Opportunities for Increasing Penetration Levels of Renewable Energy

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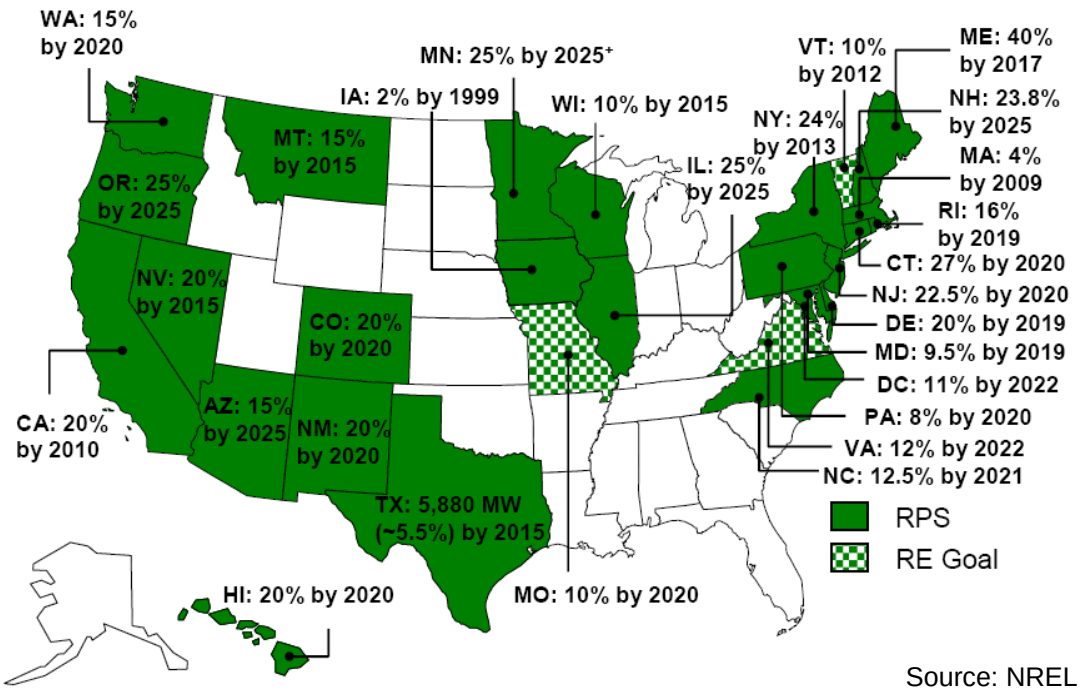
Overview:

- Renewable Energy Portfolio Standards
- Trends in Renewable Energy development
- Planning for Large-scale Renewable Power Integration
- Levelized Cost of Generation
- Hybrid Renewable Energy solutions
- Plug-in Hybrid Vehicles - Load Balancing
- Case studies with large scale integration
- Roles of Energy Storage
- Advanced Generator Power Electronics
- Summary

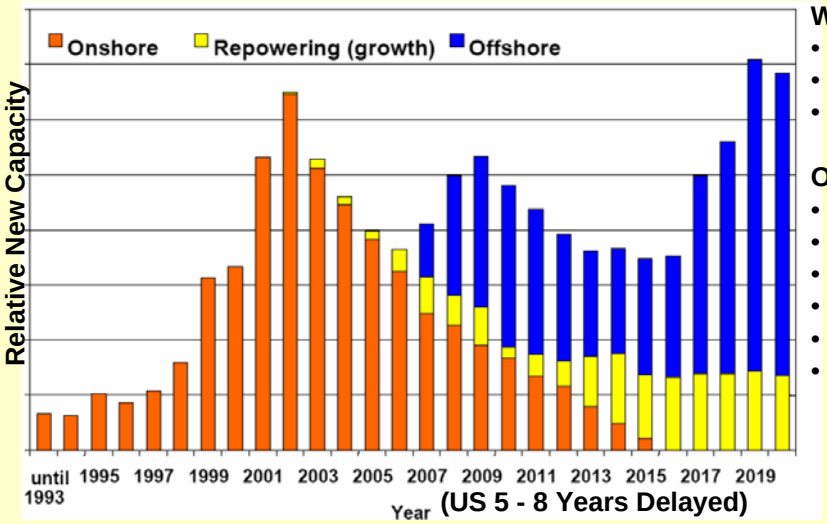
U.S. States - Renewable Portfolio Standards



Source: NREL

By 2025, we will need approx. 428 GW of new generation and capacity

Wind Power Trends and Issues



(US 5 - 8 Years Delayed)

