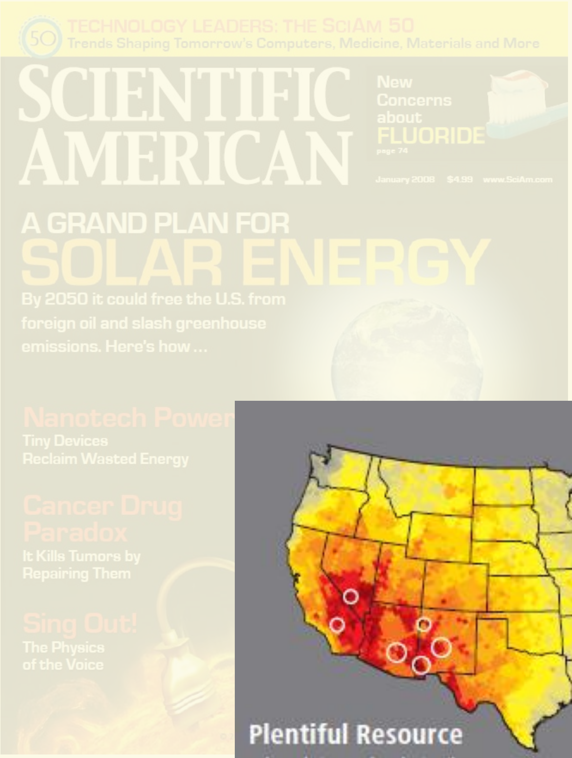
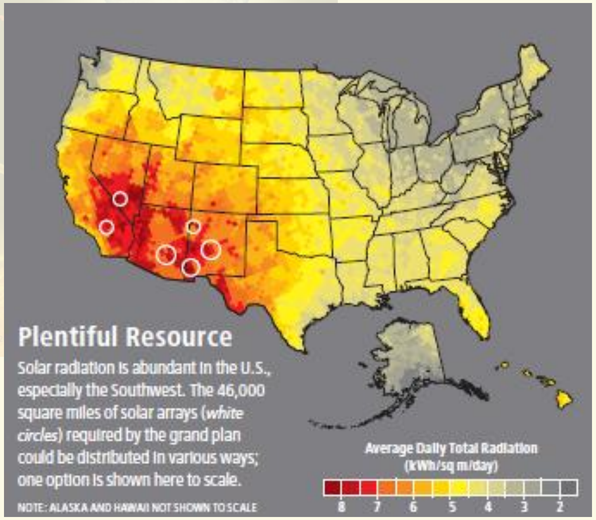
A Linear Programming Model to Support Development and Maintenance of a Solar Grand Plan Deployment Schedule

DRAFT PROJECT REPORT:
January 2011

The project builds an implementation pathway for the Solar Grand Plan

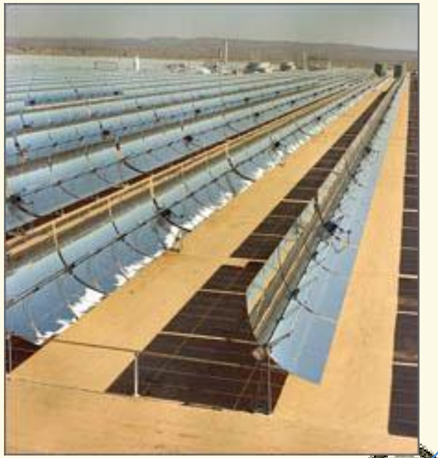
Project began with the Solar Grand Plan…





…and an assignment to provide a realistic deployment schedule

- Transmission capacity limits
- Power grid stability
- Load scheduling and energy storage
- Spinning reserve requirements
- Project construction timelines
- Material availability



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The approach determined optimal costs and timeframes for Solar Grand Plan implementation

- A linear programming model balanced energy demand, generation capacity, transmission capacity, and regulatory requirements to optimize the deployment schedule
- Peak and total power generation and demand were balanced for day and night in winter and summer
- Several tradeoffs were evaluated for each region
  - Local vs. remote power generation, balancing improved transmission costs with higher solar capacity factors in southern/western regions
  - AC vs DC transmission, balancing higher DC capital costs with increased transmission efficiency
  - Near term capital cost expenditure versus staged capacity installation

