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COUPLING WIND POWER AS A RENEWABLE SOURCE TO NUCLEAR ENERGY AS A CONVENTIONAL ENERGY OPTION

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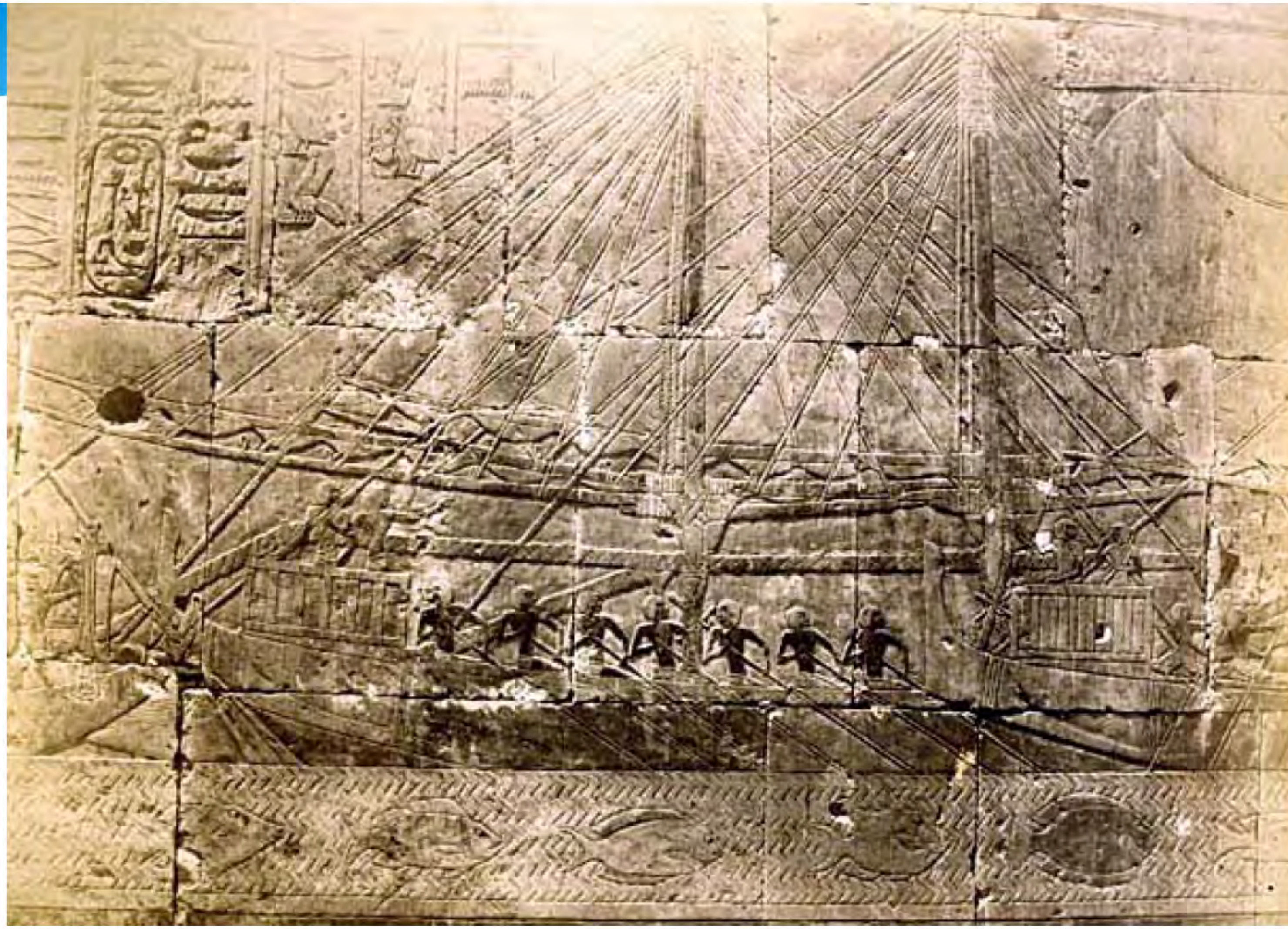
ABSTRACT

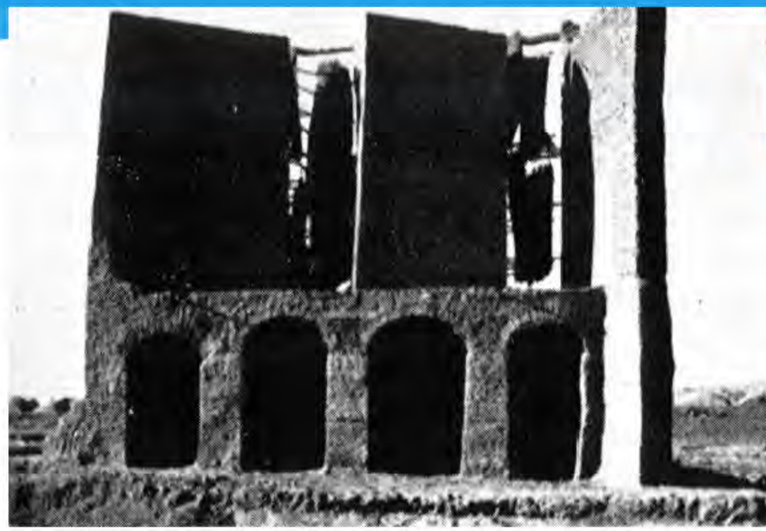
The coupling of wind power production as an intermittent supply to nuclear power generation as a base load supply is discussed. Wind turbines on a standby operational mode are net importers of power for their control and yaw mechanisms. They need a supply of about 5 kW of power from an existing grid. They also require the vicinity of a power grid with excess capacity to export their generated power.

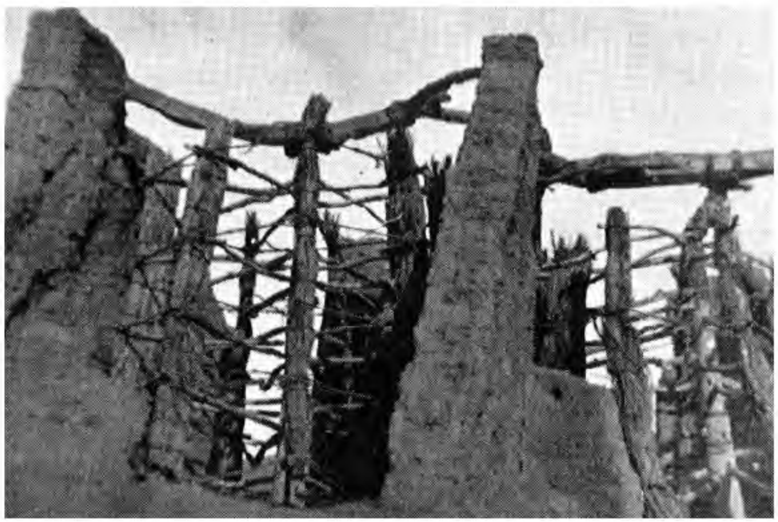
A choice is the construction of wind farms in the immediate vicinity, low population density population zones around nuclear power plants. An example is the Grand Ridge wind farm adjacent to the LaSalle nuclear power plant near Versailles, Illinois.

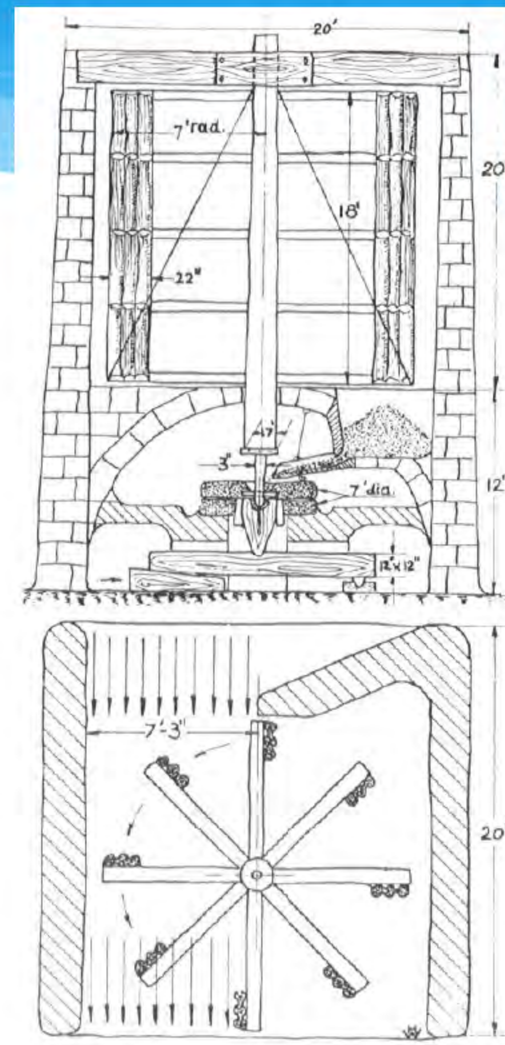
Since the best wind resources in the USA are located far from the industrial and population centers there is a need for connection to the grid trough High Voltage Direct Current (HVDC). Due to ramping considerations, the planned introduction of 20 percent of electrical wind production in the USA by 2020 would pose challenging grid stability issues. Energy storage alternatives such as hydrogen production, compressed air, flywheels, superconducting magnets and pumped storage need careful consideration.



Relief of sail boats on the walls of the Al Deir Al Bahari Queen Hatshepsut's Temple at Luxor, Egypt, commemorating a trading expedition to the land of Bunt.







Vestiges of a vertical panemone wind mill at Seistan, Iran. The rotors were made from fabric or bundles of reeds and wood.

Alexandria, Egypt's Moulins du Gabari, built on a hill overseeing the harbor of Alexandria, showing their furled sails.

Wind Resources of Egypt

In 2005, the New and Renewable Energy Authority (NREA) in cooperation with Risö National Laboratory published a Wind Atlas for Egypt based on observations and numerical simulations of the wind conditions in Egypt. The goal was "*to provide reliable and accurate wind atlas data sets for evaluating the potential wind power output from [...] wind turbine installations.*"

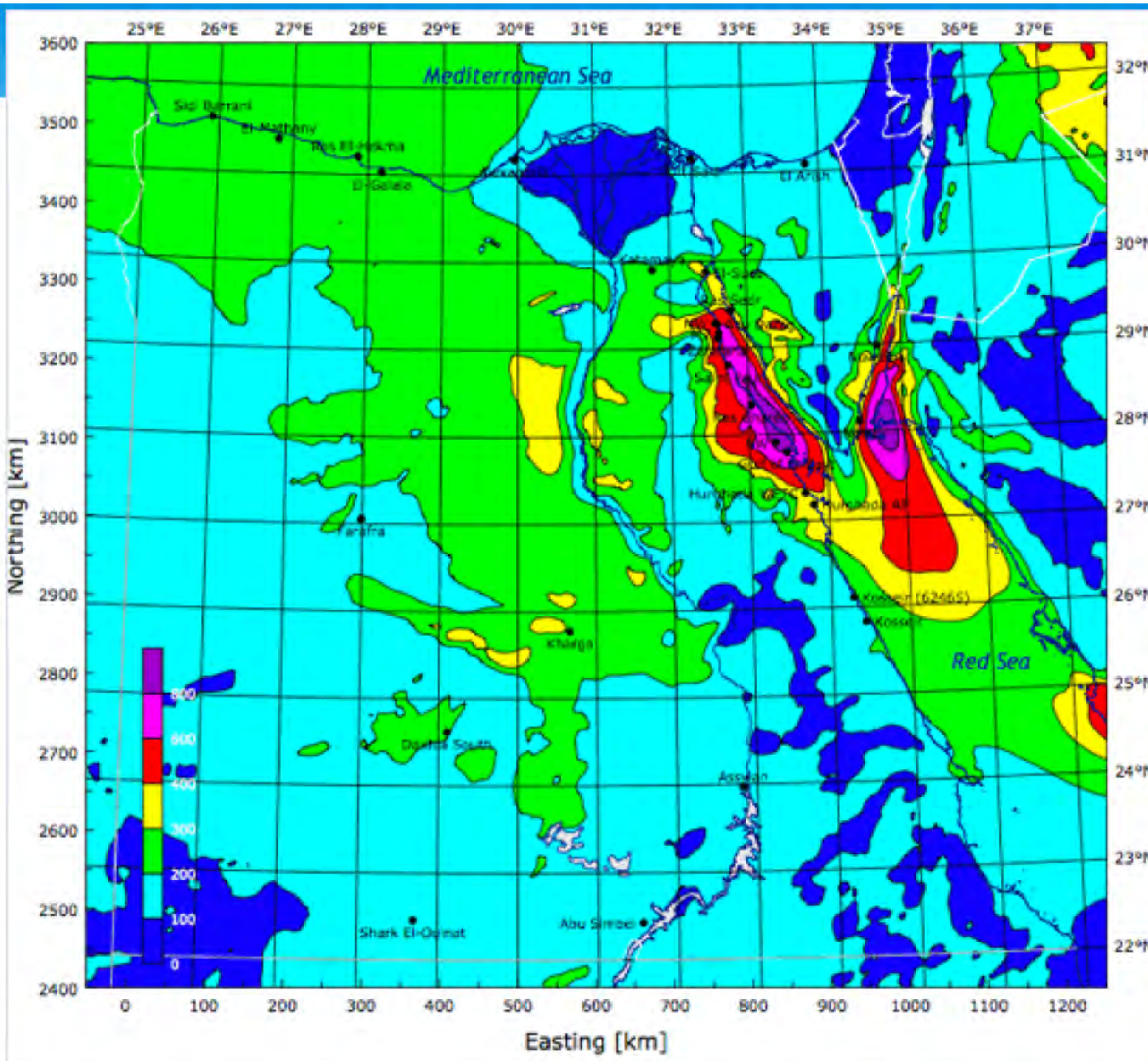
* The result of this eight years lasting program can be seen in the figures, which show the mean wind speeds on land and sea, respectively, at a height of 50 m above ground level (a.g.l.). The reddish colors represent higher wind speeds up to 10 m/s as average. Especially in the Gulf of Suez and the region around Ras Ghareb or Ras Zaafarana the winds blow very strongly and quite continuously with a capacity factor of almost 70 percent.

* It is not surprising that a wind farm was built in Ras Zaafarana with a total rated power of 430 MW (planned: 600 MW total) at an average wind speed of 9 m/s and an average capacity factor of 55 percent. Yet, the capacity factor has been significantly lower in the winter months and higher the rest of the year.