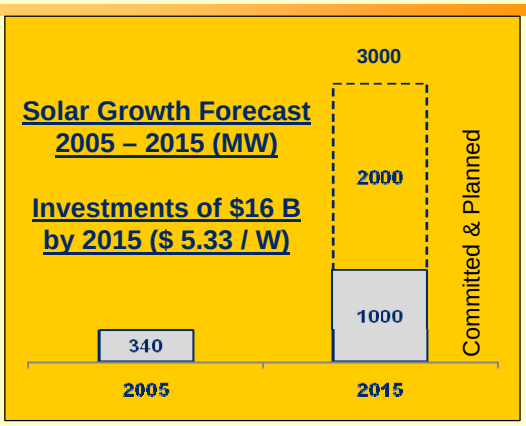
Worldwide Capacity:
- **93.8 GW in 2007**
- **19.7 GW added in 2007**
- **5.2 GW added in US - 2007**

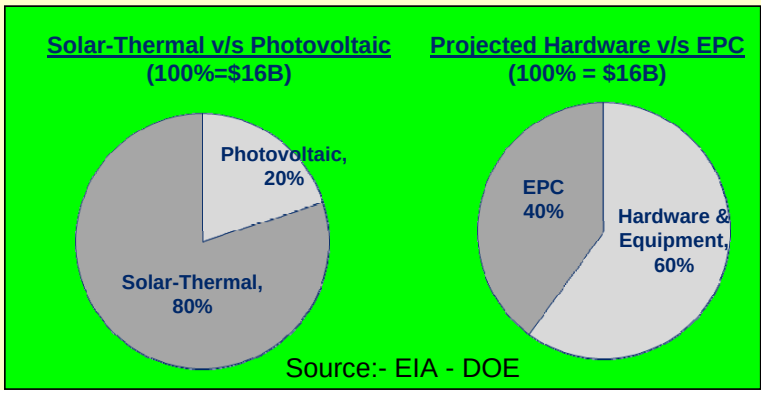
Offshore: 1080 MW - 2007
- **Short Transmission**
- **Land usage conflicts**
- **Improved production**
- **Less intermittency**
- **Improved capacity factors**
- **40 GW proposed in Europe**

Repowering:
- **2.2 to 4.3 increased production**
- **Reduction of number of wind turbines**
- **Increased capacity factor of 1.5 to 3.5**
- **Less visual impact**
- **Short permitting time**