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Approach – Model Parameters

- Decision Variables – Used/stored generation; AC/DC transmitted generation; New generation/transmission/storage capacity
- Indices – Years (21); Seasons (2); Time of Day (2); Regions (96); Generating Technologies (5)
- Inputs – Pre-existing generation & transmission capacity; RPS requirements; generating reserve and spinning reserve requirements; fuel cost projections; capital, FOM, VOM cost projections; regional and generation specific capacity factors; expected transmission losses

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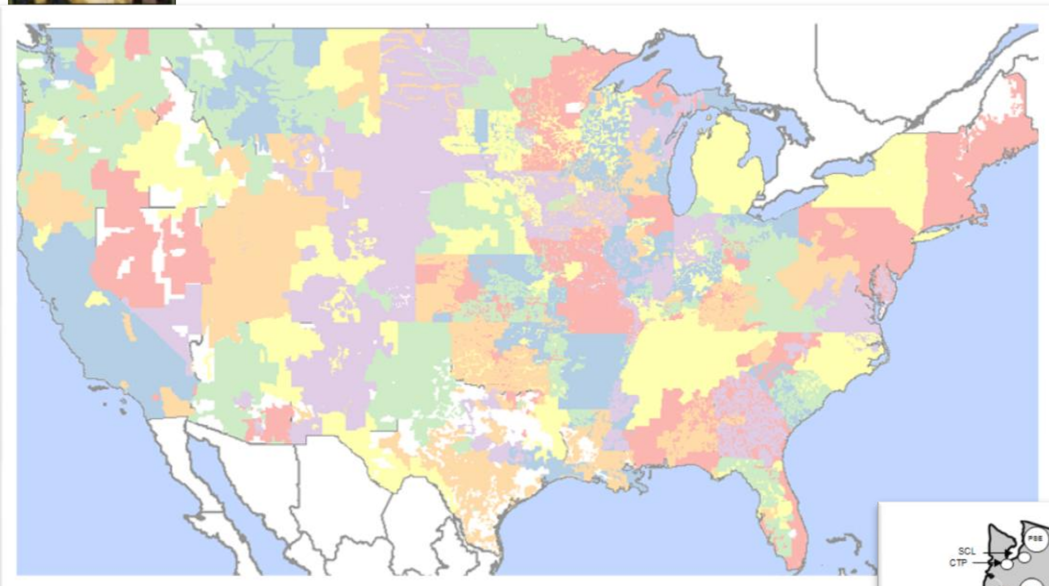
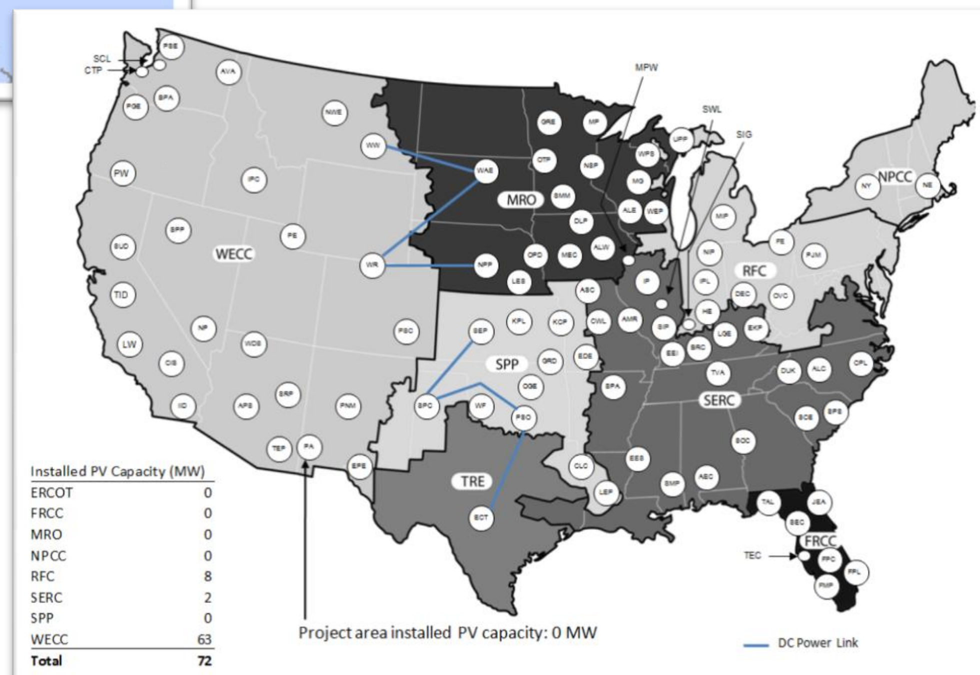
The nodal model contains 96 balancing authorities with both AC and DC transmission possible between each node



