DOE Solar Energy Technologies Program Peer Review

CSP Market Transformation: Market Analysis and Grid Integration

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This presentation does not contain any proprietary or confidential information.

Quality, Productivity, Accomplishment

- Primary Responsibilities of NREL:
  - CSP Market Analysis
    - Use and Development of CSP within the REEDS Model
    - Environmental Impact Analysis
    - Policy Analysis (RECs, Financing, GHG Emissions)
    - Solar/Wind Correlation Study
  - Grid Integration and Optimized Dispatch Analysis
  - Transmission Policy Support
  - Support BLM PEIS for Solar
- Budget: $535K (FY08)
- Team (at NREL):

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•Craig Turchi
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•Walter Short
•Paul Denholm
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•Garvin Heath
•Doug Dahle
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•Patrick Sullivan
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Quality, Productivity, Accomplishment

Prior Accomplishments

- Adapted the Wind Deployment System Model to include CSP parabolic trough with storage; subsequent addition of other renewable energy models resulted in establishment of a more general Regional Energy Deployment System model known as ReEDS

Major Recent Accomplishments (roughly FY08) (details to follow)

- Used ReEDS in FY08 for policy impact analysis (30% ITC) and R&D impact analysis; results shared with Al Gore's Climate Change Solutions Summit
- Participated and supported regional transmission analysis efforts including analysis supporting the ongoing western wind and solar integration study and the involvement within Western Renewable Energy Zone (WREZ) study group
- Established CSP Market Transformation Project to encompass the growing and diverse factors (land access, environmental impact, transmission, grid integration, etc.) affecting CSP market penetration

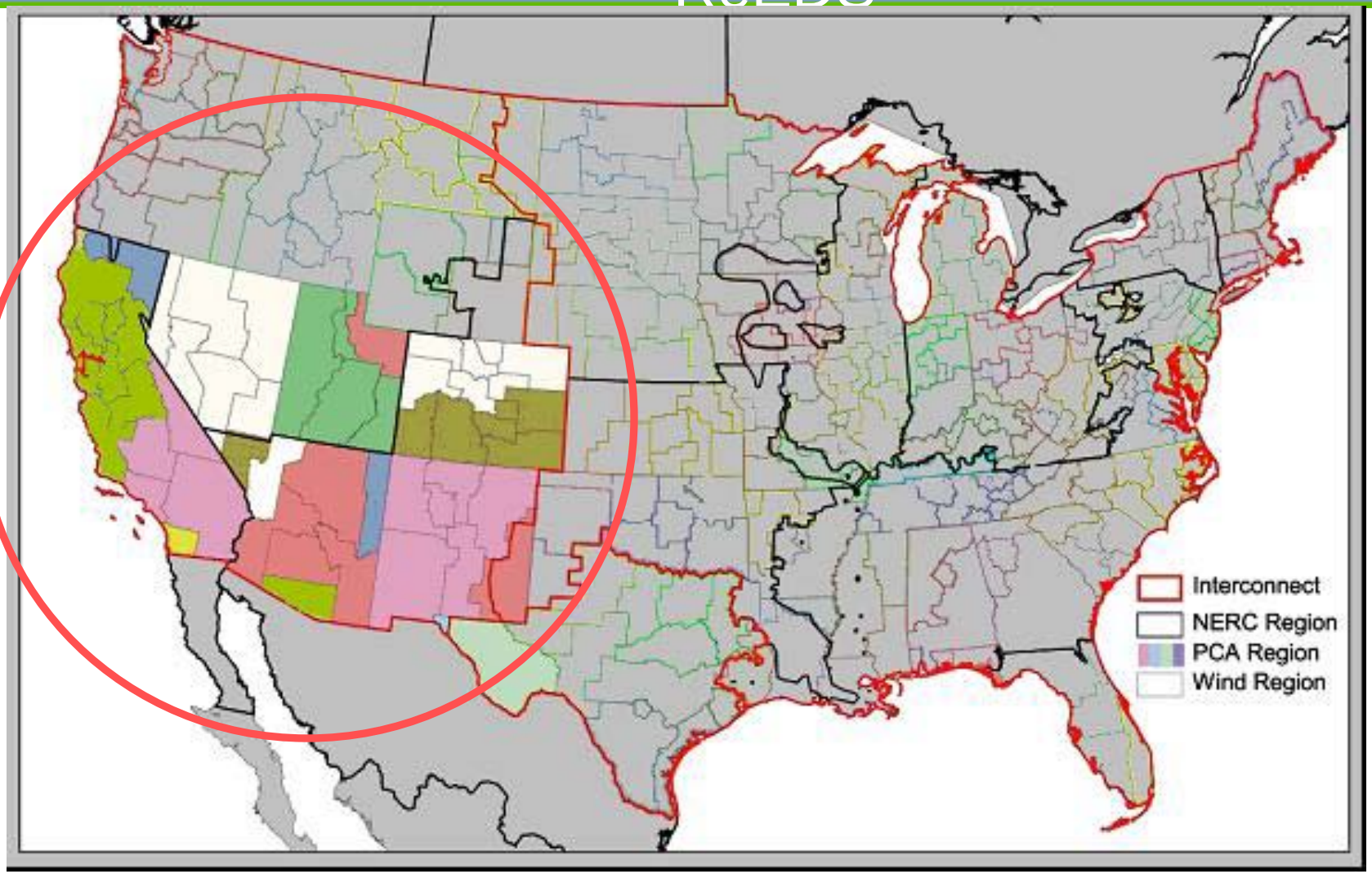
CSP Market Analysis

ReEDS Model

(Regional Energy Deployment System Model)

