U.S.-JORDAN ELECTRIC POWER TRANSMISSION PARTNERSHIP EXECUTIVE EXCHANGE VISIT FOR THE NATIONAL ELECTRIC POWER COMPANY (NEPCO) OF JORDAN

WITH ARIZONA PUBLIC SERVICE

October 2 to 11, 2009

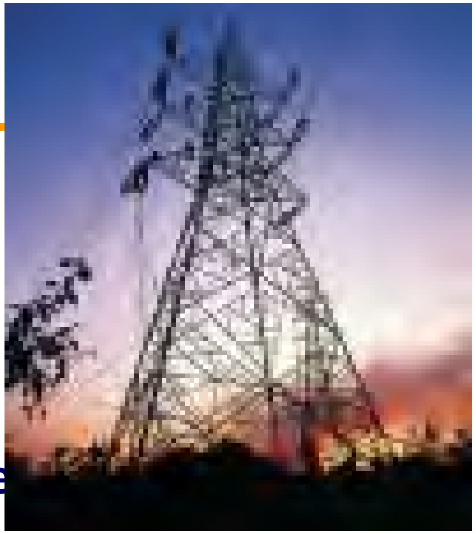
in Amman, Jordan

Technical Issues of Integrating Renewable Energy Power Plants into the Grid

John Lucas Manager

Transmission Planning and Engineering

Outline



- Renewable Energy Integration Efforts in USA
  - State Renewable Portfolio Standards (RPS) goals
  - Western Renewable Energy Zones Project (WREZ)
  - Western Wind and Solar Integration Study
  - Southwest Area Transmission Group (SWAT) and Re Transmission Task Force (RTTF)
  - California Renewable Energy Transmission Initiative (RETI)
  - Nevada Renewable Energy Transmission Access Advisory Committee (RETAAC)
  - New Mexico Renewable Energy Transmission Authority (RETA)
  - Utah Renewable Energy Zone (UREZ) Task Force
- Technical Issues with integration into the grid

USA Renewable Integration

- 29 States have renewable portfolio standards (RPS)
- 18 States have Energy Efficiency Resource Standards
- RPS requires a percent of energy sales or installed capacity to come from renewable resources.
- RPS percentages increase incrementally from a base year to an ultimate target.

Renewable Energy Portfolio Standards (RPS)

29 States including D.C. have an RPS

WA: 15% by 2020

OR: 25% by 2025; small utilities 5-10%

ID: Priority to DR, EE, and in-state RE

CA: 20% by 2010; goal: 33% by 2020

NV: 20% by 2015; solar 5% per year

UT: 20% by 2025

CO: 20% by 2020; co-ops & munis 10%; includes 4% solar

AZ: 15% by 2025; includes 30% DG

NM: 20% by 2020; co-ops 10%

TX: 5,880 MW by 2015; goal: 10,000 MW by 2025

HI: 20% by 2020; *proposed increase to 40%* by 2030 agreed to for 2009 session

MT: 15% by 2015

ND: 10% by 2015

SD: 10% by 2015

NE: studying RPS

KS: goal - 20% wind by 2020

MN: 25% by 2025 Xcel 30% by 2020

IA: 105 MW in RPS goal: 1,000 MW wind by '11

MO: 15% by 2021; at least 2% solar

OK: Studying an RPS

AR: Utility IRPs to include RE

WI: 10% by 2015

IL: 25% by 2025

MI: 10% by 2015, and new RE capacity: 1,100 MW by 2015

OH: 12.5% by 2025; 0.5% solar

IN: 2 bills introduced

KY: Report recommends RPS

ME: 40% by 2017 goal: 3 GW wind by 2020

NH: 23.8% BY 2025

VT: 25% by 2025

MA:15% by 2020; two goals: 250 MW solar 2017; 2 GW wind 2020

RI: 16% by 2019

CT: 23% Class I/II by 2020 4% Class III by 2010

NY: 25% by 2013

PA: 8% Tier I, 10% Tier II by 2020; 0.5% solar set-aside

NJ: 22.5% by 2020; 2% solar

DE: 20% by 2019, with 2% solar

DC: 20% by 2020, with 0.4% solar

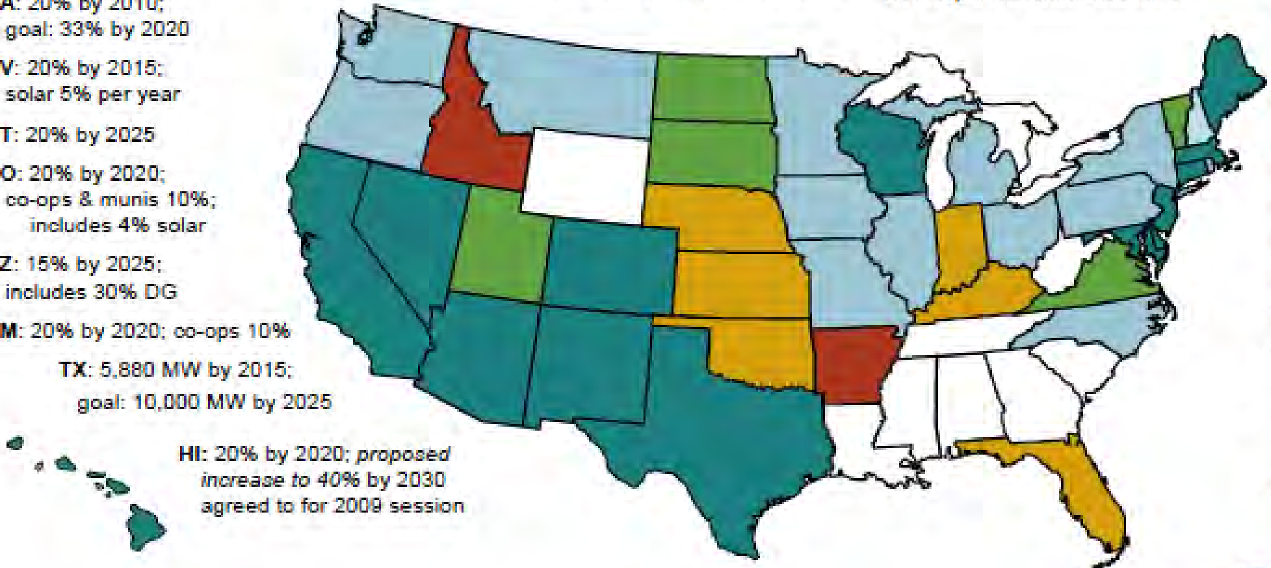
MD: 20% by 2022, with 2% solar

VA: 12% by 2022

TVA: 50% of generation from zero- or low-carbon sources by 2020*

NC: 12.5% by 2021 co-ops & munis: 10% by 2018

FL: draft RPS to legislature: 20% by 2020



- RPS
- Strengthened/ amended RPS
- Voluntary standards or goals
- Proposed RPS or studying RPS
- Other renewable energy goal

Updates at: http://www.ferc.gov/market-oversight/mkt-electric/overview/elec-ovr-rps.pdf

Notes: An RPS requires a percent of an electric provider's energy sales (MWh) or installed capacity (MW) to come from renewable resources. Most specify sales (MWh). Map percents are final years' targets. Details, including timelines, are in the Database of State Incentives for Renewables and Energy Efficiency: http://www.dsireusa.org . Alaska has no RPS; TVA's goal is not a state policy: the Public Power Authority called for 50% of generation from zero- or low-carbon sources by 2020.

Abbreviations: DG: distributed generation; DR: demand response; EE: energy efficiency; IRP: integrated resource plan, RE: renewable energy.

Sources: Derived from data in: EEI, EIA, LBNL, PUCs, State legislative tracking services, DSIREUSA, Pew Center, and the Union of Concerned Scientists.

Updated February 6, 2009

Electric Market Overview: Energy Efficiency Resource Standards (EERS) and Goals

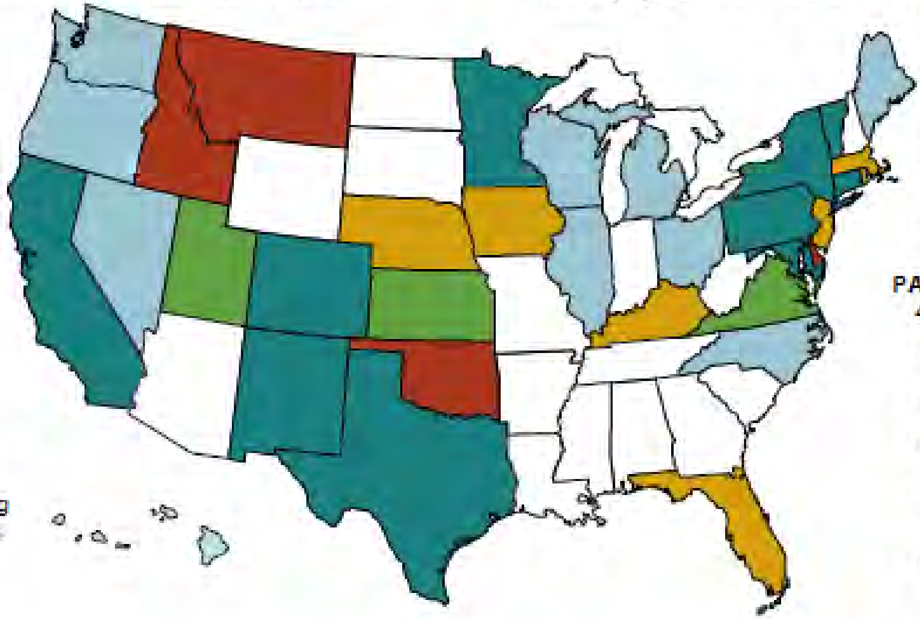
18 States have Energy Efficiency Resource Standards

NE: Energy Plan stresses multi-sector EE improvements
KS: Advocates voluntary utility programs, not mandate
OK: PSC approved quick-start DR programs, including EE

MN: 1.5% annual savings based on prior-3 years average, to 2015
IA: utilities to submit EE goals to achieve 1.5% annual savings; awaiting approval
MI: 1% annual savings from prior year's sales to 2012

WI: EE in RPS
IL: reduce energy 2% by 2015 (EE) and 0.1% from prior year (DR)
OH: reduce peak 8% by 2018; 22% energy savings by '25, starting 2009
KY: proposed RPS-EE to offset 18% of projected 2025 demand

WA: must pursue all cost-effective conservation
OR: IOU 2008 goals 34 MW; administered by Energy Trust OR
CA: 1% annual energy savings 2004 – 2013 ~23,183 GWh, 4,885 peak MW by 2013
ID: Energy Plan sets conservation, DR, EE as priority resources
MT: Governor's initiative – 20% state agencies energy savings by 2010
NV: EE up to 25% of RPS by 2015
UT: EE incentives in RPS goal
CO: 11.5% energy savings 2009 – 2020 ~ 3,669 GWh
NM: use EE and DR to save 10% of 2005 retail electric sales by 2020
TX: 20% of load growth by 2010, using average growth rate of prior 5 years
HI: 20% savings of net electric sales by 2020; up to 50% of RPS



ME: 10% EE by 2017 – new since 2005; DR & EE as SOS priority resources
VT: 2009 – 2011 goals of 2% annual savings; administered by Efficiency VT
MA: 25% of electric load from DSR, EE by 2020: capacity and energy
NY: 15% electric use reduction by 2015 from levels projected in 2008
CT: 1.5% annual savings 2009-19, from 2007, using all cost-effective EE
RI: reduce 10% of 2006 sales by 2022
NJ: BPU proceeding on EERS to reduce consumption, peak demand
DE: creating a Sustainable Energy Utility; EE, RE, DG, DR as SOS priorities
PA: reduce energy consumption 3% and peak 4.5% by 2013 as percent of 2009-10 sales
MD: reduce per cap electricity use & peak 15% by 2015 from 2007
VA: reduce 10% of 2006 sales by 2022
NC: EE to meet up to 25% of RPS to 2011; later to 40%
TVA: reduce peak demand 1,400 MW by 2012 with EE, DR *
FL: PSC to adopt new goals to reduce electric consumption, peak demand

Updates at: http://www.ferc.gov/market-oversight/mkt-electric/overview/elec-ovr-eeps.pdf

- EE as part of an RPS law, rule, or goal
- EERS by regulation or law (stand-alone)
- Voluntary standards (in or out of RPS)
- EERS pending regulations, proposed, or studied
- Other energy efficiency entity, rule, or goal

* TVA's "EE and DR Plan" is from the Public Power Authority, and is not a state policy.
Abbreviations: DG – distributed generation; DR - demand response; DSR – demand-side resources; EE - energy efficiency; E&G: electric and gas utilities; IRP – integrated resource plan; RPS: Renewable Portfolio Standard; SOS: Standard Offer Service
Sources: ACEEE, EPA, Regulatory Assistance Project, Union of Concerned Scientists, State regulatory and legislative sites; State Efficiency Agency reports; trade press

Updated March 10, 2009

Source: FERC Market Oversight @ FERC.gov

Efforts in Western US on Renewable Resource Integration

- **Western Governors Association, and US Department of Energy (DOE)**
  - **Western Renewable Energy Zones (WREZ)**
- **Southwest Area Transmission – Renewable Transmission Task Force (SWAT-RTTF)**
- **National Renewable Energy Lab (NREL) Western Wind and Solar Integration Study**

National Renewable Energy Lab (NREL) Western Wind and Solar Integration Study

Overview

- **Goal**
  - **To understand the costs and operating impacts due to the variability and uncertainty of wind, PV and concentrating solar power (CSP) on the WestConnect grid**
- **Utilities**
  - **Arizona Public Service**
  - **El Paso Electric**
  - **NV Energy**
  - **Public Service of New Mexico**
  - **Salt River Project**
  - **Tri-State G&T**
  - **Tucson Electric Power**
  - **Xcel Energy**
  - **WAPA**

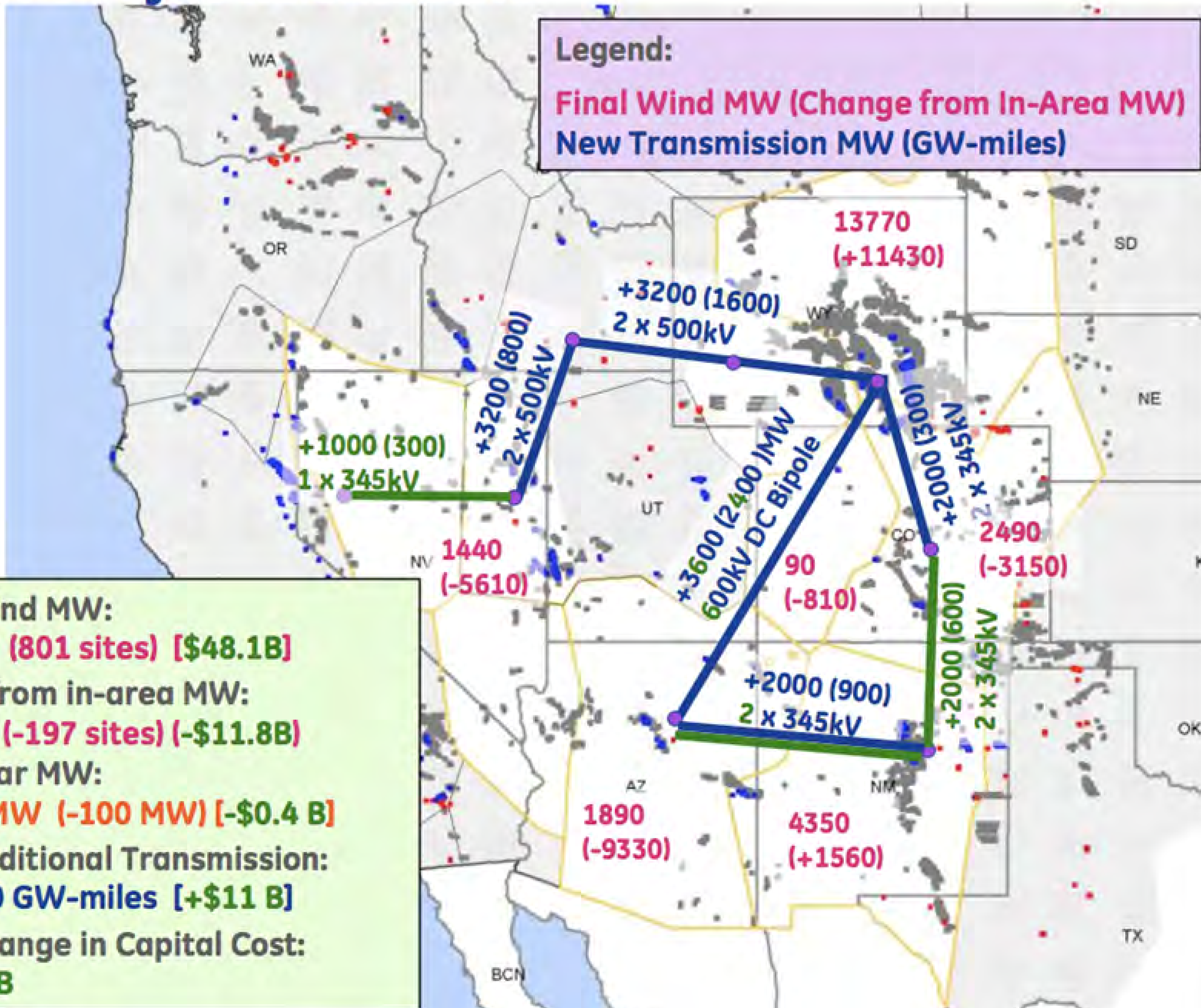
Scenario Overview

In	Footprint	Rest of	WECC
Wind	**Solar**	**Wind**	**Solar**
10%	**1%**	**10%**	**1%**
20%	**3%**	**10%**	**1%**
30%	**5%**	**20%**	**3%**

- **Baseline – no new renewables**
- **In-Area – each transmission area meets its target from sources within that area**
- **Mega Project – concentrated projects in best resource areas**
- **Local Priority – Balance of best resource and in-area sites**
- **Plus other scenarios yet to be determined (high solar, high capacity value, high geographic diversity)**

Solar is 70% CSP and 30% distributed PV. CSP has 6 hours of thermal storage. Penetrations are by energy.

Mega Project Scenario



Total Wind MW:
24040 (801 sites) [$48.1B]

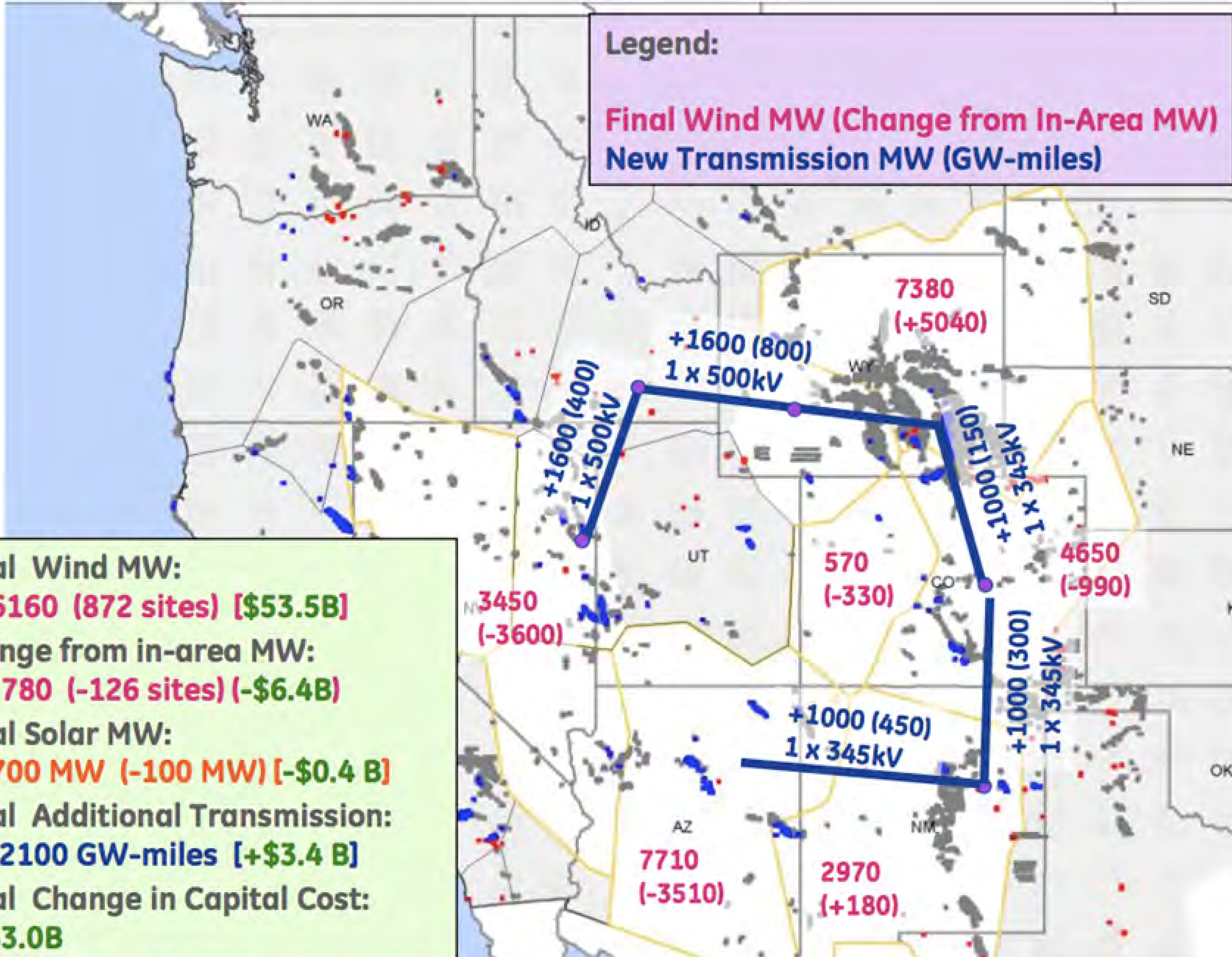
Change from in-area MW:
-5940 (-197 sites) (-$11.8B)

Total Solar MW:
5700 MW (-100 MW) [-$0.4 B]

Total Additional Transmission:
+ 6900 GW-miles [+$11 B]

Total Change in Capital Cost:
- $1.2B

Local Priority Scenario



Total Wind MW:
26160 (872 sites) [$53.5B]