Approximately 130 existing balancing authorities have been reduced to a symbolic model based on existing interconnections and geographic proximity

Over 20,000 electric generating facilities and 10,000 utility transmission interconnections were reviewed to determine initial generation and transmission capacities



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Several scenarios tested the model and highlighted key issues for implementing the Solar Grand Plan

- Scenario 1 – Base Case
  - Limited solar-specific renewable portfolio standard; existing wind and hydro power provide the majority of renewable energy demand in the United States; renewable energy doesn't exceed 20% of generation in the next 20 years
  - Energy demand per Department of Energy projections
  - No carbon tax or renewable energy financial incentives
  - Parametric analyses run on PV capital cost, RPS levels, and transmission construction capacity
- Scenario 2 – Power-Only Case
  - 20% solar power required by 2030 in peak energy markets; 50% renewable energy total supply in United States; no energy storage capacity available
  - Energy demand per Department of Energy projections; construction capacity increased
  - No carbon tax, but PV capital cost and minimal transmission subsidies exist
  - Parametric analyses run on PV capital cost, RPS levels, and transmission construction capacity

Scenarios (cont'd)

- Scenario 3 – Power and Transportation Case
  - 20% solar power required by 2030 in peak energy markets; 50% renewable energy total supply in United States; no energy storage capacity available
  - Daytime energy demand per Department of Energy projections; nighttime demand increased 20% to account for plug-in hybrids; construction capacity similar to Scenario 2
  - Carbon tax implemented; PV capital cost and transmission subsidies exist
  - Parametric analyses run on PV capital cost, RPS levels, storage availability, and transmission construction capacity

Key Findings (I)

- Cost of DC Transmission is prohibitively expensive and is a primary limiting factor in transmission of renewable energy
  - Forced construction of solar power in the Solar Grand Plan project area does not result in corresponding transmission buildout in the base case – e.g., the model finds it less expensive to strand generation assets than to construct transmission; significant cost breaks must be applied for generation expansion to occur
- Solar power requirements above 20% within the next 20 years appear infeasible without storage capacity and a significant public funding commitment
  - Calculated capacity costs escalate above acceptable levels and the model becomes unstable when attempting to apply required solar installation levels in consideration of construction time/material limitations

Key Findings (II)

- Extended timeframes will be necessary to convert to a primarily renewable energy based economy
  - The model becomes unstable when RPS values over 50% are entered in the next 20 years
- The addition of plug-in hybrids will limit the ability of solar generation to supply the bulk of the U.S. power generation needs without significant research into storage technology
  - Storage costs must be reduced below $40/MWh of capacity for this technology to become installed in the model without forcing. Currently the model selects intermittent wind and fossil generation over storage technology supplied by solar
- The transmission plan necessary to achieve a start of the Solar Grand Plan can be achieved within the next 20 years for a relatively minimal cost to the consumer
  - Scenario 1 and 2 transmission buildouts occur with cost increase of less than $0.01/kWh to the consumer.