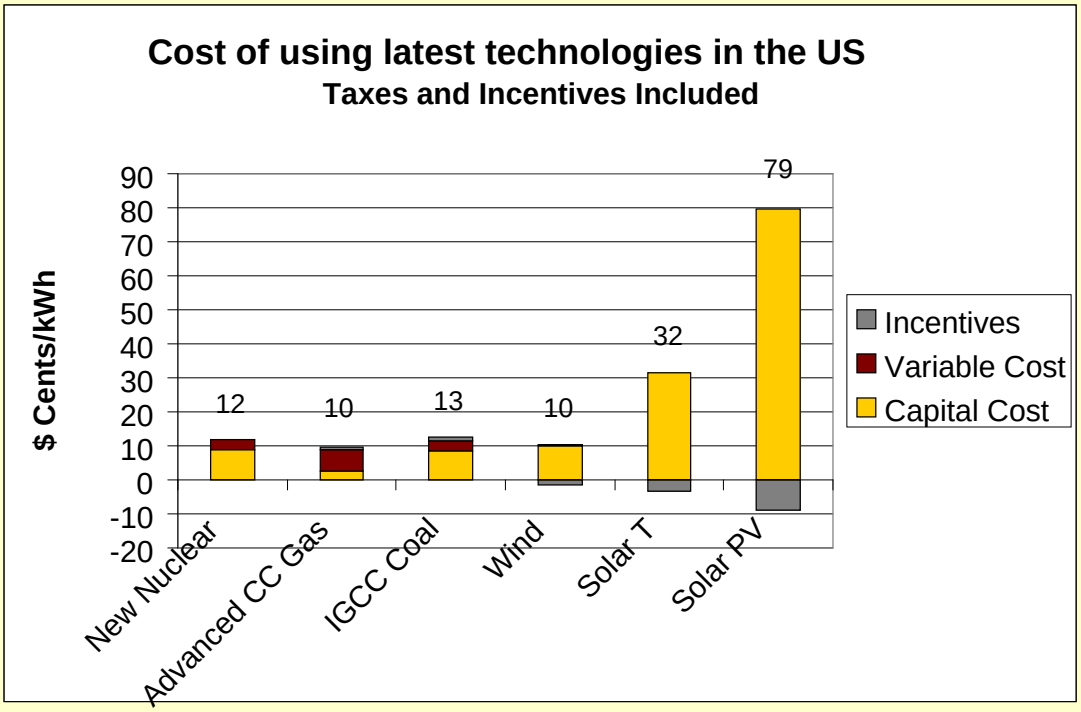
High Altitude Wind Power

Solar Market Growth $ 16 B in USA by 2015





Levelized US Costs of Generation 2007

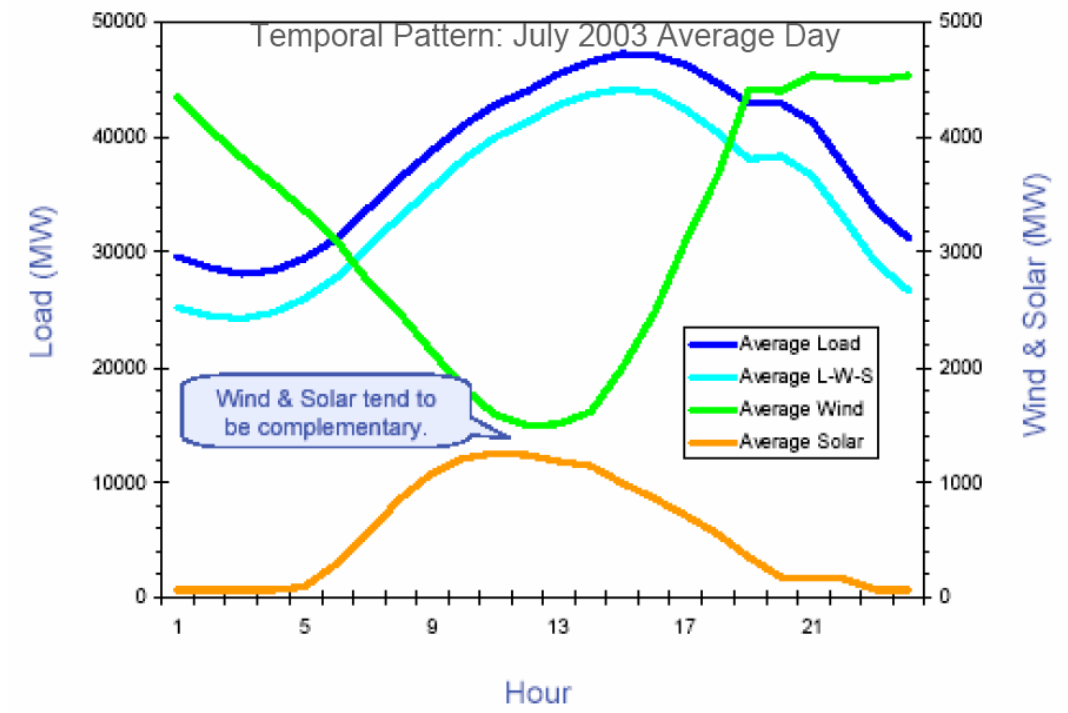


Need feed-in tariff structure (Europe) for USA to increase penetration

Planning Issues for Large-scale Renewable Power

- Business-as-Usual with local < 20% penetration levels
  - Increased effort in system planning – Intermitted nature.
  - Voltage support – Local and system-wide FACTS
  - Low-Voltage Ride-Through (LVRT) Requirements
  - Generator balancing and regulation.
  - Resource and load forecasting
- Increased efforts for > 20% penetration levels
  - Hybrid and matched hydro, solar, geothermal, wind generation, etc.
  - SmartGrids – Demand Response
  - Advanced renewable generator PE
  - Add energy storage – central and distributed
  - Asynchronous links – HVDC
  - Non-electric energy carriers – Hydrogen, etc.