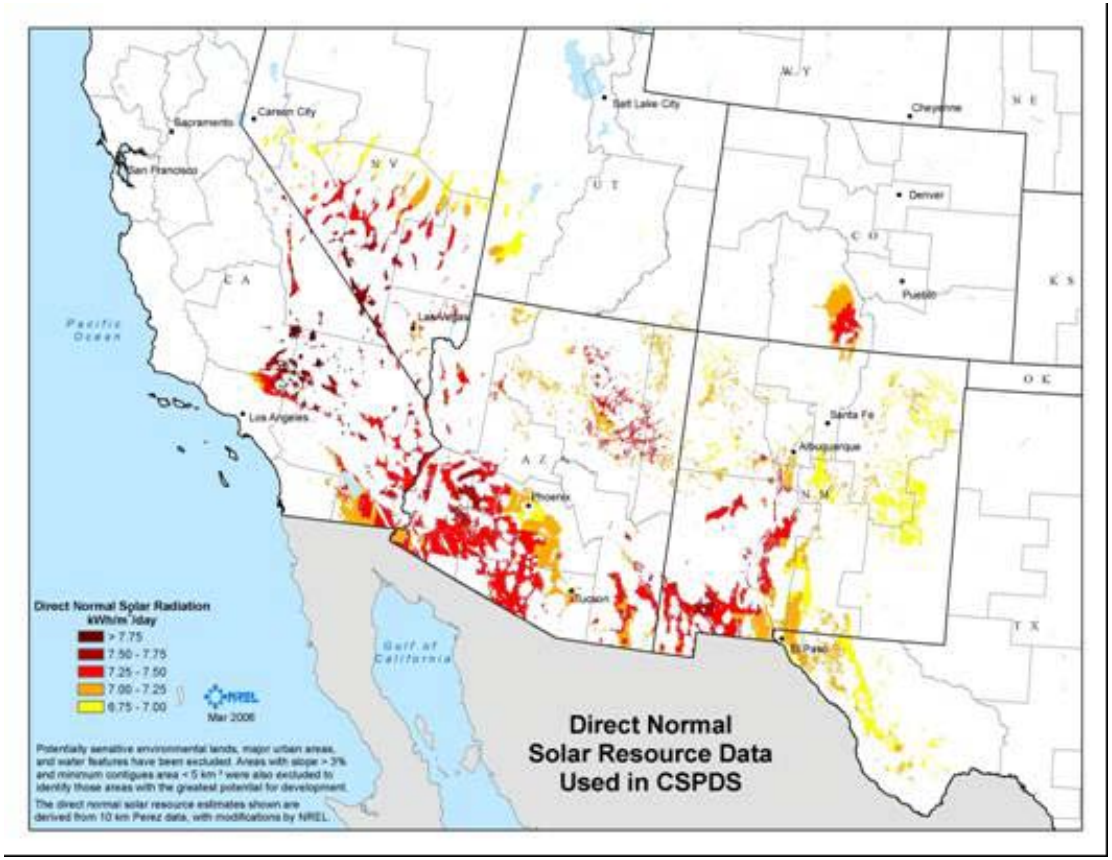
- A multi-regional, multi-time-period model of capacity expansion in the electric sector of the U.S. (Will expand to the transportation sector)
- Designed to estimate market potential of renewable energy in the Lower 48 electric sector for the next 20 to 50 years under different technology development and policy scenarios