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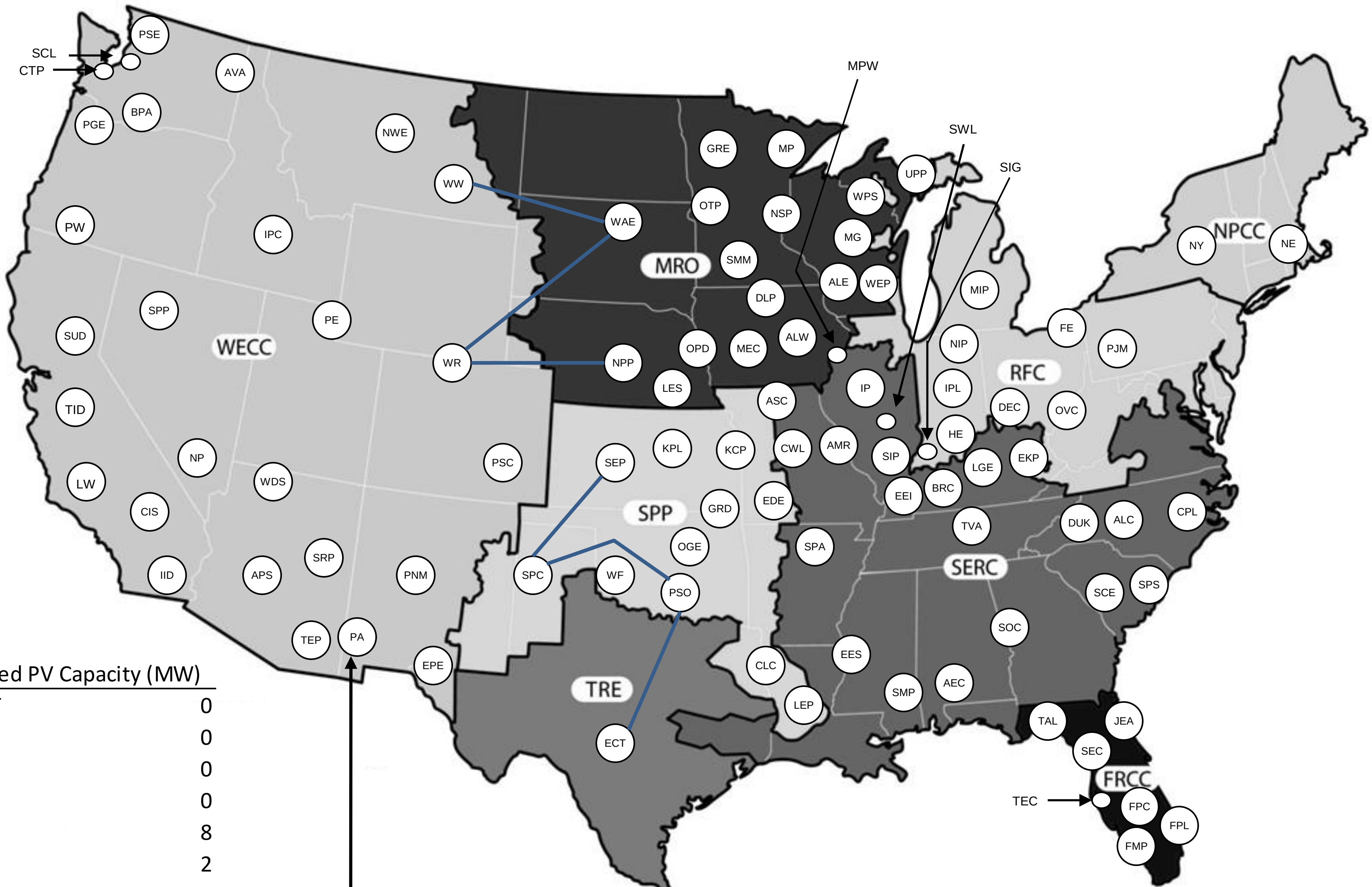
Base Case Initial Deployment



Installed PV Capacity (MW)	
ERCOT	0
FRCC	0
MRO	0
NPCC	0
RFC	8
SERC	2
SPP	0
WECC	63
Total	**72**

