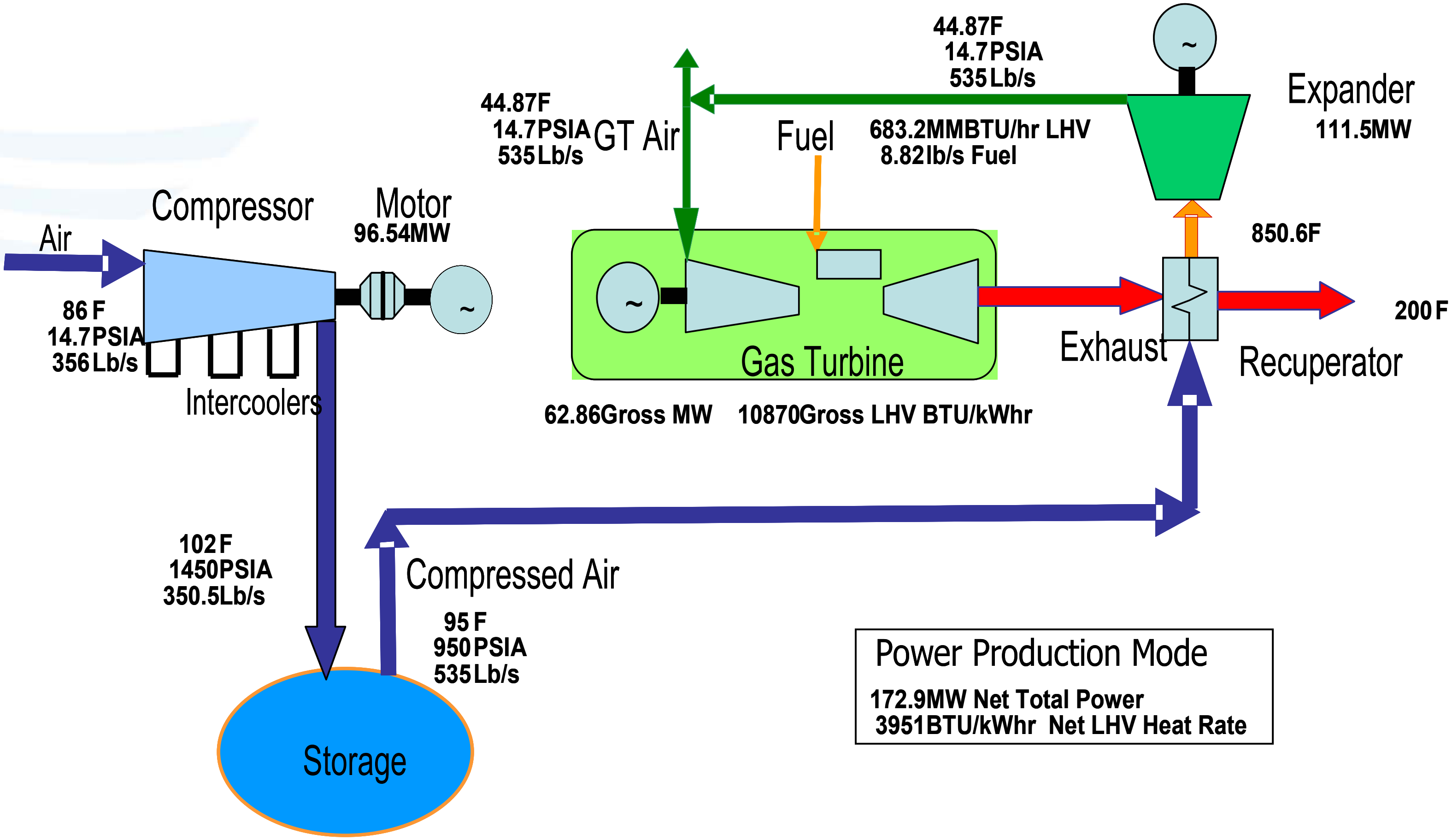
CAES w/ Bottoming Cycle and Inlet Air Chilling (GE 7B, ~160 MW)



Power Production Mode

172.9MW Net Total Power
3951BTU/kWhr Net LHV Heat Rate

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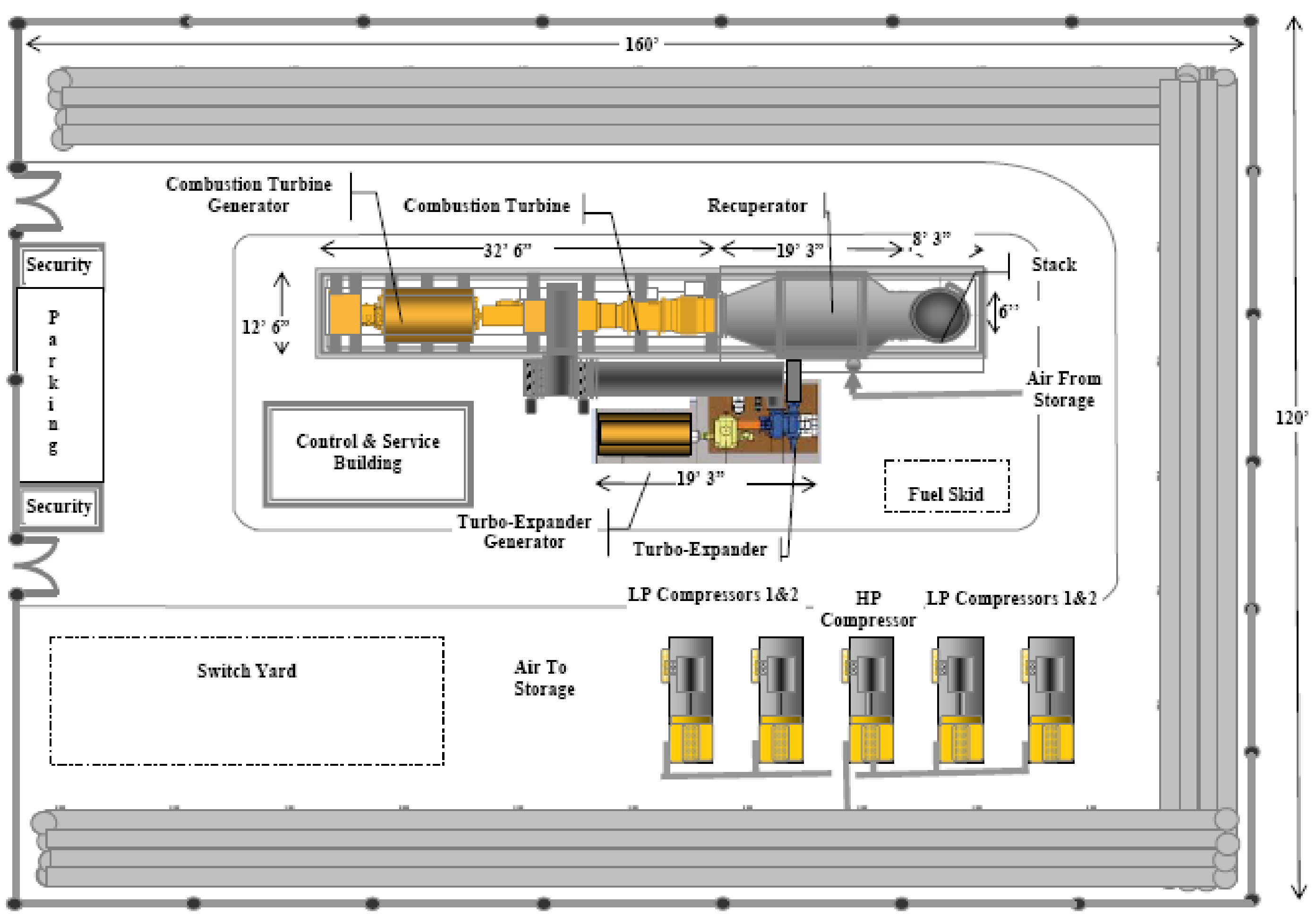
15 MW CAES w/ Above Ground Storage Drawing



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CAES Technology Comparison

	CAES 1st Generation	CAES 2nd Generation w/ Air Injection*	CAES 2nd Generation w/ Inlet Chilling*	2nd Generation CAES w/ Above Ground Storage
Technology	Custom burners and equipment from Dresser Rand on a single shaft	Uses off-the-shelf equipment including CT on separate shafts – Scalable 15 to 430 MW	Uses off-the-shelf equipment including CT on separate shafts – Scalable 15 to 430 MW	Uses off-the-shelf equipment including CT on separate shafts – Scalable 15 to 430 MW
Air Emissions (No SCR)	No dry-low NOx burner	CT burner technology	CT burner technology	CT burner technology
Working Air Pressure	~650 – 900 psi	400 psi - 2,000 psi+	400 psi - 2,000 psi+	400 psi - 1,200 psi+
Total Power, MW	110	433	427	15
Off-peak Power, MW	85	318	313	12
Plant Heat Rate, Btu/kWh	~4,000	~3,800	~3,800	~4,000
Constructor Costs (2008 $)	~$1200/kW	~$750/kW	~$750/kW	~$1250/kW

* Based on 7FA CT, Can be scaled to sizes ~150MW and ~300MW

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Combined Cycle vs Second Generation CAES

	Combined Cycle	**Second Generation CAES**
Technology	*Proven technology, water presents numerous issues*	*Proven technologies combined in a novel way*
Siting	Load, land rights and NIMBY drive siting	Load, land rights, NIMBY drive siting, *geology, and price deltas,*
Ancillary Services	Spinning and Non-spinning reserve	Area Regulation, Spinning, and Non-spinning reserve, Black-start Capable of ramping very quickly
Emissions	2/3 of the base CT (on a per MW basis)	1/3 of the base CT (on a per MW basis)
Variable Cost (see chart on subsequent page)	(Heat Rate x Gas Price) + VOM (i.e. (7.5x$10)+4=$79)	(Offpeak Power Needed x Offpeak Power Price) + (Heat Rate x Gas Price) + VOM (i.e.(.73*$40)+(3.9x$10)+2.5=$71)
Positive Drivers	Gas Price Rises, Market Heat Rate Expansion, Capacity Prices Rise	Gas Price Rises, Market Heat Rate Expansion, Capacity Prices Rise, *Coal Price Falls, Volatility Increases, Wind Increases, Ancillary Services Prices Increase*
Constructor Costs - $2008	$950/kW	*$750/kW*

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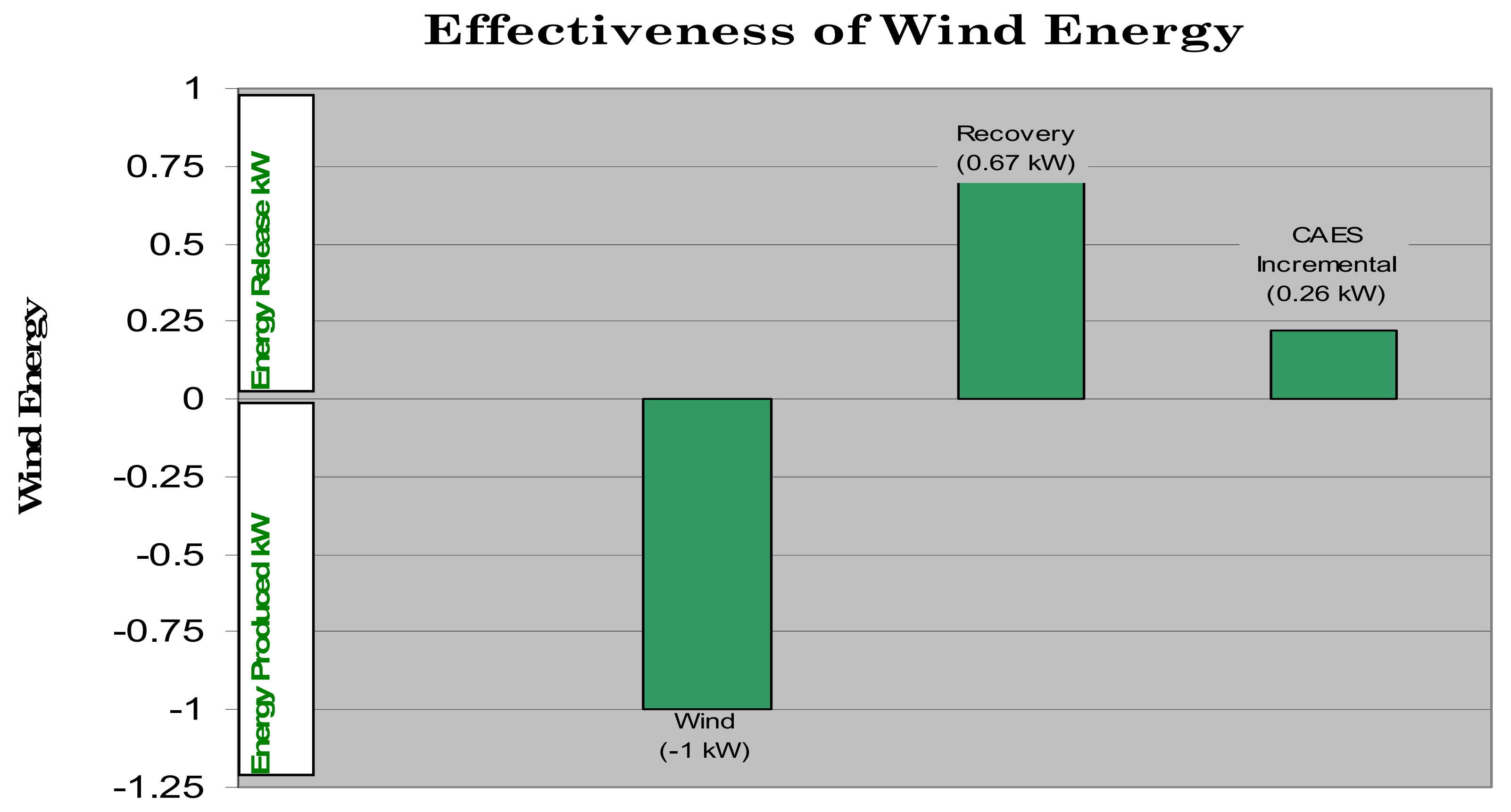
1 kWh of Stored Off-peak Energy Returns over 0.9 kWh of Peak Energy



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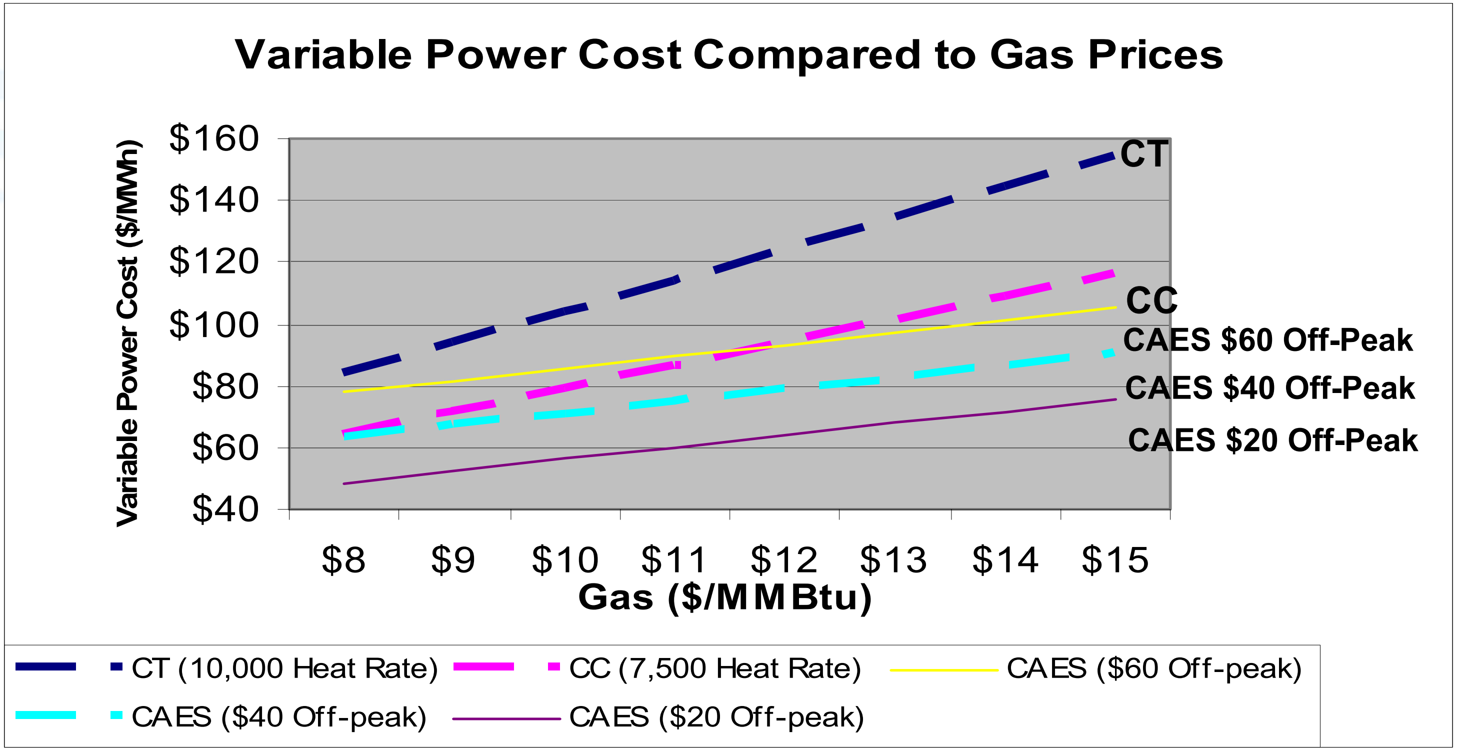
CAES Has Lower Variable Costs than CCs and CTs

- **Under most realizable scenarios, CAES produces power at a lower cost than a CC & CT**



CO2 Equivalent GHG emission rate (kg CO2/MWh)

IGCC - V	IGCC - C	Wind/CAES	Wind/Nat Gas	Nat Gas CC
829	132	86.5	224	440

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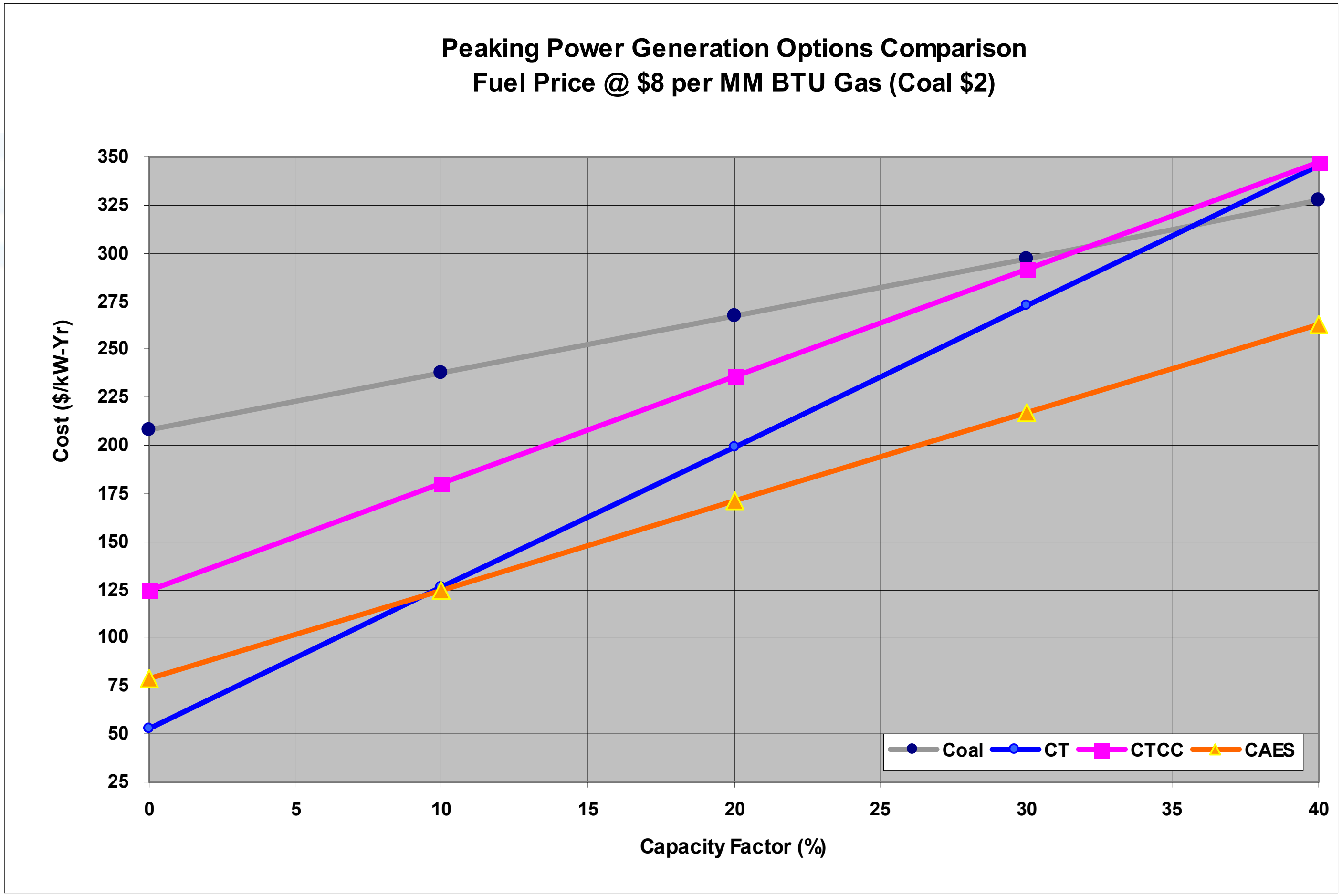
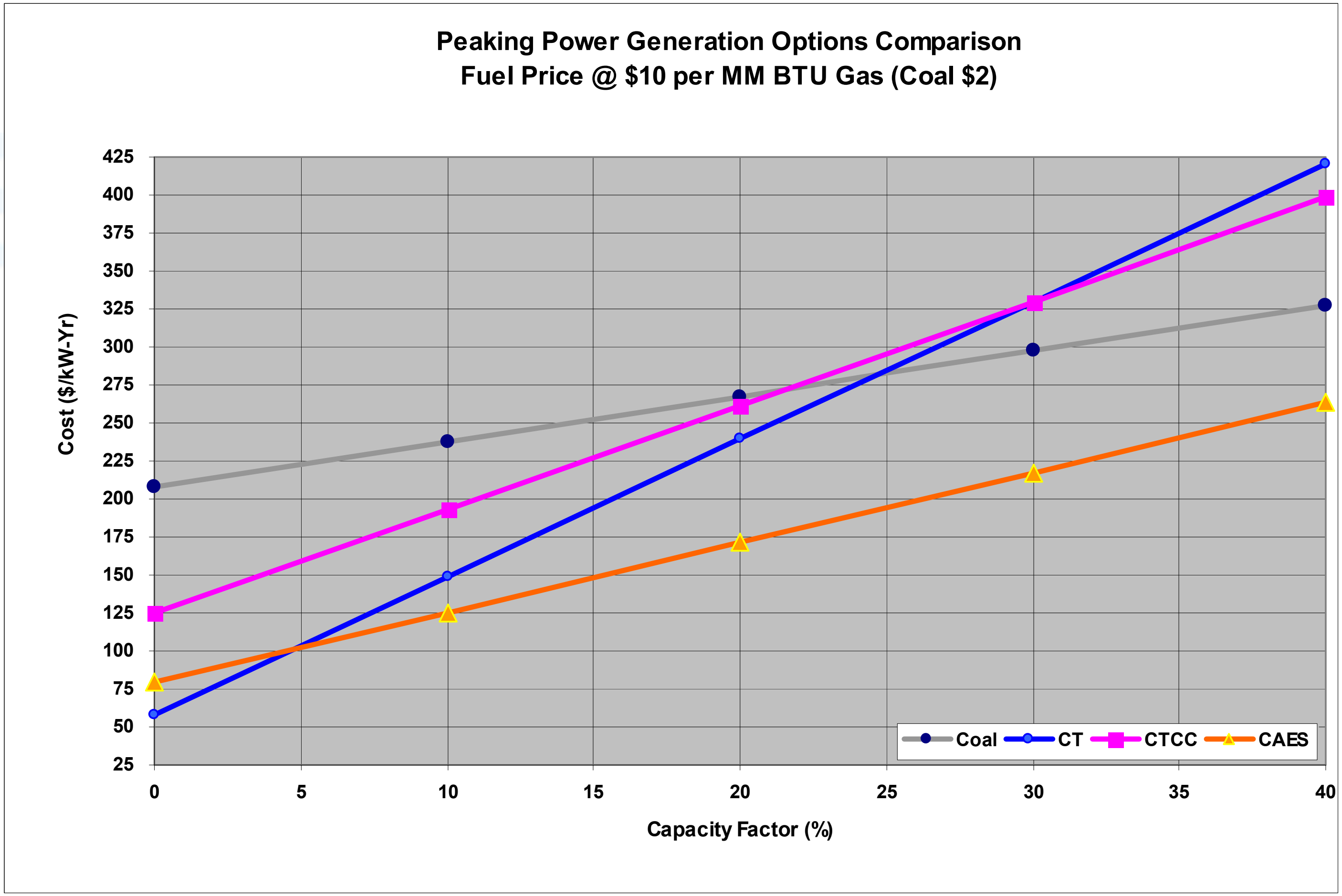
Comparative Analysis of Generation Costs for Coal. CT, CC and CAES plants



Energy Storage and Power LLC

Comparative Analysis of Generation Costs for Coal. CT, CC and CAES plants



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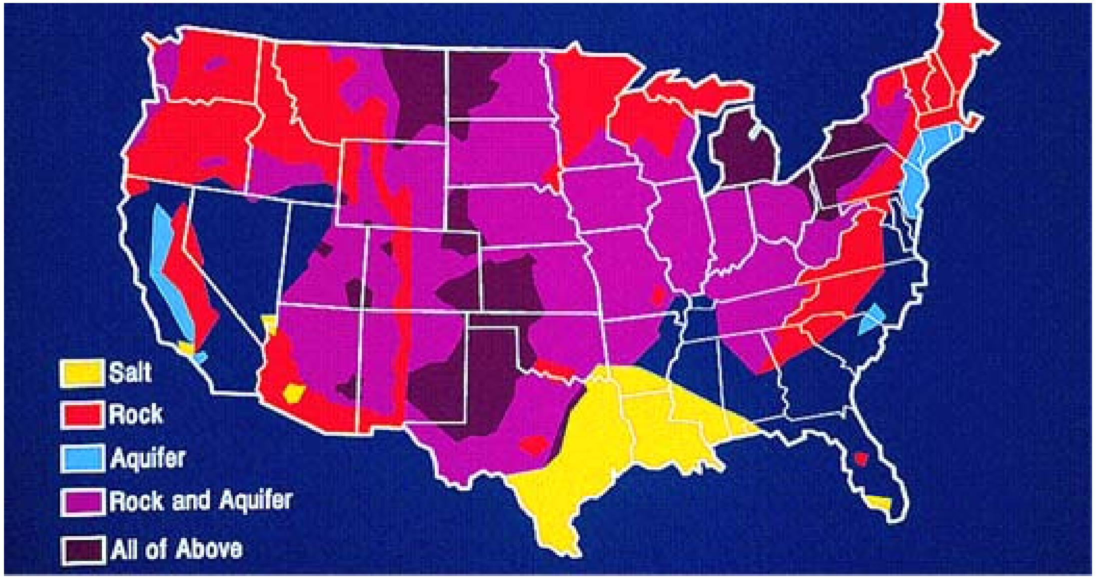
US Geology – 80% of U.S. Favorable to CAES Storage

- CAES storage options are available in large parts of the country
- A 300 MW CAES Unit requires a 21 MMCF cavern for 8 hours of storage
- Fifty 300 MW CAES Units require 1,050 MMCF (1BCF) of physical storage capacity
- To put that in perspective, the Natural Gas Storage industry today is 8,323 BCF in size



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Source: ES&P, Energy Information Administration and EPRI

CAES Environmental Considerations

- Environmental considerations, as always, are location specific but in general there are less environmental concerns for permitting a 2nd generation CAES plant than for a new combined cycle
  - The combustion turbine's emissions are diluted with the output of the air cycle, reducing PPM emissions by roughly 1/3
  - There is no steam cycle so limited water needs for a CAES plant
- Cavern permitting is well developed for the mining and gas storage industries
- The humid air injection process lowers NOx emissions

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Strategic Needs of CAES

- **Current state of CAES**
- Proven technology with substantial lessons learned applied to an already successful deployment
- Provides both bulk storage, management of intermittent generation resources, and optimization of the transmission network.

- **Next Steps to Implementation**
- Continue to optimize CAES to improve economics of application
- Identify economically viable applications and interested sponsors
- Supply chain prepared to respond to the request to build

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ES&P’s Role

- **Second generation CAES improves project economics by optimizing unit to the electric market and site at a lower capital cost.**
- **ES&P is a concentrator and creator of CAES technology**
- **A provider of technology license for 2nd generation CAES project**
- **Will develop infrastructure for unit delivery to the power industry**
- **Will provide technical specifications and conceptual engineering** optimizing unit configuration based on energy market requirements
- **Can provide Tailored delivery**:
  - **Prepare and evaluate RFQ, and serve as owner’s engineer for CAES process during construction,**
  - **Provide plant on an EPC basis with appropriate commercial guarantees, *or***
  - **Own and operate CAES plant**

Supply Chain

- Equipment:
  - Combustion Turbine (GE, Siemens, Westinghouse)
  - Compressors (MAN Turbo, Dresser Rand, Mitsubishi, Hitachi, Rolls-Royce, Ingersoll Rand)
  - Expanders (MAN Turbo, Dresser Rand, Mitsubishi, Siemens, Skoda, Atlas Copco, GE, Alstom)
  - Heat Exchangers (RPG Technologies, Nooter/Eriksen, Deltech, BHEL)
- Engineers
  - Engineering Storage and Power optimizes the CAES unit cycle
  - Design layout of unit simpler than a combined cycle plant
- Constructors
  - Above Ground (generation industry)
  - Below Ground (gas storage industry)

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EPRI Advanced CAES Demonstration Plant Schedule – Is one working to find good applications and reduce project development cost

Project Phases:

1. 🟨 Engineering Design, Costing, RFP and Select Winner
2. 🟩 Construct Plant
3. 🟦 Monitor Plant Performance and Reliability

Estimated Phased Schedule:	2008	2009	2010	2011	2012	2013	2014
300 MW - 10 Hr. Plant Using Below Ground Air Store	🟨	🟨	🟩	🟩	🟩	🟦	🟦
15 MW - 2 Hr. Plant Using Above Ground Air Store	🟨	🟨	🟩	🟩	🟦	🟦	

Notes:

1. Collaborative participants (Up to 10) have “off-ramp” if they wish to not host the Phase 2 construction work
2. Final size of plant will be determined by phase 2 host utilities
3. All participants will obtain project results from both plants and from other phases of the project

Summary

- Compressed Air Energy Storage is perfect for utilities who want to manage their existing transmission and substation infrastructure
- CAES is critical for wind or solar developers, to allow you to sell the renewable energy when the demand is highest, not when Mother Nature decides
- CAES is ideal for IPPs, as a preferred generation source relative to simple cycle plants, combined cycle plants and pumped storage plants as it is a simpler, cheaper, cleaner and more powerful alternative
- CAES is interesting for the gas storage industry as there are tremendous synergies between the businesses

Contact Us

Second Generation CAES is ready for prime time commercial roll–out.

Questions*?*

By Phone
866-941-CAES (2237)

By Email
Roy Daniel: RDaniel@EnergyStorageAndPower.com
Dr. Michael Nakhamkin: MNakhamkin@EnergyStorageAndPower.com

Thank You!

Energy Storage and Power LLC

3.1 Kent Holst, Iowa CAES Plant- Challenges and Prospects

Kent Holst is the Development Director for the Iowa Stored Energy Park (ISEP). He has served in this position since the formation of Iowa Stored Energy Plant Agency in 2005. Before then he served on the ISEP Committee of the Iowa Association of Municipal Utilities. Mr. Holst was the General Manger of Traer, Iowa Municipal Utilities (TMU) for 22 years until his retirement in 2004. Prior to joining TMU, he was a John Deere farm equipment dealer. He has a B.S. degree in Agricultural Business from Iowa State University.

THE IOWA
STORED
ENERGY
PARK

Iowa Stored Energy Park

CAES Scoping Workshop
NYSERDA
Columbia University
New York City
October 21, 2008

Kent Holst, Development Director
Iowa Stored Energy Park

Today’s Presentation

History

Challenges

Next steps

History

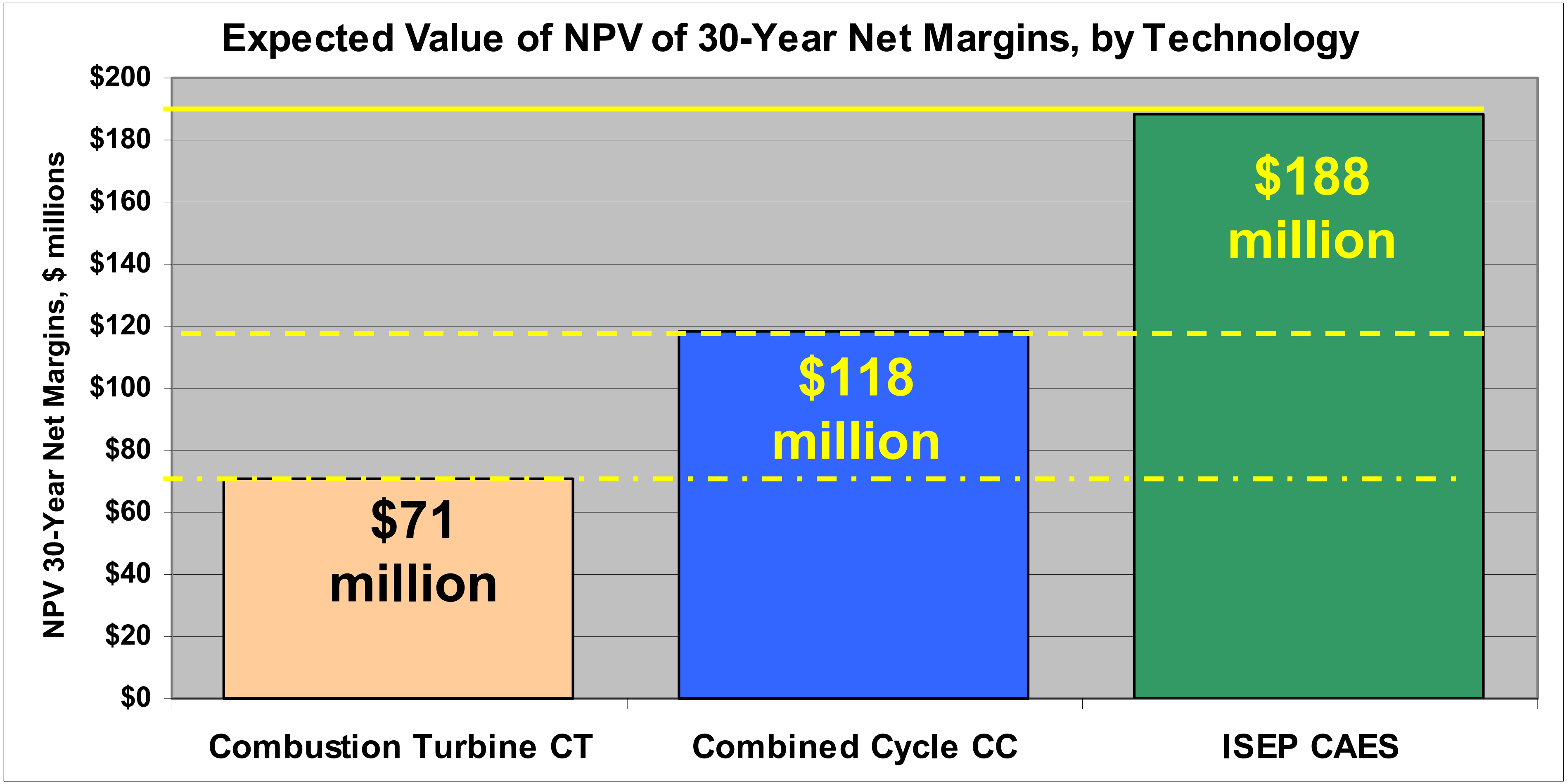
Coal?

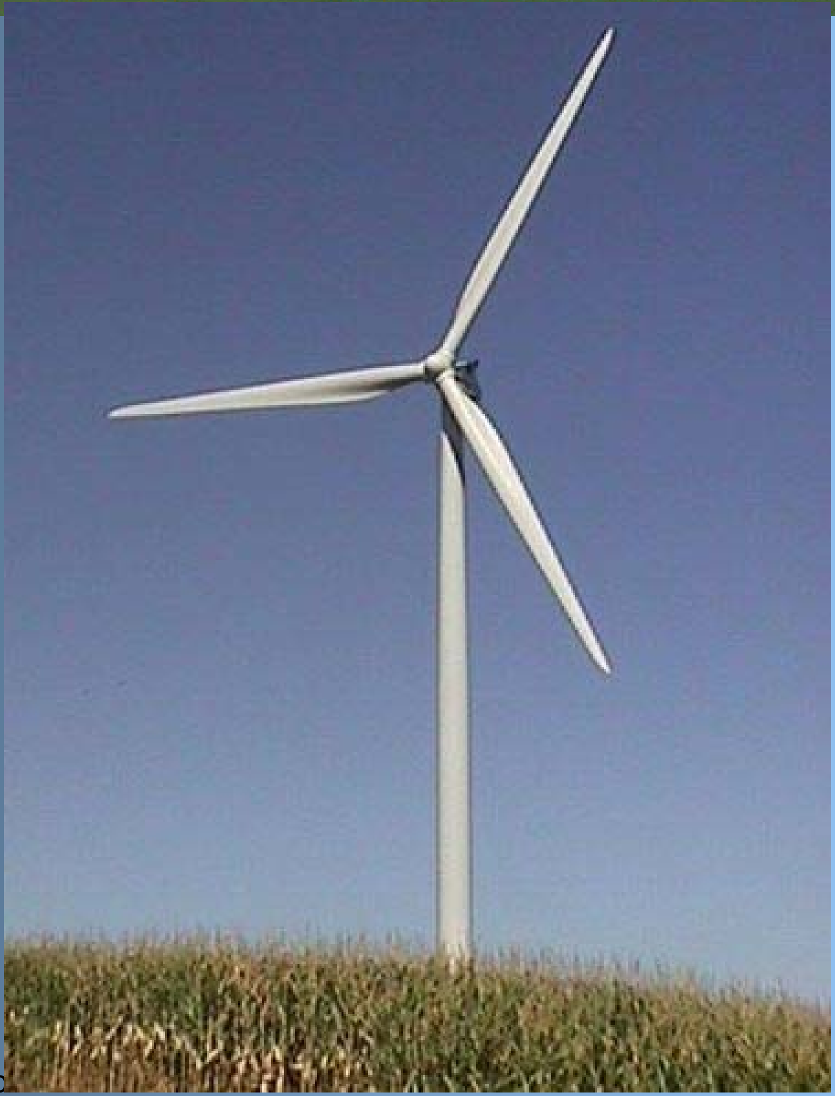
Intermediate.

CAES!

Challenges

1. Finding geologic formation.
2. Low tolerance for risk.
3. Economic feasibility.
4. Inadequate resource software.


Expected Value of NPV of 30-Year Net Margins, by Technology
NPV 30-Year Net Margins, $ millions
$200
$180
$160
$140
$120
$100
$80
$60
$40
$20
$0
$71 million
$118 million
$188 million
Combustion Turbine CT
Combined Cycle CC
ISEP CAES



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Next steps:

1. Drill two test wells.
2. Pump tests, water & air.
3. Refine computer modeling.
4. Sell it.

Funding

1. Municipal utilities –$1.15 million.
2. DOE - $6 million.
3. Iowa Power Fund - $3.2 million.

Questions?

3.4 Dave Marchese, Norton Energy Storage: CAES Resiliency in Uncertain Markets

David Marchese is Vice President at Haddington Ventures. He is active with the boards of directors of CAES Development Company (Norton Energy Storage), Bobcat Gas Storage, and Endicott Biofuels.
Before joining Haddington in 2006, Dave was a managing partner at Eschelon Energy Partners, a Houston based private equity fund targeting investments across the energy value chain. Dave has an MBA and Bachelors of Engineering both from Vanderbilt University.

Norton Energy Storage and CAES: Resiliency in Uncertain Markets

Dave Marchese

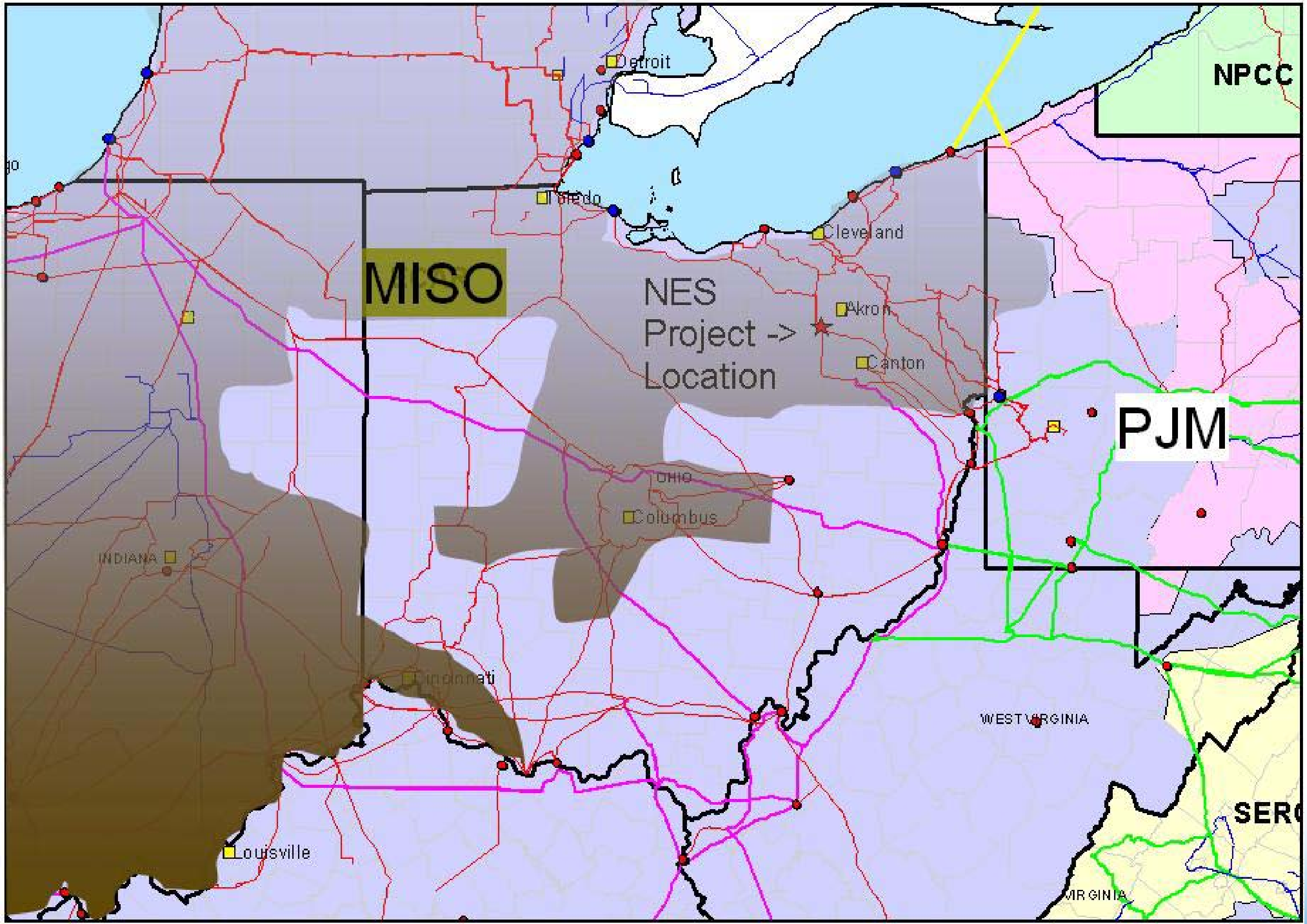
Vice President, Haddington Ventures

October 21, 2008

Overview of Haddington Ventures

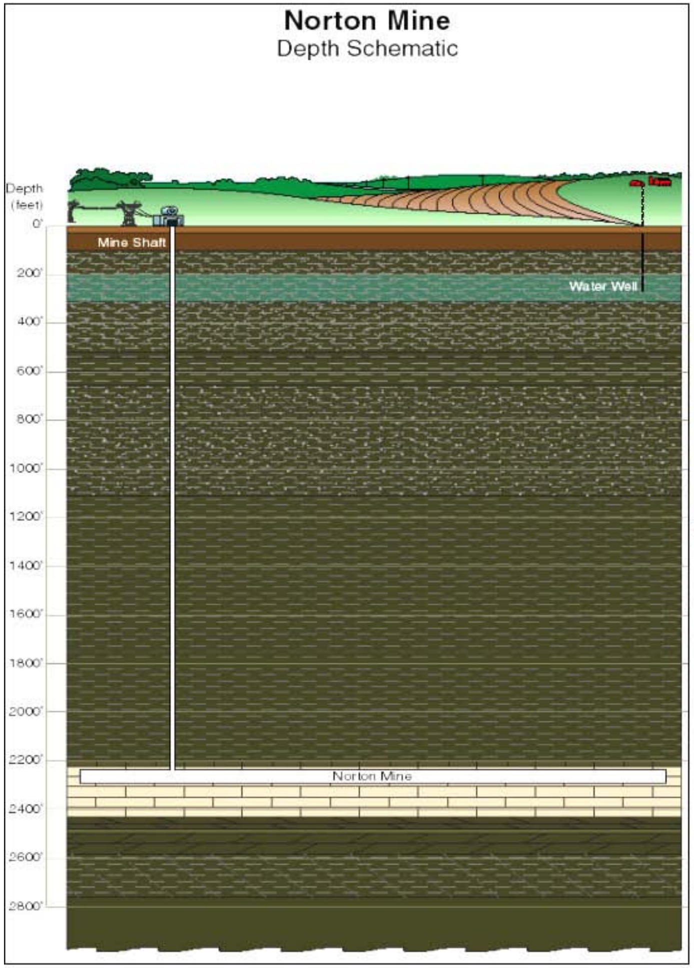
- Private Equity Fund Manager
  - $330 mm under management in Haddington Energy Partners (HEP) I, II, and III
- Specialize in mid stream energy infrastructure– pipelines, gathering, processing, storage, and specialized refining and power – across all hydrocarbons
- Haddington principals founded TPC Corporation in 1984, the largest independent natural gas storage developer in U.S.
  - TPC sold to PacifiCorp in 1997 for $420 mm
- Haddington principals have had extensive prior subsurface project development successes
  - Moss Bluff and Egan Gas Storage (TPC)
  - Lodi Gas Storage (HEP)
  - Bobcat Gas Storage (HEP)
  - Norton Energy Storage (HEP)
  - Magnum Energy Hub (HEP)
- In latest HEP Fund, HEP III sold a 50% interest in Bobcat Gas Storage to GE Energy Financial services. Bobcat (Phase I) is a $300 mm 15.6 BCFW project, with multiple phases thereafter.

Project Location



- The Project is located in the City of Norton, within Summit County, in Northeast Ohio, with the Norton Mine encompassing approximately 92 acres
- The Project Site is approximately 3 miles east of FirstEnergy's Star substation, a major Transmission/Load center
- Norton is located close to MISO/PJM Seam

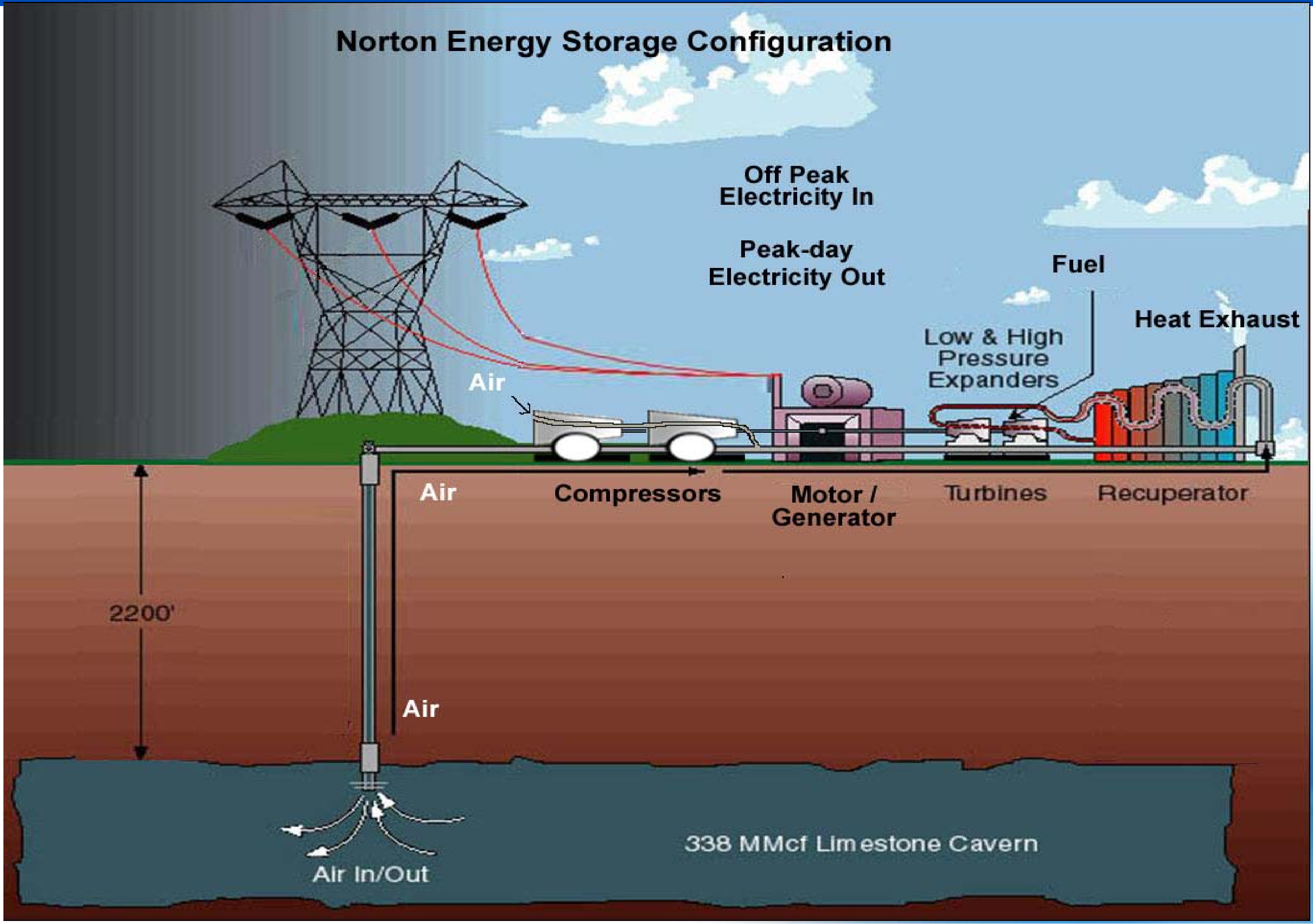
Mine


Norton Mine
Depth Schematic

- Lies 2,200 feet below the surface and covers an area of approximately 540 acres with a total storage volume of 338 million cubic feet and a capability of storing 82 BCF of compressed air

- Developed laterally from the shaft areas using a system of rooms and pillars (rooms were developed at three different heights: 17ft, 28ft and 42ft)

CAES System


Norton Energy Storage Configuration
Off Peak
Electricity In
Peak-day
Electricity Out
Fuel
Heat Exhaust
Low & High
Pressure
Expanders
Air
Air
Compressors
Motor /
Generator
Turbines
Recuperator
2200'
Air
338 MMcf Limestone Cavern
Air In/Out

Norton Energy Storage: Project Example

- Site Evaluation
  - Site acquisition- CDC Searched over 5000 sites and acquired all rights to the surface and subsurface facilities and storage at the Norton project with an available title insurance commitment .
  - Sandia National Laboratory/Hydro Dynamics completed exhaustive underground tests around the suitability of the mine for air storage.
  - Phase I Environmental survey and water and discharge analysis.
  - Mine sealing and air well design.
- Federal, State and Local Authorization
  - FERC jurisdictional order and Ohio Power Sitting Board (OPSB) permit to construct.
  - EPA permits covering full build
  - City and local agreements and permits.
  - Electric transmission access and interconnection agreements.
- Equipment Vendors & Service Agreements
  - Equipment vendor selection
  - Water supply arrangements.
  - Complete facility design and layout (FEED study) and EPC cost estimates.
- Market Study
  - Initial RFP with interested parties
  - Market study

The Evolution of Norton Energy Storage

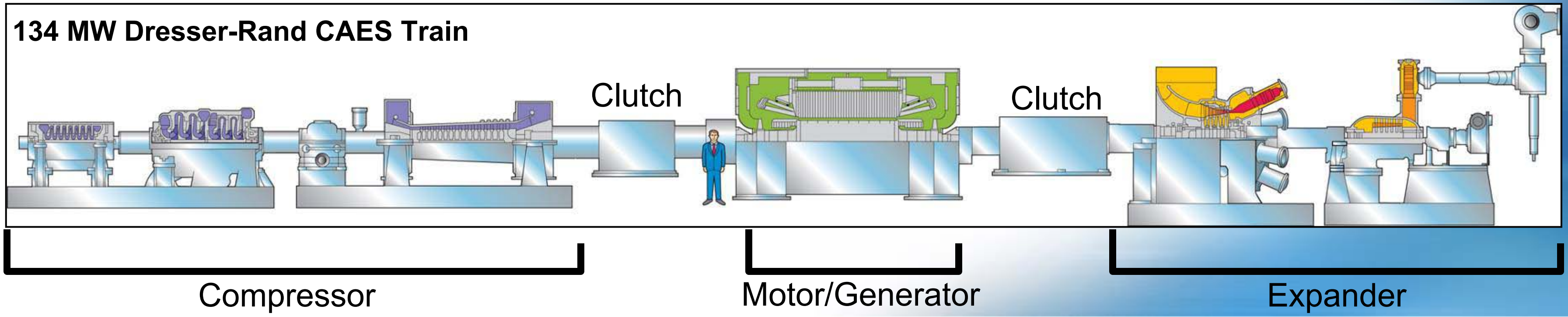
	Role	Date	Status
Haddington Entities	Provided all risk capital, development skills, and subsurface storage expertise.	1999 to present	Remains owner of NES and manages NES development resources.
Alstom	Major generation equipment provider.	2001-2006	Withdrew supply support December, 2006 citing insufficient internal resources
Dresser-Rand	Comprehensive "firm" NES power island proposal submitted March, 2008.	Late 2007 to Present	CEO level support and industry leading knowledge.
MISO	Transparent hourly price market enhances energy storage value.	April 2005 to present	New Ancillary Markets in 2008. New Resource Adequacy requirements in 2009.
Ohio Legislation	Creates renewable mandates and energy storage recognition.	May 2008	Legislation encourages utility investment in new advanced generation and reliability enhancement projects.

Development Progress Update

- Equipment Update
  - Dresser-Rand equipment cost and performance specs are completed.
  - Burns and Roe cost estimate work for balance of plant complete
- Major Permit Update
  - Ohio Power Siting Board (OPSB) construction permit, previously scheduled to expire November 2008, now extended to May 2011
  - URS engaged to file modified Ohio EPA permit; Received September 2008.
- MISO Transmission
  - New interconnection filing complete, granting Norton second Queue position in the Eastern Region of MISO.
  - System Impact Study Agreement and deposit received by MISO, study results expected in early November 2008.
- Market Update: Merchant Value
  - R.W Beck study on intrinsic and extrinsic valuation of Norton complete.
  - Several tolling counterparties interested

Norton Project Design Approach

- Provide all major equipment for power island and compressors through a single vendor (Dresser-Rand) with a single point of responsibility
- Same arrangement and equipment as McIntosh CAES plant
- Major components including expanders and compressors optimized for Norton CAES design
- Economy of shared motor-generator
- Positive locking devices (clutches) provide synchronous condensing option
- Multiple units provide operational flexibility, redundancy for reliability, and facilitate maintenance and repair programs



134 MW Dresser-Rand CAES Train

Norton: A Project for Today's Power Needs

- MISO Needs Flexible Generation
  - Coal unit retrofits are being implemented
    - Decreases coal cycling ability
    - Increases value for regulation service
    - Retirements of old, marginal coal units likely (150-200 MW and less) as 2010-2012 nears
  - "Real" capacity reserve margins in old "ECAR"/MISO are now in single digits
  - Increasing amounts of wind energy will:
    - Depress off-peak prices
    - Complicate grid operations
    - Adversely effect grid stability
- Regulatory Changes are Positive
  - Increased Ohio public policy focus on wind creates need for firming energy storage
    - Ohio has goal of 25% advanced energy by 2025
  - Increased focus on system reliability (through NERC/FERC/RFC)
  - Use of grid for long range transport of energy
- Commodity Markets are More Transparent
  - Wholesale market (MISO) has been operating three years
    - MISO hourly energy prices are now more transparent
    - On-peak/off-peak spreads are dynamic and volatile

New Ohio Energy Bill Legislation

- Senate Bill 221, effective 5/1/2008
  - Norton Energy Storage qualifies as both “advanced energy storage” and “a renewable energy resource,” i.e. NES service meets new Ohio renewable standards
  - Legislation allows utilities to recover PPA/toll for “new build” energy and capacity to be recovered in rates
  - 50% of utility renewable mandate must be supplied by in-state resources, like NES
  - Combined with resource adequacy tariff, SB 221 will help stimulate bilateral toll market in MISO

Skills required to develop CAES

- Project development
  - Site selection
  - Permitting
  - Local public relations
  - Negotiations to secure rights to location
  - State and federal permitting
- Underground
  - Selection of underground formation suitable for air storage
  - Initial evaluation of size and shape, both via power market analysis and geology analysis
  - Geomechanical analysis of cycling and stability
  - Testing and analysis of physical properties of formation
- Power
  - Equipment vendor selection
  - Interconnection of facility to gas and power infrastructure
  - Equipment specification
  - Market analysis for equipment sizing

Options for Utilities on CAES

- Develop CAES assets internally
  - Provides utility full economic benefit and control over the asset
  - Would require addition of staff knowledgeable in underground structures
  - Would divert resources from other capital expenditure projects
  - Introduces development risk to utility
- Observe external development and acquire when initial development risk is mitigated
  - Allows utility to analyze risks when the project is “fully baked”
  - Does not secure utilities’ rights to facility
- Sign long term tolling agreements for assets to support independent developers
  - Provides utility with the economic benefits of the asset without initially exposing the utility balance sheet to development risk
  - Allows utility some input into the design, siting and schedule of the asset
  - May preclude utility from fully monetizing all “extrinsic” value depending on the toll

CAES in The Future

Haddington seeks dialog with utilities as we look to develop CAES assets in other markets and would be interested in working on a toll or development partnership.

Dave Marchese
Vice President
Haddington Ventures
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Houston, TX 77057
www.hvllc.com
713-532-7992
dmarchese@hvllc.com

4.1 Mike Nakhamkin, CAES Technology

Michael Nakhamkin has been a leader in the Compressed Air Energy Storage field for nearly two decades. He has technically supervised all stages of project execution for the 110 MW McIntosh, Alabama CAES plant. He has 16 U.S. patents, 7 of them patents on the various concepts of the CAES technology.
He is the author of 4 books and over 80 publications in industry trade journals including Combined Cycle Journal, Power Engineering and Gas Turbine World. Dr. Nakhamkin has a Ph. D. in Mechanical Engineering from Kaliningrad Marine Industry Institute (1968): Thesis on Combustion Turbine Advanced Thermal Cycles and Transients. He has BS and MS in Mechanical Engineering from Kharkov Polytechnic Institute (1956).