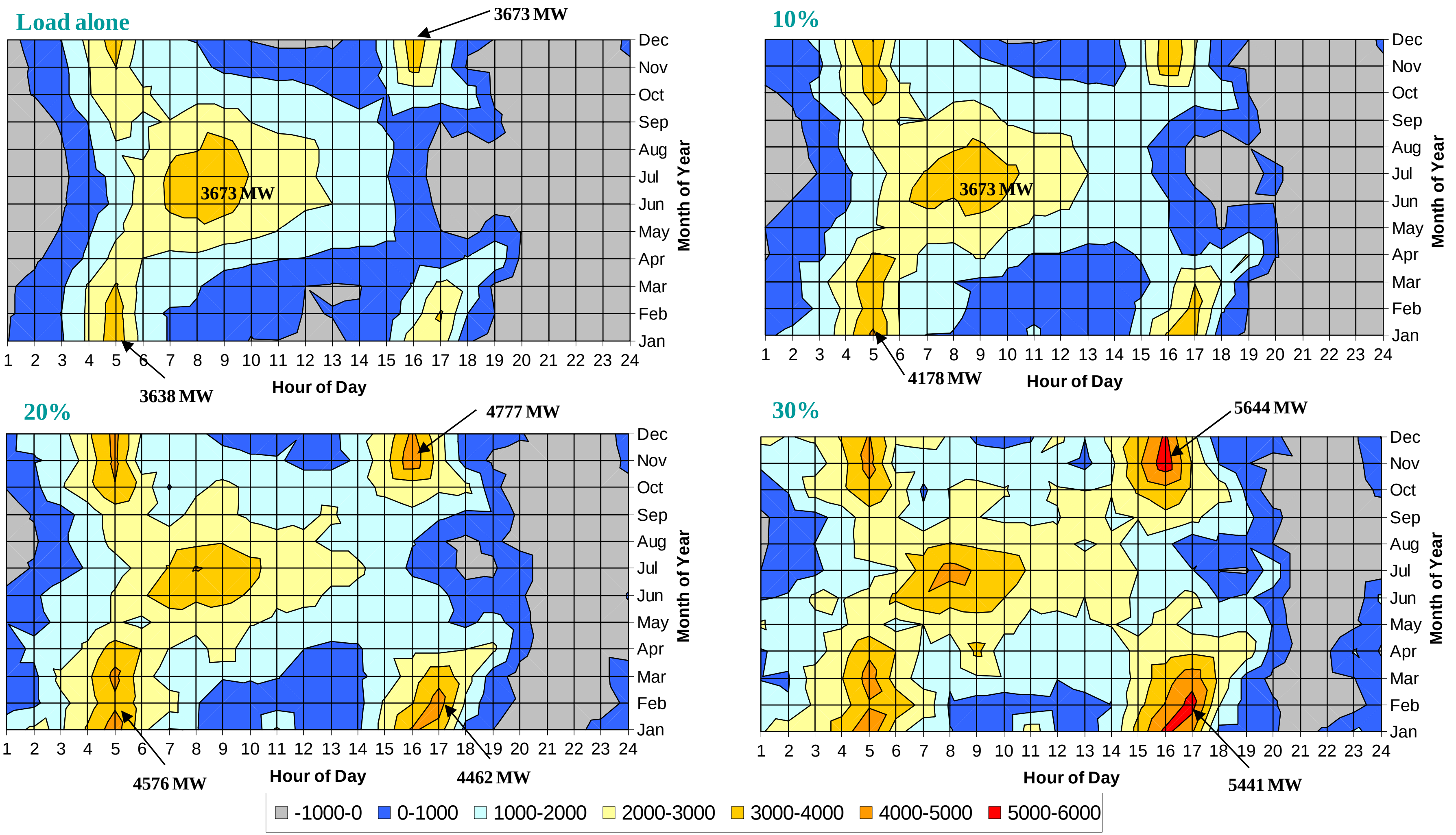
Change from in-area MW:
-3780 (-126 sites) (-$6.4B)

Total Solar MW:
5700 MW (-100 MW) [-$0.4 B]

Total Additional Transmission:
+ 2100 GW-miles [+$3.4 B]

Total Change in Capital Cost:
-$3.0B

Study Footprint - Timing of Extreme Net Load Up-Ramps
(Local Priority Scenario)

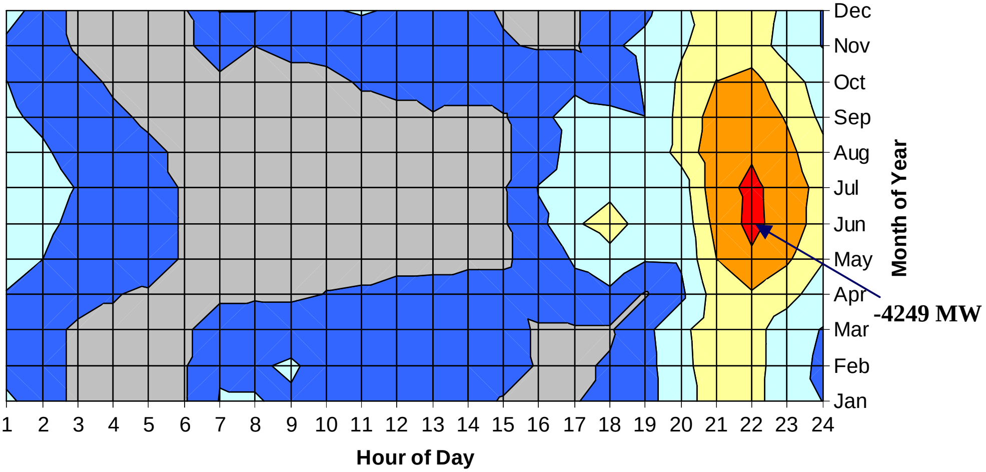


Wind/solar drops drive extreme up-ramps in late afternoons during late fall and winter

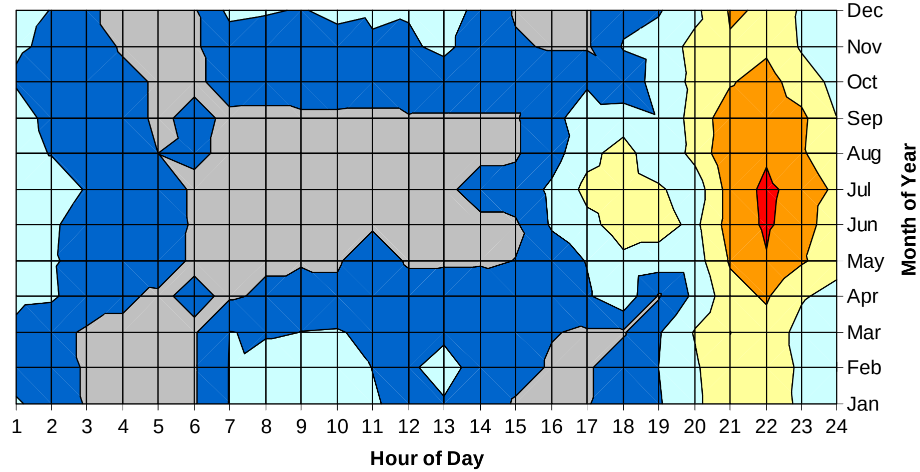
Study Footprint - Timing of Extreme Net Load Down-Ramps

(Local Priority Scenario)

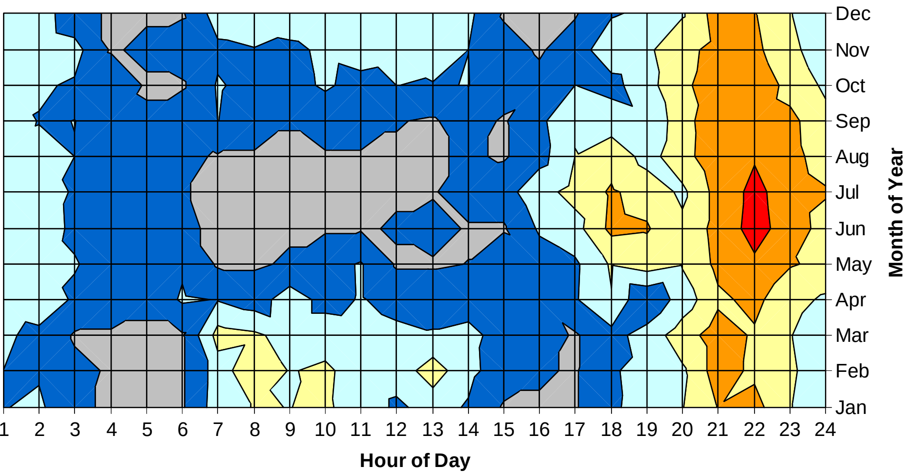
Load alone



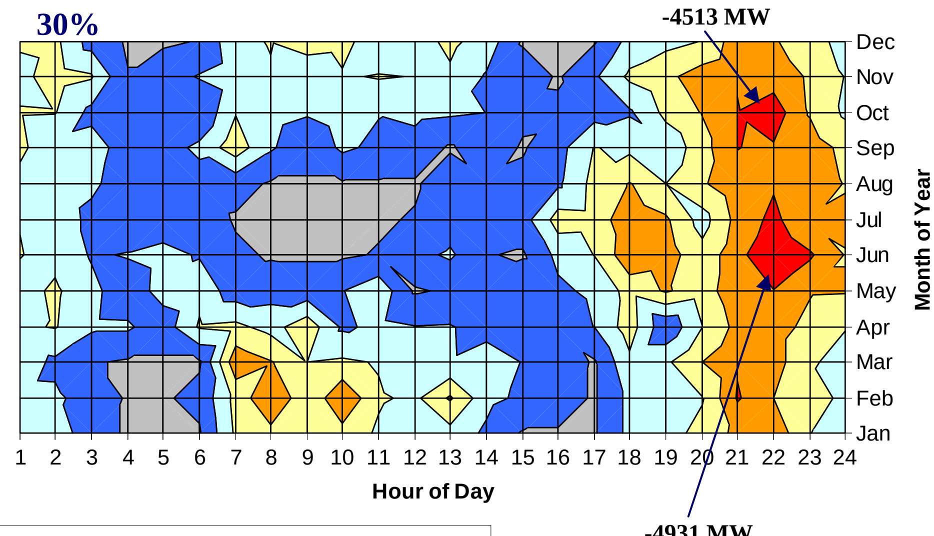
10%



20%



30%



-5000--4000 | -4000--3000 | -3000--2000 | -2000--1000 | -1000-0 | >0

APS

Extreme down-ramps driven by summer/early fall evening load roll-off

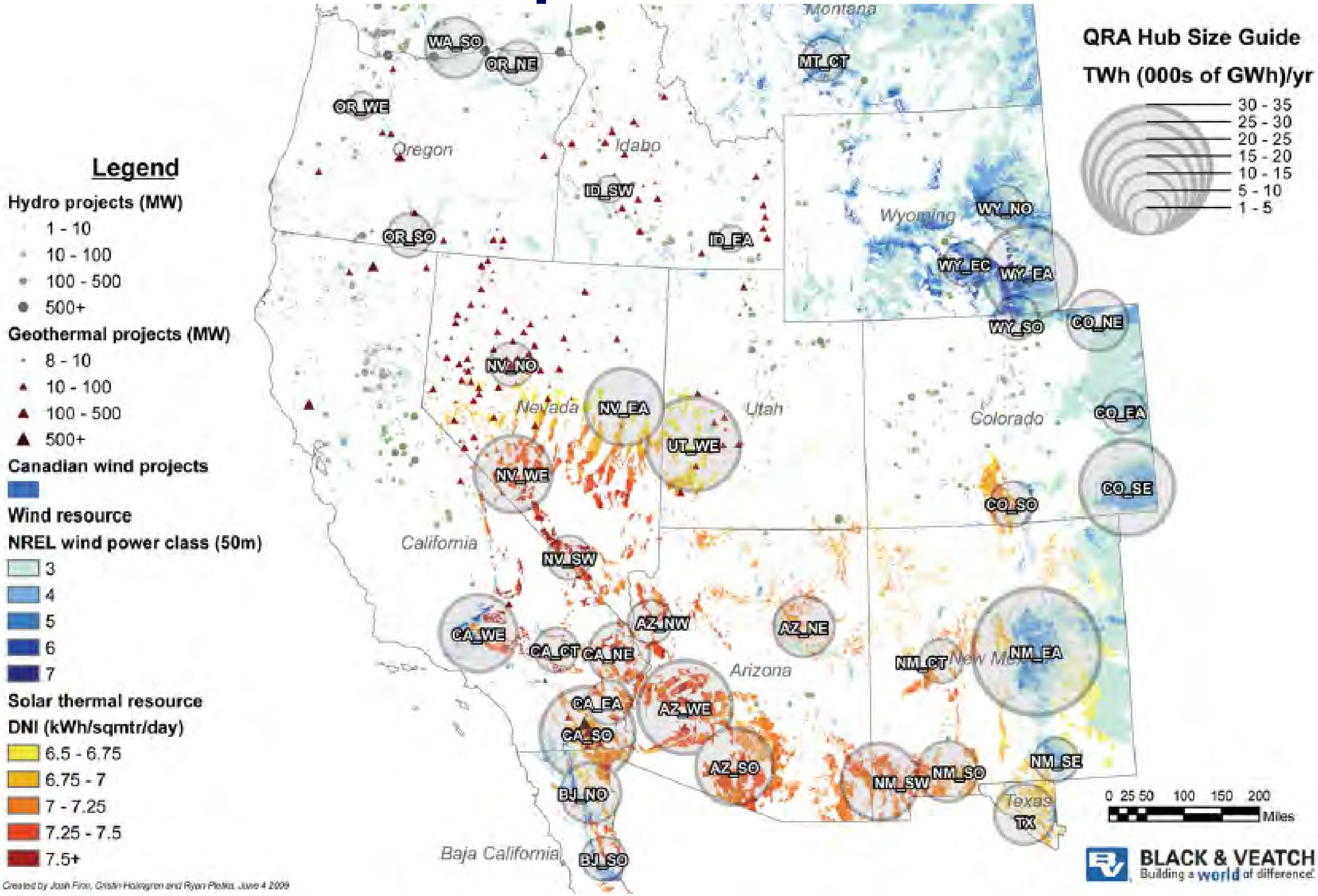
NREL Western Wind and Solar Integration Study Statistical Analysis Conclusions

- **Significant monthly/seasonal variation of wind and solar energy within footprint and across areas**
- **Relatively small observable difference among scenarios, but more pronounced at area level**
- **At footprint and area level, net load variability tends to be high during fall/winter late afternoons due to simultaneous load rise, and wind/solar roll-off**
- **Wide area balancing → greater diversity, less relative variability and extreme ramps**

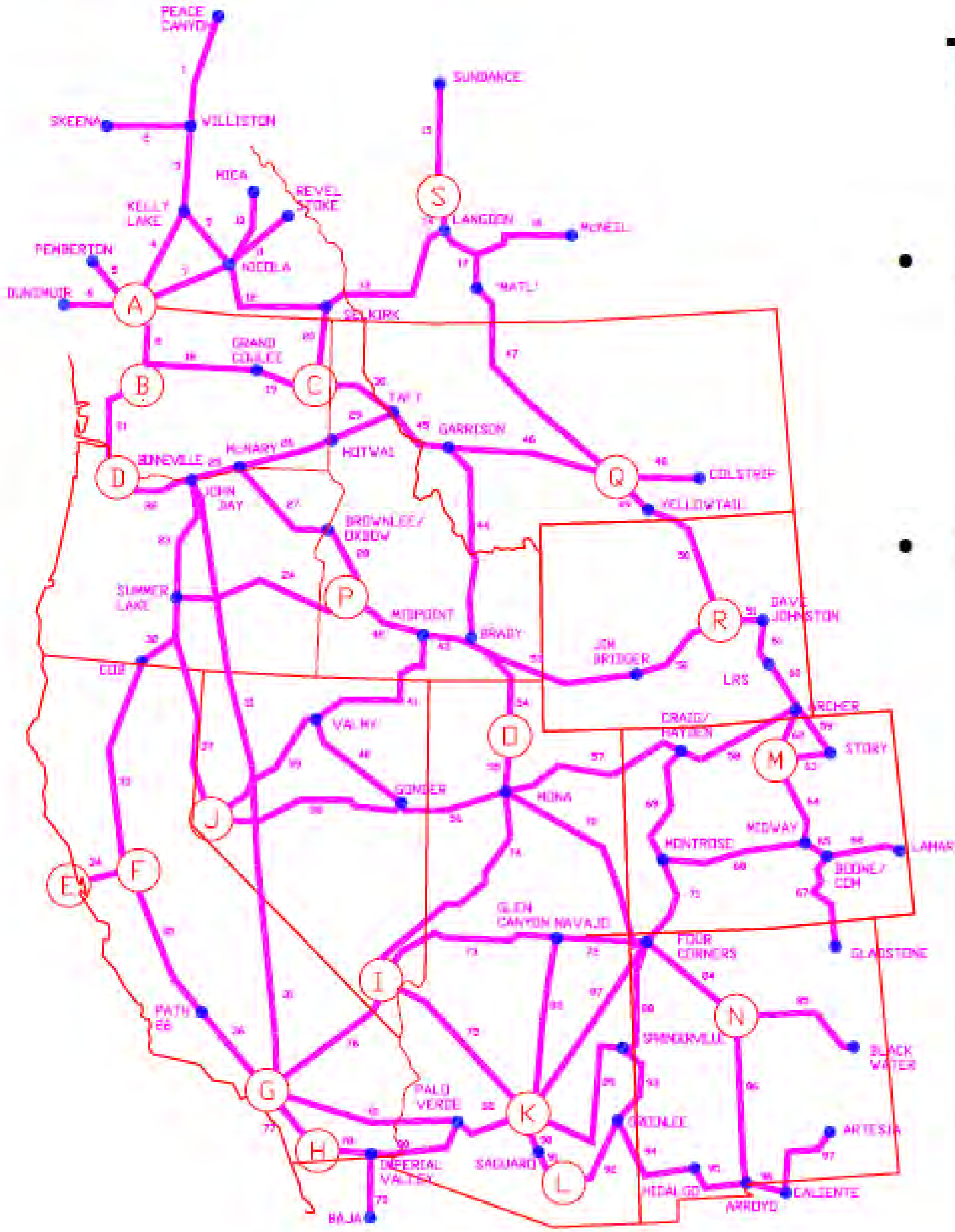
WREZ

- The WREZ seeks to identify those areas in the West with vast renewable resources to expedite the development and delivery of renewable energy to where it is needed. Renewable energy resources are being analyzed within 11 states, two Canadian provinces, and areas in Mexico that are part of the Western Interconnection.
- The WREZ project will generate:
  - reliable information for use by decision-makers that supports the cost-effective and environmentally sensitive development of renewable energy in specified zones, and
  - conceptual transmission plans for delivering that energy to load centers within the Western Interconnection.
  - The project also will evaluate all feasible renewable resource technologies that are likely to contribute to the realization of the goal in WGA's policy resolution that calls for the development of 30,000 megawatts of clean and diversified energy by 2015.

WREZ Hub Map



Legend
Hydro projects (MW)
1 - 10
10 - 100
100 - 500
500+
Geothermal projects (MW)
8 - 10
10 - 100
100 - 500
500+
Canadian wind projects
Wind resource
NREL wind power class (50m)
3
4
5
6
7
Solar thermal resource
DNI (kWh/sqmtr/day)
6.5 - 6.75
6.75 - 7
7 - 7.25
7.25 - 7.5
7.5+
QRA Hub Size Guide
TWh (000s of GWh)/yr
30 - 35
25 - 30
20 - 25
15 - 20
10 - 15
5 - 10
1 - 5
Montana
Oregon
Idaho
Wyoming
Nevada
Utah
Colorado
California
Arizona
New Mexico
Texas
Baja California
WA_SO
OR_NE
OR_WE
OR_SO
MT_CT
ID_SW
ID_EA
WY_NO
WY_EC
WY_EA
WY_SO
CO_NE
CO_EA
CO_SE
CO_SO
NV_NO
NV_EA
NV_WE
NV_SW
UT_WE
CA_WE
CA_CT
CA_NE
CA_EA
CA_SO
AZ_NW
AZ_NE
AZ_WE
AZ_SO
NM_CT
NM_EA
NM_SE
NM_SW
NM_SO
TX
BJ_NO
BJ_SO
0 25 50 100 150 200
Miles
BLACK & VEATCH
Building a world of difference
Created by Josh Finn, Cristin Holmgren and Ryan Pletka, June 4 2009



Transmission Segments

- Representative Paths
  - Existing corridors
  - ~ 100 segments
  - Tabulation of miles
- Final Tasks
  - Link to WREZs in coordination with E&L
  - Eliminate redundancy

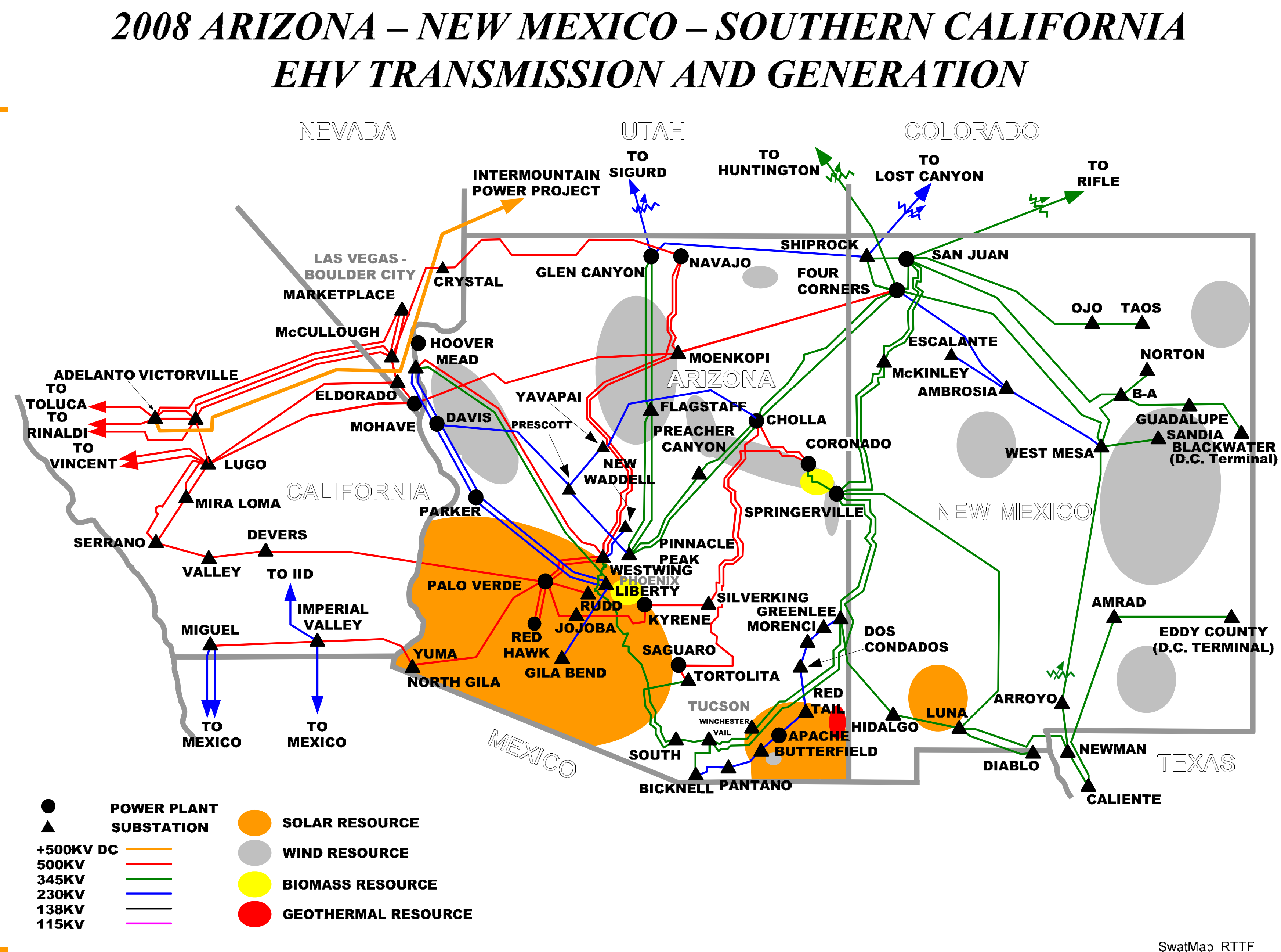
Ⓐ	Load Zone
•	Key Substation
╲╱	Line Segment