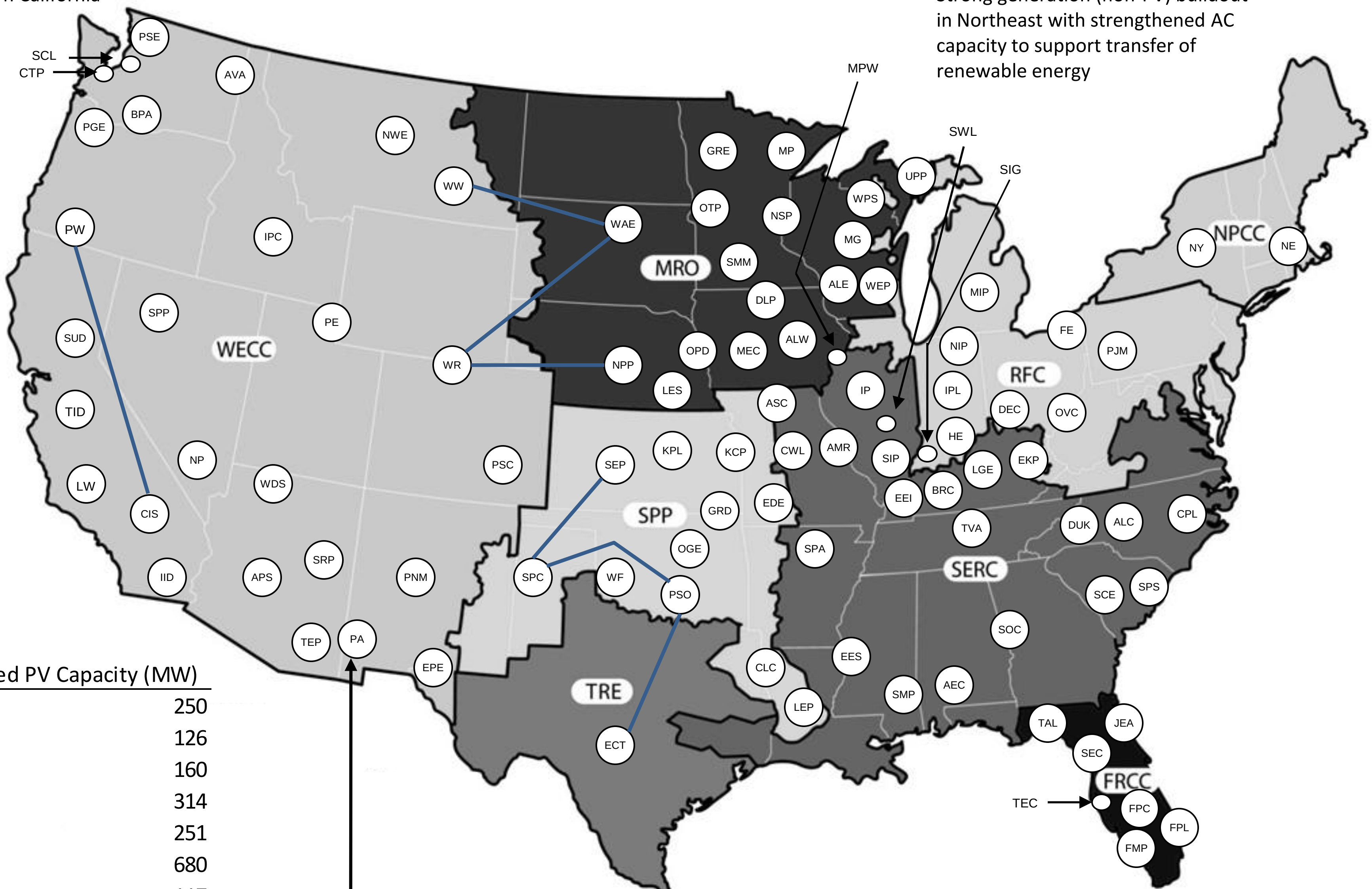
Project area installed PV capacity: 0 MW

DC Power Link

Base Case – Year 5

Improved AC & DC transfer capacity in West with significant transfer between Pacific Northwest and Southern California

Strong generation (non-PV) buildout in Northeast with strengthened AC capacity to support transfer of renewable energy



Installed PV Capacity (MW)	
ERCOT	250
FRCC	126
MRO	160
NPCC	314
RFC	251
SERC	680
SPP	117
WECC	1,286
Total	**3,184**