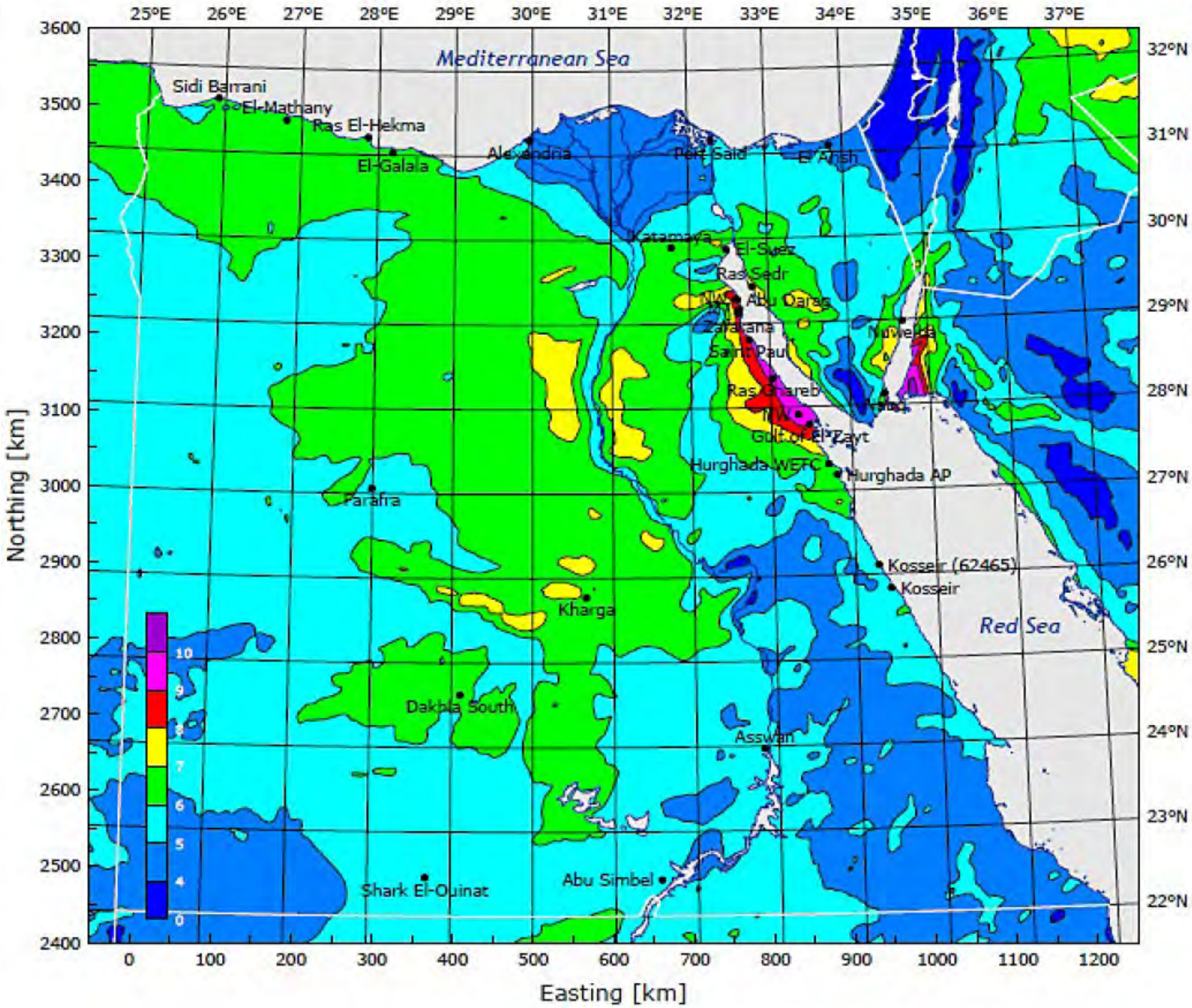
* A good location for offshore wind farms is – apart from the Gulf of Suez – the Gulf of Aqaba off the Saudi Arabian Coast. In these areas with high wind speeds and relatively high capacity factors, the annual energy output could lie between 3 – 5 GWh per installed MW, enough to power 1,000 European households with four people each for a whole year.

* Assuming an area of 180 km in length from Ras Zaafarana to the Gulf of El Zayt and 50 km in width, the potential of wind energy in Egypt is as high as 200 TWhr/yr, twice the current energy consumption of Egypt.

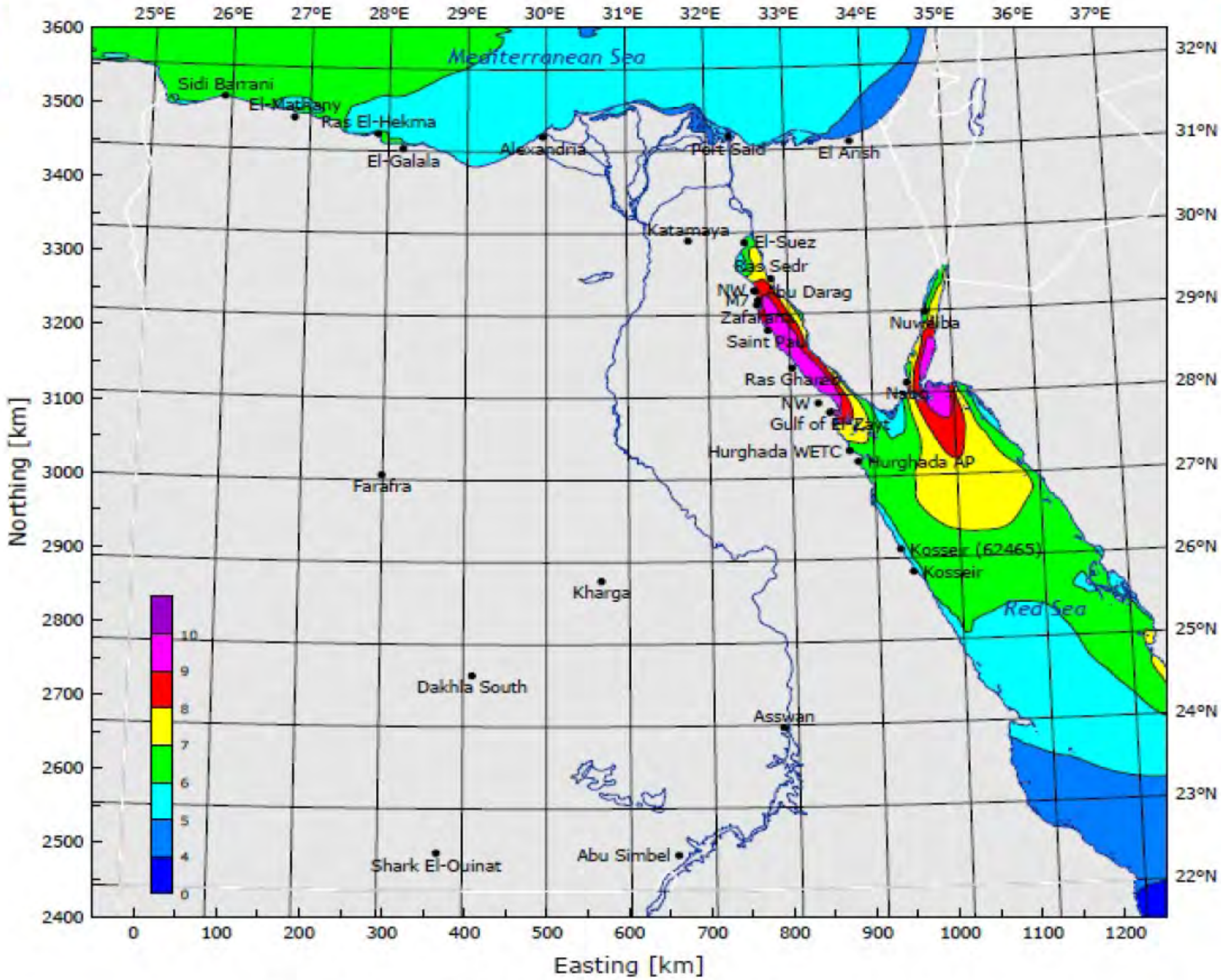
* Although the mentioned region has a high capacity factor of ~50 percent, wind energy always has the risk of intermittency. An electricity generation of only wind energy is not recommended, rather a mix of many sources like nuclear, natural gas, wind, hydro, and solar.



Mean wind power density in [W/m²] at a height of 50 m over the land surface.



Wind resource map: mean wind speed at 50 m agl (above ground level). Source: Wind Atlas of Egypt.



Offshore wind resource map: mean wind speed at 50 m above ground level, agl. Source: Wind Atlas of Egypt.

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Al Zaafarana is a desert area on the Red Sea's Gulf of Suez with a substantial wind resource speed of 9-11 m/s.

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BYPRODUCT URANIUM RESOURCES

Egypt Phosphate reserves (USGS): 100 million tonnes

Uranium resources in phosphate: Up to 40,000 MTU

Annual P_2O_5 production: +/- 90,000 tonnes

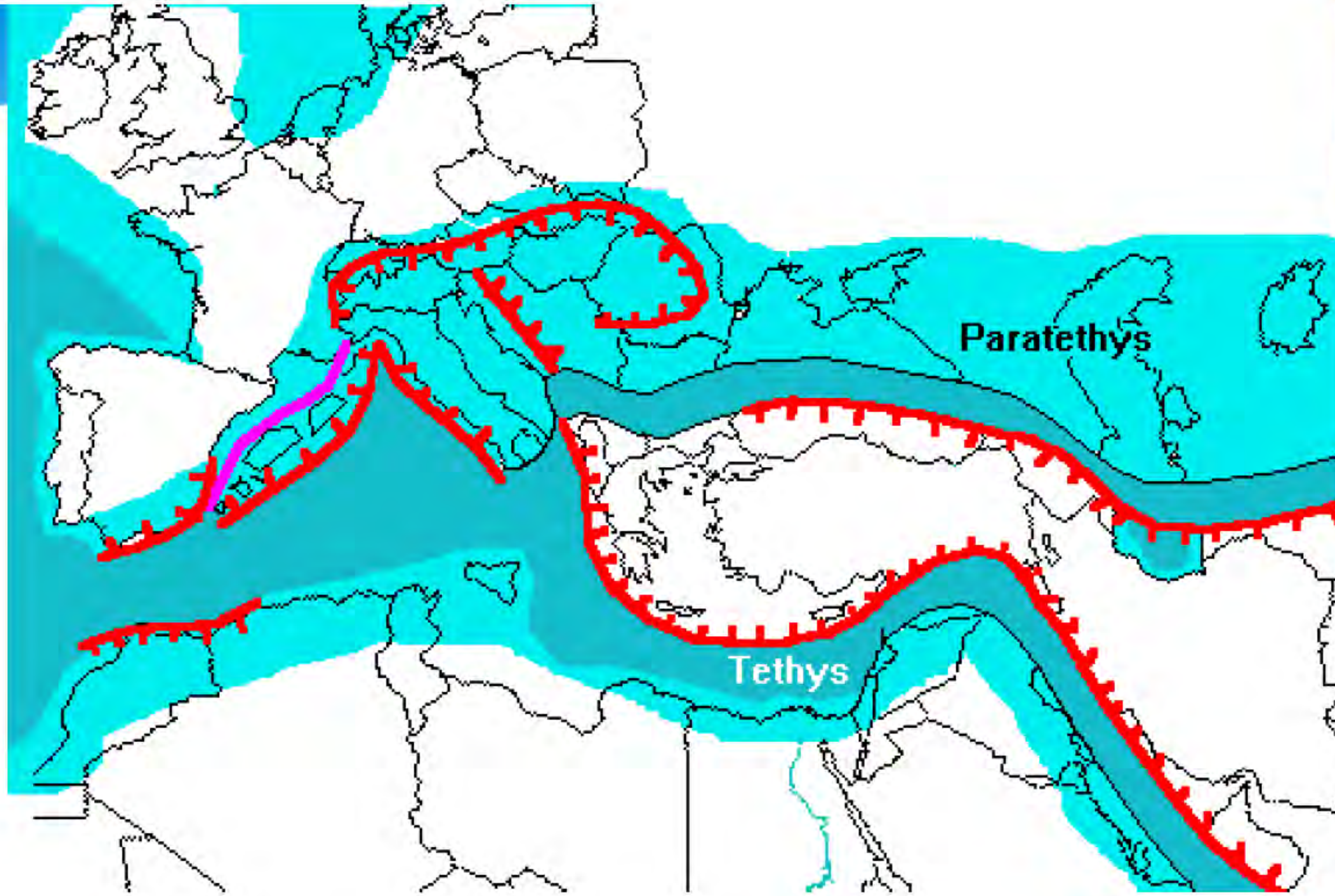
Potential Annual Uranium Production: 45,000 lbs U_3O_8 (17 MTU)

Domestic processing of 4.5 million tons of phosphate is planned, but status unclear.

Pilot extraction of uranium was carried out at lab scale in mid-2000s, but results were mixed.

If acid plant scaled up, Egypt may produce for domestic nuclear energy program in 2020 time frame.

Possible gold and copper byproduct.



Tethys Sea location 20 million years ago compared with the present day Mediterranean coast lines.