Second Generation of the CAES Technology

Dr. Michael Nakhamkin,

Energy Storage and Power, LLC, Chief Technology Officer

Columbia University, Center for Life Cycle Analysis

Compressed Air Energy Storage Scoping Workshop

October 21st, 2008

Presentation

- The 110 MW CAES Project for Alabama Electric Cooperative:
  - Thermal cycle
  - Operations, Emissions, Maintenance, R&A
  - Lessons learned

- The Second Generation of CAES Plant s:
  - Thermal Cycle
  - Simple Configuration
  - Flexibility for Optimizations , Capacity, Specific Grid Requirements and Economics
  - Uniquely Low Emissions
  - Lower specific costs $/kW
  - Delivered on EPC basis

Energy Storage and Power LLC

Energy Storage
and Power LLC

The 110 MW CAES Project for Alabama Electric Cooperative

CAES Technology Features

CAES technology was developed as a load management plant with the prime purposes:

- To store the off-peak energy that is not needed and inexpensive and to increase load factor of base-load plants (Coal, Nuclear)
- To release this energy during peak hours when energy is needed and the price is high

- The AEC's 110MW CAES Project had been driven by two factors:
  - Due to very low off peak loads, two 300 MW coal-fired plants during off-peak hours operated at very low loads with extremely high heat rates and sometimes had been shot down
  - AEC had shortage of peak power

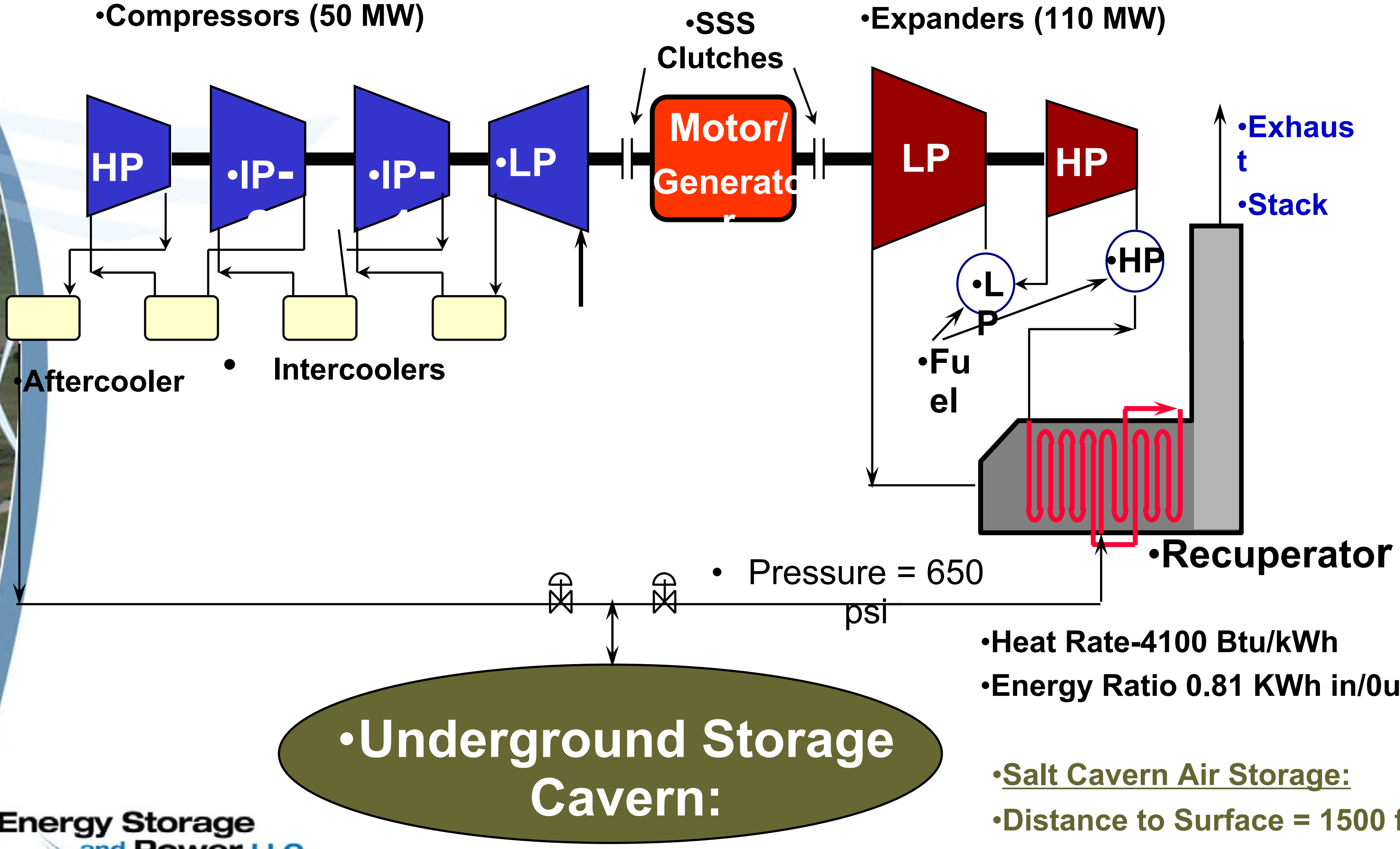
- The current development of Wind Power- the primarily uncontrollable energy source- requires the CAES plants to store wind energy produced during off-peak hours and distribute it with additional benefits during peak hours when energy is needed and cost of energy is high.

Alabama Compressed Air Energy Storage Plant
Peak Power 110 MW; 26 hrs of continuous Power Generation;
Heat rate is 4000 Btu/kWh; Off-Peak Power 51MW, Capital Cost $600/kW

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



- **Heat Rate-4100 Btu/kWh**
- **Energy Ratio 0.81 KWh in/0ut**

- **<u>Salt Cavern Air Storage:</u>**
- **Distance to Surface = 1500 ft**
- **Volume = 22MCF**

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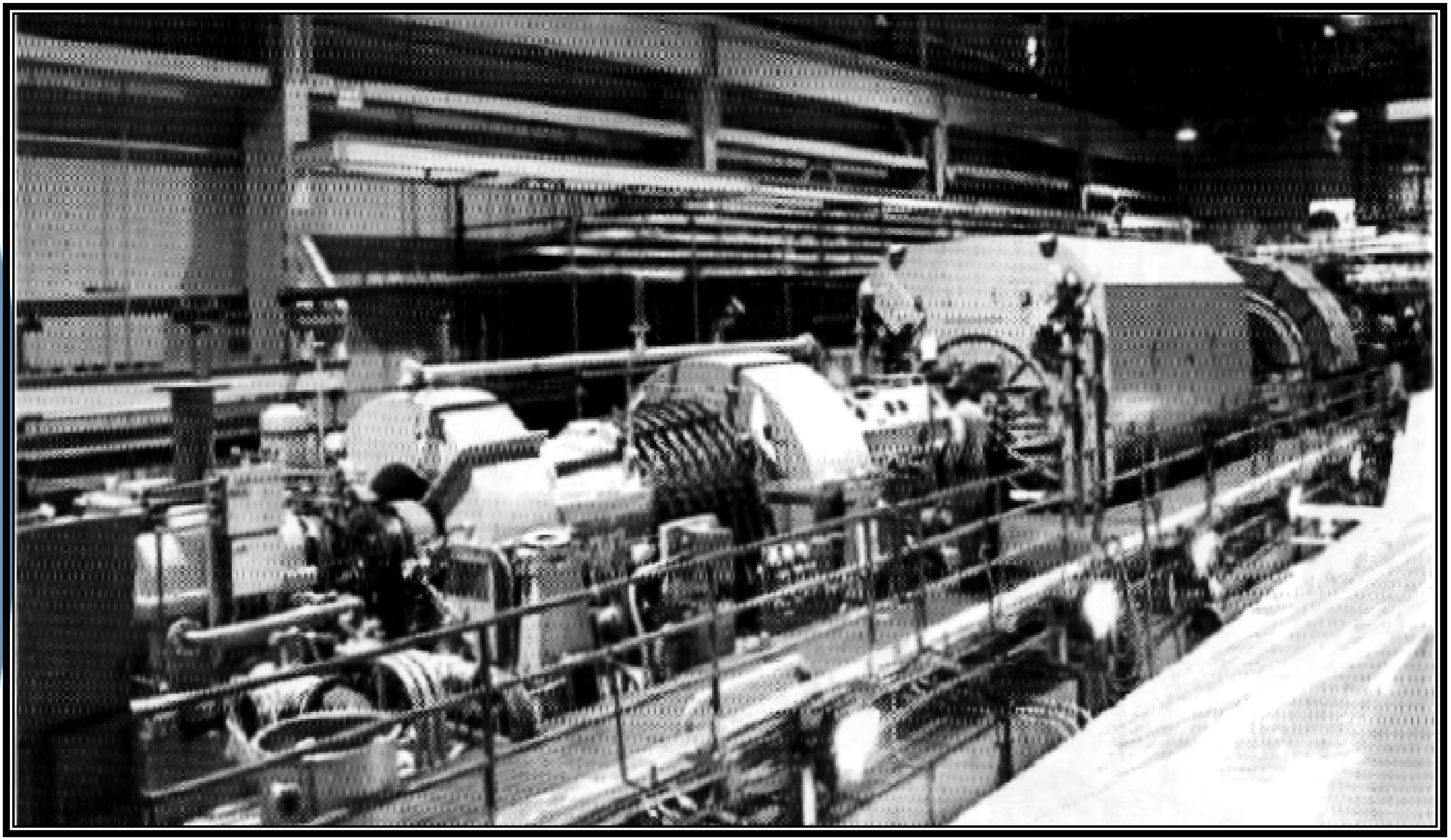
Alabama Electric Cooperative CAES Plant: 110 MW Turbomachinery Hall



- *From Left to Right:*
- *Compressors, Clutch, Motor-Generator and Expansion Turbine*

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EPRI was Co-sponsor of the CAES Project Concentrating on R&D Issues: Turbomachinery, Advanced Recuperator, Project Technical Supervision, the LP Expander TIT Increase

Ground Breaking Ceremony
Dr. R. Schainker, EPRI
Ray Claussen, AEC, VP Operations, Planning
Dr. M. Nakhamkin, ESPC

ESPC Received EPRI's Achievement Award

The 110 MW CAES Plant, Optimization, Engineering, Delivery

ESPC developed, optimized and specified the 110 MW CAES plant based on available and/or newly developed components provided by various suppliers:

The **reheat, intercooled and recuperated turbomachinery** is based on:

- Compressors and expanders provided by **Dresser Rand**
- HP and LP combustors provided by **AIT**
- Advanced Recuperator provided by **Struthers Well (patented by ESPC)**
- Underground Storage by **Parsons Brinkerhoff**
- Control philosophy for operation and Safety

ESPC was conducting technical supervision of the project execution including:

- Supervision of the turbomachinery development by Dresser Rand
- Supervision of the HP combustors development by AIT
- Development of the test procedures
- Supervised performance guarantee tests and issued the Test Report
- Under contract with EPRI, ESPC recorded key plant parameters during 1991-1994 - three years after the project commercialization, and issued “ Value Engineering” Report

The multi-component single-shaft turbomachinery train has the first of the kind unique features and unique components

Thermal Cycle:

- **Reheat expander train with HP/LP combustors**
- **Intercooled Compressor train**
- **Advanced Recuperator**
- **Turbo expander and compressor trains are integrated with the underground storage**
- **Control Philosophy- Power Control by both HP/LP fuel and air flows**

First of the kind Components Engineered for the Specific CAES Plant Application:

Dresser Rand:

  - **HP steam turbine converted into the expander and integrated with the HP combustors**
  - **The industrial expander with increased TIT from 1350F to 1500 F that required the first time applied by DR nozzles cooling**
- **AIT:**
  - **Developed unique HP combustor (800 p.s.i.a and 1000F) uniquely operating at variable airflow**
  - **Newly developed LP combustor (200 p.s.i.a 1600F) uniquely operating at variable airflow**
- **Struthers Wells:**
  - **Advanced Recuperator**

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Lessons Learned

Summarized in the published by EPRI's "Value Engineering" report (produced by ESPC)

The 110 ME CAES project is unquestionably successful- It met all performance guarantees, schedule and budget.

There are lessons learned:

The single-shaft turbomachinery train with multiple (9) components has the following deficiencies/complications:

- **No flexibility for specific compressors and expanders power requirements**
- **Operational and maintenance complications**
- **Restrictions for the plant optimizations for specific grid and economic requirements and specific underground storage parameters**

Conclusions: the separate components approach would provide operational and maintenance advantages and the plant optimization flexibilities

The CASES plant is a complicated Combustion Turbine and suppliers of major components had very limited power generation experience and had no operational and maintenance manuals for this specifically operating turbomachinery train.

Conclusions: Utilization of off-shelf /standard components operating within a typical range of operations will resolve this issues.

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Lessons Learned

Summarized in the published by EPRI's "Value Engineering" report (produced by ESPC)

The novel HP/LP combustors:

- Newly developed HP/LP combustors had no operational and maintenance experience, manuals based on experience
- The HP combustor has inherently very high NOx emissions (app. 70 p.p.m.v.)
- The LP combustor is customized for this train and has higher than CTs NOx emissions
- HP combustors limiting the storage parameters

Conclusions:

- **Novel HP/LP combustors should be avoided**
- **It is better to burn fuel in DLN combustors developed by OEMs**

Single compressor and expander trains have significant limitation s as it relates to optimization of the energy storage and power generation cycles.

Conclusions: Multiple compressors and expanders provide operational and maintenance advantages

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Second generation CAES Plants is Capitalizing on AEC Project Experience and Lessons Learned

Simplicity, Reliability, Flexibility for Meeting Specific Power and Operating Requirements and Underground Storage Specifics

Power is generated by:

- a stand alone combustion turbine and
- stand-alone standard expanders operating w/o combustors and utilizing the CT exhaust gas heat - the air bottoming cycle (similar to steam bottoming cycle for CC plants)

The storage is pressurized by multiple stand-alone off-shelf motor driven compressors

The fuel is burned only in CT’s DLN combustors (there is no additional fuel burners/combustors)

Every components is operating within a typical range

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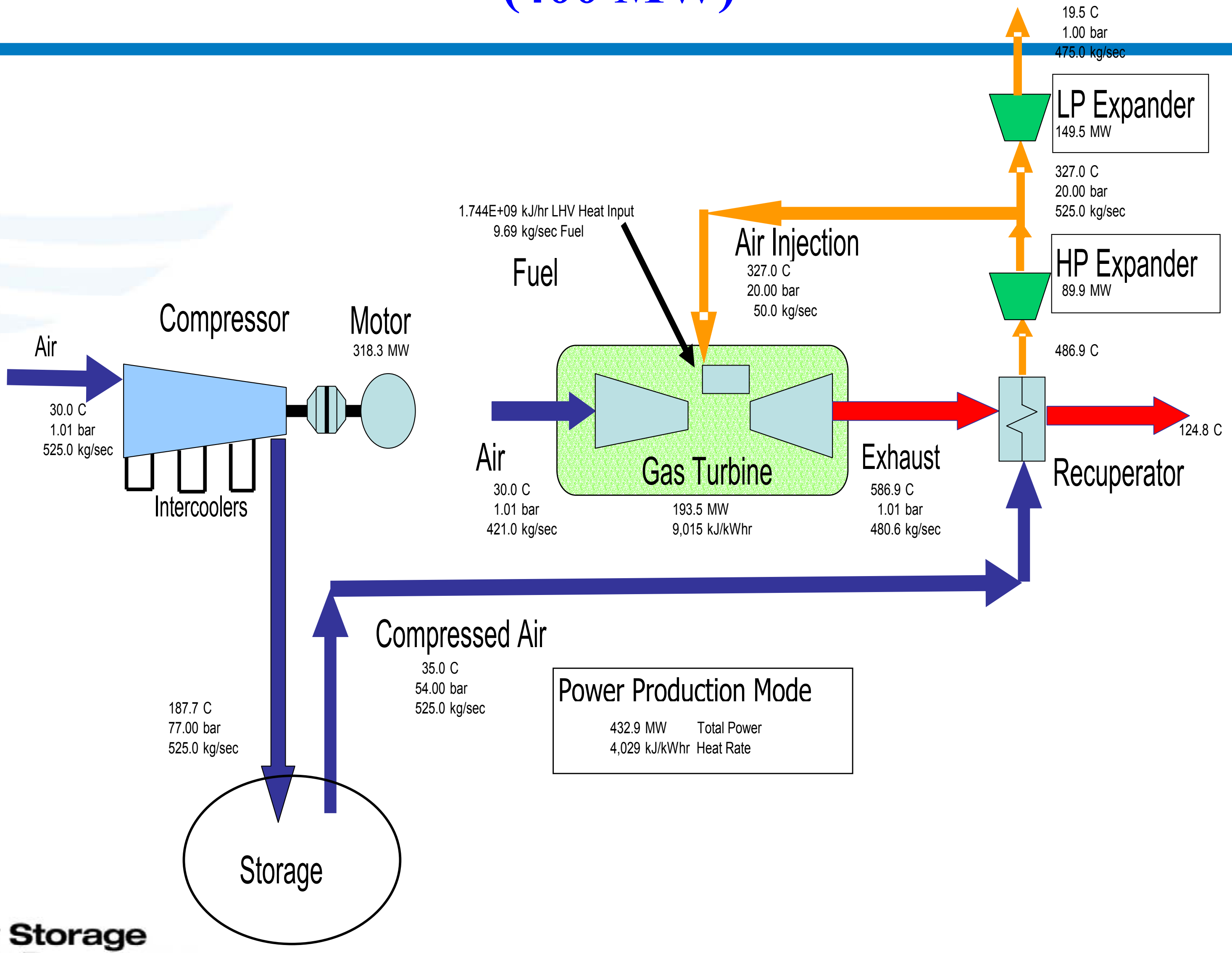
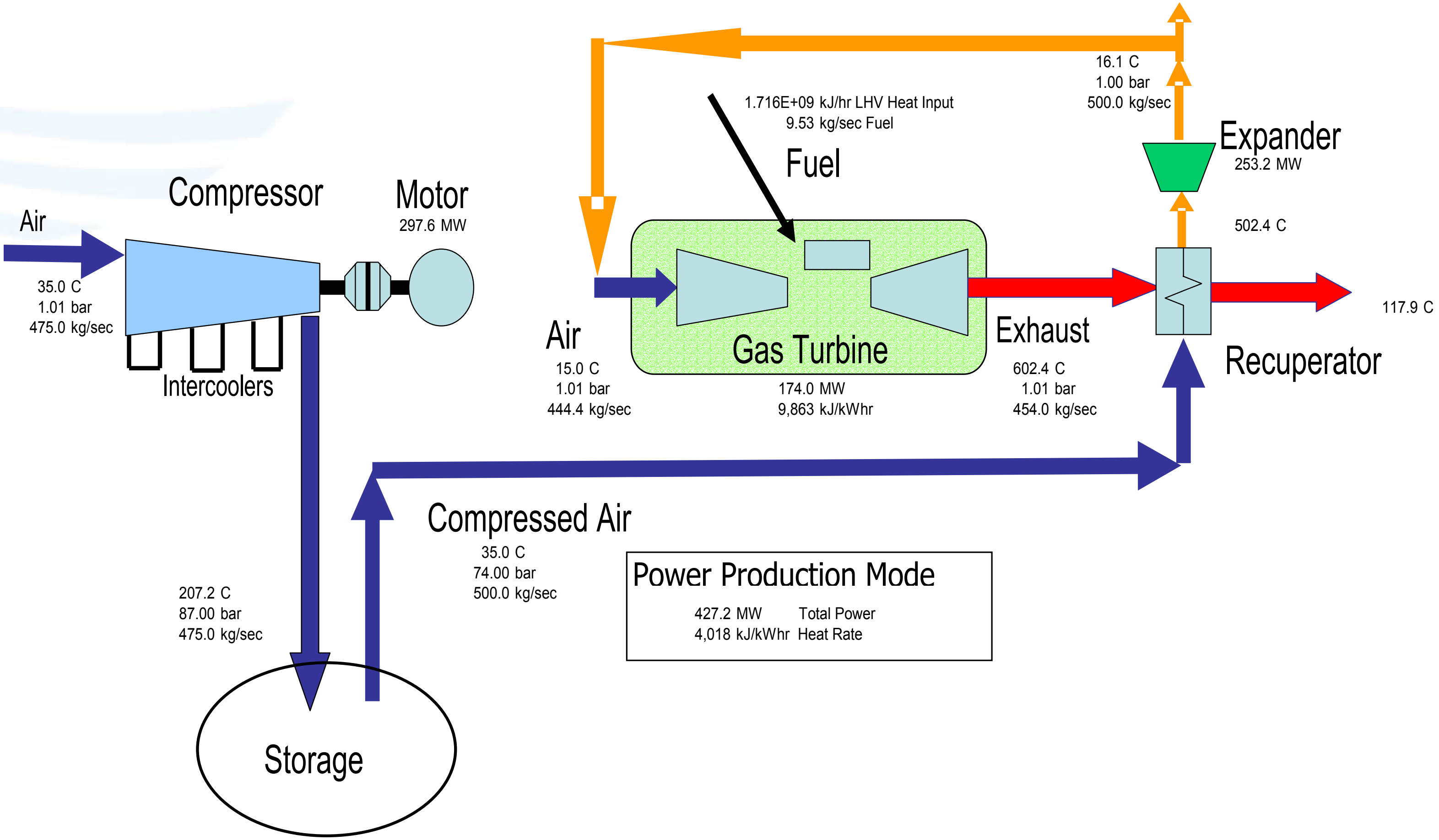
CAES Plant Concept Based on GE 7241with CT Power Augmentation w. Air injection and Bottoming Cycle Expanders (400 MW)



Energy Storage and Power LLC

CAES Plant Based on GE 7241 with Bottoming Cycle Expanders and the CT Power Augmentation by Inlet Chilling (400 MW)

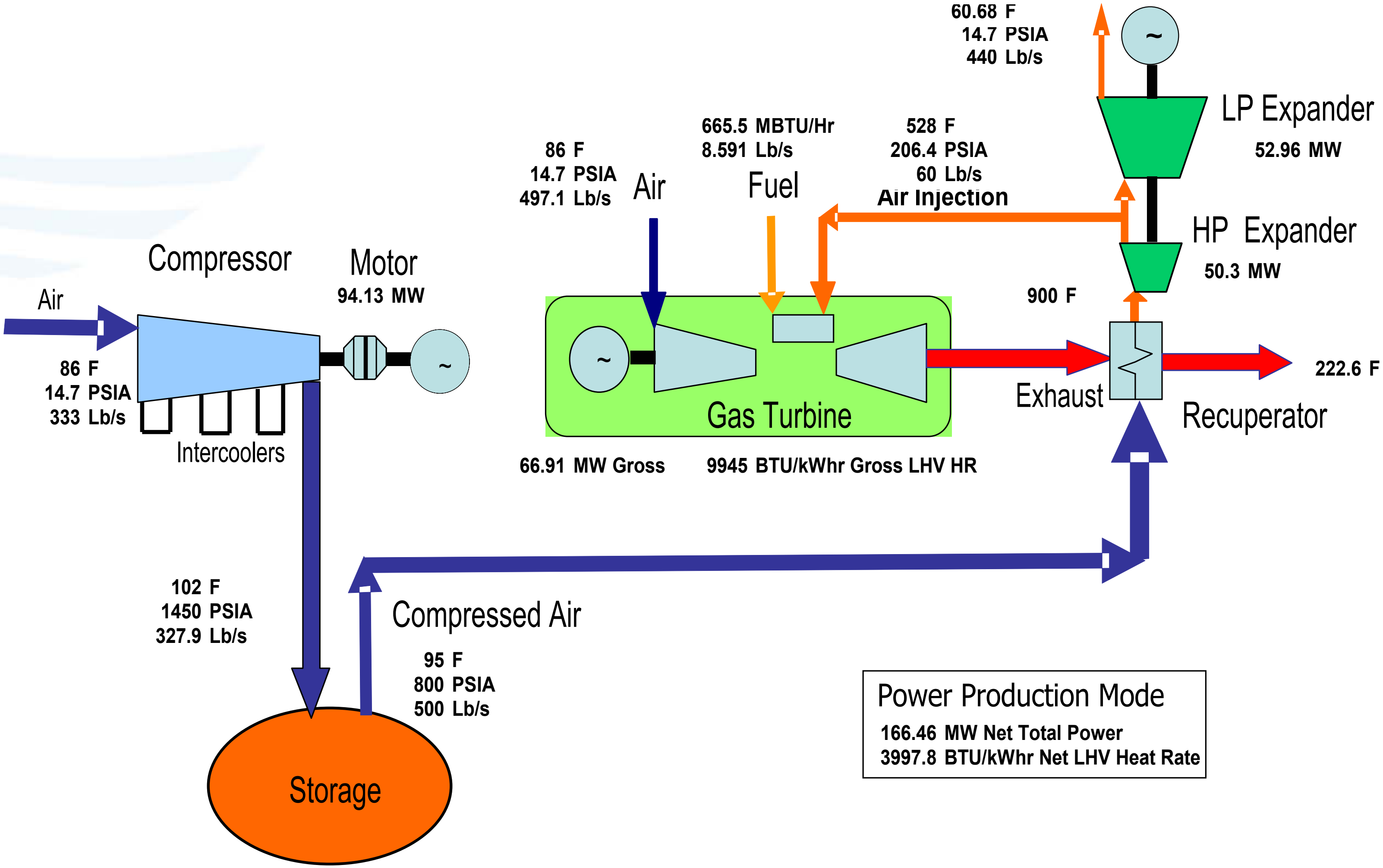


Power Production Mode

427.2 MW Total Power
4,018 kJ/kWhr Heat Rate

Energy Storage and Power LLC

CAES Plant Concept Based on GE 7B with CT Power Augmentation w. AI and Bottoming Cycle Expanders (160MW)



60.68 F
14.7 PSIA
440 Lb/s

LP Expander
52.96 MW

665.5 MBTU/Hr
8.591 Lb/s

528 F
206.4 PSIA
60 Lb/s
Air Injection

86 F
14.7 PSIA
497.1 Lb/s

Air

Fuel

HP Expander
50.3 MW

Compressor

Motor
94.13 MW

Air

86 F
14.7 PSIA
333 Lb/s

Intercoolers

900 F

Gas Turbine

Exhaust

222.6 F

Recuperator

66.91 MW Gross

9945 BTU/kWhr Gross LHV HR

102 F
1450 PSIA
327.9 Lb/s

Compressed Air

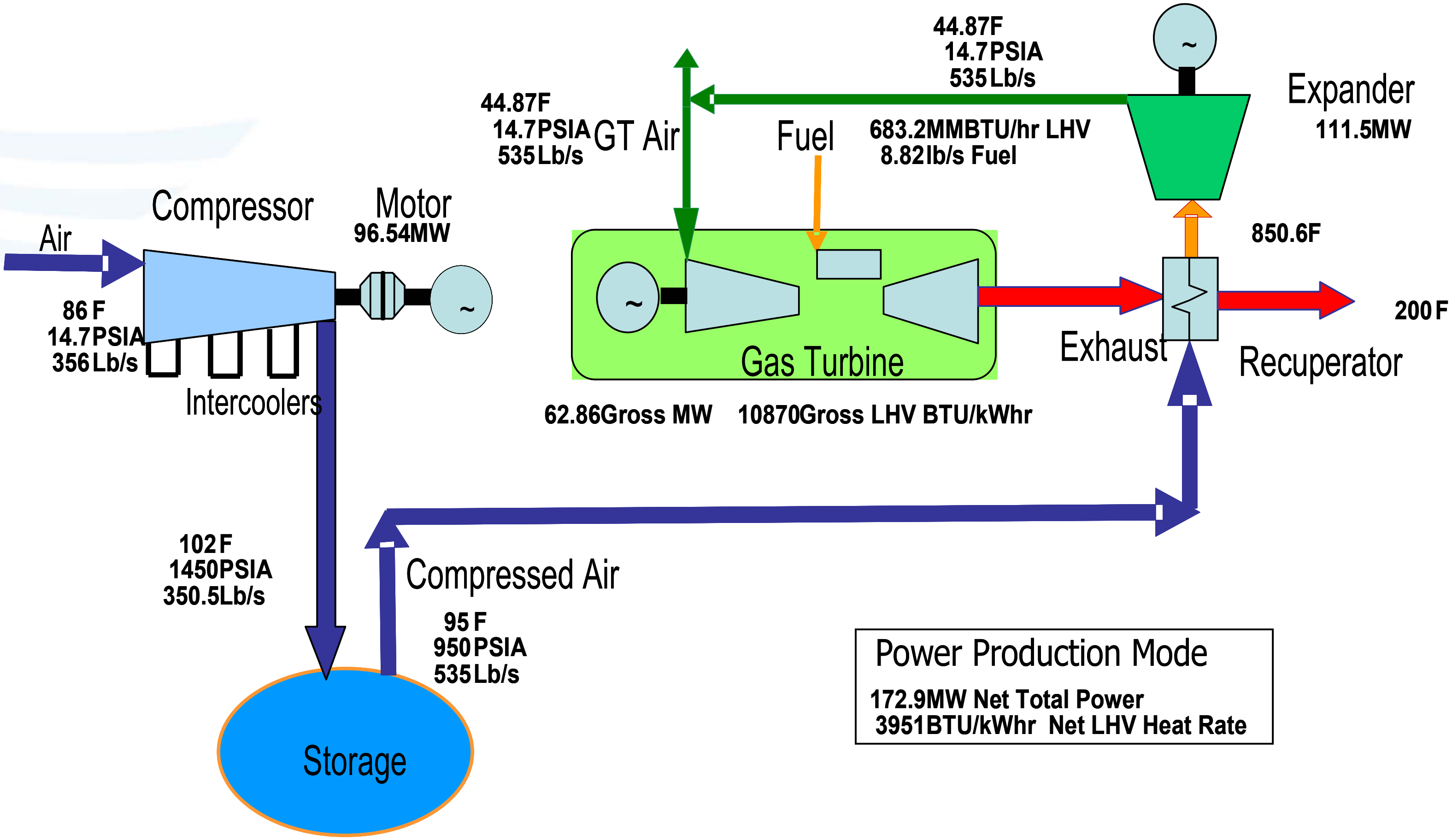
95 F
800 PSIA
500 Lb/s

Storage

Power Production Mode
166.46 MW Net Total Power
3997.8 BTU/kWhr Net LHV Heat Rate

Energy Storage and Power LLC

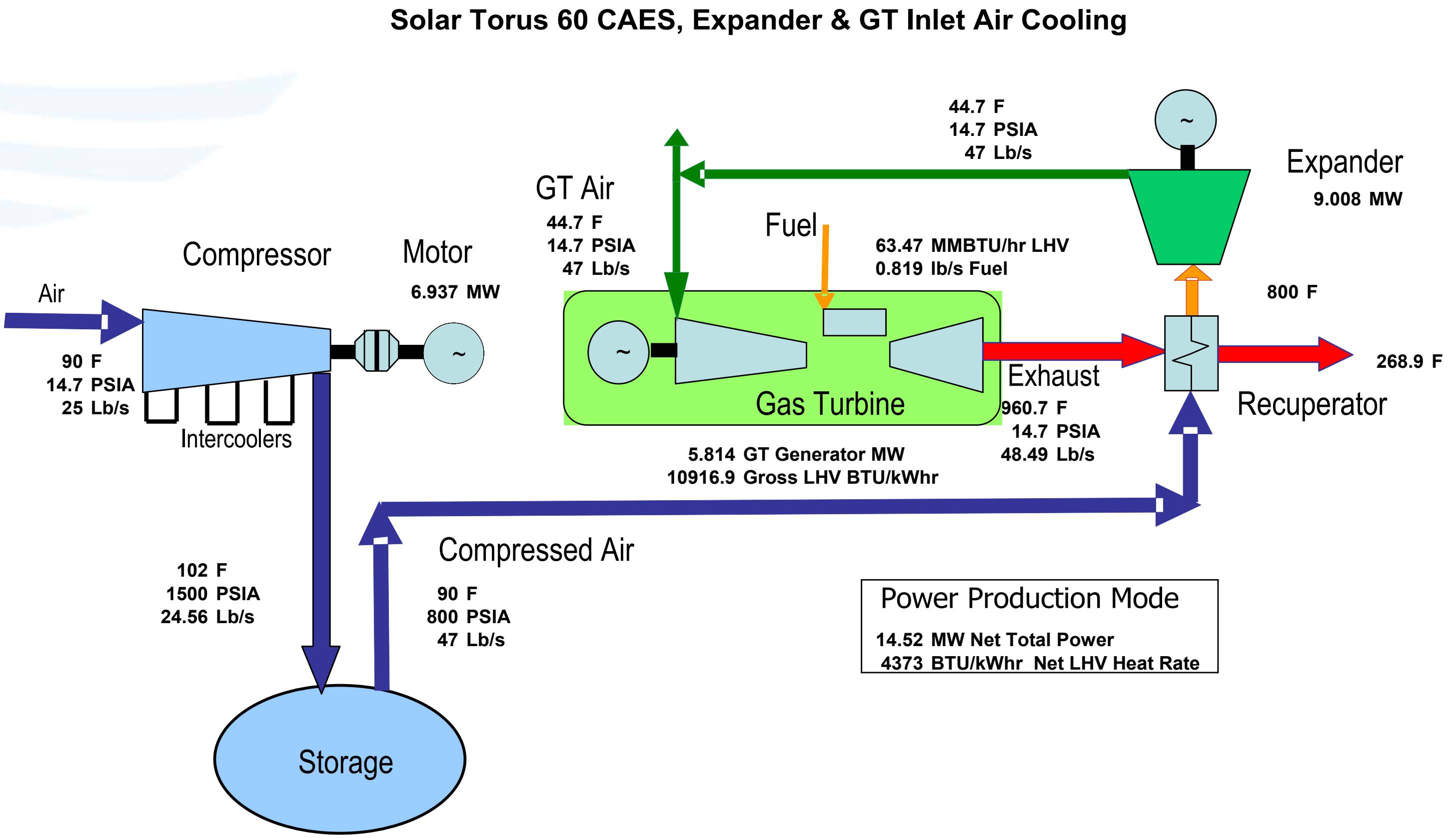
CAES Plant Based on GE 7B with Bottoming Cycle Expanders and the CT Power Augmentation by Inlet Chilling (160 MW)



Power Production Mode

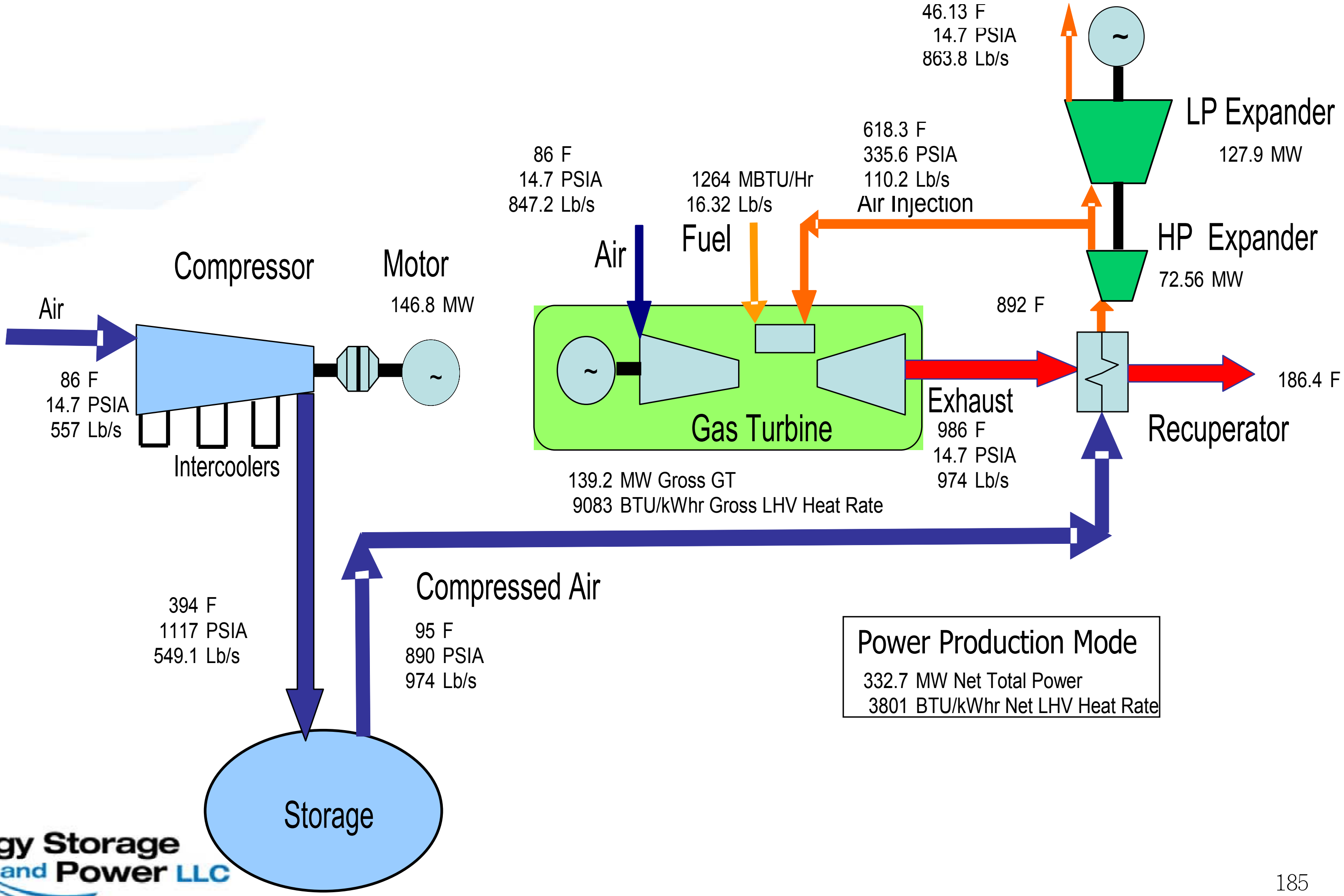
172.9MW Net Total Power
3951BTU/kWhr Net LHV Heat Rate

CAES Plant Based on Taurus 60 with Bottoming Cycle Expanders and CT Power Augmentation w. Inlet Chilling (15MW)



Energy Storage and Power LLC

CAES Plant Concept Based on GE 9171E with CT Power Augmentation w. Air injection and Bottoming Cycle Expanders (300 MW)

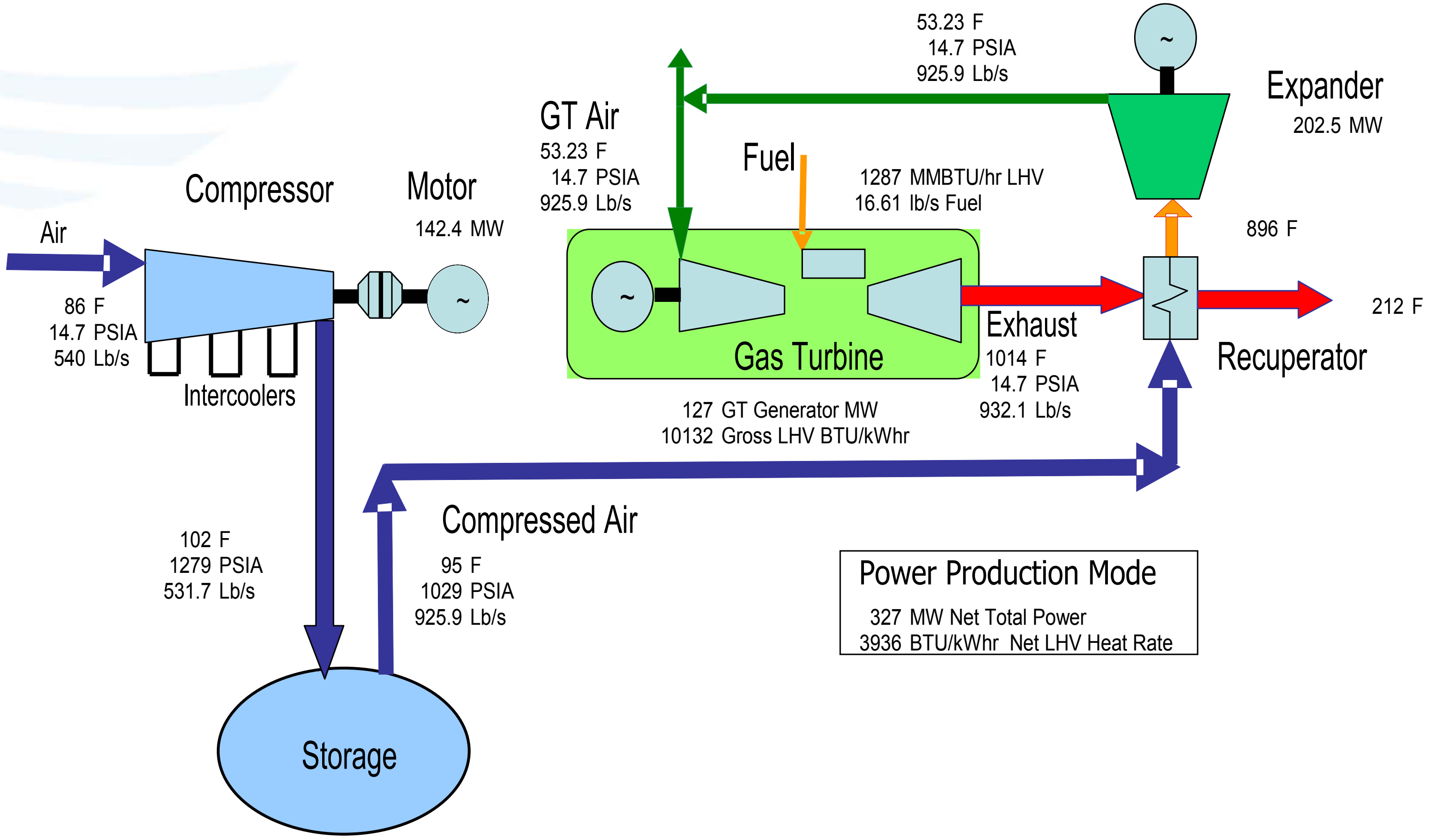


Power Production Mode

332.7 MW Net Total Power
3801 BTU/kWhr Net LHV Heat Rate

Energy Storage and Power LLC

CAES Plant Based on GE9171E CTwith Bottoming Cycle Expanders and CT Power Augmentation w. Inlet Chilling (300MW)



Power Production Mode

327 MW Net Total Power
3936 BTU/kWhr Net LHV Heat Rate

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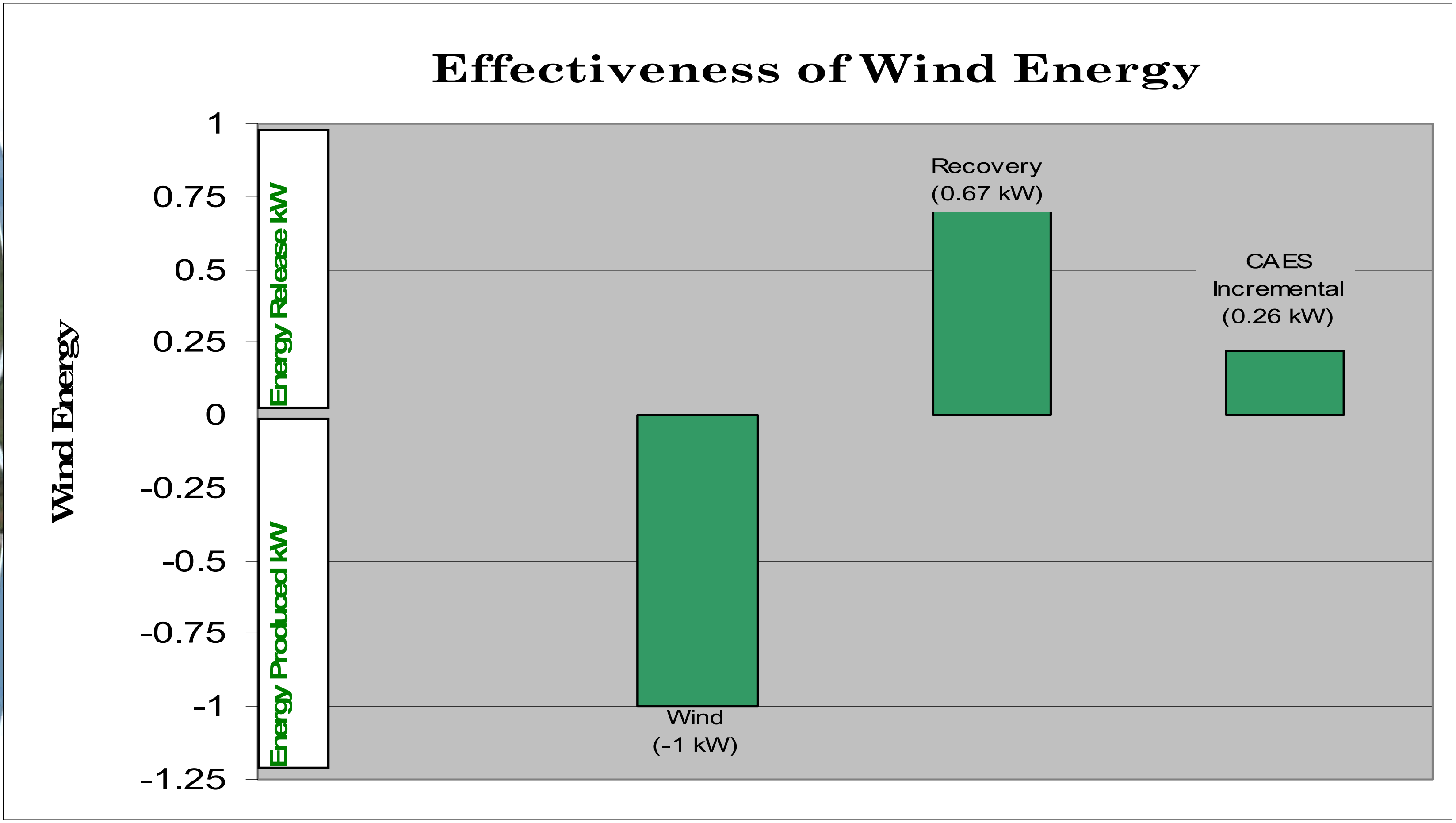
1 kWh of Stored Off-peak Energy Returns over 0.9 kWh of Peak Energy



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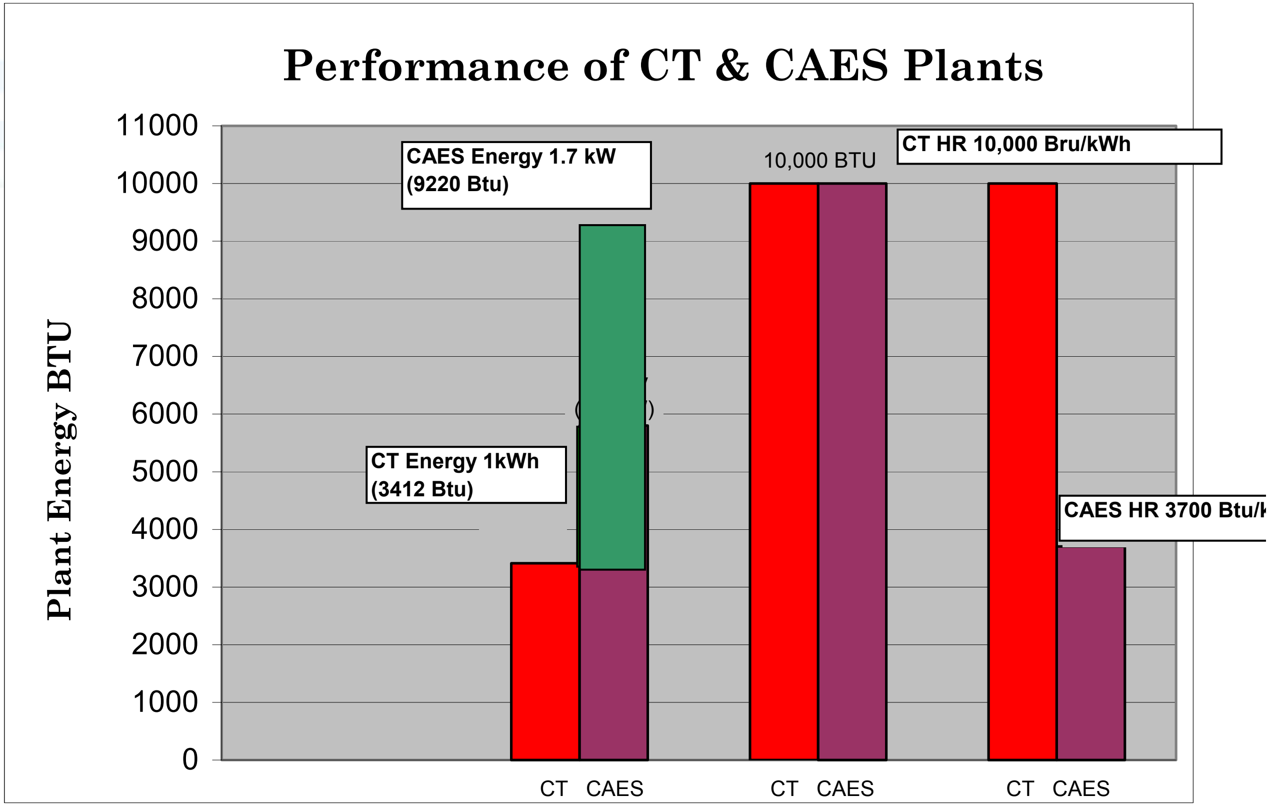
CAES Plant Power consist of 1.kW of CT Power and 1.7kW Green Power



Energy Storage and Power LLC

Second generation CAES Plants is Capitalizing on AEC Project Experience and Lessons Learned

Power is generated by:

- Combustion turbine w. Power Augmentation and
- Green Power Generated by Expanders operating w/o combustors and utilizing the CT exhaust gas heat - the air bottoming cycle (similar to steam bottoming cycle for CC plants)

The fuel is burned only in CT's DLN combustors (there is no additional fuel burners/combustors)

Emissions- CT low Emissions are Diluted by Additional Green Power

The storage is pressurized by multiple off-shelf motor driven compressors

Every components is operating within a typical design range

Flexibility to optimize the CAES plant for specific grid conditions, power requirements economics and underground storage specifics

Significantly lower capital costs and Better operations

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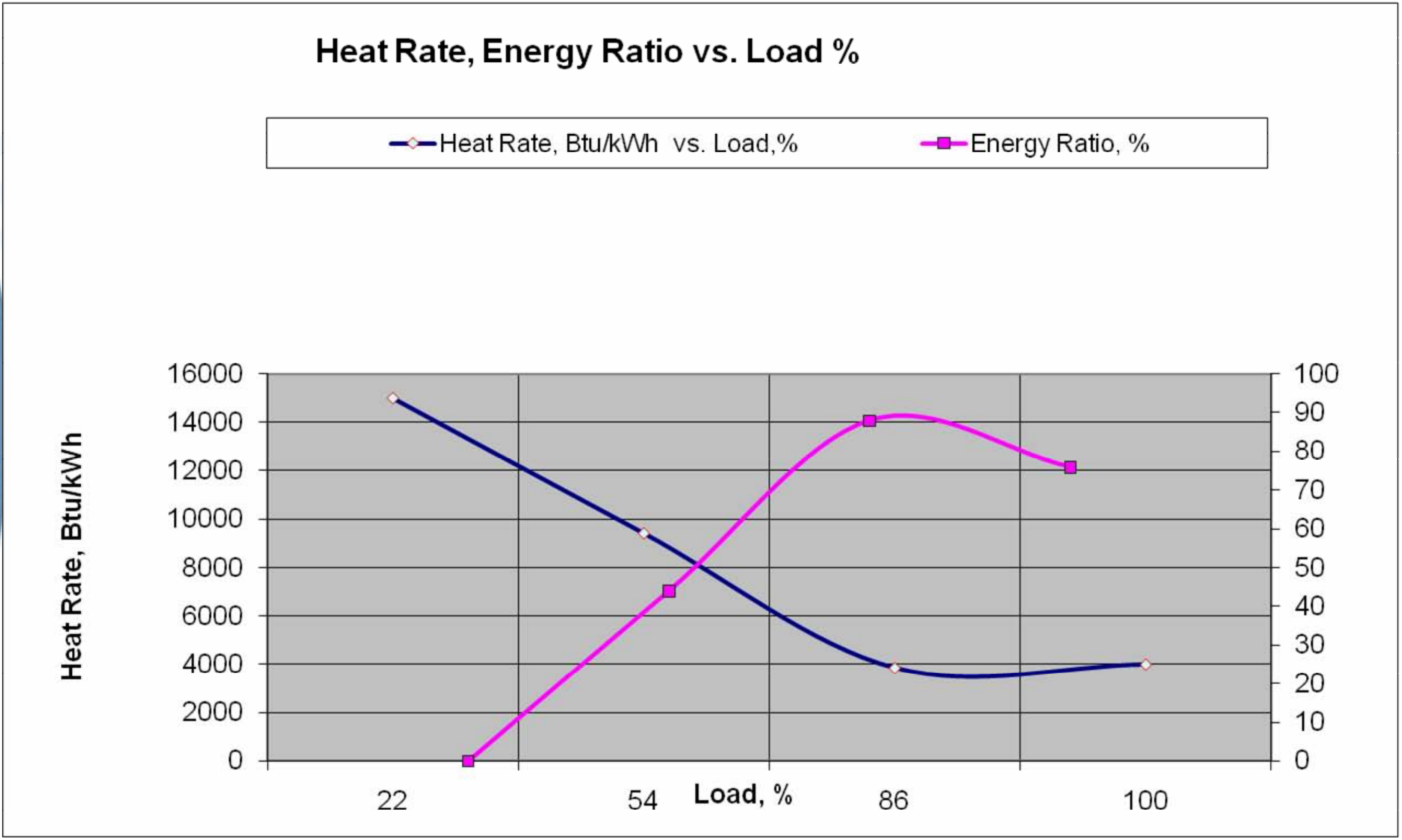
Heat rate and Energy Ratio at Part load Operations



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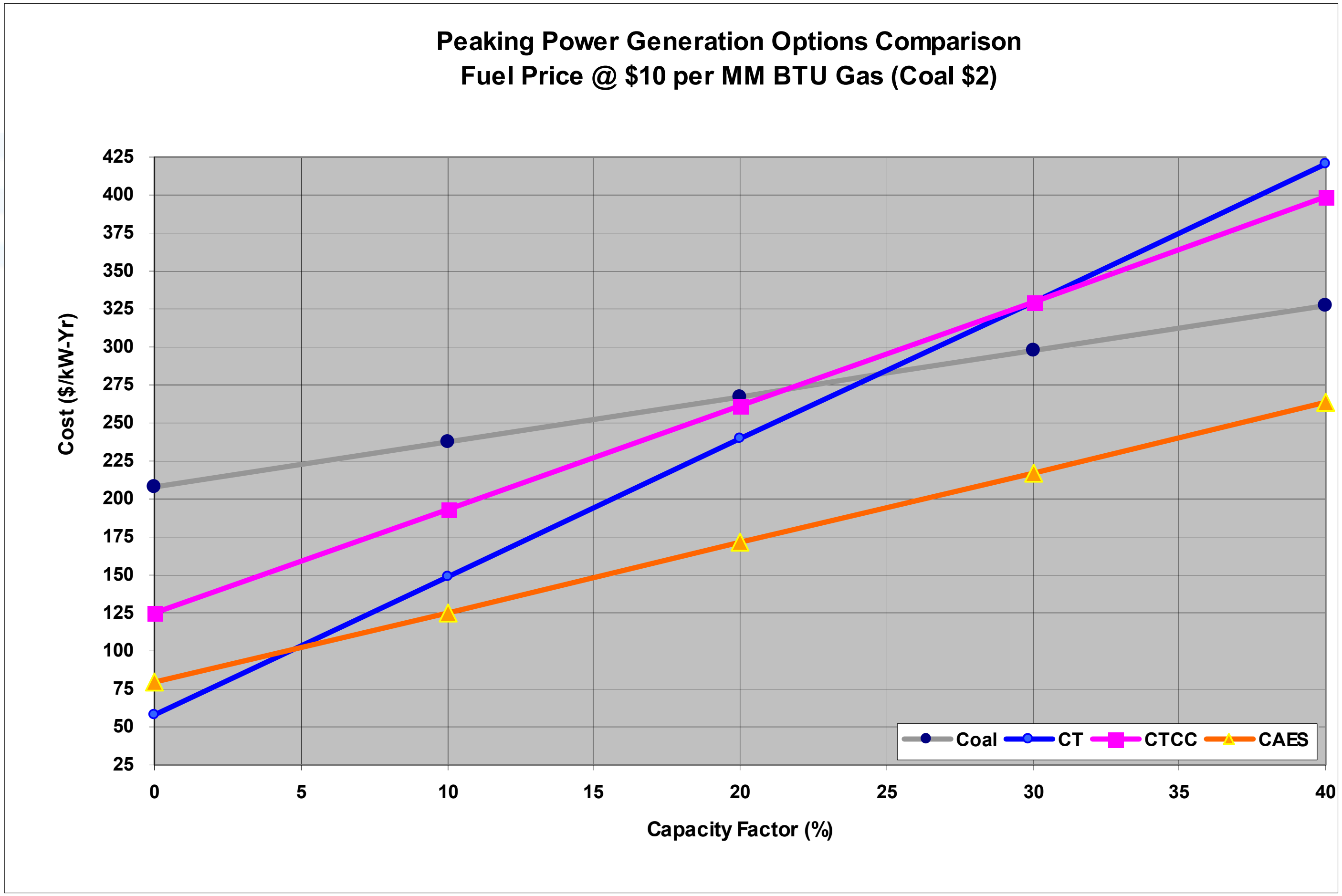
Comparative Analysis of Generation Costs for Coal. CT, CC and CAES plants



Energy Storage and Power LLC

ES&P with its subcontractors is delivering CAES projects on EPC basis. Estimated specific costs of the overall project including underground storage is approximately $750-800/kW. Delivery time is approximately 30 months, primarily controlled by a combustion turbine delivery

These concepts are based on various combinations of the major standard /off – shelf components-existing or new combustion turbines, air compressors, air expanders and heat recovery recuperator –all integrated with a compressed air storage and engineered for specific operational, economic and geological conditions.

As it relates to the selection of a combustion turbine, customers have a choice of selection a combustion turbine based on their preferences and ESPC will design/engineer the CAES Plant based on the selected combustion turbine. These h&m balances are based on GE7FA, GE 7EA and GE 7B CTs for 400 MW, 300 MW and 150 CAES plants respectively

Suppliers of Off-Combustion Turbine standard components include but not limited to:

Air Compressors: MAN Turbo, Dresser-Rand, and Ingersoll-Rand

Turbo-Expanders: Major OEM’s with IP back pressure steam turbine technology; MAN Turbo, Skoda, Atlas Copco, and Hitachi

Recuperator: RGP Engineering, Nooter/Eriksen, Deltech, and BHEL

ESPC has a number of qualified EPC contractors for delivery of CAES projects with typical warranties and guaranties and with typical commercial terms.

4.2 Harry Miller, Dresser-Rand Compressor Technology

Harry Miller is the Product Manager in Marketing of Turbo Products at Dresser-Rand. His career in turbomachinery began 33 years ago with Dresser Clark, and he has held a variety of Design Engineering and Marketing positions, most recently, being Manager of Development Engineering and Leader of the DATUM Development Team. His has also worked as a mechanical construction engineer for the Pennsylvania Power & Light Company. He has a B.S.M.E. from Northeastern University, and a M.B.A. degree from Lehigh University. His areas of expertise include turbo compressor and gas turbine design and application. He has authored several technical papers and contributed to several patents.