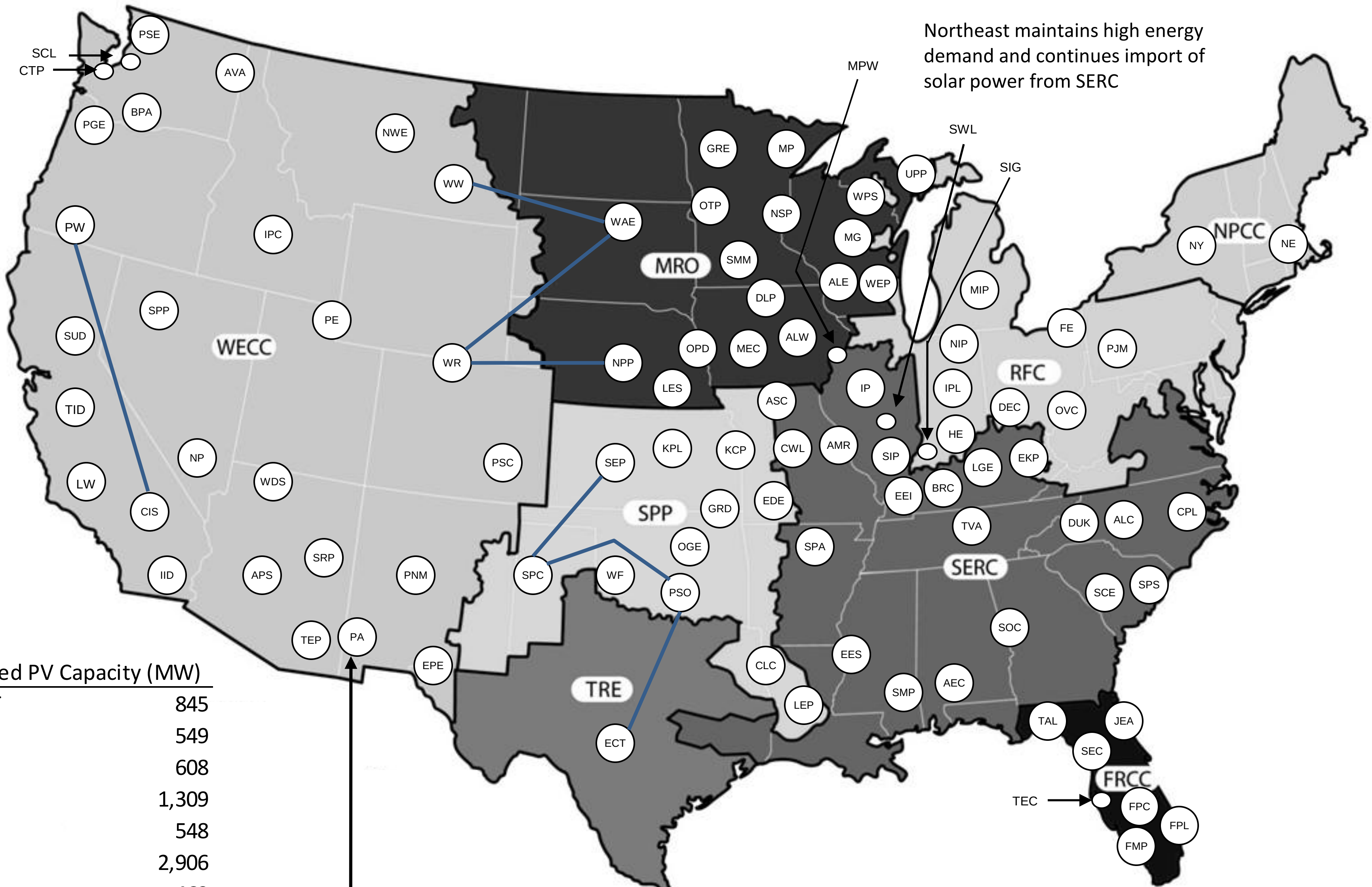
Project area installed PV capacity: 0 MW

Southern and Central United States remain self sufficient with respect to solar power

Base Case – Year 20

Continuation of AC & DC transfer capacity improvement trends throughout the West

Northeast maintains high energy demand and continues import of solar power from SERC