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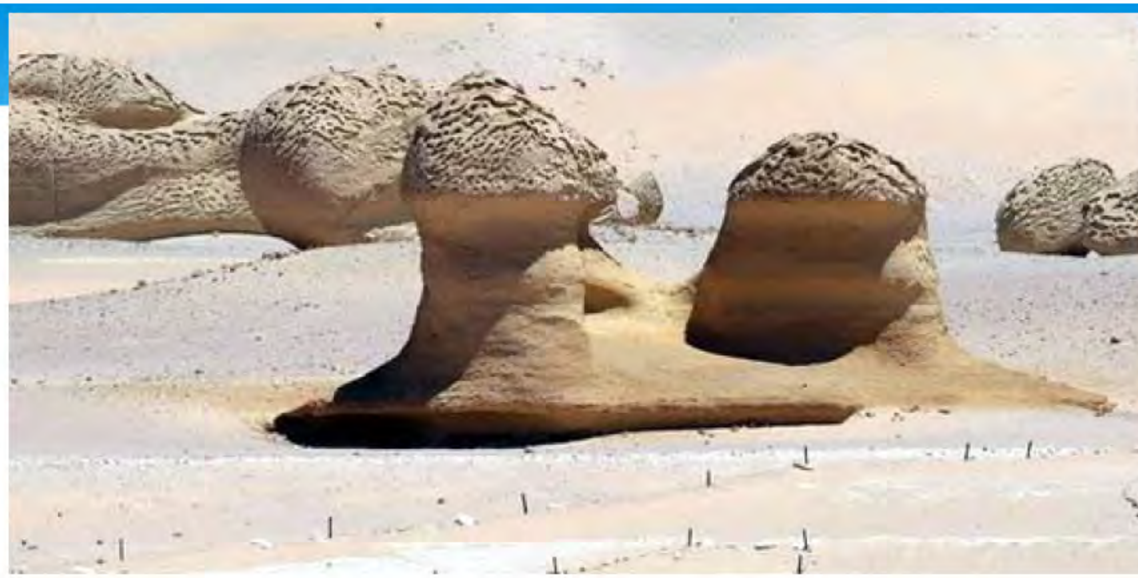
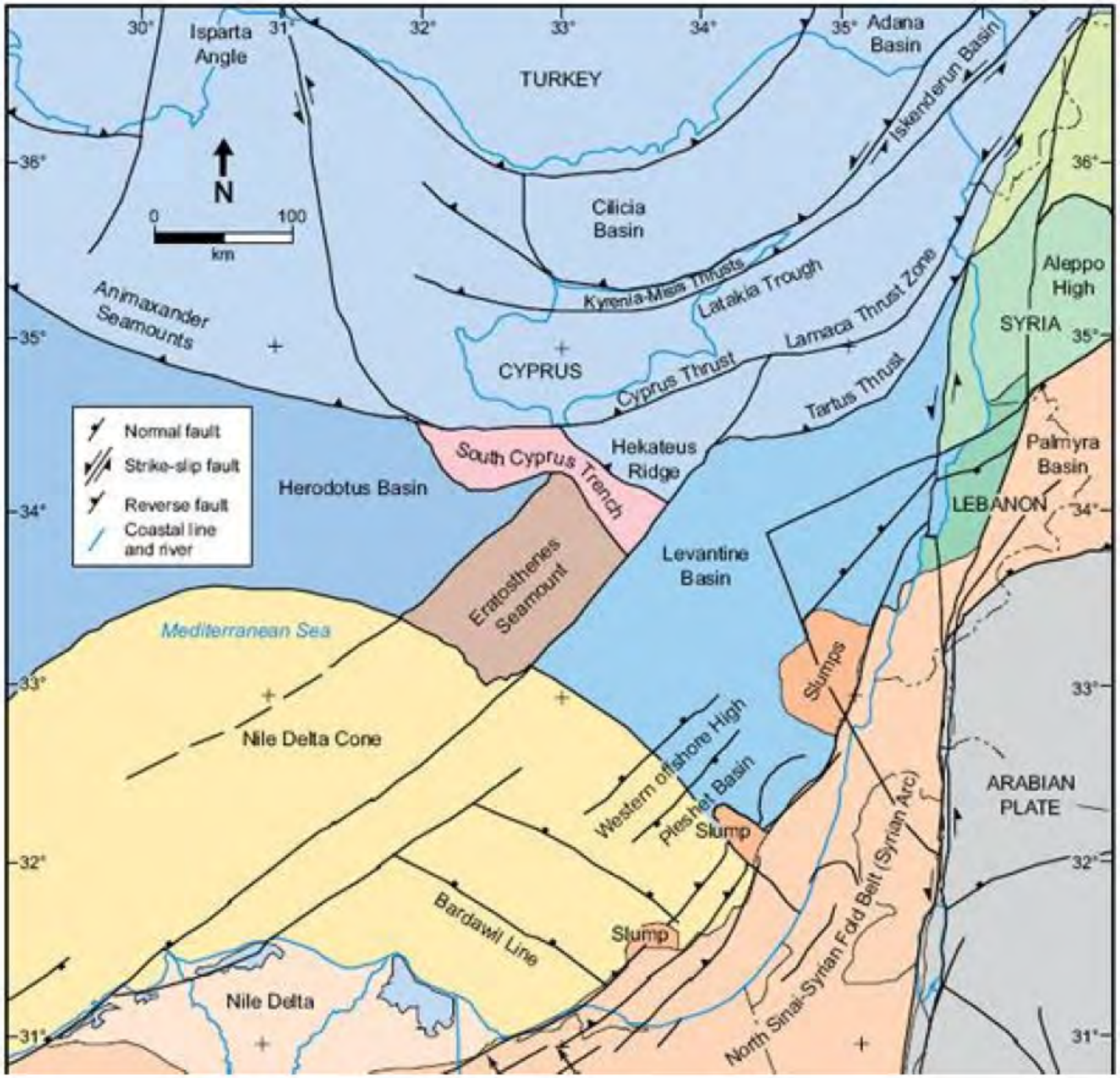


Valley of the Whales, Wadi Al Hitan or the Zeuglodon Valley, Fayoum, Egypt, as part of the ancient Tethys Sea.



Nile Delta Cone and Levantine Basin

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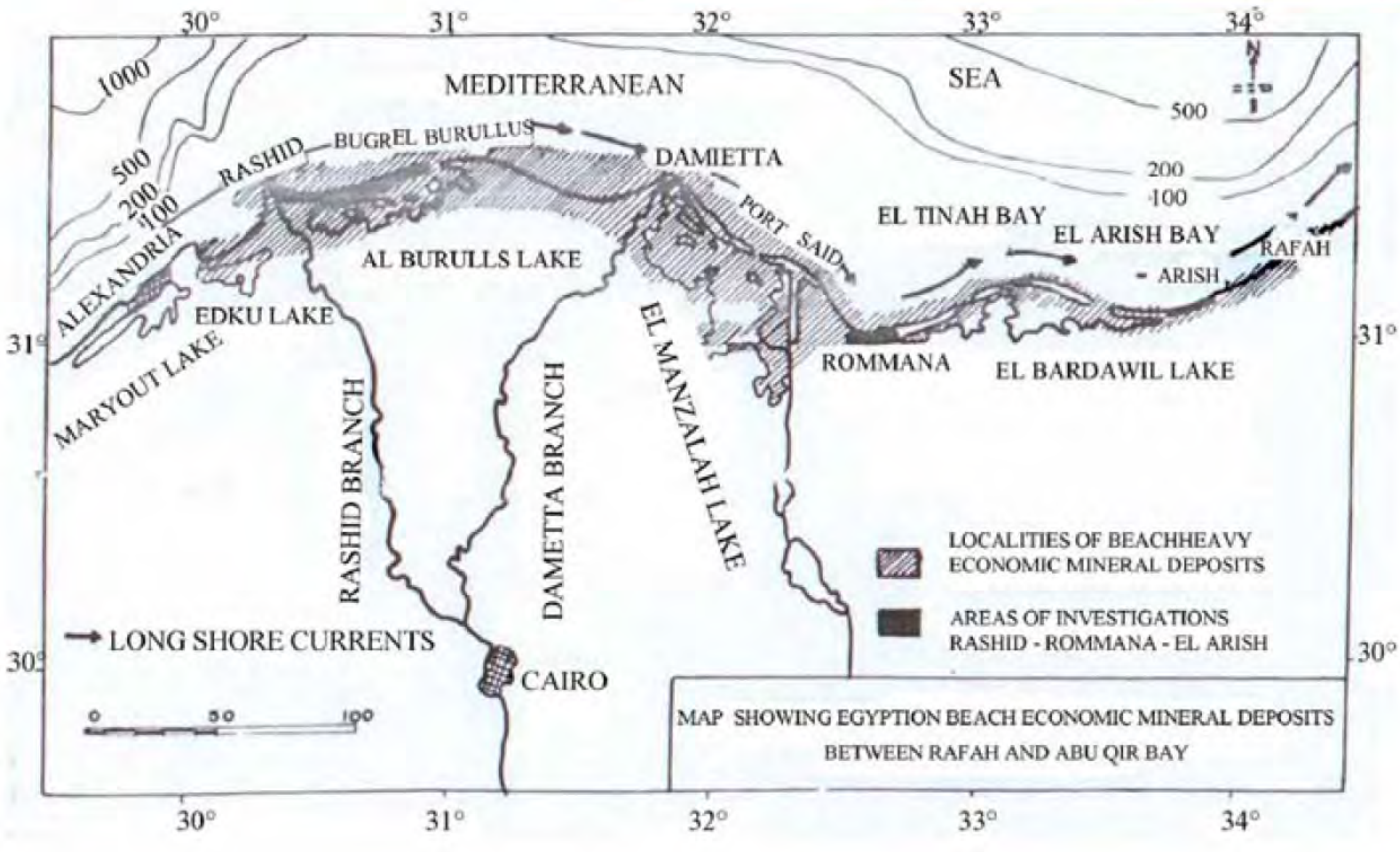

Black Sand Deposits.

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Uranium deposits in Egypt.

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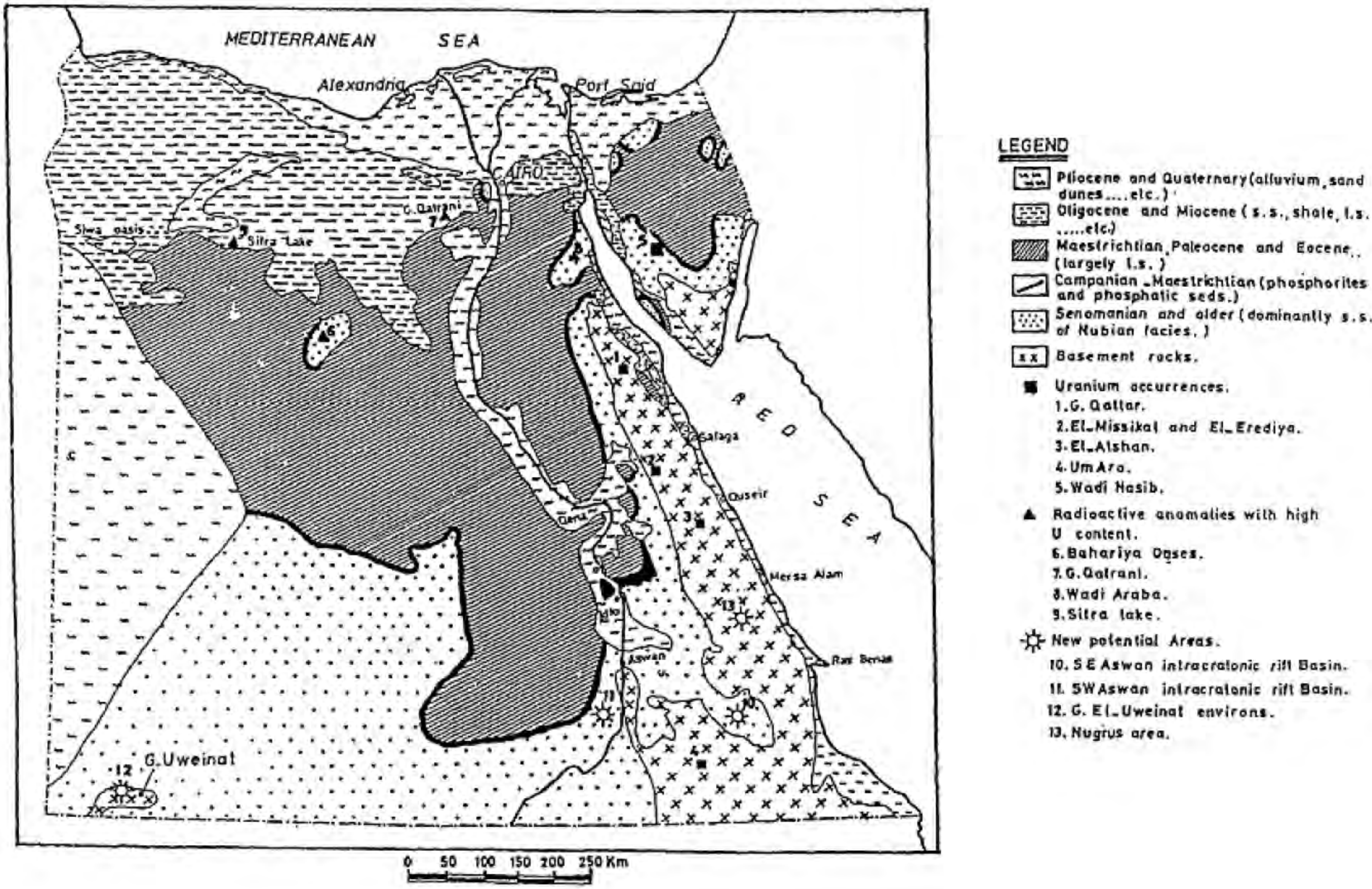

Uranium potential in Egypt.

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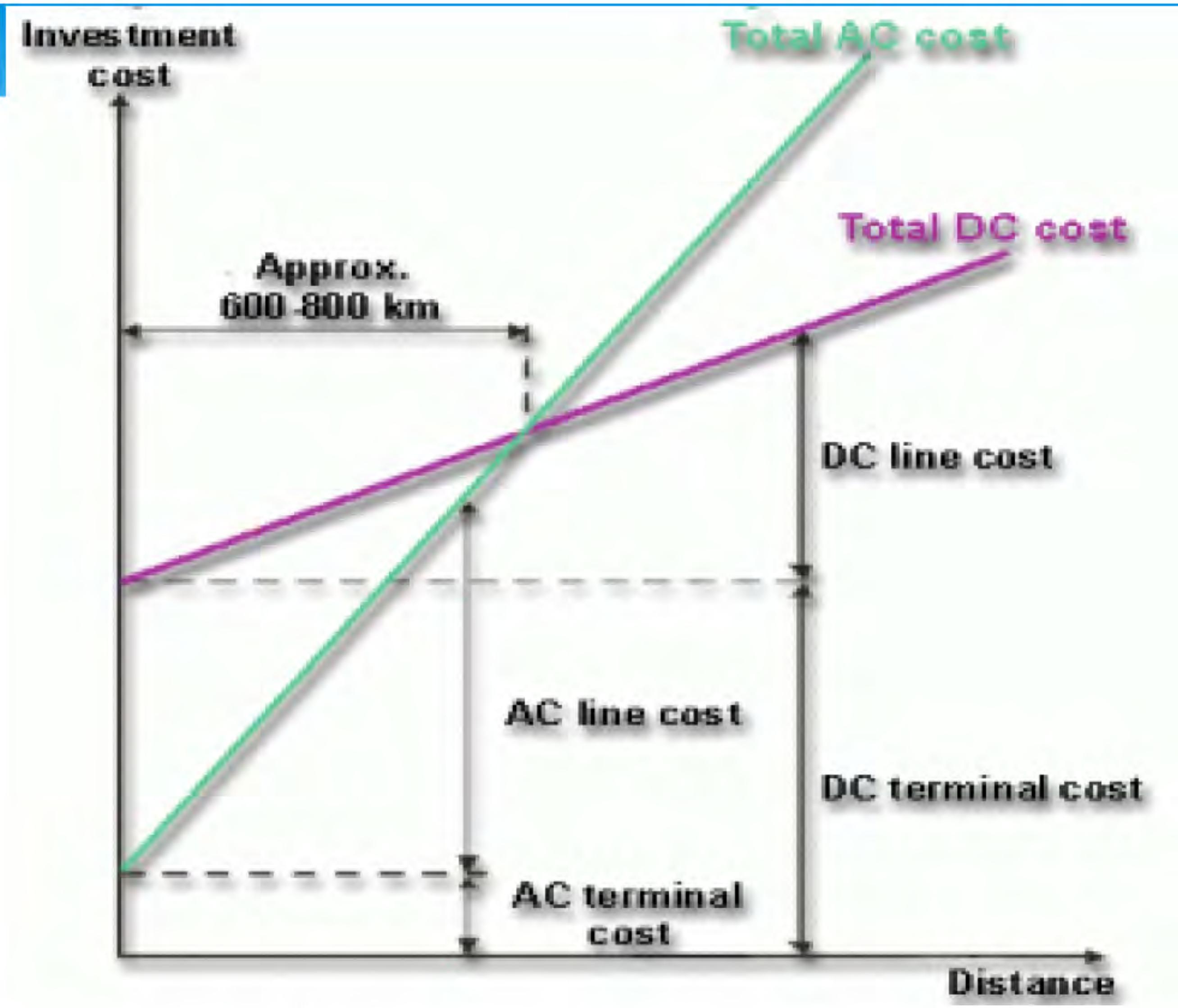
WIND POWER INTEGRATION CHALLENGES