McIntosh CAES Experience NYSERDA - Columbia University Compressed Air Energy Workshop

Phil Hoffmann, Harry Miller, Jason Kerth

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Safe Harbor Disclosure

Some of the information contained in this document contains "forward-looking statements". In many cases, you can identify forward-looking statements by terminology such as "may," "will," "should," "expects," "plans," "anticipates," "believes," "estimates," "predicts," "potential," or "continue," or the negative of such terms and other comparable terminology. These forward-looking statements are only predictions and as such inherently included risks and uncertainties. Actual events or results may differ materially as a result of risks facing Dresser-Rand Company (D-R) or actual results differing from the assumptions underlying such statements. These forward-looking statements are made only as of the date of this presentation, and D-R undertakes no obligation to update or revise the forward-looking statements, whether as a result of new information, future events or otherwise. All forward-looking statements are expressly qualified in their entirety by the "Risk Factors" and other cautionary statements included in D-R's annual, quarterly and special reports, proxy statements and other public filings with the Securities and Exchange Commission and other factors not known to D-R. Your decision to remain and receive the information about to be presented to you shall constitute your unconditional acceptance to the foregoing.

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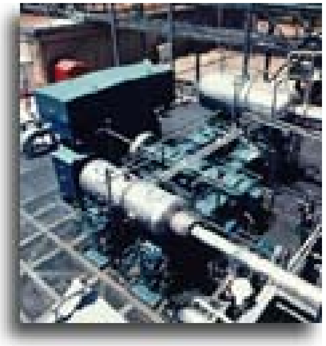
Safety Moment



- A Dresser-Rand Safety Moment...

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McIntosh CAES Plant Experience

- Commercial Operation – May, 1991
- Generation
  - 10,840 hours – 97% running reliability
  - 3,520 starts – 95% starting reliability
- Compression
  - 11,513 hours – 100% running reliability
  - 2,118 starts – 96% starting reliability

Over ½ million MW-Hrs of production

Customer continues to be pleased with the equipment and support provided by Dresser-Rand

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D-R CAES Design Approach

- McIntosh works well – don’t reinvent the wheel! That’s what our customers want.
- Make use of evolving product technologies to improve performance & reliability
  - Incorporate McIntosh lessons learned
  - DATUM compressors
  - Stronger blade materials
  - Improved controls technology
- Accept total responsibility for “power island” equipment to assure satisfactory interfaces and performance.

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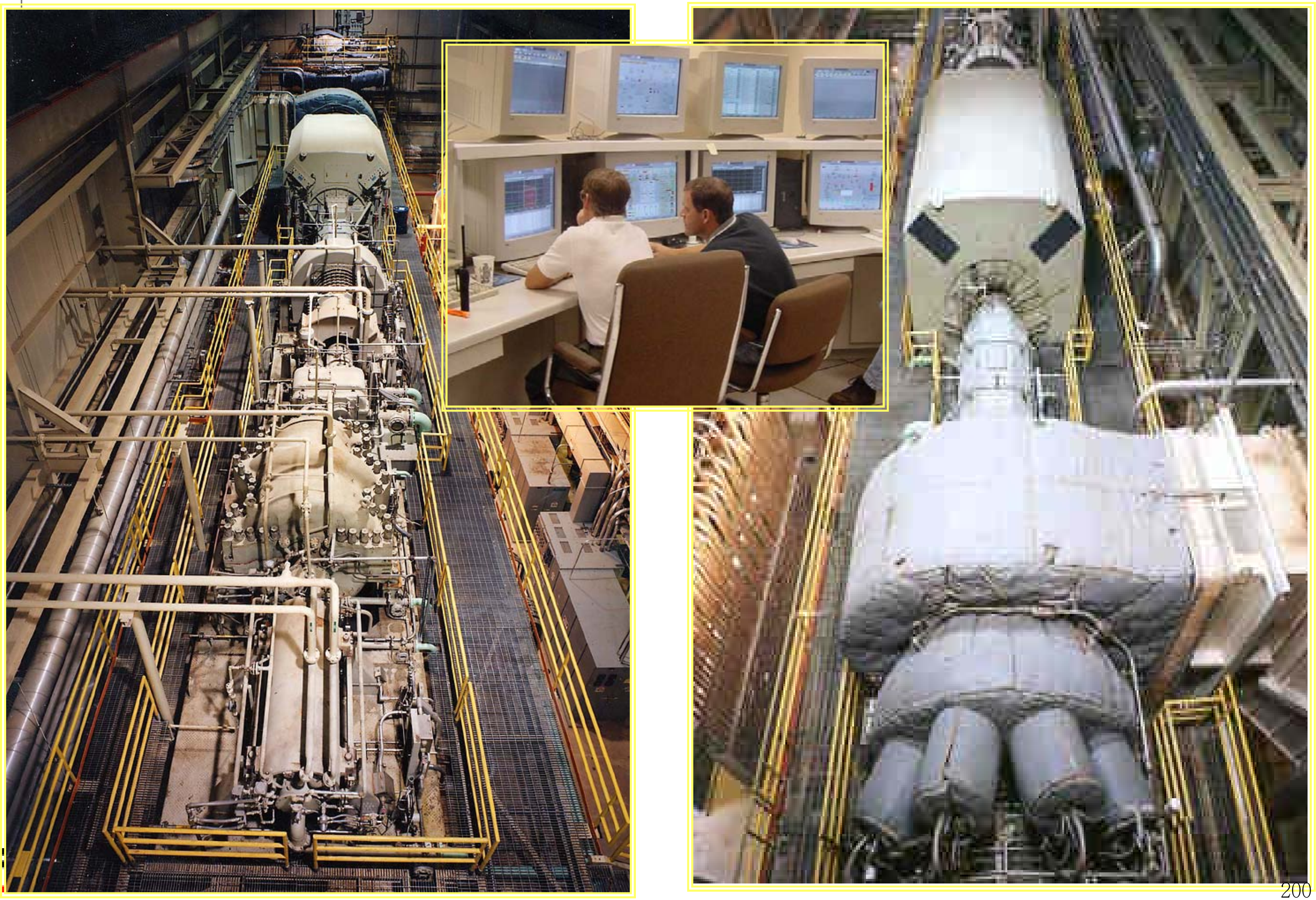
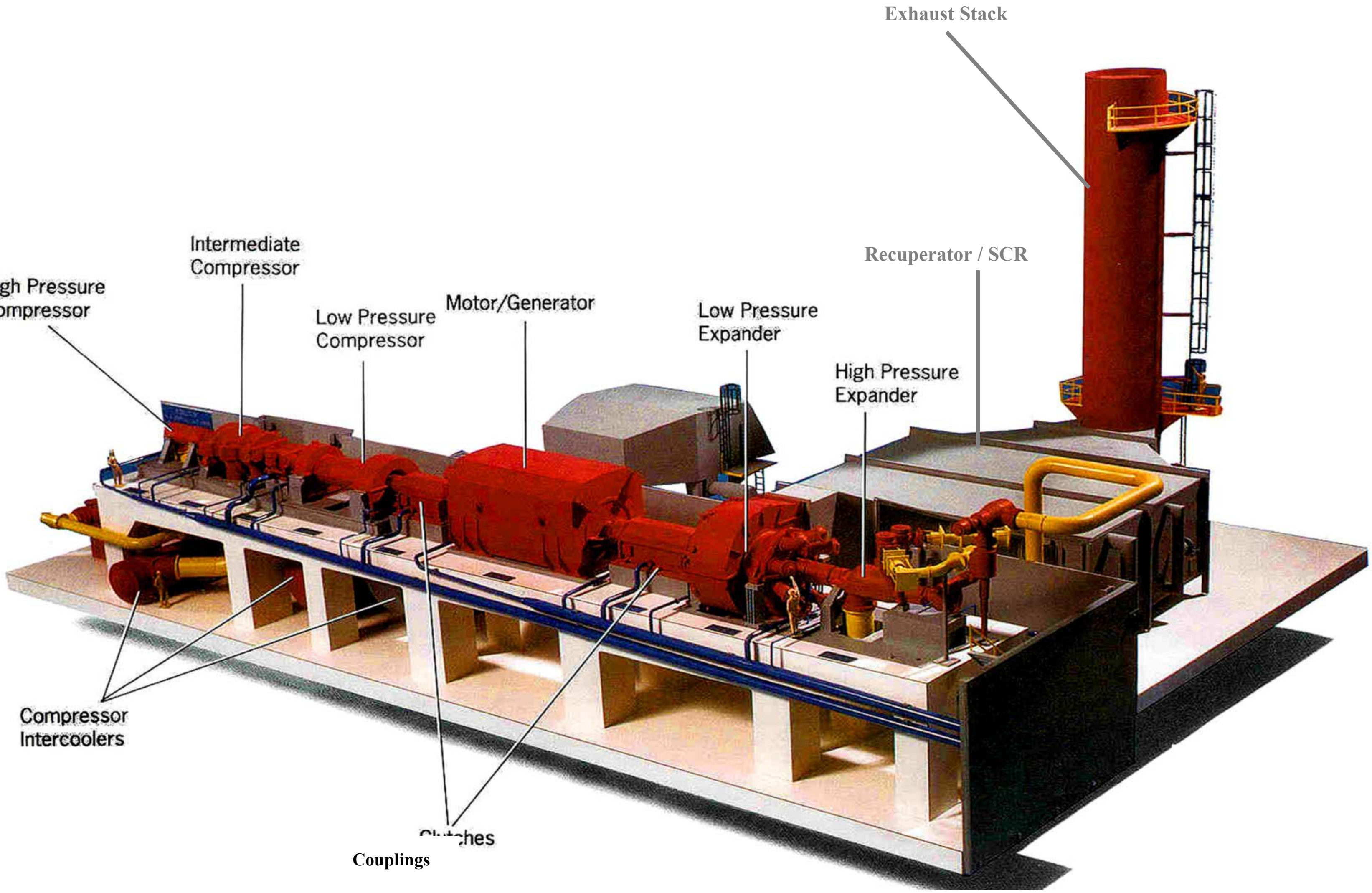
McIntosh CAES Installation



Single Train Arrangement



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Single Train Arrangement

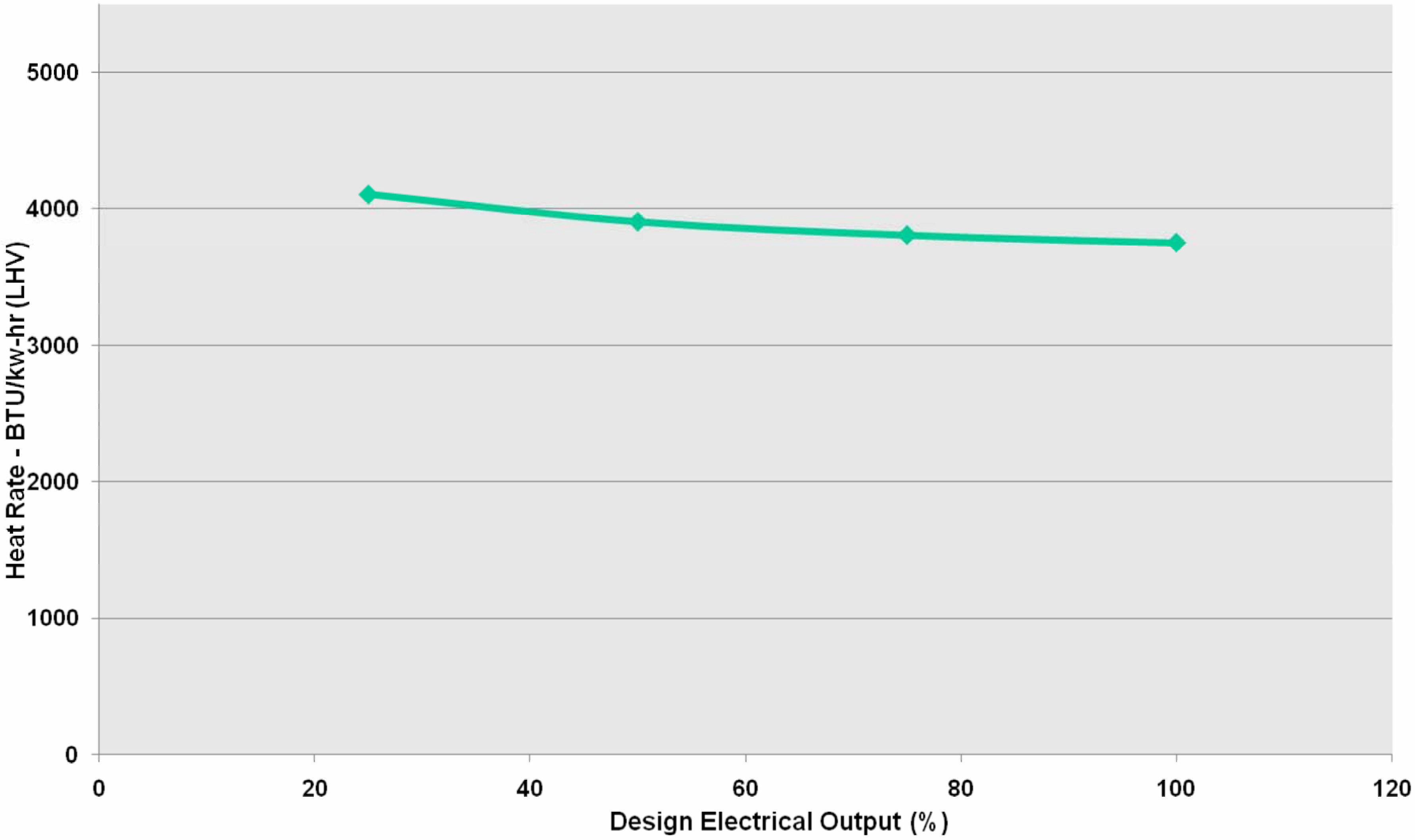
- Compact arrangement of machinery and auxiliaries. Minimizes plot space requirements
- Modular design using existing turbo-machinery frames to meet specific requirements.
- Less investment in electrical infrastructure (transformers, switchyards, protective relays, etc)
- Fast start, excellent load following and turn down characteristics

Turbine Inlet Temperature & CAES

- Conventional CT's compress air using expensive fuel so reducing Specific Air Consumption by increasing TIT is important for cycle cost efficiency
- CAES uses less expensive off-peak power for compression so the TIT needed for the most cost efficient cycle results from the integration of expected fuel & charging electricity costs
- D-R solution – 1,600° F TIT
  - Acceptable heat rate & specific air consumption
  - Lowest life cycle cost

Dresser-Rand CAES Heat Rate vs. Load

85% Eff Recuperator



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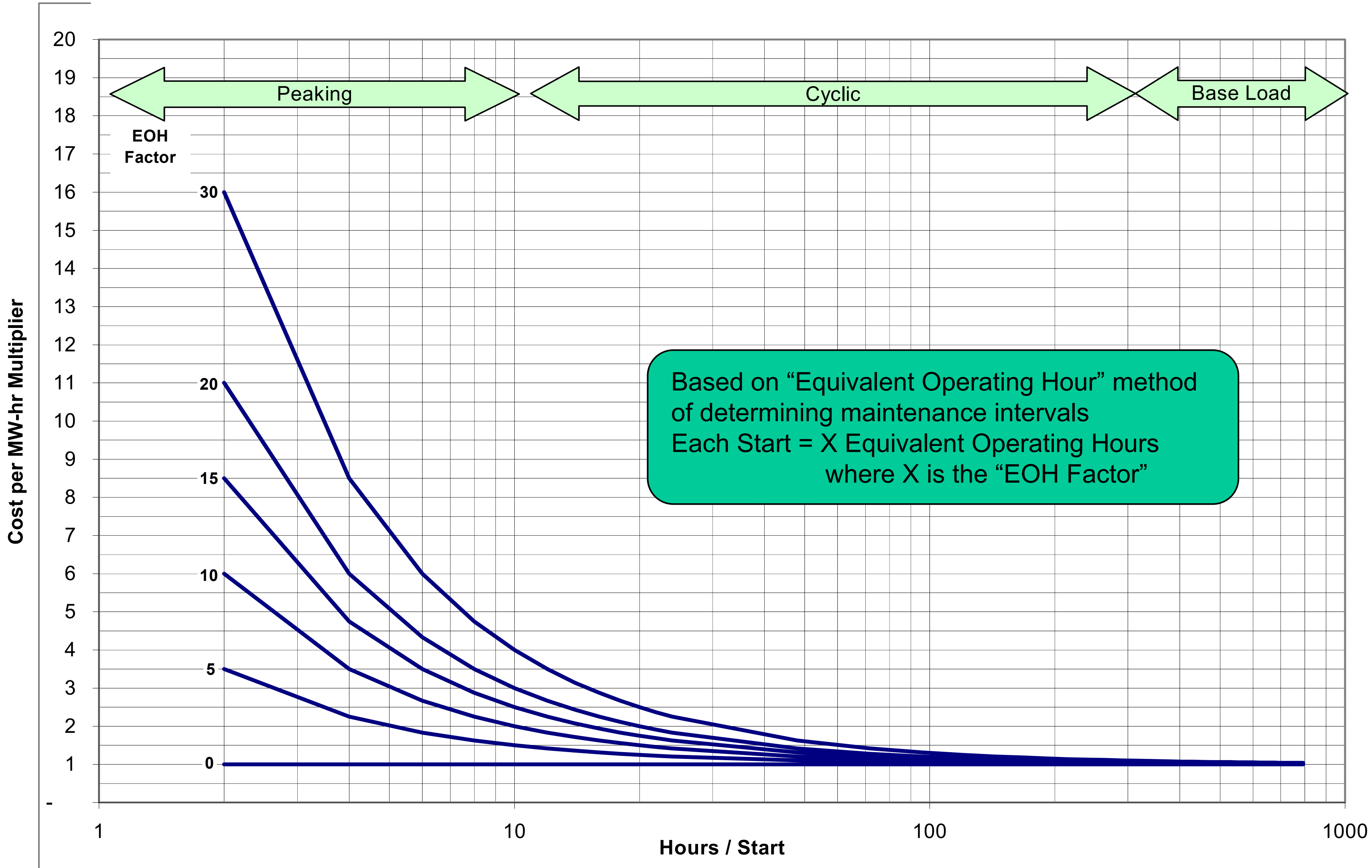
Impact of Cycling on Maintenance Costs



Based on “Equivalent Operating Hour” method of determining maintenance intervals
Each Start = X Equivalent Operating Hours
where X is the “EOH Factor”

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Emissions Abatement

- Dry Low Emissions (DLE) combustion technology is required to meet environmental standards for high TIT machines but it is costly and still requires SCR to meet permit requirements
- D-R uses Diffusion Combustors with water injection to reduce NO_x formation in conjunction with an SCR for final exhaust cleanup.
  - Lower initial cost
  - Low maintenance
  - Higher operating cost (water & NH_3)

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4.3 Michael McGill Compressor Selection and Design

Michael McGill studied mechanical engineering and business at the University of Louisville. He has worked extensively in origination of transactions for sale and purchase of electricity and gas for several companies including Shell Oil Company and Edison Mission Energy Company. Michael has devoted his efforts to development of CAES facilities for fifteen years with particular focus on integrating the mechanical capabilities of CAES systems with the operating requirements of host utilities and the financial and economic opportunities of evolving markets.

Compressor Selection and Design for CAES Service

(A conceptual approach)

Michael J. McGill

Electricity and Air Storage Enterprises, LLC

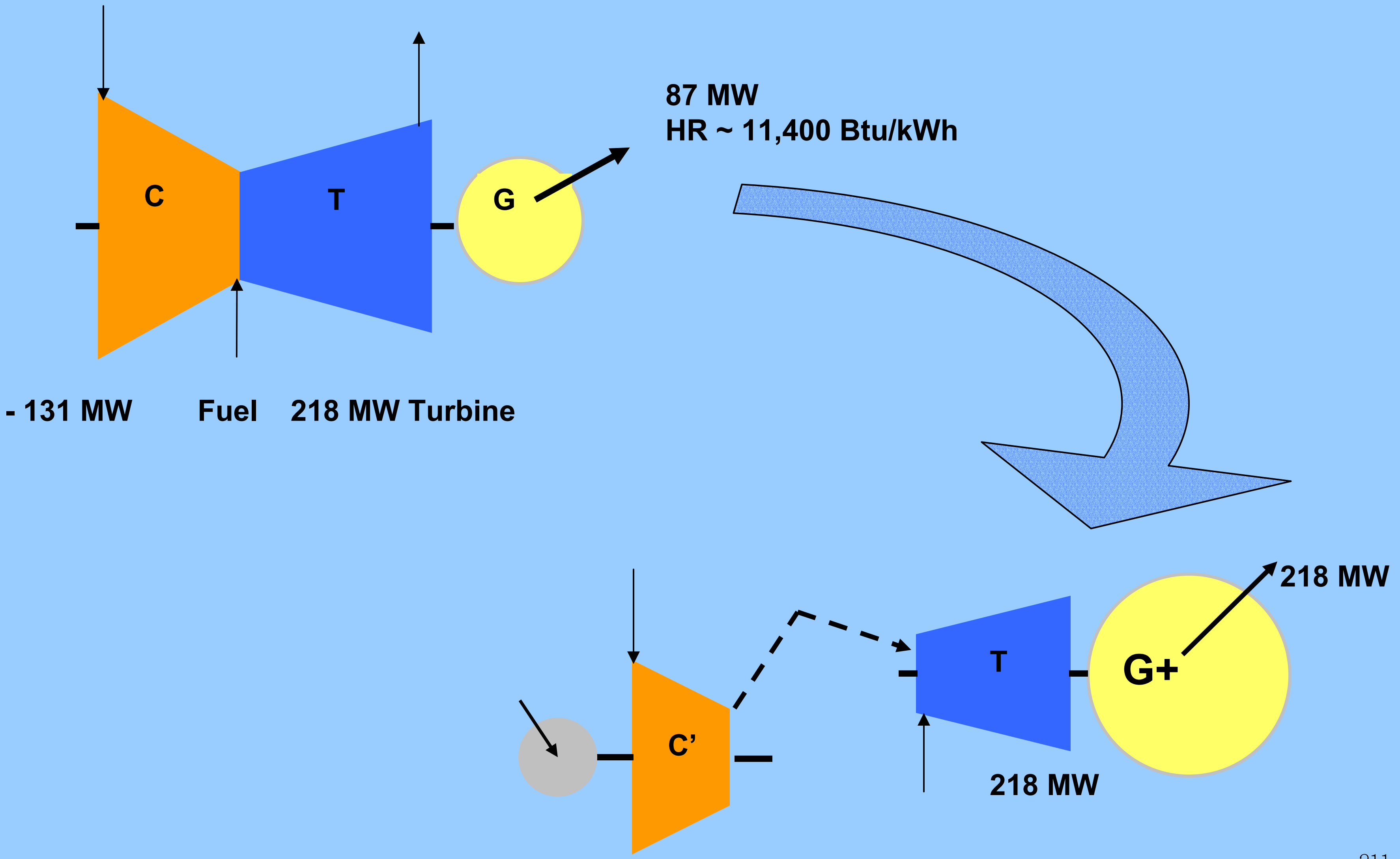
This presentation is ***not*** intended to present a recipe to tell you how to choose the right compressors.

Strategic operating and financial objectives should guide selection of compressors.

Hint: Share your commercial/operating goals with your engineer and your equipment suppliers – or be prepared for unpleasant surprises.

There is no dazzle or baffle in this presentation.

What is the enabling essence of CAES?



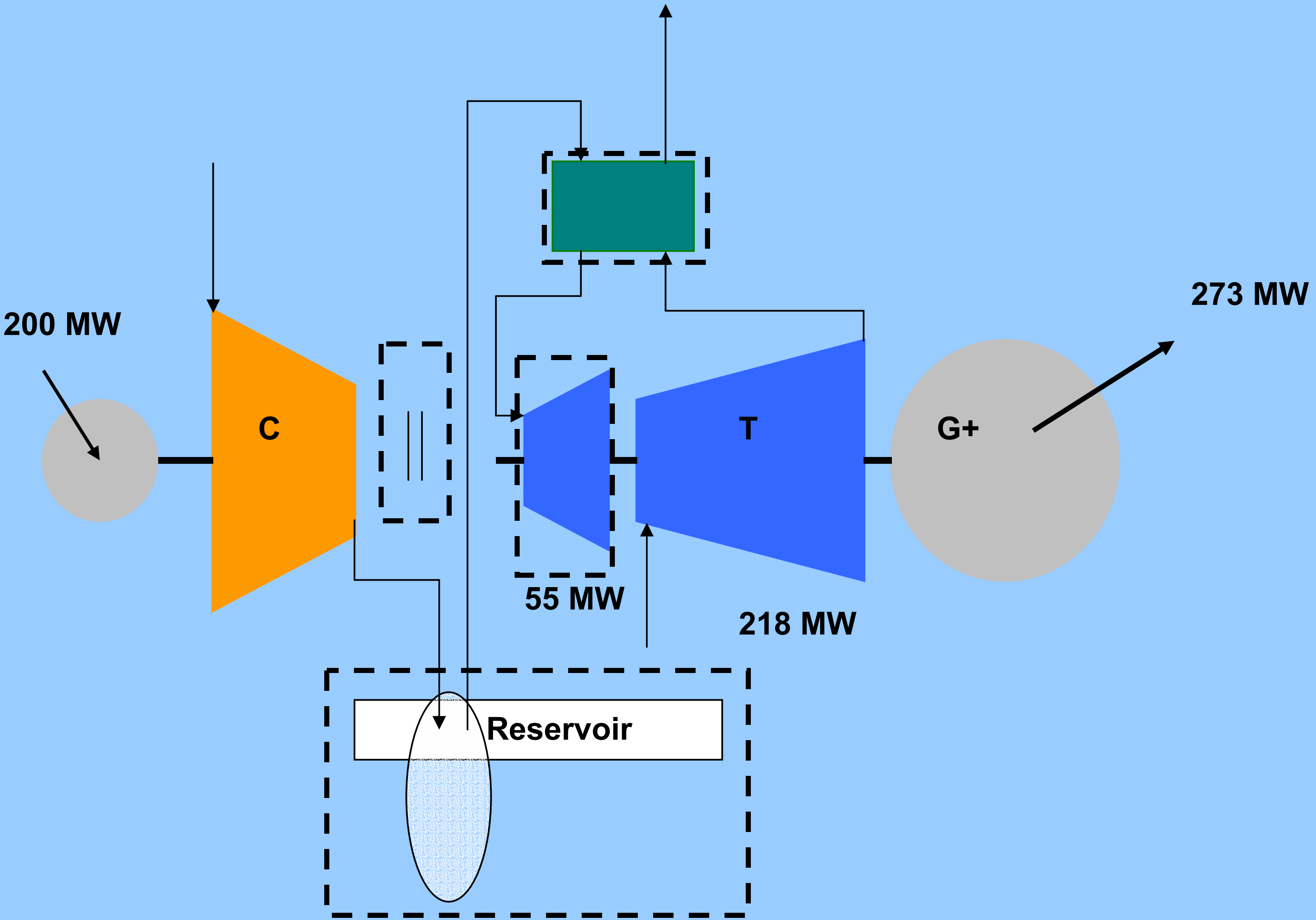
87 MW
HR ~ 11,400 Btu/kWh

- 131 MW Fuel 218 MW Turbine

218 MW

218 MW

Enhancements were added… for more output and better efficiency.



Markets have begun to recognize value of flexibility, and that CAES can provide it.

Such recognition often comes because of seemingly intractable problems rather than inspiration or insight.

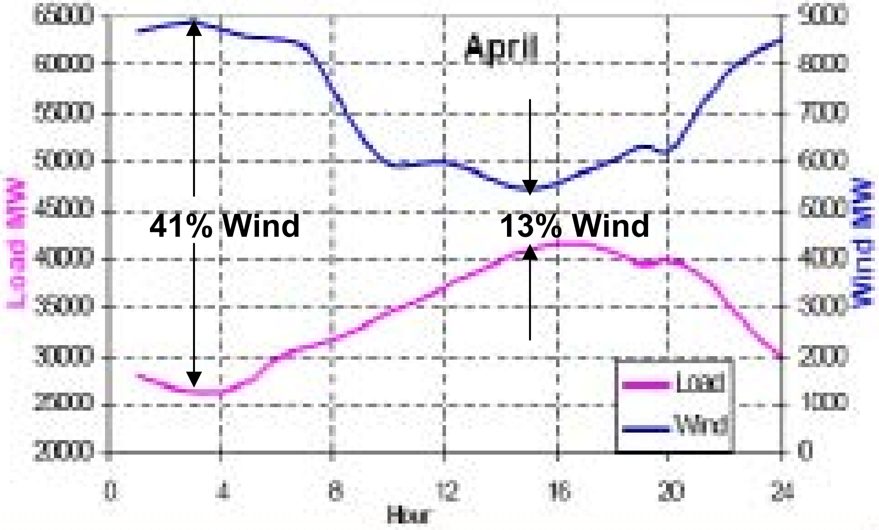
"There's no way you can do that!"

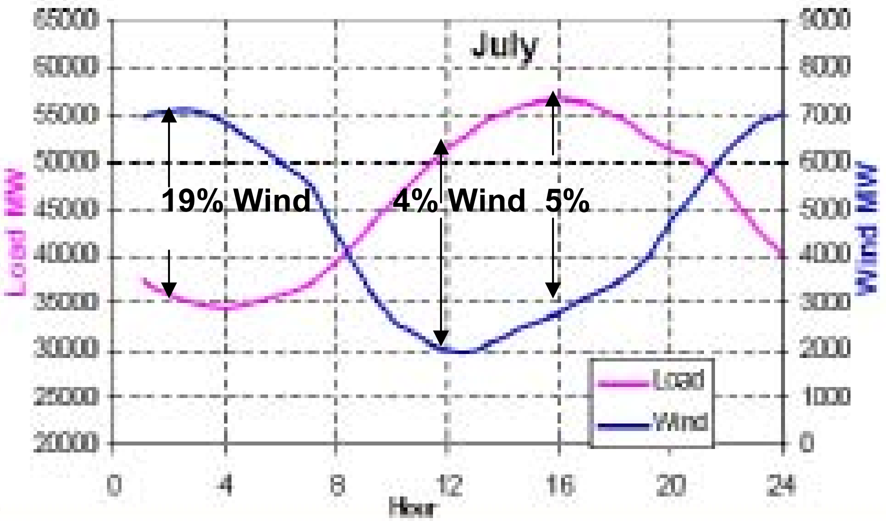
Source: ERCOT

Wind Generation Challenges

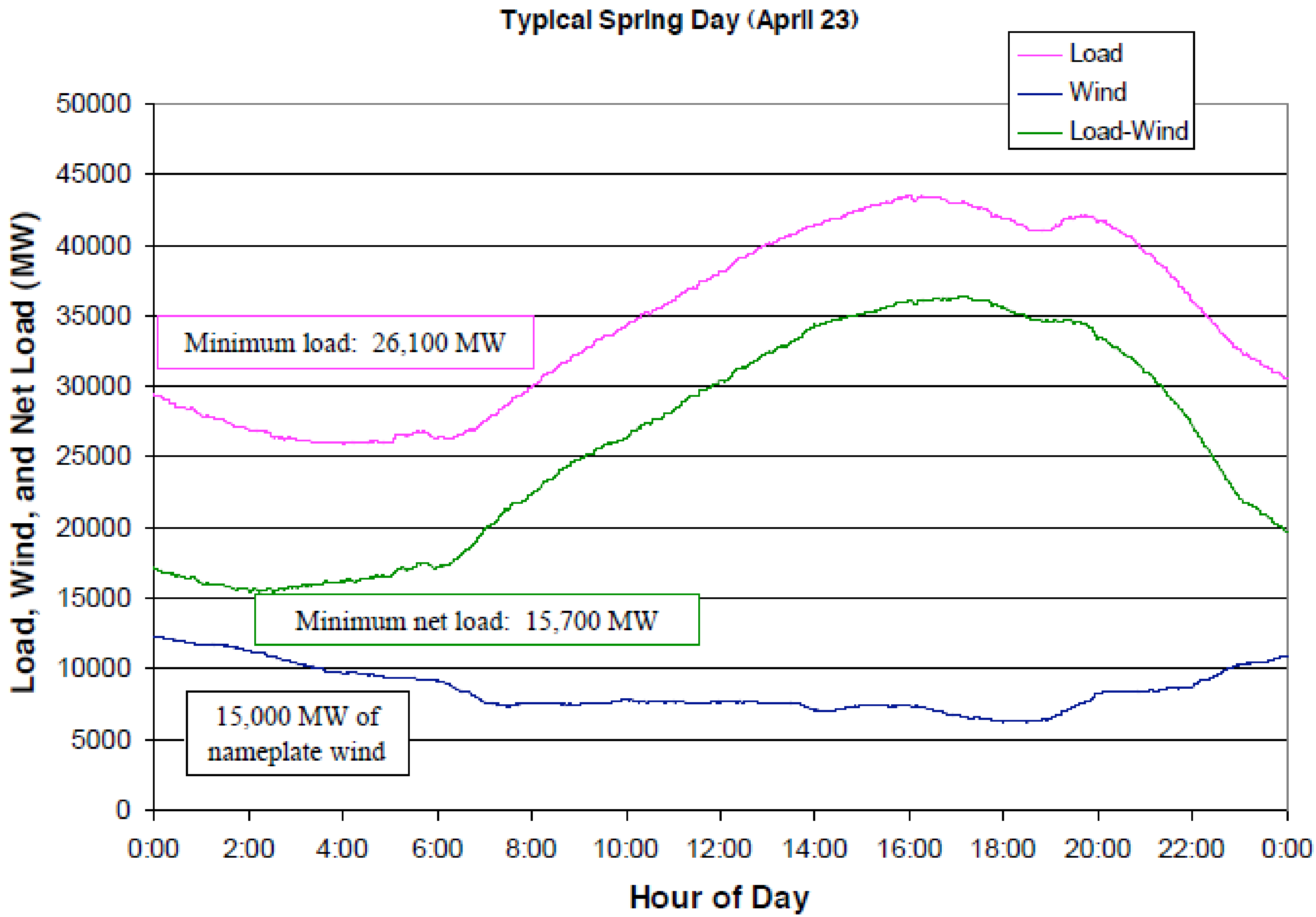
Challenging Wind & Load Patterns

- **Mornings:** Wind tends to drop sharply, while Load rises
- **Evenings:** Wind tends to rise sharply, while Load drops





“Net-Load” Calculation – An Operator’s Viewpoint

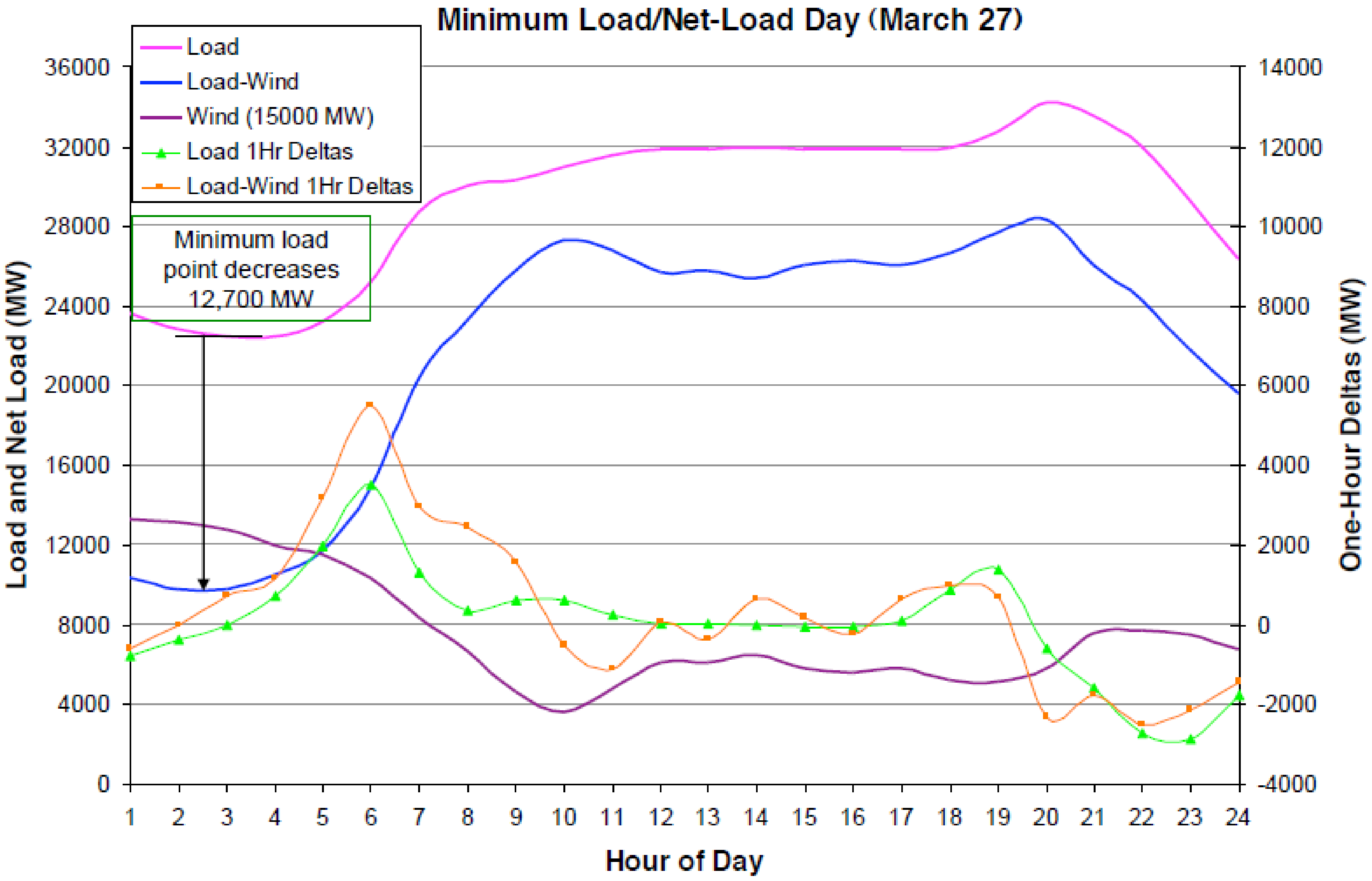


Similar to load, operator can’t control wind generation output

Net load predictability is key to reliable operations

Additional large increases in wind generation will change the typical load shape

Following Net Load



Minimum Load/Net-Load Day (March 27)

Minimum load point decreases 12,700 MW

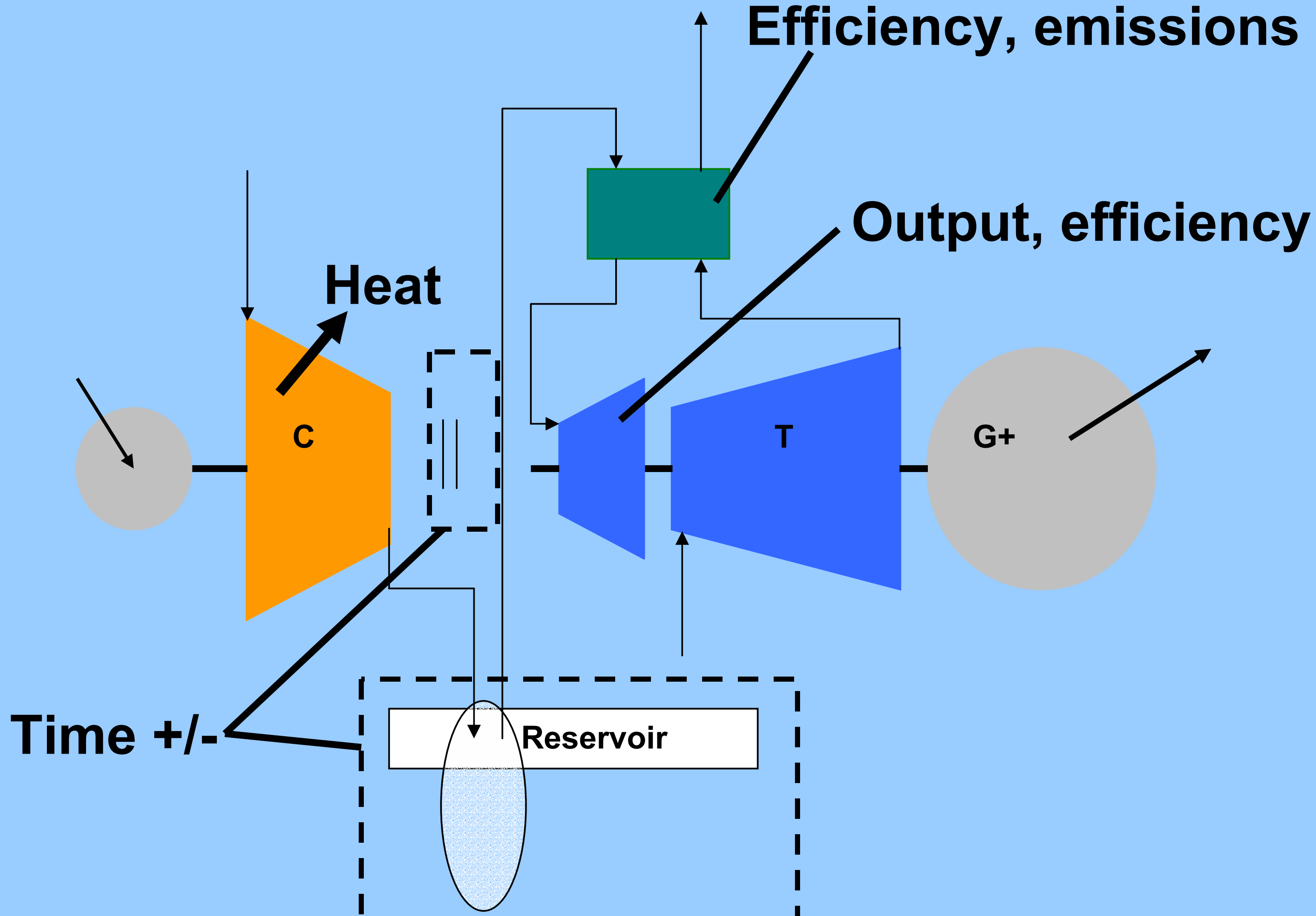
Load is variable, and is predictable (to a point).

Wind is variable, and is predictable (to a point).

Fossil generation can be varied, but must be controlled:

- Costs -- capital and especially variable costs
- Availability
  - Start times/shut-down times
  - Ramp rates (MW/min)
  - Minimum run times
  - Minimum down times
  - Major maintenance periods

Important effects



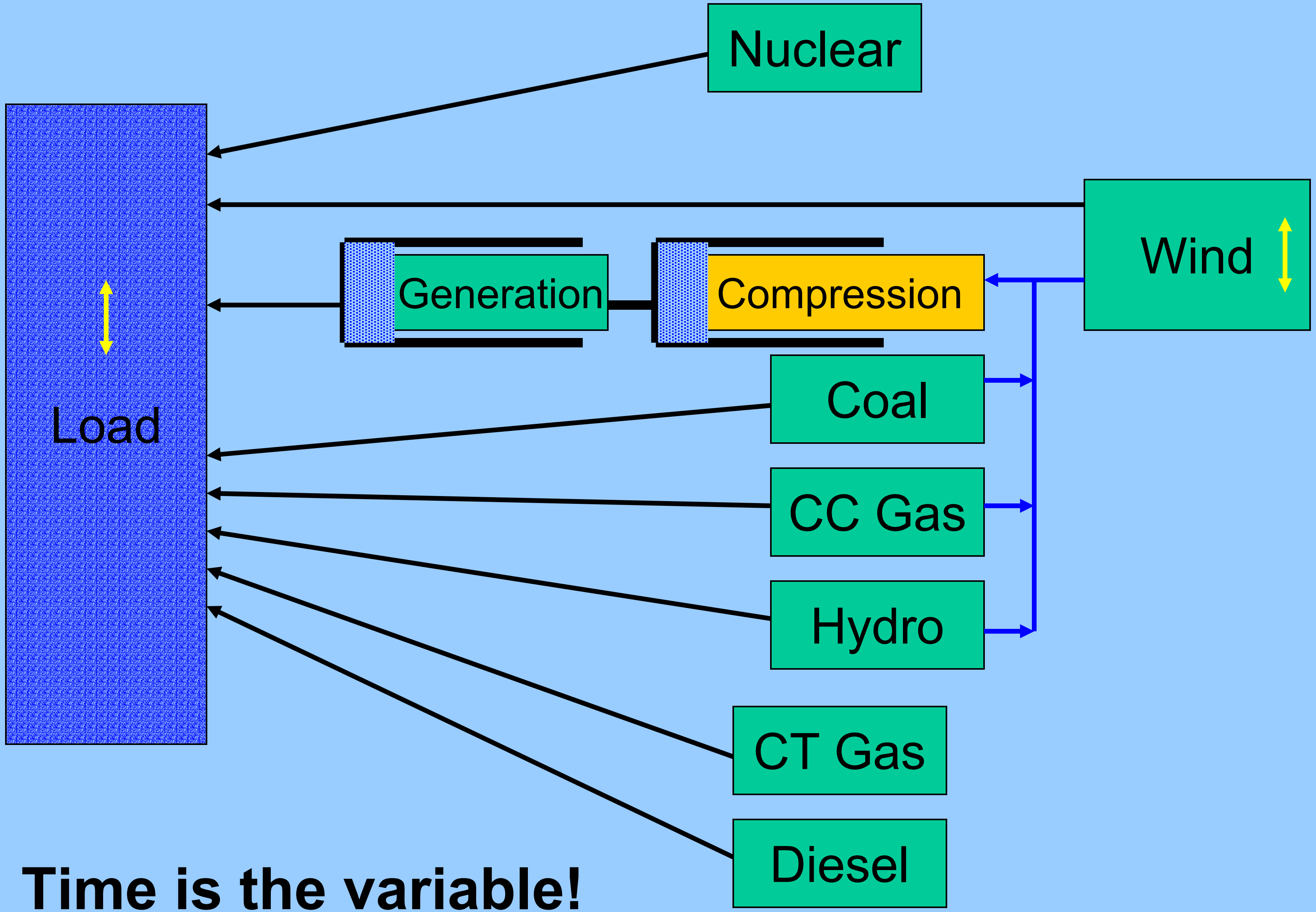
Efficiency, emissions

Output, efficiency

Heat

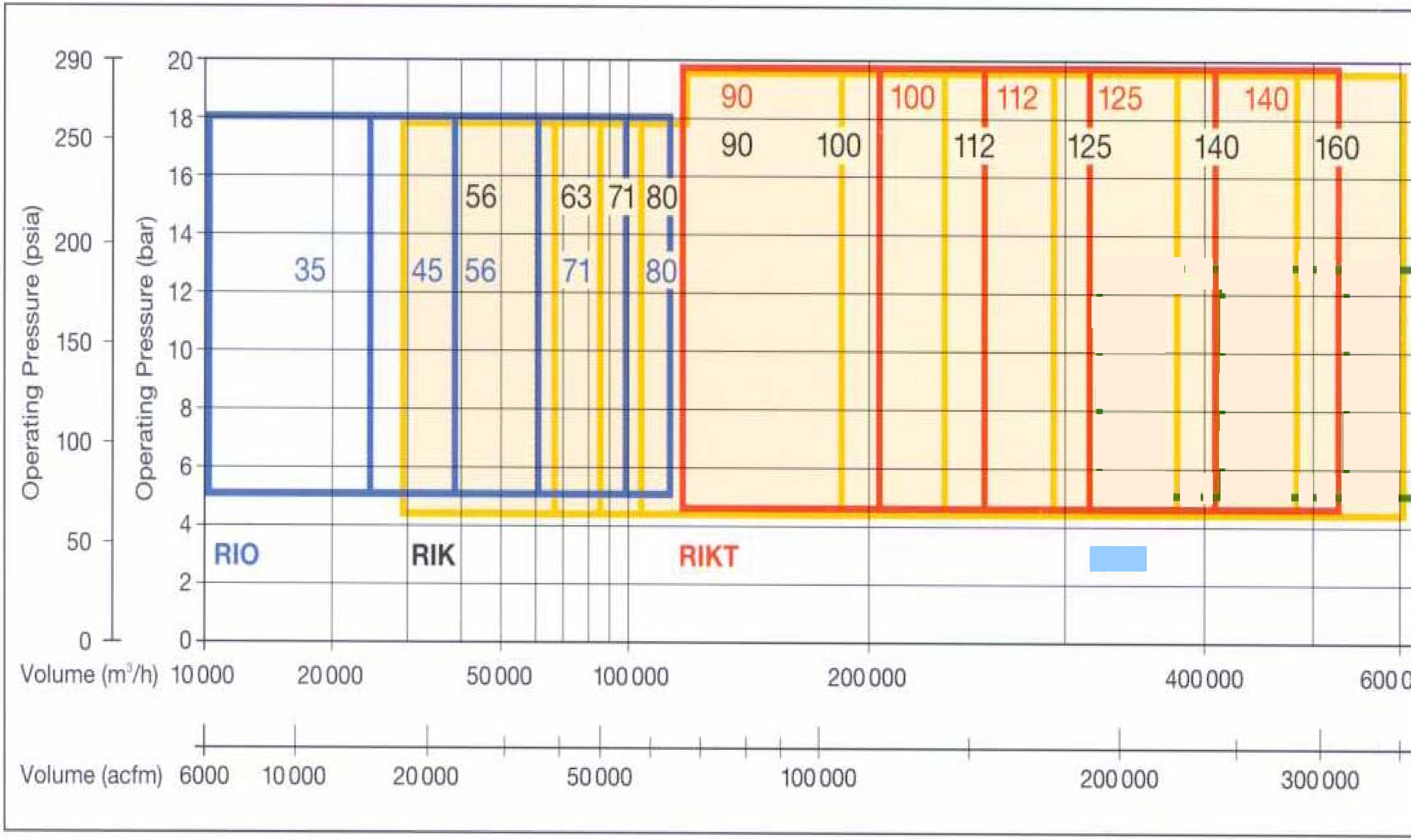
Time +/-

CAES absorbs the shocks like no other….



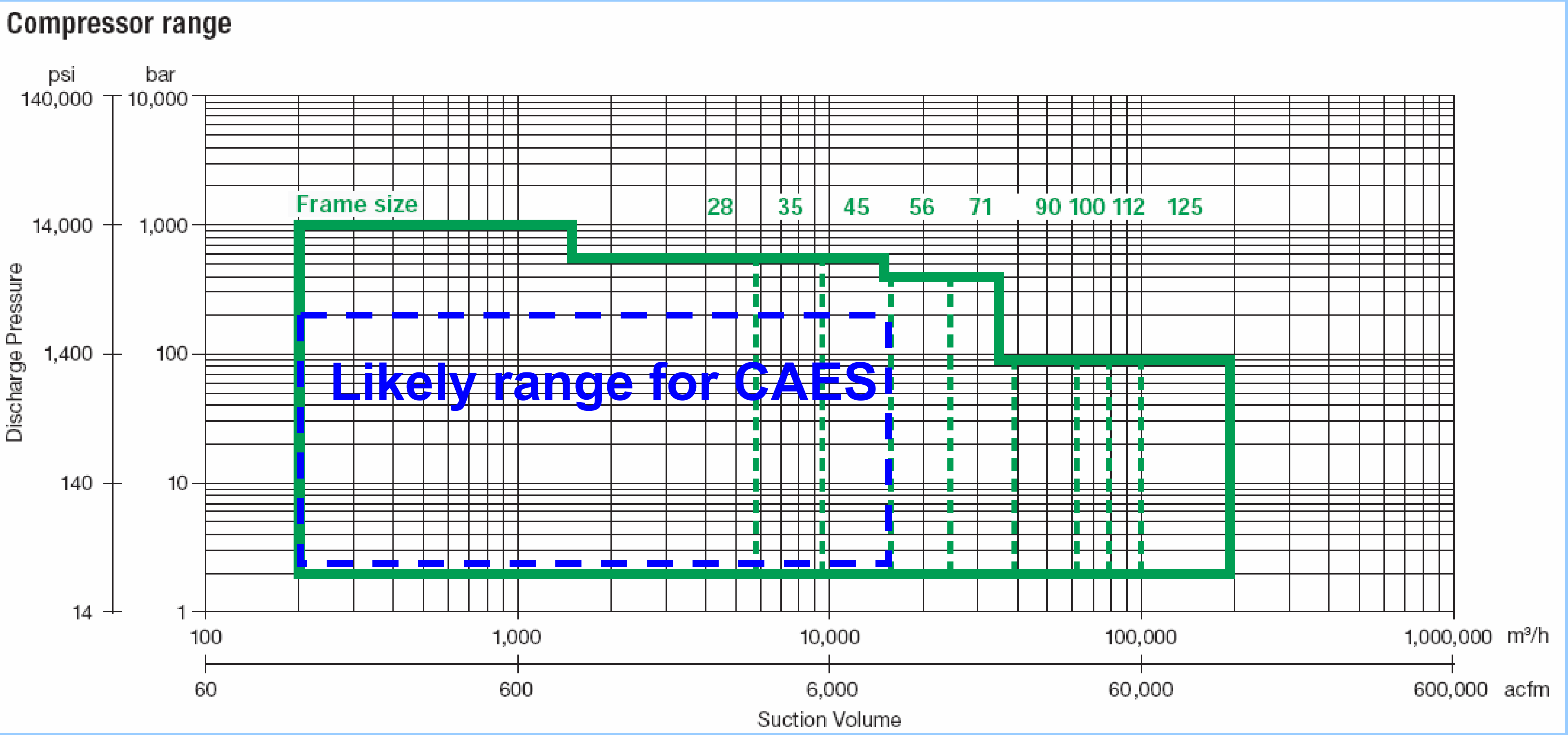
Time is the variable!

MAN Turbo
Low Pressure Compressor
Isotherm type RIK/ RIKT for large volume flows



Thanks to MAN Turbo

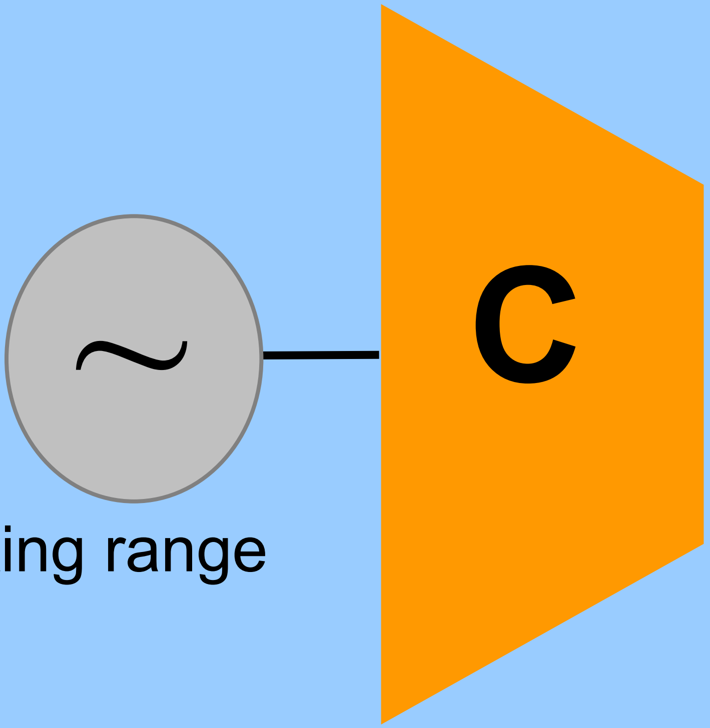
MAN Turbo
High Pressure Compressor
Centrifugal " Barrel" type RB

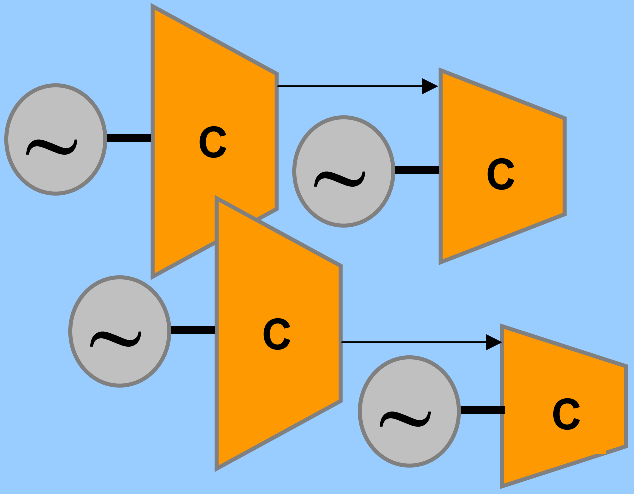


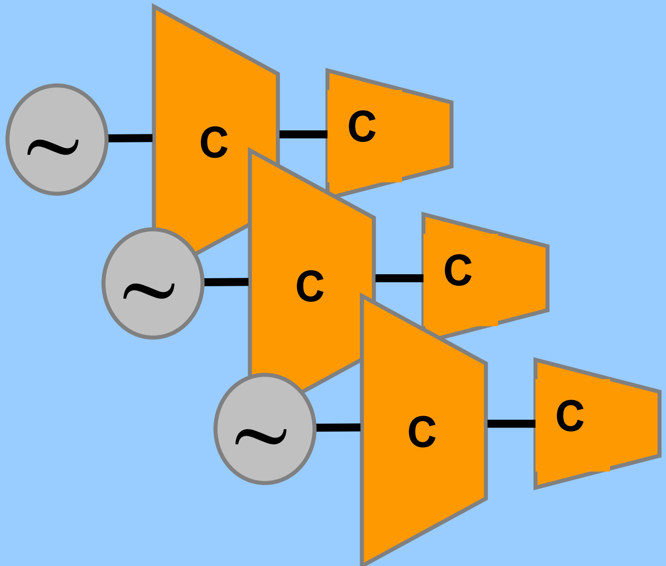
Thanks to MAN Turbo

Select compressors for:

- Operational “fit”
- Flow Rate
- Discharge pressure
- Efficiency (cost) in operating range
- Initial cost
- Operating flexibility (Forgiving? Fixed limits?)







Conclusions:

- CAES leverages time
- CAES can absorb shocks (both sides!)
- CAES enables wind development by accommodating wind operations
- Compression links:
  - Off-price generation with peak load (time)
  - Wind generation with market (time)
  - Generating technologies with market needs (time)
  - Energy supply with storage (time)

5.1 Stephen J. Bauer, Aspects of underground compressed air energy storage

Steve Bauer's field of expertise is rock mechanics/physics and has been at Sandia National Laboratories for 25 years; he is currently manager of the Geomechanics laboratory. He has planned, participated in, and managed projects that involve lab and field testing and analysis, constitutive model development, large scale rock mass response, and 3-D numerical analyses. Steve has worked in underground storage for most of his career on projects related to nuclear waste disposal, liquid storage (supporting the U.S. Strategic Petroleum Reserve), natural gas, hydrogen and air.

Underground aspects of underground compressed air energy storage (CAES)

Geomechanics Research Department

Stephen J. Bauer

Sandia National Laboratories

sjbauer@sandia.gov

Outline CAES

- **System Considerations**
- **CAES Process**
- **CAES Feasibility**
- **Site Selection**
- **Summary, R&D,?**

CAES System Considerations

- Generation needs/desires
- Public
- Regulatory requirements/constraints
- Surface requirements/constraints
- Subsurface requirements/constraints
- Environmental Considerations

CAES Process

Concept Feasibility

National/regional economics
Existing infrastructure
Power grid system
Supply/***storage needs***

Consumption economics
Regulatory Considerations
State & Local Politics

Site Selection

Size and depth of storage facilities (mines, salt caverns, reservoirs)
Proximity to transmission infrastructure
Efficiency of storage (rock type, type of container) Regulatory

Site Characterization

Rock type
Rock characteristics (mechanical/hydrological)
System modeling (mechanical/hydrological)
Regional tectonics
Facility volume, depth, and layout

Construction

Surface facilities (turbines, etc.)
Subsurface facilities (seals, wells et
Monitoring
Regulatory

Operation

Pressurization
Power generation
Monitoring

Facility Upgrades

Replacement of equipment
Subsurface performance evaluations
Monitoring

Concept Feasibility storage needs

Anywhere, US

(maybe even NY)

storage - power relationships

HOW MUCH SPACE DO YOU NEED?