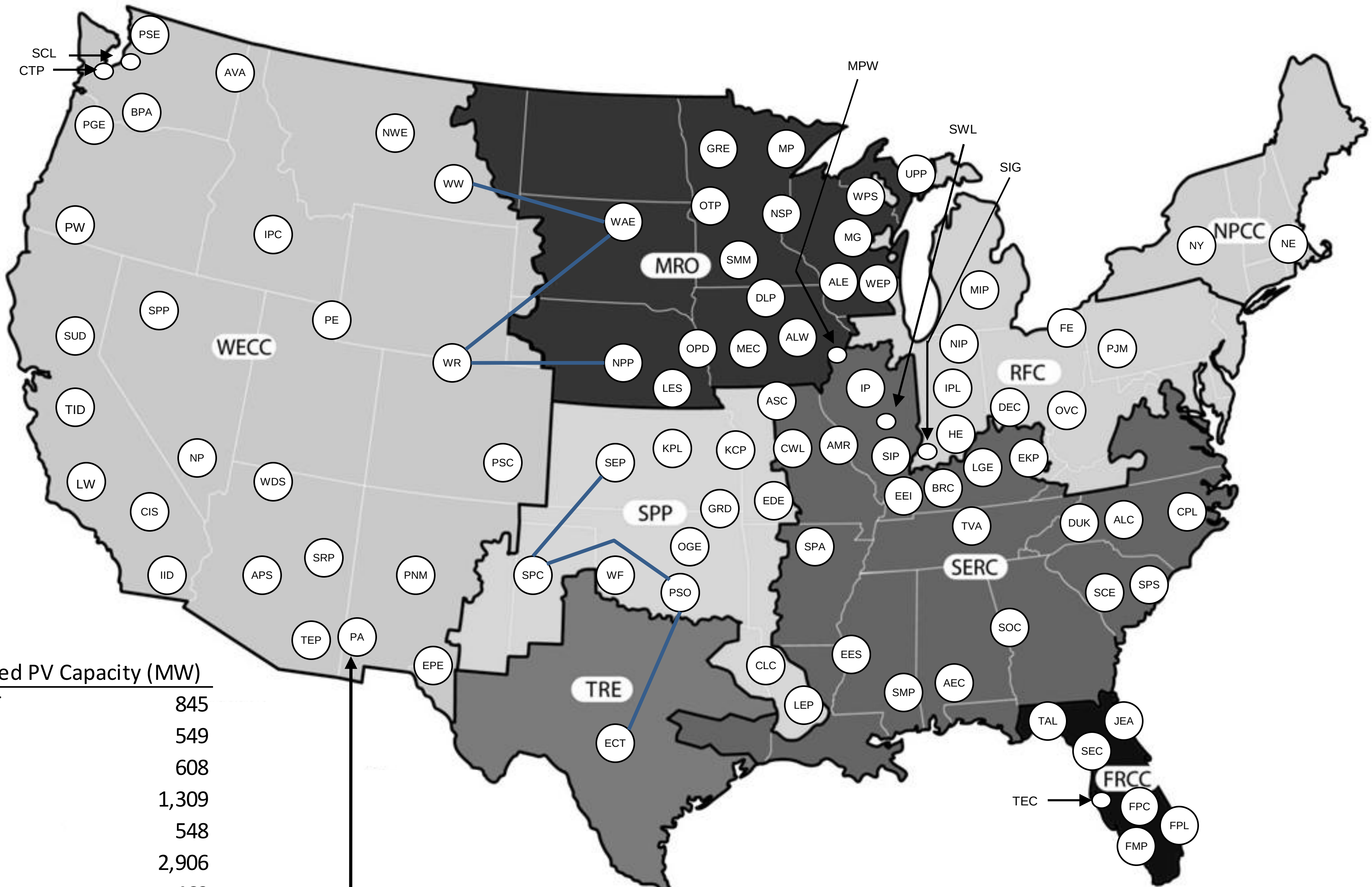


Installed PV Capacity (MW)	
ERCOT	845
FRCC	549
MRO	608
NPCC	1,309
RFC	548
SERC	2,906
SPP	463
WECC	3,835
Total	**11,064**

Project area installed PV capacity: 0 MW

Southern and Central United States continue to remain self sufficient with respect to solar power