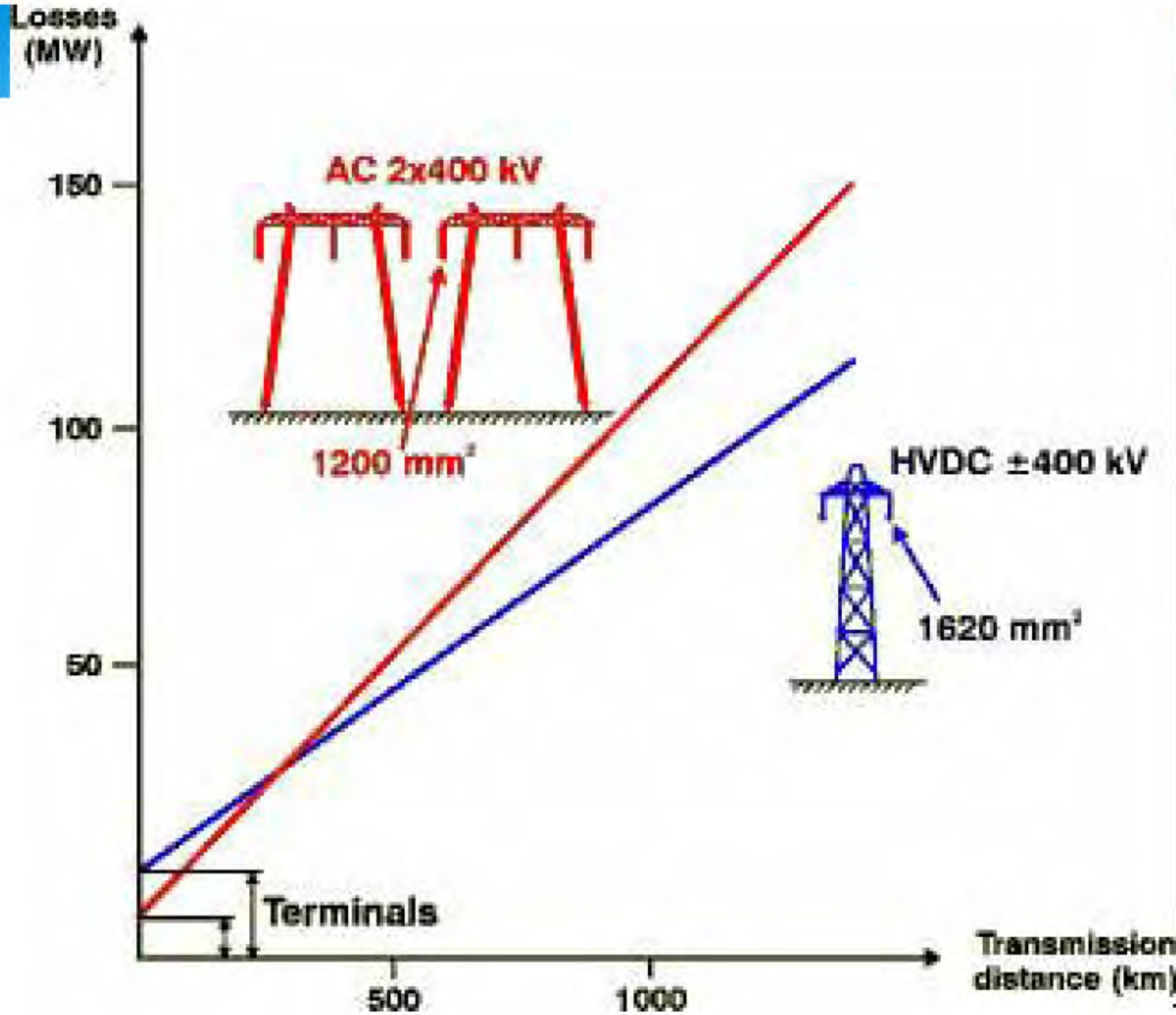
Since the wind cannot be controlled, wind plants exhibit greater uncertainty and variability in their output compared with conventional generation.

* Power systems now already handle a large degree of uncertainty, which is mostly in the loads. In power systems, generation must always be equal to the load plus the losses. Demand is constantly matched with generation to maintain the system frequency of 60 Hz in the USA and 50 Hz Europe. However, the amount of uncertainty is increased with wind. Wind's variability and uncertainty have been shown to increase the operating costs for the non-wind portions of the system, but generally only by modest amounts.
* Several investigations have been done with truly high (up to 25 percent energy and 35 percent capacity) penetrations of wind and have concluded that power systems can handle such levels of penetration without compromising system operation.
* The importance of detailed wind resource modeling has been clearly demonstrated. This modeling allows the ability to capture wind impacts, both for individual wind plants and among multiple wind plants in an area.
* During light-load conditions (such as at night), it is more difficult to maintain system balance when levels of wind penetration are high. The solution to this problem will entail some combination of wind curtailment, wind ramp-rate mitigation, switching in more loads during light-loaded periods, and flexibility of the other generating units.
* Flexibility may come from sources such as high-ramp-rate fossil generators, hydro power, pumped storage, and demand response.
* The value of sharing balancing functions over large regions which have a diversity of loads, generators, and wind resources has been clearly demonstrated. The electric power industry seems to be moving in this direction, which will significantly aid in the integration of large amounts of wind power by reducing operating costs associated with the variability of wind.

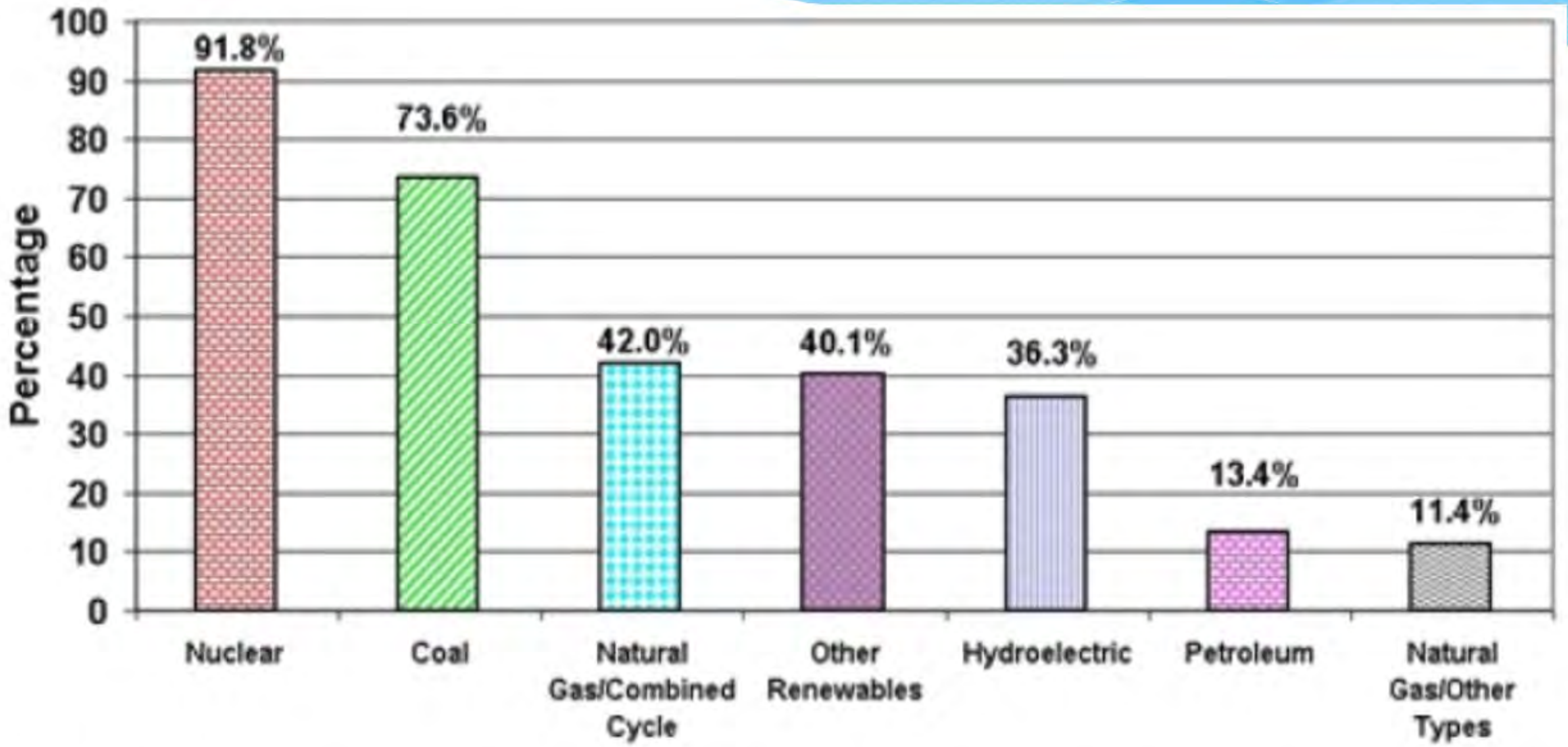
Desertec concept for Europe, Middle East and North Africa, Eumena. Source: Desertec Foundation.



Investment cost breakeven distance for AC and DC electrical transmission. Source: ABB.



Comparison of the losses for overhead line transmissions of 1200 MW with AC and HVDC.



Source: Energy Information Administration, Form EIA-860, "Annual Electric Generator Report;" Form EIA-923, "Power Plant Operations Report."

Average Capacity Factor by Energy Source, 2007.

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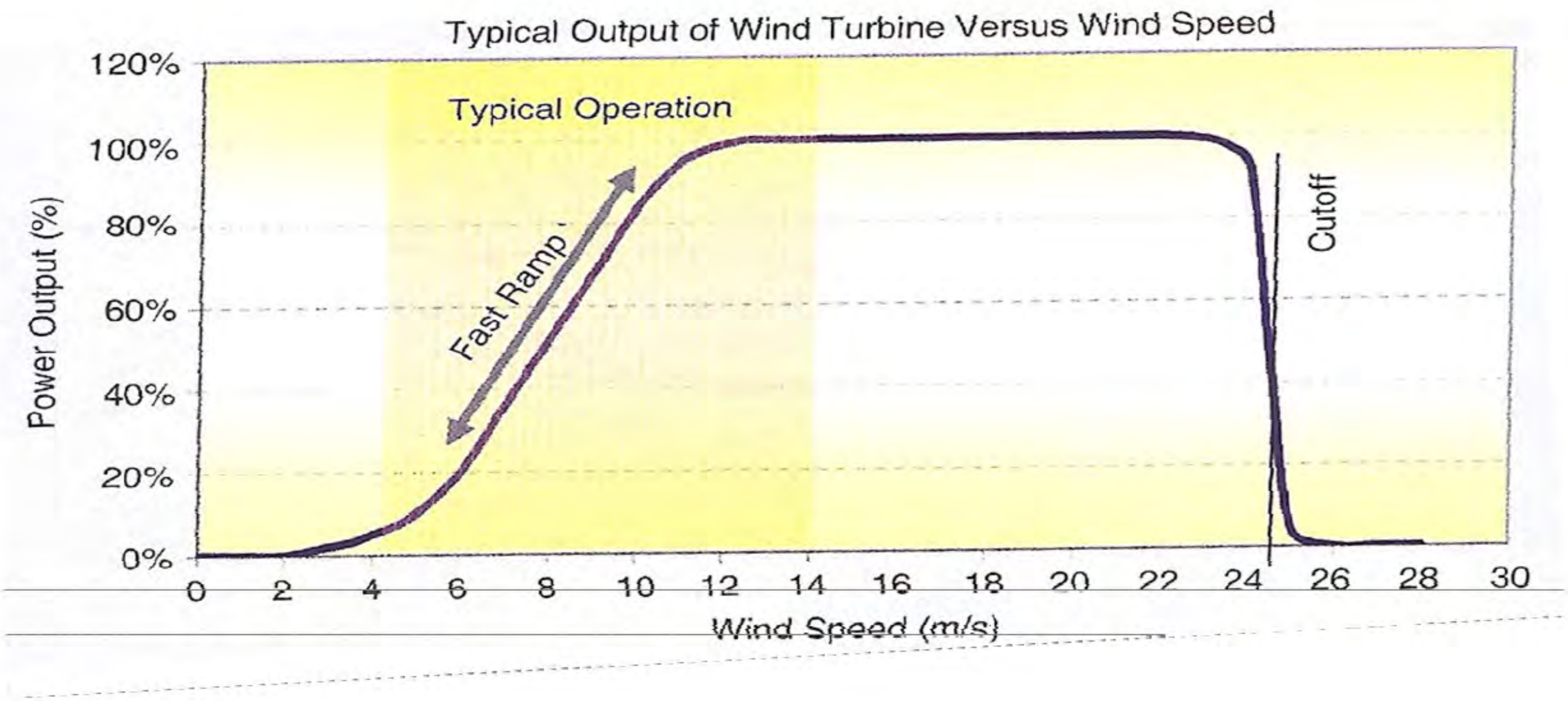
Wind Intermittence

The electrical grid is not an electricity storage device, and adding wind turbines decreases the grid stability.