WHERE DOES IT NEED TO BE?

WHAT FLOW RATES DO YOU NEED?

FOR HOW LONG?

Site Selection Host Rock Considerations- constraints

- at depth in competent rock
- well sealed container
- large volume
- can deliver air at desired rates
- favorable stress state
- can withstand pressure cycles
- no detrimental conditions/circumstances

Concept Feasibility

storage needs

Desirable Siting Conditions

- **Depth : 500 - 1500m**
- **Volume > 0.2 x10^6 m^3**
- **Competent structure, non-oxidizing**
- ***In situ* stresses compatible with desired pressures**
- **Favorable hydrologic conditions**
- **Favorable openings**
- **Competing circumstances**

Site Selection Host Rock Considerations

- Mines- as is, lined, curtained, resealed
- Caverns (salt)
- Reservoirs - aquifers, gas, fractured systems, engineered

Site Selection Host Rock Considerations - Mines

- Potential for pre-existence of large underground volumes
- Excellent permeability
- Potential for *in situ* characterization
- Potential for recorded history
- Often a conflict between desired use and development history (maximize extraction)
- Often good electrical connections
- Beneficial use for old mines
- Limited locations
- Good chance of flooding*

*may need to be engineered

Inside a mine

Site Selection Host Rock Considerations - Reservoirs

- Potential for pre-existence of significant underground volumes
- “Natural” environment for intended purpose
- Limited *in situ* characterization
- Potential for known reservoir history
- From history - performance
- Near well bore conditions important
- Possibly many boreholes required for flow
- Relatively constant pressure operation

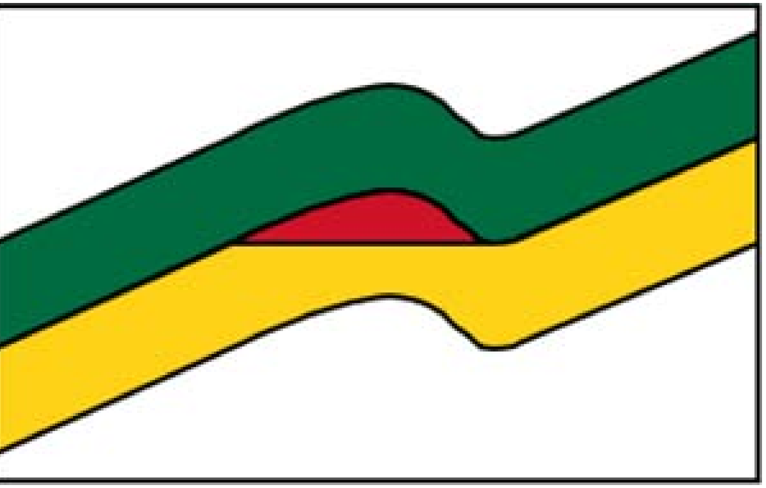
Site Selection Logical Path - Reservoirs

Geomechanics Research Department

- Review of area geology
- Porous media surrounded by impermeable media
- Porosity- pore or fractured
- Impermeable barrier for containment
  - **structural**
  - **stratigraphic**
  - **engineered***
- Site Characterization/Analyses
- Flow characteristics consistent with needs

Structural trap

Geomechanics Research Department



Anticlinal structural trap

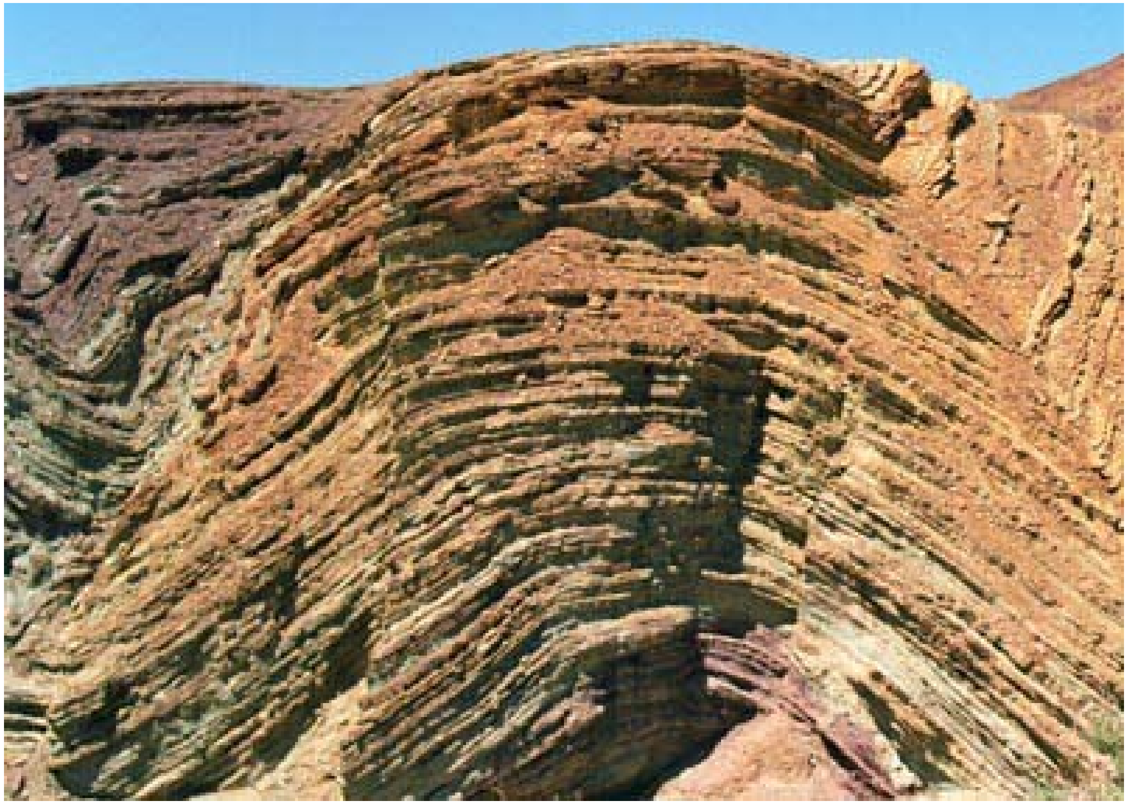
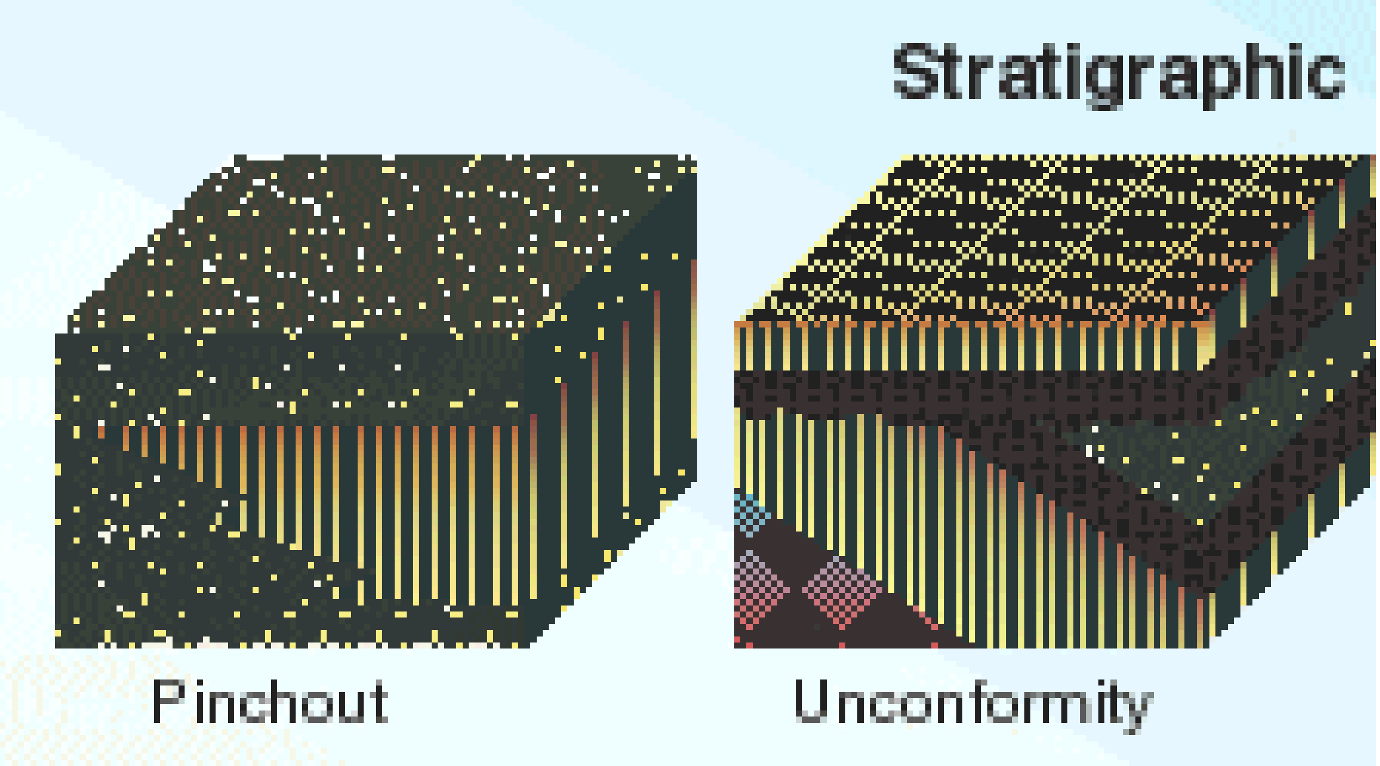


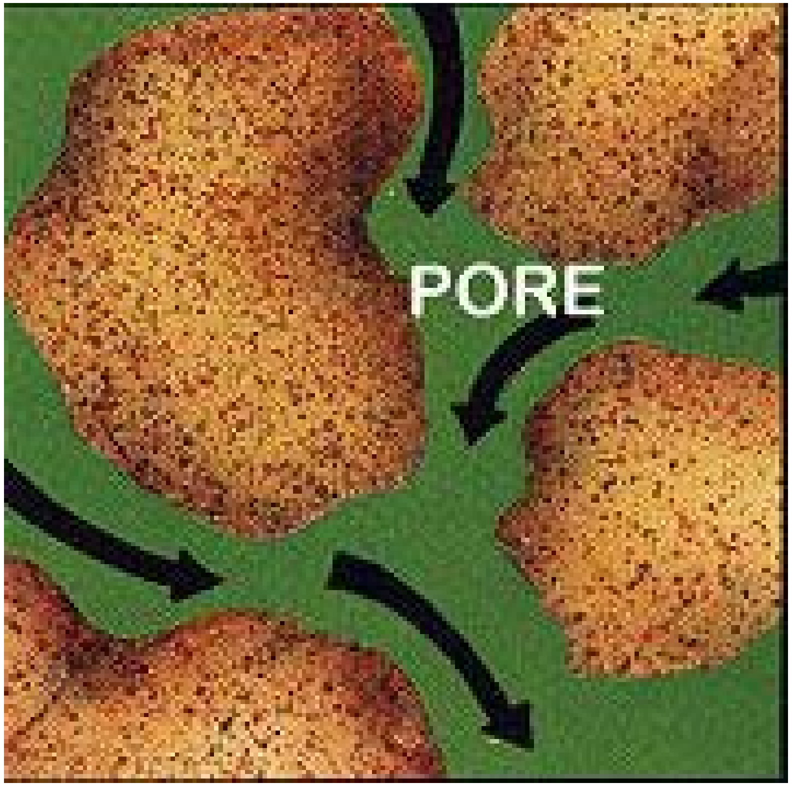
photo courtesy of Cleet Carlton of Golden Gate Photo (fair use policy)

Stratigraphic trap



Porosity

Geomechanics Research Department



Site Selection Critical Parameters - Reservoirs

- Adequate volume = porosity x rock volume

  (then increase rock volume by 1-2 orders of magnitude)
- Impermeable containment – how to determine?
- Adequate/attainable flow characteristics
  - single or multiphase flow
  - testing and calculations

Estimates for reservoirs

Start with mass flow rate needed

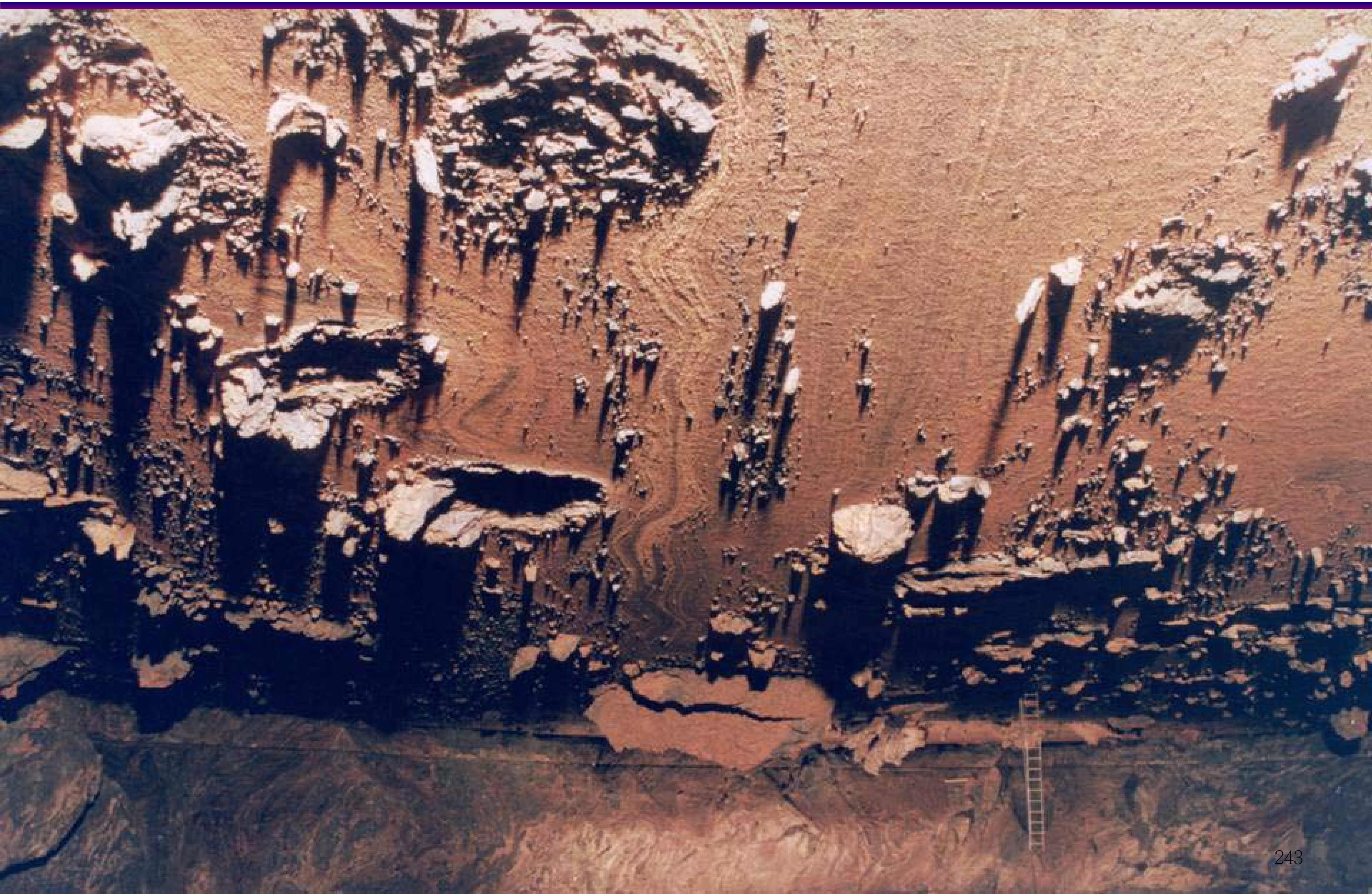
Porosity minimum 15% (PEI)
Permeability > 300 md (PEI)
Rock volume f(porosity, permeability)
Number of wells
Size of wells

Other items: closure, caprock, etc

Site Selection Host Rock Considerations – Salt Caverns

- Potential for pre-existence of significant underground volumes
- Cavern development technology well understood
- Domal versus bedded salt
- Excellent permeability
- Limited *in situ* characterization
- Development, well history important
- Conflict between desired use/development history (developed for brine vs. storage)
- Need to dispose of brine
- New development costs fairly well established
- Mechanical properties very important
- Performance analyses needed

Inside a cavern



Inside a cavern

Summary

- Opportunities exist for containers for underground compressed air storage in geologic formations
- Geology, rock mechanics, flow characteristics are all important

Research Opportunities

Systems Approach

Can surface technology needs change underground requirements?

Homework on availability (study geology)

Evaluate reservoir engineering in concert with geology (generic studies)

Engineered Reservoirs

Mine sealing technologies

Salt caverns will work well- break down regulatory barriers

Site specific conditions importatnt

Improved Efficiencies

- Thermal energy recovery
- Low pressure turbines

5.2 Langhorne "Taury" Smith, Geological Potential and Considerations for Underground CAES in New York State

Langhorne Smith is a reservoir characterization specialist. He currently heads the Reservoir Characterization Group at the New York State Museum in Albany, NY where he has worked since 2000. He holds a B.S. degree from Temple University and a Ph.D. from Virginia Tech. He worked for Chevron as a development geologist for two years and then as a research scientist at the University of Miami before talking his job at the Museum. Dr. Smith is currently working on the geology of the natural gas reservoirs of New York, geological carbon sequestration potential and other subsurface geological projects.

Opportunities for Subsurface Compressed Air Energy Storage in New York State

Taury Smith

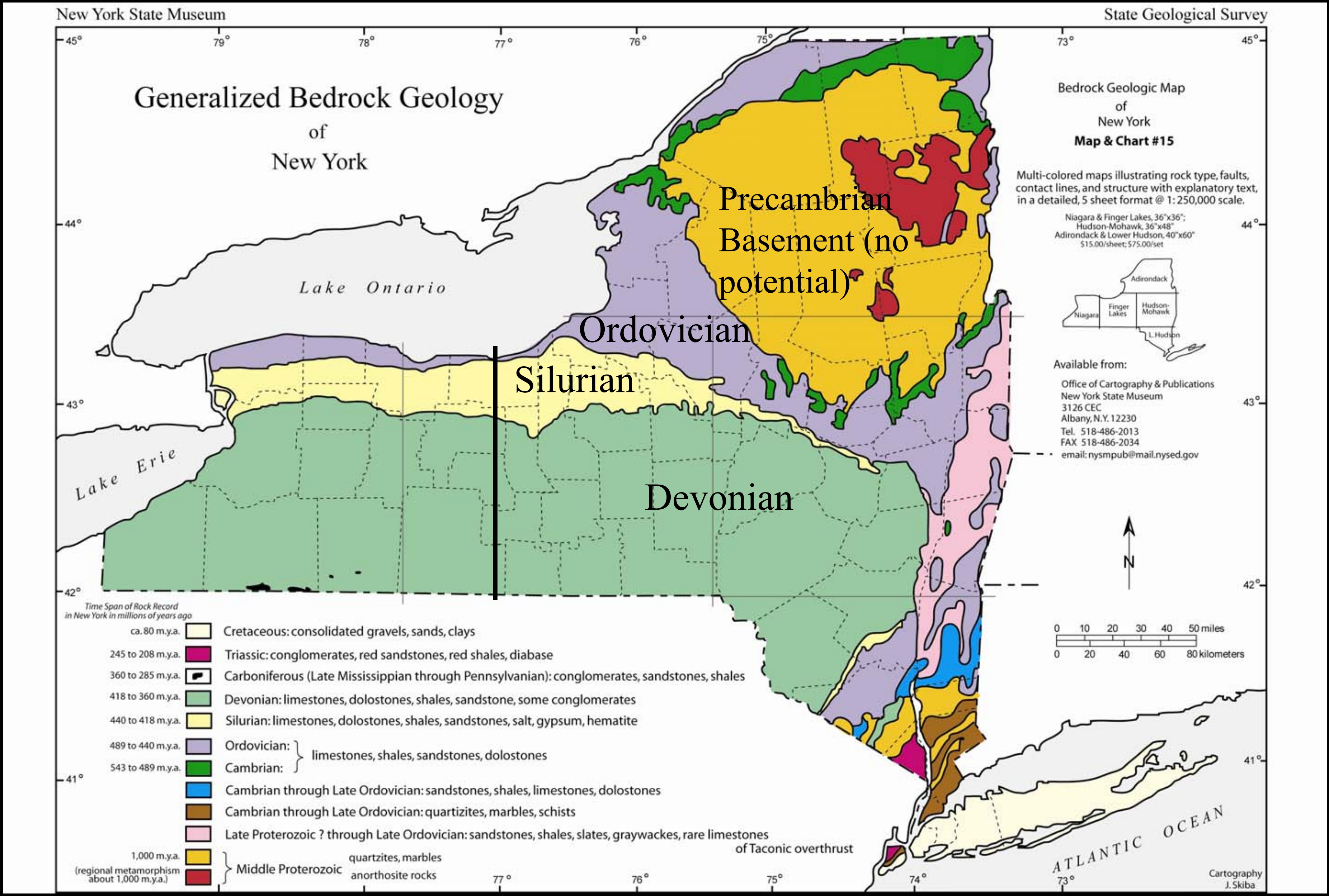
New York State Museum

Reservoir Characterization Group at the New York State Museum

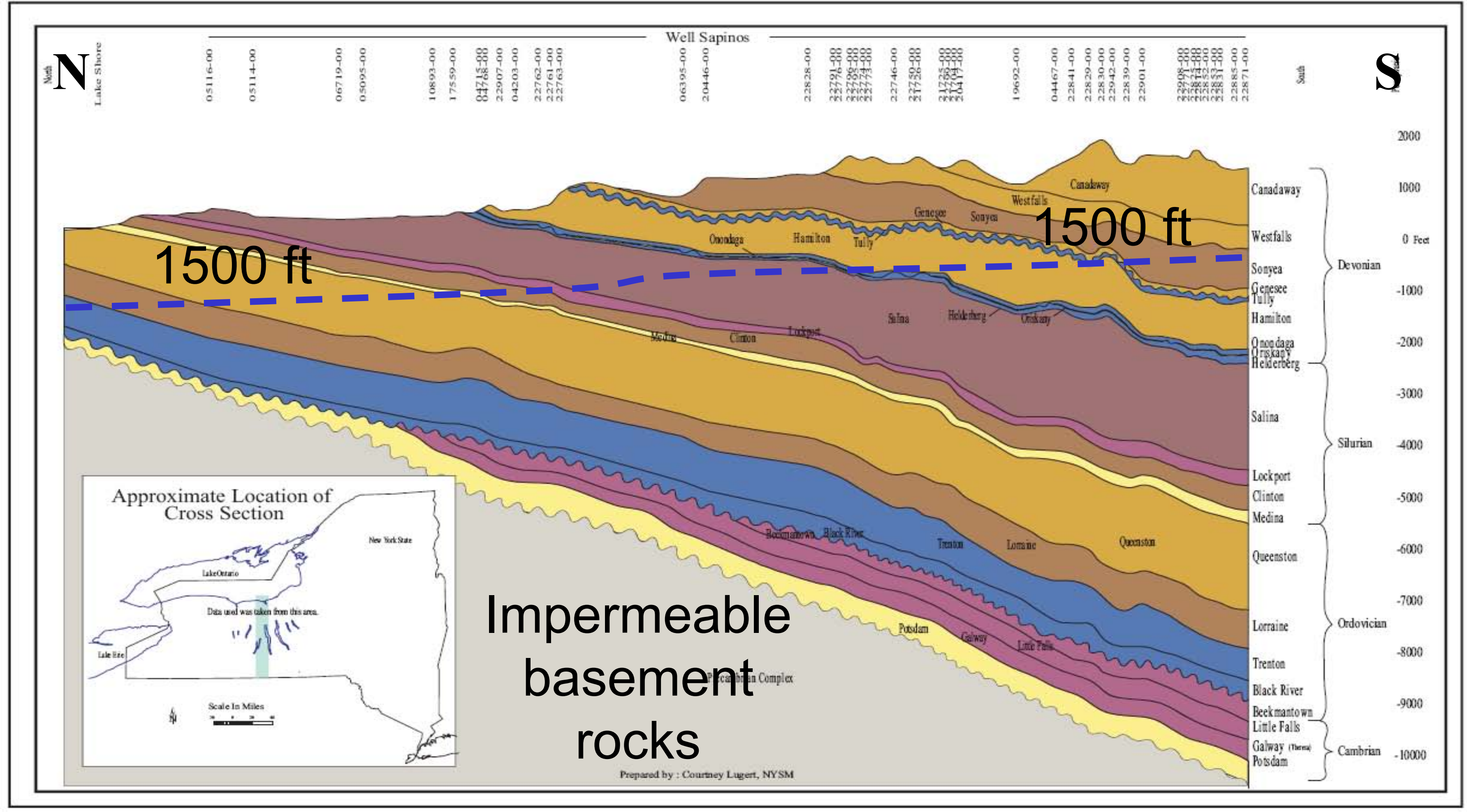
NYSERDA

Subsurface CAES

- Depth should be between >1500 feet below the surface
- Ideal Characteristics: No faults or fractures, well sealed vertically and laterally, highly porous and permeable
- Best Opportunity in NY would be in Salt Caverns, secondary opportunities in depleted natural gas reservoirs

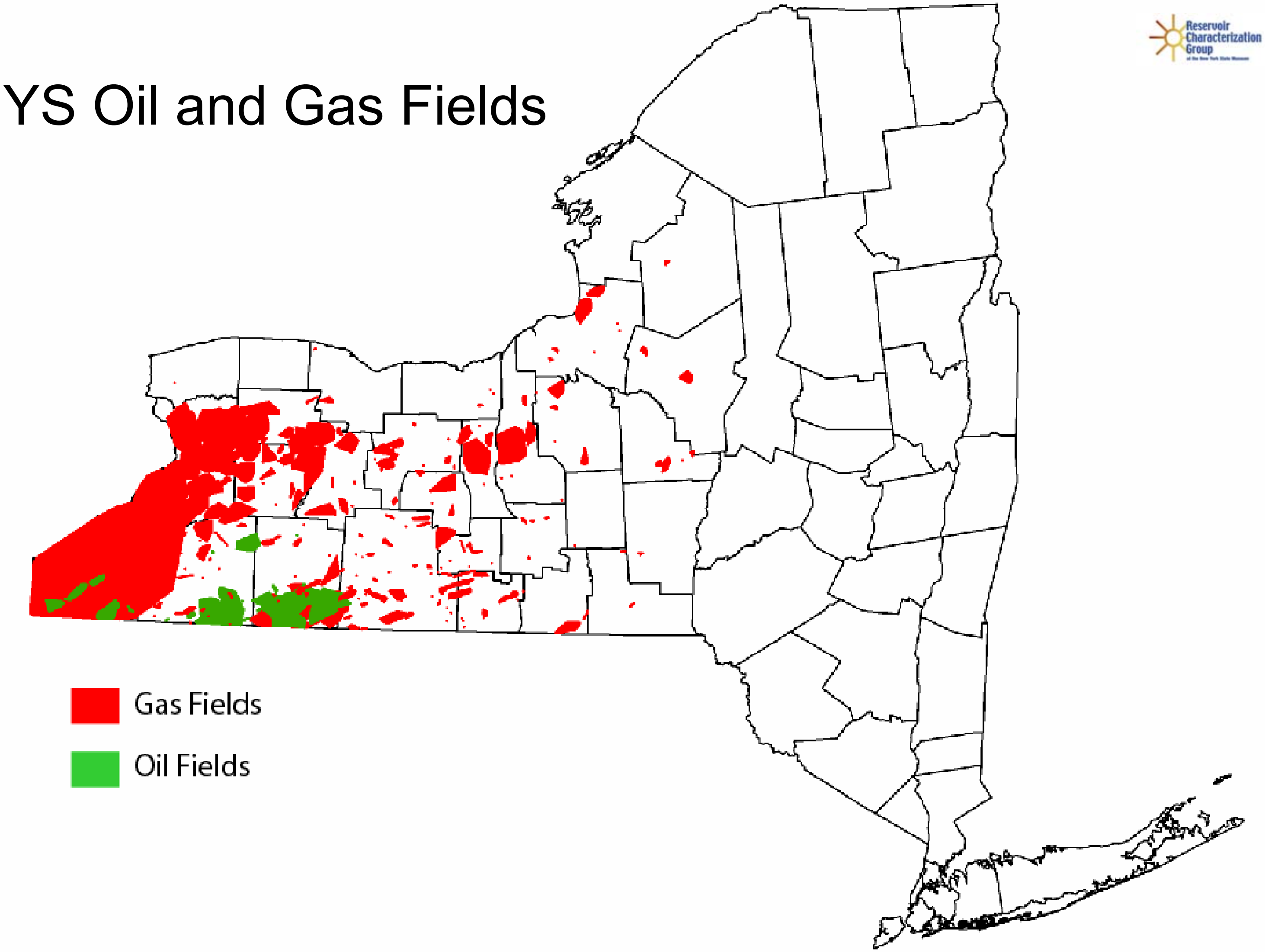


Bedrock geologic map of New York – Layers dip gently to South



Layers dip or get deeper to the south – Any unit under consideration would need to be at least 1500 feet deep

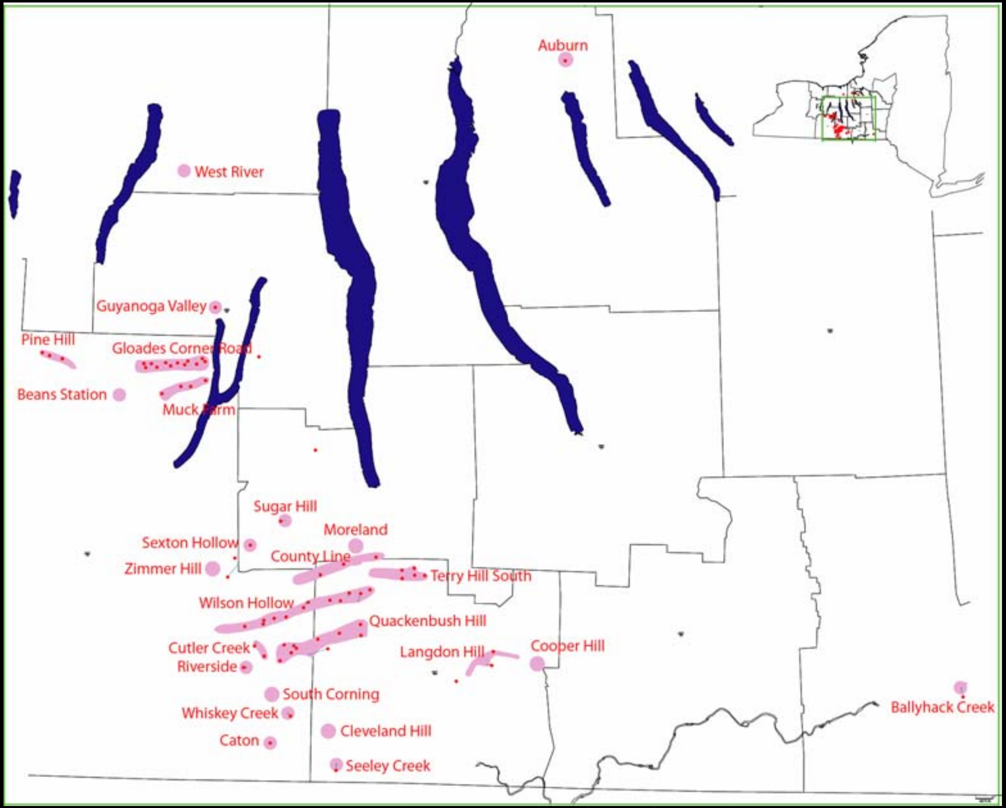
NYS Oil and Gas Fields



Some of New York's depleted oil and gas reservoirs could possibly be used for CAES but most of them have pretty low porosity and permeability

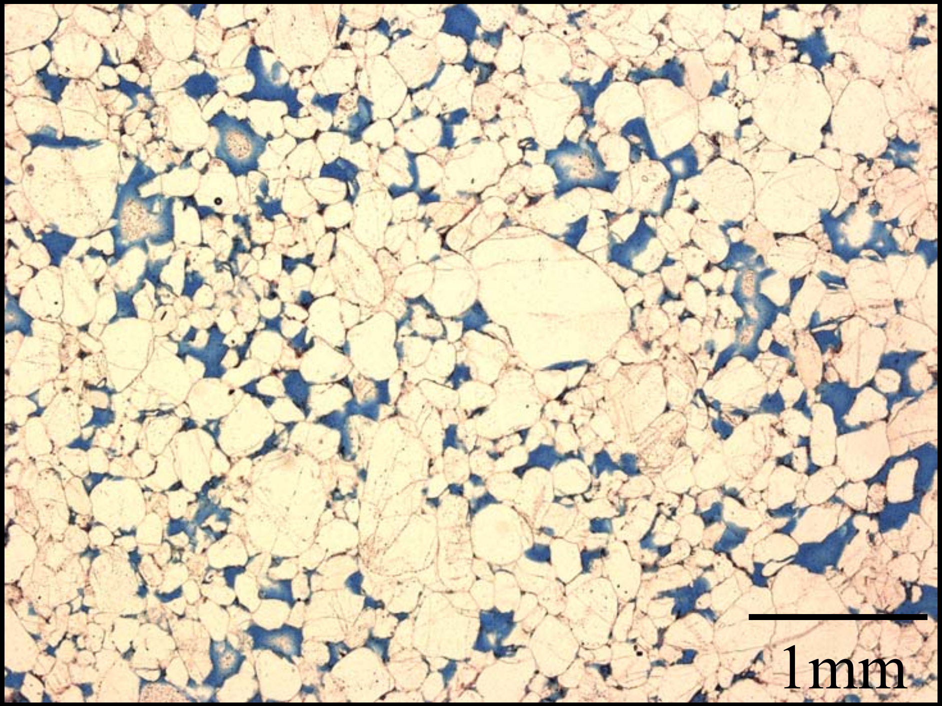
Depleted Reservoirs

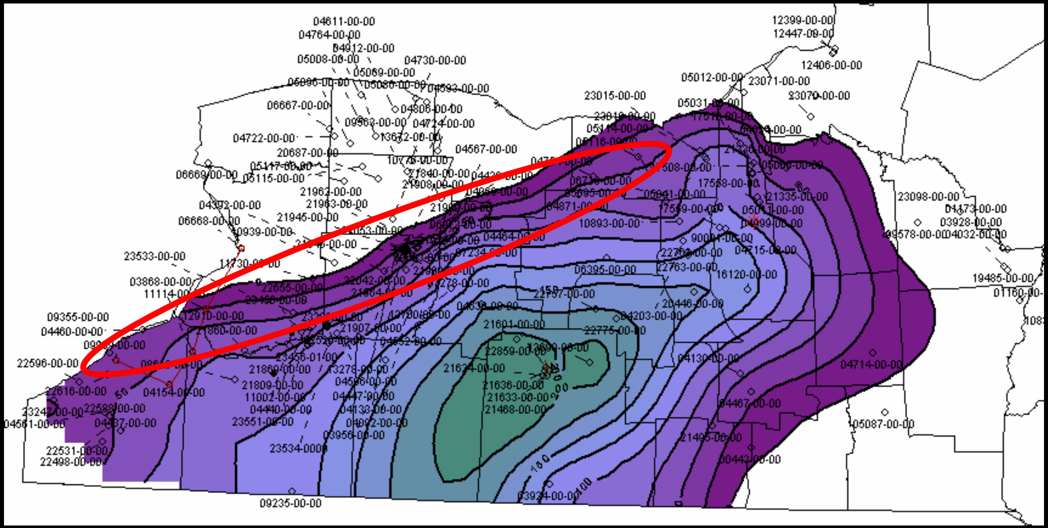
- Most of New York’s depleted reservoirs either have low porosity and permeability requiring hydrofracturing
- Most of the higher porosity and permeability reservoirs are already used as gas storage facilities so there would be competition for the pore space
- There may be an additional need for pore space with Geological Carbon Sequestration
- There are some that are still producing which might work also (but need time to finish production)



Best opportunity might be in porous dolomite from Black River Formation – our biggest gas producer today – problem is that these fields are fault related and the faults may extend some unknown distance from the well bore

There may be competition for this pore space as most good gas reservoirs are converted to natural gas storage fields, which can make a lot of money for their owners



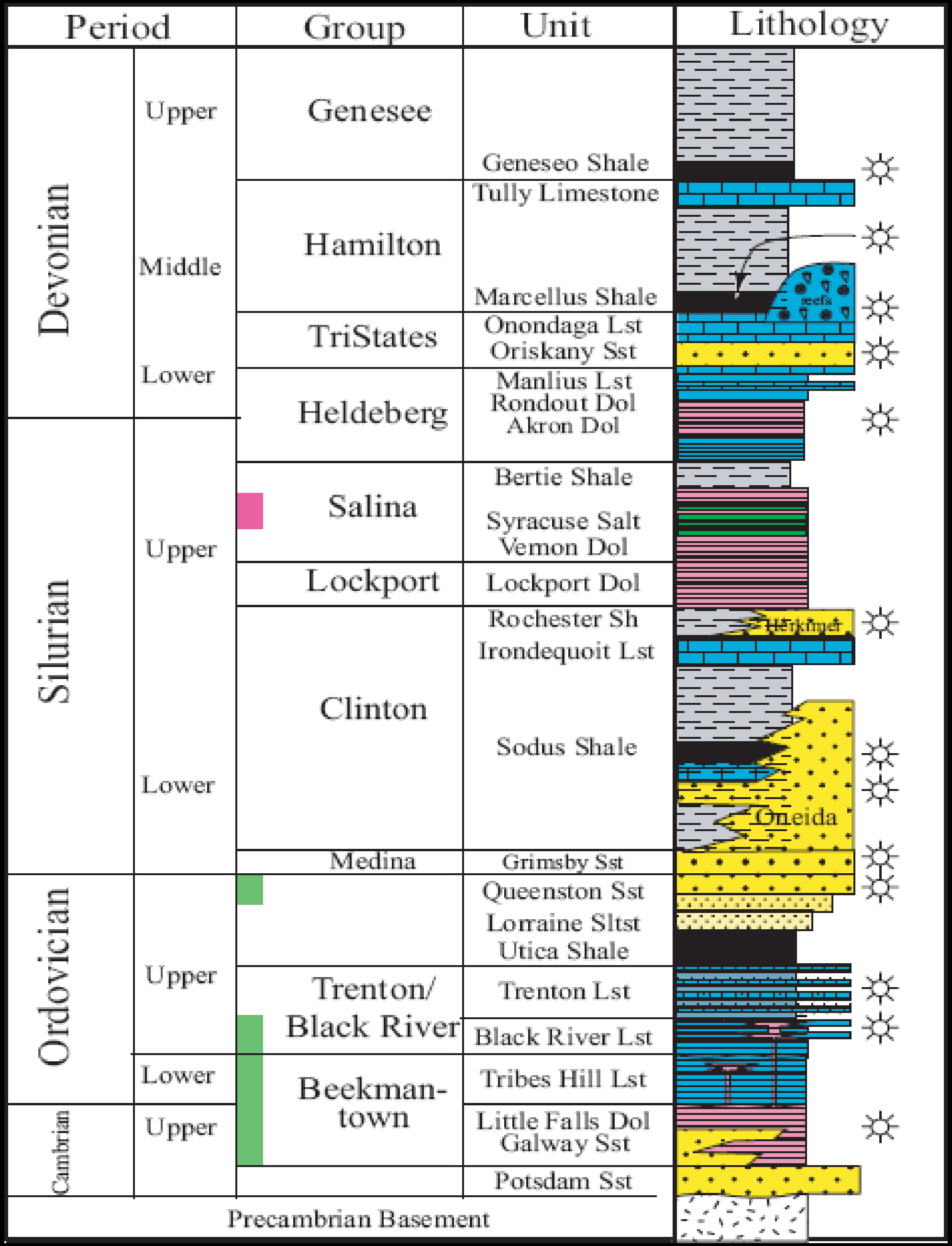


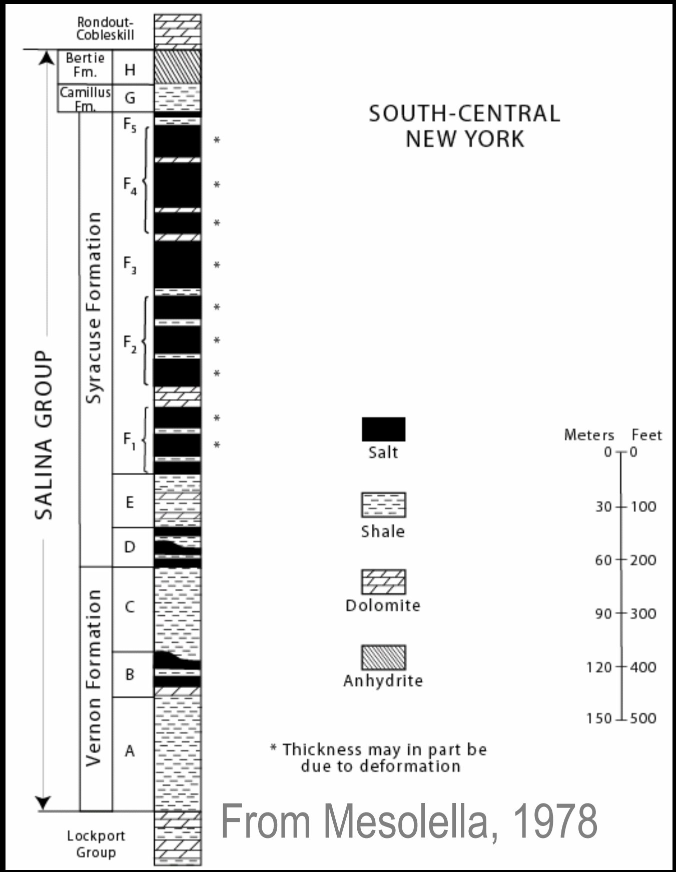
Red circle around area with good porosity

Another opportunities is in the Rose Run Sandstone, which has produced some gas but is mainly a saline aquifer – not porous everywhere need to study distribution of porosity in this and other formations

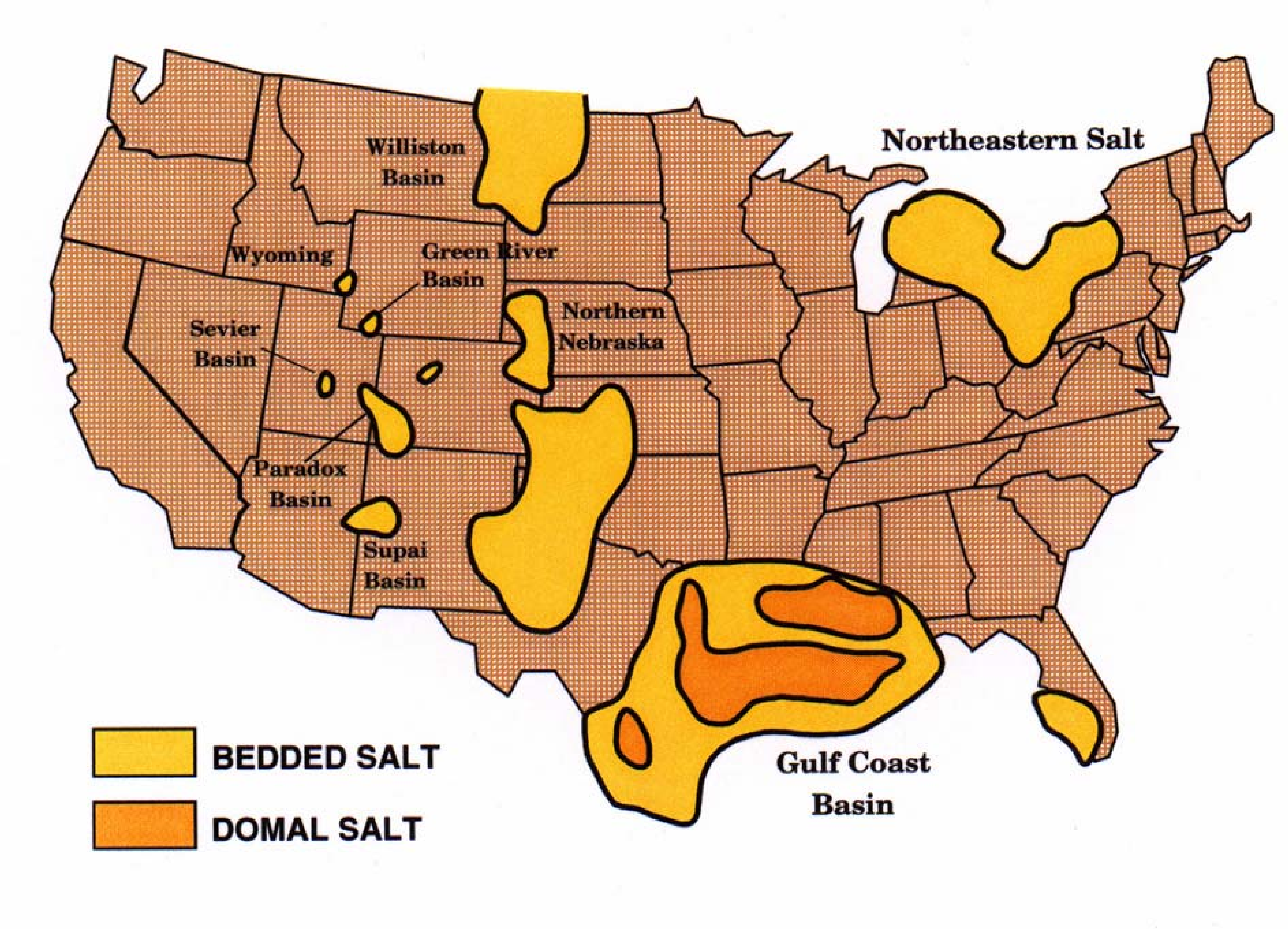
Subsurface Formations of New York

The best opportunity will be to make caverns in the salt of the Silurian Salina Group

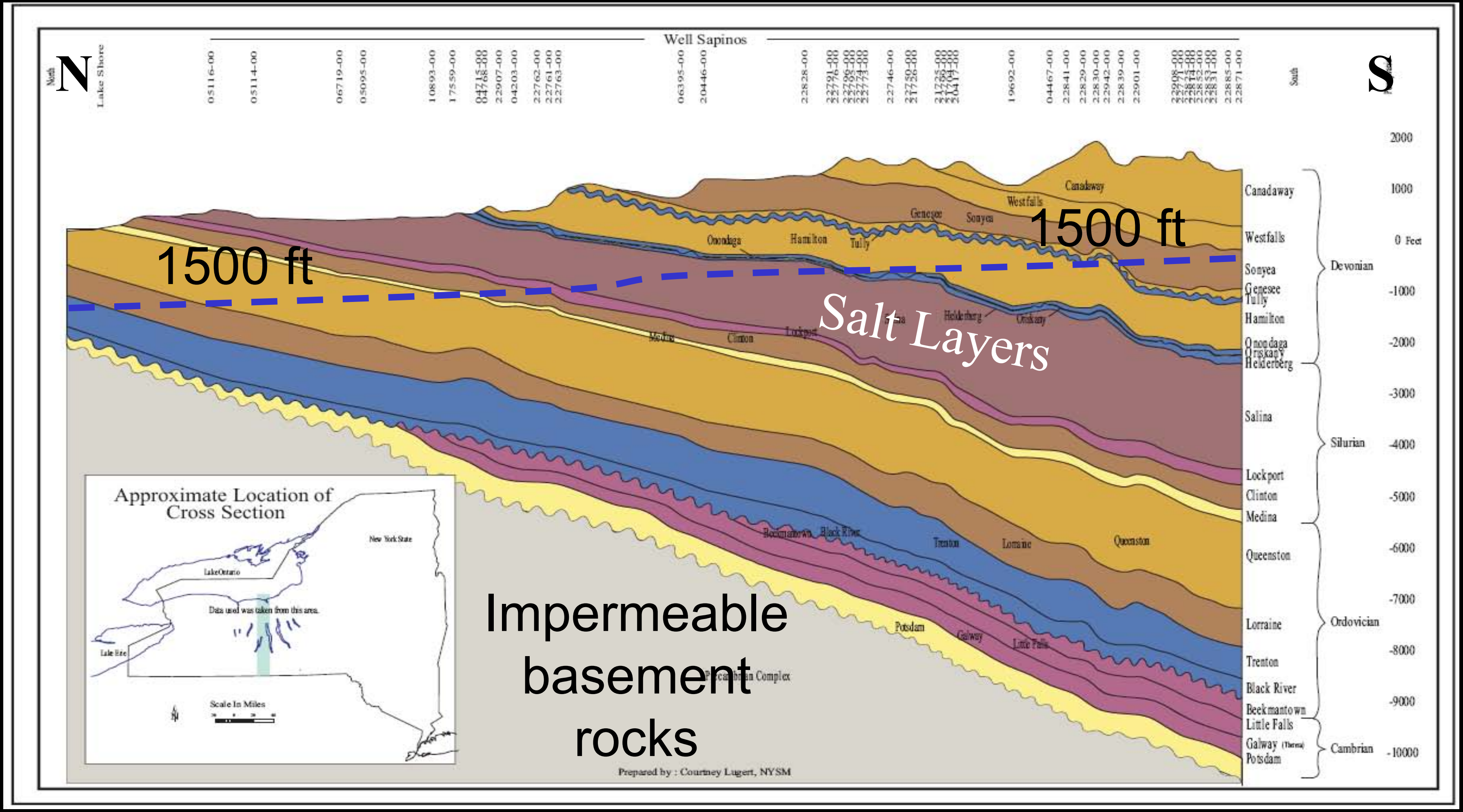




From Mesolella, 1978



Not many parts of the country have this opportunity



Prepared by : Courtney Lugert, NYSM

1500 ft

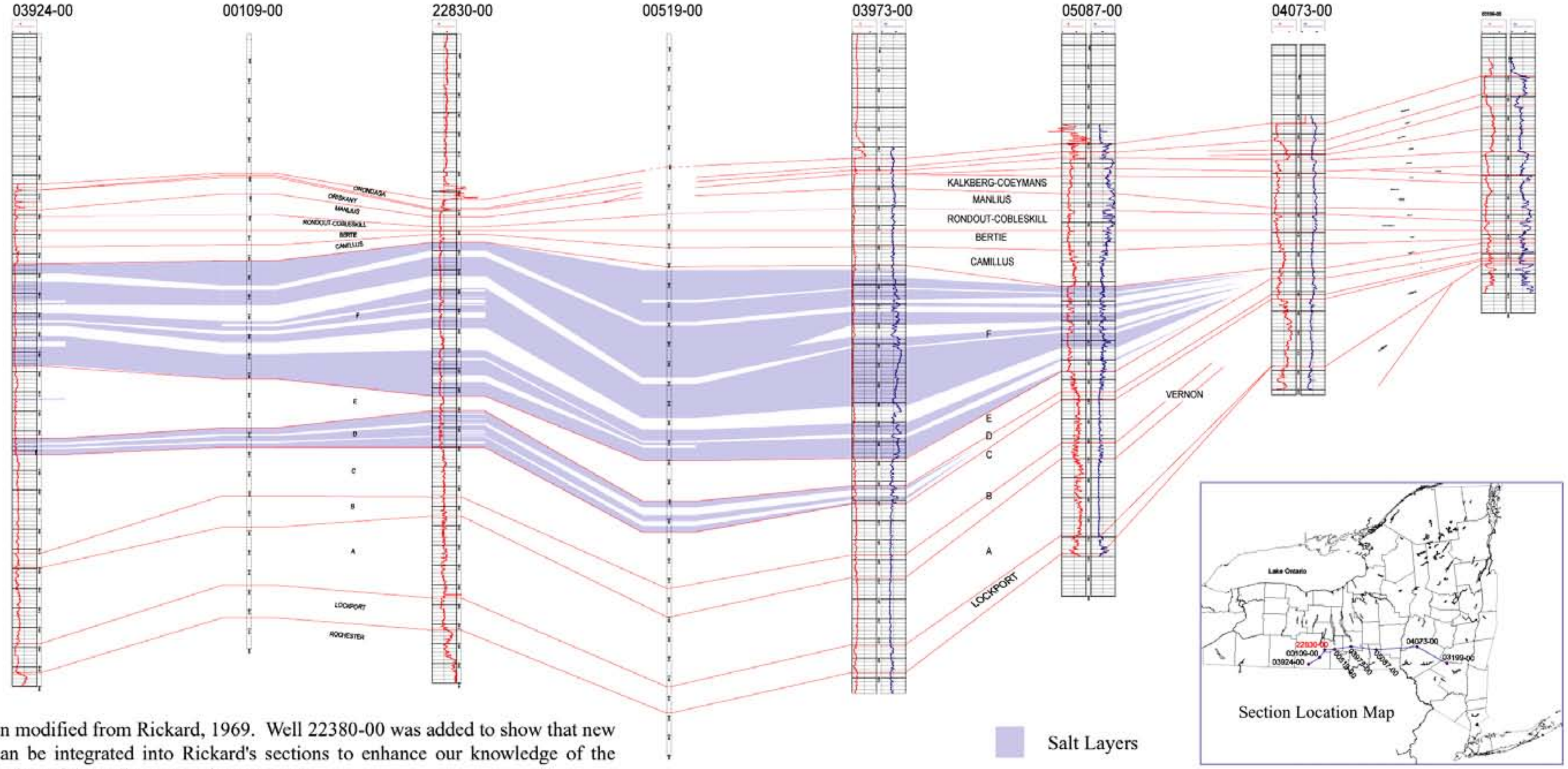
1500 ft

Salt Layers

Impermeable basement rocks

Layers dip or get deeper to the south – The Salt is in the Silurian Salina Formation – the 1500 foot minimum depth requirement

SILURIAN CROSS SECTION



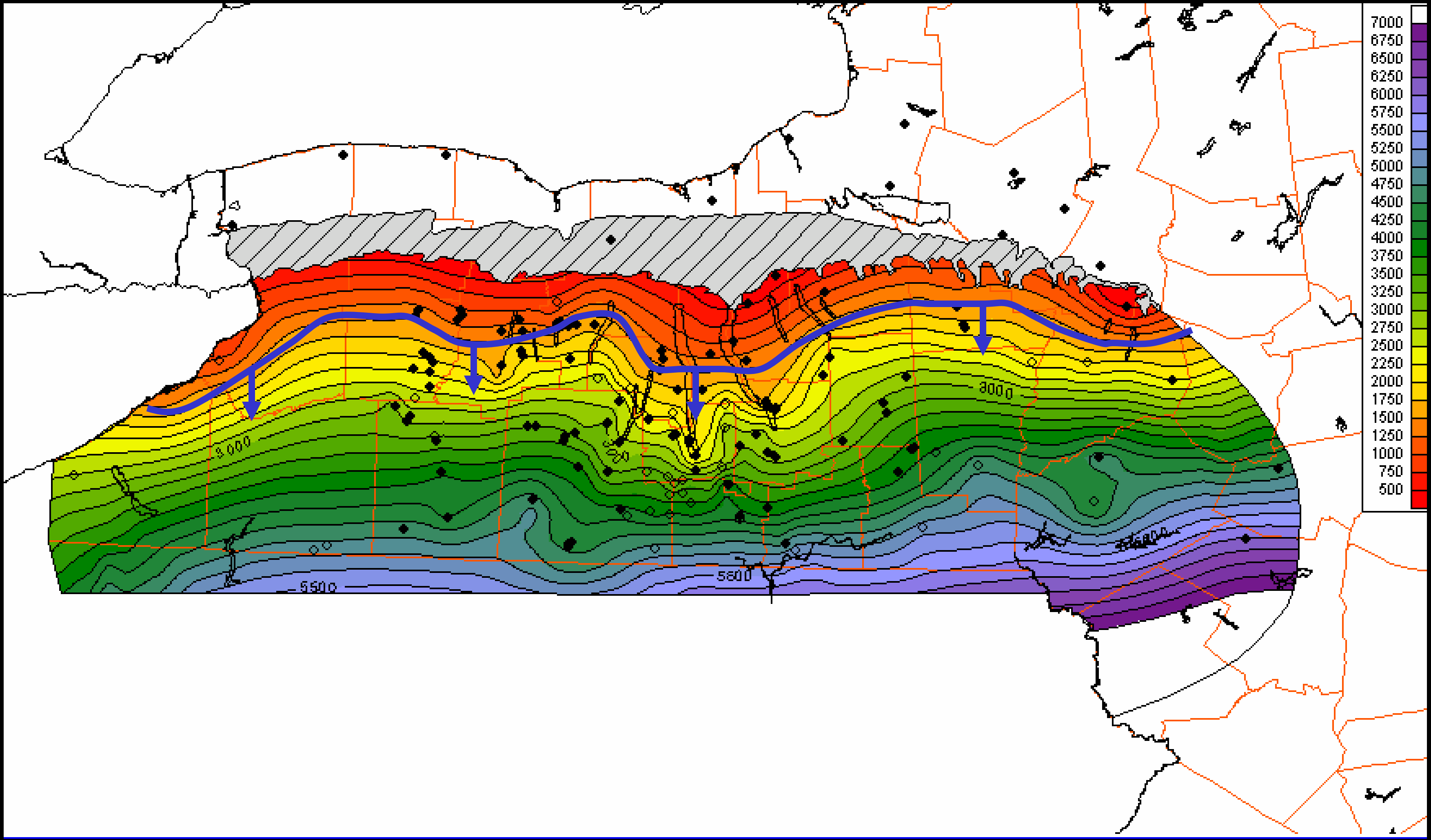
🟪 Salt Layers

Section Location Map

Section modified from Rickard, 1969. Well 22380-00 was added to show that new data can be integrated into Rickard's sections to enhance our knowledge of the distribution of the Salina Group in New York.