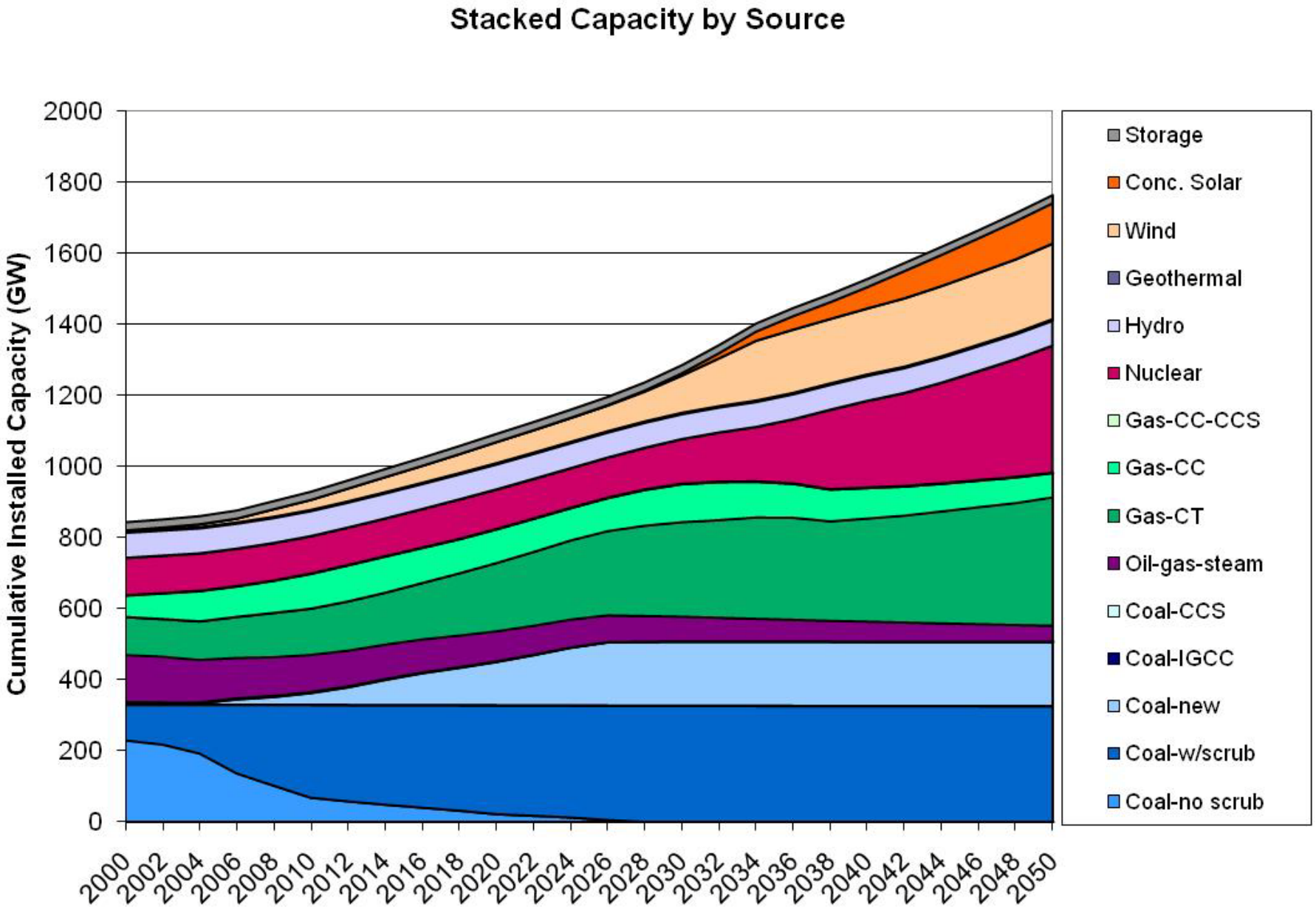
Active CSP Regions in ReEDS



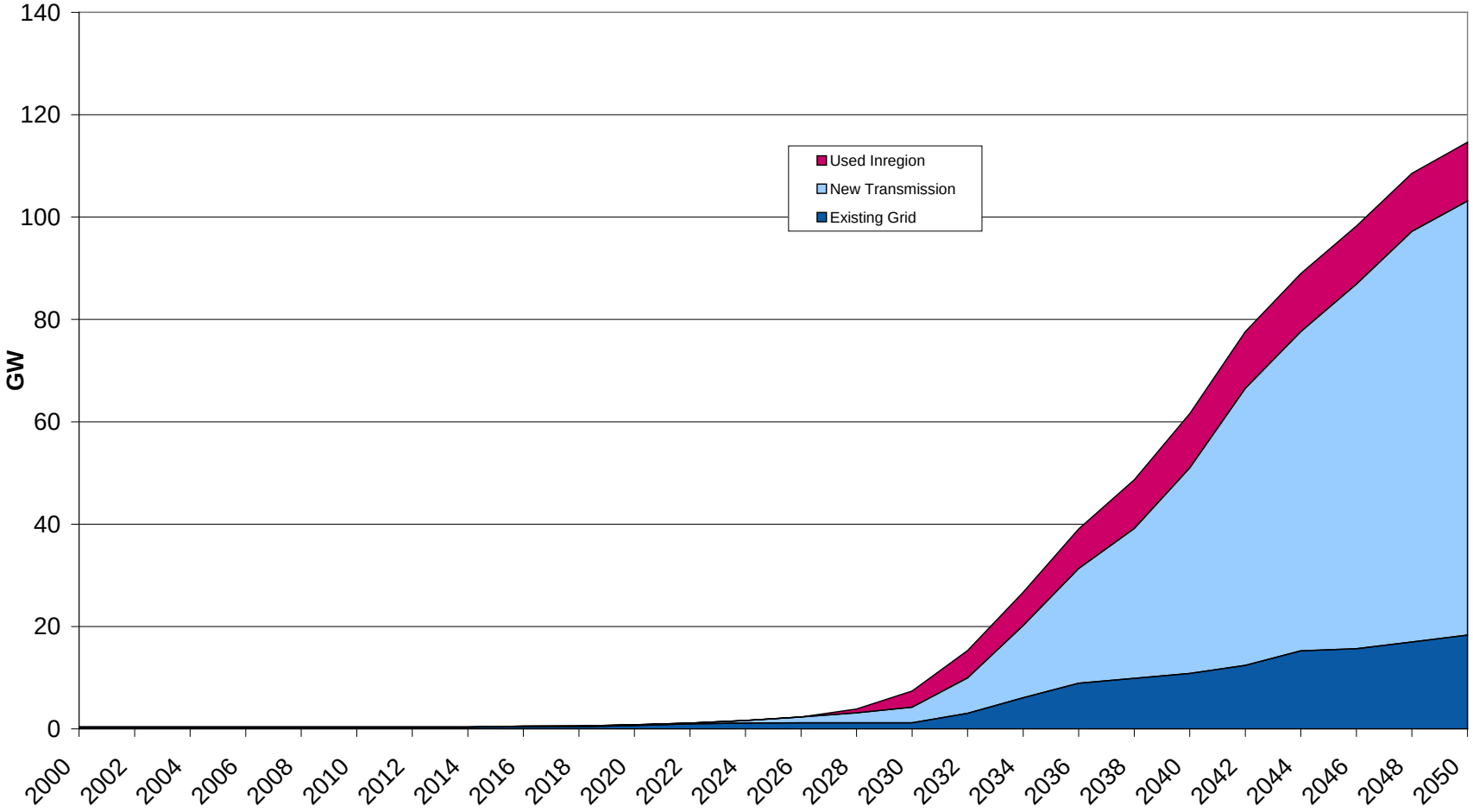
Solar Resource "Binning"