Complementary Renewable Portfolio Mix

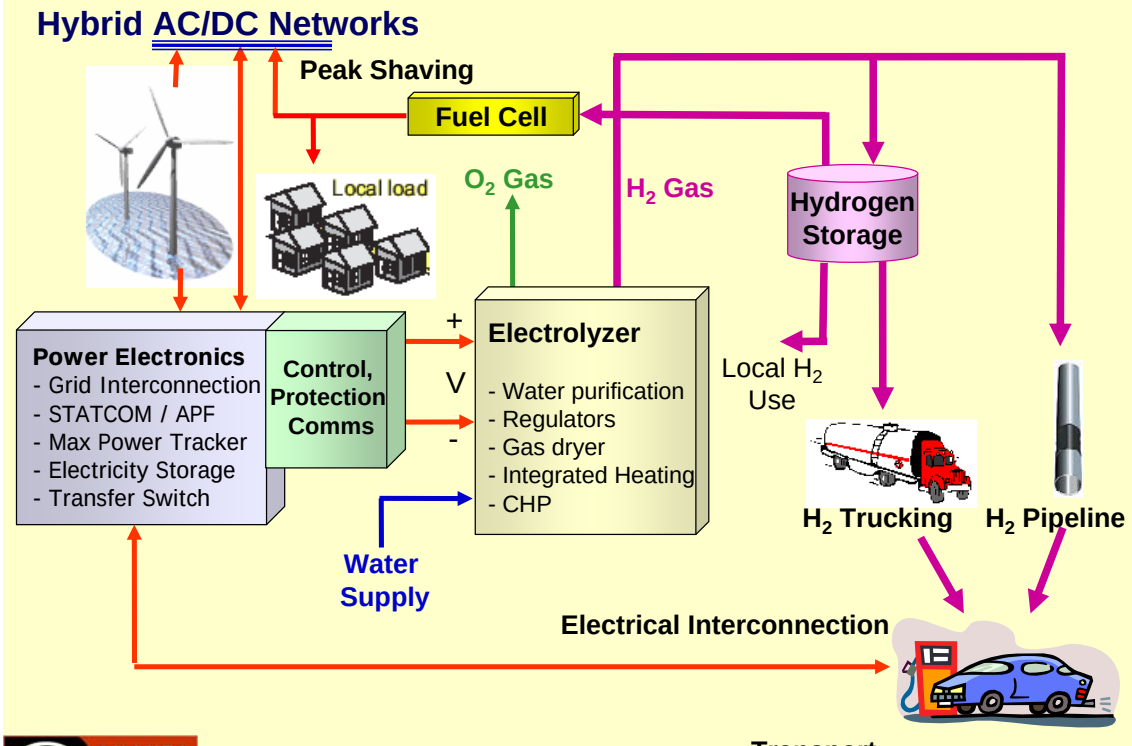


Sources:- PG&E and CEC PIER

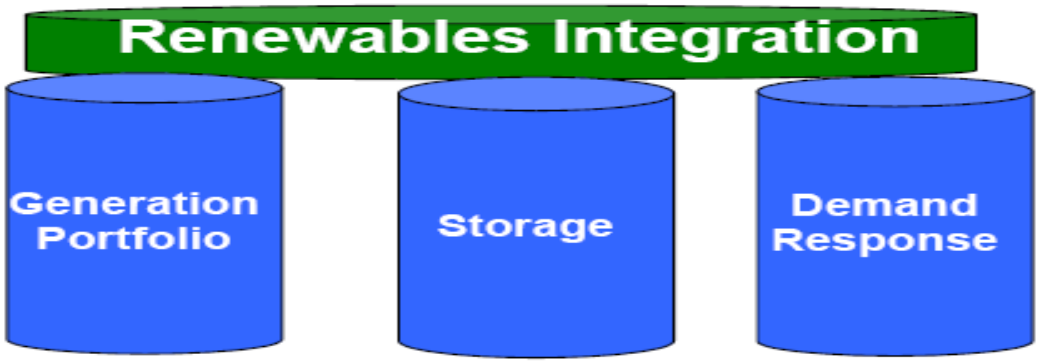
Plug-in Hybrid Cars (PHEV) – Load Balancing

- Several Manufacturers will start mass production in 2009
- Peak loading Dx issues – SmartGrid AMI
- Distributed Storage for Wind and Solar Power Balancing
- 600 GWh DESR potential from 10% of 200 million US passenger cars
- Linking different fuel options and energy transport mediums

Hybrid Energy Carrier Options



Approach to Large Scale Renewables Integration



- Hybrid Energy Mix
- Advanced PE
- Fast Ramping
- Wide Operating Range
- Regulation capability

- Peak shaving
- Dispatch Renewables
- Mitigate Over Gen.
- Voltage Support & LVRT
- F-Regulation capability
- FACTS Integration
- Power Quality

- Price sensitive load
- Responsive to ISO
- Frequency Response
- Responsive to Wind
- SmartGrid / AMI
- Gen. - load match
- PHEV