[Click here for key to map]

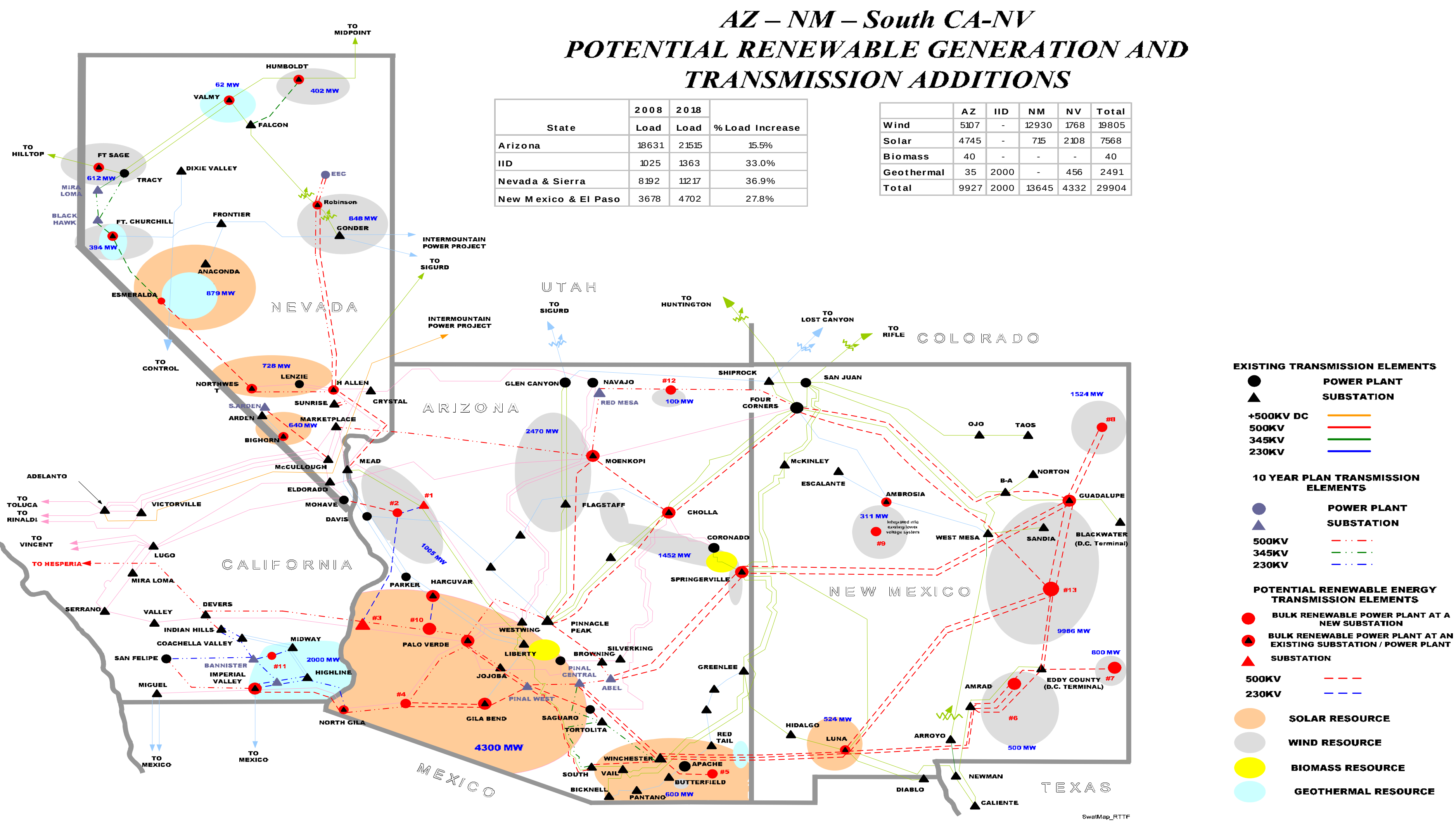
SWAT RTTF / ARRTIS

- **Regional planning group that focuses on potential renewable energy development and transmission options to bring renewable energy to the load.**
- **Includes Arizona, New Mexico, Nevada and Southeastern California.**
- **Current effort includes detailed potential renewable generation areas, transmission options, and technical studies.**

Renewable Resource Location



Potential Transmission Additions

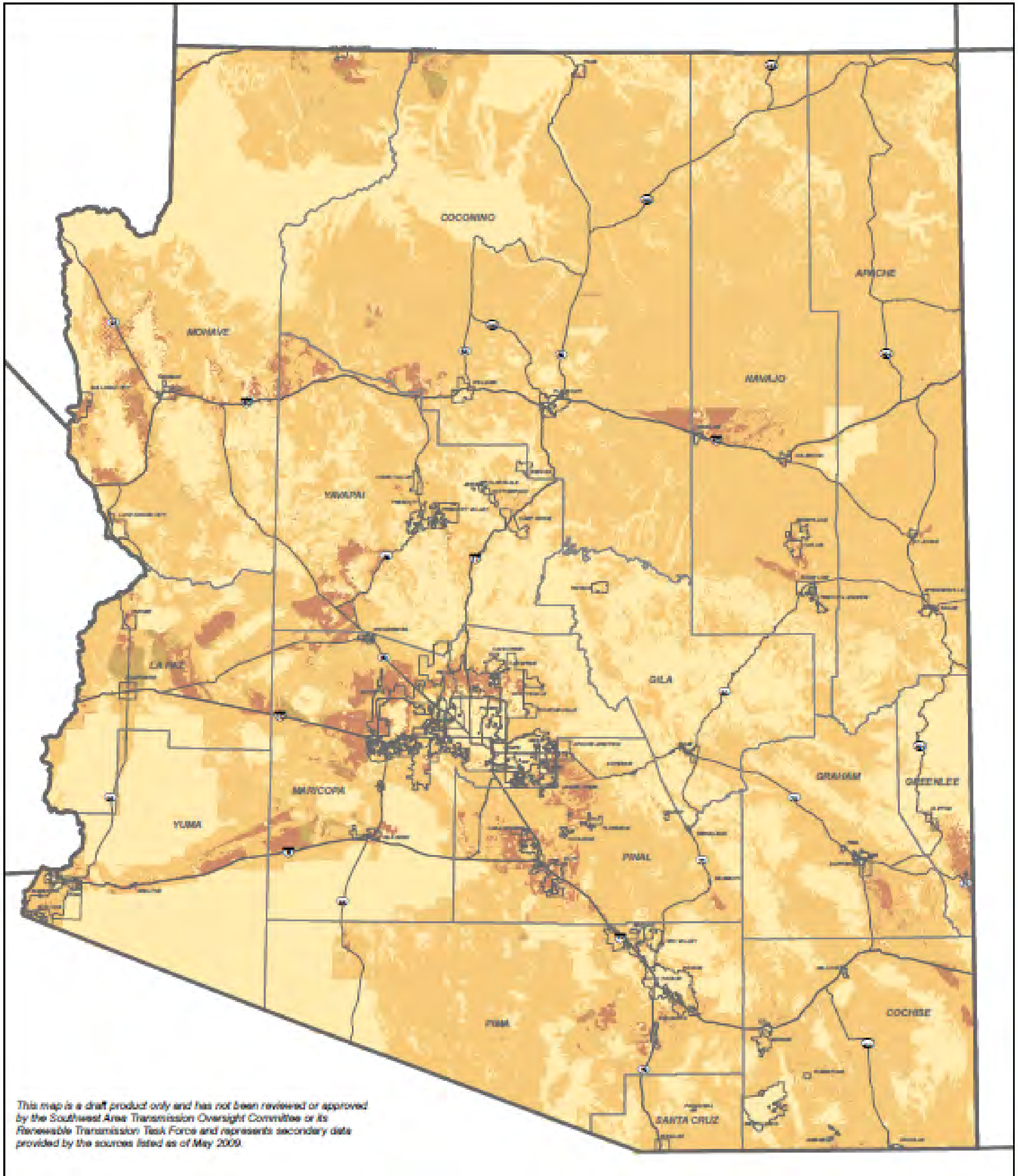


State	2008 Load	2018 Load	% Load Increase
Arizona	18631	21515	15.5%
IID	1025	1363	33.0%
Nevada & Sierra	8192	11217	36.9%
New Mexico & El Paso	3678	4702	27.8%

	AZ	IID	NM	NV	Total
Wind	5107	-	12930	1768	19805
Solar	4745	-	715	2108	7568
Biomass	40	-	-	-	40
Geothermal	35	2000	-	456	2491
Total	9927	2000	13645	4332	29904

Renewable Resource Locations

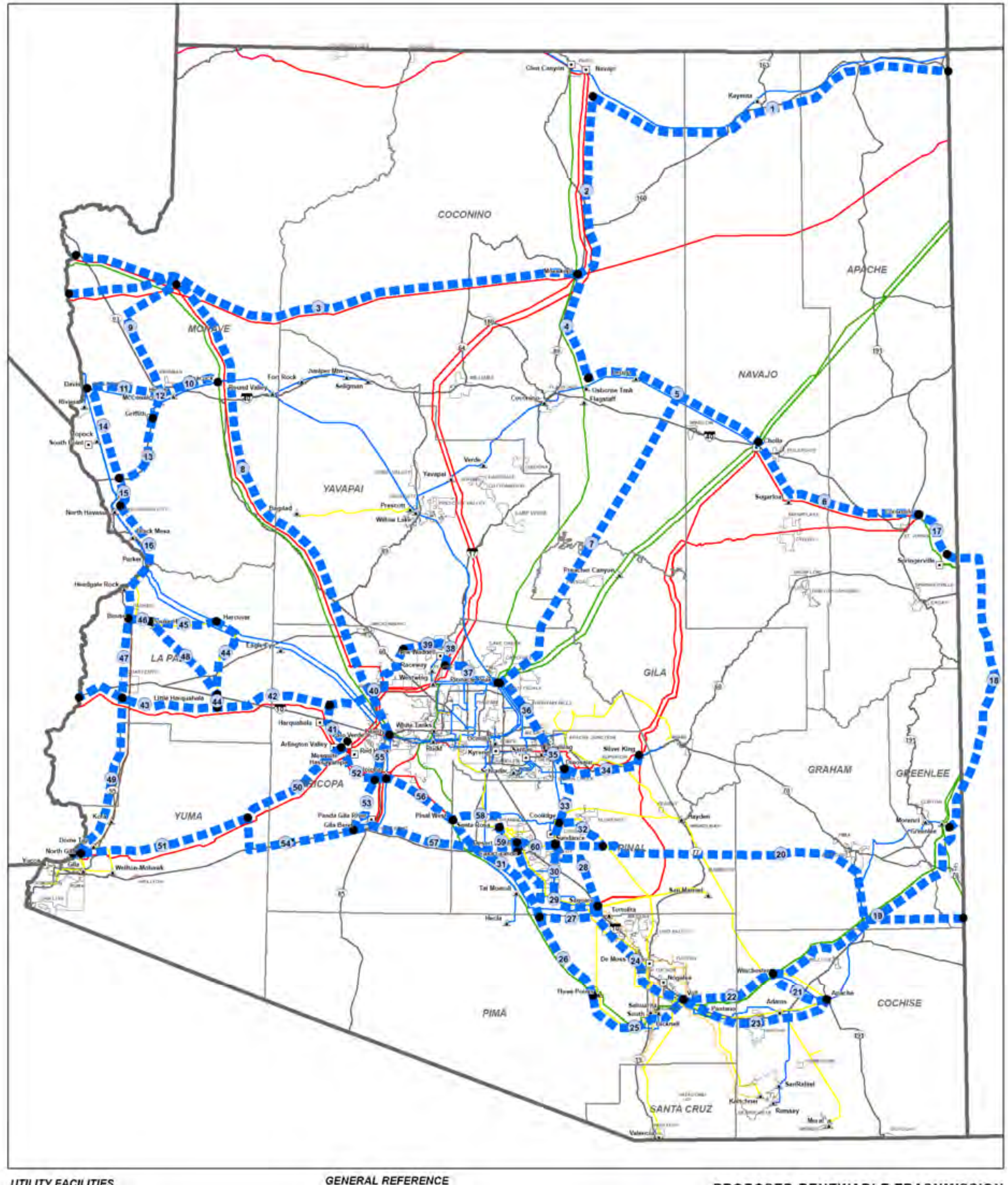
From SWAT ARRTIS Group



*Dark areas represent highest potential for renewable energy development based on several filters.

APS

SWAT
Potential Transmission Options
Assimilated Map – 5/20/2009

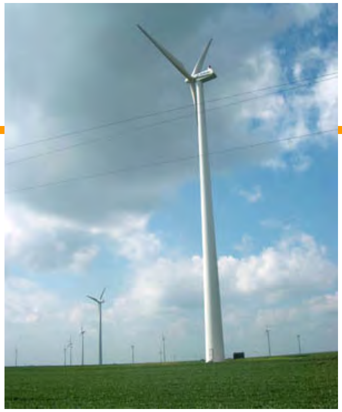


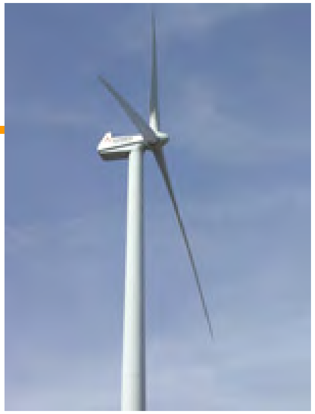
Renewable Resource Output Variability

- **Unlike conventional sources, renewable output is highly variable**
- **Power system is designed to handle variability in load.**
- **Renewable resources add another aspect to the variability**
- **Balancing variable loads with variable resources can become difficult.**

Technical Issues

Wind

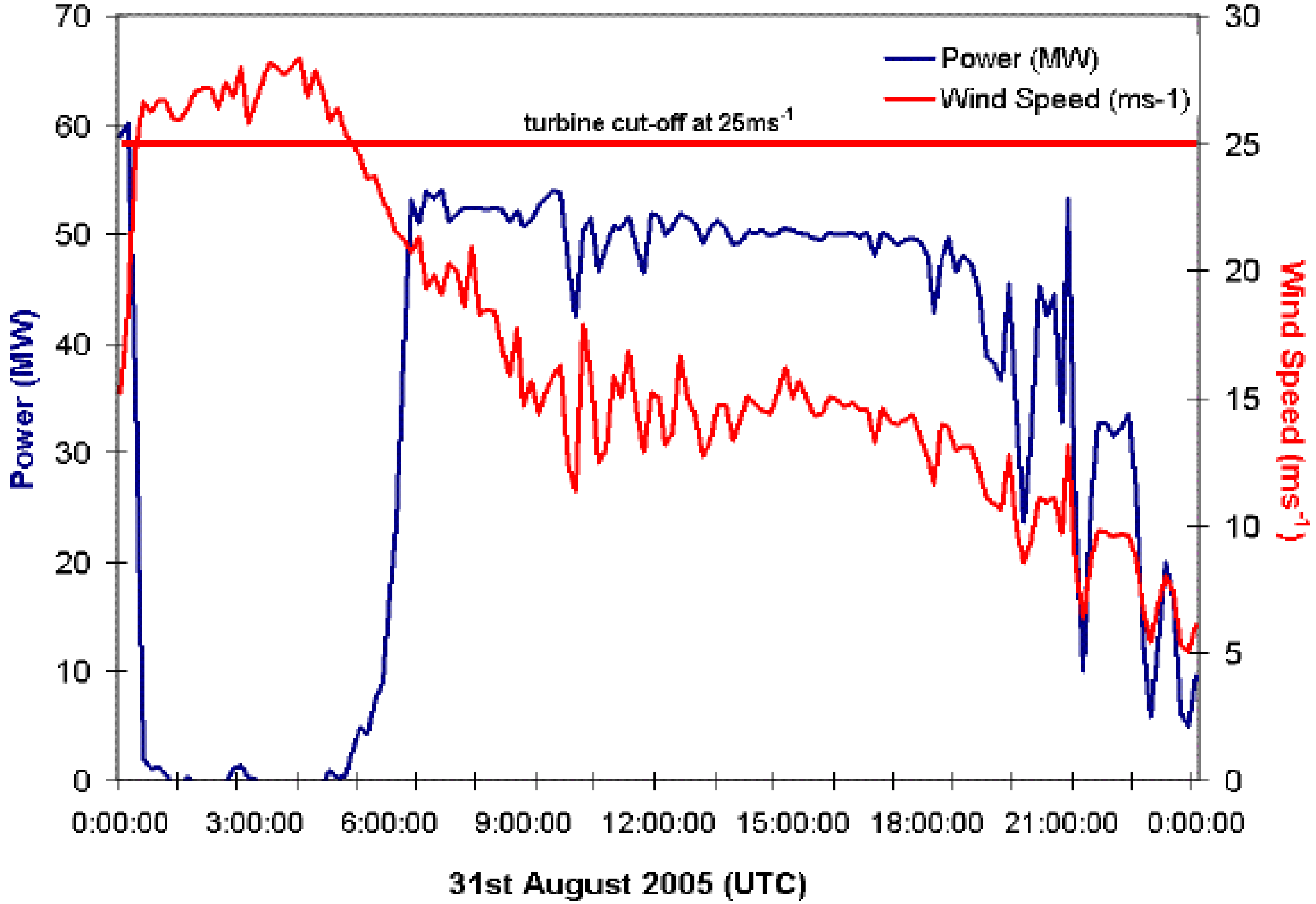




- Variability is high in both long and short term
  - Difficult to determine (in the long term) at what time during a day or what time of year wind output will peak
  - Wind output can peak during system peak load (late afternoon), or in the middle of the night (low system peak)
- Wind Class
  - The higher the wind class, output variability can decrease

Renewable Resource Output Variability

- **High wind speeds can shut down wind generation**



Source: H. Outhred, Meeting the challenges of Integrating Renewable Energy Into Competitive Electricity industries

Renewable Resource Output Variability

Solar

- Variability
  - Output curve is typically the same over the course of a day (i.e. output peaks and valleys around the same times)
- Affected by cloud cover
  - Could be difficult to determine output in day ahead or longer
  - Easily determined during load following time periods
- Winter vs Summer Max Output
  - During wintertime, max output typically decreases
- CSP plants can have molten salt storage
  - More reliable dispatch during day time
  - Dispatchable energy after sun sets
- PV Units can be place near the load
  - Can shift peak load time
  - Makes distribution planning difficult
    - Can more feeders be served off a transformer due to PV units?

Balancing variable loads with variable resources can become difficult

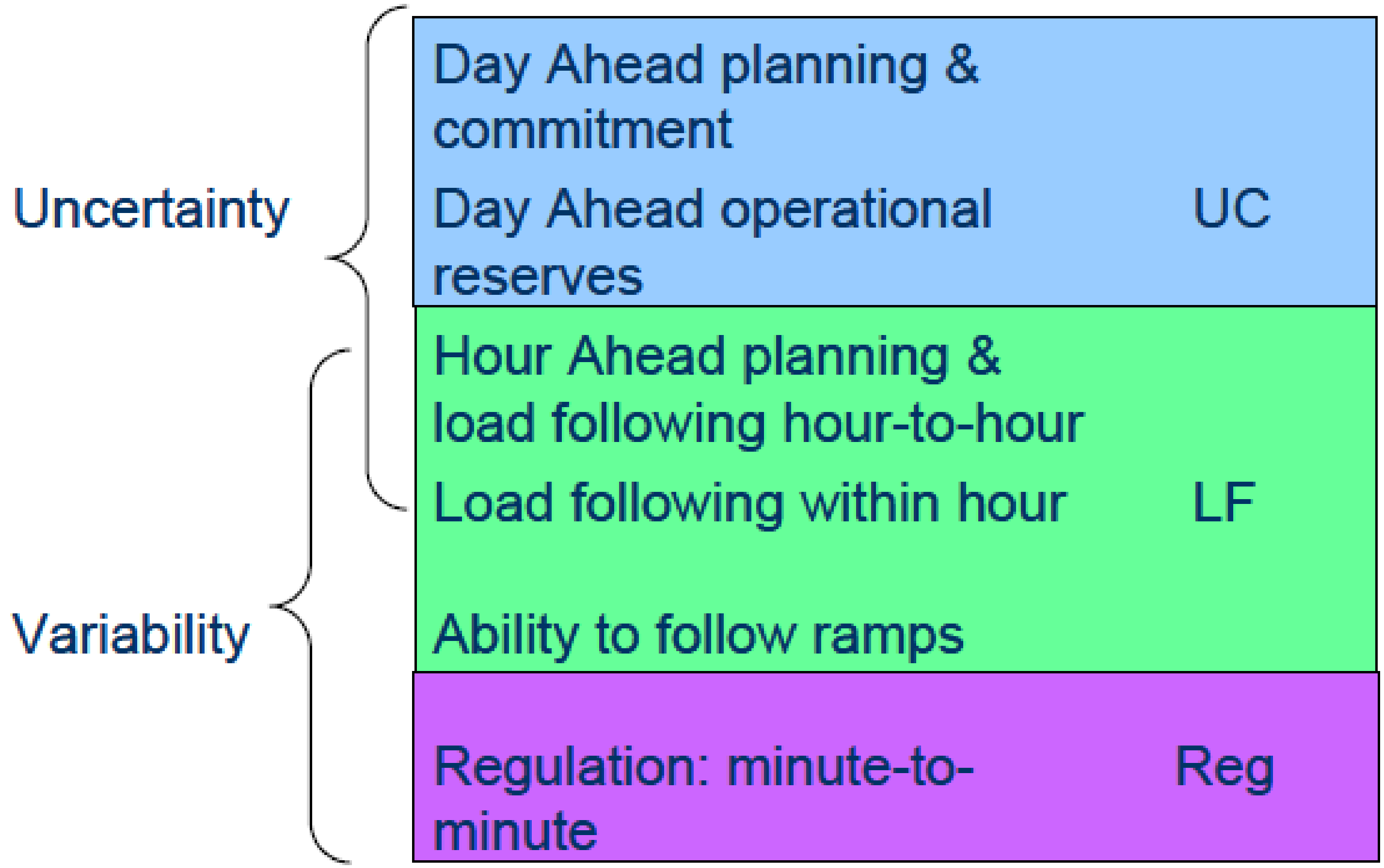


Figure 28 – Relationship between effects of variability and uncertainty, APS planning functions, and the ancillary services of unit commitment (UC), load following (LF) and regulation (Reg).