Solar Class	Radiation Levels (kW/m2/day)
Class 1	6.75 - 6.99
Class 2	7.00 - 7.24
Class 3	7.25 - 7.49
Class 4	7.50 - 7.74
Class 5	7.75 - 8.06

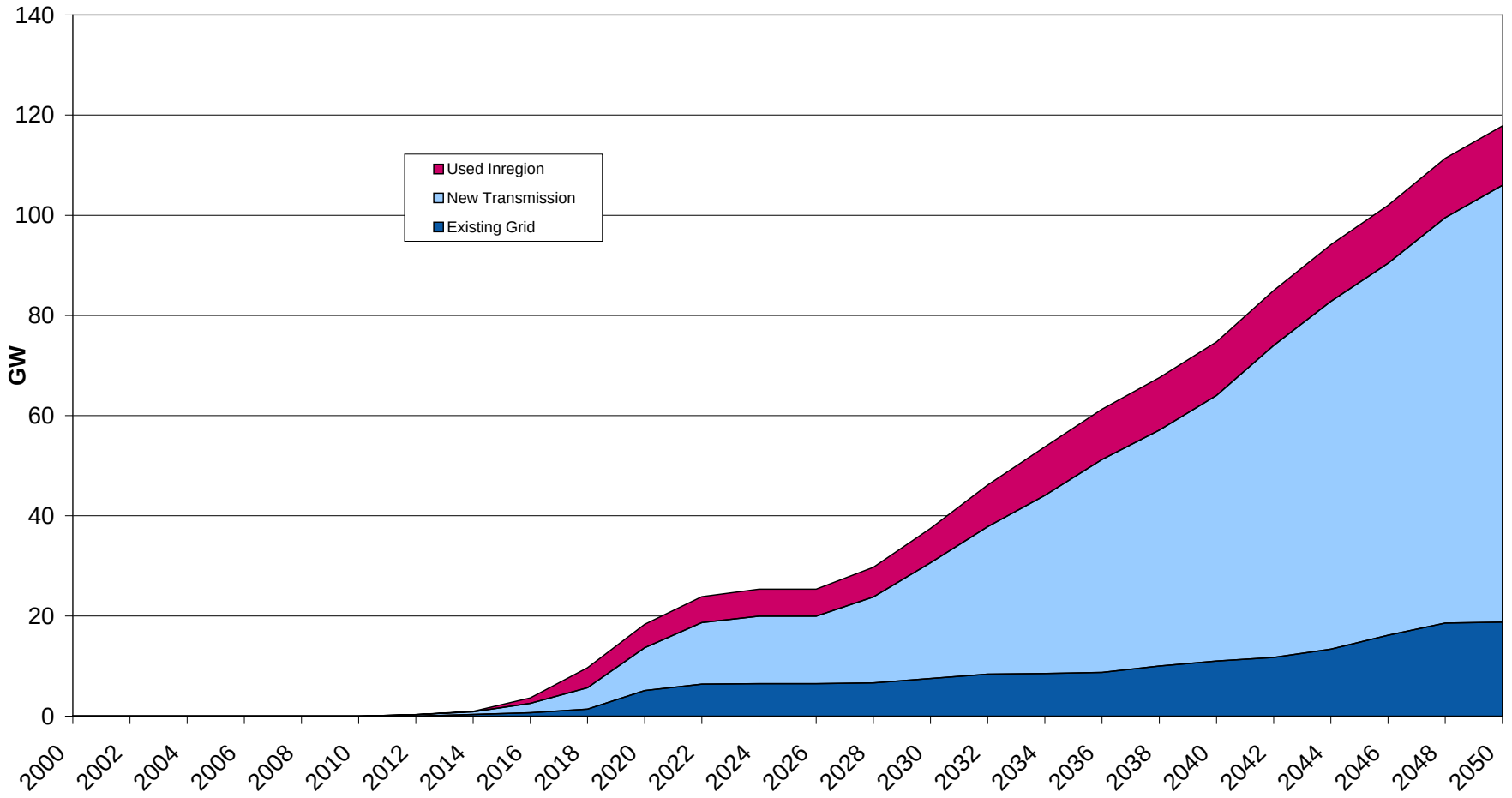



Stacked Capacity by Source
Cumulative Installed Capacity (GW)
2000
1800
1600
1400
1200
1000
800
600
400
200
0
2000
2002
2004
2006
2008
2010
2012
2014
2016
2018
2020
2022
2024
2026
2028
2030
2032
2034
2036
2038
2040
2042
2044
2046
2048
2050
Storage
Conc. Solar
Wind
Geothermal
Hydro
Nuclear
Gas-CC-CCS
Gas-CC
Gas-CT
Oil-gas-steam
Coal-CCS
Coal-IGCC
Coal-new
Coal-w/scrub
Coal-no scrub