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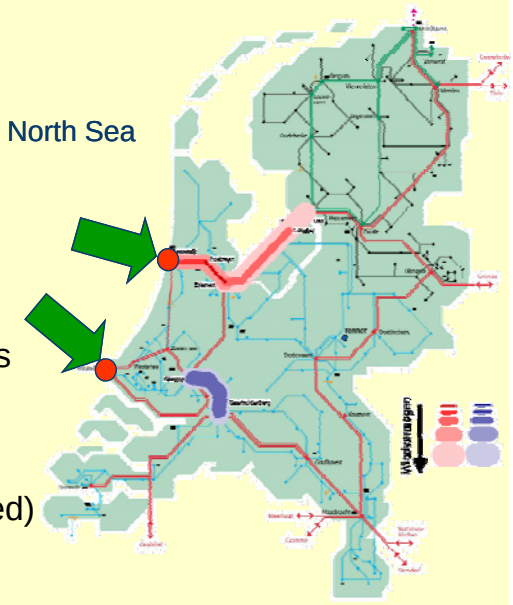
Network Interconnection of 6 GW Offshore Wind

- 6 GW Wind by 2020 in 20 GW load (30%)
- Total cost 10 000€
- On-shore dynamic and static reactive power demand 2 - 6 GVAr
- Network upgrades - 650 M€
- 25-70 km offshore (AC or DC) Tx
- Bundling 150 kV AC offshore wind farm connections into 2 380 kV Offshore hubs
- 5th Harmonic resonance between cable capacitance and short-circuit reactance:
- Utilizing 2 HVDC links (BritNed & NorNed)
- Hybrid (AC + DC) off-shore network is preferred solution
- 2007 – 300 MW built out



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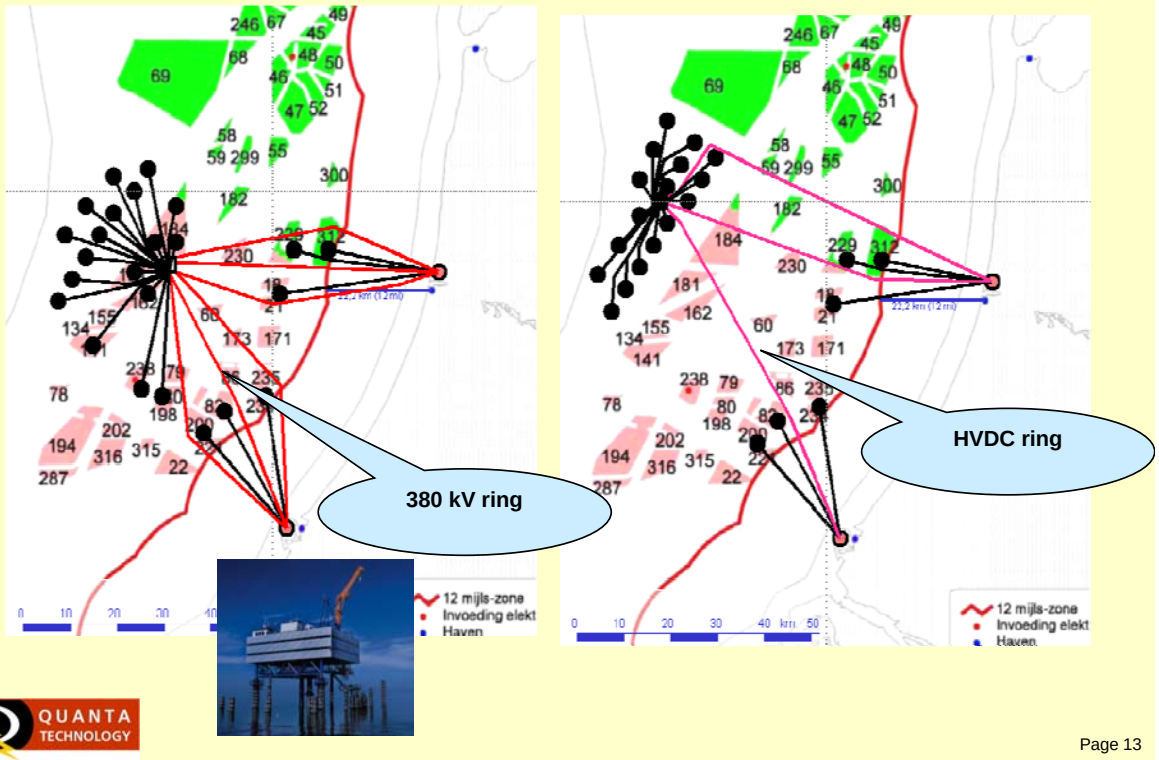
Grid Inter-connection Alternatives