Source: APS Wind Integration Study

Balancing variable loads with variable resources can become difficult

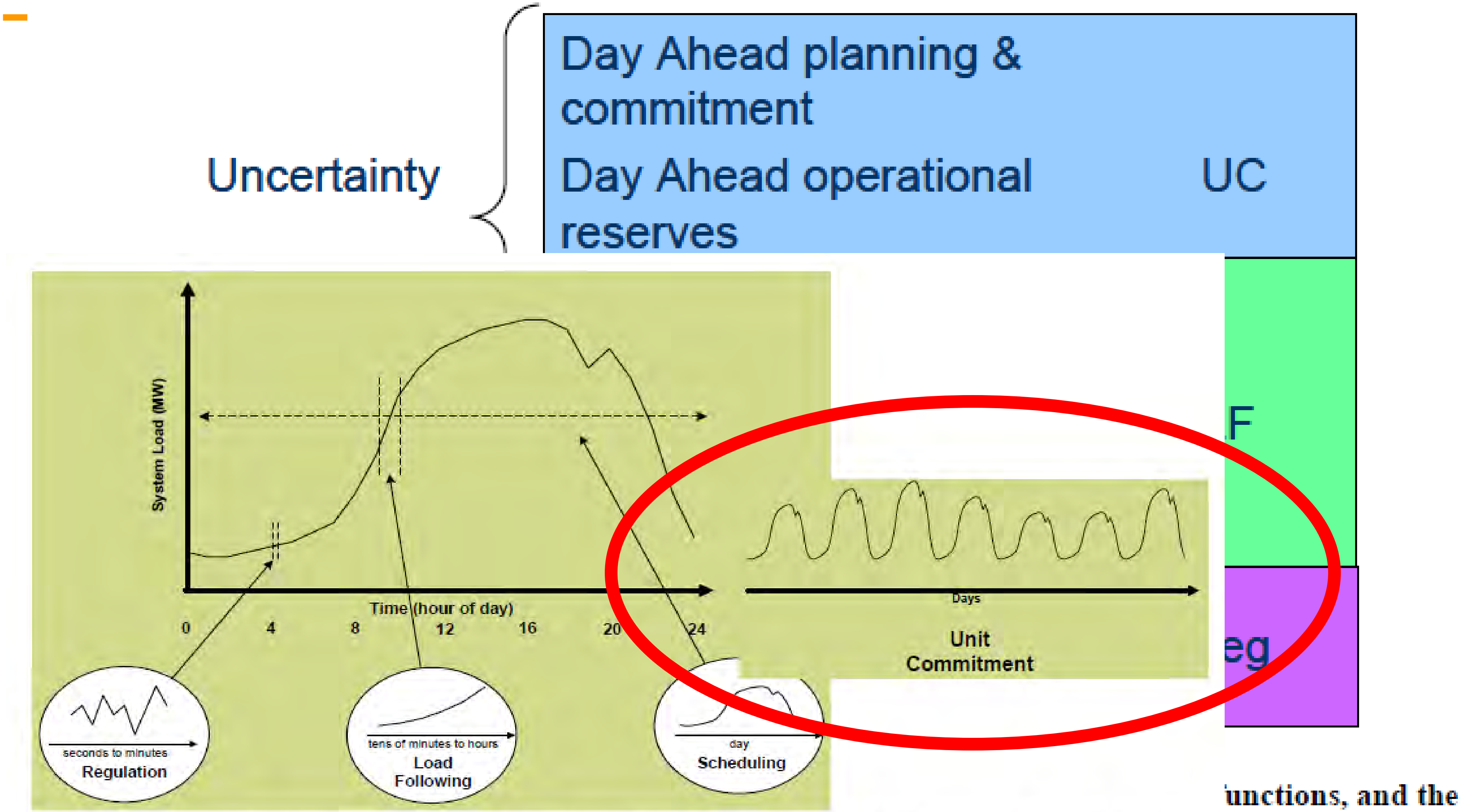


Figure 1 – Time scales of importance when considering power system impacts of integrating wind energy (source: National Renewable Energy Laboratory).

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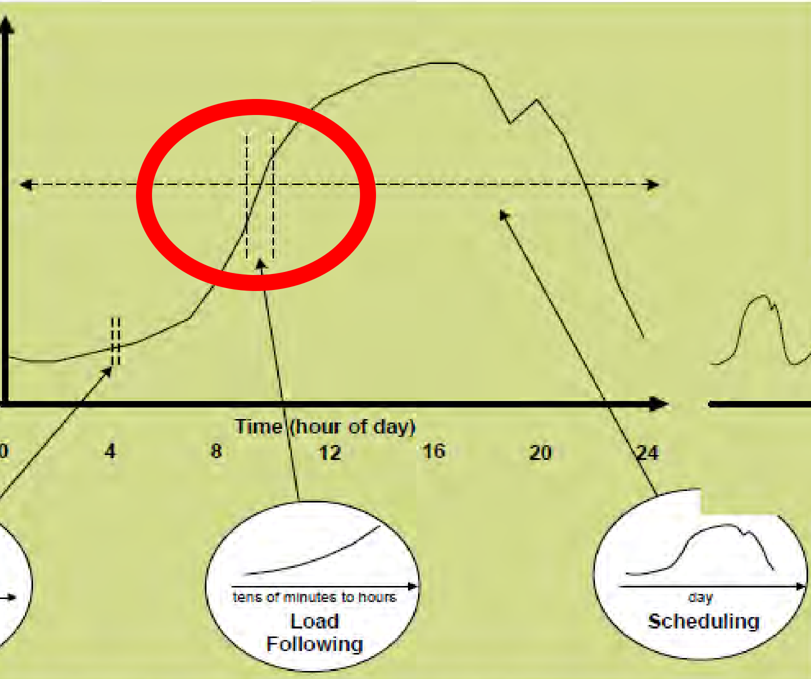

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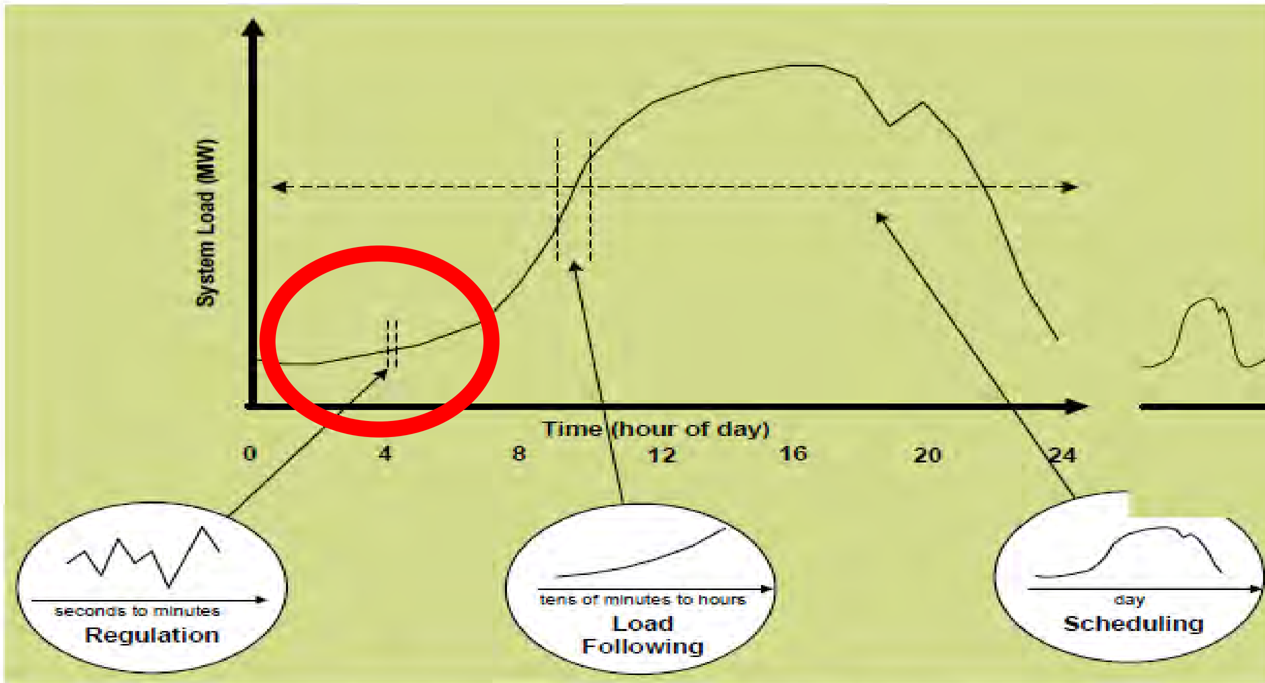
Variability

Day Ahead planning & commitment Day Ahead operational reserves	UC
Hour Ahead planning & load following hour-to-hour Load following within hour Ability to follow ramps	LF
Regulation: minute-to-minute	Reg

Figure 28 – Relationship between effects of variability and uncertainty, APS planning functions, and t... ancillary services of unit commitment (UC), load following (LF) and regulation (Reg).

Source: APS Wind Integration Study

Balancing variable loads with variable resources can be



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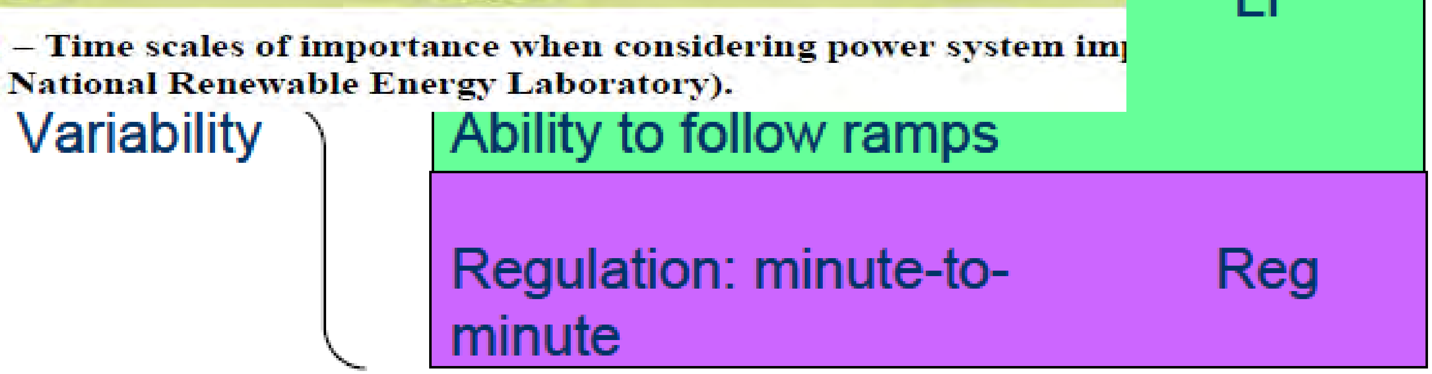
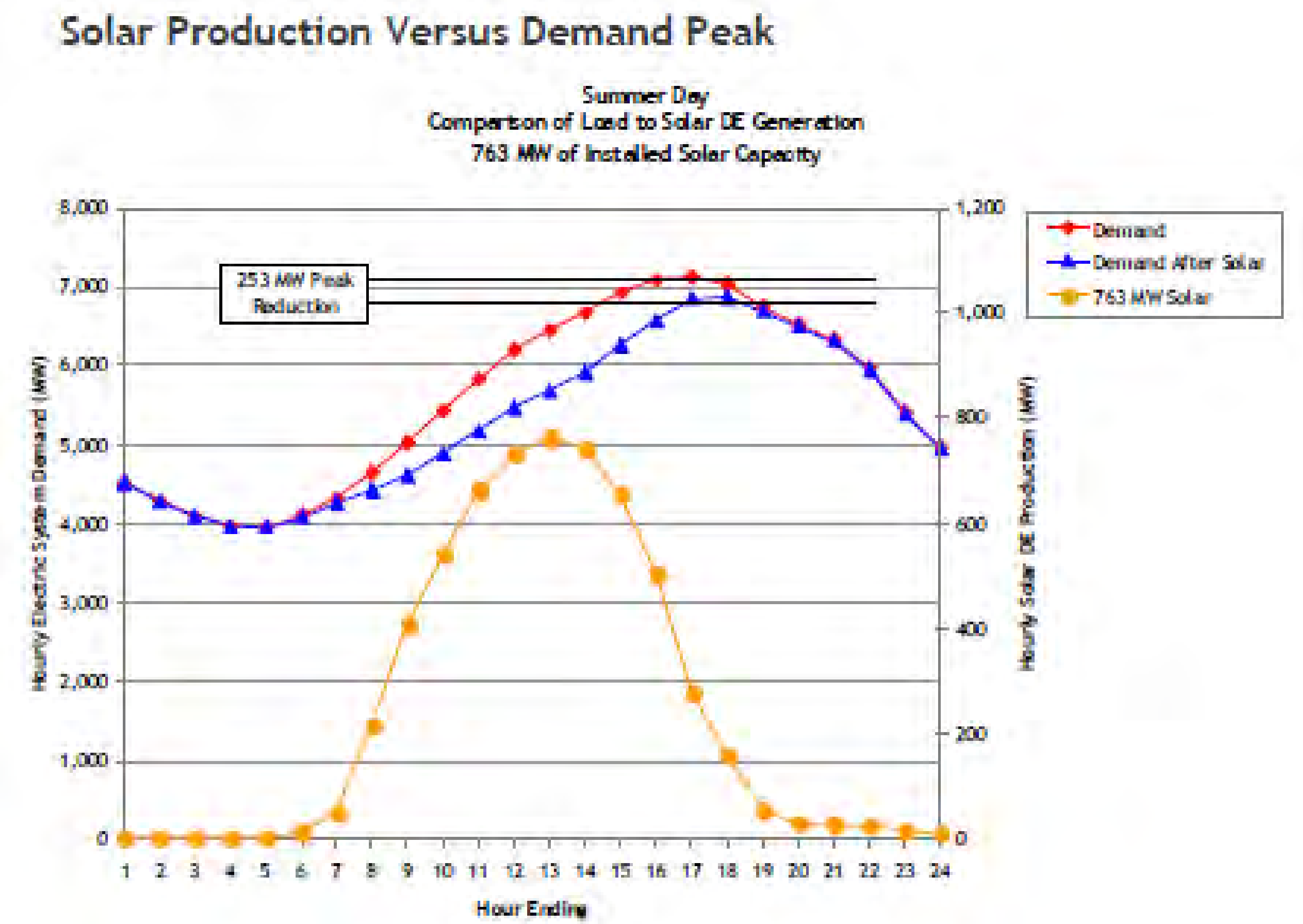


Figure 28 – Relationship between effects of variability and uncertainty, APS planning functions, and the ancillary services of unit commitment (UC), load following (LF) and regulation (Reg).

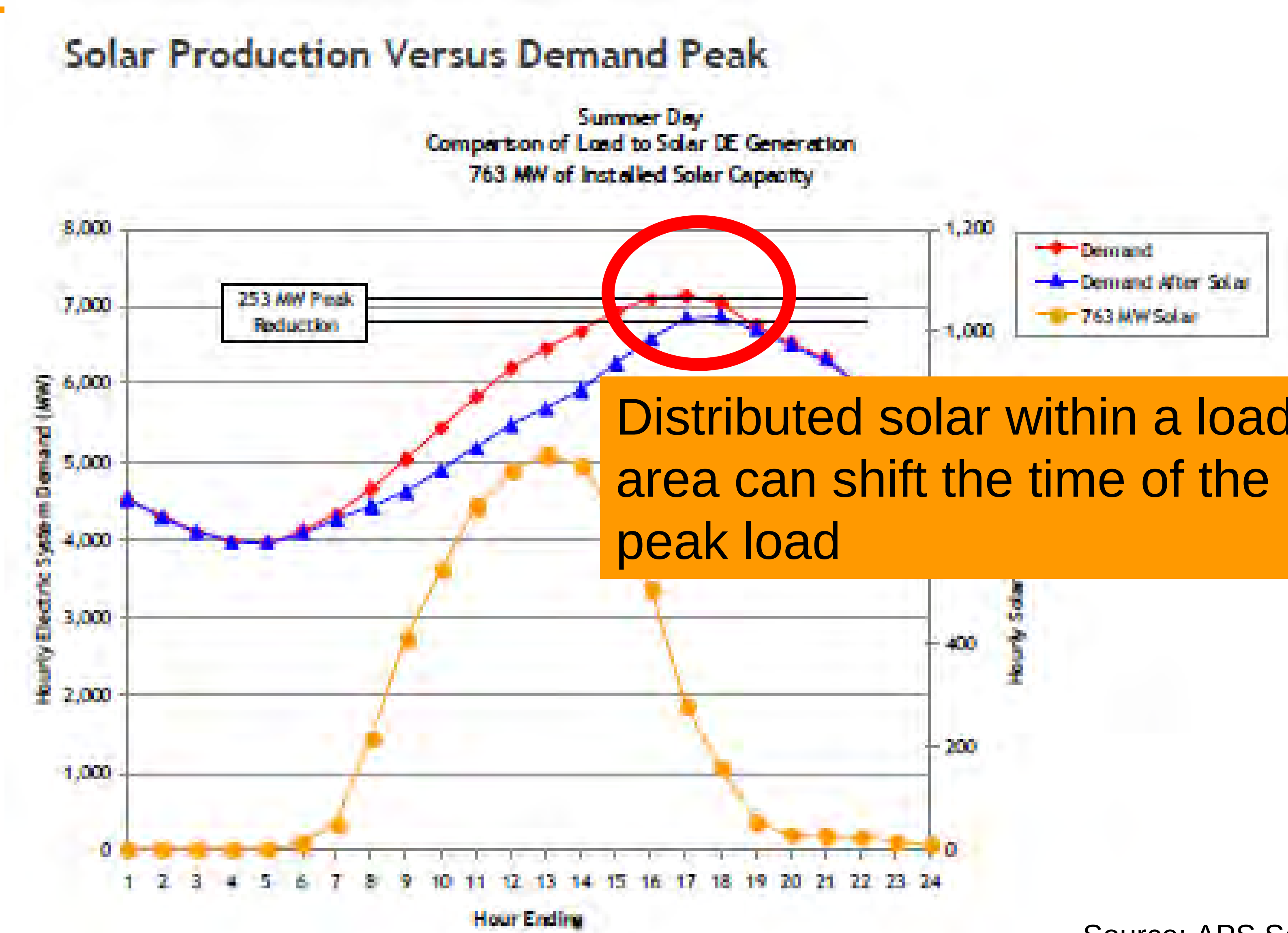
Source: APS Wind Integration Study

Solar Output vs. Load (APS)



Source: APS Solar DE Study

Solar Output vs. Load (APS)



Distributed solar within a load area can shift the time of the peak load

Source: APS Solar DE Study

Renewable Resource Output Variability General Issues

- **Power output dependent on meteorological conditions**
  - **May be intermitting**
  - **May require higher level of reserve power**
- **Large plants can have measurable impact on system operating cost**
  - **Variability of output might increase system operating cost**
  - **At higher penetrations, increased operating generation reserves may be necessary**

Storage

- Increased storage will increase operating reserves
- May not be cost effective
- Current storage
  - Natural Gas
  - Hydro
- Concentrated solar plants can decrease output variability by utilizing molten salt storage
  - Can increase control output and scheduling of solar CSP plant
  - Decreases variability and uncertainty of solar resource