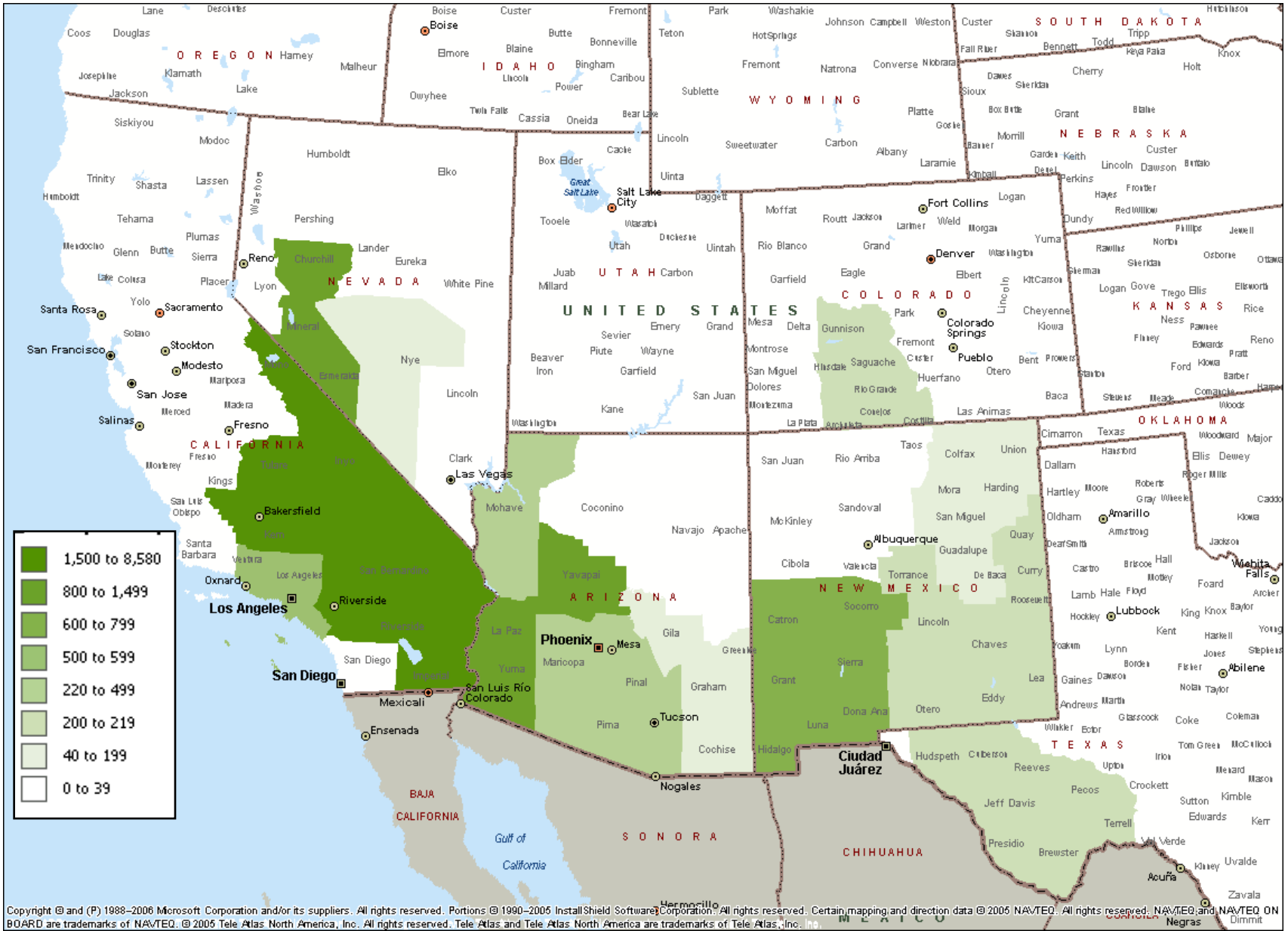
Cumulative CSP Capacity
No Extension of Solar ITC



Cumulative CSP Capacity
8-Year Extension with Declining ITC



CSP Capacity in 2020 with ITC Extension



Grid Integration and Optimized Dispatch Analysis

Background
Model Description

- We used a dispatch model to determine operation of a CSP plant with varying solar field and storage size
  - Dispatch model maximizes profits subject to constraints on CSP and storage operation
  - Model formulated as a mixed-integer linear program
- Energy prices and solar availability are based on historical hourly data from a handful of control areas in the southwestern United States
- CSP operations and capabilities were based on estimates in NREL's Solar Advisor Model (SAM) of a 110 MW CSP plant