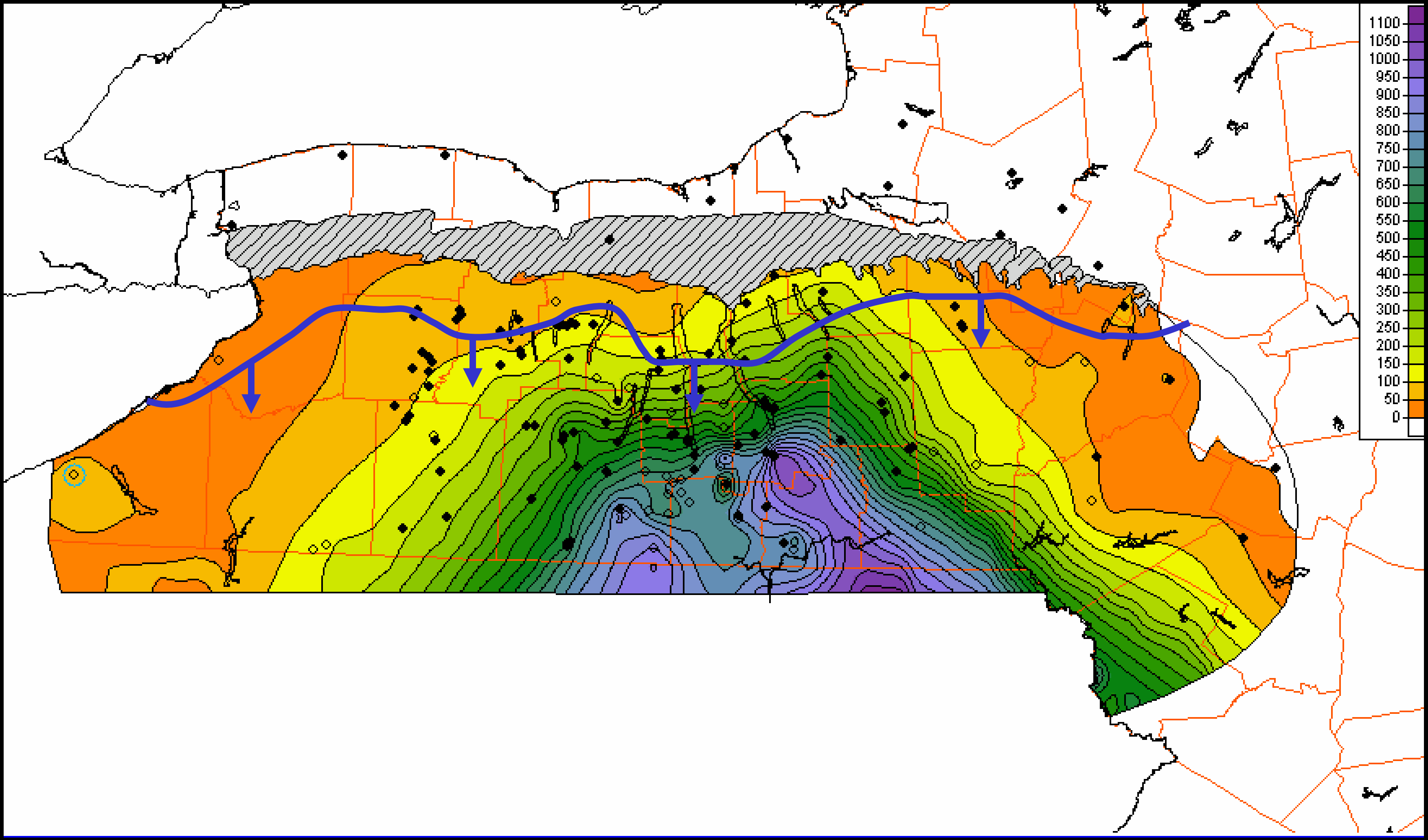
The Salt Layers are continuous from Lake Erie to the middle of the State where they thin and pinch out

Depth of Salt below Surface
Datum – Ground Level

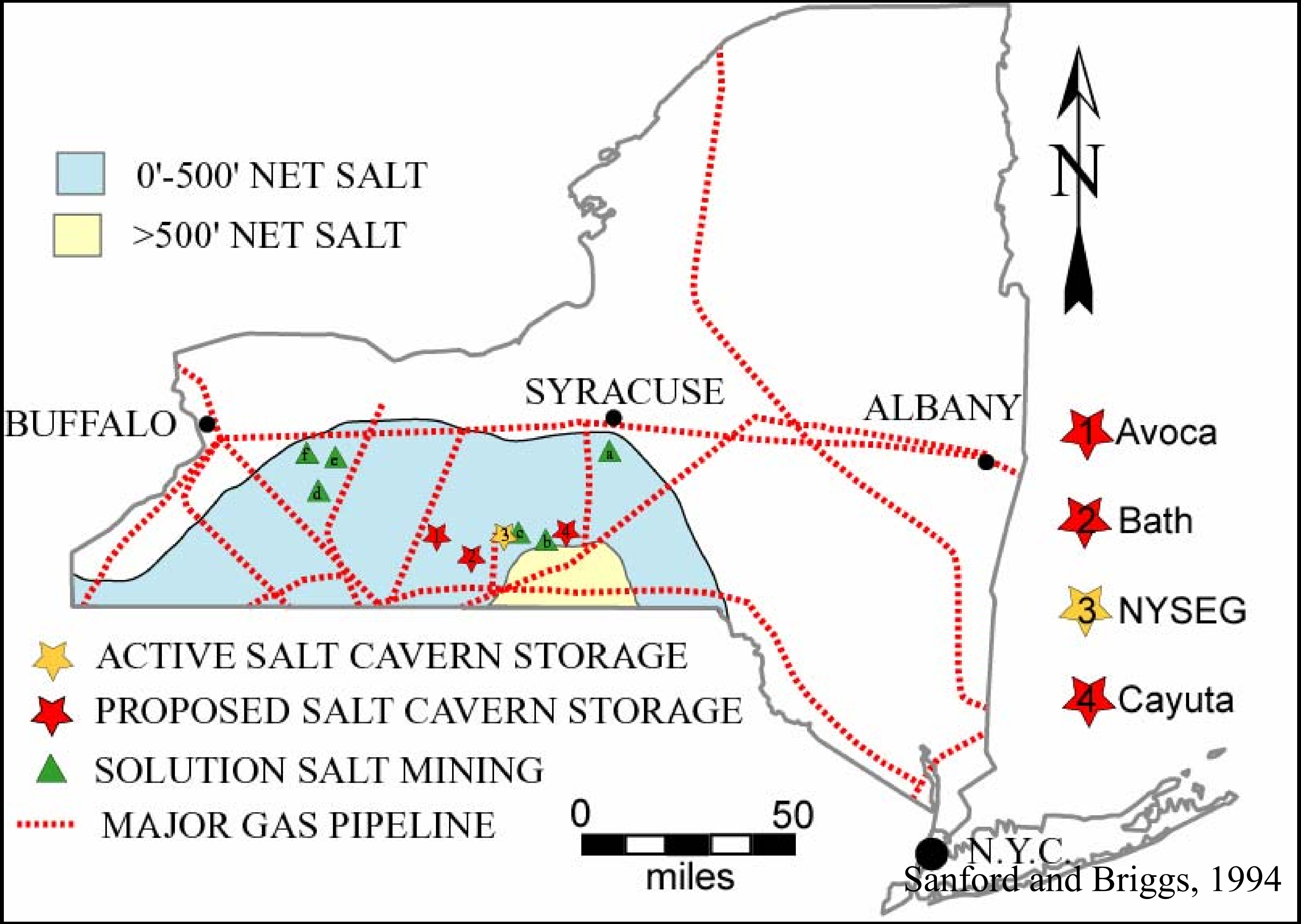


The CAES caverns would need to be south of the 1500 foot contour

Thickness of Syracuse F-unit



Anywhere in the colored area below the blue line would have potential

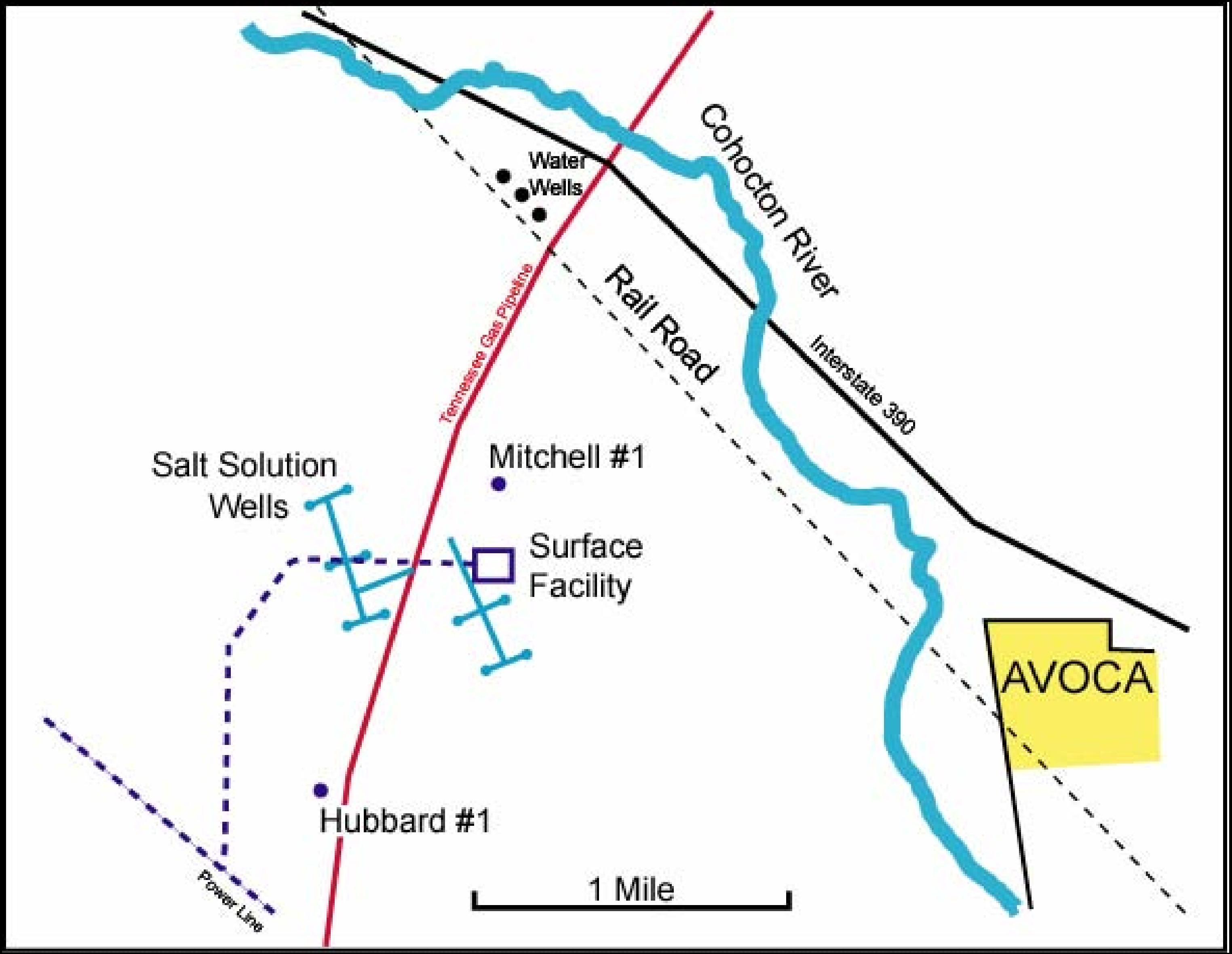


Sanford and Briggs, 1994

Would probably want to locate near a gas pipeline or gas field

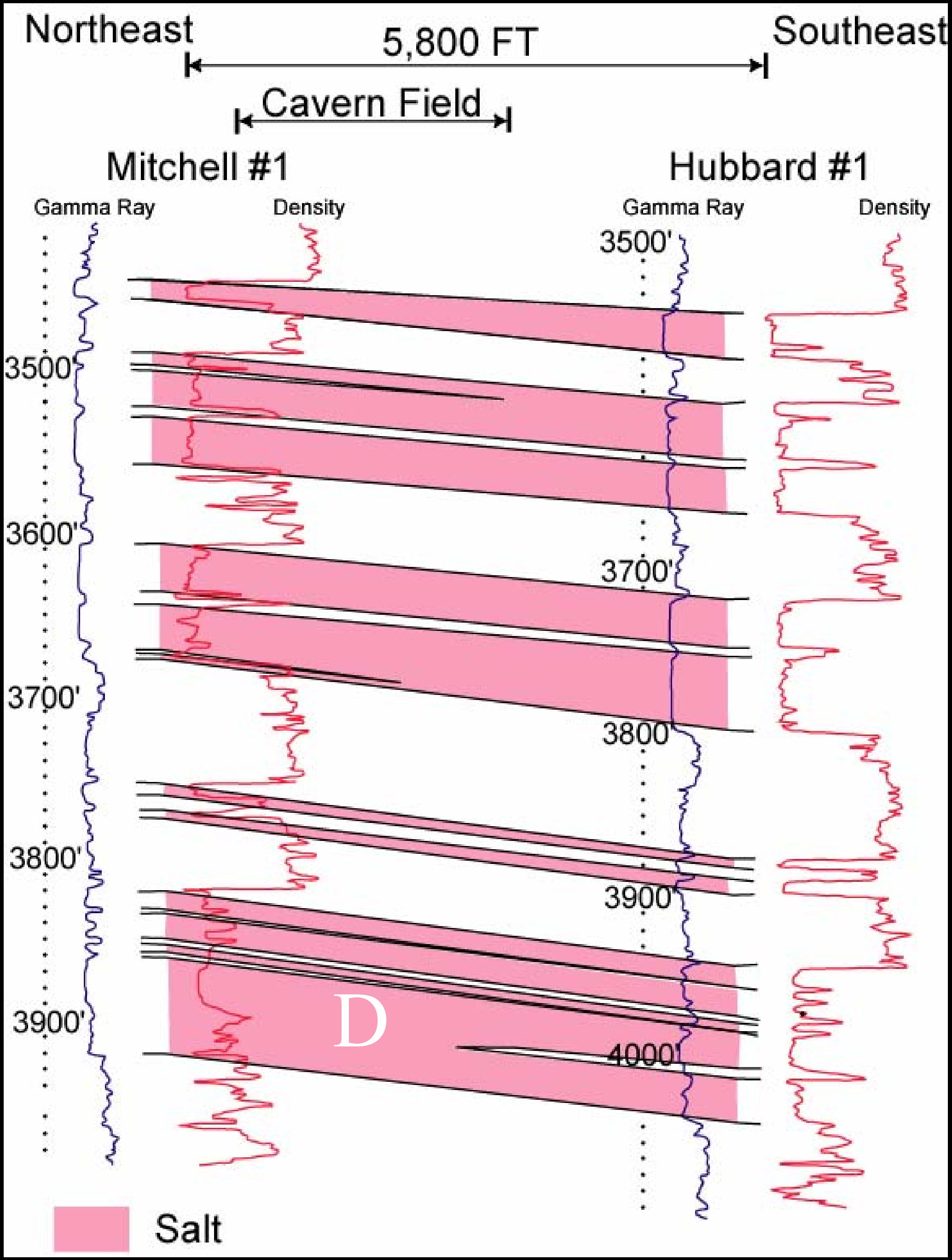
Brine Disposal

- Making the caverns should not be a problem
- It is disposing of the brine that is produced during this process that presents the biggest challenge
- Injection of brine into deeper formations is the most appealing idea
- There just are not many porous and permeable Formations

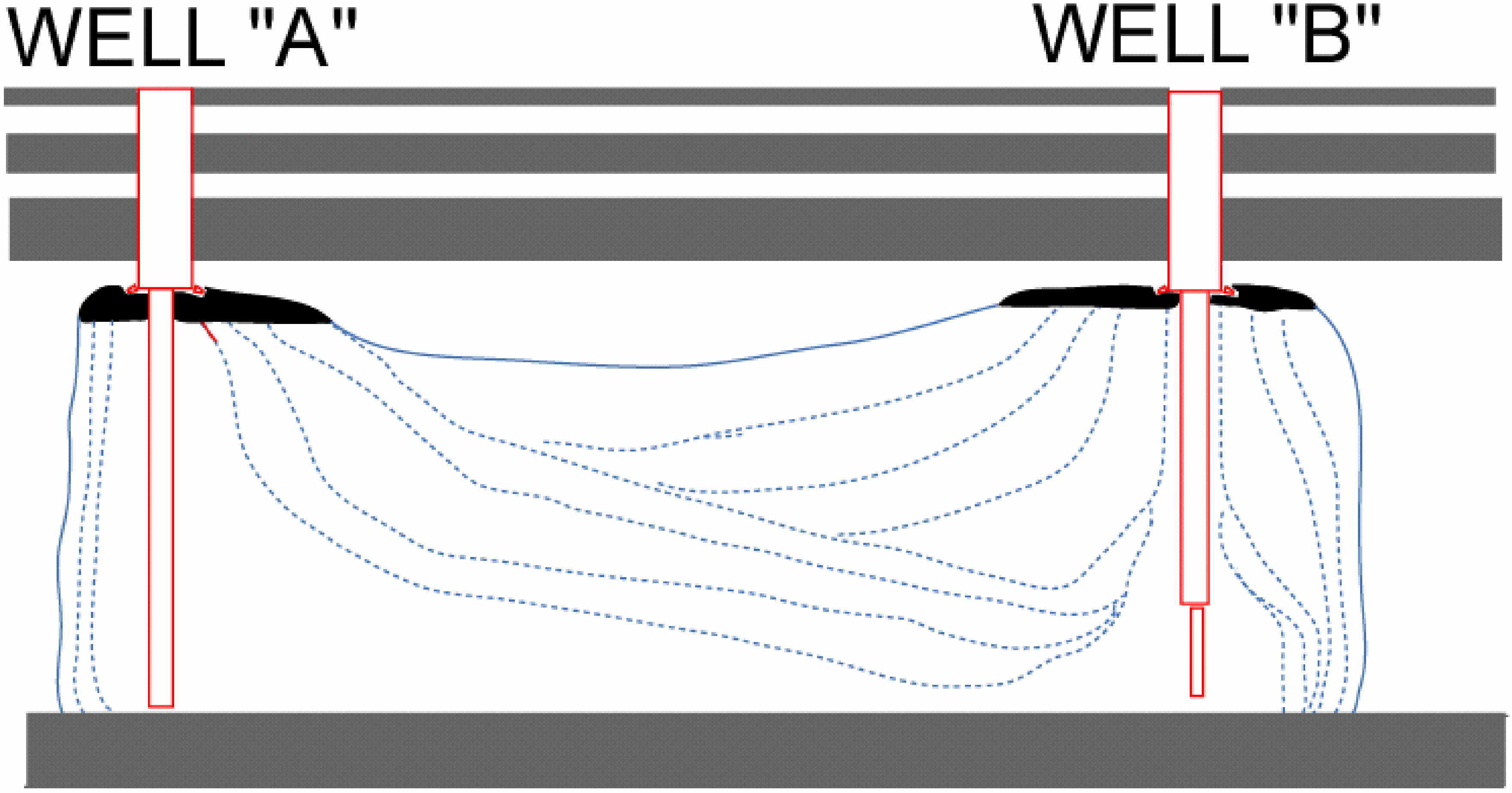


Avoca Gas Storage Project – Wanted to make large salt caverns for gas storage (>5 BCF which is significantly larger than we would need for CAES)

Avoca Well Correlation (Morrill, 1994)



Salt thickness consistent through field area



STEP 5 Leaching From Well B

What Happened?

- Everything worked except **brine disposal** – no permeable formations, earthquakes induced during injection, project went bankrupt after $100 million investment
- Never dissolved an ounce of salt
- Moral of the Story – solve brine disposal problem first, not last

Brine Injection Challenges

- Have done study of brine injection potential
- Significant volumes of brine produced during solution mining (8 volumes of brine to make 1 volume of cavern)
- Need good porosity and permeability in disposal reservoirs
- The problem in New York:
  - Porosities and permeabilities in NY and much of the Appalachian Basin are low

PERIOD		GROUP	UNIT		LITHOLOGY	ENVIRONMENT	POROSITY/ PERM.	OIL OR GAS RESERVOIR TYPE	CURRENTLY USED FOR STORAGE	POTENTIAL AS BRINE DISPOSAL RESERVOIR
DEVONIAN	UPPER	GENESEE	WEST RIVER ITHICA RENWICK SHERBURNE PENN YANN GENESEO		SHALE WITH MINOR SILTSTONE AND LIMESTONE	DEEP MARINE BASIN				NO
			TULLY		LIMESTONE WITH MINOR SILTSTONE AND LIMESTONE	LOW ENERGY			YES, 1, GILBERT	MAYBE
	MIDDLE	HAMILTON	MOSCOW LUDLOWVILLE SKANEATELES MARCELLUS		SHALE WITH MINOR SANDSTONE AND CONGLOMERATE	DEEP BASIN, UNDERWATER DELTA CHANNELS, TIDAL FLATS, OFFSHORE BARS DEEP BASIN, POOR CIRCULATION OF OXYGEN		GAS		MAYBE
			ONONDAGA		FOSSILIFEROUS LIMESTONE & REEFS	SHALLOW MARINE, MEDIUM- LOW ENERGY		GAS, REEF AND FAULT GENERATED FRACTURES	YES, 2, FRACTURED LS AND PINNACLE REEF	MAYBE
	LOWER	TRISTATES	ORISKANY		QUARTZ SANDSTONE	NEAR SHORE, SHALLOW MARINE, HIGH ENERGY	-ave. 9% -open fractures, 200-800 md	GAS, FORMATION PINCHES OUT LOCALLY FORMING TRAPS, ANY CLOSED STRUCTURALLY HIGHER POSITION	YES, AT LEAST 9	MAYBE
		HELDERBERG	MANLIUS RONDOUT		LIMESTONE AND DOLOSTONE	TIDAL, SHALLOW MARINE SHALLOW MARINE, HIGH SALINITY				NO
SIURIAN	UPPER		AKRON-COBLESKILL		DOLOSTONE AND LIMESTONE	SHALLOW MARINE, NORMAL SALINITY	< 5% < 1md	OIL AND GAS, BASS ISLAND TREND, STRUCTURAL TRAPS, FRACTURES	YES	MAYBE
		SALINA	BERTIE CAMILLUS SYRACUSE VERNON		SHALE, DOLOSTONE, ANHYDRITE AND HALITE	SHALLOW SHELF, HIGH SALINITY RESTRICTED MARINE PLAYA OR LAKE COASTAL PLAIN, SHALLOW SHELF			YES, 1- LPG, 1 OPERATIONAL AND SEVERAL PROPOSED NAT. GAS, CENTRAL NY	NO
		LOCKPORT	LOCKPORT		LIMESTONE AND DOLOSTONE STROMATALITE MOUNDS	SHALLOW SHELF TO CARBONATE FLATS		GAS, PINNICALE REEF, NO MAJOR PRODUCTION		NO
	LOWER	CLINTON	ROCHESTER IRONDEQUOIT		SHALE SANDSTONE LIMESTONE	OPEN MARINE SHELF WARM, CLEAR, SHALLOW SHELF		GAS, STRATIGRAPHIC		NO
			WILLOWVALE SAUQUOIT WOLCOTT SODUS BEAR CREEK FURNACEVILLE KODAK		SHALE SANDSTONE AND SHALE LIMESTONE SHALE HEMATITE & IRON ORE SANDSTONE	NEAR SHORE, SUBTIDAL QUIET WATER TO SHALLOW SHELF SHALLOW MARINE IN DEPRESSIONS BETWEEN NEAR SHORE RIDGES OF SAND				
		MEDINA	GRIMSBY WHIRLPOOL		SANDSTONE AND SHALE	DELTAIC - SHALLOW TURBULENT WATER		GAS, SAND DOMINATED CHANNEL DEPOSITS, PRODUCED FROM FRACTURES	10 GAS STORAGE FIELDS IN WESTERN NEW YORK	MAYBE
ORDOVICIAN	UPPER		QUEENSTON		SANDSTONE AND SHALE	DELTAIC, BRAIDED STREAM	AS HIGH AS 1940 md	GAS, UP DIP FACIES CHANGE	POTENTIAL GAS STORAGE	YES
			OSWEGO LORRAINE UTICA		SHALEY SANDSTONE SHALE WITH SANDSTONE AND SILTSTONE	NEAR SHORE AND BEACH SHALLOW AND MODERATELY DEEP MARINE DEEP BASIN		PORPOSED GAS, GAS SHALE		NO
	MIDDLE	TRENTON-BLACK RIVER	TRENTON BLACK RIVER		FOSSILIFEROUS LIMESTONE DOLOSTONE AND HYDROTHERMAL DOLOMITE	SHALLOW MARINE, TIDAL FLATS AND SLOPE SHALLOW SHELF		GAS, VUGGY HYDROTHERMAL DOLOMITE, FRACTURES-TUG HILL AREA		YES
	LOWER	BEEKMAN-TOWN	TRIBES HILL		DOLOSTONE, LIMESTONE AND SILSTONE					
	UPPER		LITTLE FALLS THERESA (GALWAY)		DOLOSTONE SANDSTONE	TROPICAL COASTAL COMPLEX	Numerous porous zones in upper portion of L.F.	GAS, vuggy dolomite, STRUCTURAL CLOSURE OF FRACTURE SYSTEM	POTENIAL STORAGE RESERVOIR	YES
			POTSDAM		AND SANDY DOLOSTONE QUARTZ SANDSTONE		Basal Potsdam extremely porous and permeable			
PRECAMBRIAN			MARBLE QUARTZITE etc>		METAMORPHIC AND IGNEOUS ROCKS					NO

🟨 YES

- Right Lithology
- Good Porosity and Permeability
- History of Production
- Not used as a storage reservoir

🟪 MAYBE

- All of the above and currently used for storage

⬜ NO

- No good reservoir properties

Brine Disposal

- Systematic Study of brine disposal reservoirs revealed that there are a few formations that might accept brine
- There is competition for the more porous and permeably formations from gas storage and CCS
- Other options include salt mining, pipelines or trucking to ocean, low-rate release into rivers during high-water events, evaporation in ponds

Conclusions

- There is some potential for CAES in depleted reservoirs but there is competition for the pore space
- The best opportunities lie with salt caverns
- The problem is where to put the brine that comes from salt dissolution
- There is some potential for injecting the brine, but this cannot be taken for granted
- There are other possible options for brine disposal but a solution to this problem should be developed before undertaking a cavern project

5.3 Jon Myers, Location Independent Engineered Reservoir Systems: An Alternative to Conventional Reservoir Models

Jon Myers, is a Co-Founder and CEO of SEQEnergy.
Jon Myers is a 'serial' high tech entrepreneur having founded companies in computing, software and services. Prior to founding his first business in 1996, Myers spent seventeen years on Wall Street as an executive in a number of roles. Myers was educated at Williams College and Kellogg Graduate School of Management.

SEQEnergy LLC

Presentation for

NYSERDA / Columbia University

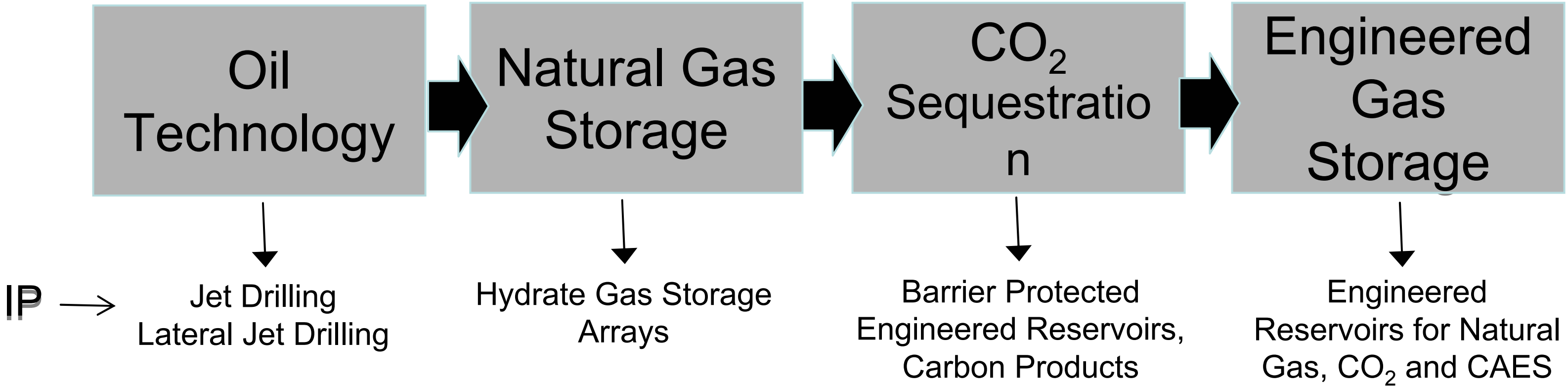
CAES Workshop

October 21, 2008

Historical Perspective

- SEQEnergy is focused on developing new gas storage technologies that can improve efficiency and return on assets
- Proprietary method for construction of gas storage reservoirs to address the risk of site scarcity and the need for location optimization

SEQEnergy Technology Applications Flow Chart



Oil Technology → Natural Gas Storage → CO_2 Sequestration → Engineered Gas Storage

IP → Jet Drilling
Lateral Jet Drilling

Hydrate Gas Storage Arrays

Barrier Protected Engineered Reservoirs, Carbon Products

Engineered Reservoirs for Natural Gas, CO_2 and CAES

Business Challenge

- Current models for gas storage introduce business risks
  - *Scarcity*: Limited availability of sites with acceptable pre-conditions
    - Potentially large increase in demand would exacerbate the problem
  - *Time*: Time and cost to find, test and qualify sites
  - *Scale*: Facility scale limited or determined by size of reservoir
  - *Location*: Reservoir locations may not be optimal
  - *Safety and Rights*: Difficult to mitigate safety and rights issues

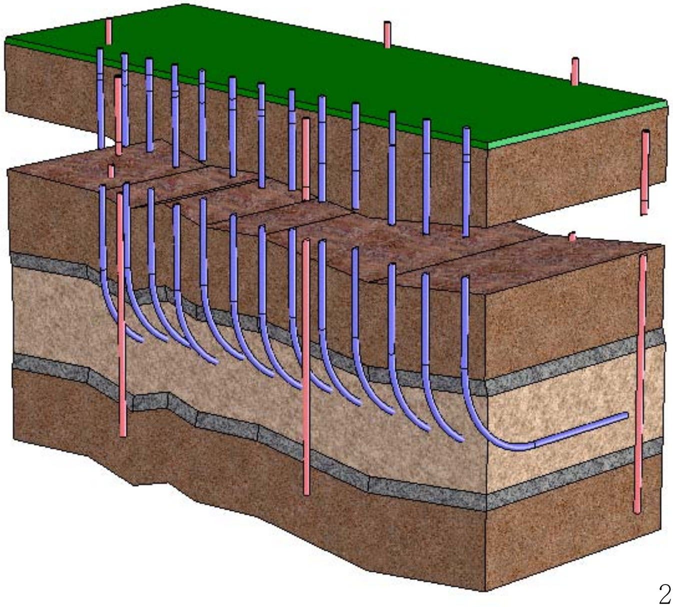
Reservoir Solution Objectives

"What if there were a way to construct a safe, optimally located and sized gas storage reservoir?"

- An engineered gas storage solution will meet these objectives:
    - *Strategic:* Capable of placing gas storage where it is needed, independent, as much as possible, from conventional geologic requirements
    - *Economic*: Cost-effective and comparable to conventional alternatives
    - *Scalable*: Turn-key system capable of integration with gas and power transmission and power production systems throughout the world

SEQ Storage System

- Patented non-excavated, pressure-balanced, barrier isolated storage
  - Storage in *porosity* of the geology – *no* excavation
  - Geology provides the balancing containment pressure
  - Containment enhanced by insertion of barriers
    - Reservoir is isolated, monitored and repairable
  - Scalable from 10,000 MCF to 10 BCF
  - Constructed with conventional, proven systems
- Proven analog
  - Natural gas storage in depleted fields
  - Storage in porosity is done today on large scale in depleted fields



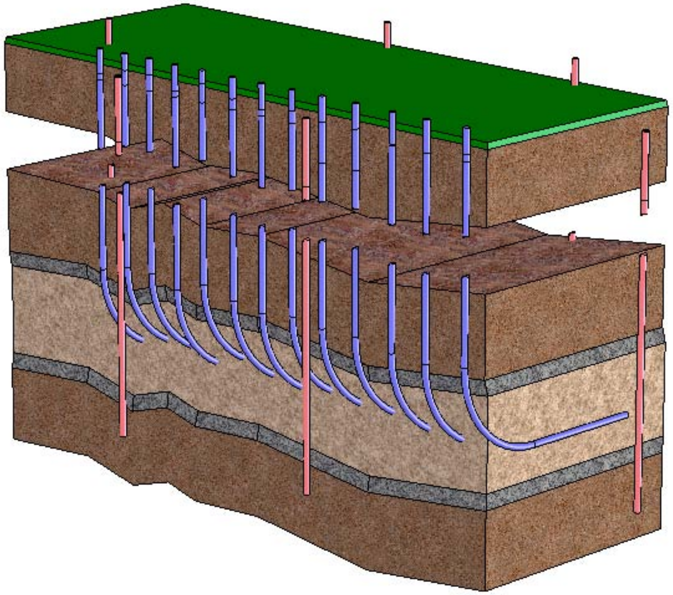
Business Benefits

- Economics of SEQEnergy Reservoir System are consistent with current costs for conventional reservoirs
  - Projected CO_2 ~ $12 per CO2 tonne, comparable to leading projections for CO_2 sequestration[1]
  - Projected Natural Gas ~ $13 per MCF, comparable to salt dome development cost[2]
  - Projected CAES ~ $0.35 per Watt, in range of projections for conventional reservoirs[3]
- Locatable in much of the U.S. without the requirement for conventional geologic features
- Scalable solution capable of meeting customer's optimal scale requirement
- Engineered control, safety and management features

1. MIT Energy Initiatives
2. Energy Information Administration
3. Dr. James Mason

Conclusion

- SEQEnergy is interested in working with CAES sponsors
  - Determine requirement for engineered (vs. traditional) reservoirs
  - Proof of concept in development of a prototype SEQ reservoir
- We invite your comments and questions!
- Thank You



6.1 Rahul Walawalkar, CAES Performance Requirements & Opportunities in NY

Rahul Walawalkar, is a Sr. Energy Consultant with Customized Energy Solutions. Since 2004, Rahul has been involved in evaluating economics of emerging energy storage technologies in deregulated electricity markets. He has authored a number of papers in this area including reports for New York State Energy Research and Development Authority (NYSERDA), American Public Power Association (APPA) and National Energy technology Labs (NETL). He has also worked as an Energy & IT Analyst with various companies including EPS Capital Corp, Alliance to Save Energy (ASE) and Tata Infotech Ltd. Rahul received a Ph.D. in Engineering and Public Policy from Carnegie Mellon University in 2008. He obtained Masters in Energy Management at New York Institute of Technology in 2003 and completed undergraduate studies in Electrical Engineering at Walchand College of Engineering, India in 1997. He is a Certified Energy Manager (CEM) and Certified Demand Side Management (CDSM) Professional.

CAES PERFORMANCE REQUIREMENTS & OPPORTUNITIES IN NY

Rahul S. Walawalkar Ph.D., CEM, CDSM

Sr. Energy Consultant

CUSTOMIZED ENERGY SOLUTIONS

Compressed Air Energy Storage (CAES) Scoping Workshop

Columbia University, NY: October 21st 2008

-Preliminary Draft –not to be quoted or cited-

Acknowledgement

- This research is funded in part by NYSERDA.
  - Mark Torpey, Program Manager
  - Greg Pedrick, Project Manager

- I acknowledge important contributions of
  - James Harvilla, Program Manager, NYSEG
  - Lisa Hoffman, President, Southern Tier Environmental Services
  - Netra Thakur, Analyst, Customized Energy Solutions
  - Rick Mancini, Director, Regulatory Affairs, NY for Customized Energy
  - Stephen Fernands, President, Customized Energy Solutions
  - Dr. Robert Schainker, EPRI
  - Dr. Mike Nakhamkin, Director & CTO, Energy Storage & Power LLC.

Outline

- Electric & Gas Infrastructure in NY
- Overview of NYISO
- Opportunities for CAES in NYISO
  - Energy Arbitrage
  - Ancillary Services
- Performance Criteria for CAES
- Conclusions

NY ENERGY INFRASTRUCTURE & GEOLOGY FOR STORAGE

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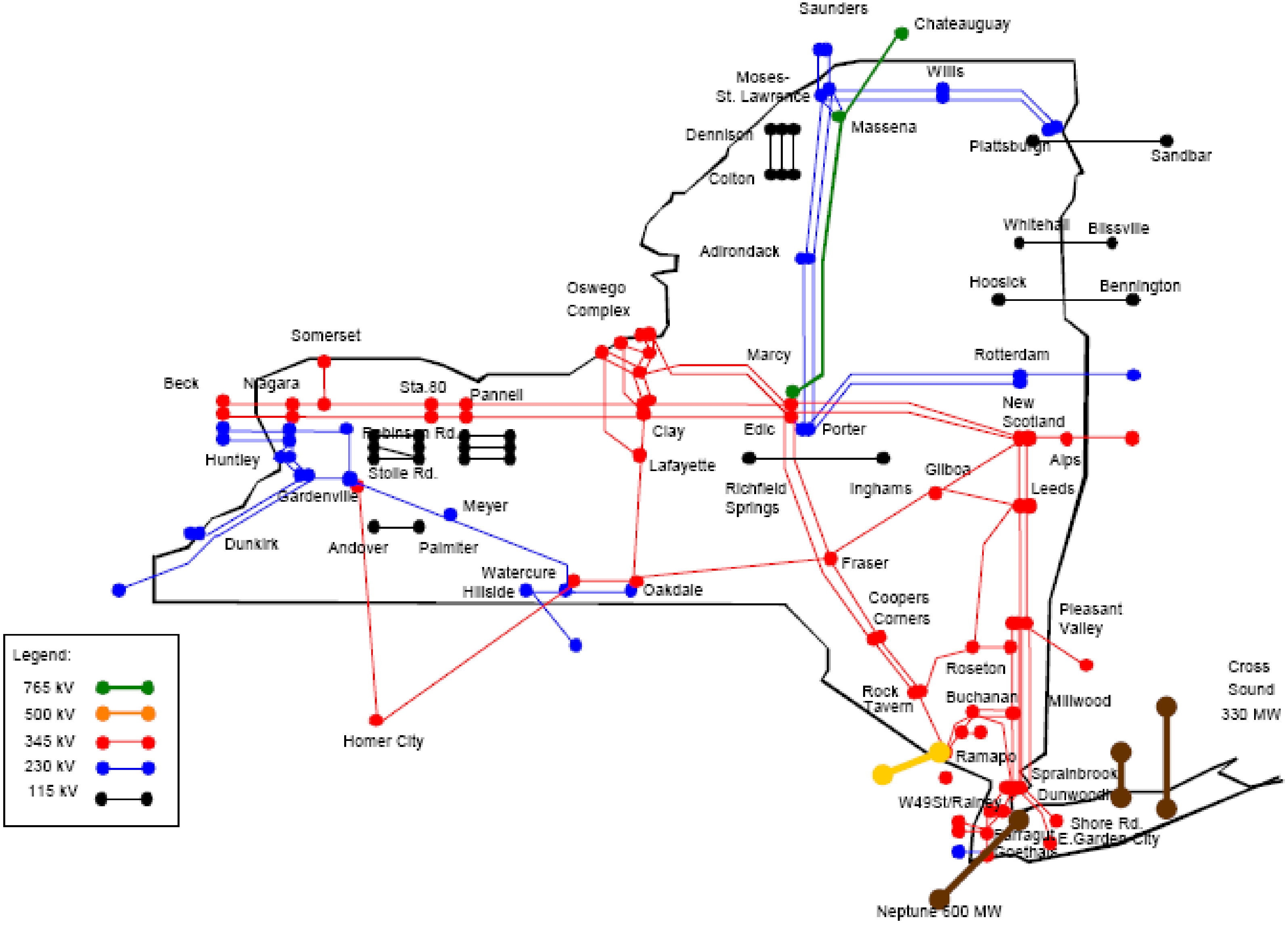
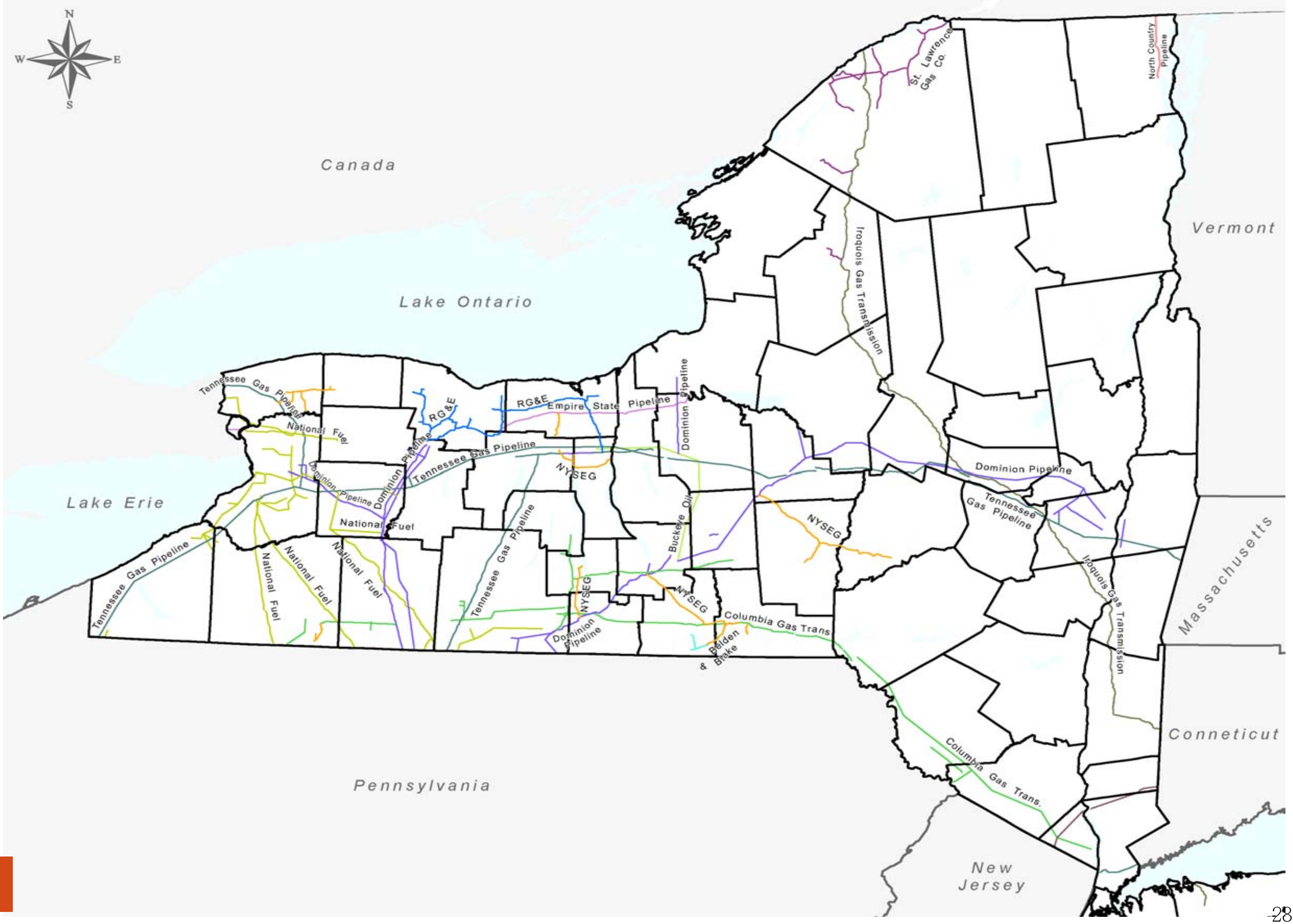
NY: Electric Transmission System



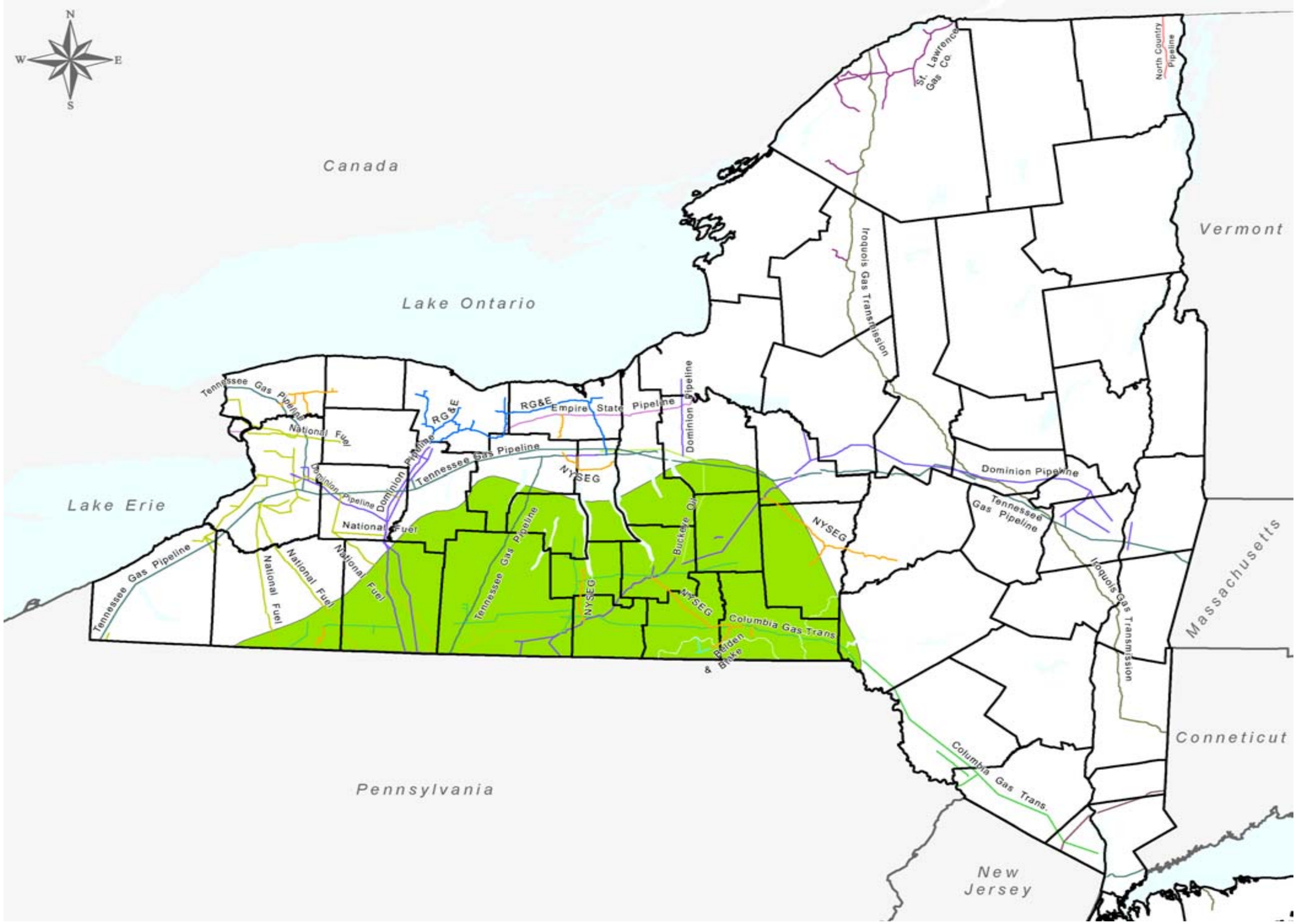
NY: Gas Transmission Lines



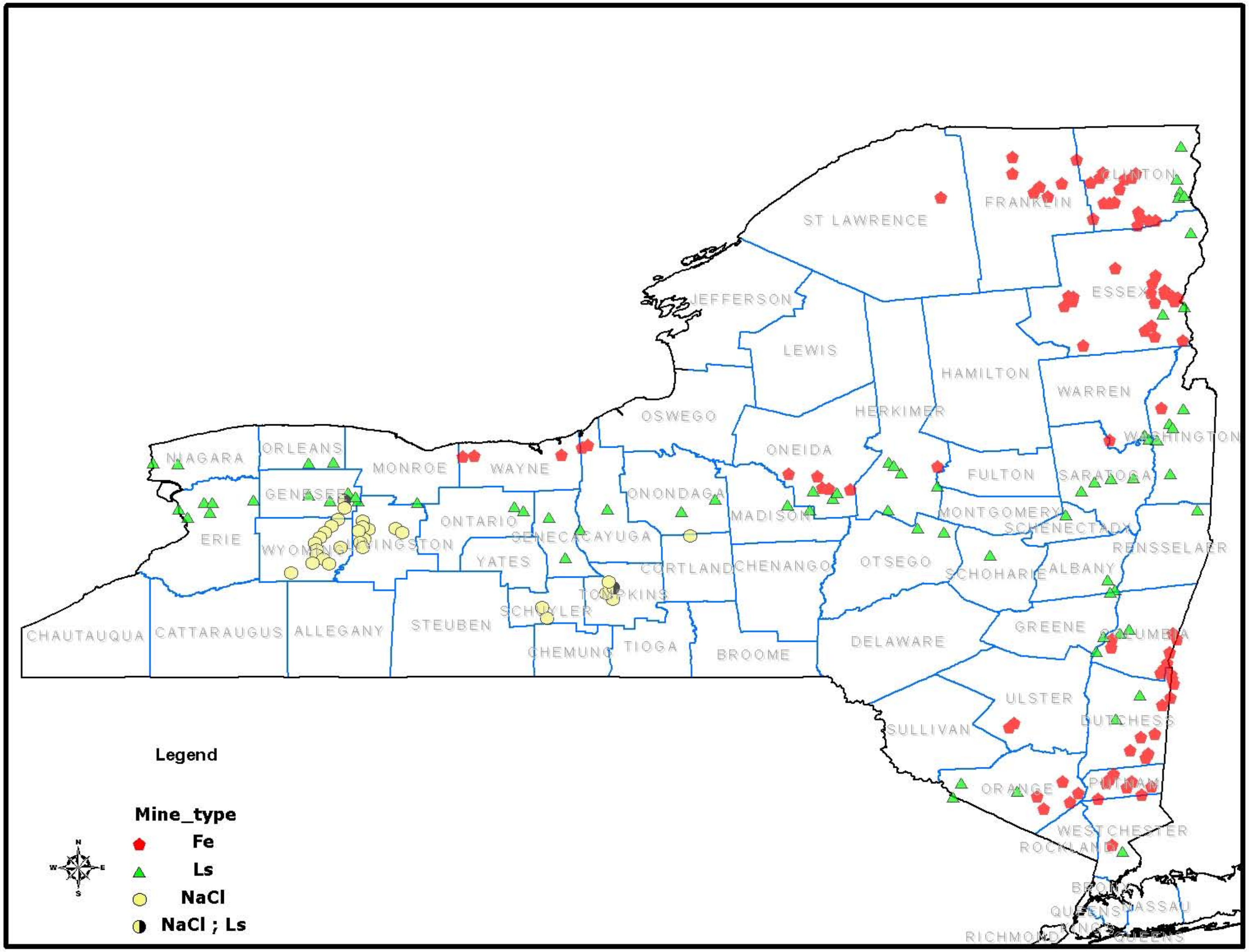
Geology Suitable for CAES

- Existing or new salt caverns
- Depleted oil or gas reservoirs
  - Marcellus Shale
  - Trenton Black River
- Certain types of aquifers
- Abandoned mines
- Rock formations

NY: Salt Caverns



NY: Mines


ST LAWRENCE
FRANKLIN
CLINTON
ESSEX
JEFFERSON
LEWIS
HAMILTON
WARREN
OSWEGO
HERKIMER
WASHINGTON
ONEIDA
NIAGARA
ORLEANS
MONROE
WAYNE
FULTON
SARATOGA
GENESEE
ONONDAGA
MADISON
MONTGOMERY
SCHENECTADY
ERIE
WYOMING
LIVINGSTON
ONTARIO
SENECA
CAYUGA
RENSSELAER
YATES
CORTLAND
CHENANGO
OTSEGO
SCHOHARIE
ALBANY
TOMPKINS
SCHUYLER
CHAUTAUQUA
CATTARAUGUS
ALLEGANY
STEUBEN
CHEMUNG
TIOGA
BROOME
DELAWARE
GREENE
COLUMBIA
ULSTER
DUTCHESS
SULLIVAN
ORANGE
PUTNAM
WESTCHESTER
ROCKLAND
BRONX
QUEENS
NASSAU
KINGS
RICHMOND
QUEENS
Legend
Mine_type
Fe
Ls
NaCl
NaCl ; Ls
N
S
E
W

OVERVIEW OF NYISO

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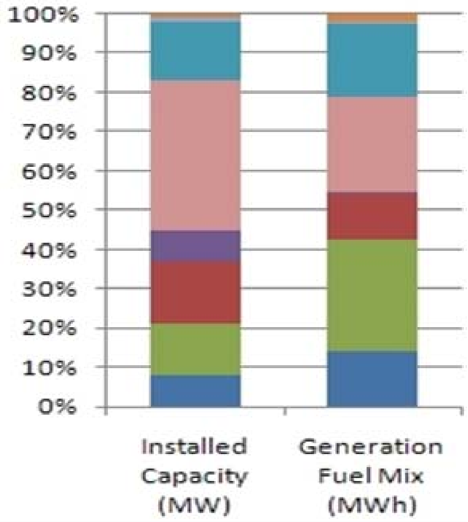
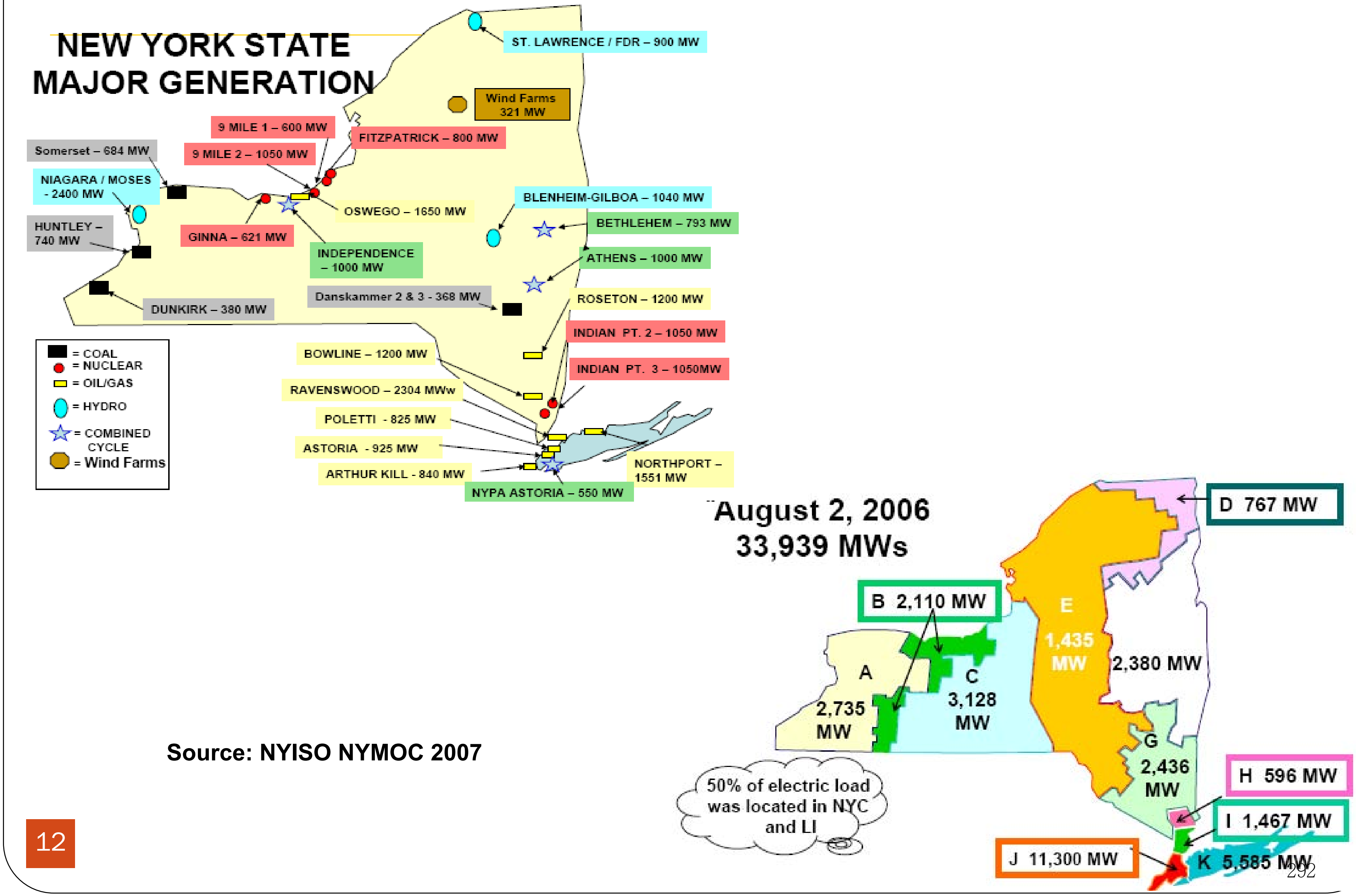
Overview of NYISO

	NYISO
Population Served	**19 Million**
States (All or parts of)	**NY**
Generation Units	**235+**
Peak Load (Pre 2006)	**33.9 GW (32.1 GW)**
Generation Capacity	**39.7 GW**
Generation Mix 🟧 Other 🟦 Wind 🟦 Hydro 🟥 Gas & Oil 🟪 Oil 🟥 Natural Gas 🟩 Nuclear 🟦 Coal	