Storage Options

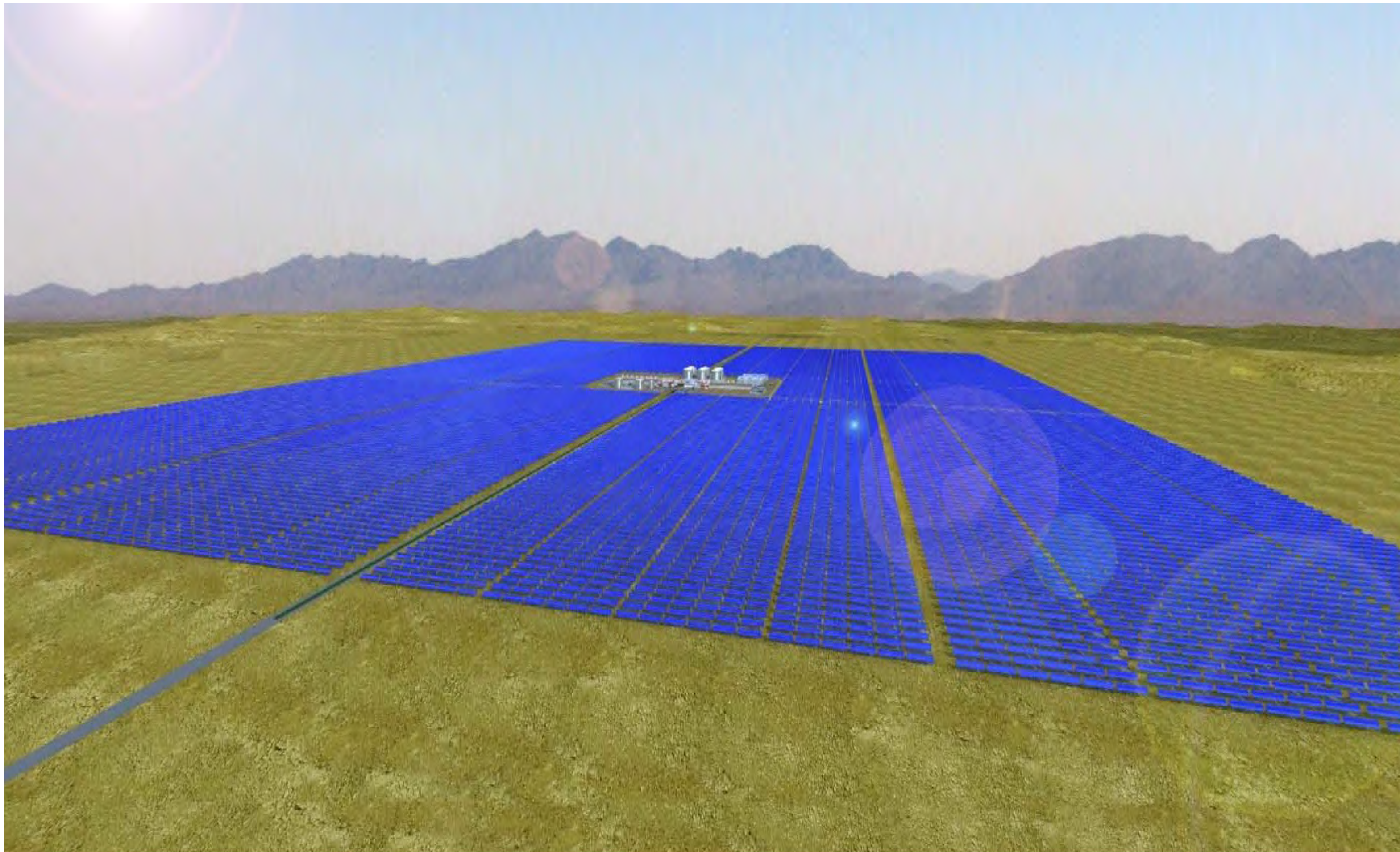
- Thermal
  - Molten Salt
    - Efficient, low cost medium
    - Possible 6 hours of storage
  - Steam accumulator
    - Stores heat as pressurized steam
    - One hour storage
  - Graphite heat storage
- Batteries
- Fuel Cells
- Pumped water

Solana Solar Generating Station

Project Facts

- Solar trough with 6 hours of thermal storage
- 2,700 parabolic trough collectors covering 3 square miles
- 280 megawatts (enough for 70,000 homes)
- Located 70 miles southwest of Phoenix
- Tentative completion date of 2011 and will employ 85 highly skilled technicians when fully operational
- APS selected Abengoa Solar as the project partner
- 30 year PPA with all the energy delivered to APS

Solana Solar Generating Station



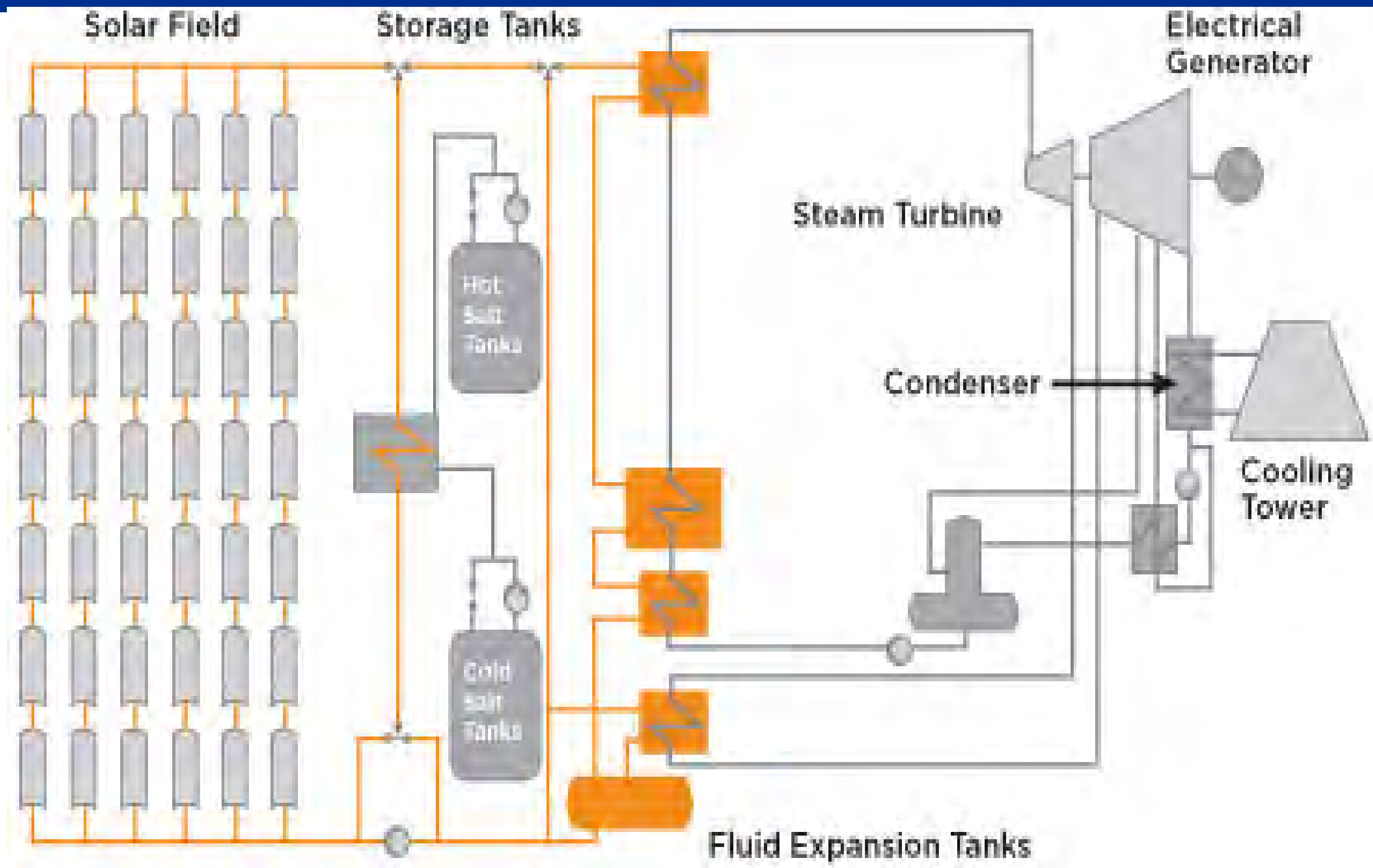
Renewable Energy

Solana Solar Generating Station

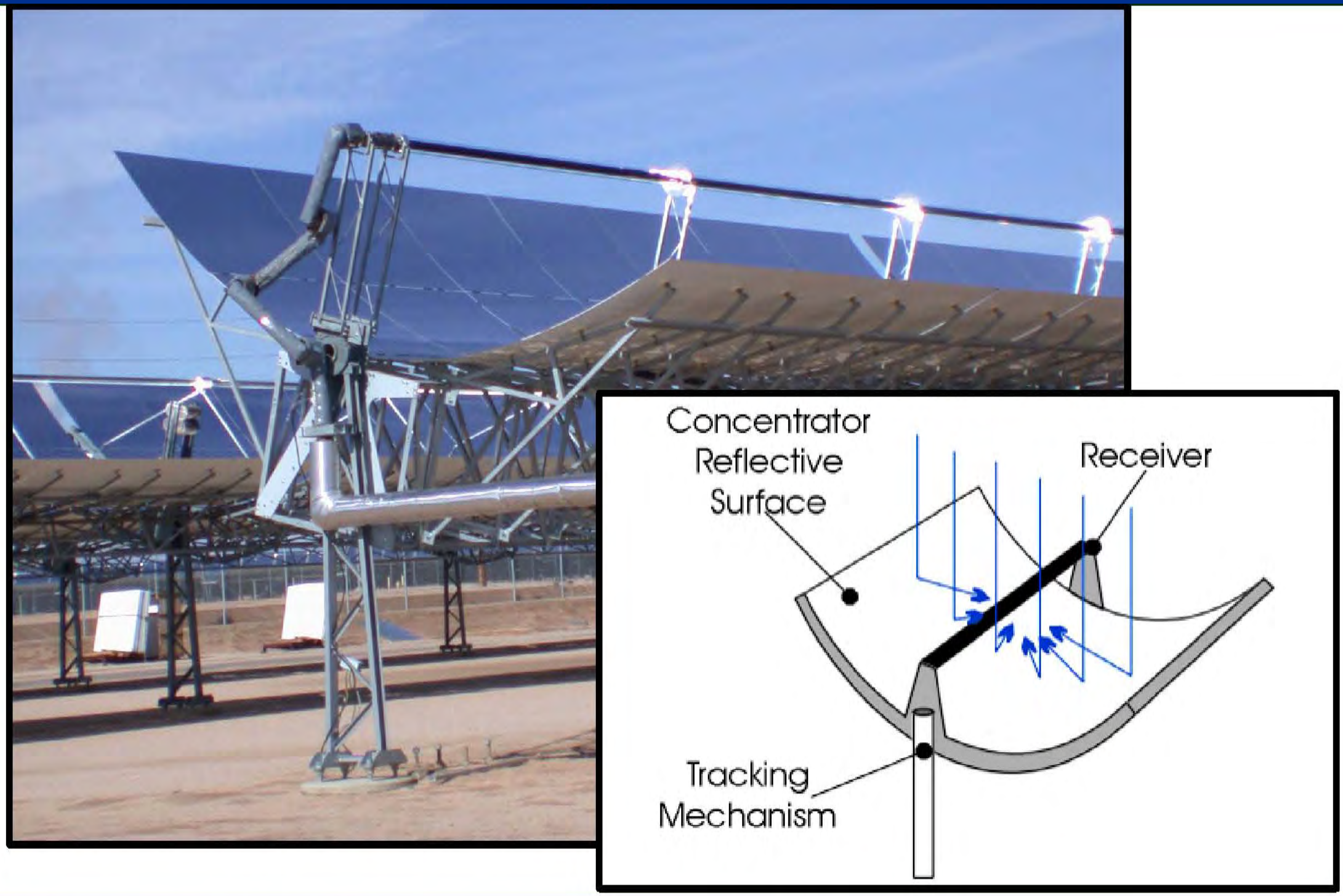
Renewable Energy

Solar Thermal

Focusing Solar Energy Onto a Heat Transfer Fluid



Solana Technology - CSP



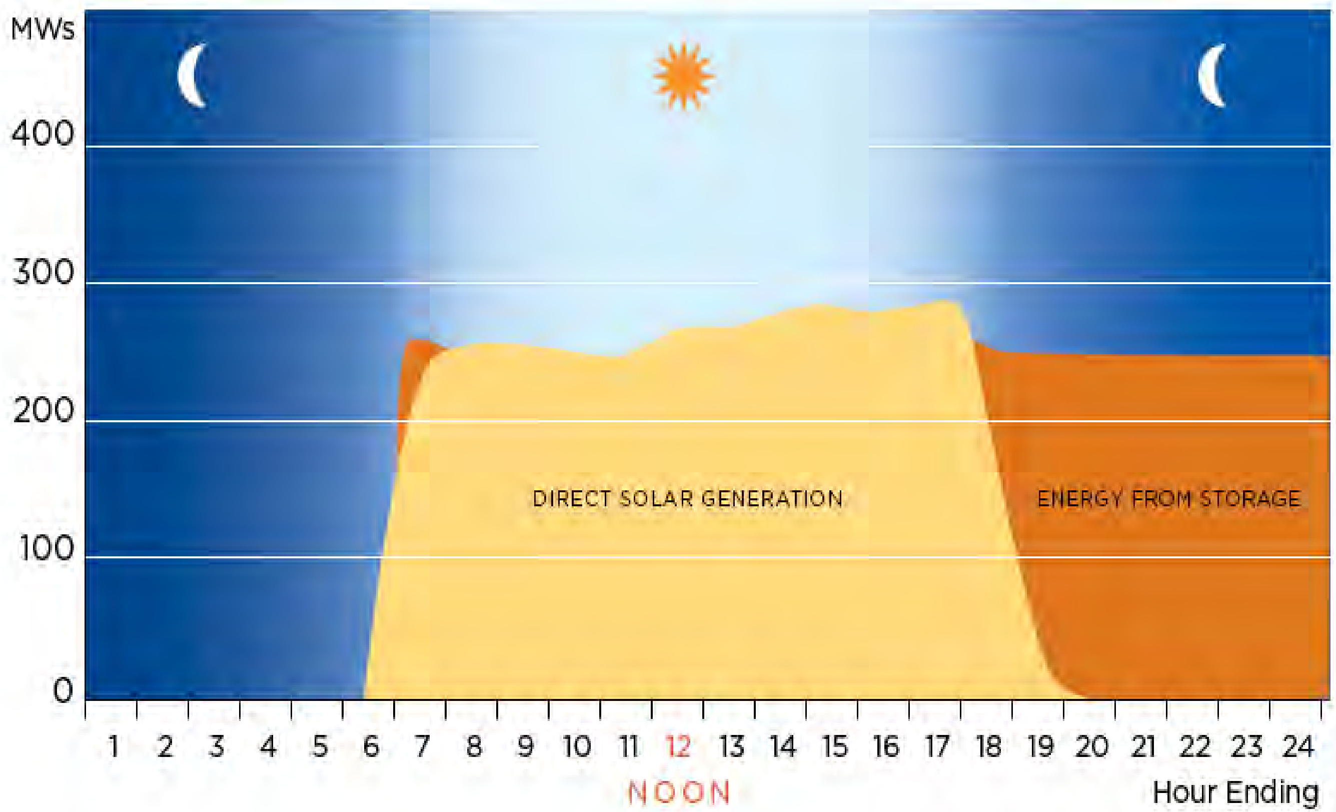
Molten-Salt Storage System

Spain – 7hrs, 50MWe
APS – 6 hrs, 280 MWe

- Over 4 times as large
- 6 tanks

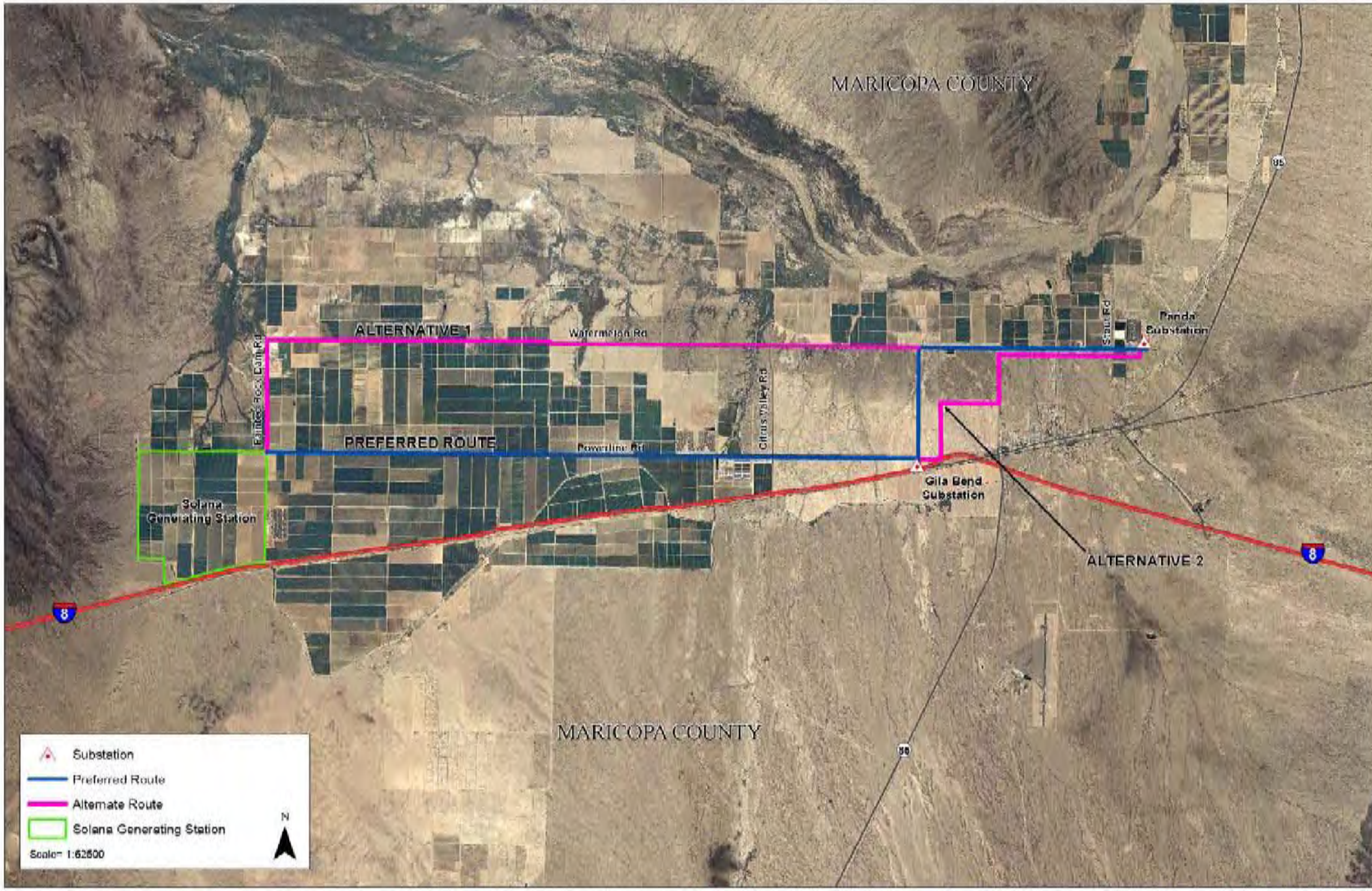
Molten-salt storage used at Solar Two

Solana Summer Operation



Renewable Energy

Solana Project Siting



APS

Renewable Energy

Siting Challenges

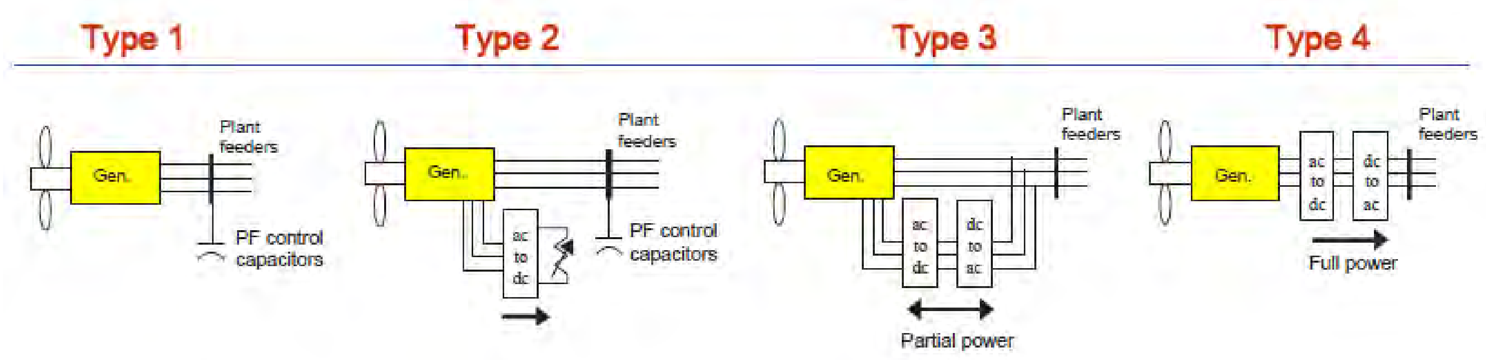
- Southwest is Transmission Constrained
  - Available transmission capacity is limited
  - Transmission costs can affect project economics
- Solar Developments are Large
  - Solana land use is approx. 3000 acres
  - Solar is approx. 9 acre / MW
  - Requires relatively flat terrain, quality sun
  - All siting issues are larger – Biological, Archeological, Environmental, etc.
  - Arizona has a large amount of public lands
- Water is a concern
  - Solana is 3000 acre ft / year (wet cooling)
  - Historic use is approx. 27,000 acre ft / year
  - Hybrid or dry cooling may be considered in future

Siting Opportunities

- Renewables has strong support
  - Environmental community
  - Arizona Corporation Commission
  - State policy makers
  - Public
- Solana is located in low impact area
  - Low population
  - Disturbed lands
  - Power line corridors already exist
  - Located in high potential renewable zones

Wind Control

- Fault and low voltage ride through
  - Avoid cascading outages
  - Increase reliability
- Cannot be controlled like conventional generation
  - Ramp rate limits
  - Operate below potential so that wind output can be increased if needed
  - Curtailment at low load, high wind conditions
- Induction generator (Types 1 and 2) have high reactive power needs
  - Doubly fed asynchrounous generator (Type 3) and full converter interface design (Type 4) help minimize reactive power need



Solar Control

- CSP plants behave like conventional steam generation units
  - With the caveat that the resource is variable.
- PV systems operates near unity power factor
  - May need additional reactive power sources during low voltage event
  - IEEE 1547 requires inverters disconnect for voltage sag
  - Relaying/Islanding issues
    - At the distribution level, during a fault inverters may remain online
      - May continue to supply current = maintain fault current and cause protection relays to lock open
      - Inverters may be damaged by reconnect

APS

Other Issues

- Wind
  - Resources typically located in transmission constrained areas.
  - In Arizona, additional long transmission lines are needed to schedule wind resource to load
    - Not necessarily the case if wind in energy connected and displaced from conventional resources using transmission path
- Solar
  - Water
    - Can be difficult to obtain in desert areas

Questions?

Integrating Large Scale Nuclear Plants into the Grid

John Lucas Manager

Transmission Planning & Engineering

Overview

- **Nuclear Power Plant Overview**
  - **Operation**
  - **Safety**
  - **Issues**
- **Palo Verde Nuclear Plant**
- **Palo Verde / Hassayampa Switchyard System**
- **Technical Analysis:** **based on ANPP / Palo Verde 500kV Switchyard Interconnection Procedures**
  - **Power Flow**
  - **Short Circuit**
  - **Transient Stability**
  - **Sub Synchronous Resonance**

The Power of Nuclear

The energy contained in <u>one</u> fuel pellet . . .