Storage Dispatch
Generation Shifting

- Adding storage to a CSP plant allows for generation to be shifted between hours to follow price patterns
- This example highlights this effect:
  - The highest price is in hour 22, but there is no sunlight
  - Without storage, all of the energy is sold before hour 1
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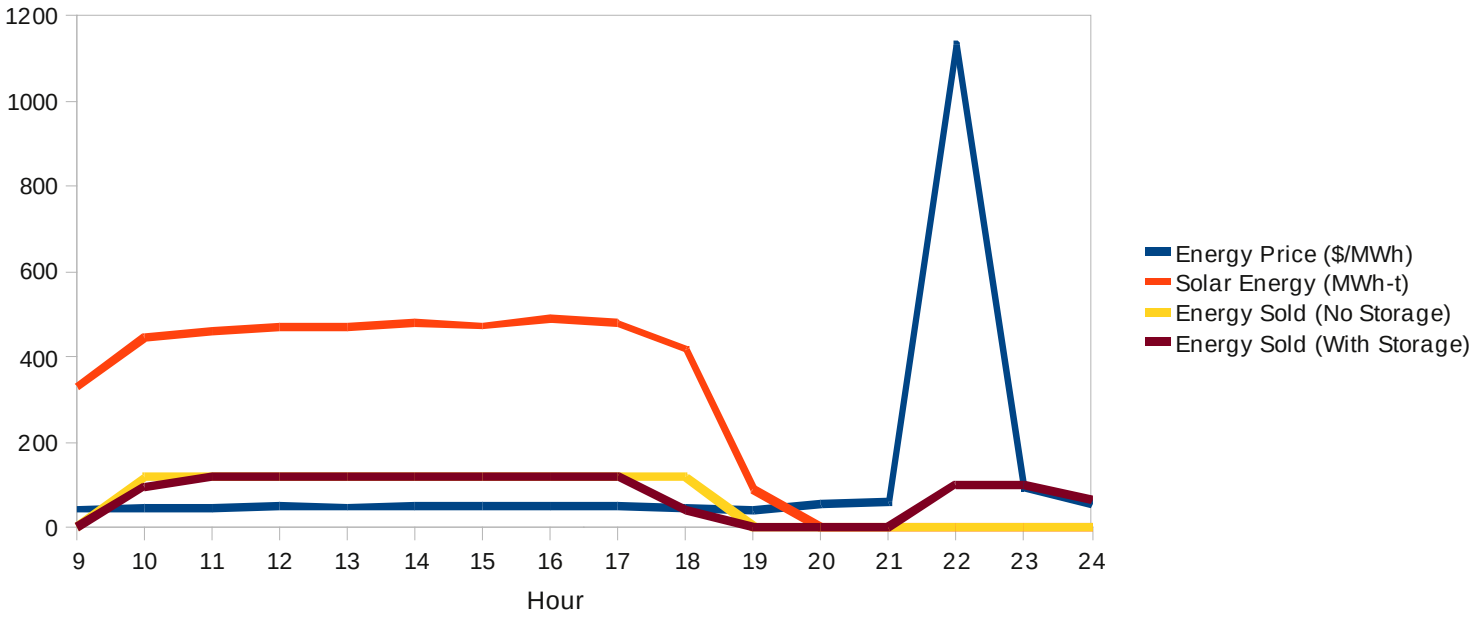