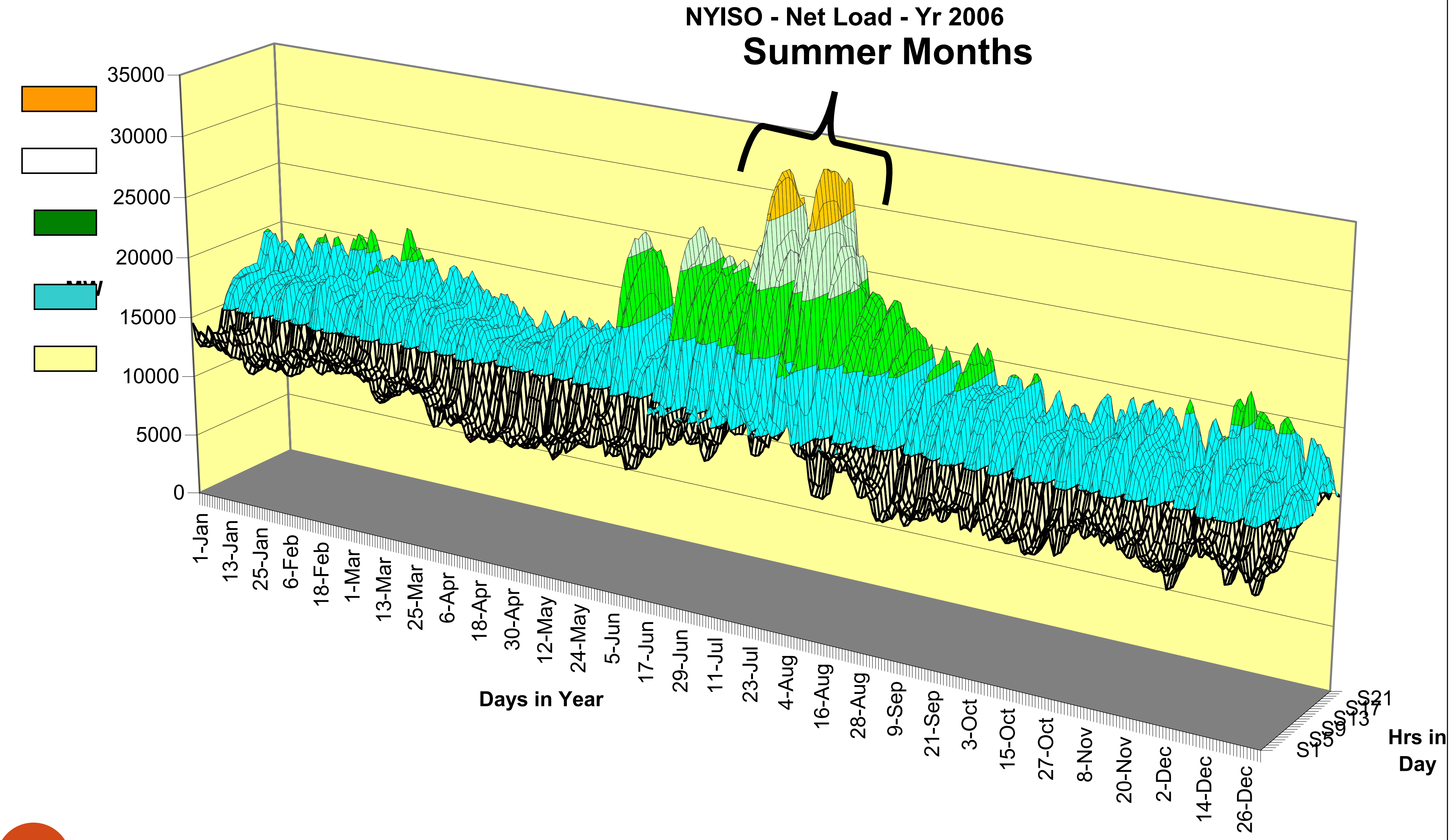
Source: NYISO & FERC

NYISO Major Generation & Zonal Loads

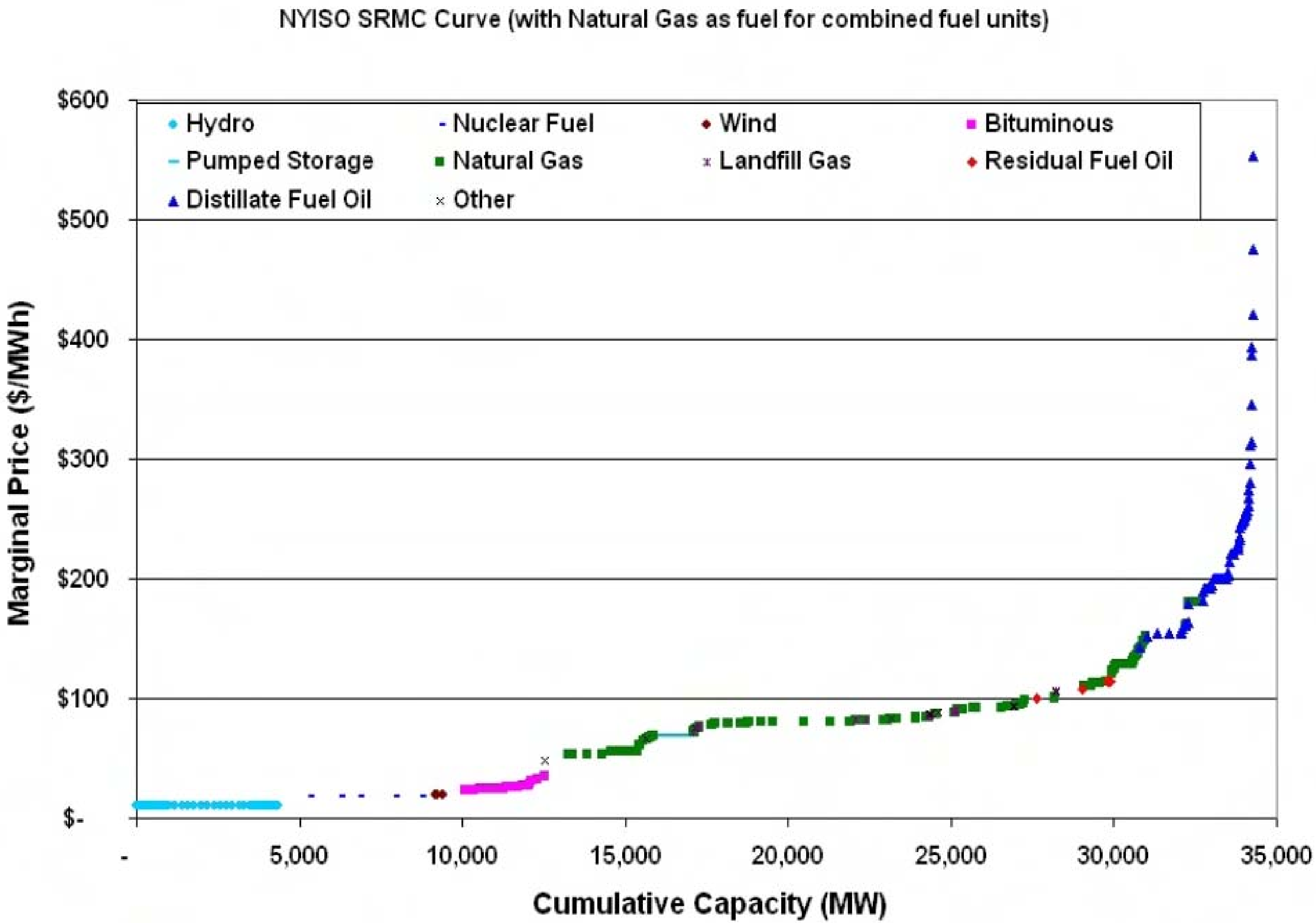


Source: NYISO NYMOC 2007

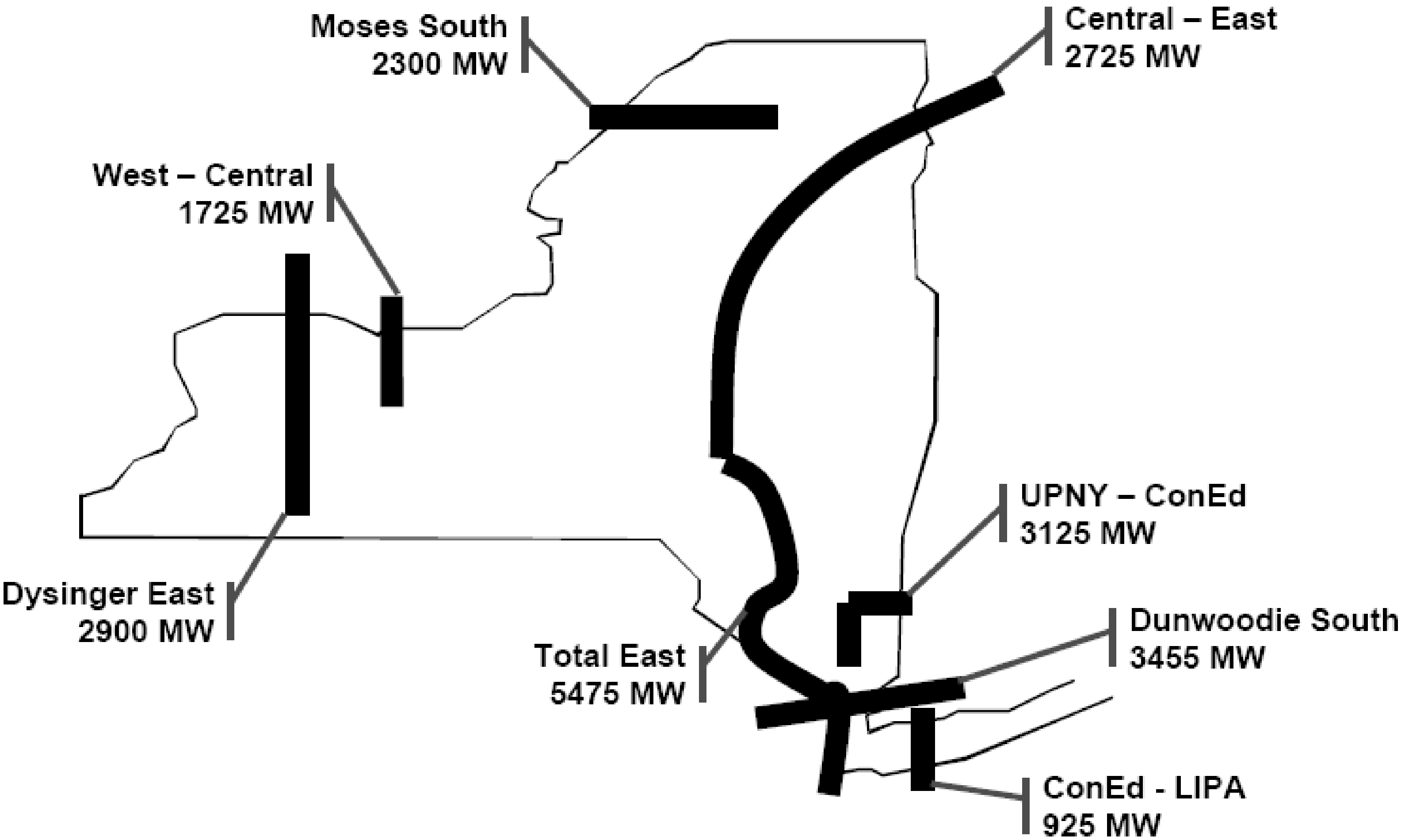
NYISO Net Load - 2006



NYISO Short Run Marginal Cost Curve

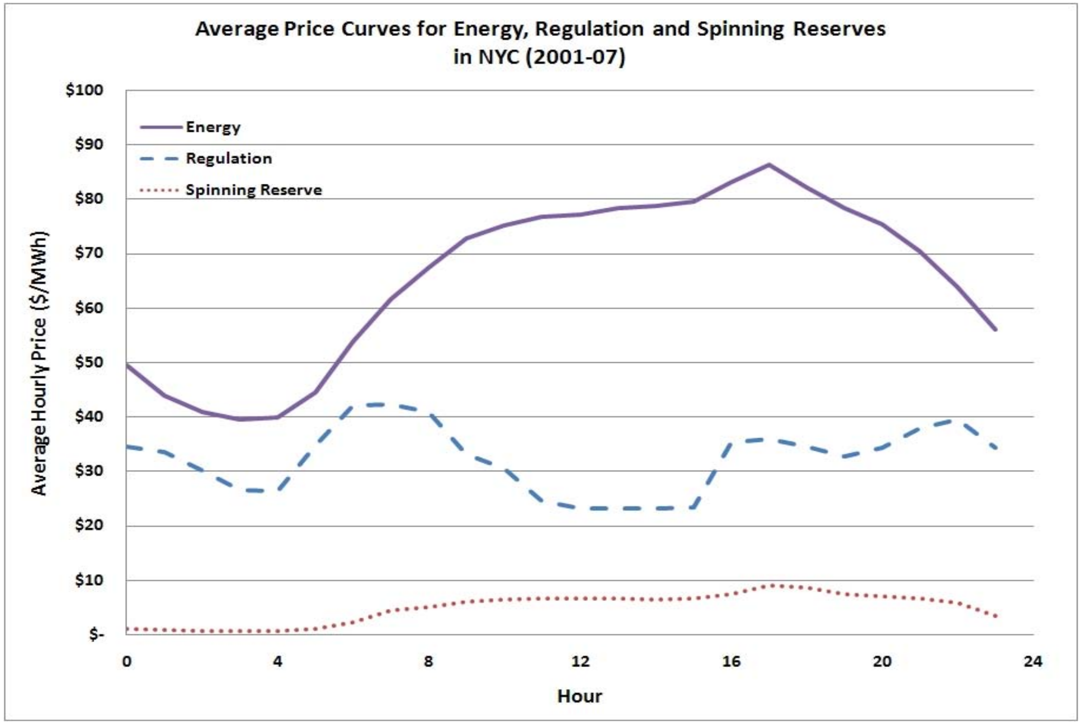


NY: Electric Transmission Interface Limits



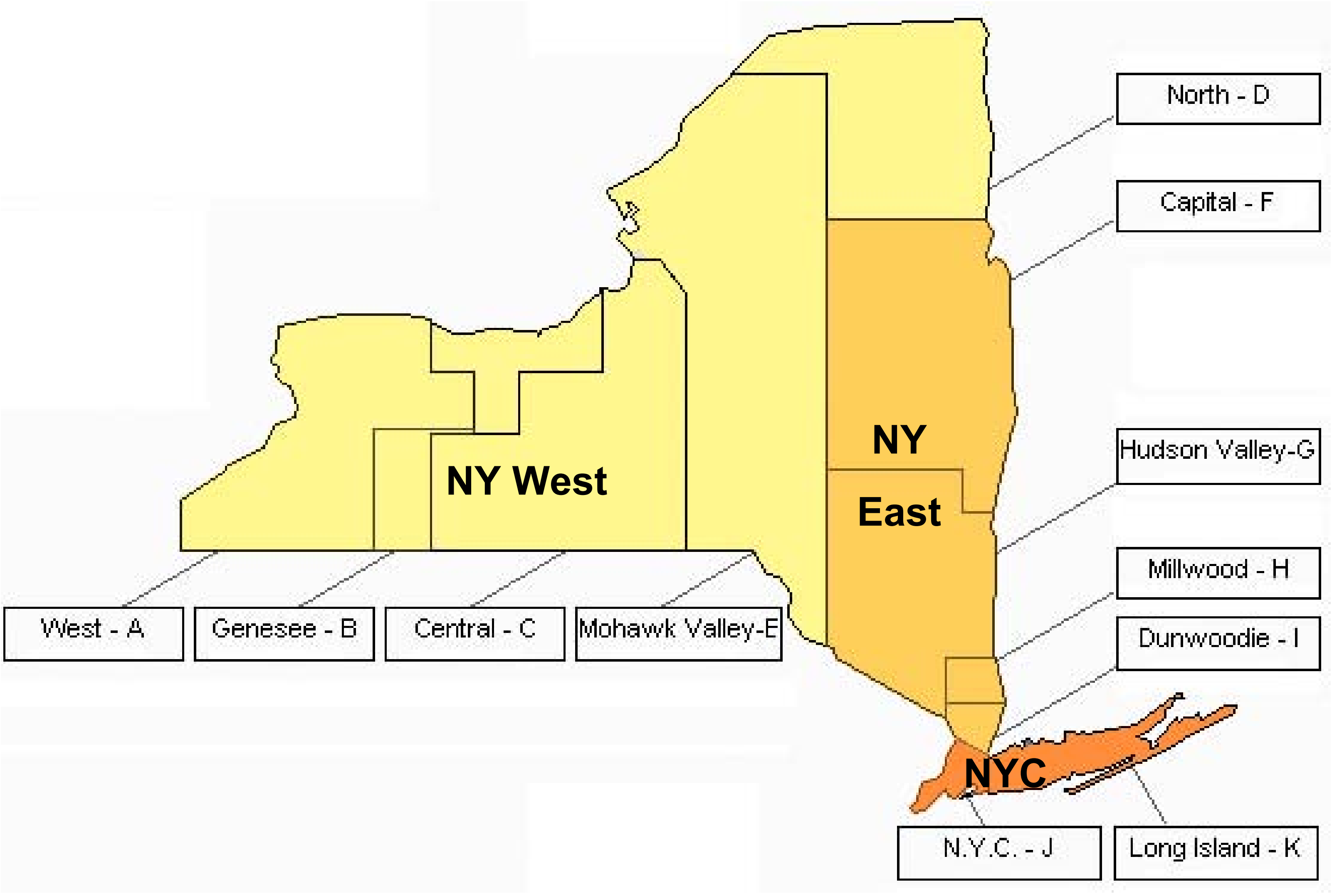
Source: NYISO NYMOC 2007

Opportunities For CAES

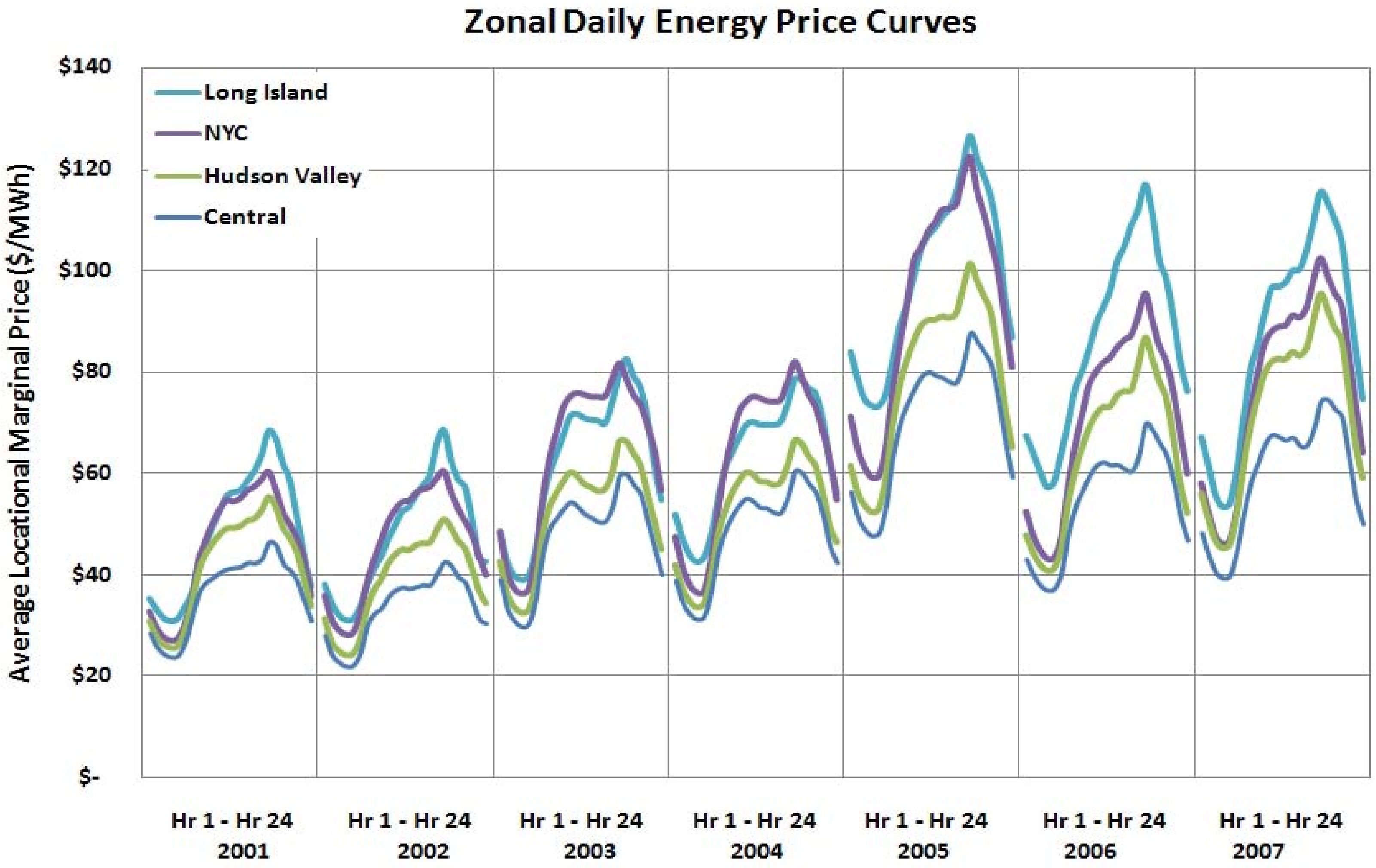


- Energy Arbitrage
- Ancillary Services
  - Regulation
  - Reserve
- Installed Capacity (ICAP)
- Deferral of investment in
  - Peaking Generation
  - Transmission & Distribution
- Supporting Renewable Energy Sources
  - NYISO is anticipating more than 3000 MW of wind over next 4-5 years
  - Environmental Emissions Credits

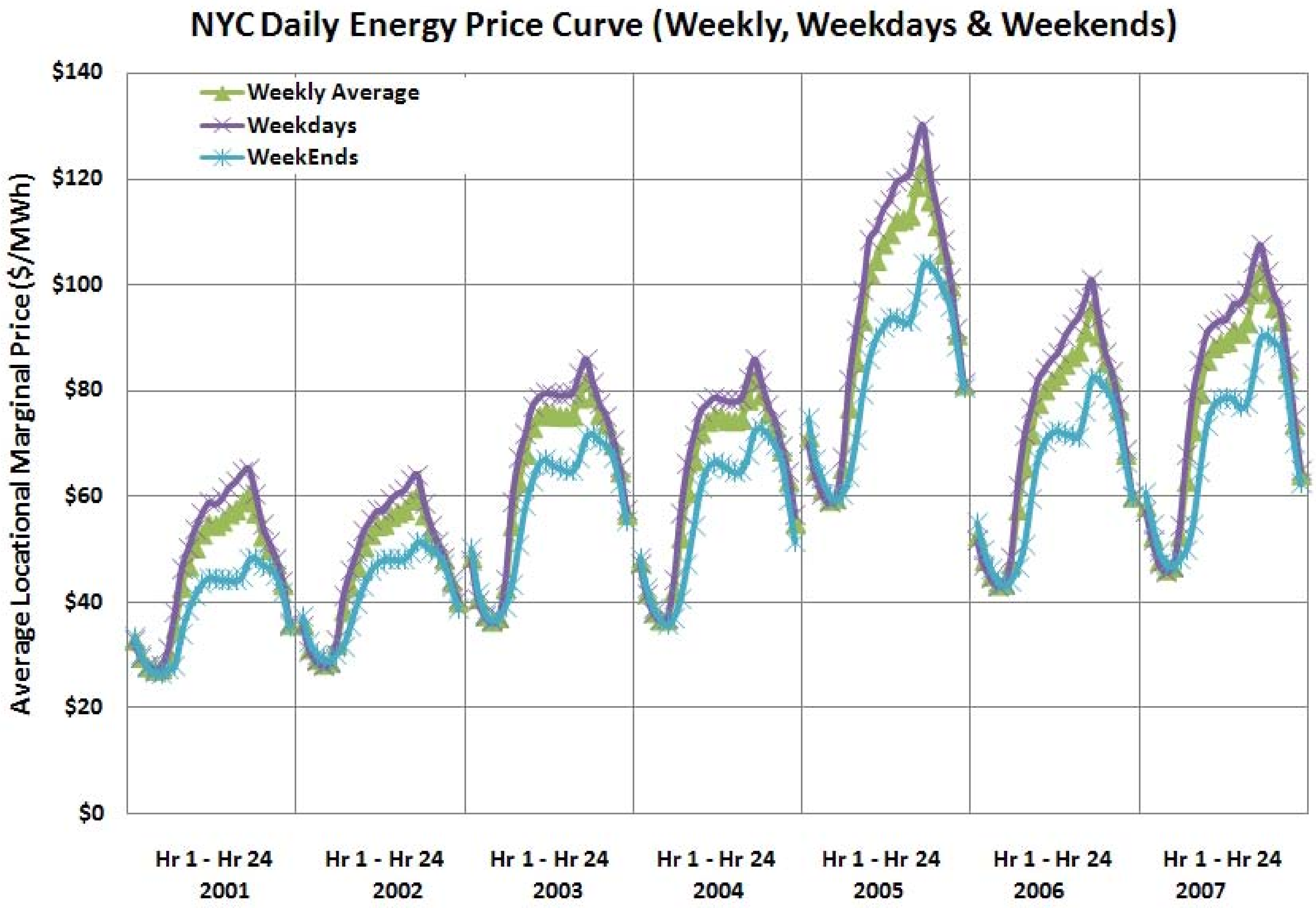
NYISO: Regions



NYISO Average Energy Price Profiles



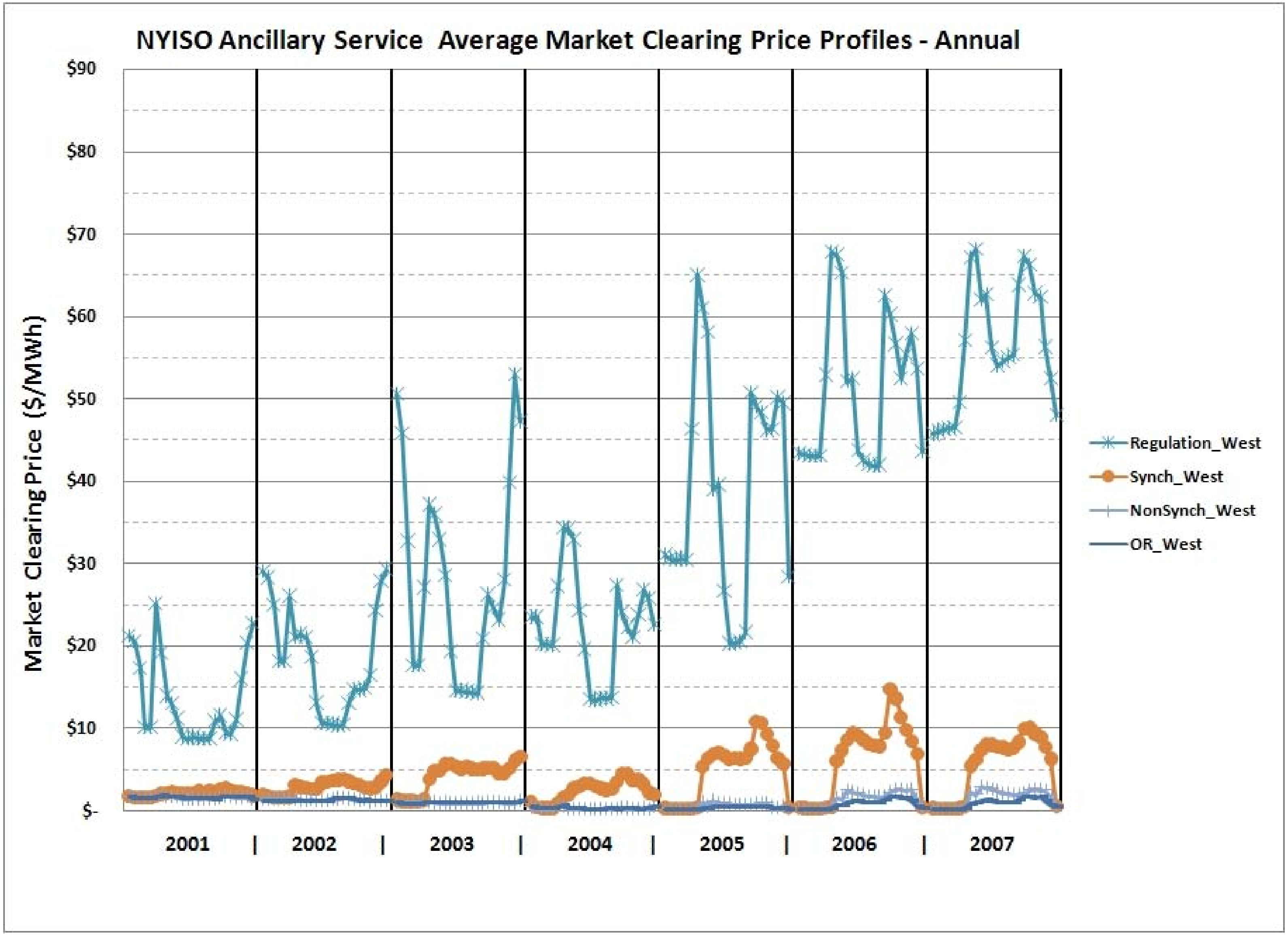
Energy Price Profiles for NYC



Ancillary Services Summary

	Location Dep	Provider	Pricing Method
Reg. /Freq. Response	**No**	**NYISO / Self Sched.**	**Market Based**
Operating Reserve	**Yes**	**NYISO / Self Sched.**	**Market Based**
Voltage Support	**Yes**	**NYISO**	**Embedded**
Black Start	**Yes**	**NYISO**	**Embedded**

Ancillary Service Price Profiles

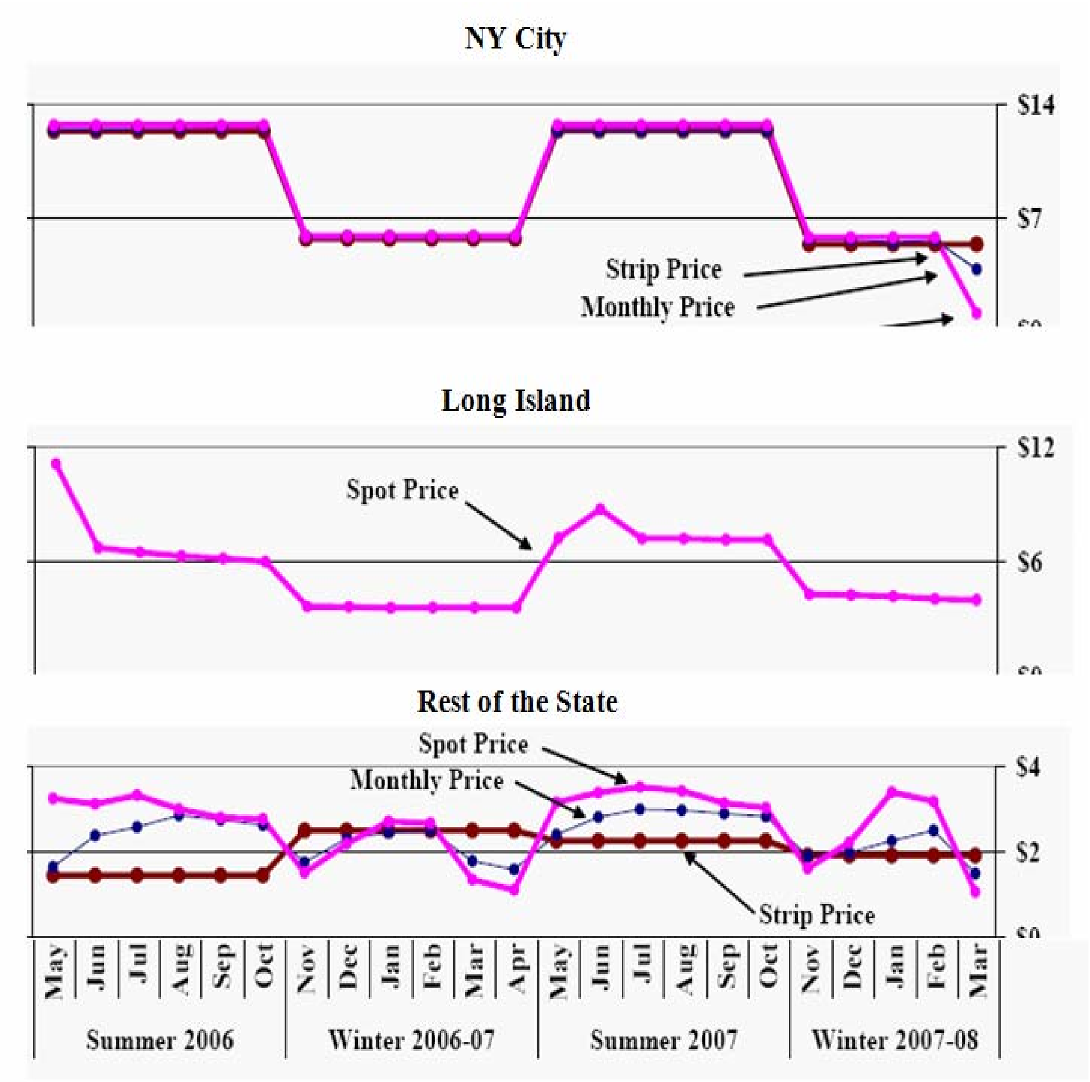


Other Ancillary Services

- Voltage Support
  - Annual payment of $3919 / MVAr
  - Capability decided based on tests performed by NYISO
  - Penalty for non performance
- Black Start
  - Requires ability to start without any outside supply
  - Units are selected based on ability to participate in bulk power restoration plan

Capacity Credit

- NYISO has a locational ICAP requirement
  - 80% for NYC
  - 99% for Long Island
- NYISO may create additional locational ICAP requirement for NY Southeast region
  - Zone G to Zone I



Source: NYISO State of the Market Report 2007

FACTORS AFFECTING PERFORMANCE OF CAES

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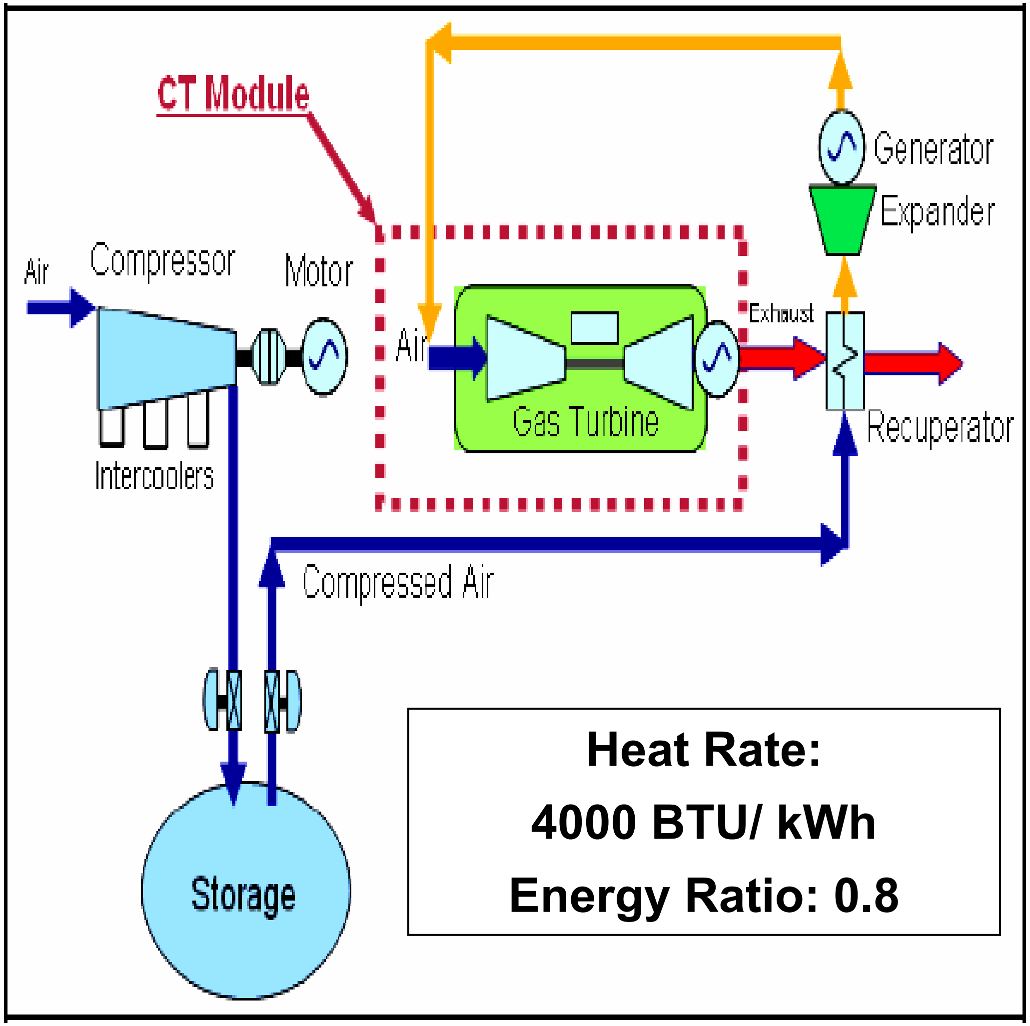
FACTORS AFFECTING CAES ECONOMICS

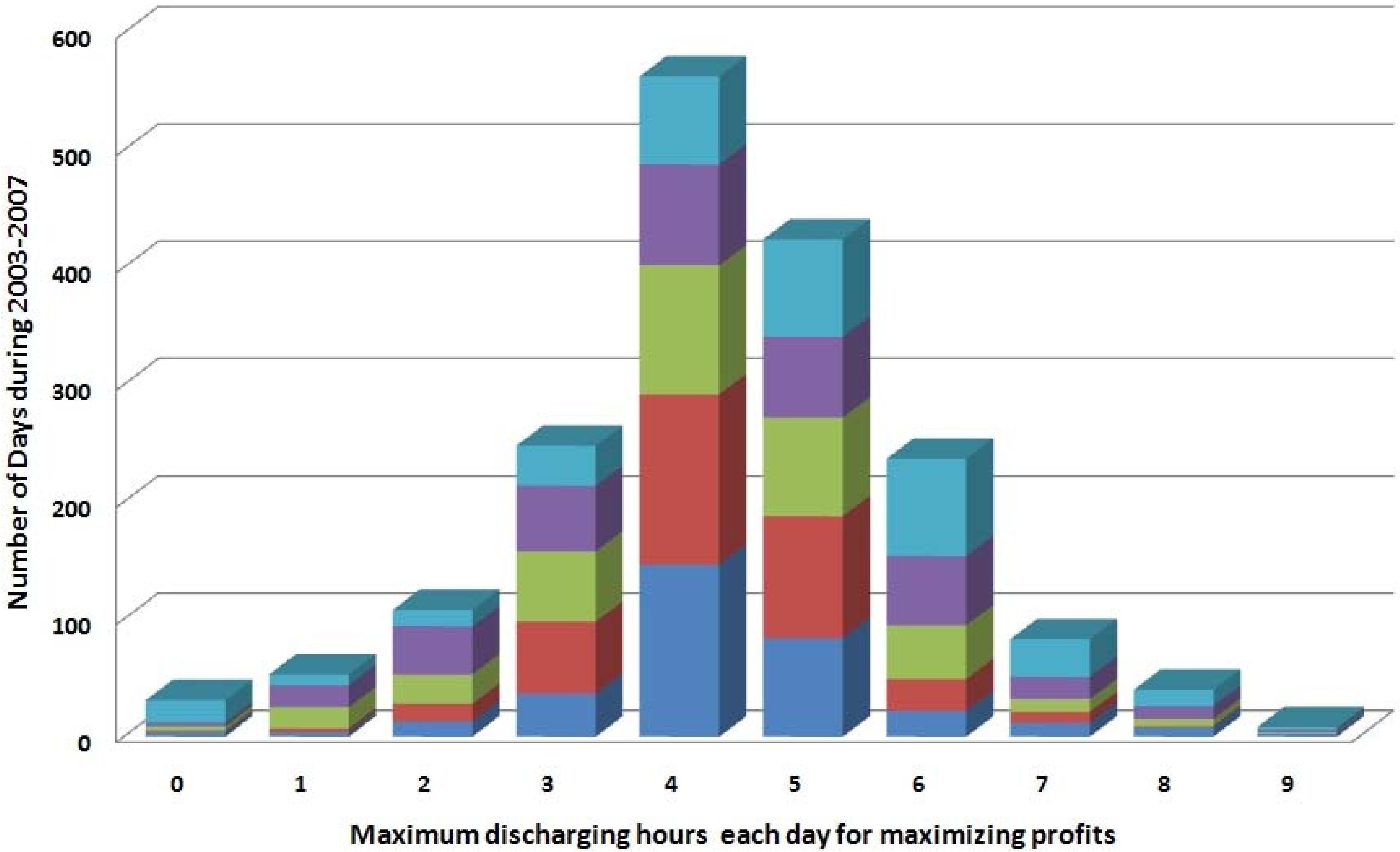
- CAES Design
  - Heat Rate
  - Energy Ratio
  - Power Ratio
  - Ramp rate
  - Response time
  - Storage Duration



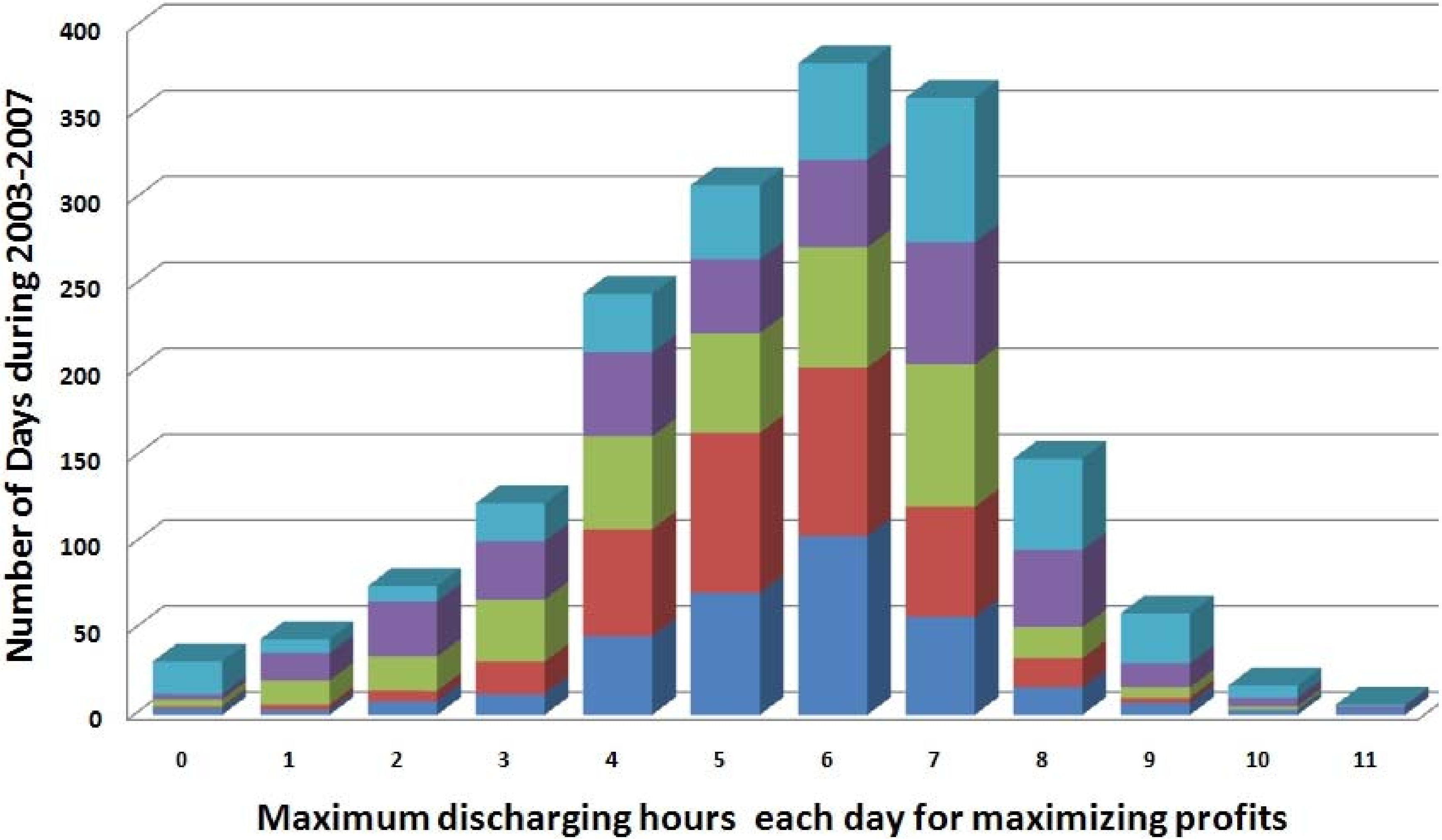
Heat Rate:
4000 BTU/ kWh
Energy Ratio: 0.8

Source: Dr. Robert Schainker, EPRI

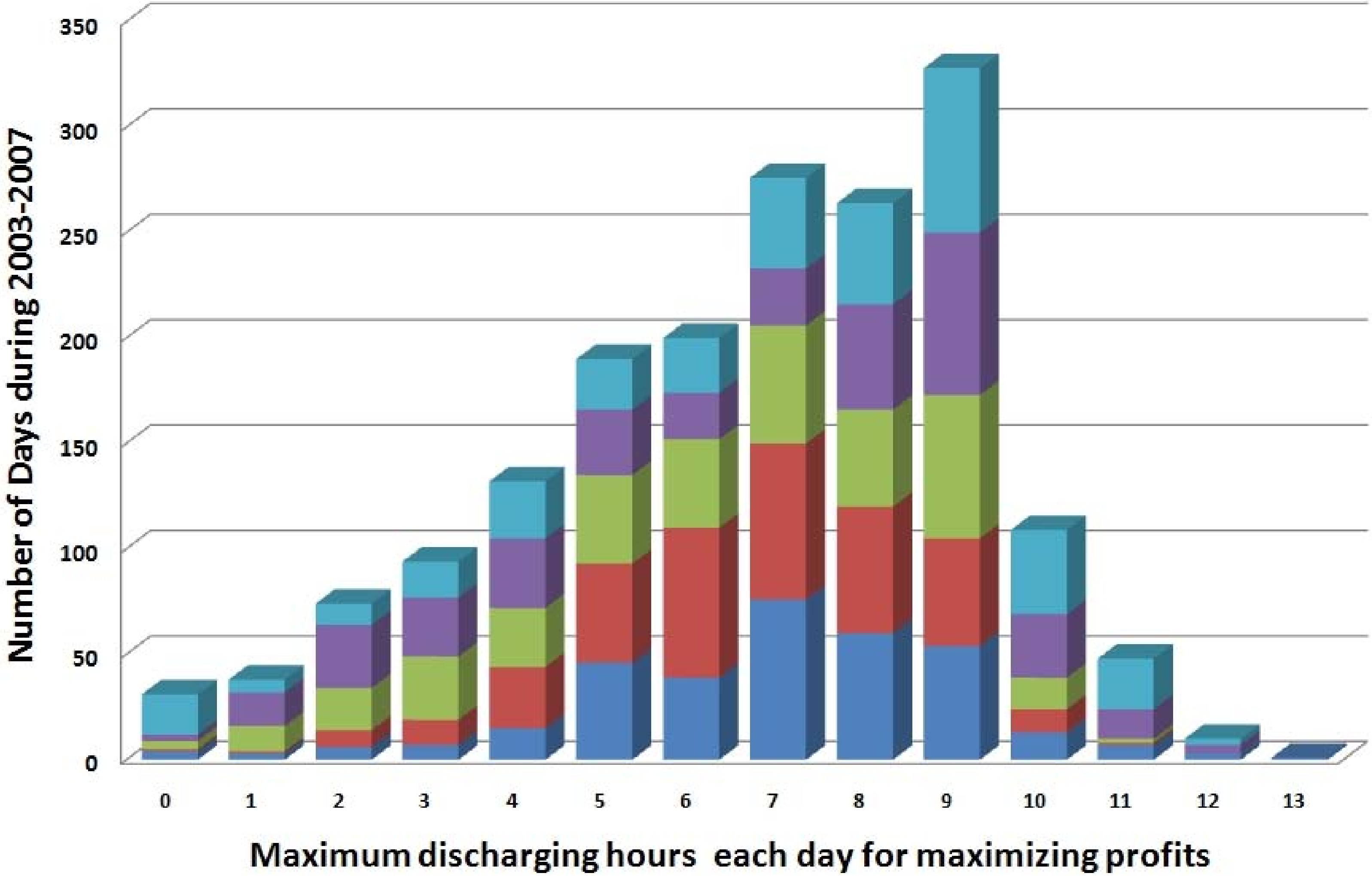
Optimal Operating Hours (Power Ratio 0.5)



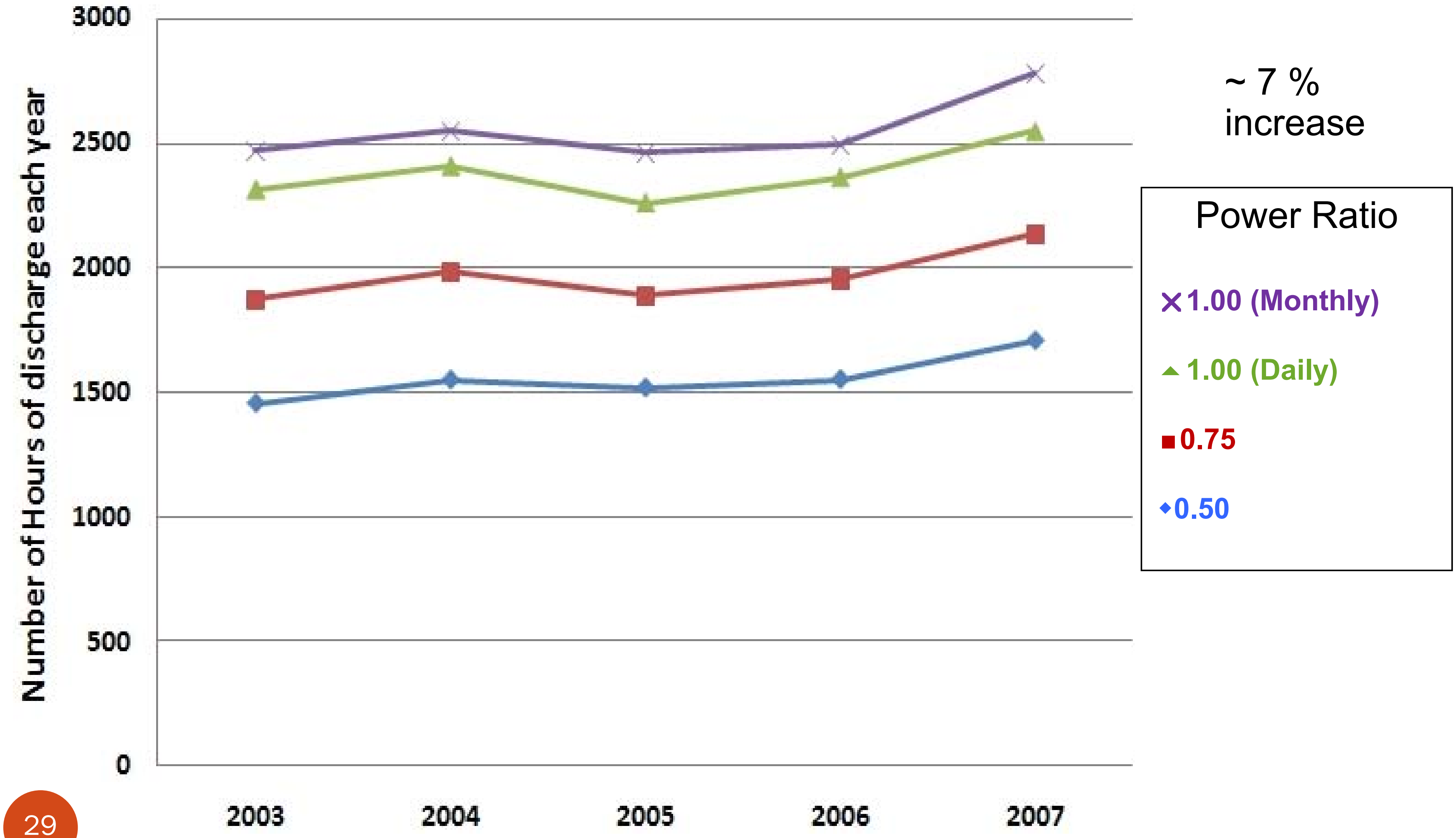
OPTIMAL OPERATING HOURS (POWER RATIO 0.75)



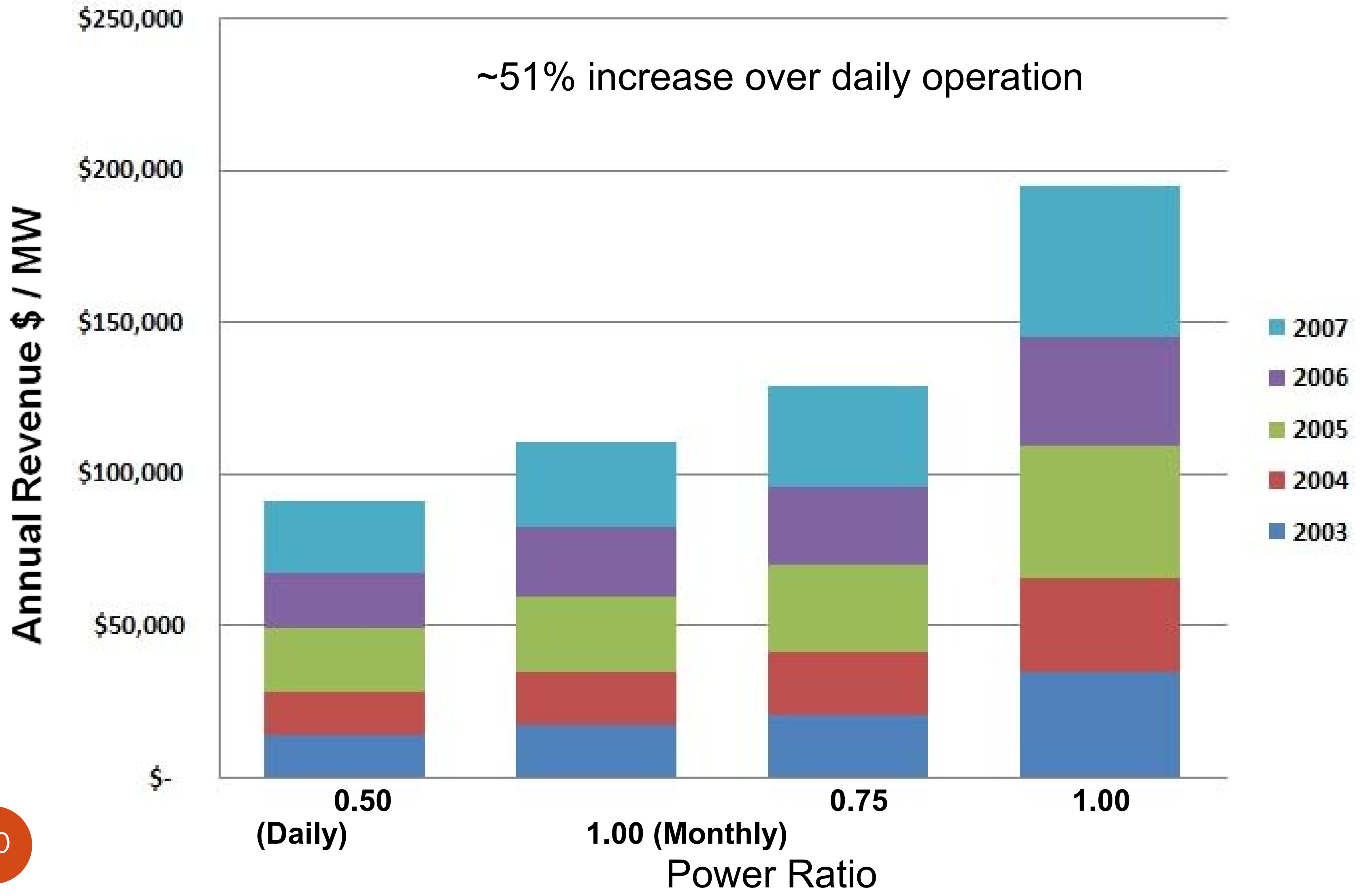
Optimal Operating Hours
(Power Ratio 1.0)



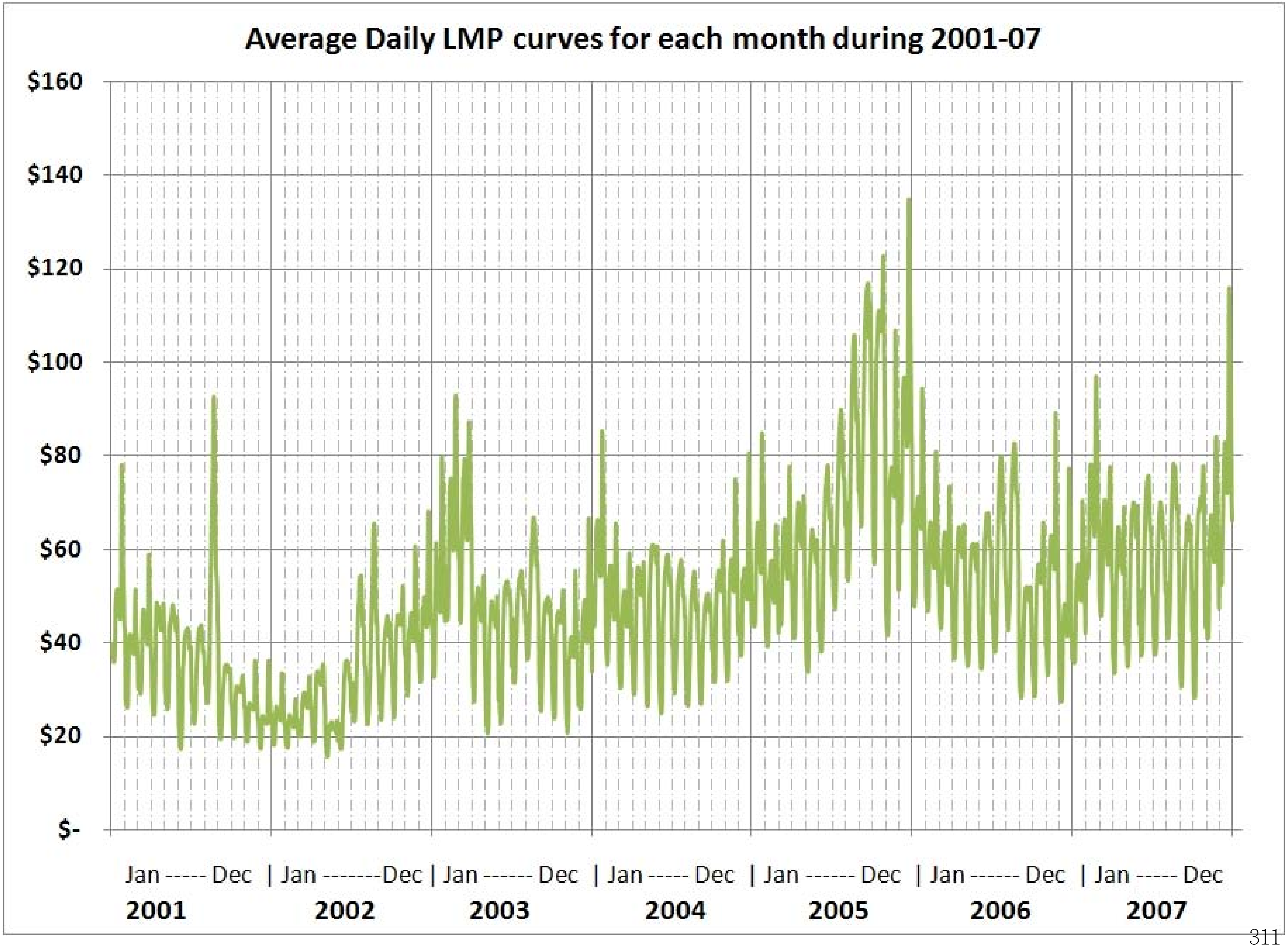
Annual Operating Hours
With Daily & Monthly Optimization



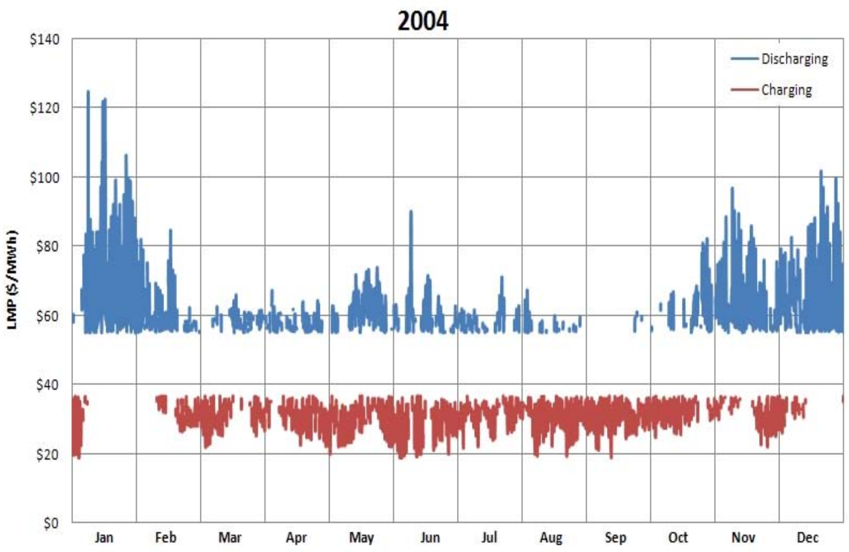
Expected Net Revenues with Daily & Monthly Optimization



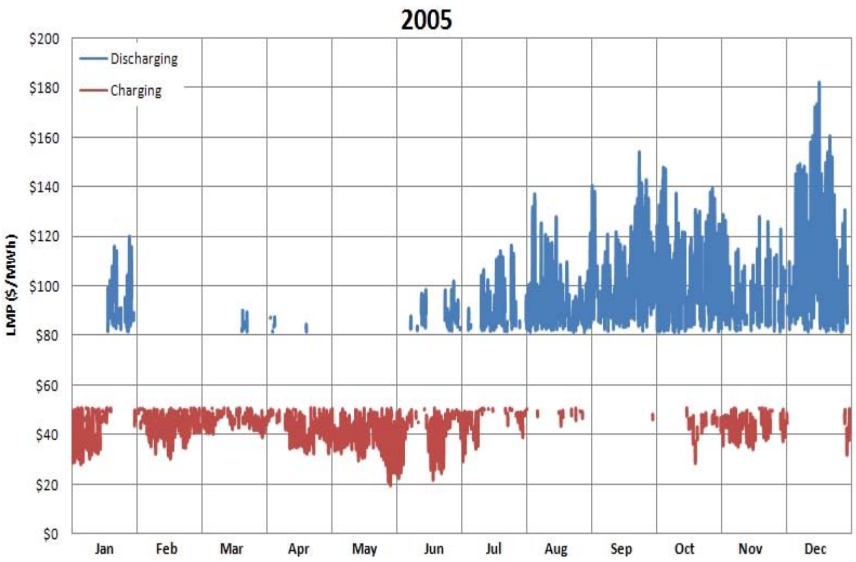
Potential For Seasonal Optimization ???