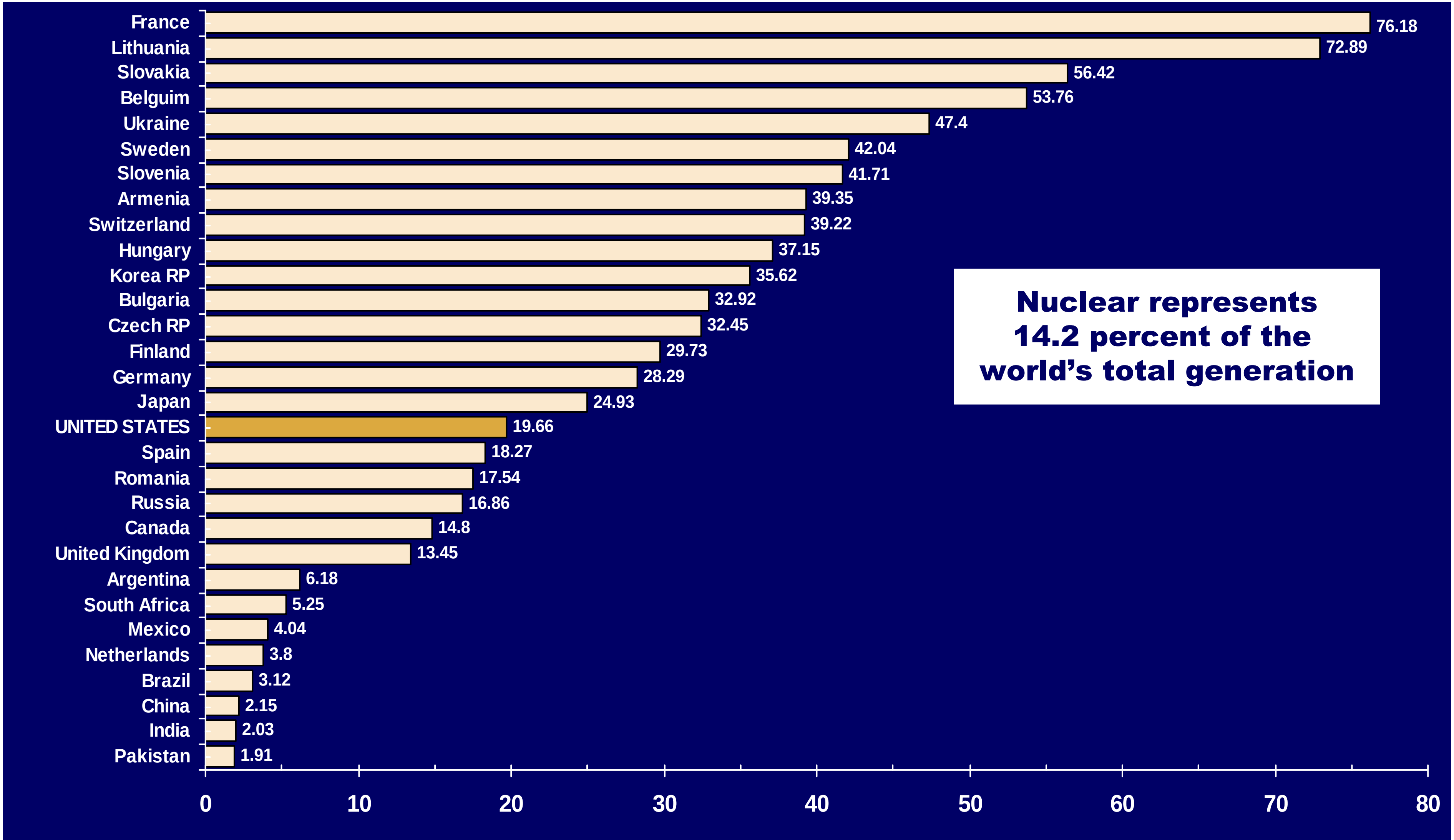
=

Three barrels of oil (165 gallons)

One ton of coal

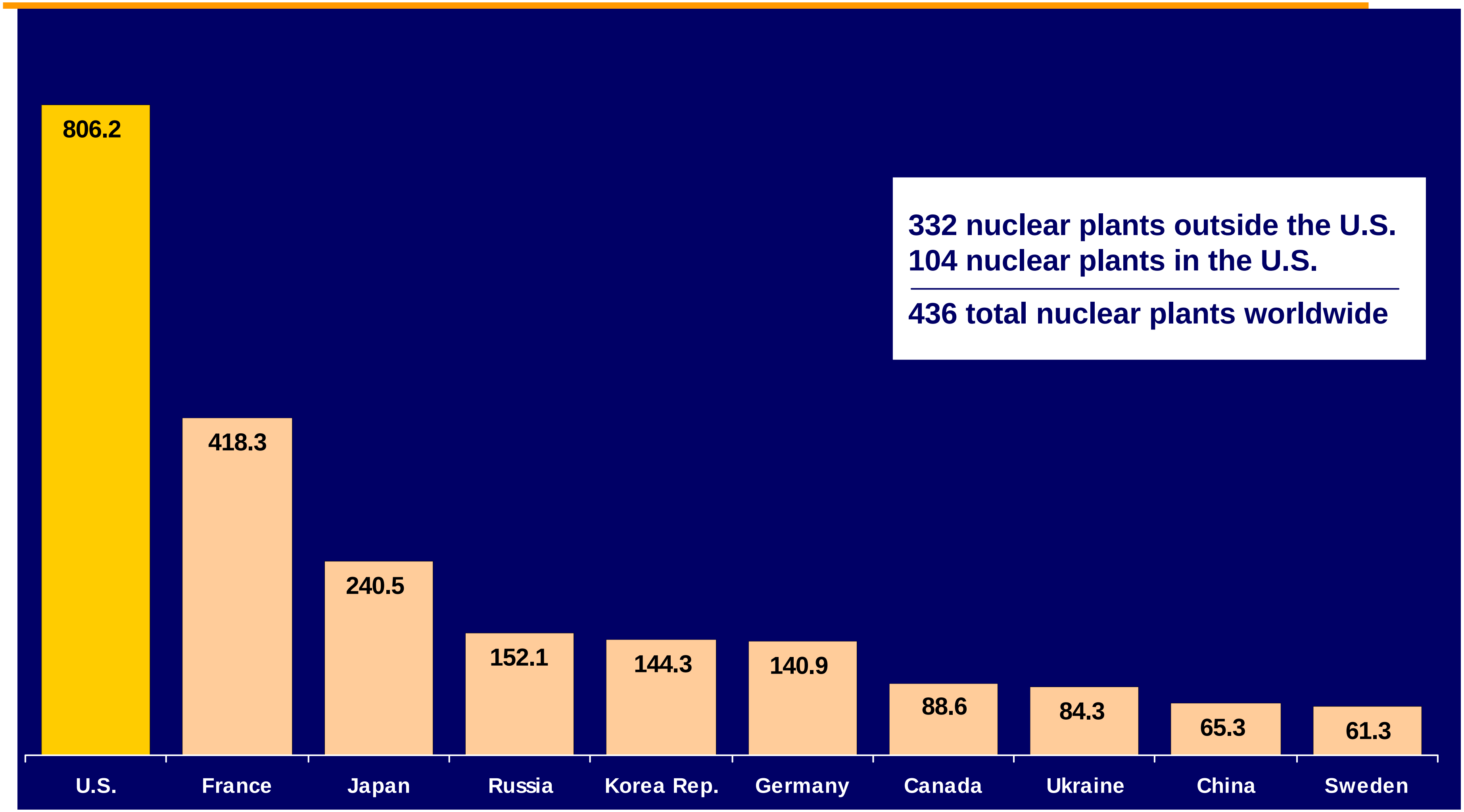
17,000 cubic feet of natural gas

World Nuclear Power Generation *Percentage of Total Generation in 2008*



SOURCES: DOE Energy Information Administration and International Atomic Energy Agency

World Nuclear Power Generation
Top 10 in Billion Kilowatt-hours — 2008



SOURCES: DOE Energy Information Administration and International Atomic Energy Agency

Nuclear Power Plant Overview

- Normally operated in baseload mode
  - Less frequently in load following mode

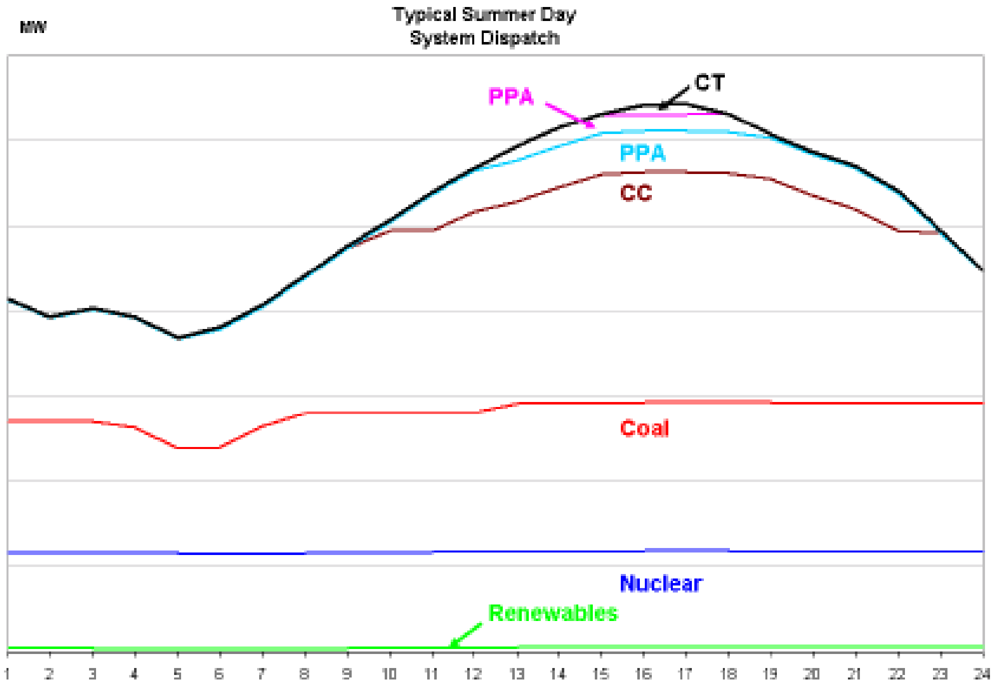


Figure 6 – Dispatch stack of APS system resources to meet load during a typical summer day (CC = Combined Cycle Natural Gas, CT = Combustion Turbine, PPA = Power Purchase Agreement).

Source: APS Wind Integration Study

Nuclear Power Plant Overview

- **Integration of nuclear power plant (NPP) brings nuclear safety requirements that impose additional requirements on the grid design, operation and stability.**
  - **NPP's nuclear chain reaction can be turned off in seconds.**
    - **Heat is still generated, and needs to be removed to prevent overheating of reactor fuel**
    - **Therefore reactor coolers need long term, stable source of electricity.**
  - **Power can come from the grid, or on-site emergency backup, and needs to be reliable**
    - **Need at least two independent circuits sources for grid connection**

Nuclear Power Plant Overview

- Issues due to large scale NPP integration
  - Off-peak demand might be too low to operate in baseload mode
  - Not enough reserve generating capacity
    - Needed to ensure stability during planned outages
  - Unexpected outage of NPP could trigger a severe imbalance between generation and load
    - Causes frequency and voltage dips
    - Possible grid collapse if additional power sources are not connected in time.

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Nuclear Power Plant Overview

- Load rejection
  - How fast can nuclear unit ramp down due to load loss
    - Up to 50% load rejection can be accommodated without unit trip by:
      - Backing down the steam turbine
      - Diverting steam
      - Insertion of control rots

Nuclear Power Plant Overview

- Grid Frequency or Voltage Drop
  - Counter Measures
    - Spinning Reserve
    - Additional generation start up
    - Load drop
    - System islanding
  - Want plant trip as last resort
  - Pump speeds decrease
    - Reactor circulation pumps
    - Steam generator feedwater pumps
    - Long term decay heat removal systems
    - Can cause inadequate core cooling leading to reactor trip

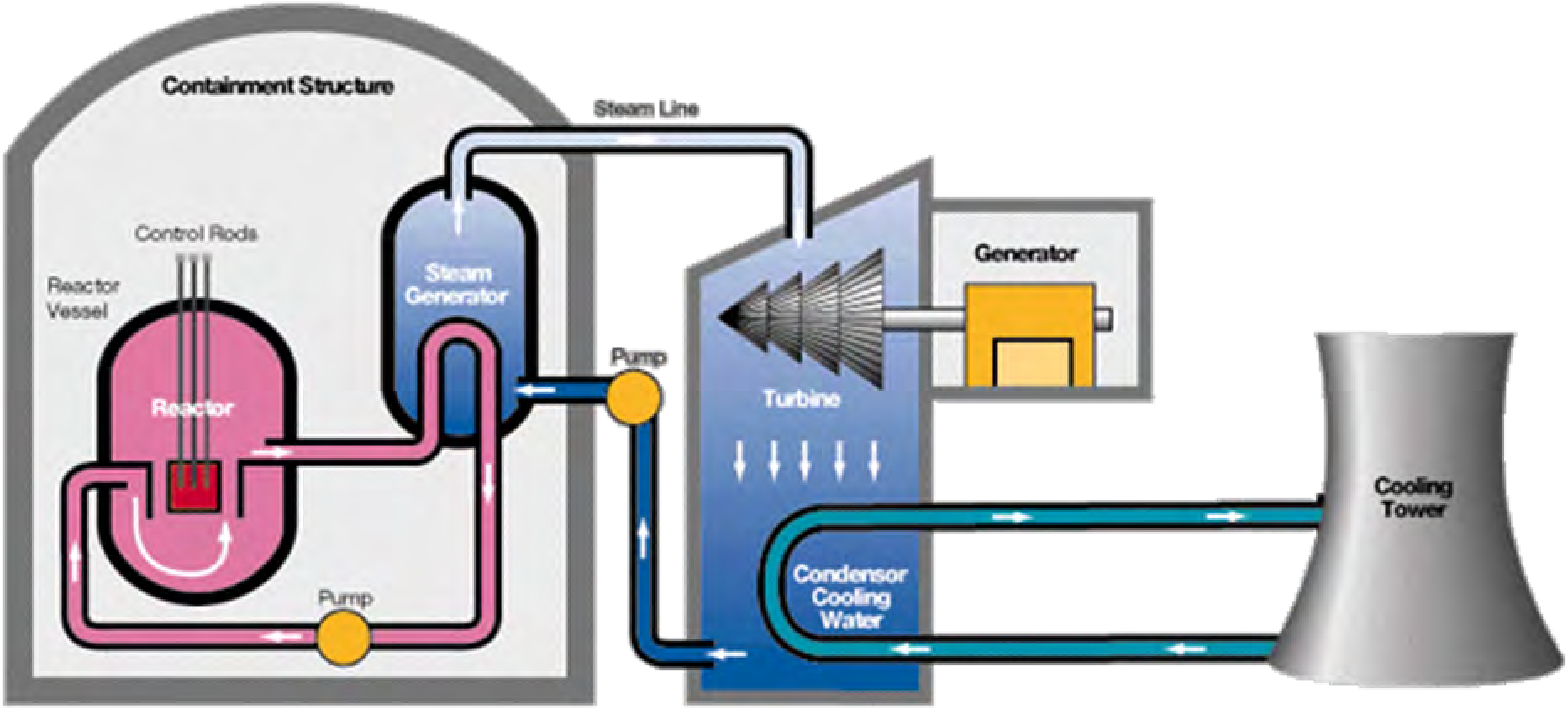
Nuclear Power Plant Overview

- **NPP Plant Trip**
  - **Plant is subject to rapid changes in power, pressure and temperature**
  - **Shortens lifetime of plant**
  - **Lost generation can worsen degraded grid conditions**

Nuclear Generating Station Types

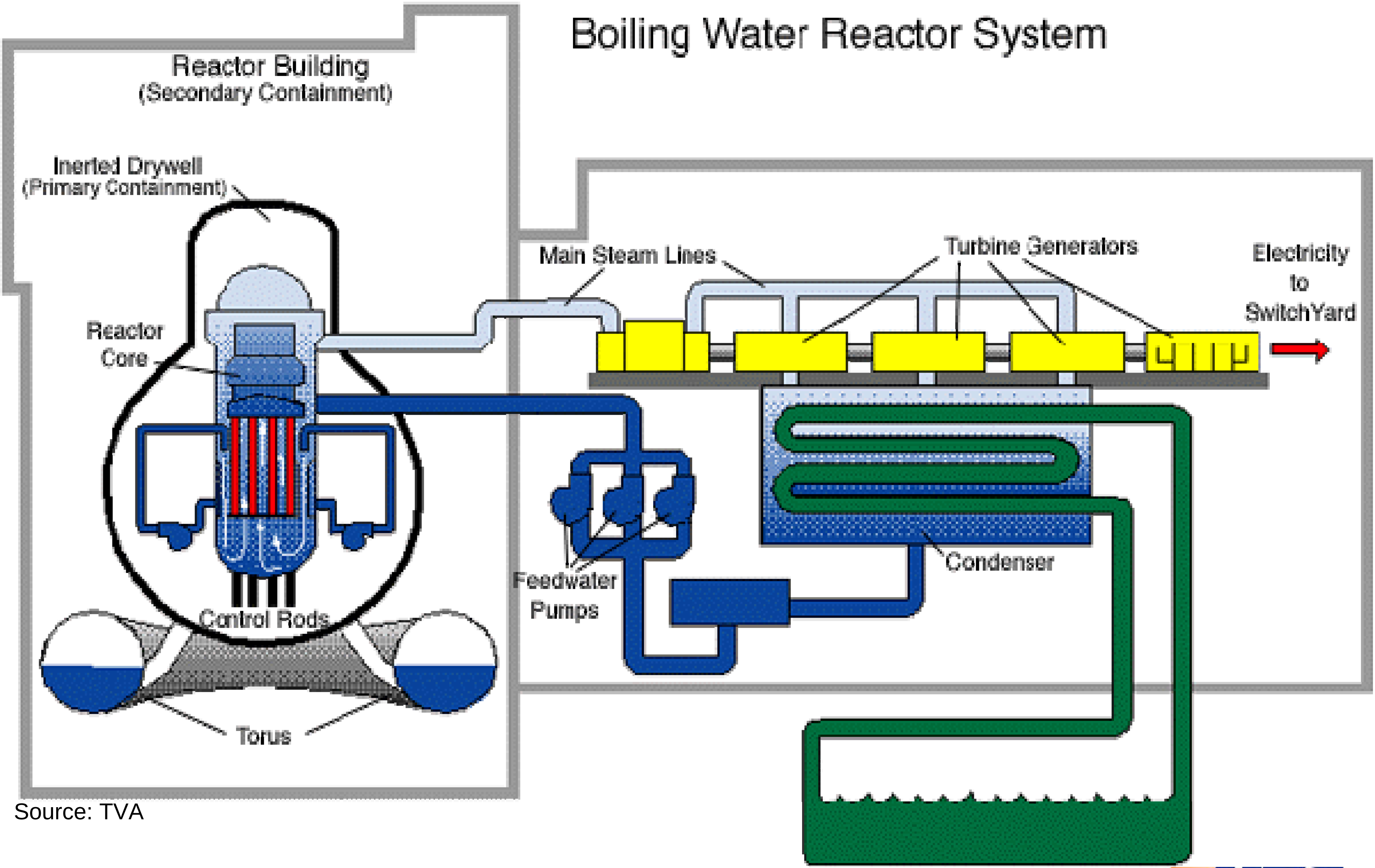
- In the United States, nearly all electrical nuclear power plants are:
  - Pressurized water reactor (PWR)
    - two coolant loops with an intermediate heat exchanger
    - Steam is not produced in reactor core
  - Boiling water reactor (BWR)
    - Single coolant loop
    - Water boils in reactor core