Storage Dispatch
Generation Leveling

- Storage allows generation to carry through low-solar periods
  - Without storage the plant must be shutdown in hours 13 and 14 and does not resume generating until hour 16
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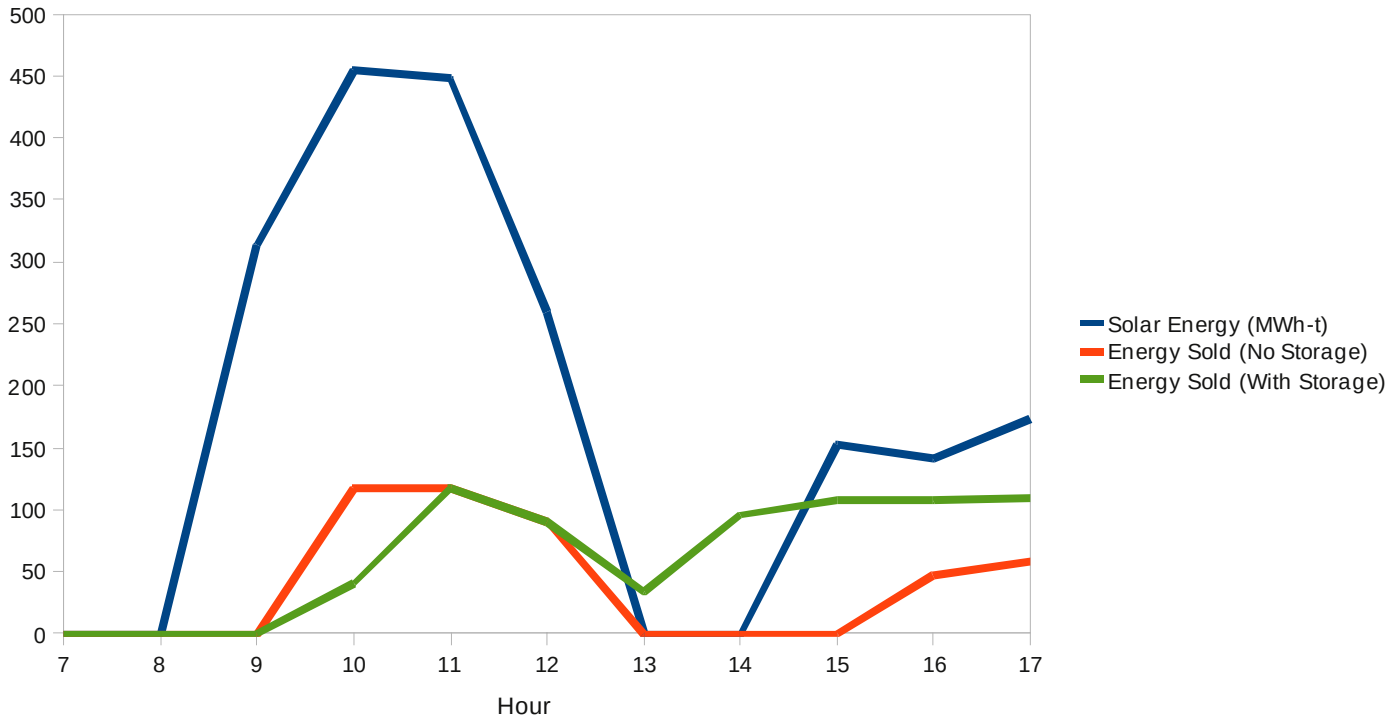
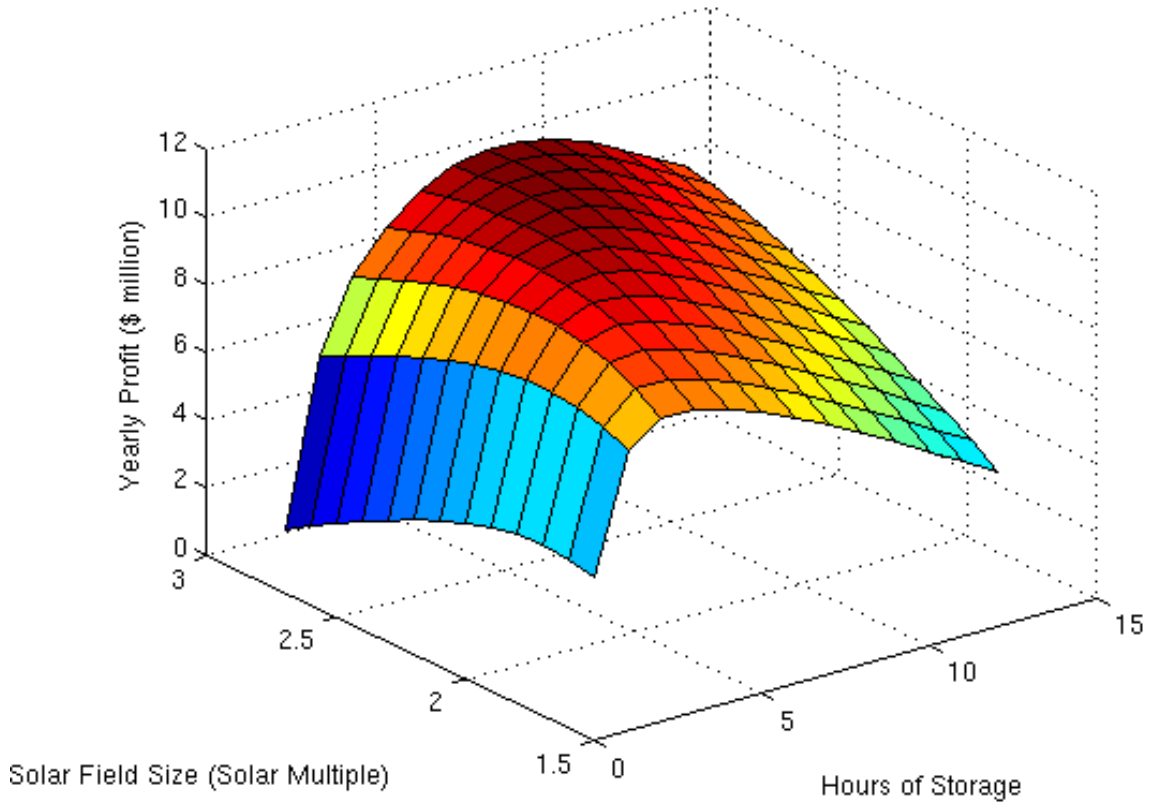


Optimizing Solar Field Size

- Figure shows annual net profit of CSP with different amounts of storage and different solar field sizes for a site in western Texas
- Profit is maximized with 6 hours of storage and a solar field with a solar multiple of 2.6