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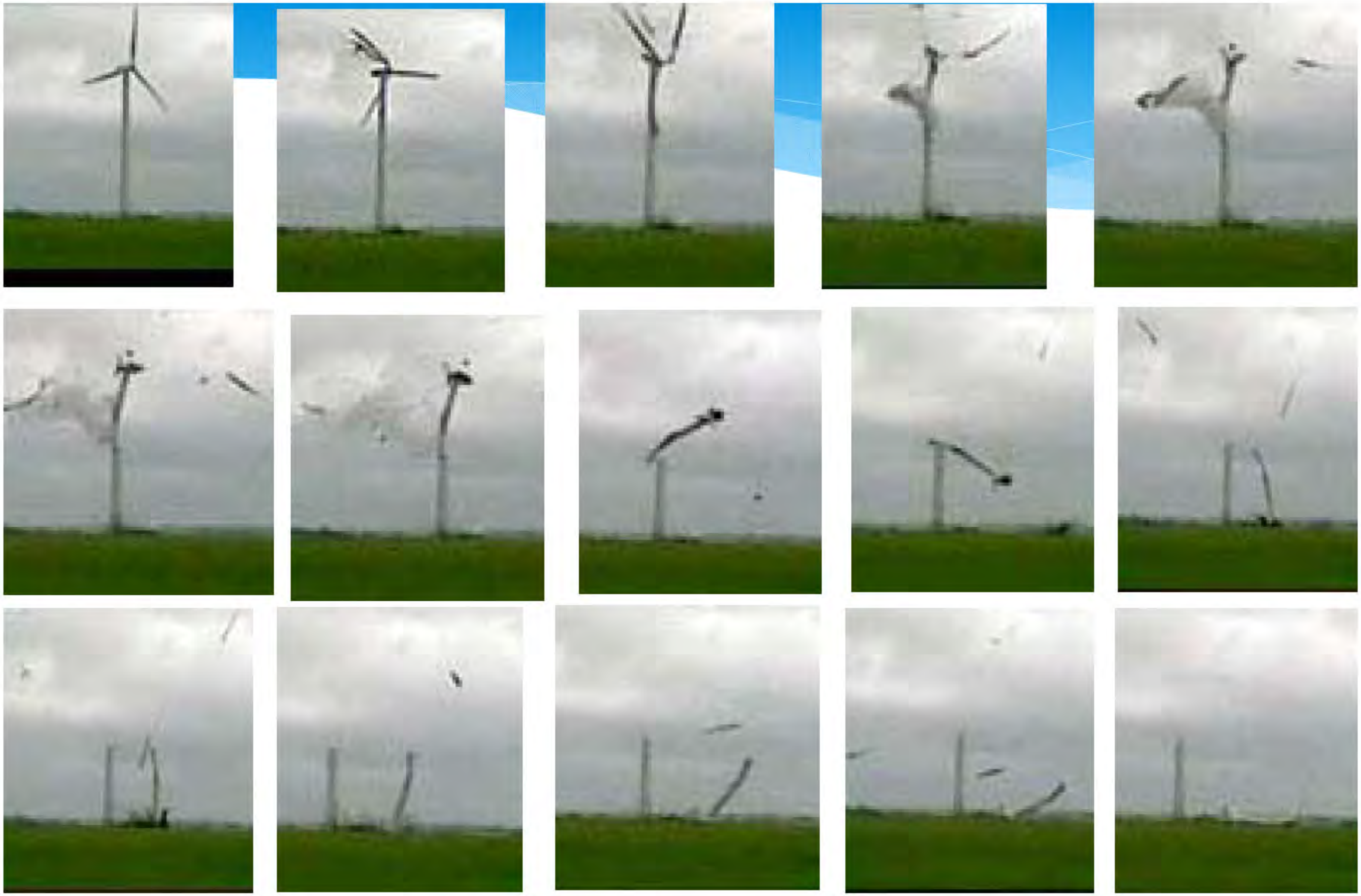
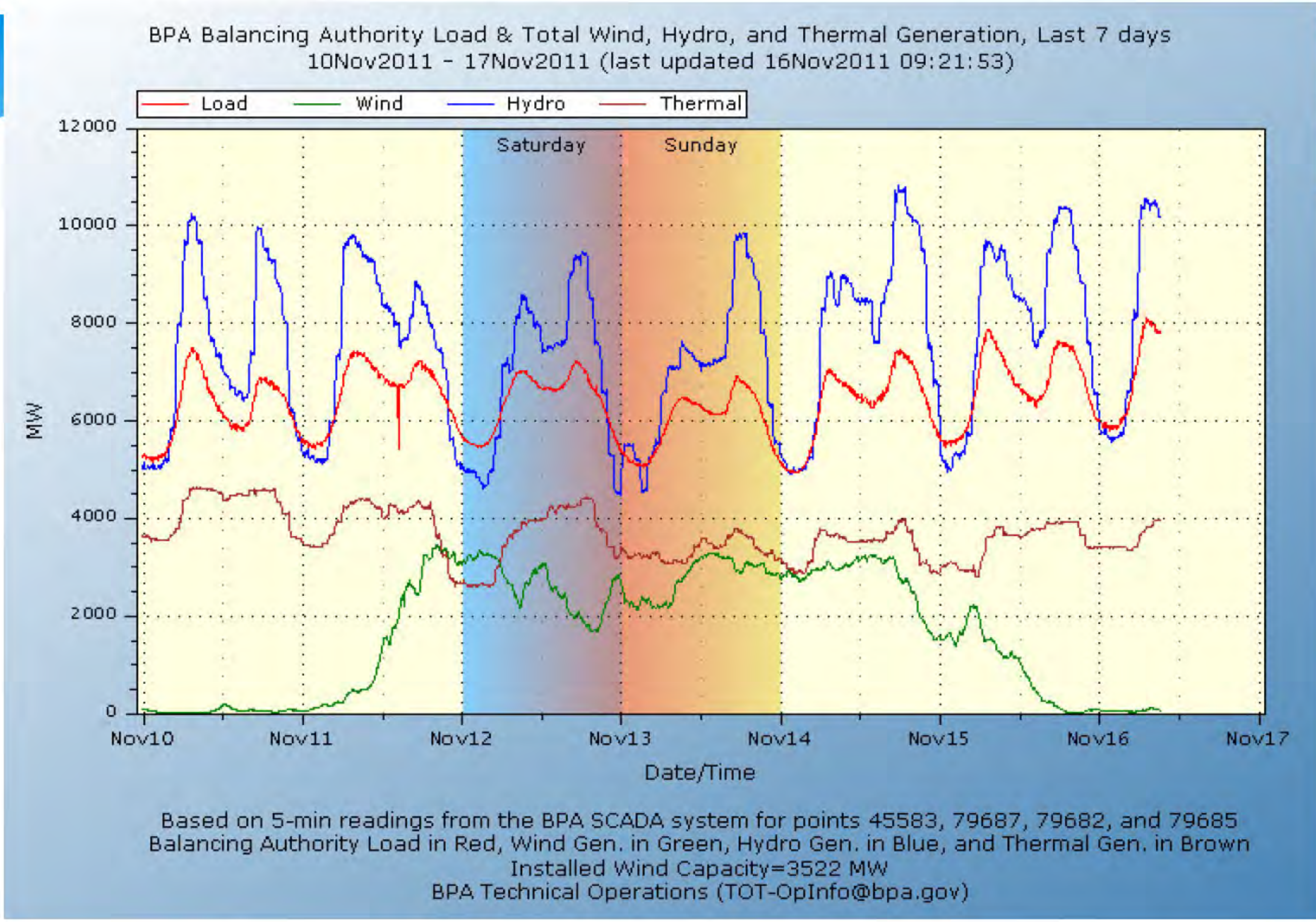
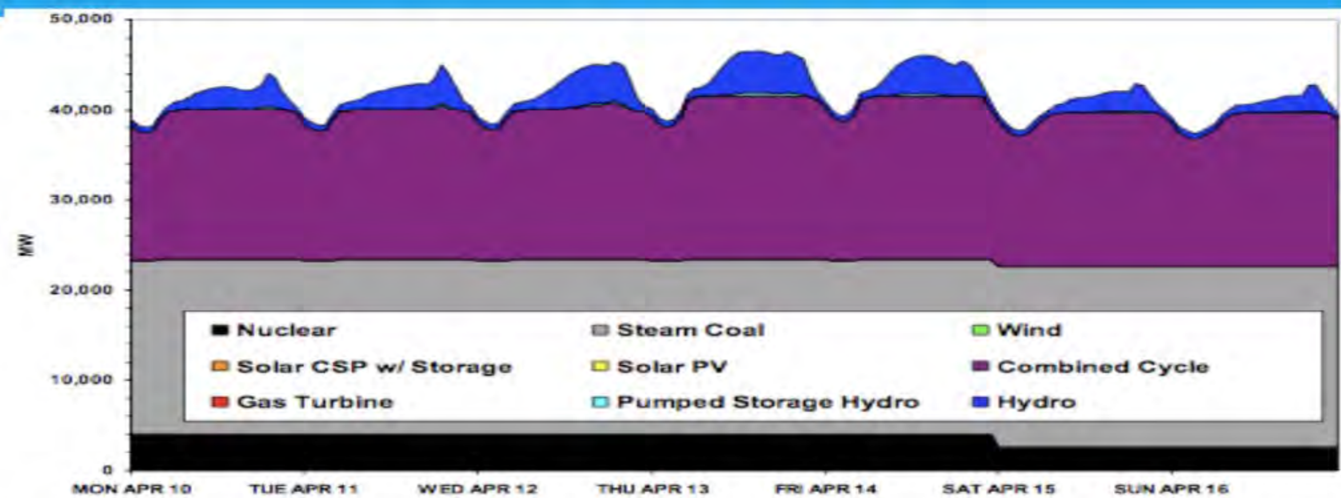


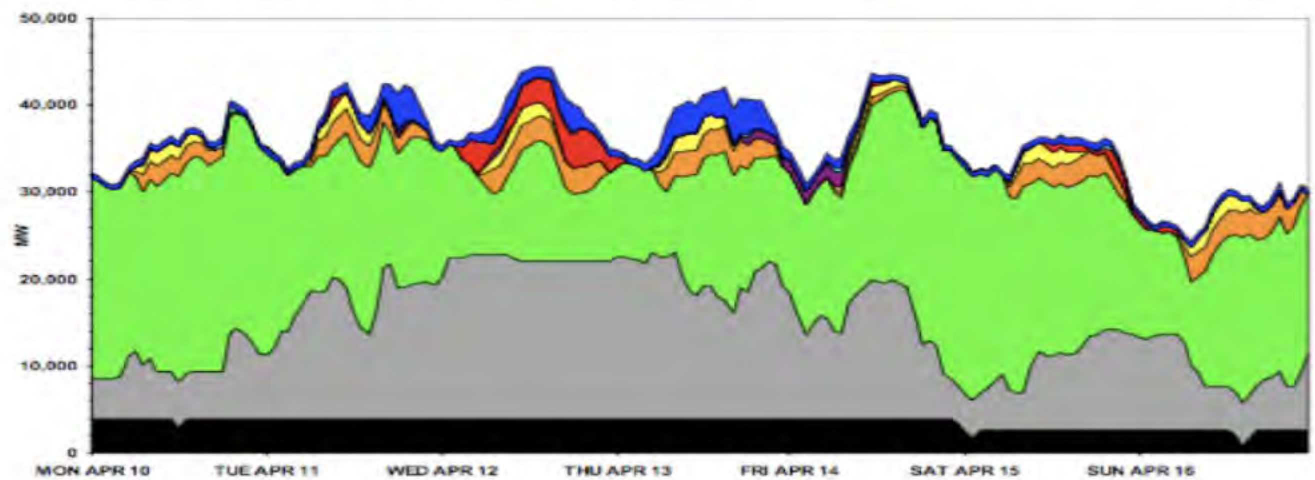
Runaway turbine disintegration clip sequence from video caused by failure of brake system, 2008.



Bonneville Power Authority, BPA Load and Wind Generation curves.



Load curves for the Western Wind Integration Study Base case - No New Renewables.



A week in April from the Western Wind Integration Study - 30% Renewables.

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Other Challenges

* **Some of the challenges with supporting increased penetration of intermittent resources are related to issues in the transmission system, distribution system, interconnection standards, operational issues, and forecasting and scheduling.**

* **Since good sites for wind are often in remote areas, planning for and executing transmission expansion is necessary to the growth of the wind sector. Furthermore, studies are needed to assess the regulation and ramping capacities of the generation mix. In regions with many thermal and nuclear plants, such ramping is not readily available. This implies long-term resource adequacy issues which need to be addressed.**

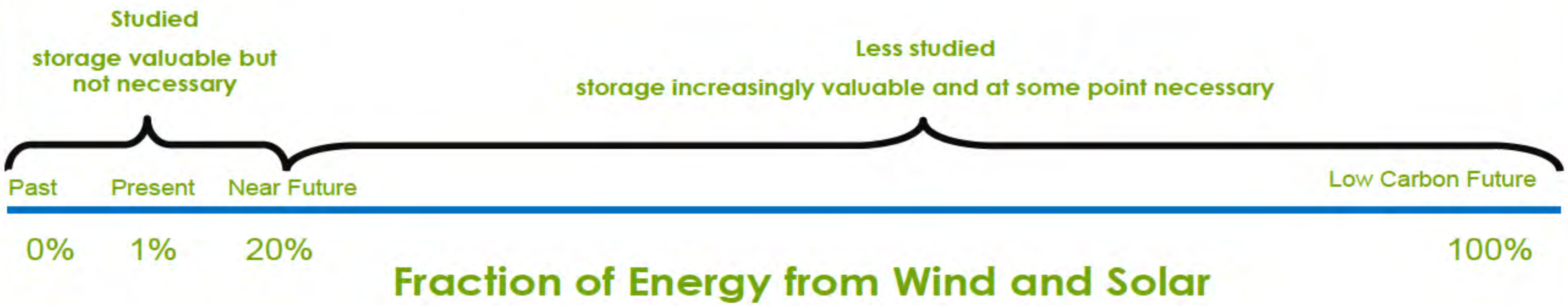
* **The steepness of the wind turbine power curve in a wind farm creates significant ramping needs as the wind speed changes.**

* **Then, at high wind speeds, when the turbine controls shut off the power generation to prevent damage due to over-speed and tensional oscillation, another operational challenge is posed to the system due to a steep reduction in generation levels.**