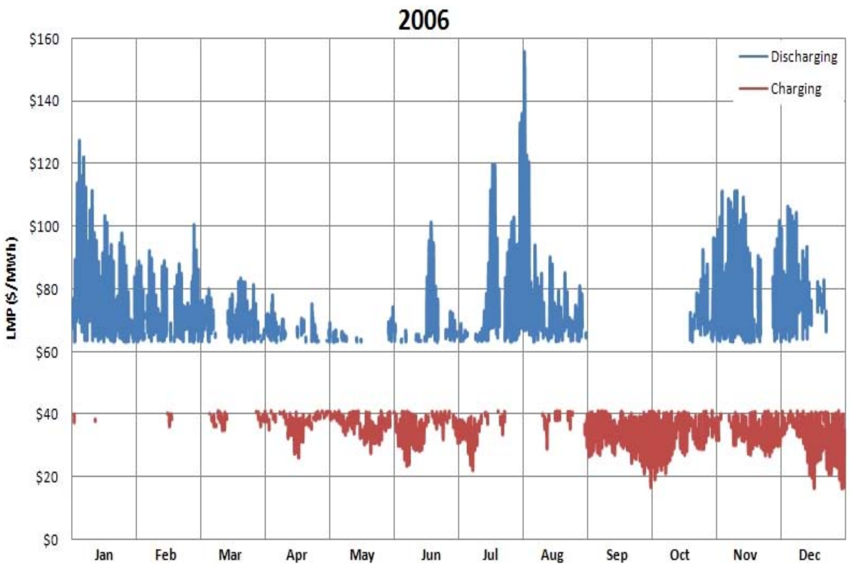
CAES Operations With Seasonal Optimization



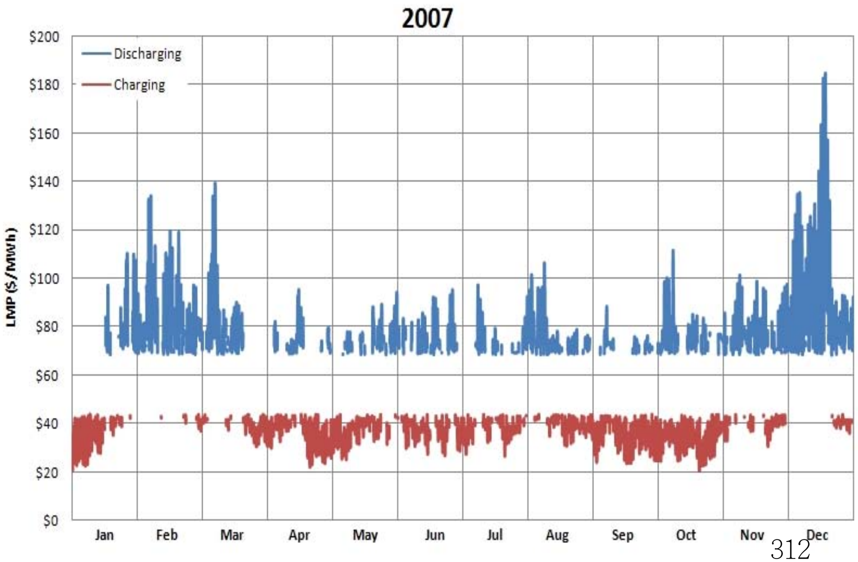
2004



2005



2006

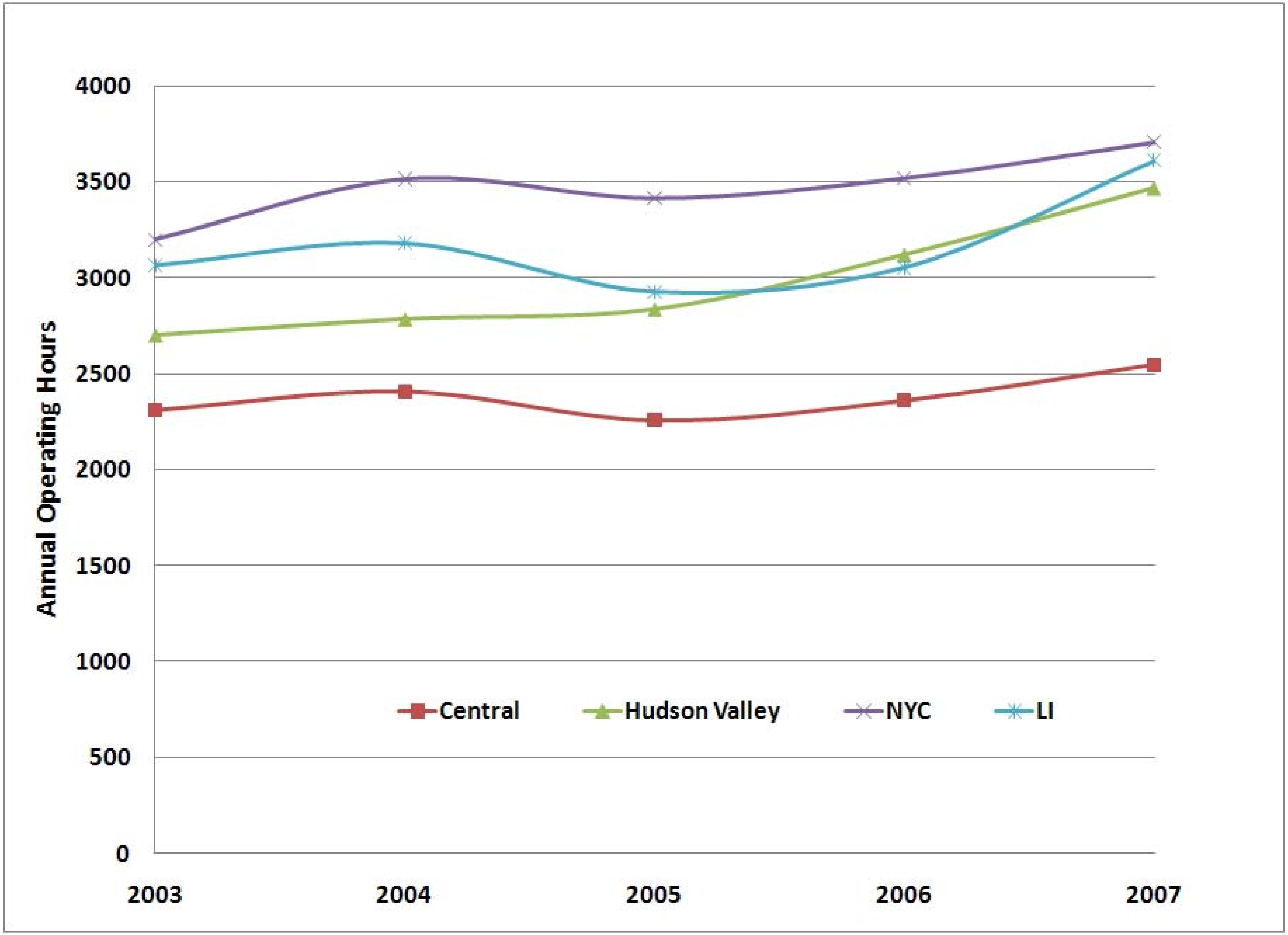


2007

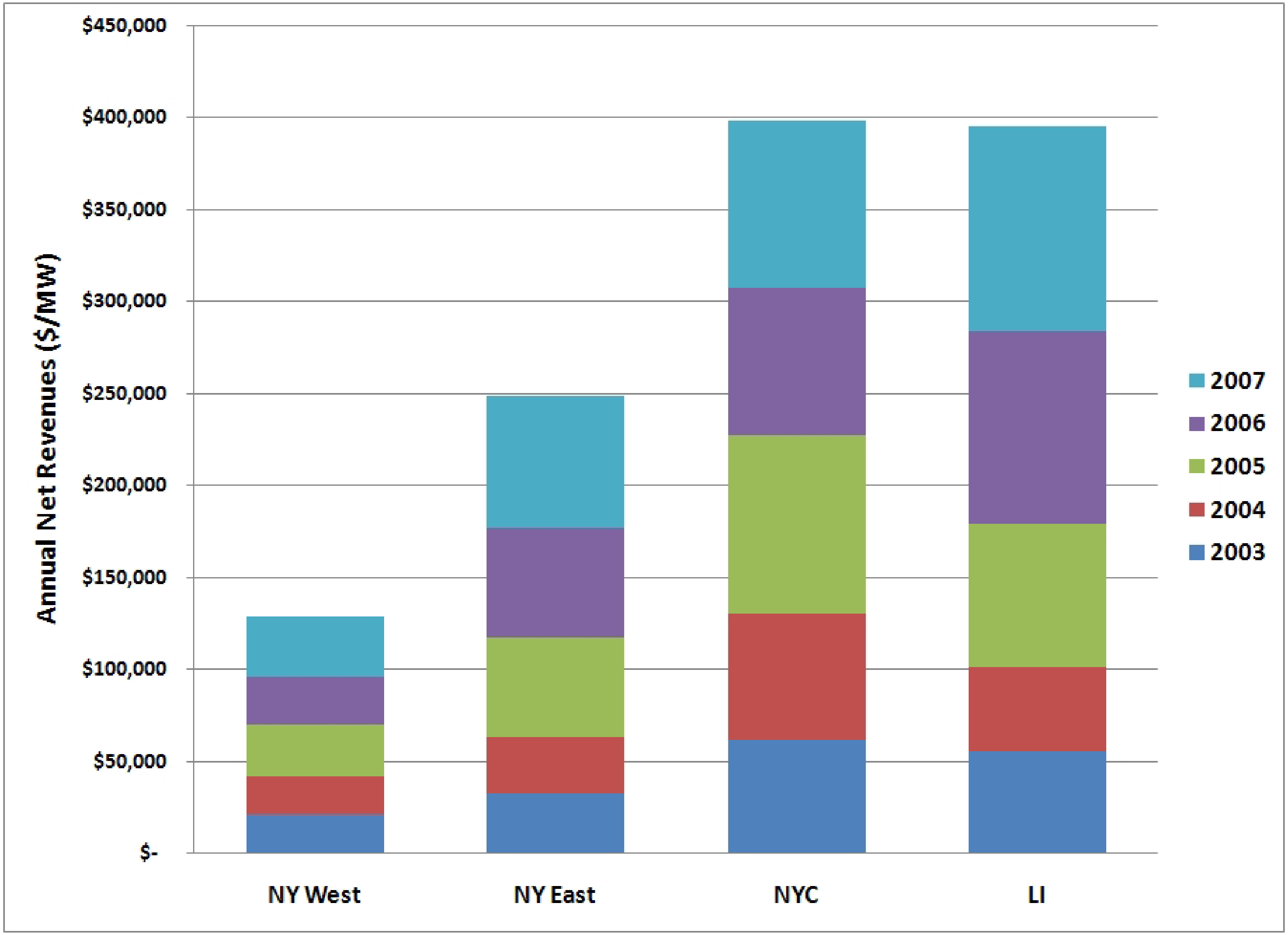
Factors Affecting CAES Economics …

- CAES Siting
  - Geological suitability
  - Natural gas delivery
  - Electric transmission network & interconnection
- CAES Revenues & Cost
  - On Peak Energy Revenues & Off Peak Costs
  - Ancillary Service Revenues
  - Interconnection costs
  - Natural Gas price

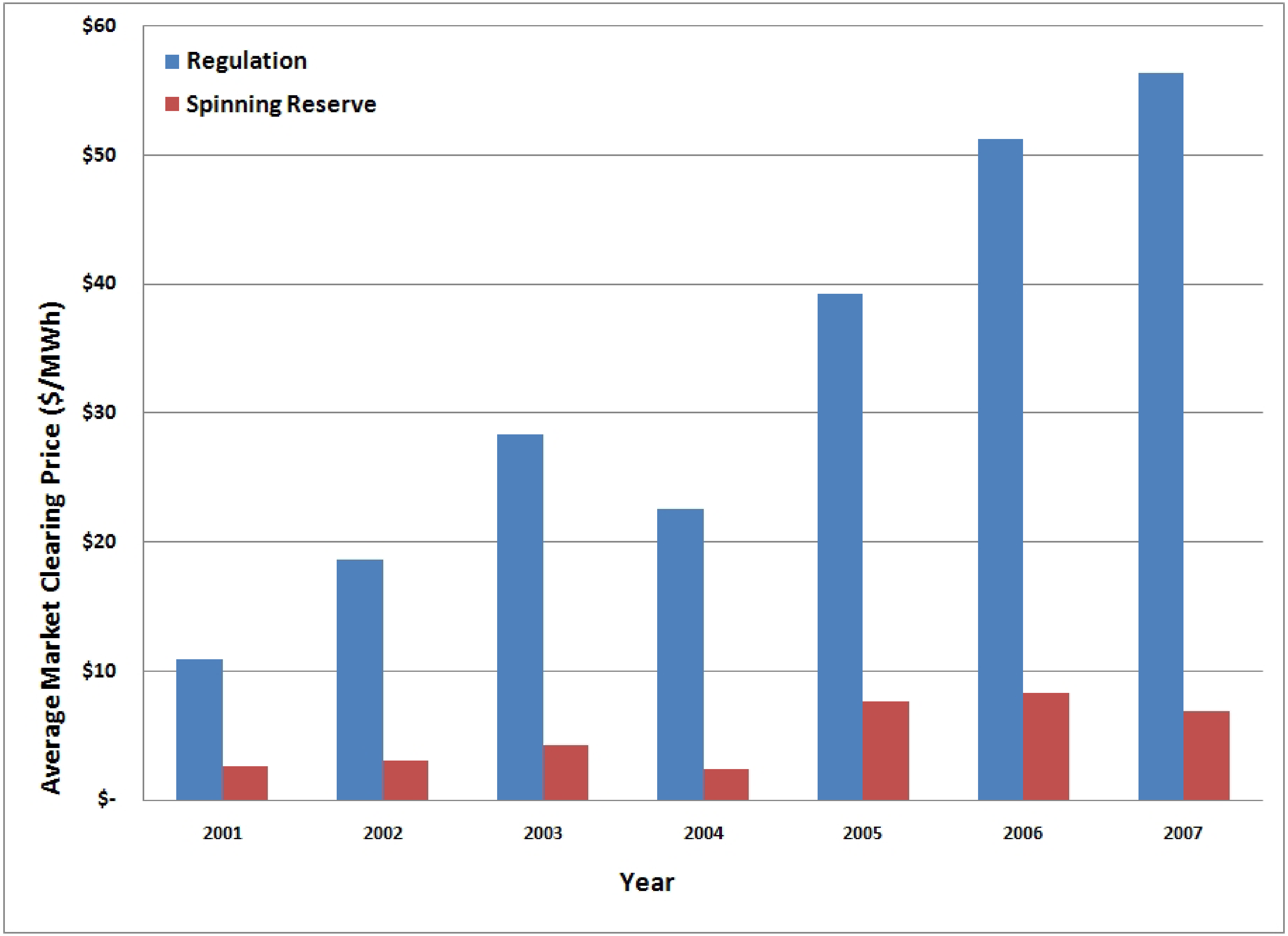
Operating Hours Across NYISO Regions



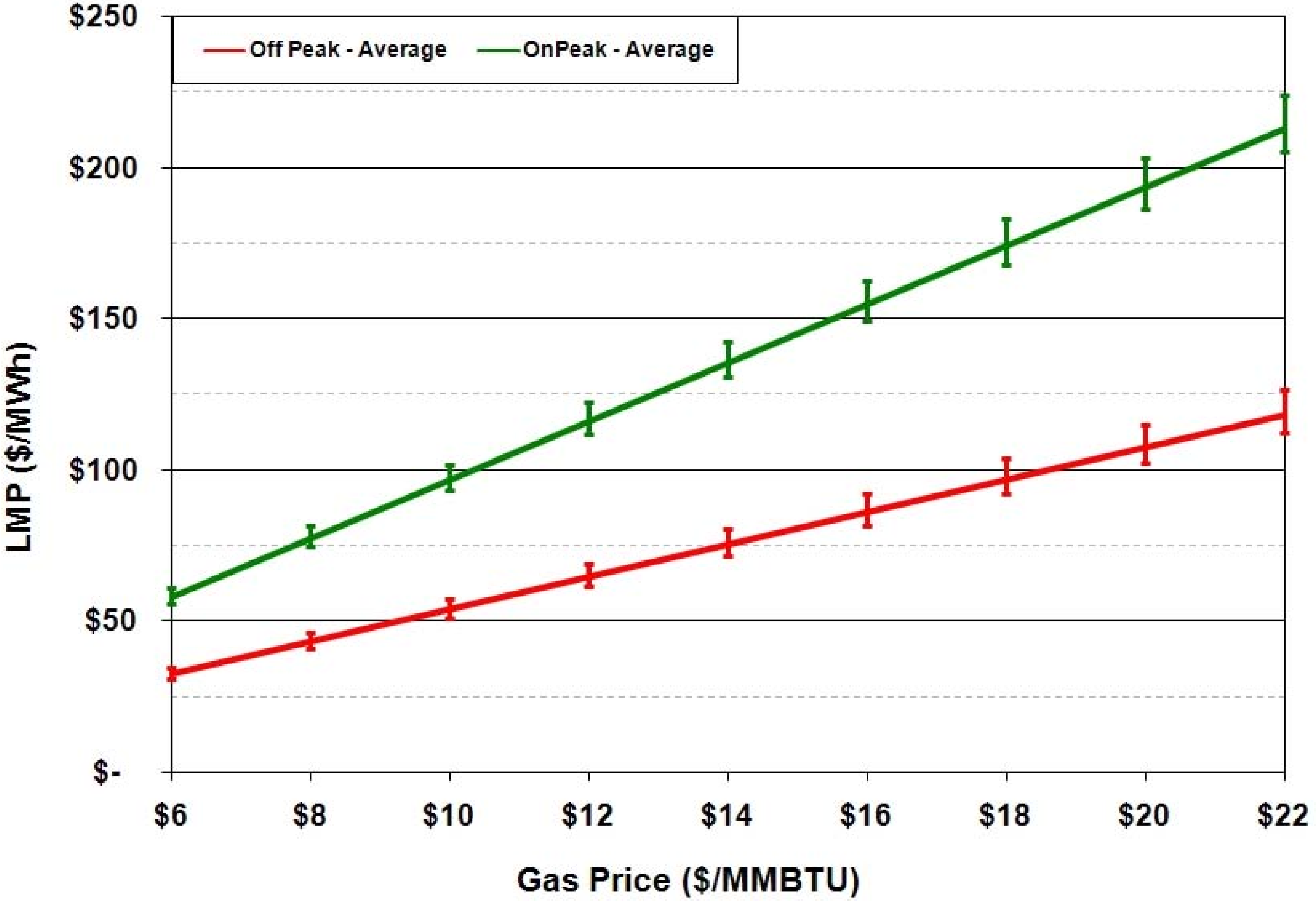
Annual Net Revenues Across Regions



Ancillary Service Revenue Potential



Effect of Natural Gas Price



FACTORS AFFECTING CAES ECONOMICS

- CAES Financing Factors
  - Capital Costs
  - Real estate and taxes
  - Cost of borrowing
  - Construction & permitting period

- Other Factors
  - Impact of wind integration in NYISO
  - Impact of environmental regulations
    - Renewable Portfolio Standard mandates
    - NYS 15x15 Program Initiative
    - Carbon Tax

Conclusions

- NY has suitable geology as well as gas and electric infrastructure that enables development of CAES projects
- NYISO offers opportunity to CAES to participate in a energy, ancillary services and capacity market
- The economics of CAES project will depend on a number of factors including
  - Design parameters of CAES
  - Location
  - Ability to capture multiple revenue streams
  - Financing
  - Environmental regulations

QUESTIONS ???

Dr. Rahul Walawalkar

215-875-9440

rahul@ces-ltd.com

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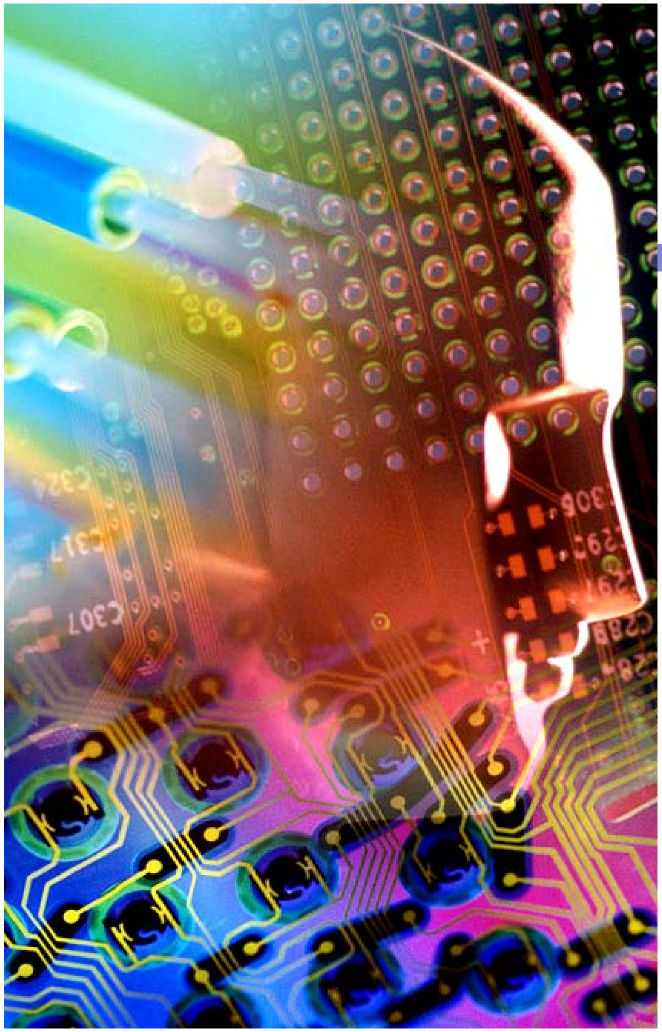
7.1 Robert Schainker, CAES Research, Development and Deployment Projects at EPRI

Robert Schainker is Senior Technical Executive in the Power Delivery and Utilization Sector of the Electric Power Research Institute (EPRI). His research activities cover energy storage technologies (with special focus on the compressed air energy storage technology), generation and transmission technologies (with special focus on strategic planning), electric grid security, transmission substations, high voltage power flow controllers, transformers, and power quality.

Dr. Schainker joined EPRI in 1978 as a Project Manager focused on improving the performance and reliability of generation plants. He has authored over 100 papers on electric utility generation, storage, and power delivery technologies. He was a key contributor designing and building the first U.S. compressed air energy storage plant (110M - 26 hours) for Alabama Electric Cooperative, and designing and building two multi-MW battery systems. He was also a key contributor designing and building two world class solid-state, high-voltage transmission flow control systems: a 320 MVA unit for American Electric Power and a 200 MVA unit for the New York Power Authority.

Dr. Schainker has given expert testimony to the U.S. Congress and to the U.S. Federal Energy Regulatory Commission on strategic planning and a wide variety of electric utility technologies to improve the efficiency of the U.S. grid. He holds two patents and he has written chapters in two encyclopedias on electric grid and energy storage technologies. He holds a BS degree in mechanical engineering, an MS degree in electrical engineering, and a PhD in applied mathematics, all from Washington University in St. Louis, Missouri.



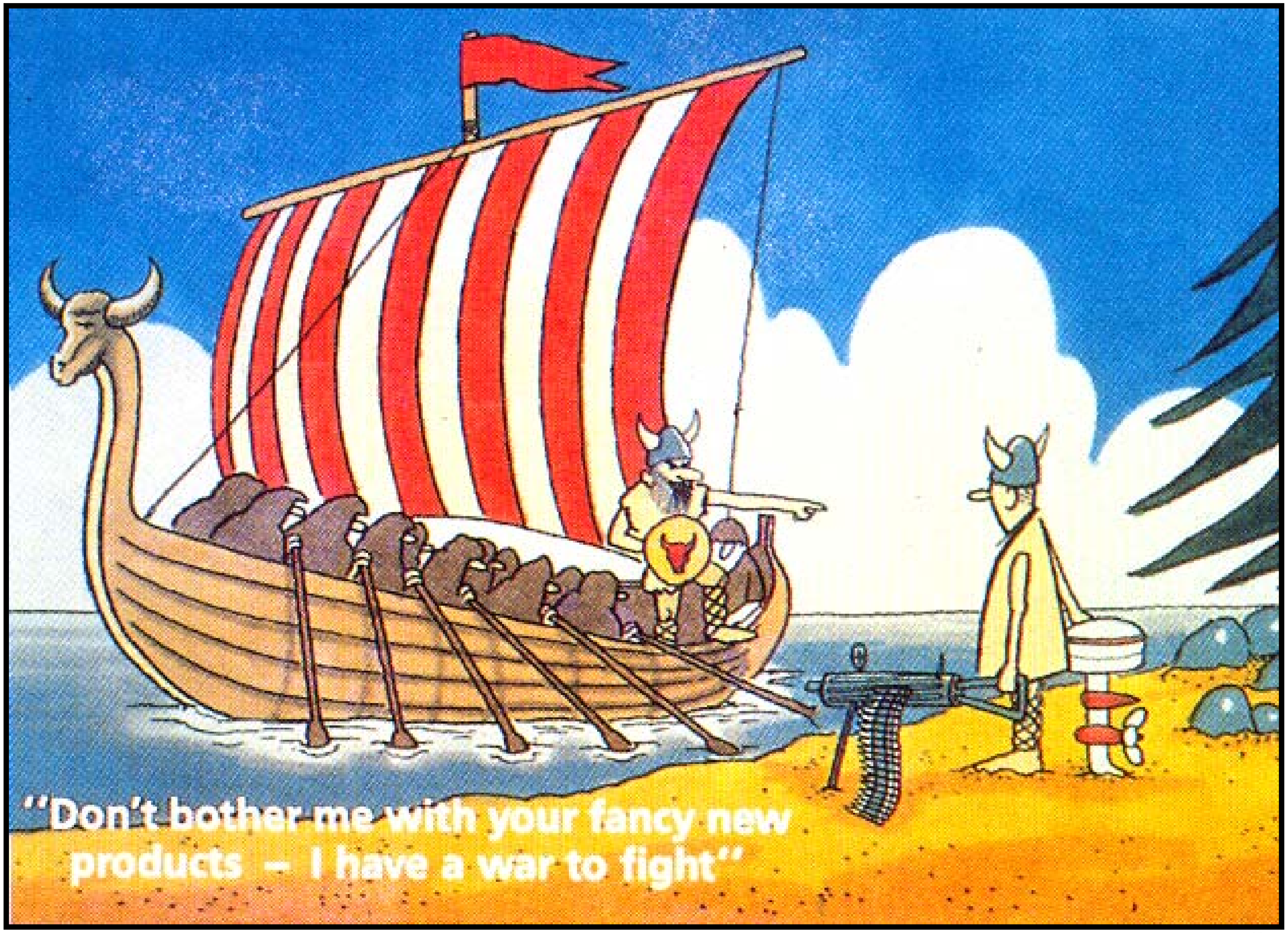
EPRI RD&D Focus: CAES

Dr. Robert B. Schainker
Senior Technical Executive

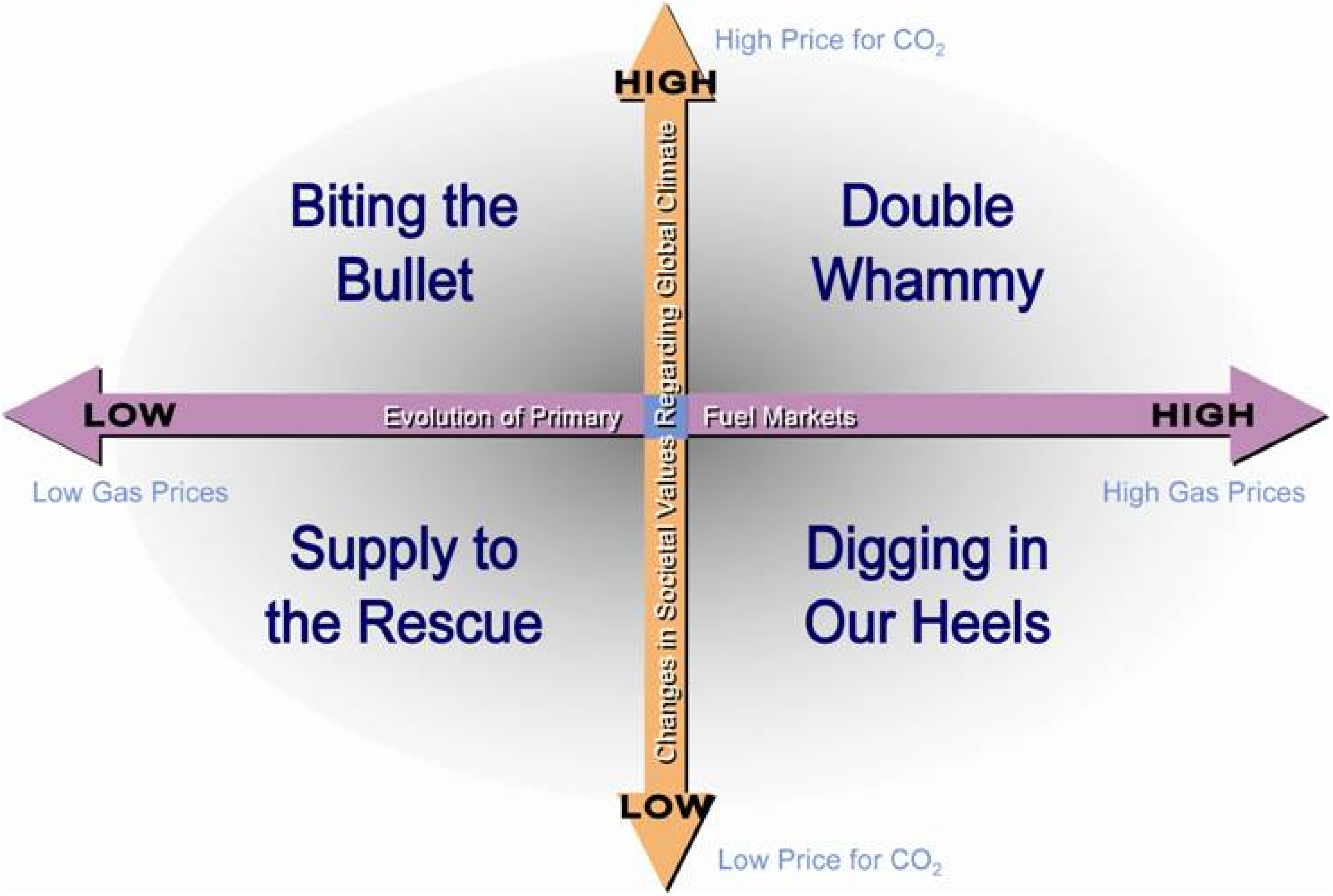
Presented at Scoping Workshop on CAES Research, Development and Deployment
October 21-22, 2008
Organized by: Columbia University (Center for Life Cycle Analysis) and the
New York Sate Research and Development Authority (NYSERDA)

"We can't solve problems by using the same kind of thinking we used when we created them."

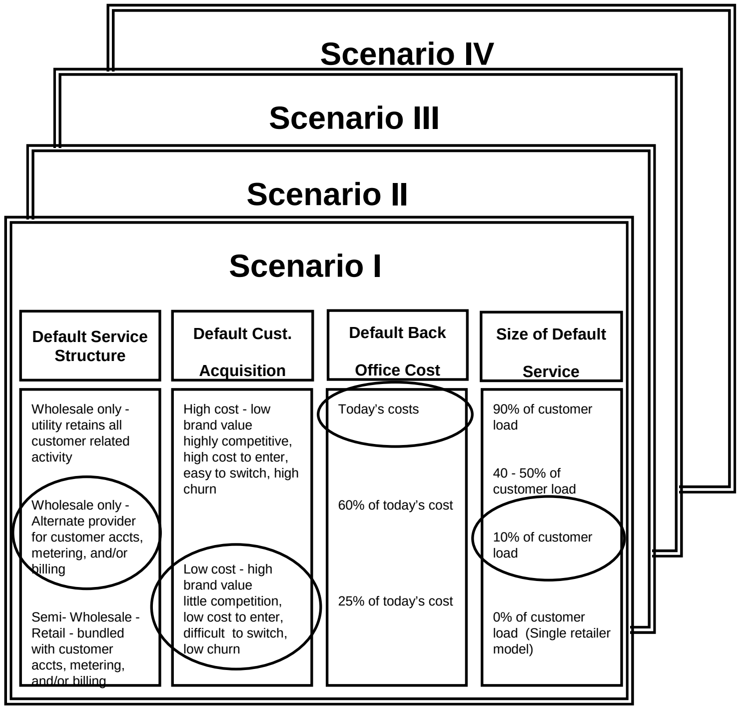
-- Albert Einstein



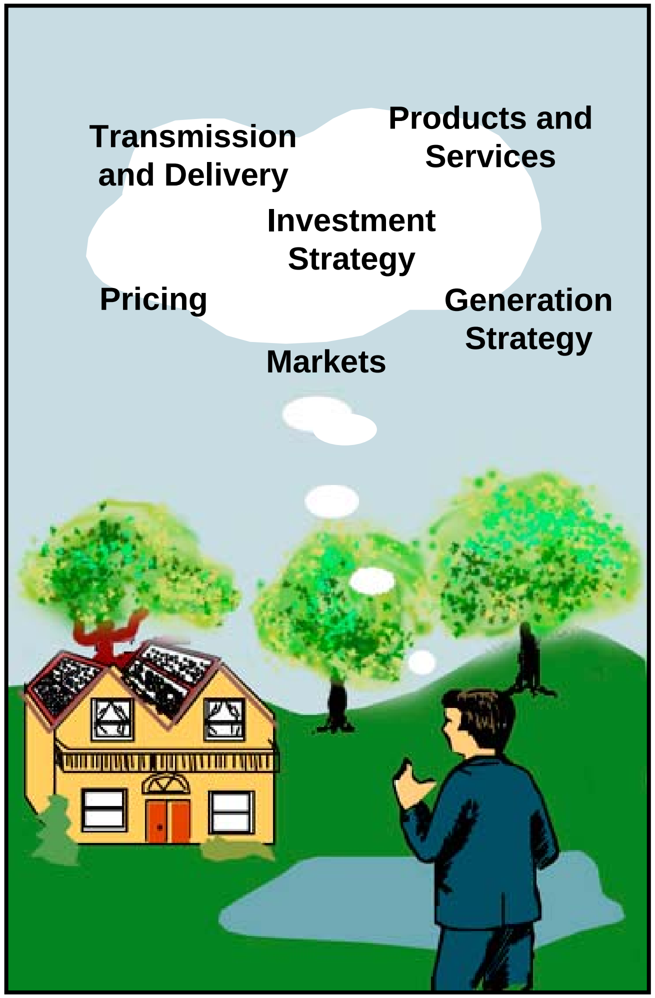
Background: EPRI R&D Technology Scenario Approach



Develop Technology Portfolios for Each Scenario



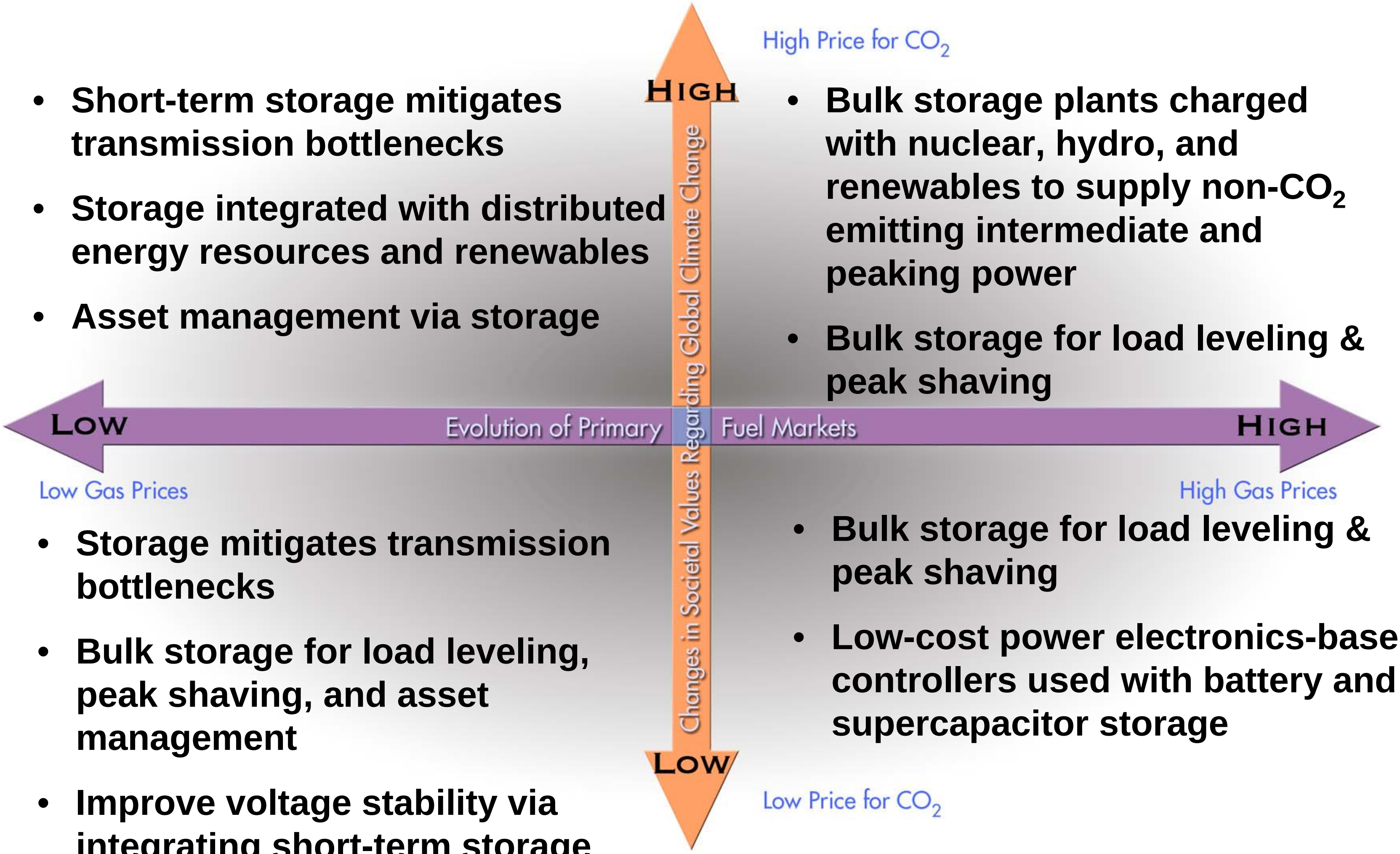
Default Service Structure	Default Cust. Acquisition	Default Back Office Cost	Size of Default Service
Wholesale only - utility retains all customer related activity	High cost - low brand value highly competitive, high cost to enter, easy to switch, high churn	[✓ Today's costs]	90% of customer load
			40 - 50% of customer load
[✓ Wholesale only - Alternate provider for customer accts, metering, and/or billing]		60% of today's cost	[✓ 10% of customer load]
Semi- Wholesale - Retail - bundled with customer accts, metering, and/or billing	[✓ Low cost - high brand value little competition, low cost to enter, difficult to switch, low churn]	25% of today's cost	0% of customer load (Single retailer model)



For each scenario, ignore how likely or improbable this combination of outcomes might be and ask:

"If we found ourselves in this world, what areas in the utility business would be most affected? How would we respond?"

Background: Critical R&D Needs: Electric Energy Storage Technology



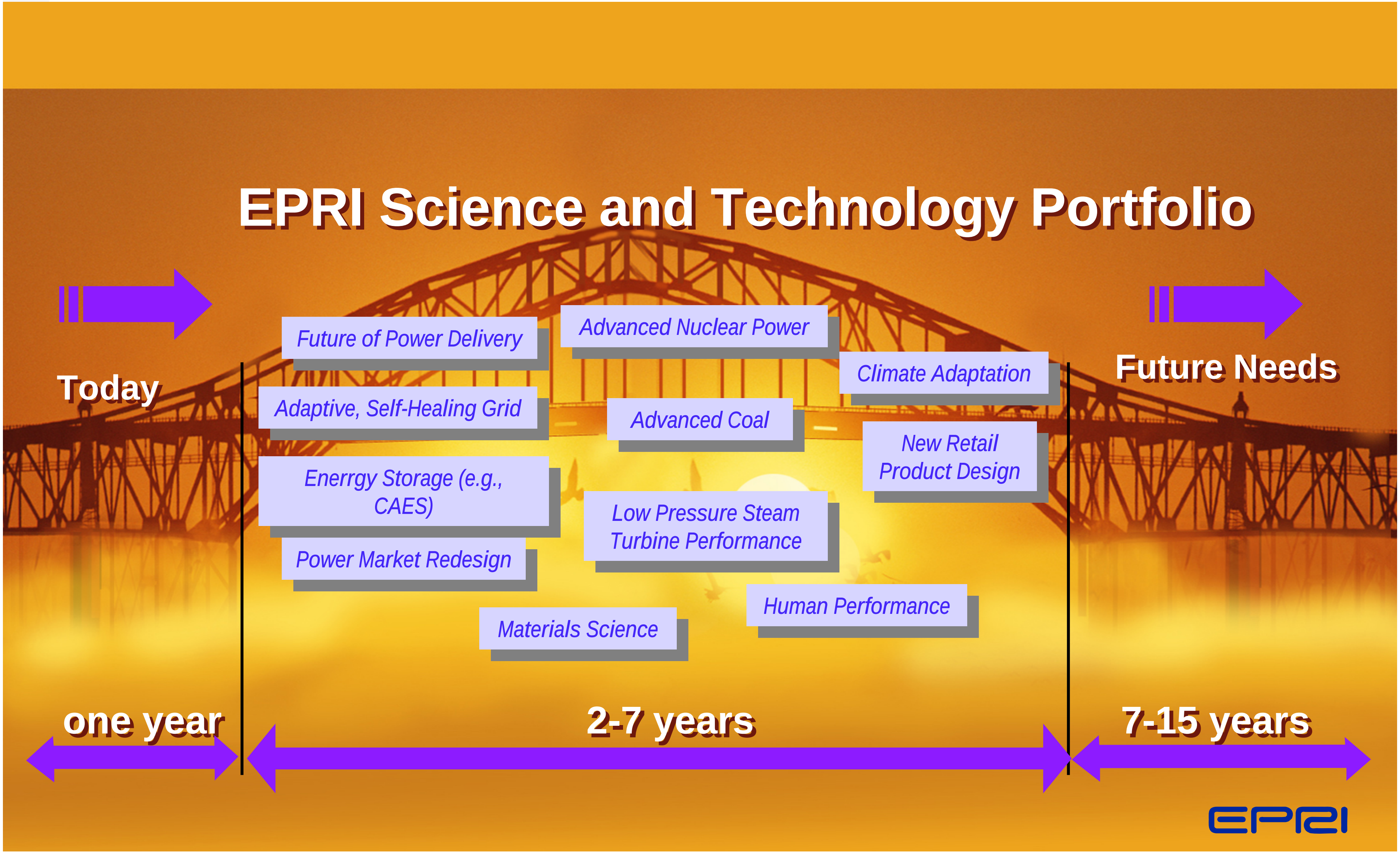
- Short-term storage mitigates transmission bottlenecks
- Storage integrated with distributed energy resources and renewables
- Asset management via storage

- Bulk storage plants charged with nuclear, hydro, and renewables to supply non-CO_2 emitting intermediate and peaking power
- Bulk storage for load leveling & peak shaving

- Storage mitigates transmission bottlenecks
- Bulk storage for load leveling, peak shaving, and asset management
- Improve voltage stability via integrating short-term storage with ac-dc-ac converters

- Bulk storage for load leveling & peak shaving
- Low-cost power electronics-based controllers used with battery and supercapacitor storage

Background: Gap Analysis



EPRI Science and Technology Portfolio

Today

Future of Power Delivery

Adaptive, Self-Healing Grid

Enerrgy Storage (e.g., CAES)

Power Market Redesign

Advanced Nuclear Power

Advanced Coal

Low Pressure Steam Turbine Performance

Materials Science

Climate Adaptation

New Retail Product Design

Human Performance

Future Needs

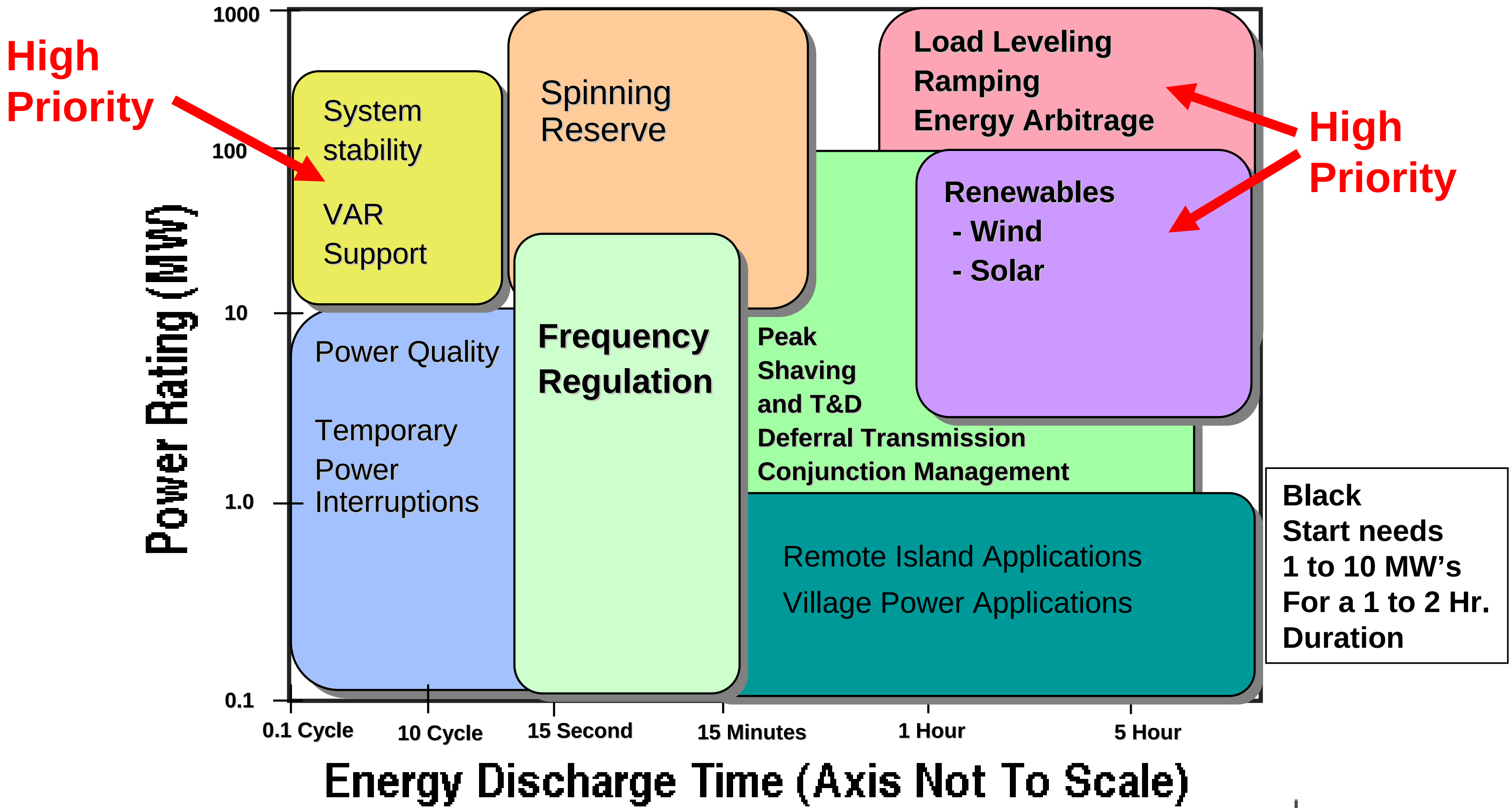
one year

2-7 years

7-15 years

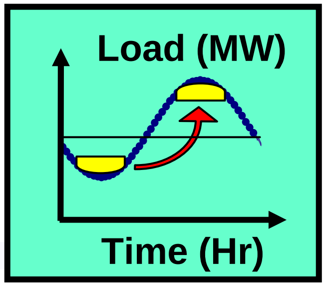
Electric Energy Storage Applications

(All Boundaries Of Regions Displayed Are Approximate)



Storage Options Vs. Utility Application

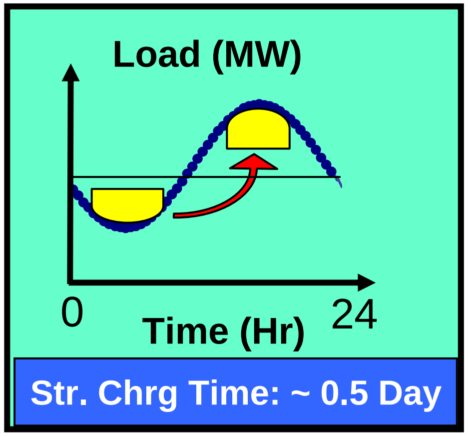
(Based on Current Technology and Current Trends)



Application → - - - - - - - - - - - - - Storage Option ↓	Transmission Stability, Power Quality	Spinning Reserve, Freq. Regulation	T/D Deferral, Transm.Decong. Peak - Shaving	Bulk Power Arbitrage, Ld .Lev'lg Rp, Ren'w
Compressed Air: Lrg. (Salt, Por.M., Rk) Small (Abv. Grd.		X X	X X	X
Pumped Hydro Underground		X X	X X	X X
Battery Types: Adv LdAcid / NaS / Adv. Flow - Redox Systems	X	X	X	X
Flywheel	X	X		
SMES	X	X	X	
Super-Capacitor	X	X	X	
Hydrogen, Lg-Term Goal				X

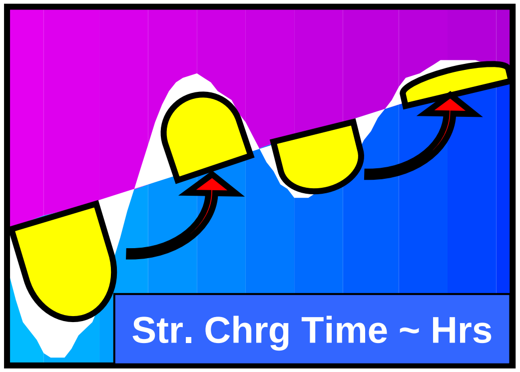
CAES Will Firm Up and Shape Wind Resources
Thus, CAES Enables Higher Penetration of Renewables

Load Leveling



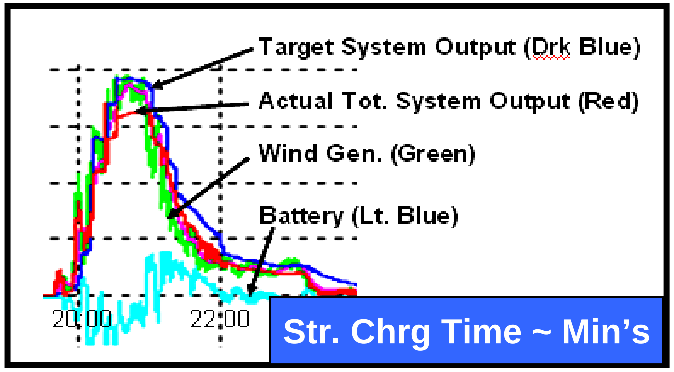
- CAES
- Pumped Hydro

Ramping:



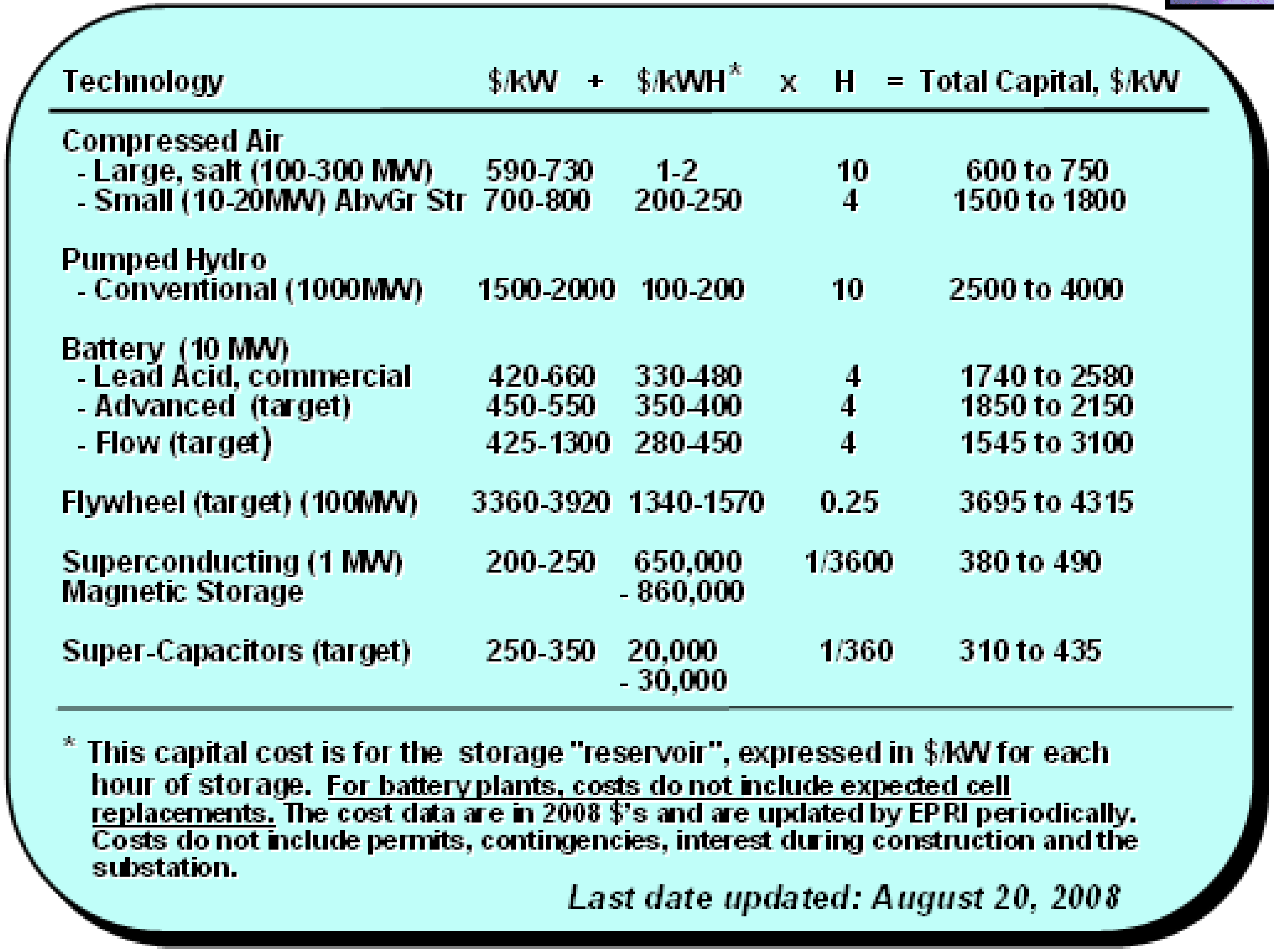
- CAES
- Pumped Hydro
- Battery, Flow type
- Note: In California ramping is a big issue

Frequency Regulation:



- CAES
- Battery, Regular or Flow Type
- SuperCap
- Flywheel
- SMES

Energy Storage Plants:
Capital Cost Comparisons



Technology	$/kW	+	$/kWH*	x	H	=	Total Capital, $/kW
Compressed Air							
- Large, salt (100-300 MW)	590-730		1-2		10		600 to 750
- Small (10-20MW) AbvGr Str	700-800		200-250		4		1500 to 1800
Pumped Hydro							
- Conventional (1000MW)	1500-2000		100-200		10		2500 to 4000
Battery (10 MW)							
- Lead Acid, commercial	420-660		330-480		4		1740 to 2580
- Advanced (target)	450-550		350-400		4		1850 to 2150
- Flow (target)	425-1300		280-450		4		1545 to 3100
Flywheel (target) (100MW)	3360-3920		1340-1570		0.25		3695 to 4315
Superconducting (1 MW) Magnetic Storage	200-250		650,000 - 860,000		1/3600		380 to 490
Super-Capacitors (target)	250-350		20,000 - 30,000		1/360		310 to 435

* This capital cost is for the storage "reservoir", expressed in $/kW for each hour of storage. For battery plants, costs do not include expected cell replacements. The cost data are in 2008 $'s and are updated by EPRI periodically. Costs do not include permits, contingencies, interest during construction and the substation.

Last date updated: August 20, 2008

EPRI CAES R&D Program Area: Objectives

Develop And Deploy CAES Plants To Lower Capital and Operational Costs, Enhance G,T&D Asset Utilization, Improve Use of Renewables, Reduce Premium Fuel Consumption, and Reduce CO_2 Emissions

EPRI's Major Research, Development and Deployment Activities

- **EPRI CAES RD&D**
  - **Value Proposition Analyses**
    - Perform Host Utility Economic Cost-Benefit Analyses
    - Develop & Deploy Real-Option Economic Evaluations
    - Develop & Deploy Strategic Benefit Tools
  - **Thermodynamic Analyses**
    - Develop / Evaluate Advanced CAES Thermodynamic Cycles
    - Develop / Evaluate Adiabatic (No/Little Fuel) Cycles
    - Perform Thermal Storage Media Evaluations
  - **Under Ground & Above Ground Air Stores**
    - Identify Underground Sites for CAES Deployment
    - Resolve Potential Depleted Gas-Field Oxygen Risk Issue
    - Resolve Potential Corrosion of Above Ground Air Store
  - **Deploy and Monitor Demo Plants**
    - Build Demo Plant Using Below Ground Air Store
    - Build Demo Plant Using Above Ground Air Store
    - Monitor Performance and Reliability of Plants

One of Edison’s Most Famous Quotes:
“In Periods of Profound Change, The Most Dangerous Thing Is to Incrementalize Yourself Into The Future.”
Bottom Line: Think “Out of the Box”

CAES Project: Phased Approach

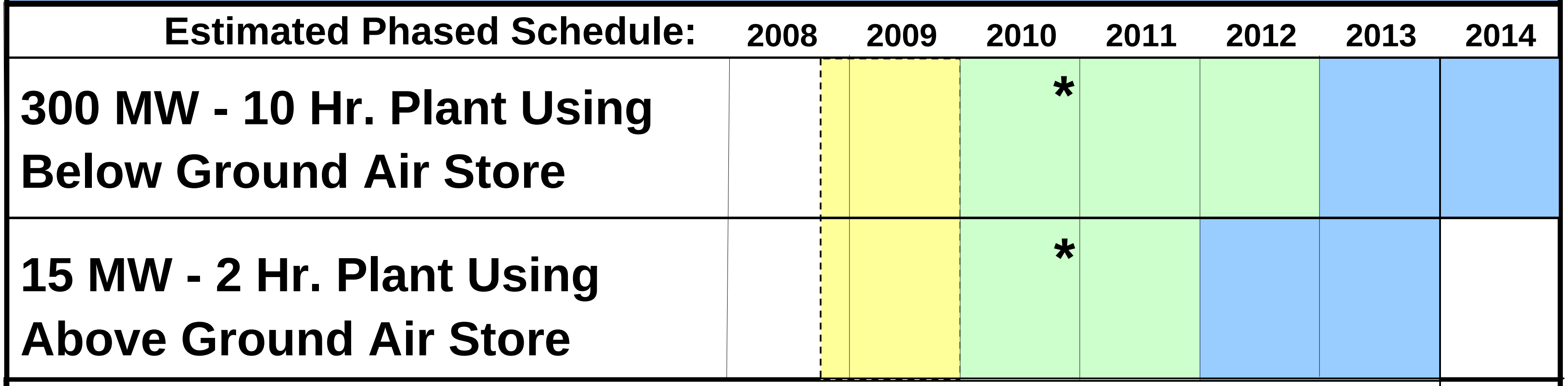
Appendix

Project Phases:

🟨 **1. Engineering Design, Costing, RFP and Select Winner**

🟩 **2. Construct Plant**

🟦 **3. Monitor Plant Performance and Reliability**



Estimated Phased Schedule:	2008	2009	2010	2011	2012	2013	2014
300 MW - 10 Hr. Plant Using Below Ground Air Store	🟨	🟨	🟩 *	🟩	🟩	🟦	🟦
15 MW - 2 Hr. Plant Using Above Ground Air Store	🟨	🟨	🟩 *	🟩	🟦	🟦	

Notes:

1. *Collaborators have "off-ramp" if no participants decide to build any type of CAES plant. Due to board decision schedules, this off-ramp will occur on 12/31/2010.
2. Final size of plant will be determined by phase 2 host utilities.
3. All participants will obtain project results from both plants and from all phases of the project.