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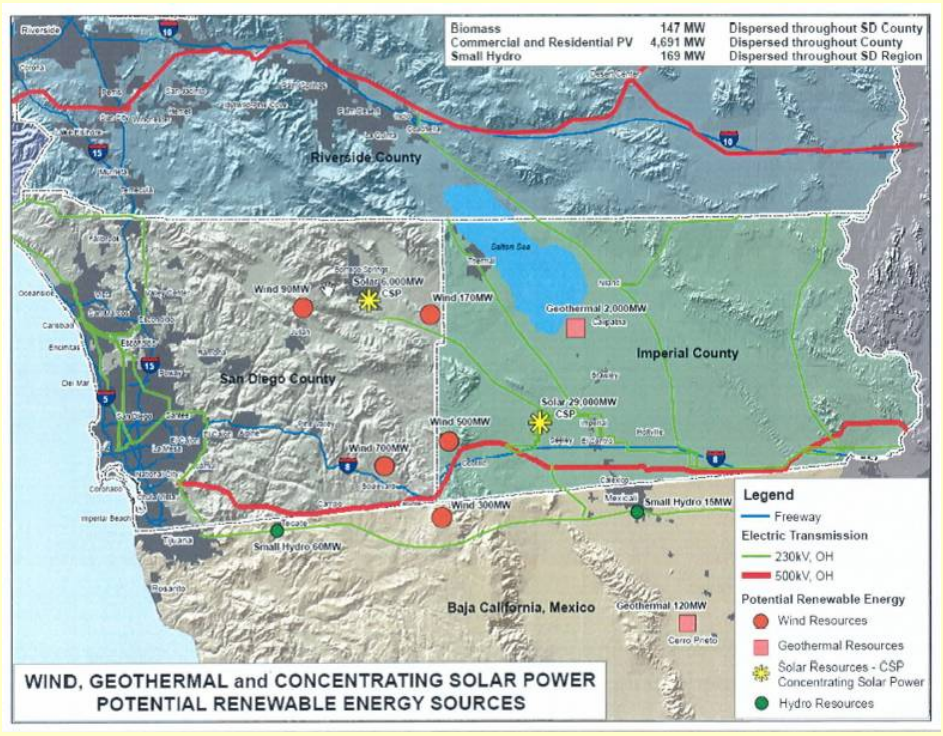
Renewable Energy Resources in Southern CA



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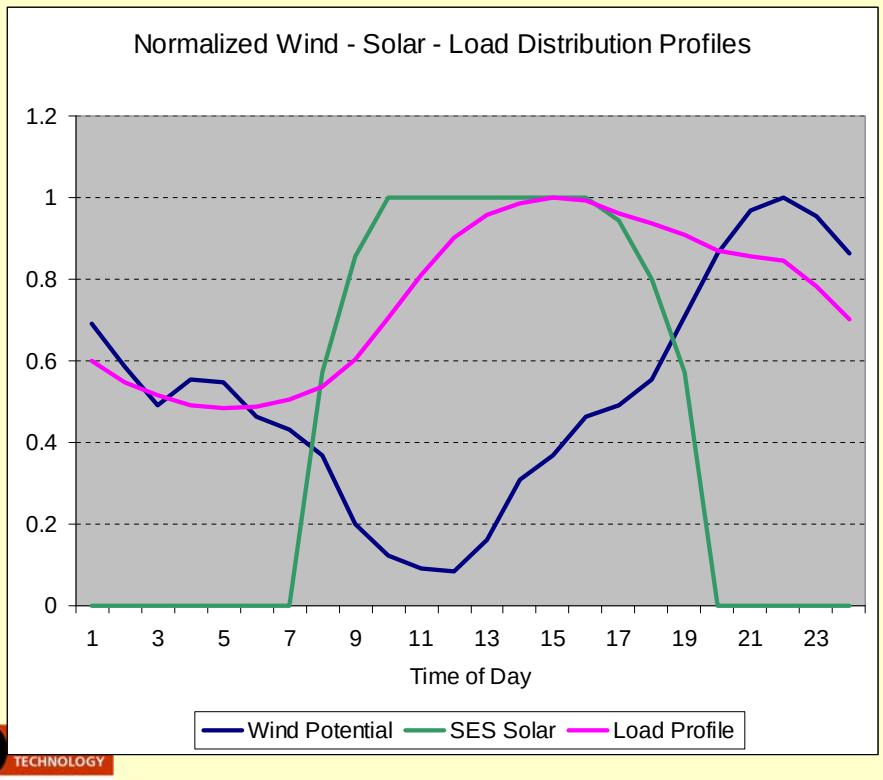
Large-scale US Wind Impact Study