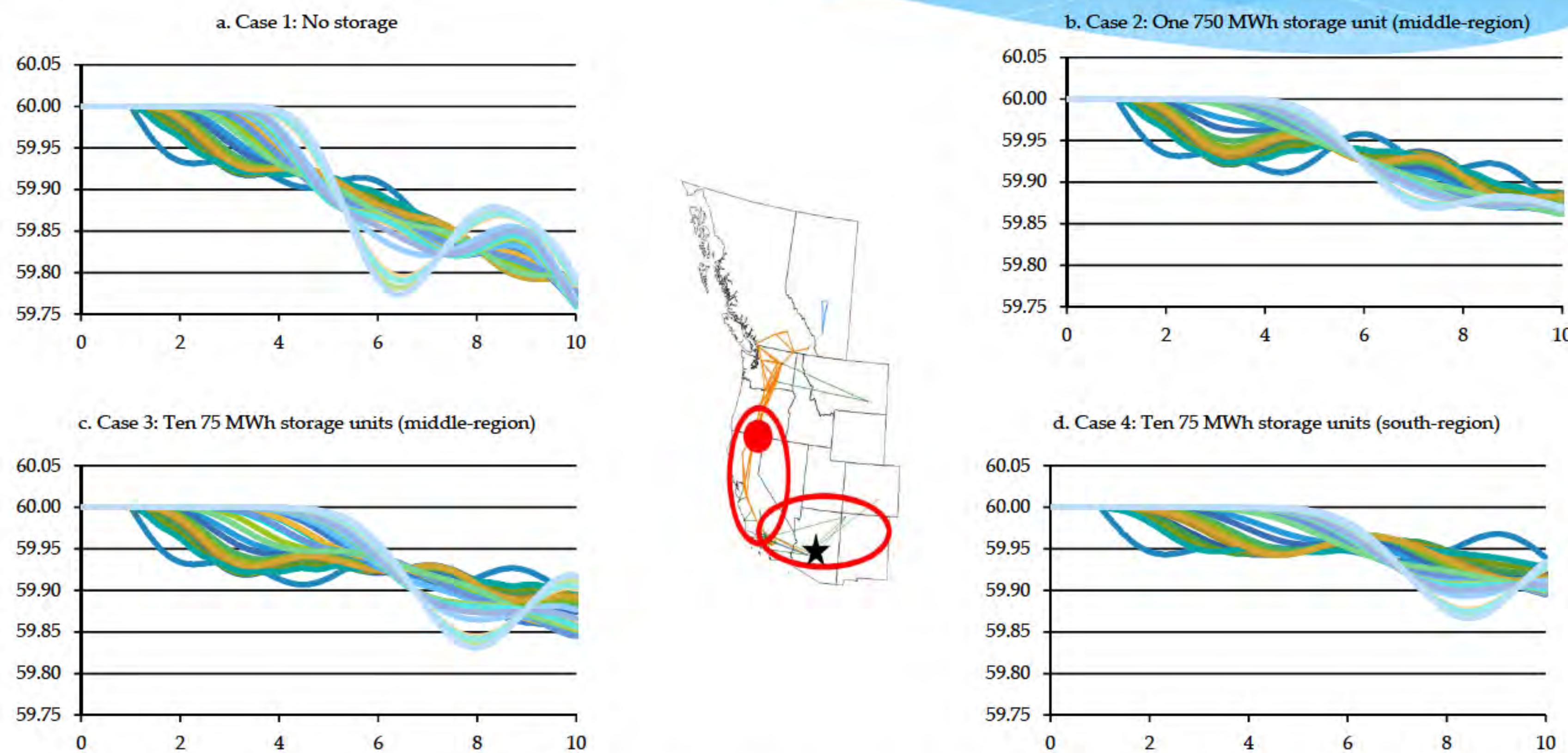
* **Another interesting challenge is that of storage. If the storage problem could be solved, that may solve some of the other major issues with wind power integration. The "must-take" policy of current power systems to wind and renewable resources can actually be considered a disincentive for wind farm operators and others to design a system to provide their own storage capability and energy balancing.**

Wind Power and Energy Storage

Energy Storage and Flexibility



- Flexibility as an alternative.
- recourses for flexibility :
- Spinning reserves.
- Non-spinning reserves.
- Hydroelectric , natural gas.



Dynamic response of Frequency (Hz) vs. Time (s) at locations along the network with different energy storage options when subject to a sudden loss in renewable energy generation in the southern part of the Western Interconnection

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Energy Storage Options

Row of HGenerators 3.4 kW turbines along water shore.

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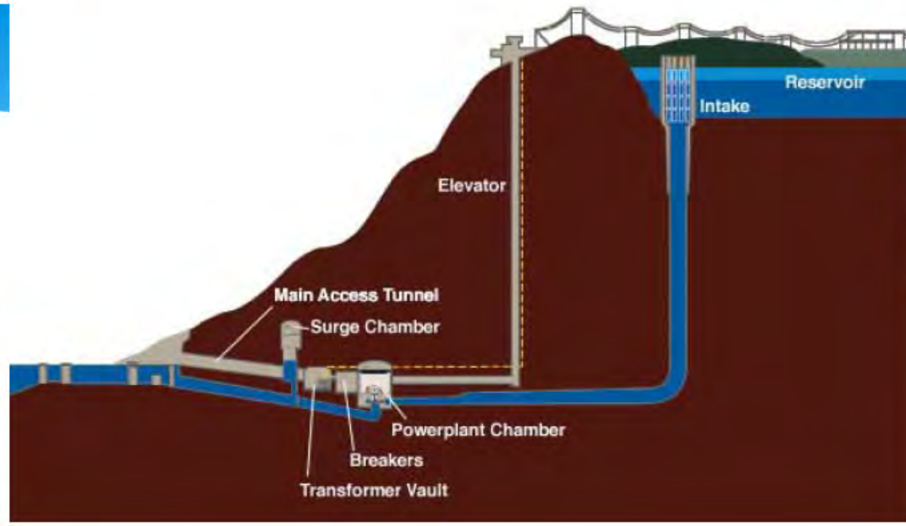
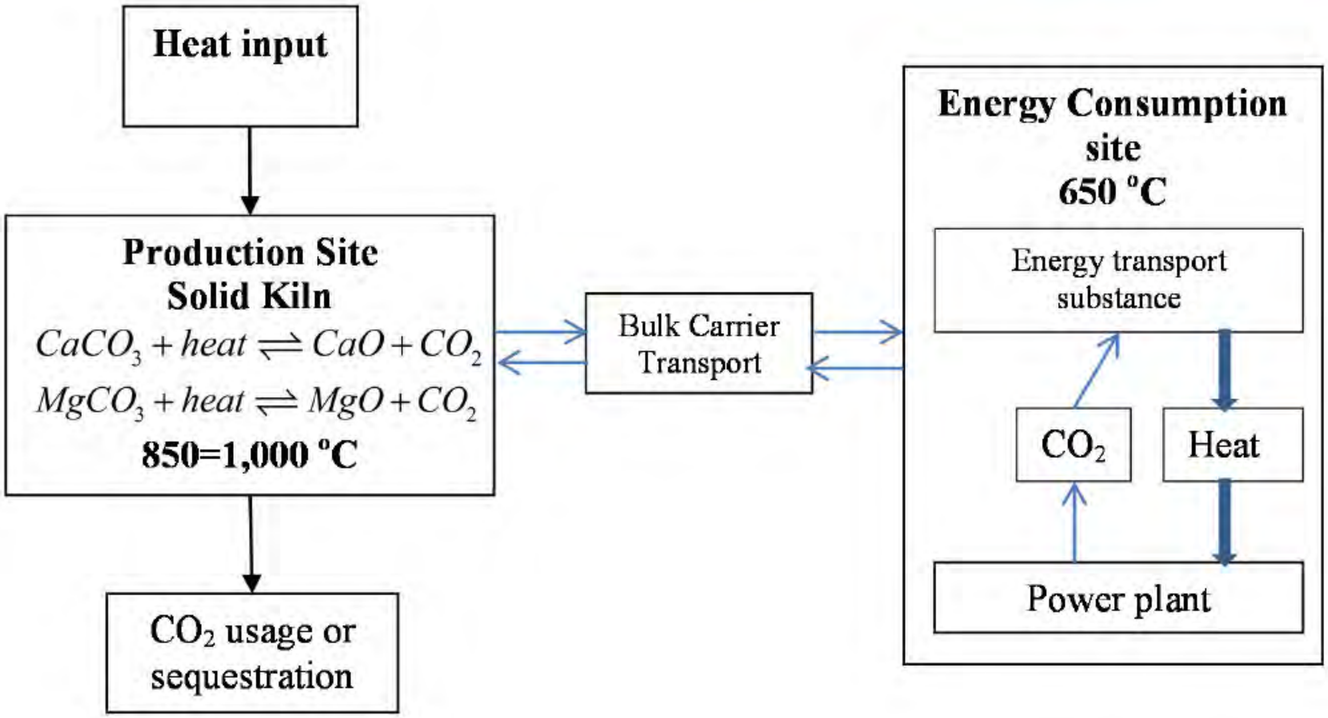
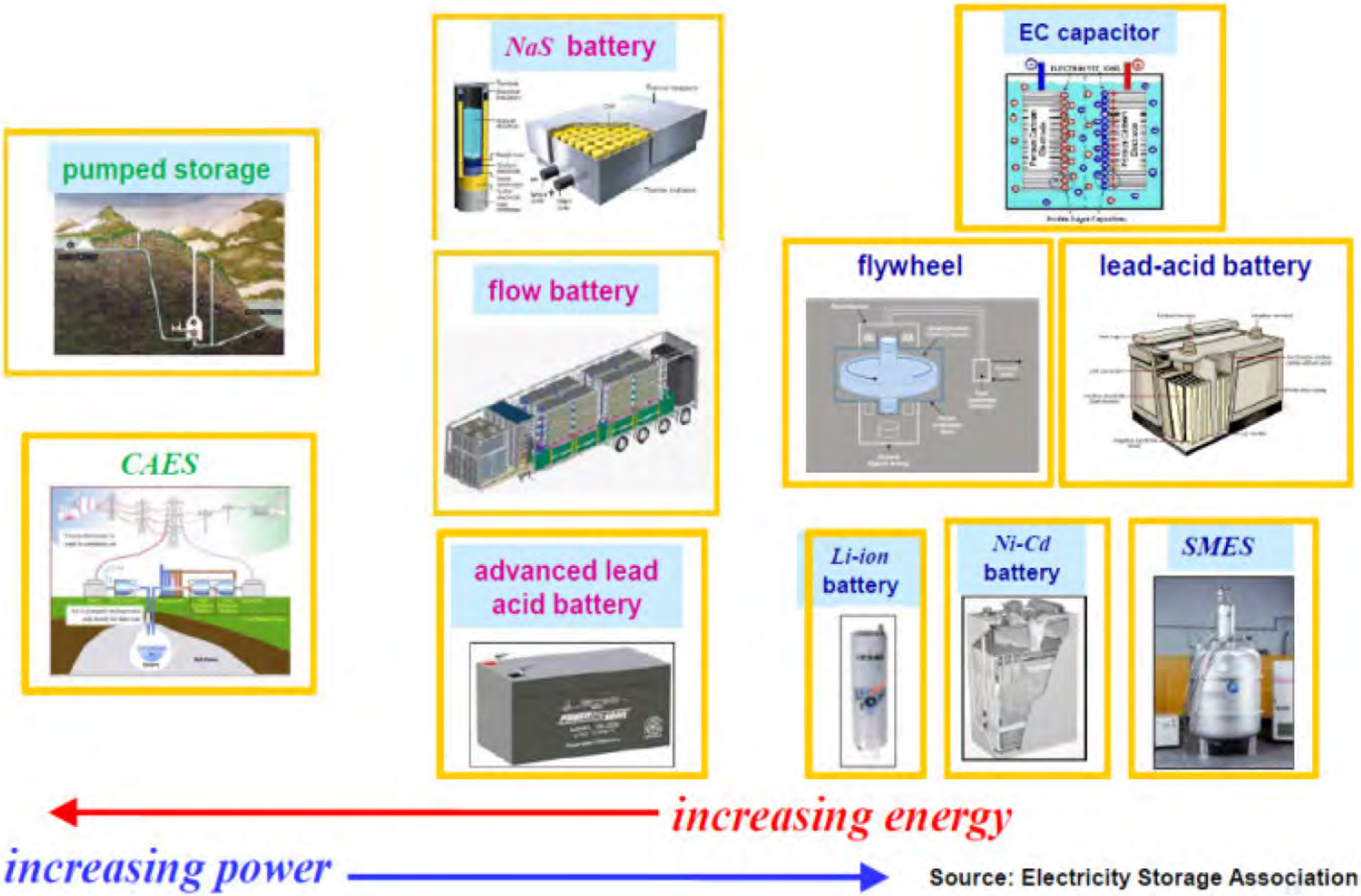


Eggberg reservoir supplies water to the Schluchsee power plant. Schluchseewerk AG Photo.



Energy storage using transport substances.

Flywheel energy storage. Source: Enercon.



Energy Storage options in relation to Energy and Power

CAES: Compressed Air Energy Storage, SMES: Superconducting Magnetic Energy Storage.