EPRI CAES Demo Plant Initiative

Appendix

CAES Plant Air Store:	2008 Phase 1	2009 Phase 1	2010 Phase 2	2011 Phase 2	2012+ Phases 2 & 3	Total
Above Ground	$1M	$3M	$6M	$10M	$6M	$26M
Below Ground	$2M	$7M	$75M	$80M	$42M	$206M
EPRI Collaboration	$2M	$6M	$6M	$6M	$6M	$26M

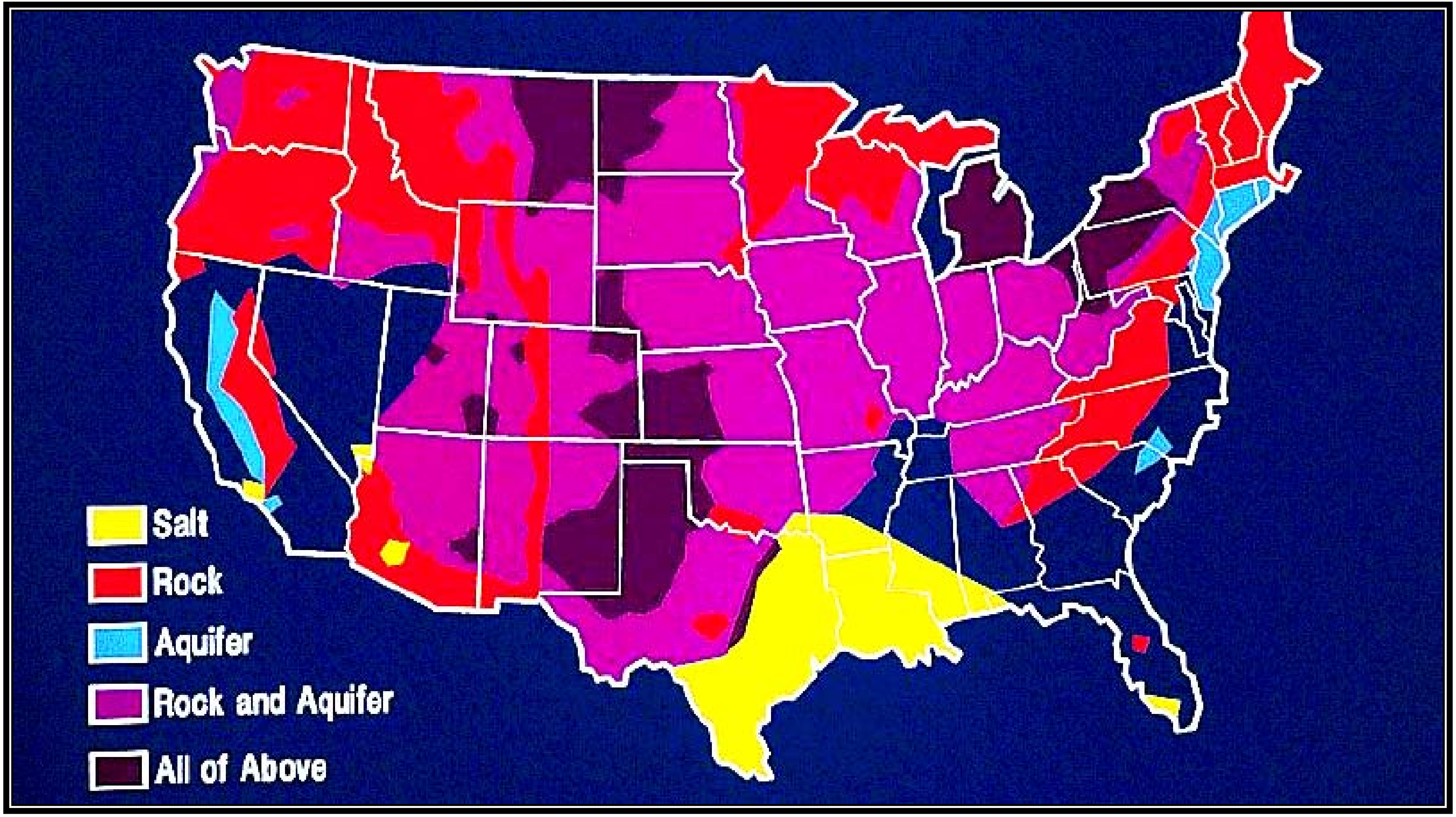
Host utility determines size of their plant. Costs above are based on the following assumptions, which will be updated during Phase 1 of Project:

- CAES plant with above ground air storage system capacity: 15MW-2 hour
- CAES plant with below ground air storage system capacity: 300-10 hour

CAES Using Underground Air Storage System

Appendix

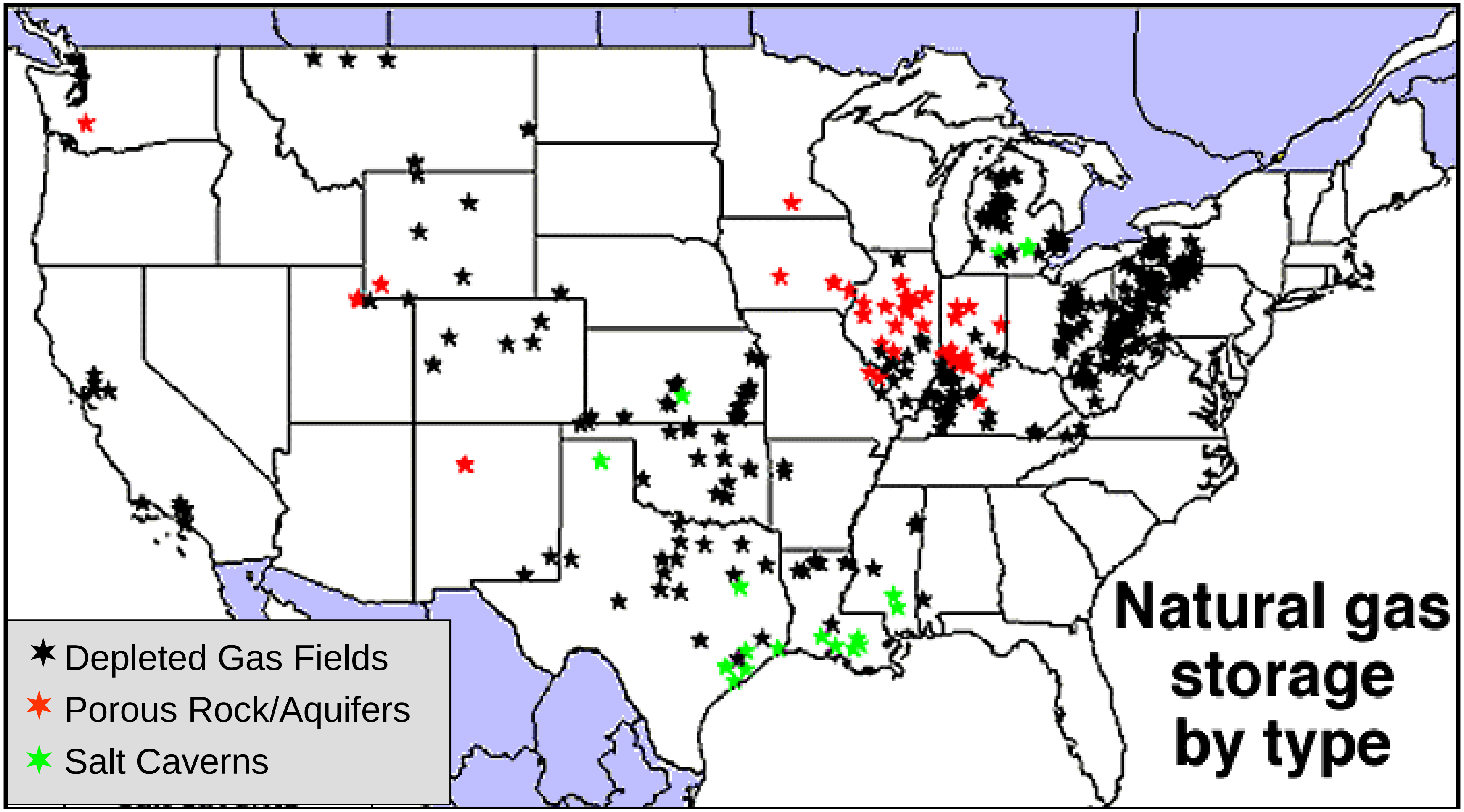
CAES Siting Opportunities Lower 48 States



Source: EPRI

Underground Natural Gas Storage Facilities in the Lower 48 States

Appendix

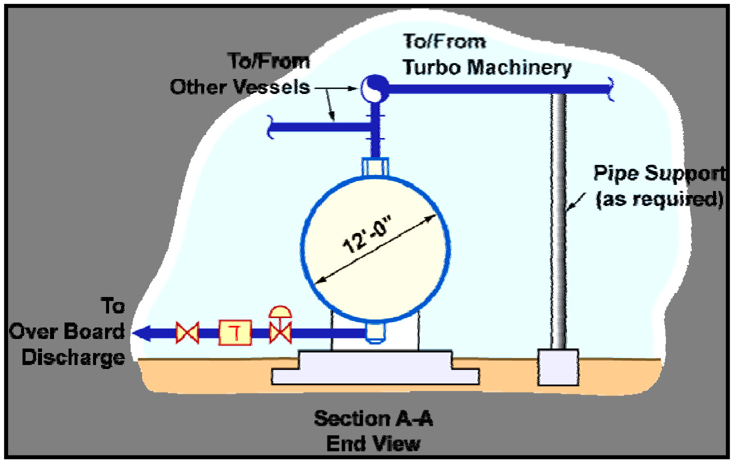


CAES Using An Above-Ground Air Storage System

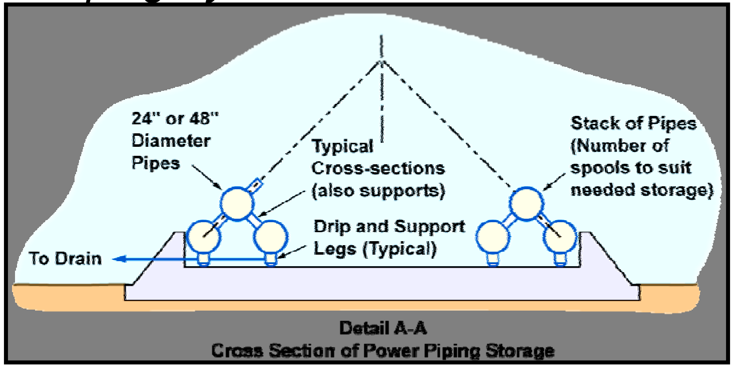
Appendix

- **Plant Size: ~ 15 MW with 2 Hours of Storage**
- **Assess technical and economic feasibility of pipe and/or vessel-based above-ground air storage systems for CAES application**
- **Assess stress-corrosion impact of CAES cyclic pressure and temperature duty**
- **Demonstrate advanced CAES plant design and assess its cost, performance and reliability**
- **Demonstrate power ramping capability to mitigate power fluctuations from wind generators**

Tanks/Vessels Used For Air Store



Piping System Used For Air Store

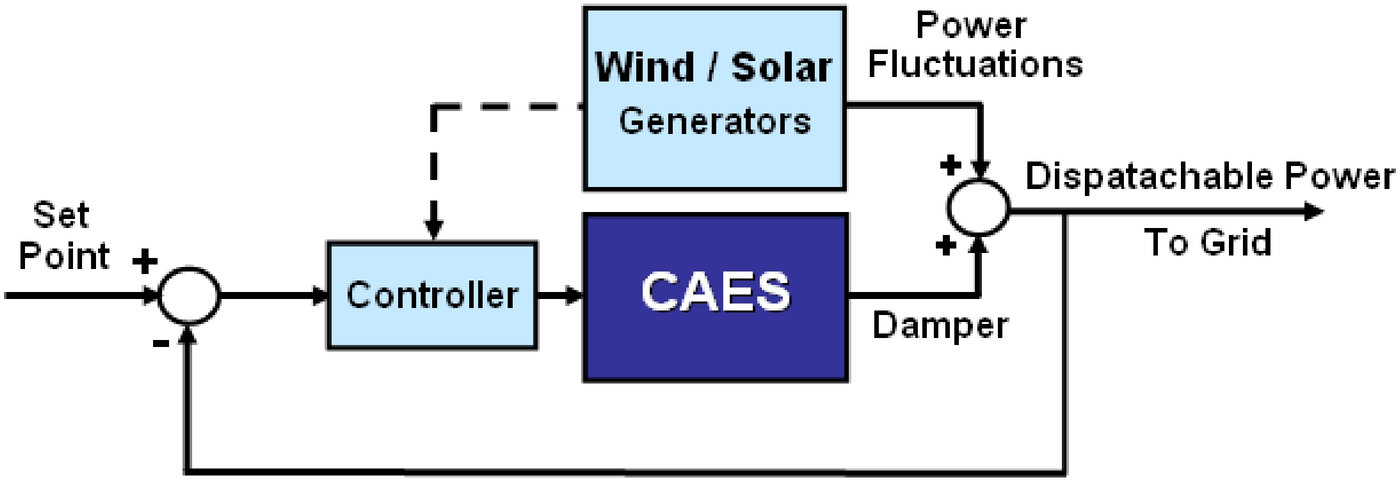


Problem: Wind/Renewable Plants Produce Power Output Oscillations or Provide Power When Not Needed, Which Limits the Value of Wind Resources

Appendix

Solution:

Deploy Electric Energy Storage Shock Absorber Plant, Which Is Sized and Controlled To Reduce Load Leveling, Ramping, Frequency Oscillation and/or VAR Problems



Don’t Let The Texas Grid Emergency Caused By Wind Generators Happen In California

Appendix

Reuters New Flash

Loss of Wind Causes Texas Power Grid Emergency

Wed Feb 27, 2008 8:11pm EST

HOUSTON (Reuters) - A drop in wind generation late on Tuesday, coupled with colder weather, triggered an electric emergency that caused the Texas grid operator to cut service to some large customers, the grid agency said on Wednesday.

Electric Reliability Council of Texas (ERCOT) said a decline in wind energy production in west Texas occurred at the same time evening electric demand was building as colder temperatures moved into the state.

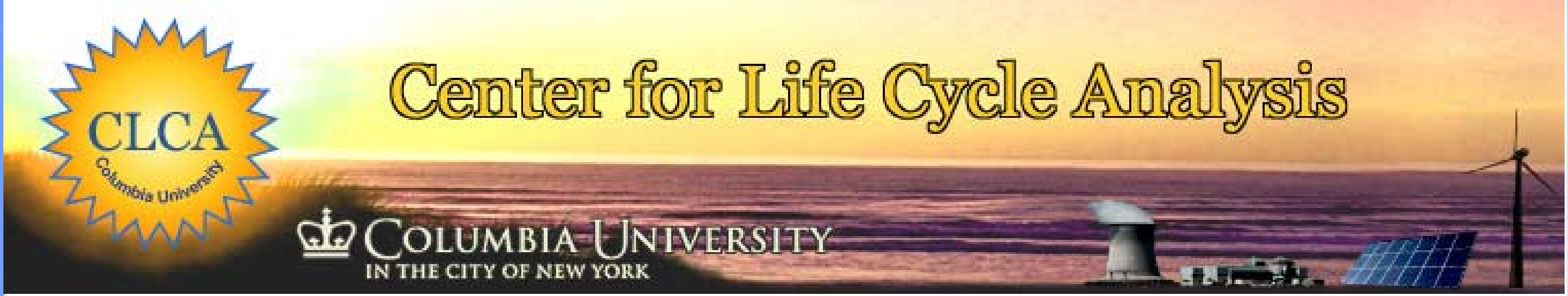
The grid operator went directly to the second stage of an emergency plan at 6:41 PM CST (0041 GMT), ERCOT said in a statement.

System operators curtailed power . . . .

7.2 Vasilis Fthenakis, PV-CAES Modeling and Assessments at Columbia University

Vasilis Fthenakis, is the founding Director of the Center for Life Cycle Analysis (CLCA) and a Professor at the Earth and Environmental Engineering Department of Columbia University. He holds a joint appointment with Brookhaven National Laboratory, as a Senior Scientist and the Head of the National Photovoltaics Environmental Research Center.

The Center for Life Cycle Analysis (LCA) of Columbia University was formed in the Spring of 2006 with the objective of conducting comprehensive LCAs of energy systems. LCA provides a framework for quantifying the potential environmental impacts of material and energy inputs and outputs of a process or product from "cradle to grave". The mission of the Center is to guide technology and energy policy decisions with data-based, well balanced and transparent descriptions of the environmental profiles of energy systems.



PV-CAES R&D at Columbia University

Vasilis Fthenakis

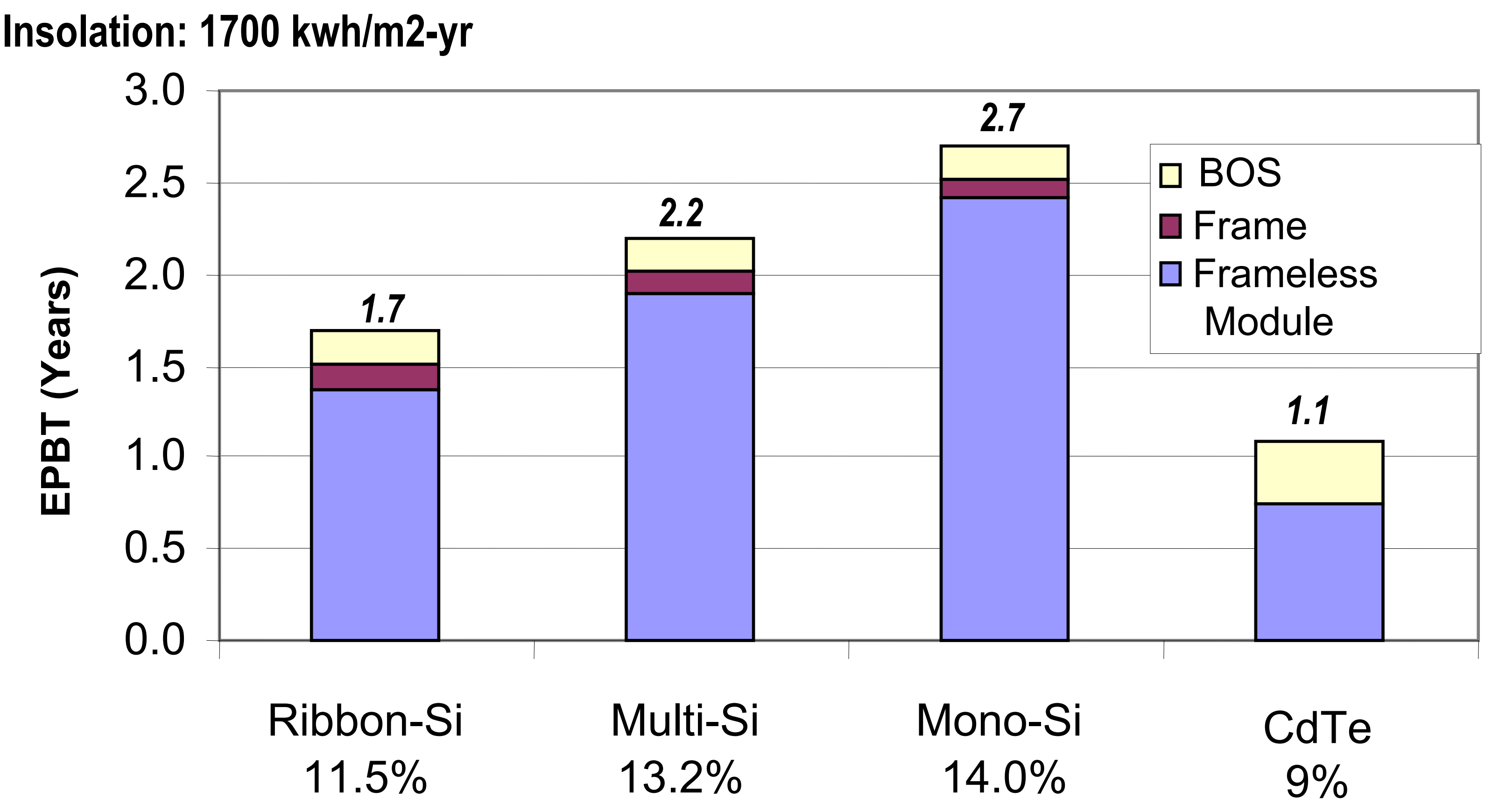
PV-CAES R&D Topics

- Environmental Life Cycle Analysis
  - CO2 & Toxic Emissions, Energy Payback Times, Land & Water use
- Modeling of PV-CAES
  - System Sizing/Optimization
  - Investigating Wind-PV Synergy
- CAES capacity in Africa

Life Cycle Analysis

- The mission of the Center for Life Cycle Analysis (LCA) is to guide technology and energy policy decisions with data-based, well balanced and transparent descriptions of the environmental profiles of energy systems

Energy Payback Times (EPBT)



Based on data from 12 US and European PV manufacturers

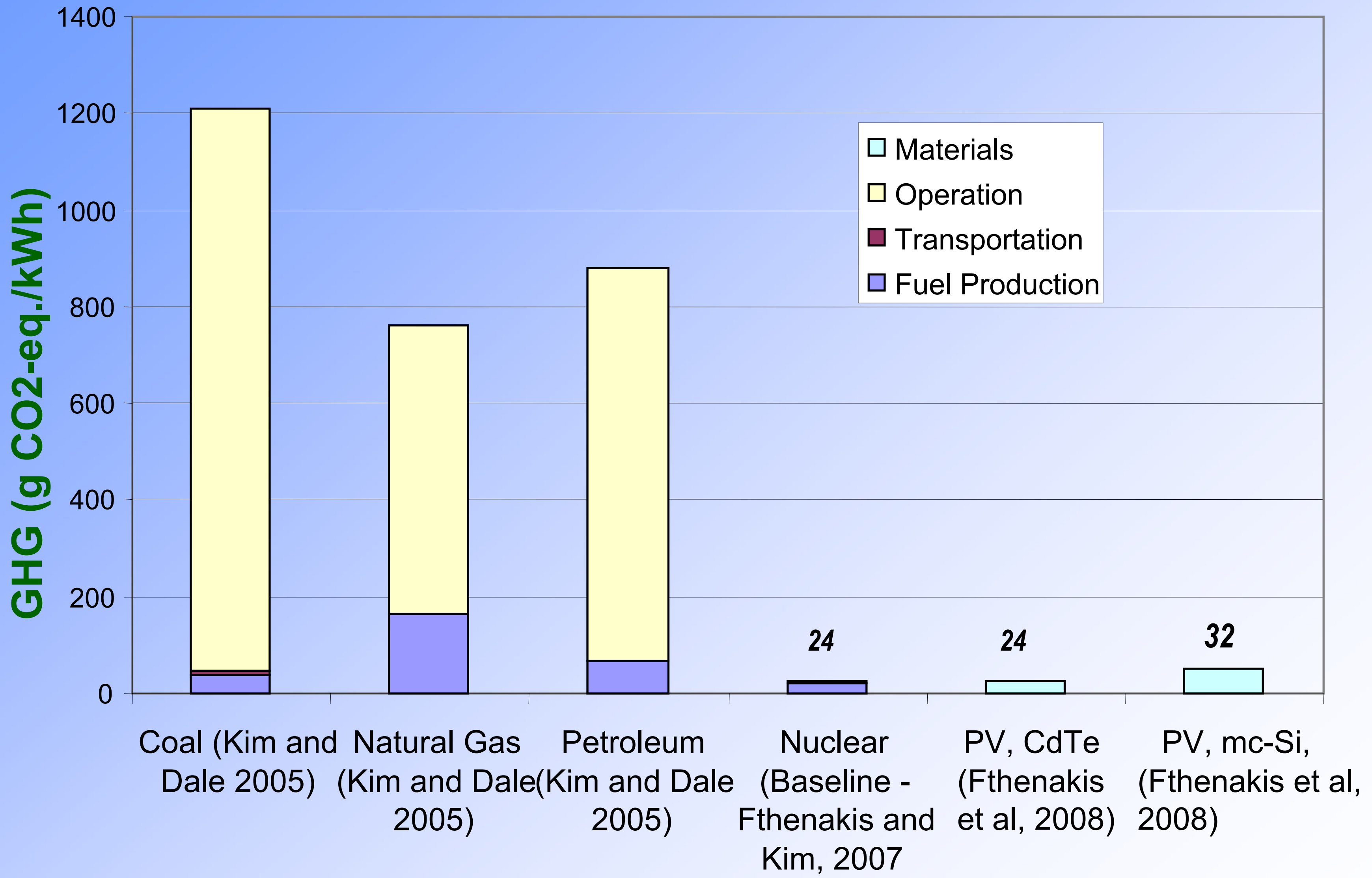
-Alsema & de Wild, *Material Research Society, Symposium vol. 895, 73, 2006*

-deWild & Alsema, *Material Research Society, Symposium vol. 895, 59, 2006*

-Fthenakis & Kim, *Material Research Society, Symposium vol. 895, 83, 2006*

-Fthenakis & Alsema, *Progress in Photovoltaics, 14, 275, 2006*

GHG Emissions from Life Cycle Analyses of Electricity Production



Fthenakis and Kim, Energy Policy, 2007
Fthenakis et al., Environmental Science & Technology, 2008.

Recognition by the Scientific Community

SCIENCE NEWS
THE WEEKLY NEWSMAGAZINE OF SCIENCE

Greener Green Energy: Today's solar cells give more

The New York Times

Photovoltaic Cells Are Still Very Green, Comparative Test Shows *February 26, 2008*

Environmental Science & Technology

Science News
February 6, 2008

ieee spectrum online
For Tech Insiders

New photovoltaics change costs
February 2008

How free is Solar Energy?

Solar Power Lightens Up with Thin-Film Technology

SCIENTIFIC AMERICAN

April 25, 2008

SCIENTIFIC AMERICAN

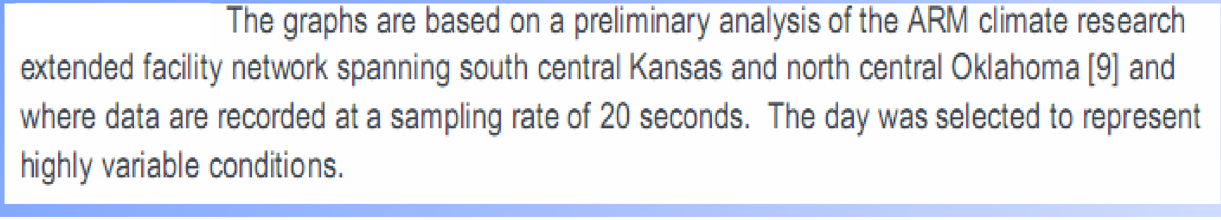
Dark Side of Solar Cells Brightens

A life cycle analysis proves that solar cells are cleaner **February 21, 2008**

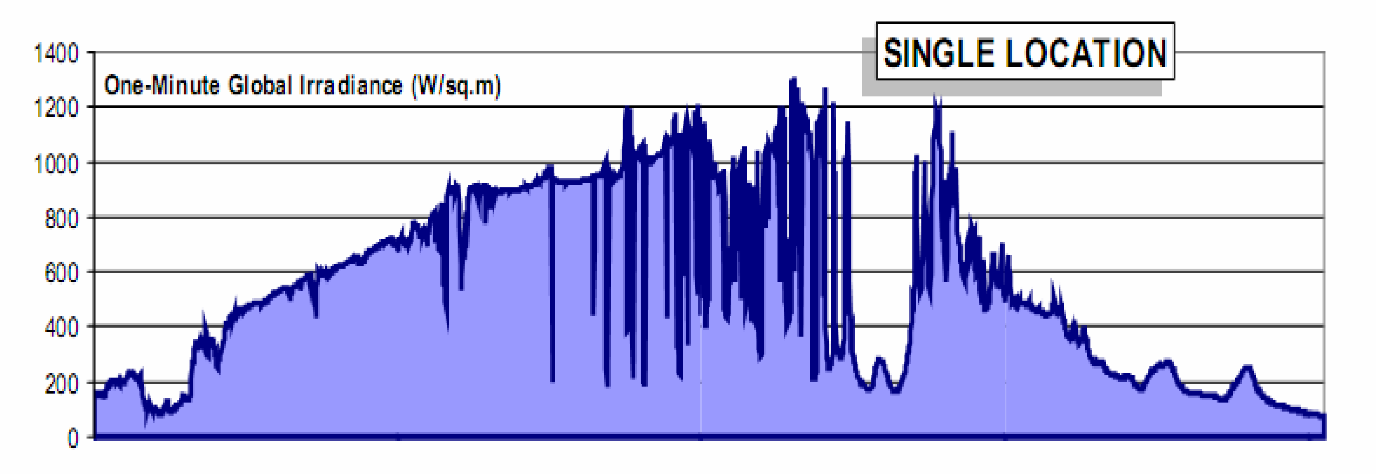
Leading the International Energy Agency Task on PV -LCA

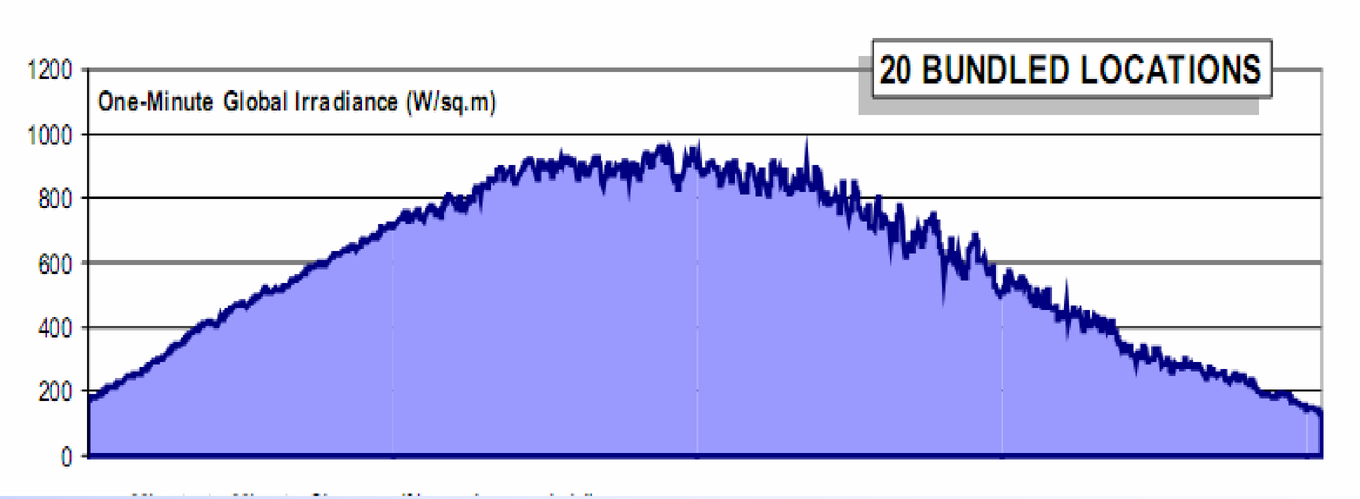
Modeling of PV-CAES Systems

PV Geographic Smoothing



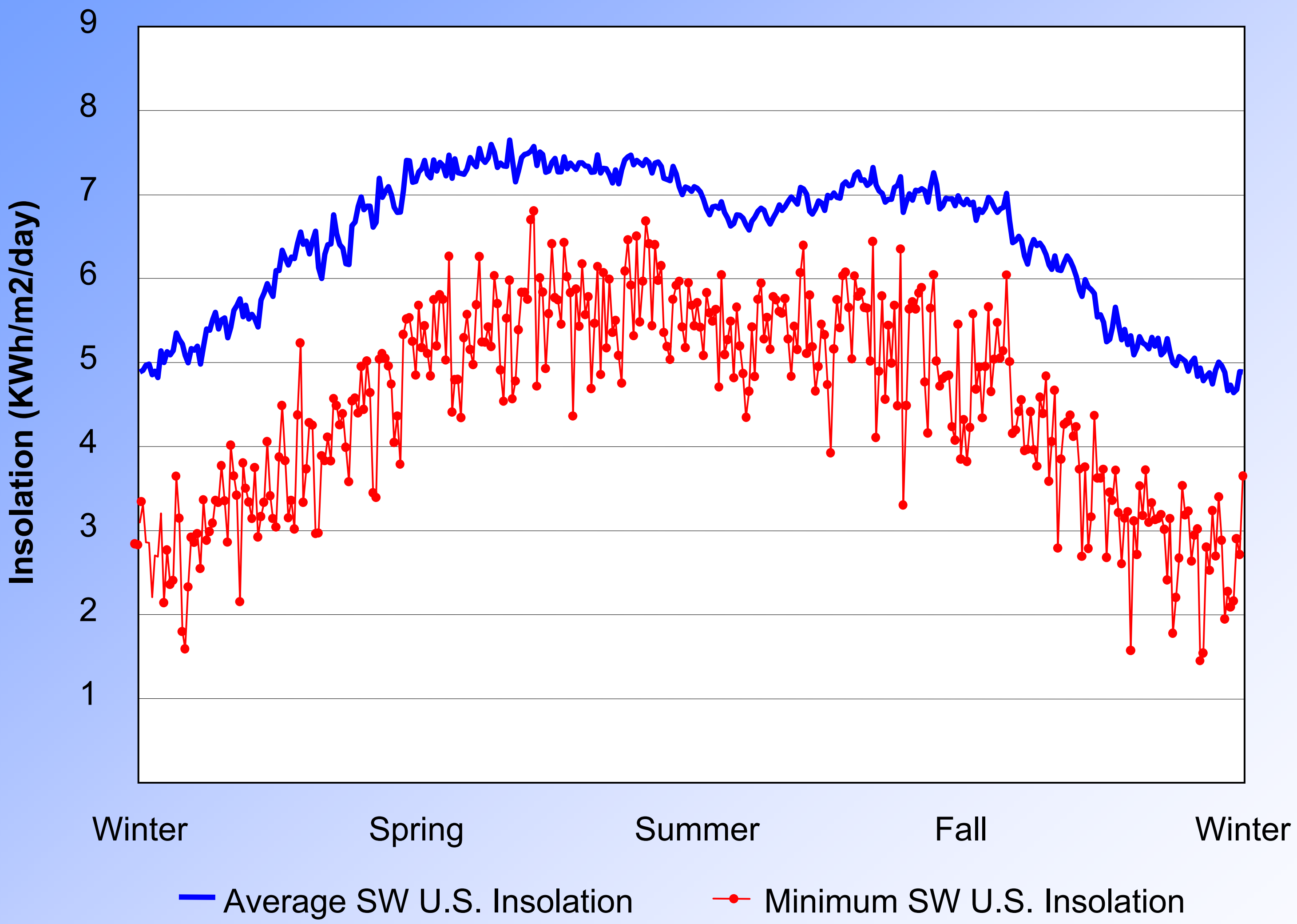
The graphs are based on a preliminary analysis of the ARM climate research extended facility network spanning south central Kansas and north central Oklahoma [9] and where data are recorded at a sampling rate of 20 seconds. The day was selected to represent highly variable conditions.





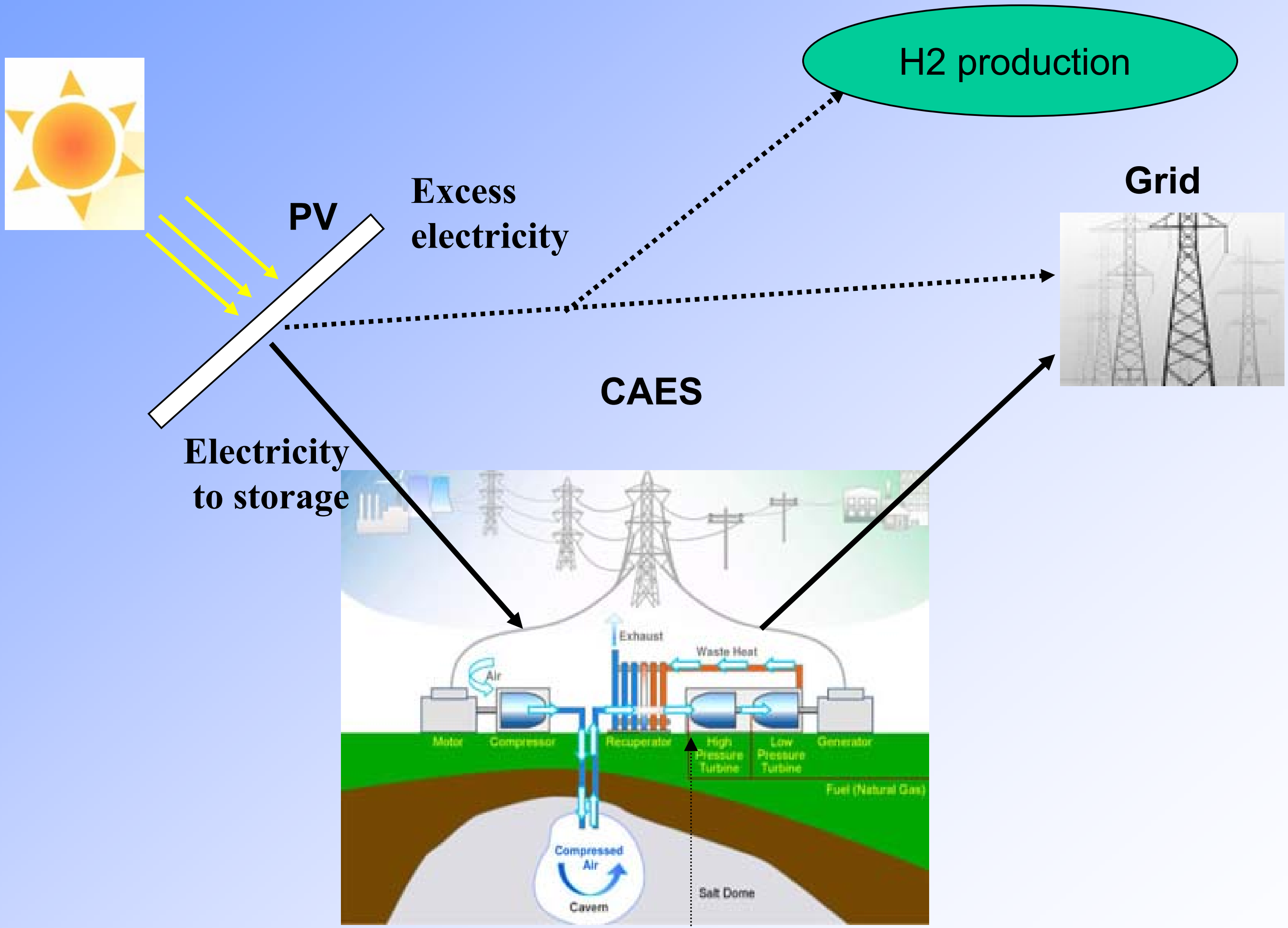
“Capacity Valuation Methods,” SEPA 02-08, Hoff, Perez, Ross, Taylor, 2008

SW Average & Minimum Insolation
(from 45 years of data)



Average and minimum 1960-2005
Insolation levels for El Paso, Albuquerque, Tucson, Phoenix, Las Vegas, Daggett,
Class 1 Stations, National Solar Radiation Database (NSDRB)

The PV-CAES Conceptual Model



H2 production

PV

Excess electricity

Grid

CAES

Electricity to storage

Fuel

The PV-CAES Integration

- Peak plants -110 MW

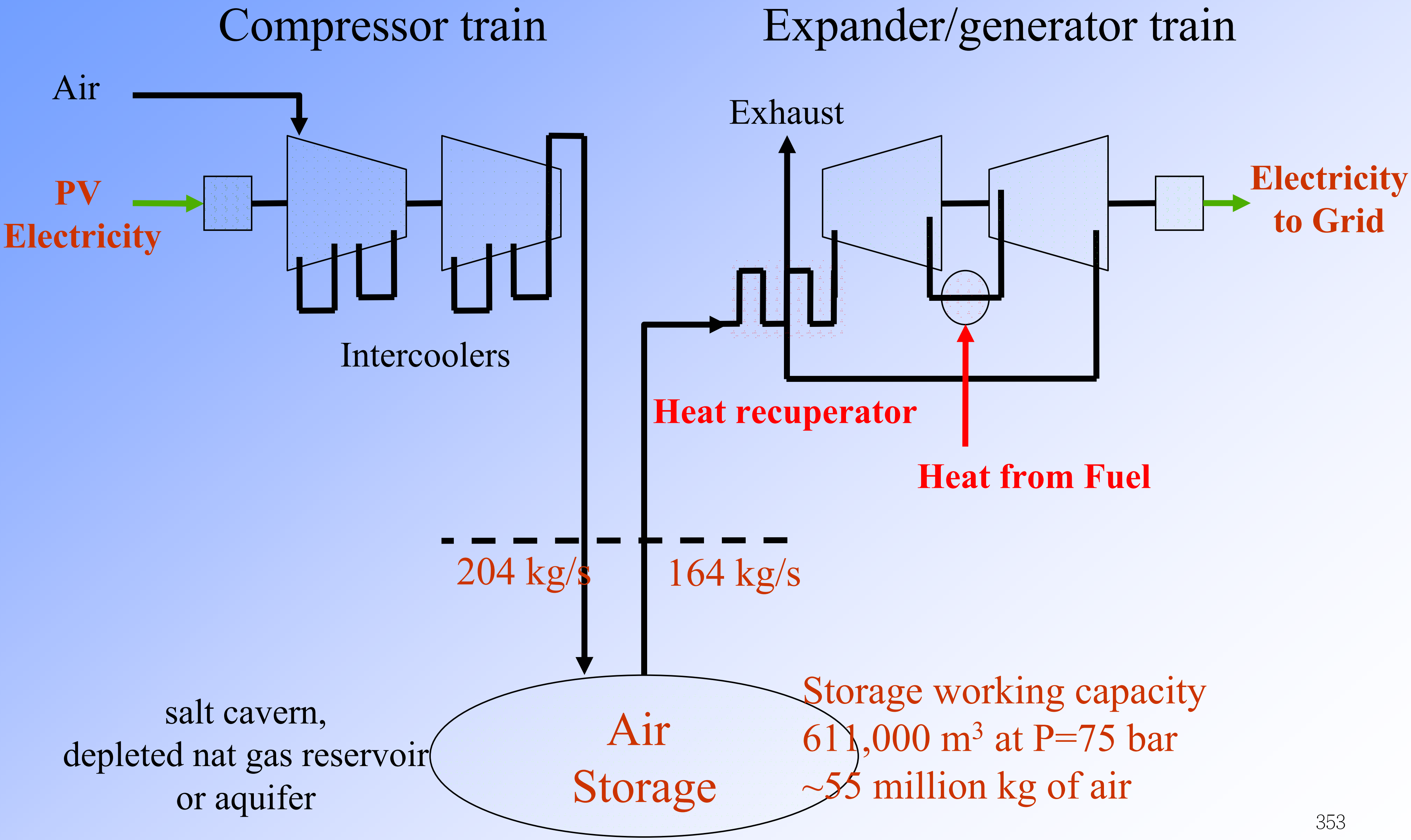
  -10 h/day M-F

  (based on the McIntosh plant)

- Base load plants -400 MW

  -24 h/day, year round

CAES System Schematic -110 MW peak plant



Compressor train

Expander/generator train

Air

Exhaust

PV Electricity

Electricity to Grid

Intercoolers

Heat recuperator

Heat from Fuel

204 kg/s

164 kg/s

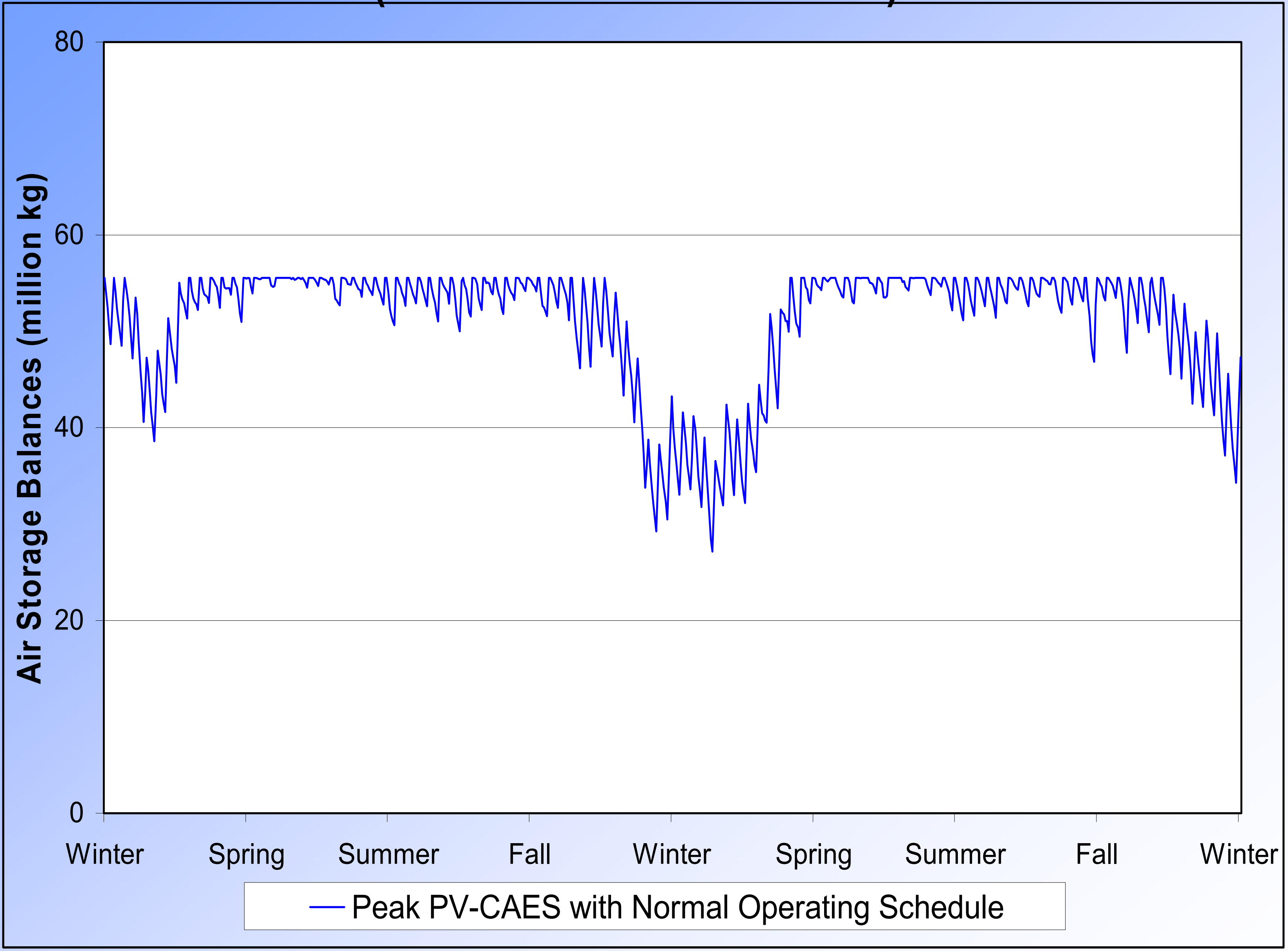
salt cavern,
depleted nat gas reservoir
or aquifer

Air Storage

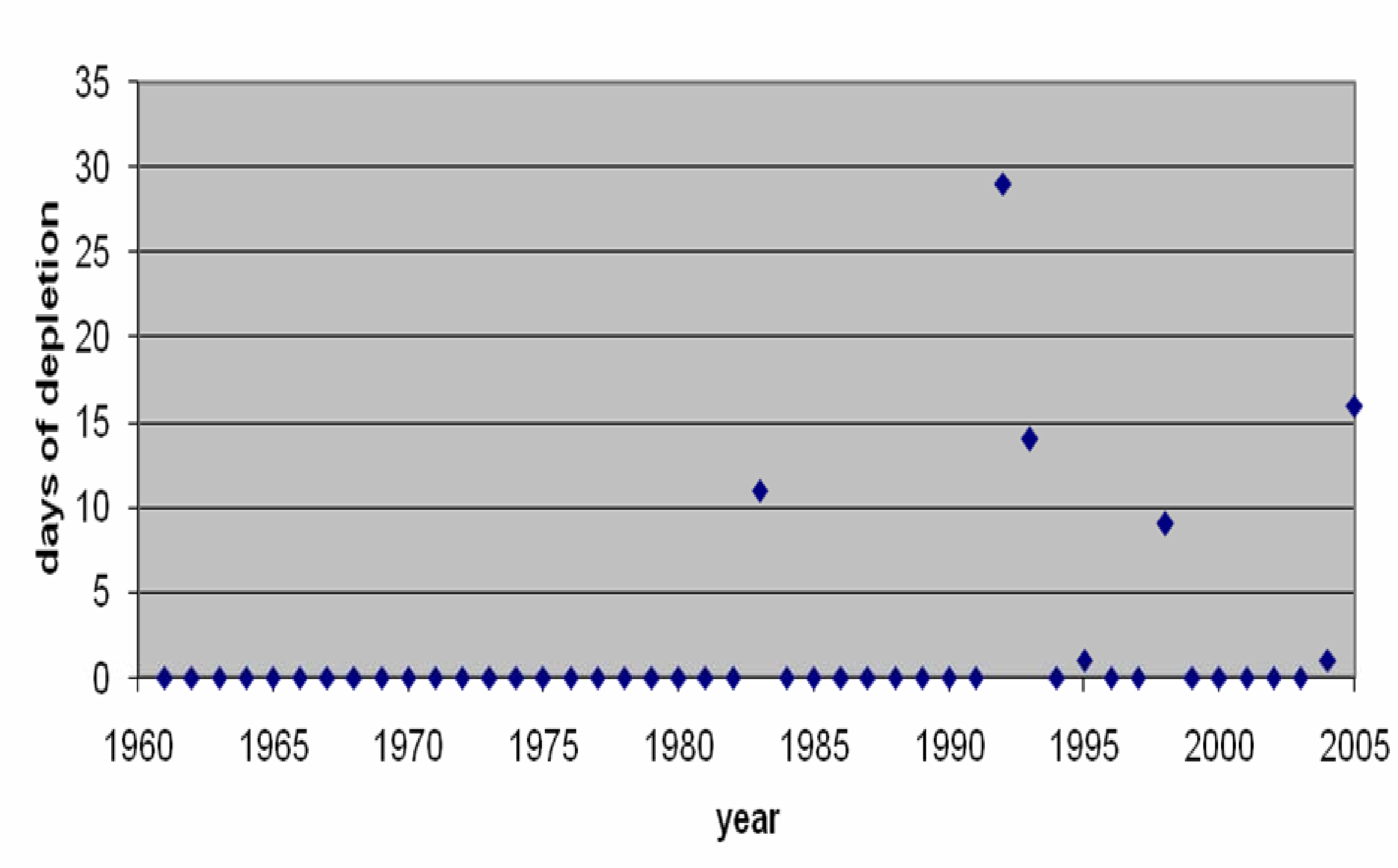
Storage working capacity
611,000 m^3 at P=75 bar
~55 million kg of air

Snapshot Air Storage Balances in CAES

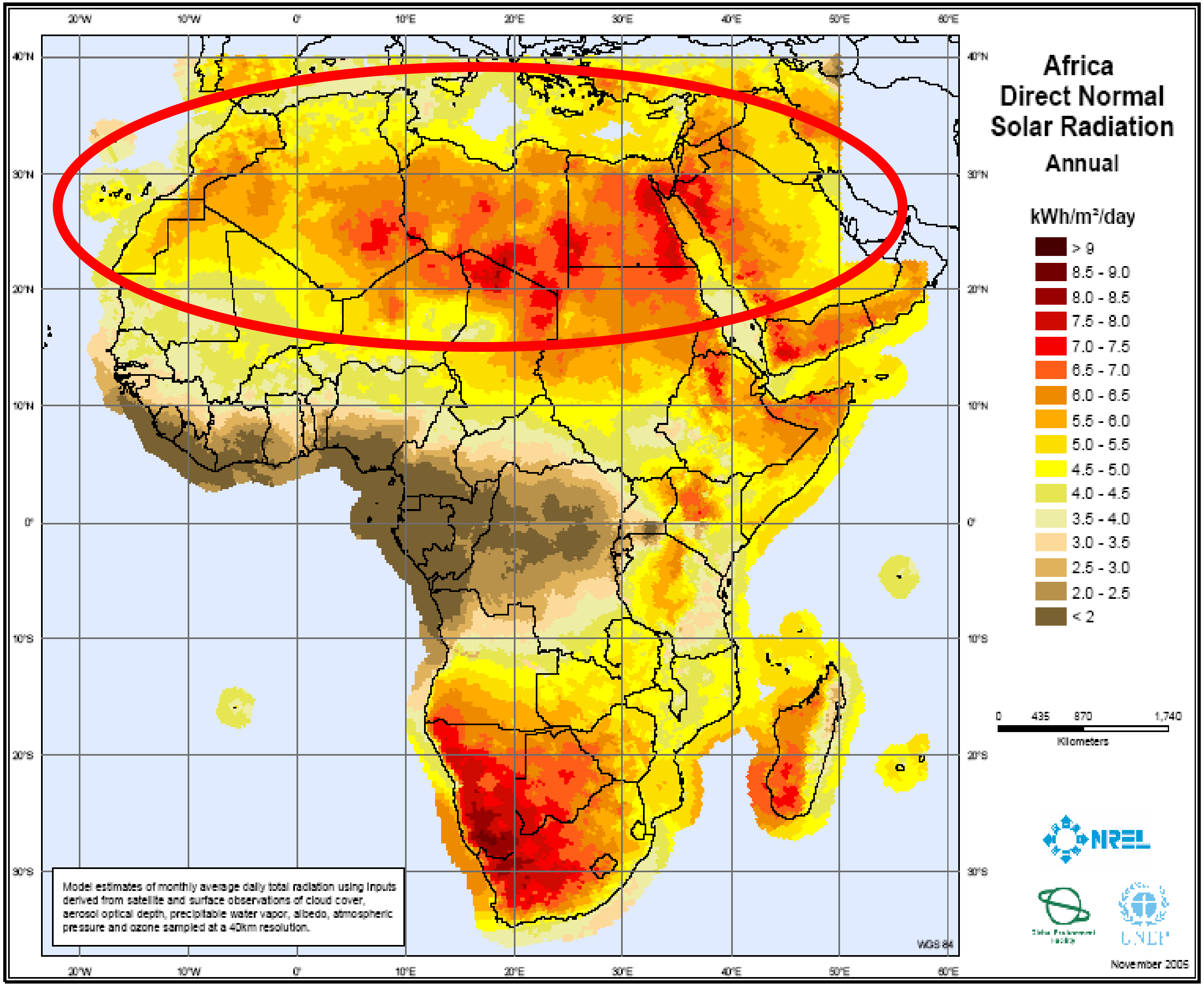
(1961-1962 insolation data)



System Availability based on 45-yr Records



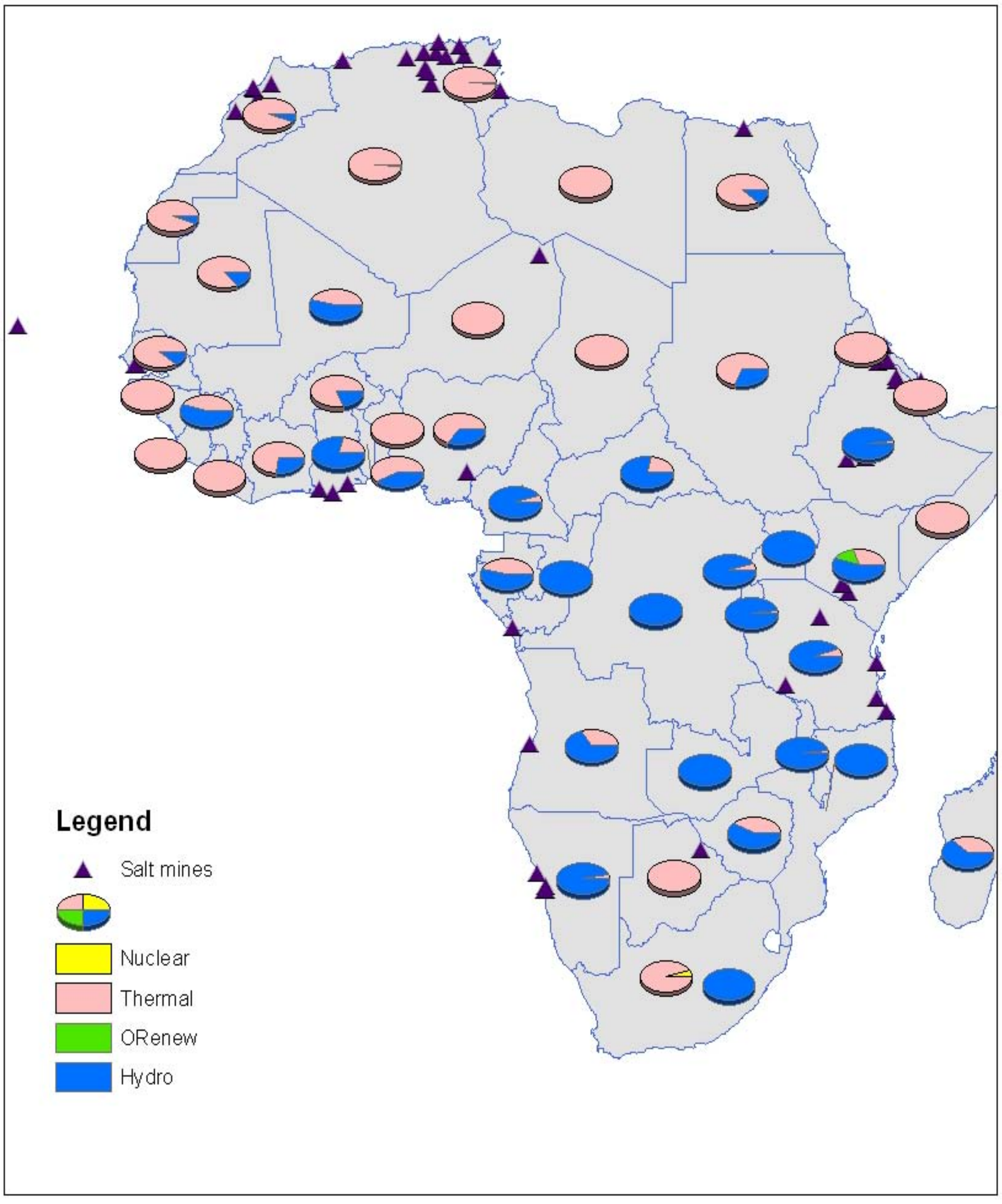
Solar Irradiation in Africa



Model estimates of monthly average daily total radiation using inputs derived from satellite and surface observations of cloud cover, aerosol optical depth, precipitable water vapor, albedo, atmospheric pressure and ozone sampled at a 40km resolution.

November 2005

Electric Power & Salt Mines in Africa



Courtesy: Vijay Modi, Mech. Engineering Dpt. Columbia