Pressurized Water Reactor



Source: TVA

Boiling Water Reactor

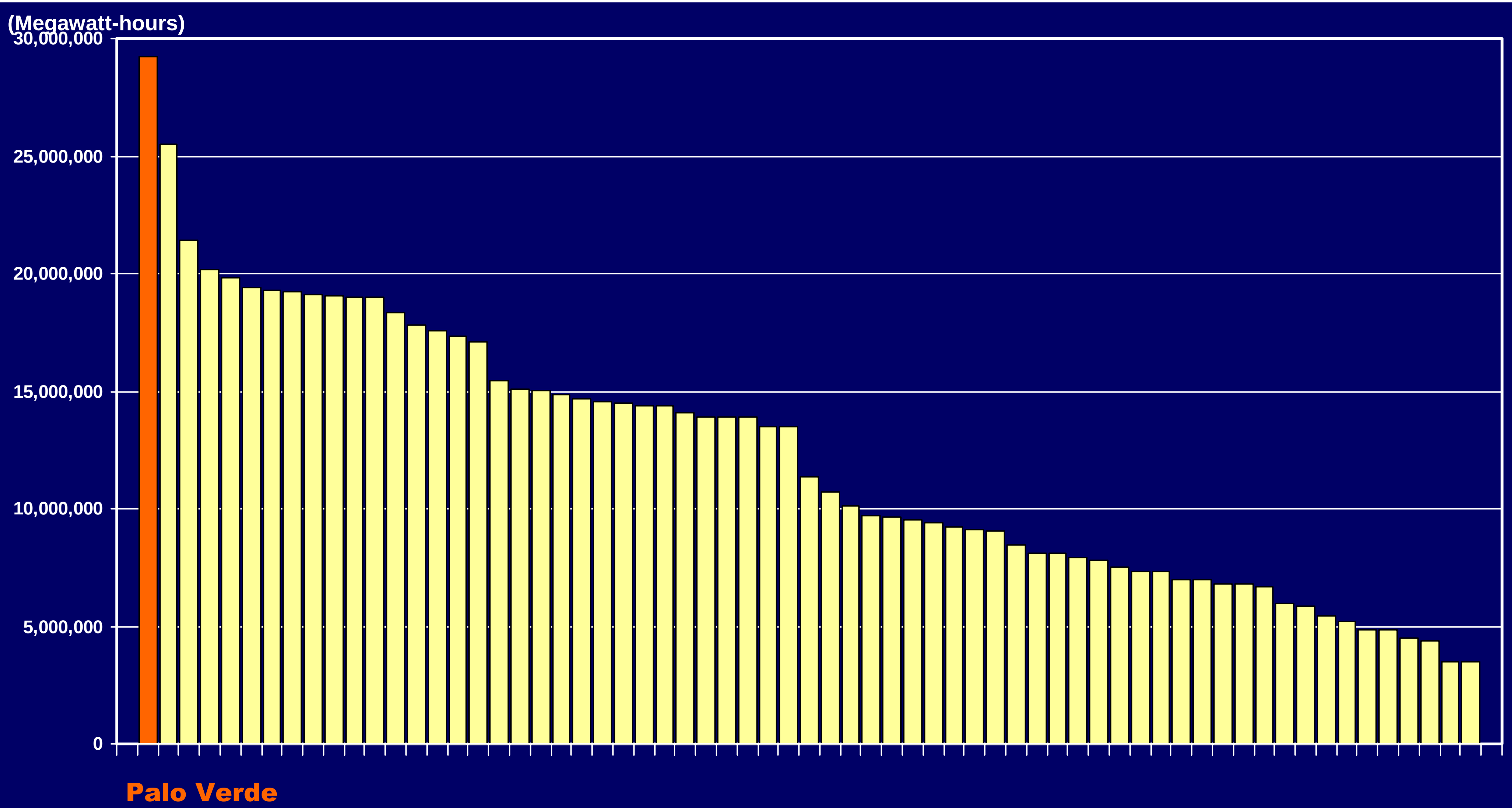


Source: TVA

Palo Verde Nuclear Generating Station

U.S. Nuclear Generation

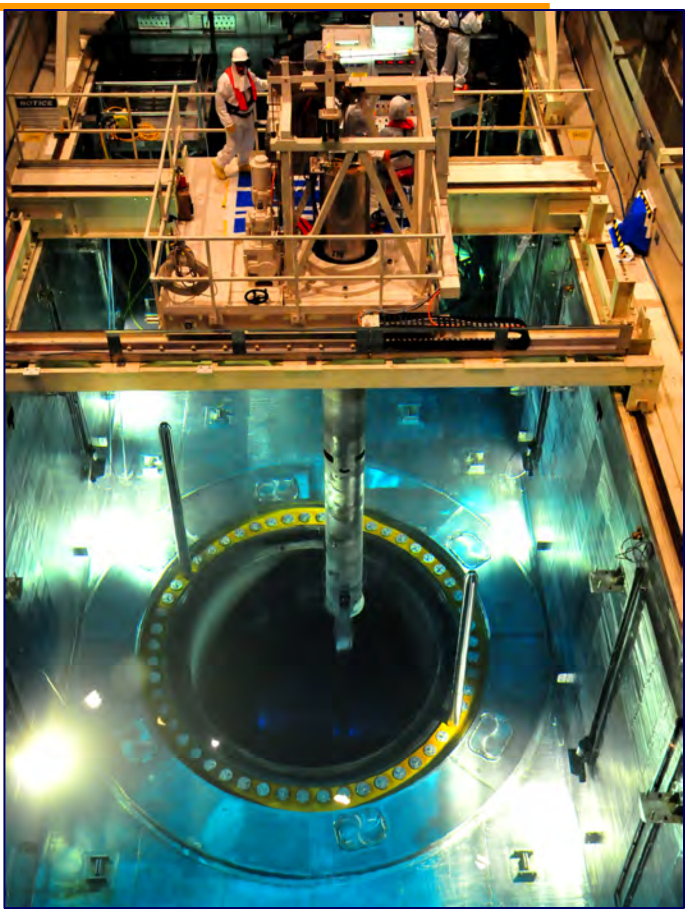
2008 Site-By-Site Total Output



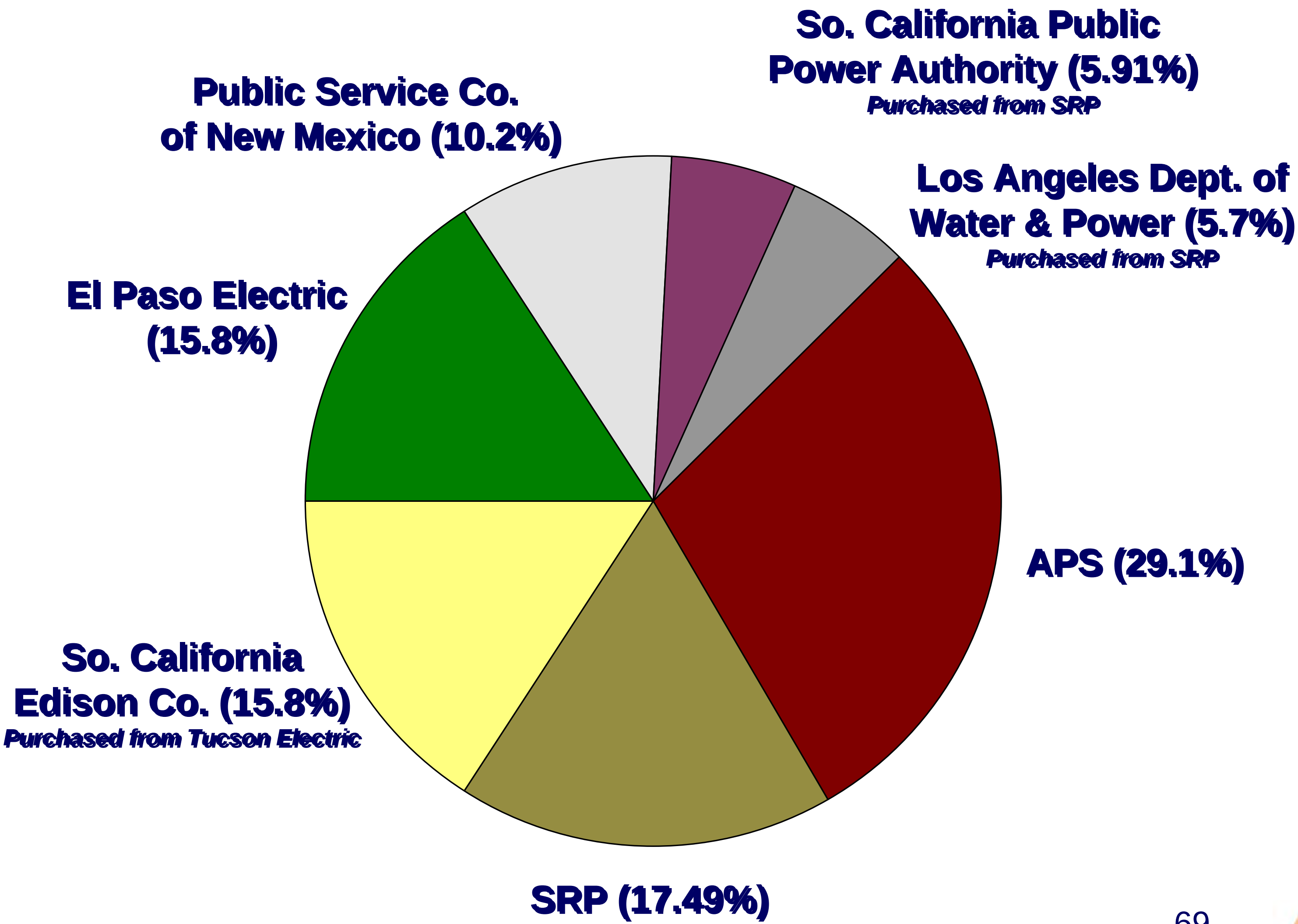
SOURCE: DOE Energy Information Administration

Palo Verde Nuclear Generating Station

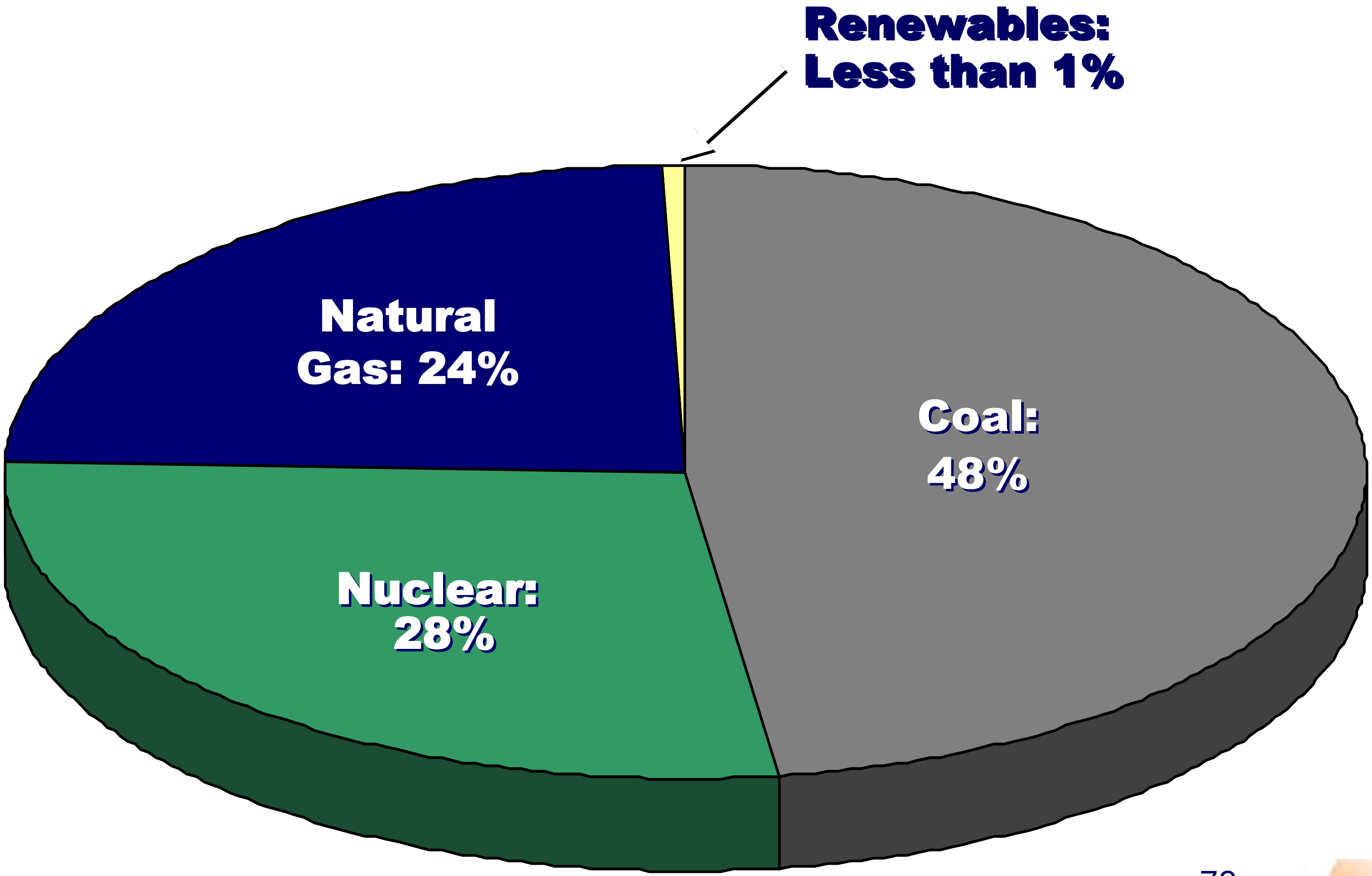
- ~55 miles west of Phoenix, Arizona
- Initial permit in 1976
- Operational by 1988
- Three units capability of nearly 4,030 MW - ~4 million people
- Only nuclear plant in U.S. that does not sit on large body of water.
- Meets cooling water needs by recycling up to 90 million gallons of wastewater daily.
- Operated by APS
- Pressurized water reactor



Palo Verde Participants – Current



APS Power Generation by Fuel Type — 2007



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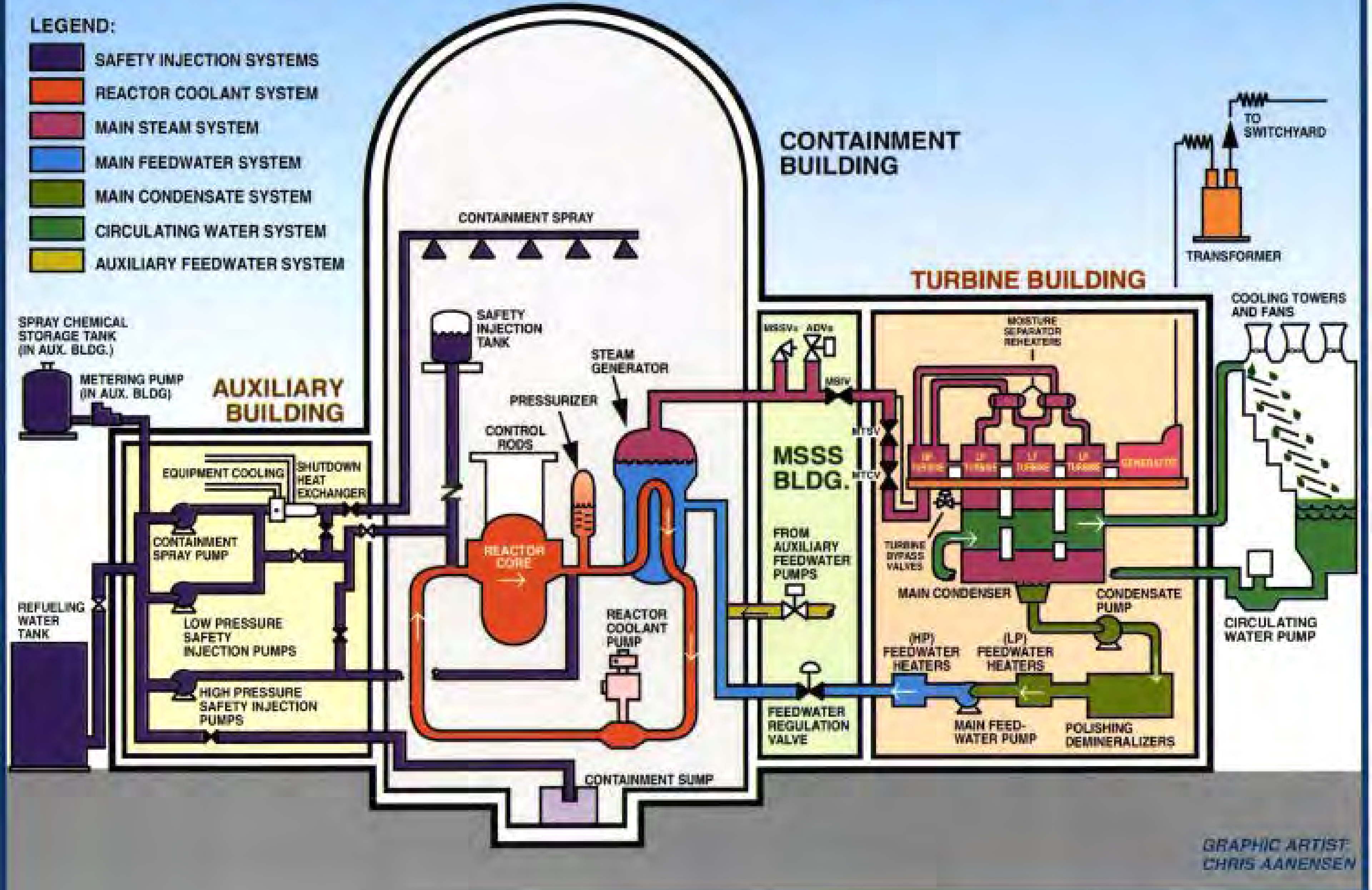
NOTE: Excludes purchased power

Environmental Benefits

- **During the first two decades of operations, Palo Verde has displaced approximately:**
  - **410 million metric tons of carbon dioxide (contributes to global warming)**
  - **345 thousand short tons of sulfur dioxide (contributes to acid rain)**
  - **670,000 short tons of nitrogen oxides (contributes to ozone depletion)**

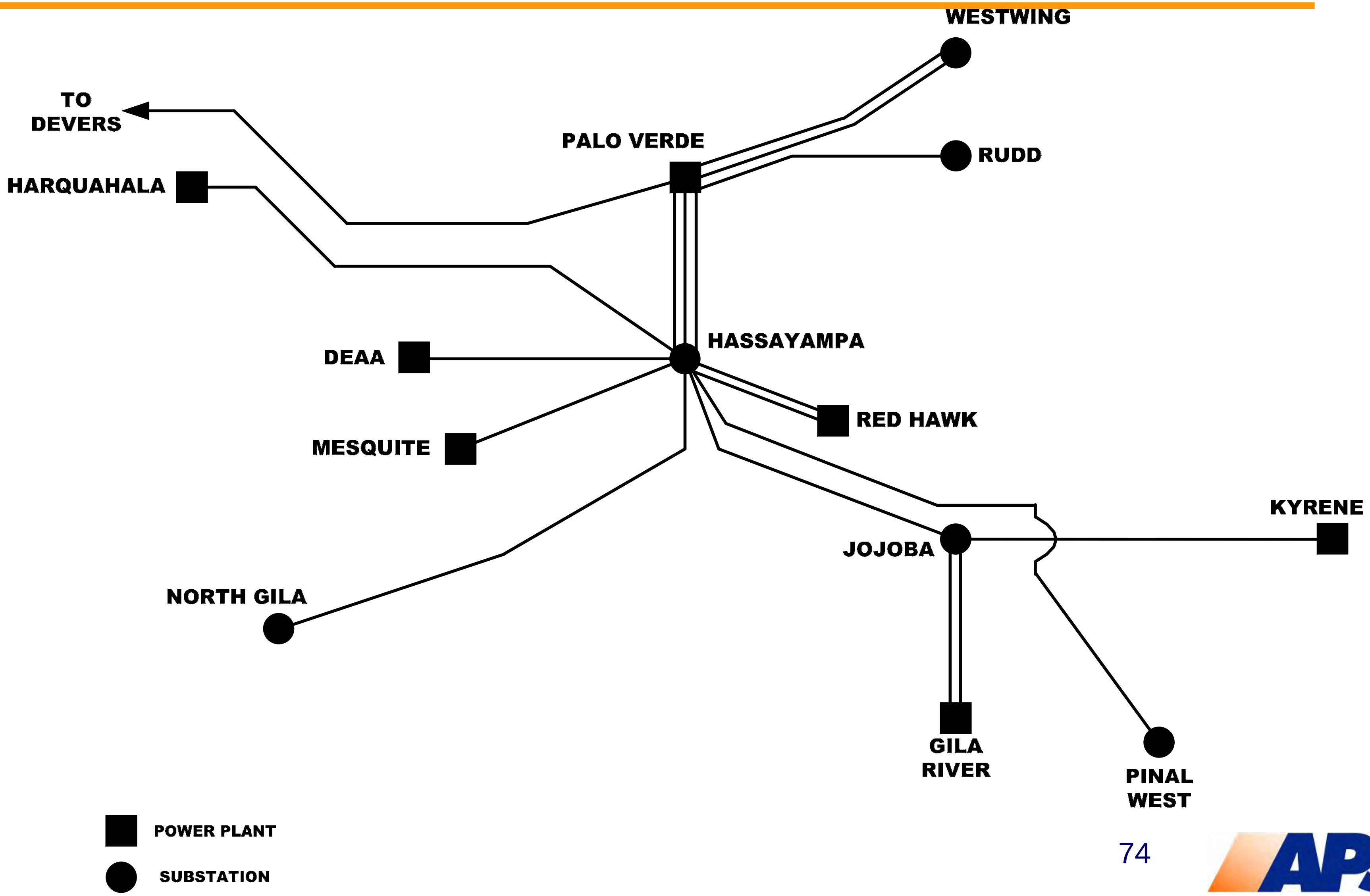
GENERAL SYSTEM DIAGRAM OF PALO VERDE NUCLEAR GENERATING STATION



Palo Verde / Hassayampa Switchyard

- Includes ~10,200 MW of generation capacity.
- 7-500kV circuits
- Market hub
- Solar interconnection point
- Focus of several 500kV ten year plan projects

Palo Verde / Hassayampa Switchyard



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Utility Scale Technical Analysis

Based on Palo Verde / ANPP Interconnection Procedure

Utility Scale Technical Analysis

- **Analysis performed**
  - **Power Flow**
  - **Short Circuit**
  - **Transient Stability**
  - **Sub Synchronous Resonance**

Power Flow Analysis

- **Normal Conditions (N-0)**
  - **All transmission facility loadings must be below normal continuous ratings.**
  - **Bus voltage deviation from the base case shall not exceed established operating limits.**
  - **Sufficient transmission capacity will be provided without relying on or unduly imposing upon any other utility's transmission system.**
  - **The transmission system will not result in an adverse impact on other major path flow limits.**

Power Flow Analysis

- Single Contingency Outage Conditions (N-1)
  - For a single contingency, no transmission element will be loaded above its emergency rating.
  - Established loading limits for other utilities will be observed.
  - Equipment emergency voltage limits (high or low) will not be exceeded for single contingency outages.
  - Bus voltage deviations from the base case voltage shall not exceed established planning limits (These limits may vary throughout the system).
  - Single contingency outages on the EHV systems will not result in loss of load.

Power Flow Analysis

- Maximum Credible, Including N-2, Contingencies
  - The N-2 disturbances are considered to be very severe; such as, loss of two 500 kV circuits within a right of way or two major import circuits.
  - Although local circuit overloads and voltage depressions may result, these shall not result in cascading outages.