Transmission Policy and Environmental Support for Solar PEIS

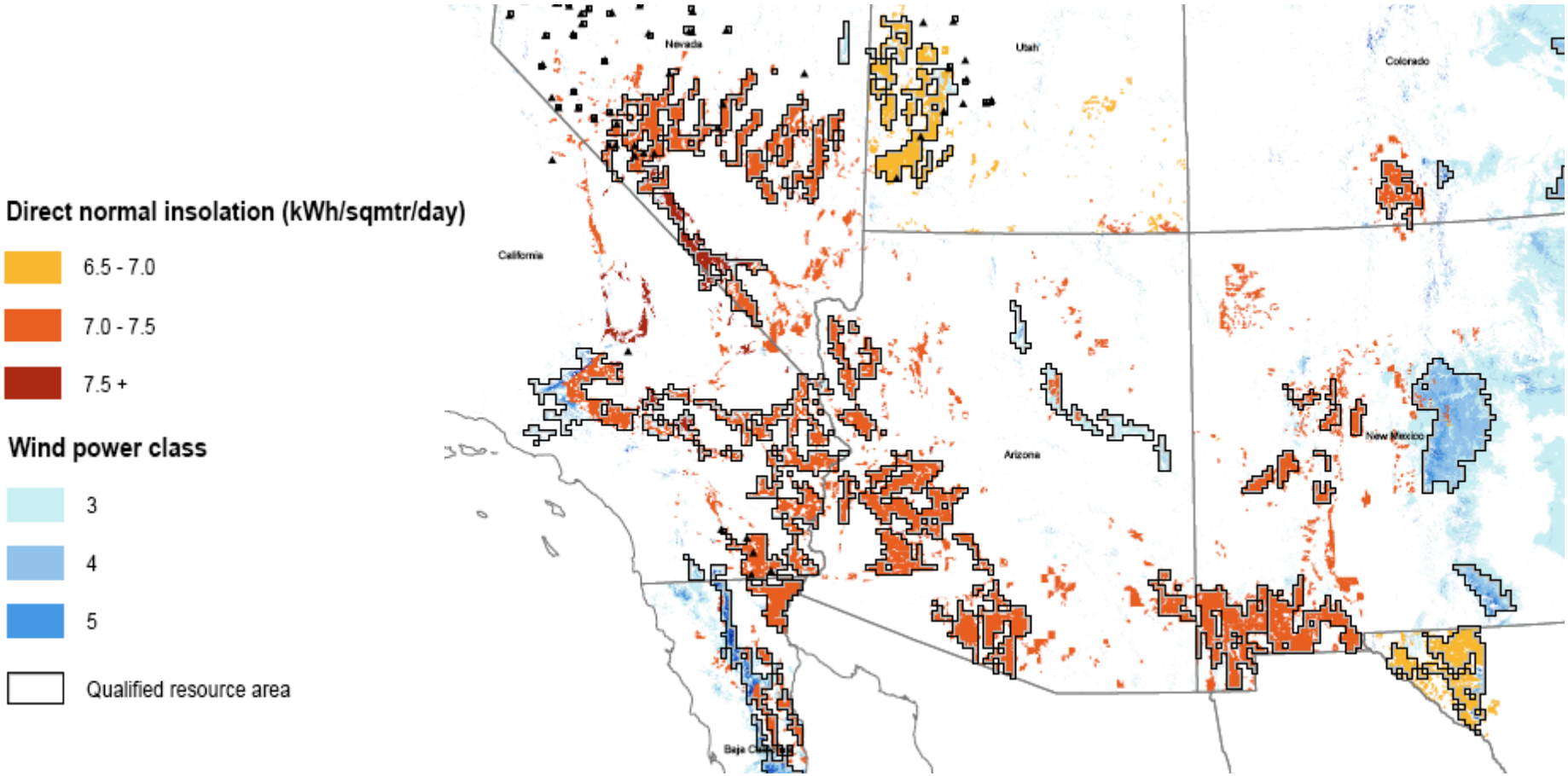
Transmission Planning Support

This activity area provides CSP program input to regional transmission planning activities, including:

- The Western Renewable Energy Zone (WREZ) Initiative of the Western Governors' Association
- Arizona Renewable Resource and Transmission Identification Subcommittee
- Southwest Area Transmission subregional planning group
- California Renewable Energy Transmission Initiative (RETI)
- Other state transmission and renewable energy zone planning activities (NV, CO, NM, UT)

Draft WREZ Solar Resource Areas

Draft WREZs released for public comment in February 2009 included approximately 100 GW of solar:



CSP Plant Life Cycle Analysis (LCA)

Objective:

Determine the life cycle environmental impacts (e.g., material consumption, CO_2 and other emissions) and net energy balance of a parabolic trough plant

Accomplishments:

- Completed LCA of current thermal energy storage systems
- Obtained agreements for data for other components and sub-systems

Future:

Complete trough plant LCA and extend to other CSP technologies; coordinate with $1M Corporate Analysis LCA meta-analysis

Resource Extraction | Component Manufacturing | Construction | Operation | Deconstruction

Future Work

- **Market Analysis**
  - Identify and reconcile ReEDS / NEMS differences
  - Continue ReEDS development and market analysis
    - Modify ReEDS to include CSP systems without storage to assess advantages of CSP configurations with storage (e.g. troughs or towers) versus solar configurations without storage (e.g. dish/Stirling or PV)
  - Correlation between wind and solar
  - 20% CSP penetration support
  - CSP policy analysis
- **Grid Integration and Optimized Dispatch Analysis**
  - Complete regional analysis of optimum level and dispatch of CSP storage
  - Assess optimized thermal storage level based on dispatch economics
  - High penetration of CSP implications for grid operation and economic value
- **Transmission & Environment Support**
  - Continue CSP stakeholder outreach to state energy, economic, and environment offices and utilities
  - Continue to improve and promote tools for GIS, market analysis, and economic impact analysis to support transmission planning
  - Complete life-cycle analysis for parabolic trough power plant and extend to other CSP technologies
  - Continue support on Solar PEIS for lands administered by the Bureau of Land Management
  - Initiate discussion with desert stakeholders regarding wildlife and environmental impacts of large solar plants; leverage effort with PEIS activities