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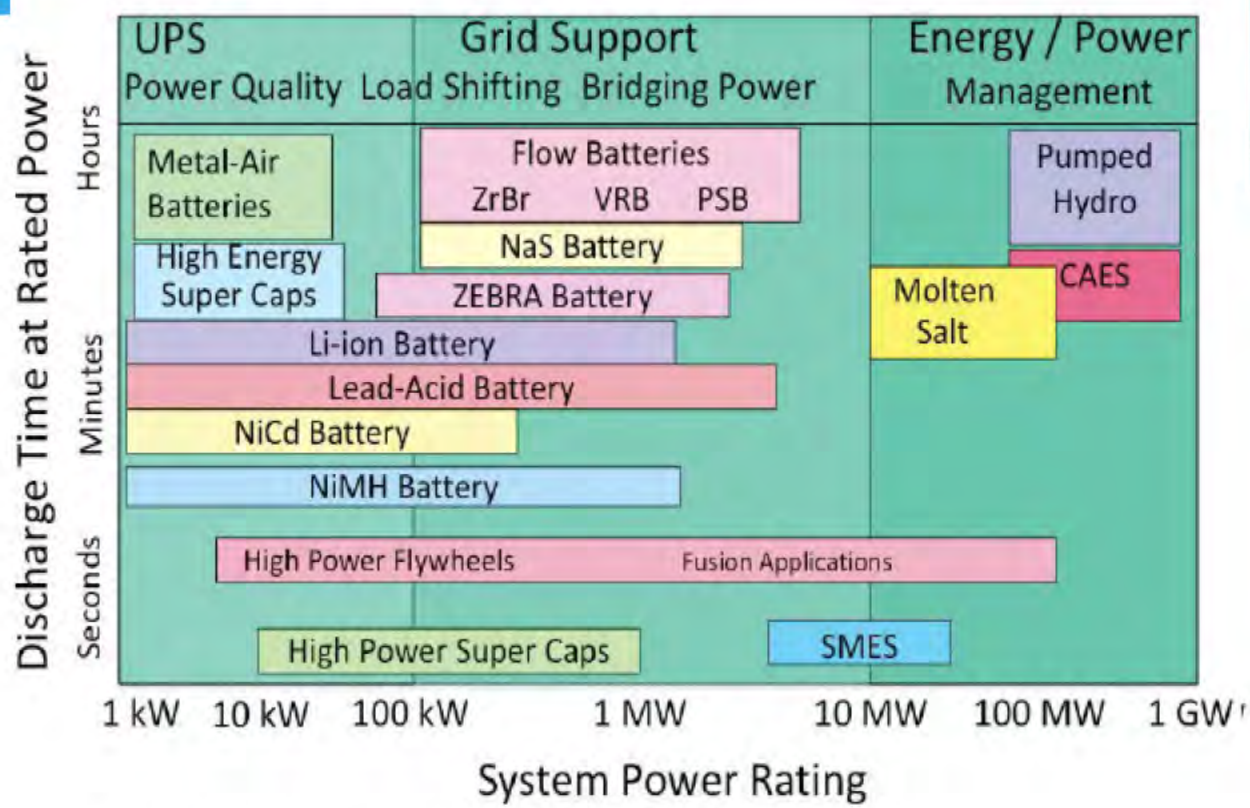
Energy Storage Options



UPS: Uninterruptible Power Supply
CAES: Compressed Air Energy Storage
SMES: Superconducting Magnetic Energy Storage
VRB: Vanadium Redox flow battery
ZEBRA: Sodium Nickel chloride NaNiCl battery
PSB: Poly Sulfide Bromide flow battery

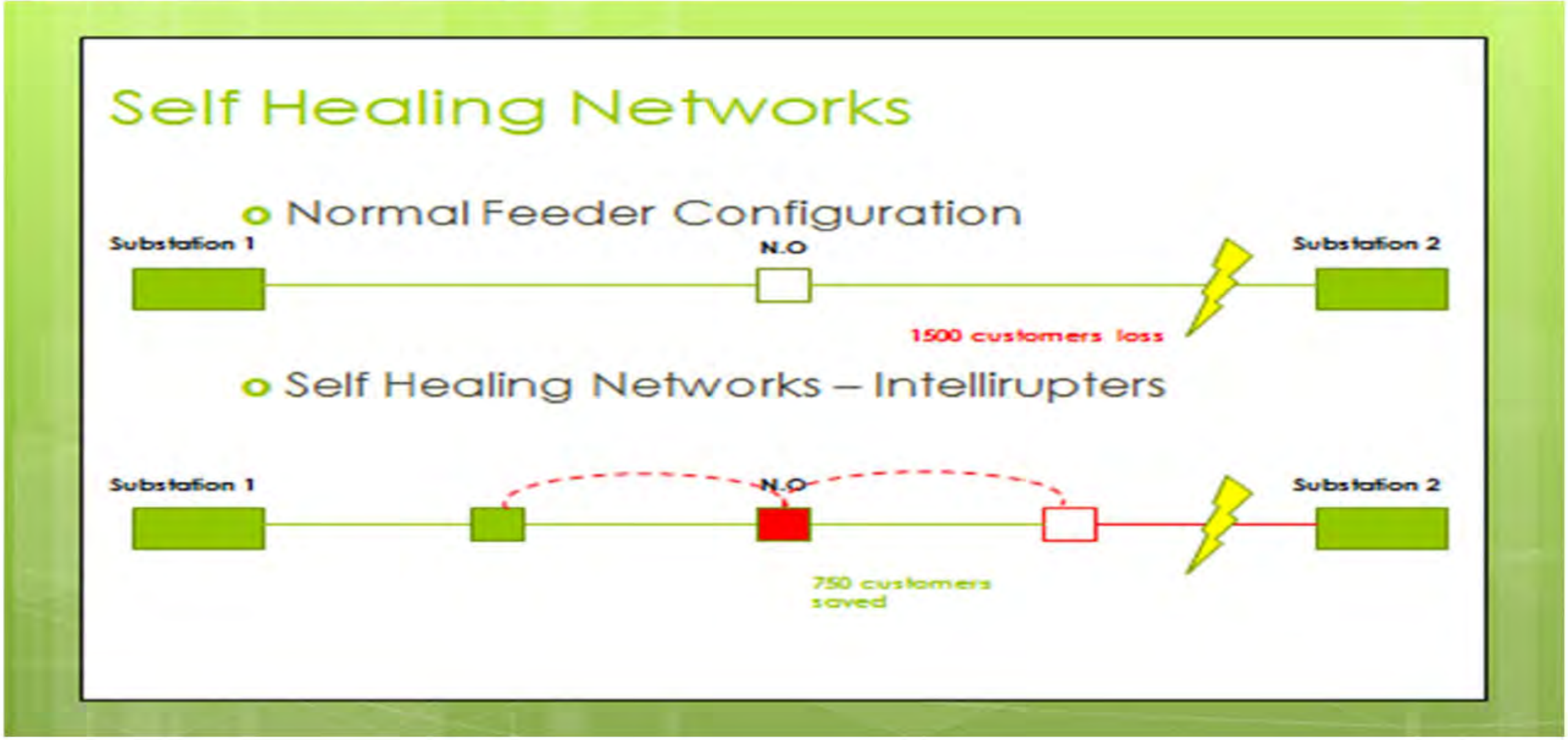
Storage Technology	Main Advantage (Relative)	Disadvantage (Relative)	Power Application	Energy Application
High-speed Flywheels (FW)	High Power	Low Energy Density	●	
Electrochemical Capacitors (EC)	Long Cycle Life	Very Low Energy Density	●	
Traditional Lead Acid (TLA)	Low Capital Cost	Limited Cycle Life	●	○
Advanced LA with Carbon Enhanced Electrodes (ALA-CEE)	Low Capital Cost	Low Energy Density	●	●
Sodium Sulfur (Na/S)	High Power and Energy Density	Cost and Needs to Run at High Temperatures	●	●
Lithium-ion (Li-ion)	High Power and Energy Density	Cost and Increased Control Circuit Needs	●	◐
Zinc Bromine (Zn/Br)	Independent Power and Energy	Medium Energy Density	◐	●
Vanadium Redox (VRB)	Independent Power and Energy	Medium Energy Density	◐	●
Compressed Air Energy Storage (CAES)	High Energy, Low Cost	Special Site Requirements		●
Pumped Hydro (PH)	High Energy, Low Cost	Special Site Requirements		●

● Fully capable and reasonable ◐ Reasonable for this application ○ Feasible but not quite practical or economical NONE Not feasible or economical

List of Energy Storage Technologies

Smart Grid

Smart Devices
Use of two-way communication
Advanced sensors and control systems
Many applications: Self Healing Networks



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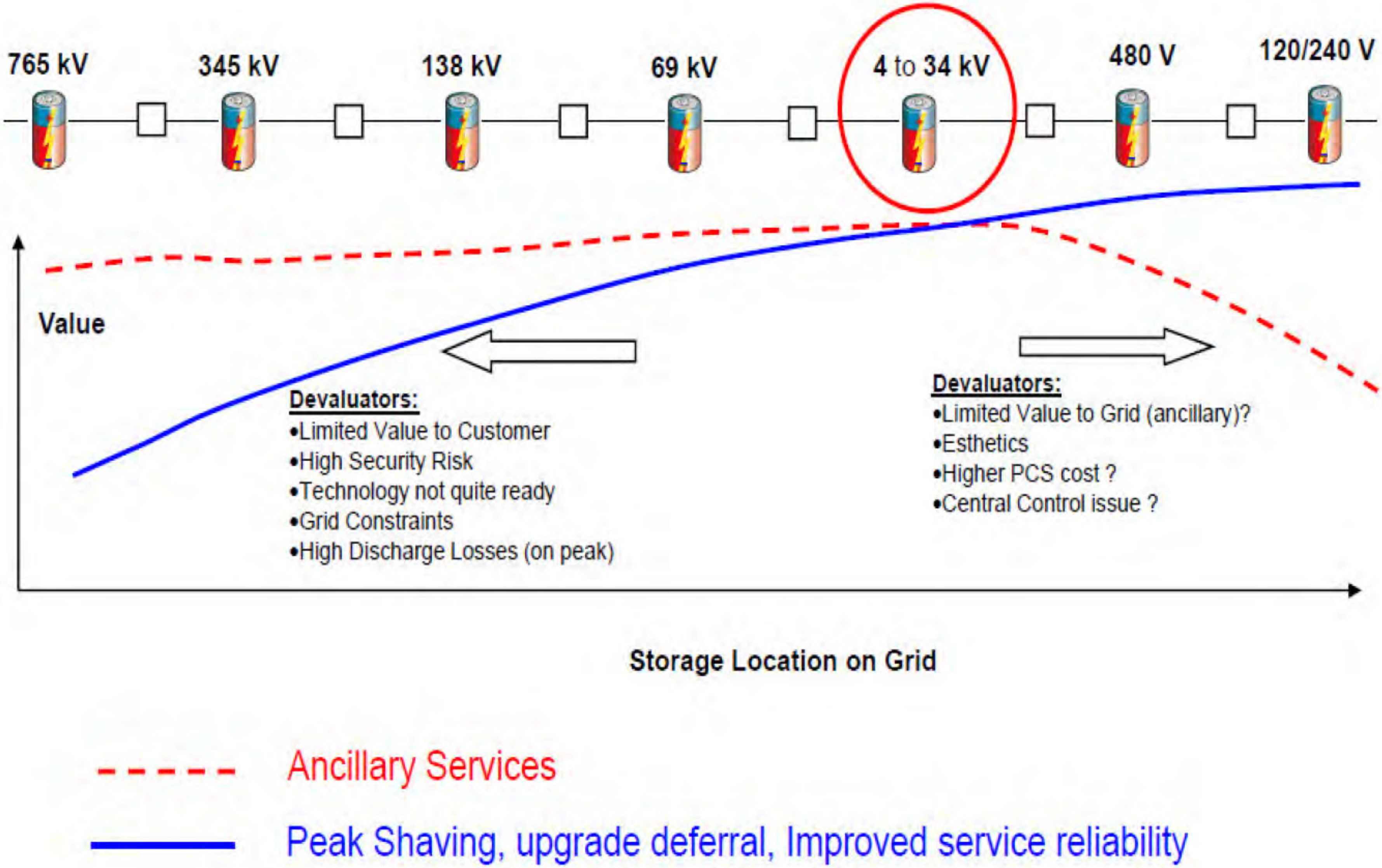

Value of Energy Storage at different Voltage levels

Grand Ridge Wind Farm and LaSalle Nuclear Power Plant

* The Grand Ridge wind farm surrounds the site of the LaSalle Nuclear Power plant near Versailles, Illinois.

* The power station is operated the Exelon Power utility and consists of two Boiling Water Reactor (BWR) units supplied by the General Electric (GE) Company around 1980. The plant started operation in 1982 and generates about 2,309 MWe, supplying the electrical needs of about 2.3 million homes. The plant employs about 800 persons on site.

* The site also has GE supplied wind turbines in the Grand Ridge wind farm operated by Invenergy. Construction was started in 2007 and was completed in 2008 with 98 MW of installed capacity.

* It uses 66 GE 1.5 SLE wind turbines with the rotor blades reaching a height of 389 feet, supplying the electrical needs of about 28,000 households.

* The wind farm covers an area of 6,000 acres around the LaSalle Nuclear Power plant in the Brookfield, Allen and Grand Rapids townships.

Wind turbines rotor blades hauled around the LaSalle Boiling Water Reactor (BWR) near Versailles, Illinois.

Completed Grand Ridge wind farm around the LaSalle nuclear power plant uses General Electric (GE) wind turbines. The power station consists of two GE BWR units.

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FUTURE PLANS

* The Grand Ridge Wind Farm Project, eventually will encompass Phases I, II, and III to approximately 250 MW, consisting of the construction of up to 166 wind turbines, operation and maintenance (O&M) building, project substation, approximately 1.5 mile generator lead line and collection system, and switchyard located in LaSalle County, Illinois.
* The total project area is 71,300 acres with the expected area of disturbance being approximately 175 acres.
* The wind farm will eventually contain 500 to 600 of the GE-built, 1.5 megawatt turbines across the entire acreage.
* Invenergy has 14 wind farms either operational or under construction throughout the USA. Exelon Nuclear owns the transmission lines, which P.J.M. System operates. Invenergy sought and was granted permission to transmit electricity on the lines with excess capacity. Exelon will continue selling electricity to its customers in without change in the company's operating procedure.
* Invenergy, meanwhile, will sell electricity generated by the wind farm to the open market. At a cost of about $140 million to $150 million, the Invenergy project turbines have 262-foot tower and 143-foot blades. The turbines are spaced 2,500 feet apart, and will take about 40 acres of cropland out of production.

DISCUSSION

* Wind and nuclear power both have their place in the coming emissions-sensitive energy environment.

* The technologies are opposite in many respects: nuclear provides base load; wind power is intermittent. Yet they have in common the fact that they can provide the grid with low-cost energy without emitting greenhouse gases.

* Support for high penetration levels of wind power requires a vast high-voltage transmission infrastructure, as the best areas for wind are typically far away from load centers. In this enhanced transmission system, High Voltage DC (HVDC) lines may have an important role to play since they have low losses and become economical for the required long stretches of new transmission lines, particularly in conjunction with the Desertec Project.