Power Flow Analysis

- Operating Voltage and Reactive Power (VAR)
  - Normal Operating voltage with defined reactive power absorption:
    - Example: Voltage at the Palo Verde 500 kV bus will be assumed to be 530 kV for the main study results. In addition, the PV/Hassayampa common bus will be bucking at 800 MVAr.
  - High/Low Voltage Sensitivity:
    - Example: A sensitivity of Palo Verde operated at 525 kV with PV/Hassayampa bucking at 800 MVAr will also be studied

Power Flow Analysis

- **Generation modeled should be at it's maximum level at the interconnection point.**
  - **Example: All Nuclear and Gas generation connected to the Palo Verde system is modeled at its maximum level.**

Power Flow Study

- Pre-Project Base Cases.
  - All base cases will be reviewed by each entity of the study group to ensure that proposed generation projects that may have an impact are represented in the base cases. This is important; since, most entities have different generation queues.
    - Example: Base case selection for the Palo Verde system will be developed to represent heavy autumn conditions. The pre-project EOR flow will be modeled at roughly 7,000 MW for all base cases

Power Flow Study

- **Post-Project Base Cases.**
  - **Example: The post-project cases will be developed by adding the proposed Project and scheduling to Arizona/New Mexico to the extent possible without exceeding established WECC operating limits. To accommodate the project output, local generation will be displaced, or if necessary load increased, within the modeled zones for the noted Arizona utilities.**

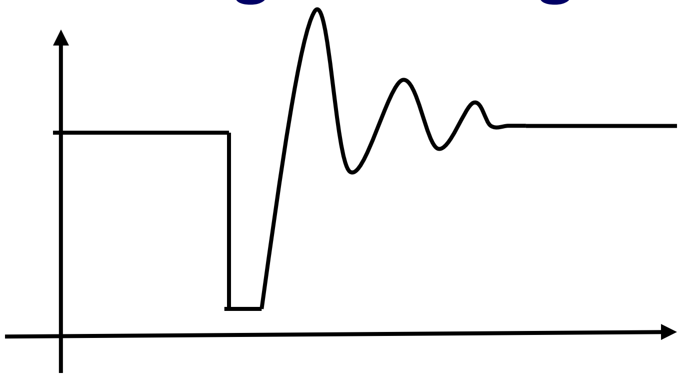
Transient Stability Analysis

- **Transient voltage dips must meet the WECC Reliability Criteria:**

Performance Level	Disturbance	Transient Voltage Dip Criteria
B	N-1	Transient Voltage Dip: Not to exceed 25% at load buses or 30% at non-load buses. Also, not to exceed 20% for more than 20 cycles at load buses. Minimum Transient Frequency: Not below 59.6 Hz for 6 cycles or more at a load bus.
C	N-2	Transient Voltage Dip: Not to exceed 30% at any bus. Also, not to exceed 20% for more than 40 cycles at load buses. Minimum Transient Frequency: Not below 59.0 Hz for 6 cycles or more at a load bus.
D	N-3	Not Specified

Transient Stability Analysis

- All machines in the system shall remain in synchronism as demonstrated by their relative rotor angles.
- System stability is evaluated based on the damping of the relative rotor angles and the damping of the voltage magnitude swings.
- A 7% generation margin will be added to the Nuclear generating units to ensure plant stability for any critical N-1 single contingency outage.



Transient Stability Analysis

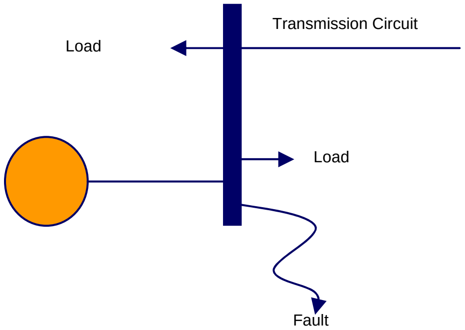
- No N-2 Cascading event:
  - Example: A single-line-to-ground fault at the Palo Verde 500 kV bus with a subsequent loss of the two Palo Verde-Westwing 500 kV circuits shall not result in a loss of synchronism for the Palo Verde plant or a wide spread of WECC cascading outages.
- Use of a common dynamics data file for the approved base cases will be used for all stability analysis.
- The dynamic data for the generator turbine, governor, excitation system and power system stabilizer will be provided by the project owner and will be incorporated into the dynamics data file
- All stability simulations will be run for a minimum of 10 seconds.

Short Circuit Analysis

- Circuit breakers exposed to fault currents in excess of 100 percent of their interrupting capacities will be replaced or upgraded, whichever is appropriate.
- System data will be based on the pre-project system configuration and will be developed from group members. In addition, future generation projects will be modeled to provide a "worst case" scenario.
- All impedances will be expressed in per unit on a 100 MVA base. The base voltage for each impedance element will be the nominal voltage for that part of the system in which the impedance occurs. Some base voltages are 69kV, 115kV, 138kV, 230kV, 287kV, 345kV, and 525 kV.

Short Circuit Analysis

- System elements represented in the model will be lines, transformers, generators and loads.
- Each element will be represented as complex impedance in the three-symmetrical component network (positive, negative, and zero sequences).
- Substation one-line diagrams and the latest breaker nameplate data will be proposed by study participants.



Short Circuit Analysis

- The short circuit program will be used to compute three-phase, single phase-to-ground, and line-out faults.
- The maximum fault current for each breaker will be determined by placing a fault on the bus and recording the fault current prior to the last breaker opening.

Short Circuit Analysis

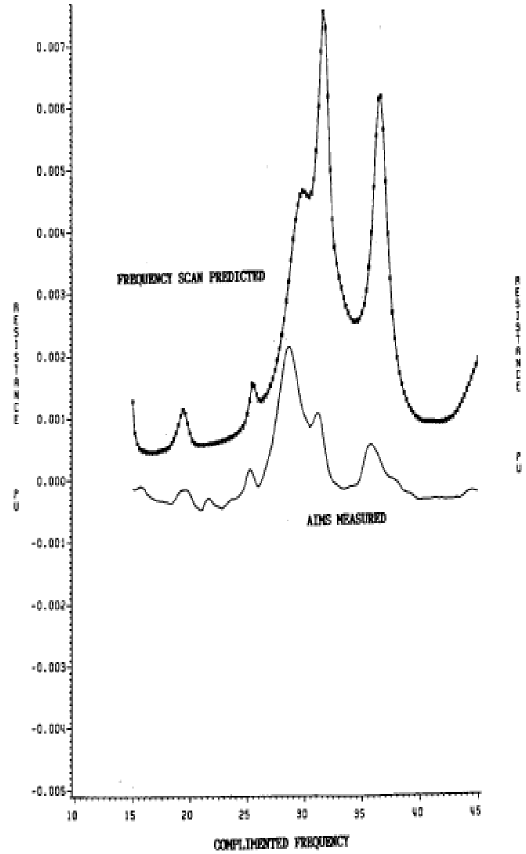
- Transmission system common bus pre-voltage is defined.
  - Example: Palo Verde Common bus at 1.05 p.u.
- Shunt capacitor banks will be omitted at all stations.
  - Normally, shunt capacitors produce a minimal effect on fault currents.
  - When they are large enough to be significant, their effect is to reduce total fault current.
  - Results are more conservative to neglect them altogether.

Short Circuit Analysis

- Shunt reactors will also be neglected since their contribution is minimal.
- Reactors connected to auto-transformer delta tertiary windings will be neglected since they cannot contribute fault current to the system.
- Phase shifting transformers will be by-passed as this would be the worst case from the fault current standpoint.
- If zero sequence data is not available for transmission lines, the assumption will be made that Xo=3X1 and Ro=0 or R1.
- Line susceptances will be modeled for all 230 kV and higher voltage

Subsynchronous Resonance Analysis

- **SSR: electrical resonant frequency on an AC transmission line as a result of series capacitor insertion**
- **Series compensated electric system resonates with the mechanical spring-mass system of a turbine generator.**
- **SSR problem identified due to major shaft damage due to SSR at Mohave generators in Nevada in the 1970s.**

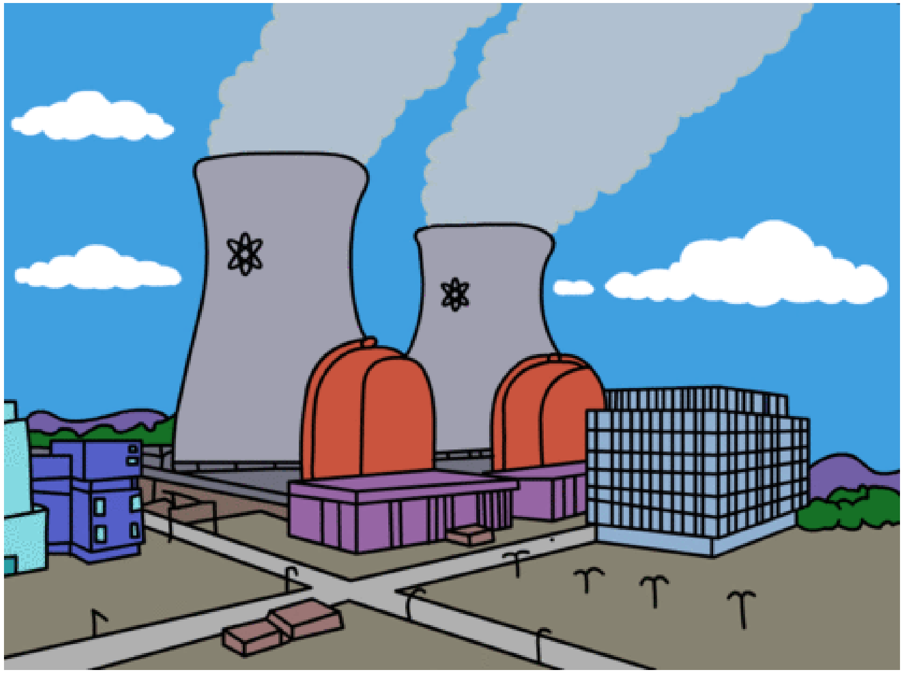


Subsynchronous Resonance Analysis

- **For interconnection at nuclear switchyard: A frequency scanning study will be completed for the full build condition in order to determine if any SSR impacts to the units result. This study will determine the extent of SSR exposure. If the frequency scanning study identifies issues, further SSR studies will be completed.**

Other Studies Involving
Palo Verde Nuclear Power Plant

- Palo Verde Risk Assessment
- Pal Verde Maximum Generation Study
- Palo Verde East Path Study
- Palo Verde Operating Study



Questions?

Planning Under Uncertian Conditions

John Lucas Manager,

Transmission Planning &Engineering

Transmission Planning Under Uncertainty – Rating Studies

- **Rating transmission facilities**
  - **In WECC, rating studies for transmission paths is separated into two activities: non-simultaneous and simultaneous rating studies.**
  - **Since the likelihood of flows on two or more paths reaching their limit simultaneously is equal to or less likely than flows on a single path reaching its limit, the study regimen is less severe for a simultaneous rating study than for a non-simultaneous rating study.**

Transmission Planning Under Uncertainty – Reliability Level

- Reliability level for disturbances
  - For different disturbances WECC now uses # outages/year to determine the level of reliability for lines or paths.

NERC/WECC category		Outages/year
A	All lines in-service	Not applicable
B	One element lost	≥0.33
C	Two elements lost	0.033-0.33
D	Multiple elements lost	<0.033

Transmission Planning During Privatization of Distribution and Generation Sectors

John Lucas , Manager

Transmission Planning & Engineering

Transmission Planning with private distribution & generation entities

- **Reliability Perspective**
  - **Independent distribution, generation (IPPs) and load serving entities (LSEs) are encouraged to join Electric Reliability Organizations as members to improved reliability coordination.**
  - **Parties choosing to forego becoming members can also participate in voting on reliability standards development activities by becoming Participating Stakeholders (WECC).**
  - **Past efforts to enforce ERO standards on IPPs have met with stiff resistance (e.g. PSS standards)**

Transmission Planning with private distribution & generation entities

- Regulatory framework in the past
  - Three categories of expansion planning currently exist in the United States.
    - Central planning
    - Regulated planning
    - Market based planning
  - Up until the present, traditional expansion planning in WECC has been regulated either at the state level or to a lesser extent the federal level.
  - Independent entities have had little input to expansion plants other than requesting interconnection service.

Transmission Planning with private distribution & generation entities

- **Regulatory framework today**
  - **In the 1980s, the Federal Energy Regulatory Commission (FERC) established broad non-discriminatory rules for requesting interconnection or transmission service between private entities and local utilities.**
  - **In the 1990s, FERC standardized their initial rules to account how transmission upgrades were paid for by the requesting parties.**
  - **Recently, states have established renewable portfolio standards (RPSs) that require utilities to acquire a percentage of their future resources from renewables.**

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Technical Ownership Boundaries

John Lucas , Manager

Transmission Planning & Engineering

Utility Boundaries in Arizona

- **FERC jurisdictional, non-jurisdictional, and municipal utilities co-exist within the State of Arizona.**
- **In addition, private generation companies also operate within the state including:**
  - **Harquahala LLC**
  - **DECA LLC (Arlington Valley)**
  - **GRMA (Gila River)**

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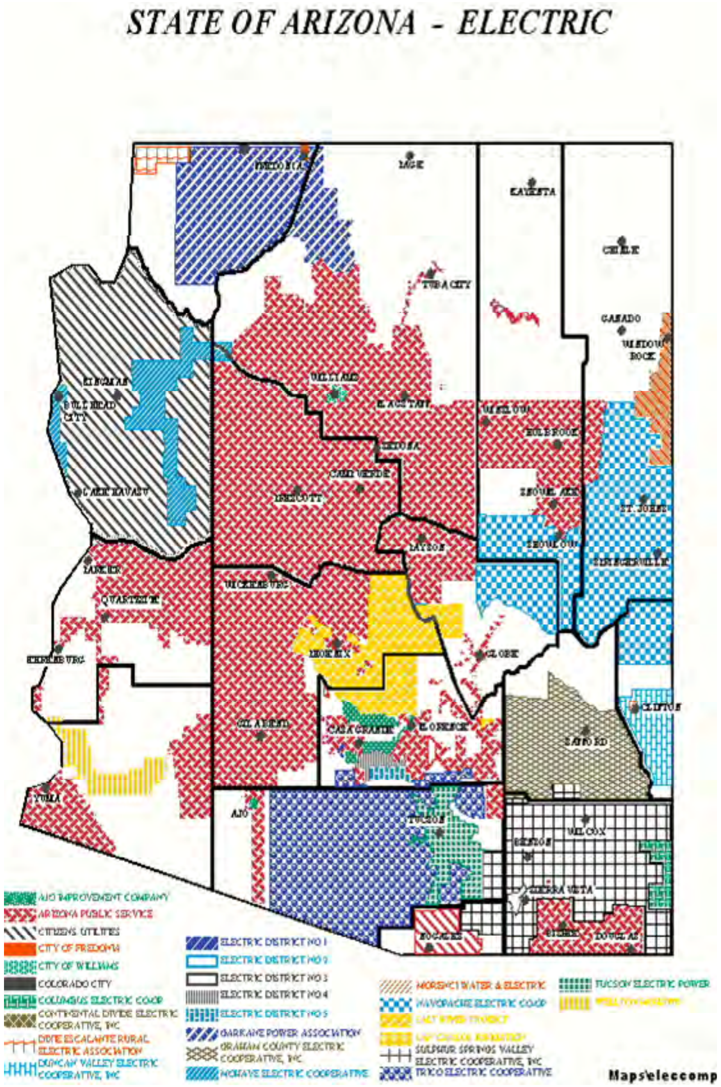
Utility Boundaries in Arizona



Short Circuit Reduction Methods

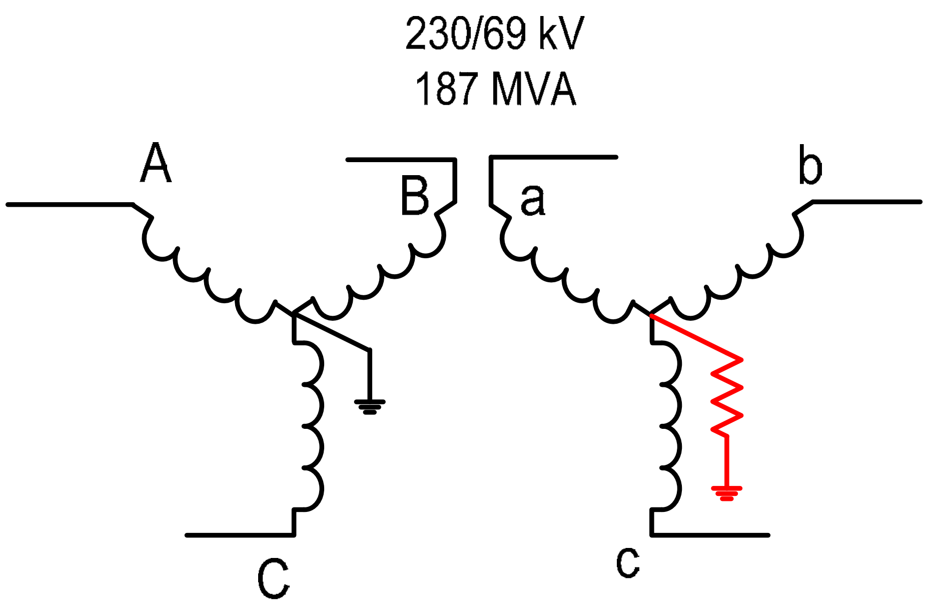
John Lucas Manager,
Transmission Planning & Engineering

Short Circuit Reduction Methods

- **Four of the most common techniques used in WECC.**
  - **Transformer neutral reactors/resistors**
  - **Current limiting reactors**
  - **Bus sectionalizing**
  - **Network sectionalizing**

APS

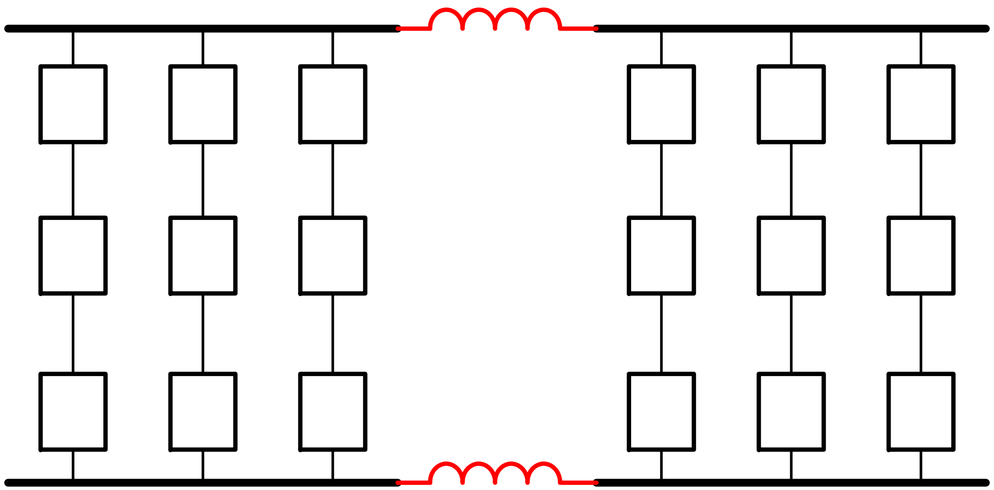
Transformer Neutral Reactors/Resistors



Advantages:
Inexpensive solution for decreasing ground fault duties.

Disadvantages: No effect on phase faults. Decreases sensitivity to relays.

Current Limiting Reactors

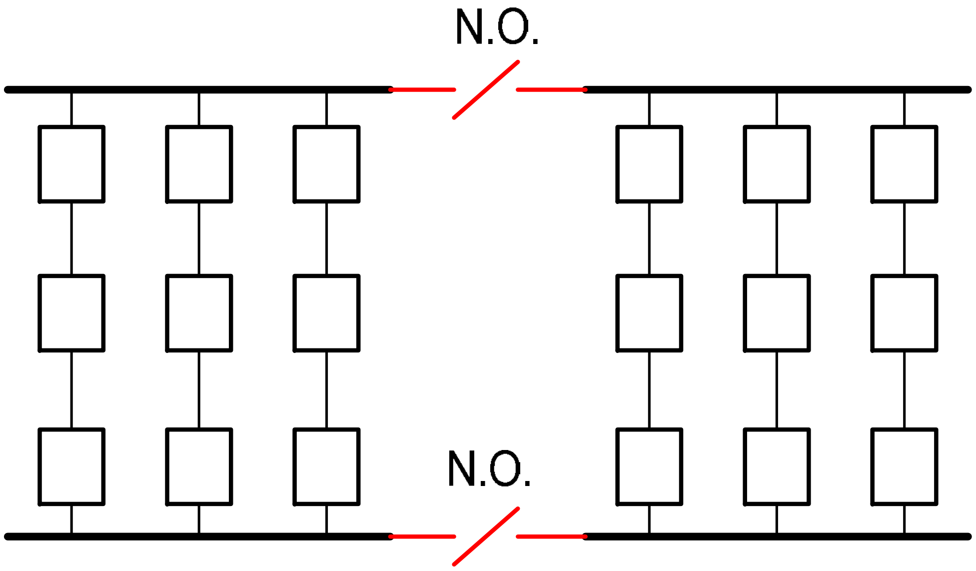


Advantages: Effectively reduces both phase and ground fault duties.

Disadvantages: Introduces potentially large fault voltages.

Example: Mead 230 kV

Bus Sectionalizing

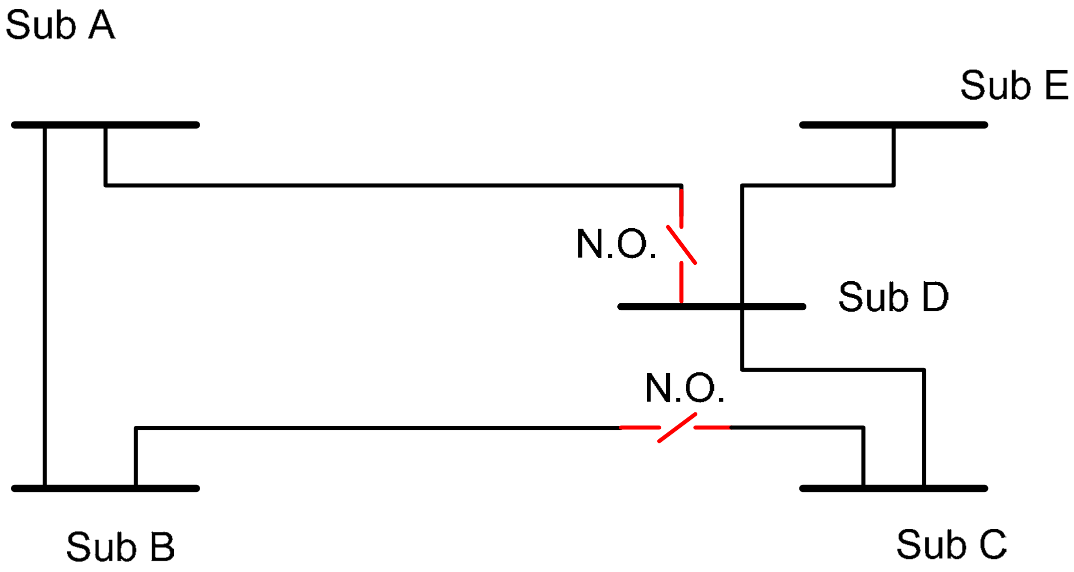


Advantages: Effectively and inexpensively reduces both phase and ground fault duties.

Disadvantages: Reduces system reliability.

Example: Westwing & W. Phoenix 230 kV

Network Sectionalizing



Advantages: Effectively and inexpensively reduces both phase and ground fault duties.

Disadvantages: Reduces system reliability and potentially transfer capability/ratings.


Questions?