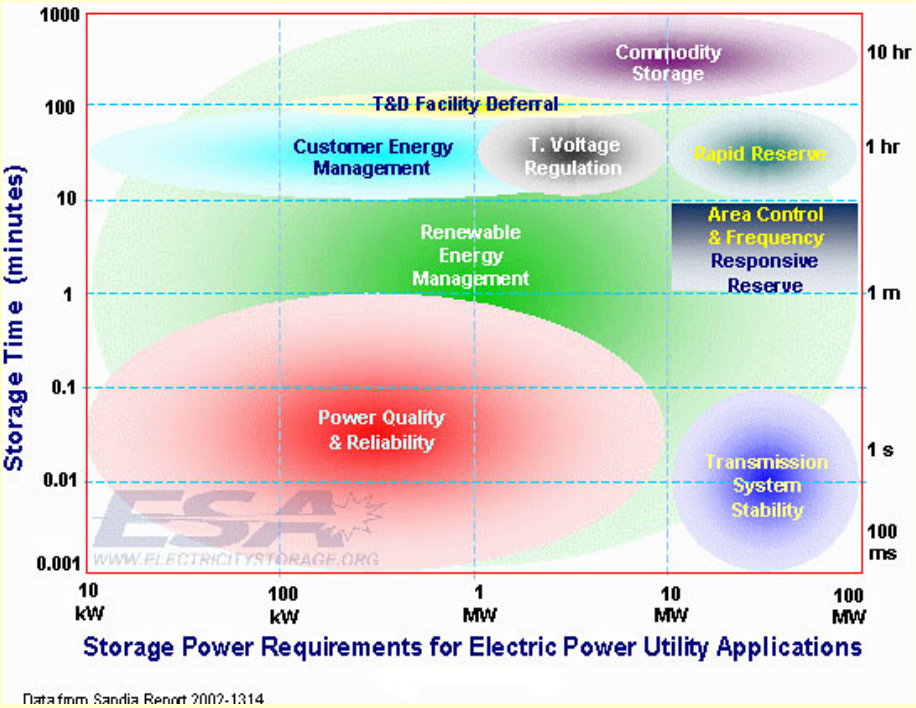
- Southern CA Renewable Energy Target
  - 2000 MW renewable energy portfolio,
  - 5,500 MW load demand in 2016 (36% penetration)
- Proposed hybrid approach to meet this requirement:
  - 1200 MW of wind generation
  - 900 MW of thermal solar generation
- Main findings and recommendations:
  - Need 500 kV transmission link
  - Utilize hybrid wind - solar generation nature.
  - Power balancing with 1200 MW of wind and 900 MW of solar.
  - Voltage support with 300 MVAr MSC and 200 MVAr STATCOMs
  - Special protection schemes and curtailment.
  - Utilize pump-storage facilities

Study hybrid impacts of 4 GW – wind – solar - geothermal

Daily Normalized Wind, Solar and Load Patterns



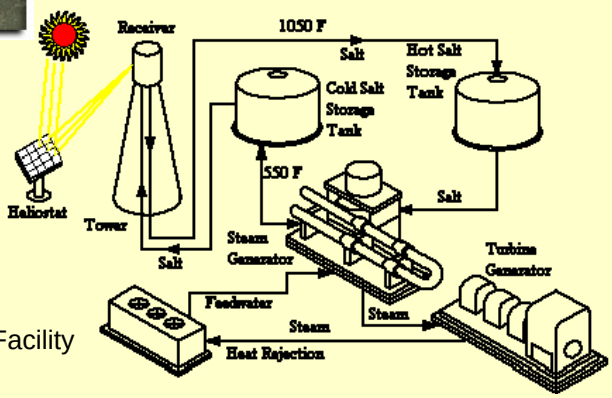
Storage Characteristics and Technologies