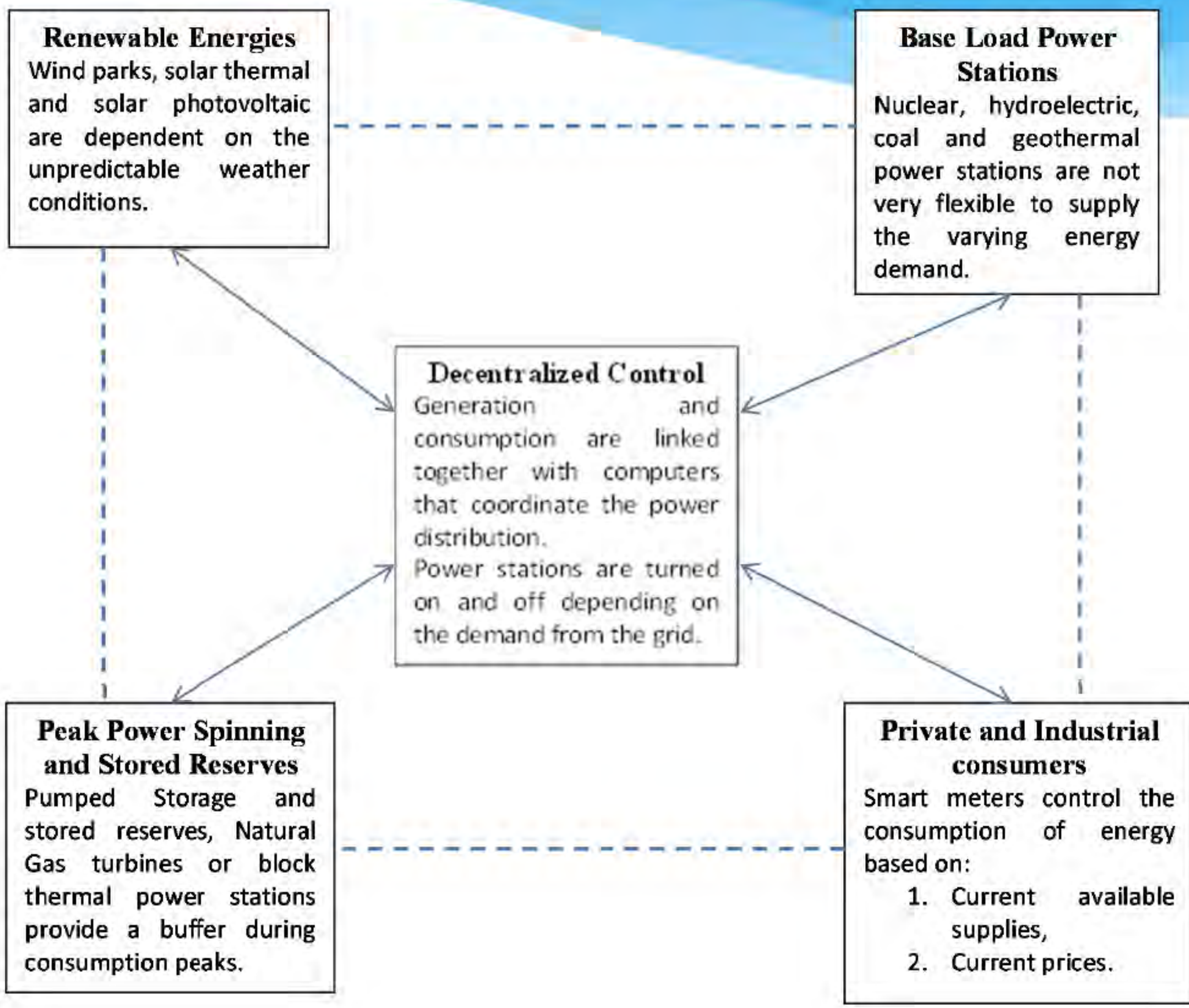
* Nuclear power is excellent for providing base load power but does not really offer the flexibility to complement the fluctuations which are natural in wind power output. It is believed that such fluctuations must be matched with high ramp-rate units such as gas turbines which change their outputs quickly and easily. The solution is not black and white; it requires a broad insight into the different mix of resources, both generation and load, which may be available to the system both now and in the future.

* Wind turbines on a standby operational mode are net importers of power for their control and yaw mechanisms. They need a supply of about 5 kW of power from an existing grid. They also require the vicinity of a power grid with excess capacity to export their generated power.

* Due to ramping considerations, the planned introduction of 20 percent of electrical wind production in the USA by 2020 would pose challenging grid stability issues. Energy storage alternatives such as hydrogen production, compressed air, flywheels, superconducting magnets and pumped storage need further consideration.

* The electric grid is evolving into a smart grid system . To allow for a greater penetration of intermittent renewables, grid-scale energy storage will be required. The solution however will depend largely on the type of intermittency being mitigated, the service being provided, the existing power system network, economic and security (both power system security and infrastructure) considerations.

Smart Electric Grid Configuration



Renewables Age, Low Carbon Age

"The world is embarking on a new industrial revolution: the "Low Carbon Age," or the "Renewables Age," with electricity replacing the depletable hydrocarbon fuels and their possible effect on climate change; and wind power is being reinvented to help satisfy the need."

"This new industrial revolution is not driven by market forces encouraging mass production for wasteful consumption. Instead, with the help of emission control laws, investment incentives, and regulations, the frugal use of the available resources is the norm."

"A new environmental movement is born. It is driven by engineering and scientific entrepreneurs starting young companies that are supported with specialized knowledge in the design and construction of highly efficient equipment. Supported by ecologists as well as electricity consumers, they are now leading industry worldwide."

"National cultures in possession of modern science and technology become immune to invasion and the seizure of their resources, assuring the future survival of their societies and ways of life; whereas those that missed the boat are doomed to fading away and eventual annihilation and oblivion by their competitors and opponents."

Renewables Age, Low Carbon Age

This offers hope to developing countries to catch up with the rest of the industrialized world. Instead of hopelessly competing within established technologies in which they lag behind, they can leapfrog into the future with the adoption of the new high technology industries, becoming world leaders in their particular niches.

Country	Installed Capacity [MW]	Percentage
China	44,733	22.7
USA	40,180	20.4
Germany	27,214	13.8
Spain	20,676	10.5
India	13,065	6.6
Italy	5,797	2.9
France	5,660	2.9
UK	5,204	2.6
Canada	4,009	2.0
Denmark	3,752	1.9
Other	26,749	13.6
Total	197,039	100.0

World cumulative installed wind capacity as of December 2010. Source: Global Wind Energy Council, GWEC.

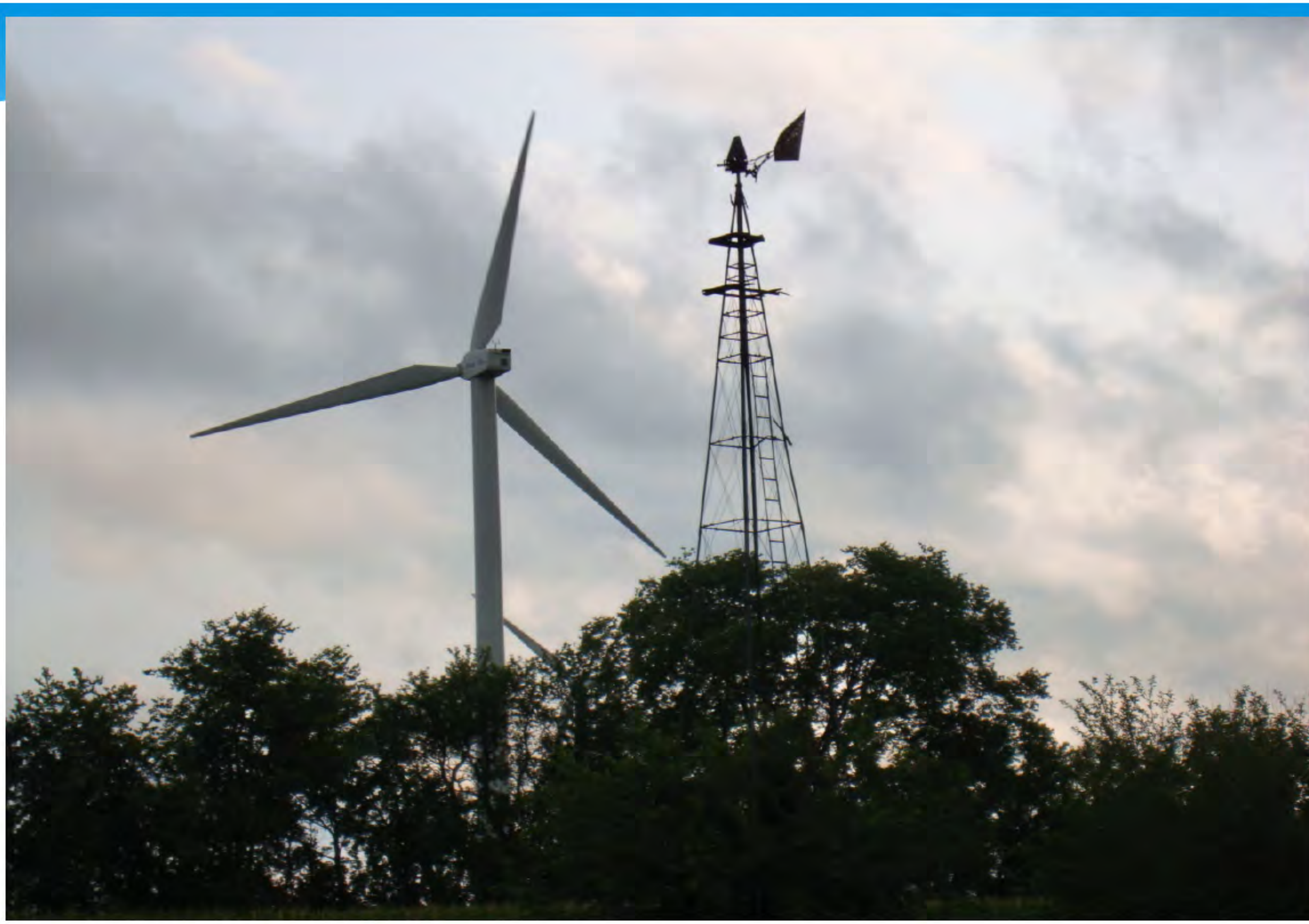
Alexandria,
Egypt
1882
130 years ago








"History does not repeat, but it does tend to rhyme," Mark Twain, USA Author.



Modern wind turbines are replacing the iconic old American wind turbine technology on the American High Plains. Photo: M. Ragheb.

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Symbiotic relationship emerging between agricultural farming and electrical wind farming in the American Midwest. Farmers in Illinois obtain attractive royalties from the installation of wind turbines on their farms while continuing to farm around them. Each turbine occupies a space of about 2.5 - 4 acres including the electrical cabling and access roads. Photo: M. Ragheb.

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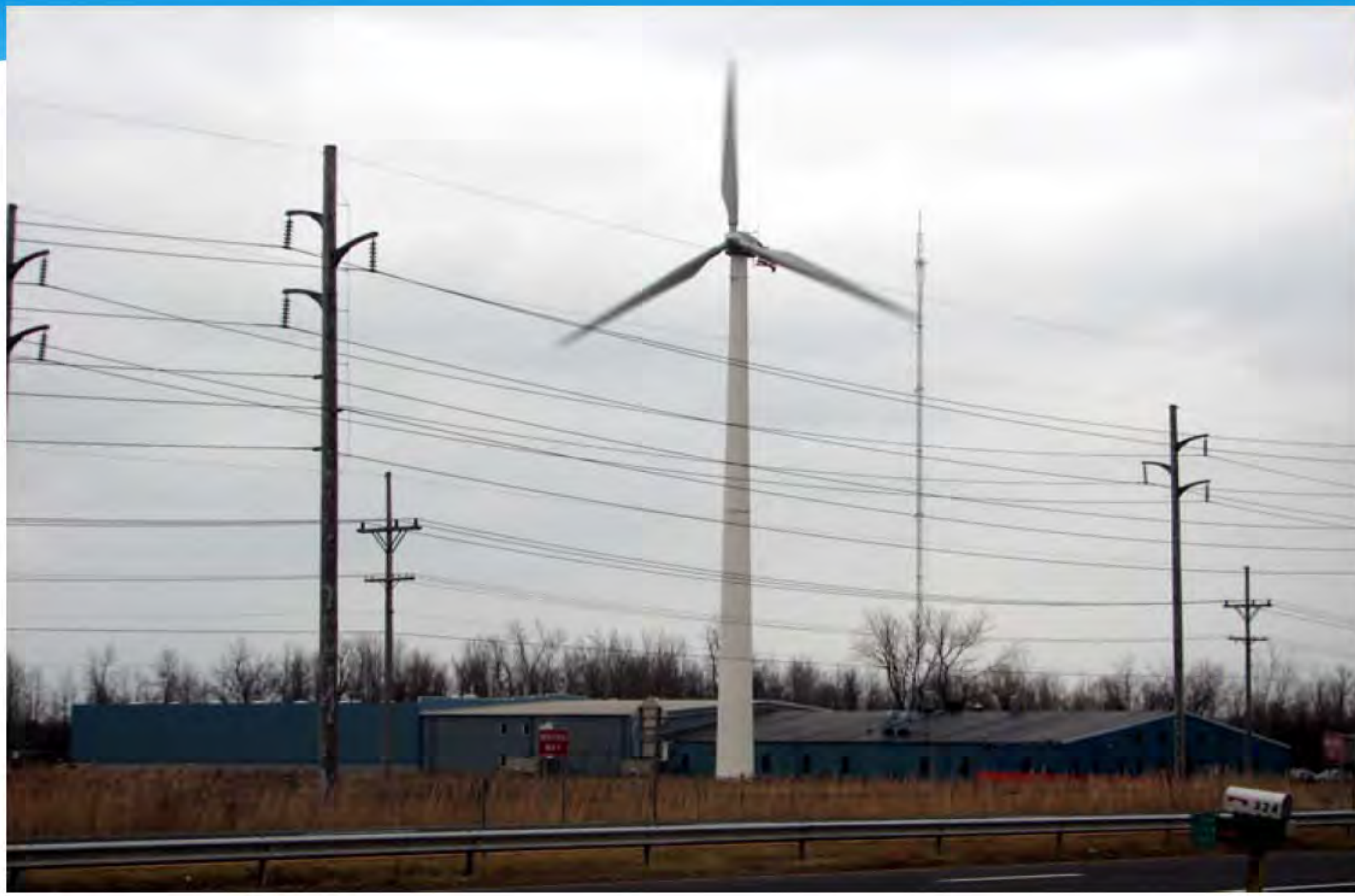

Single wind turbine providing power to a small business at Rochester, New York: Harbeck Plastics, Inc. Its surplus production can be wheeled into the electrical grid. Photographs courtesy: Chris Kabureck.

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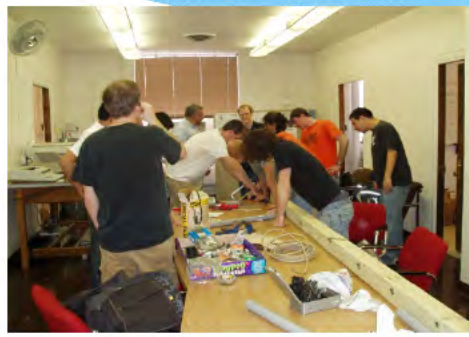
Wind Turbine Construction Project



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