The Netherlands Energy Storage Island

- Utilizing levy upgrades
- Low-head hydro

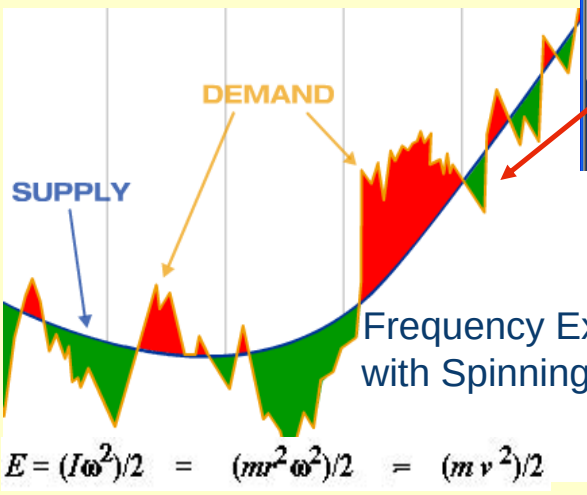
Thermal Solar with Molten Salt Energy Storage

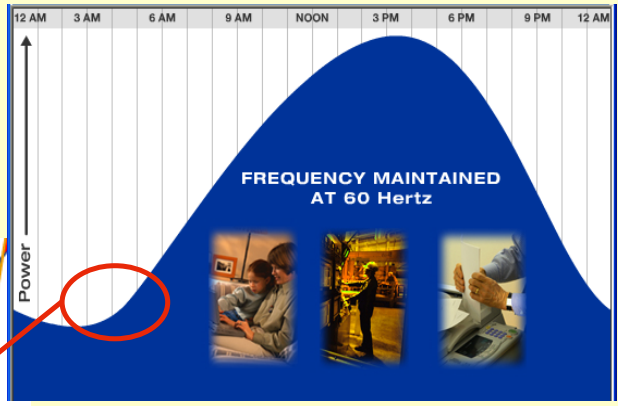


Source:- 5 MW Sandia Lab. Storage Test Facility

Flywheel Plants for Regulation Services

Short-term (1 – 15 min) Supply and Demand Curve





Daily Supply and Demand Curve

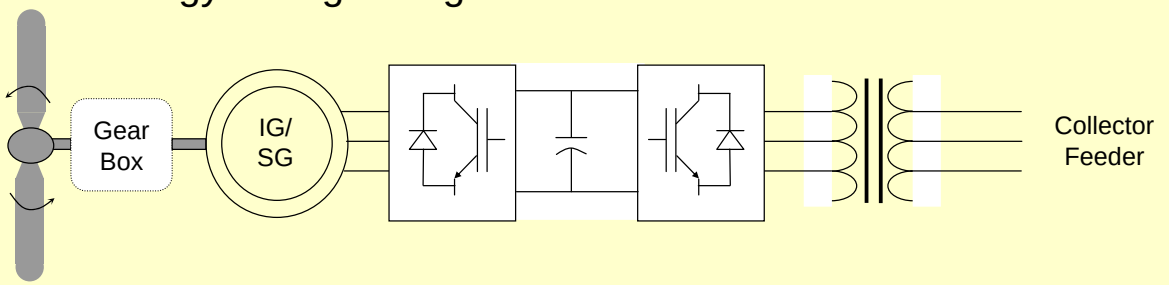
Frequency Excursions with Spinning Reserve

$$E = (I\omega^2)/2 = (mr^2\omega^2)/2 = (m v^2)/2$$

Source:- Beacon Power

Advanced Generator Power Electronics

- Variable Speed and Reactive Power control
- Dynamic Voltage Response Similar to STATCOM
- Advanced LVRT capability
- Spinning reserve emulation
- Active ancillary services – frequency regulation
- Energy storage integration



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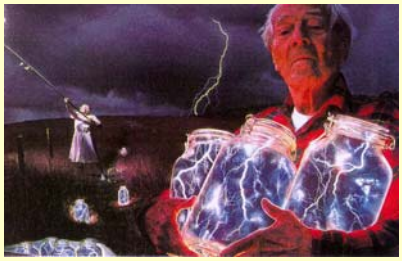
Summary:

- Most states have aggressive RPS > 10 - 25% by 2020
- Interconnection requirements are increasing
- Solutions to higher renewable penetration levels:
  - Hybrid wind, hydro, geothermal and solar generation mix
  - Energy storage
    - Short-term balancing, LVRT and Power Quality - 0.1 - 10 minutes
    - Regulation Services – 10 - 15 minutes
    - Medium-term peak shaving and load balancing 1 – 2 hours
    - Distributed Energy Storage – 600 GWh Plug-in-Hybrid potential
  - Advanced Generation Power Electronics
  - SmartGrid / AMI with Demand Response



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Thank You !