Power and Transportation Scenario Initial Deployment



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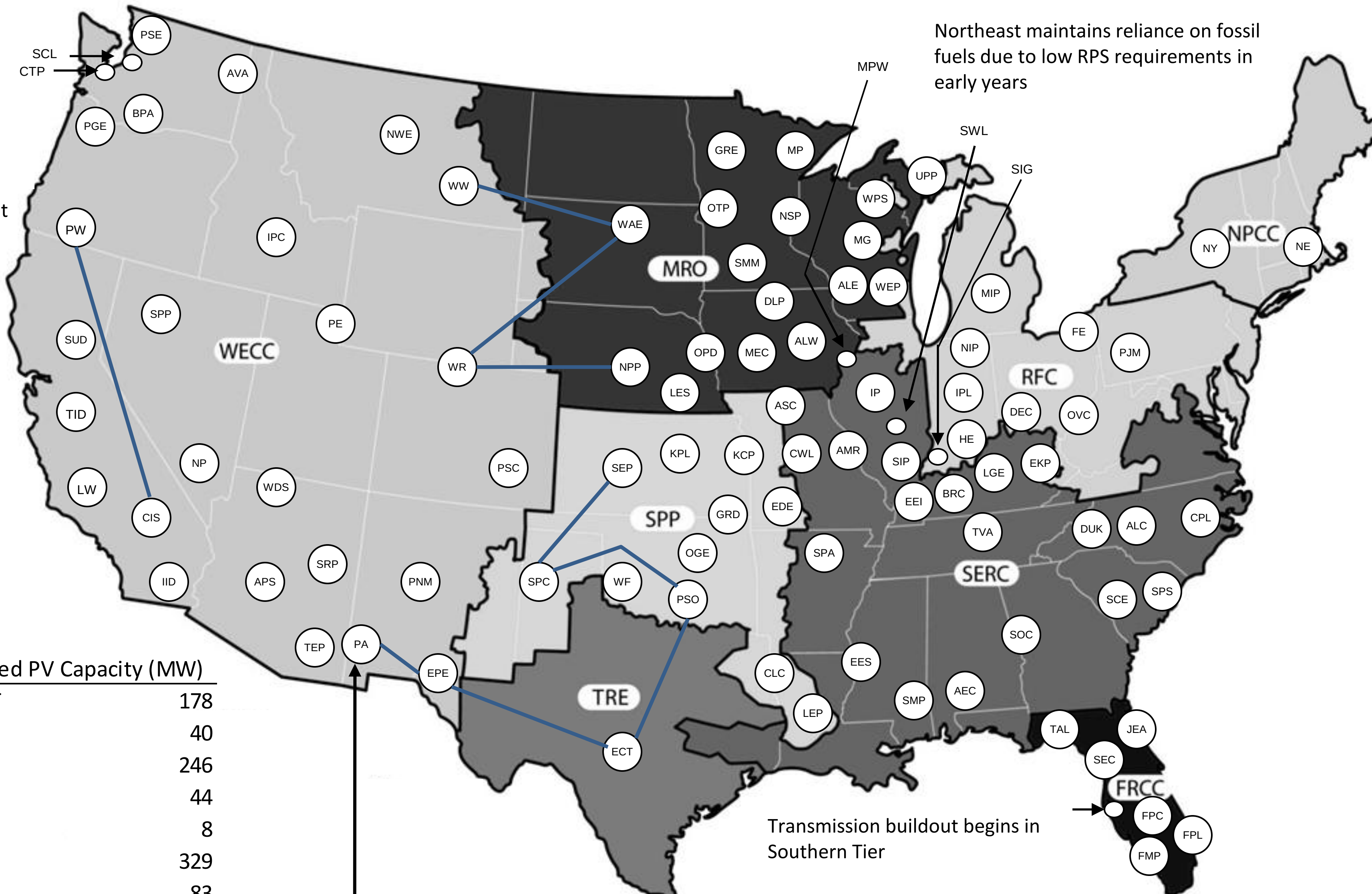
Project area installed PV capacity: 0 MW

Power and Transportation Scenario – Year 5

AC & DC transfer capacity improved throughout the West

Northeast maintains reliance on fossil fuels due to low RPS requirements in early years



Transmission buildout begins in Southern Tier

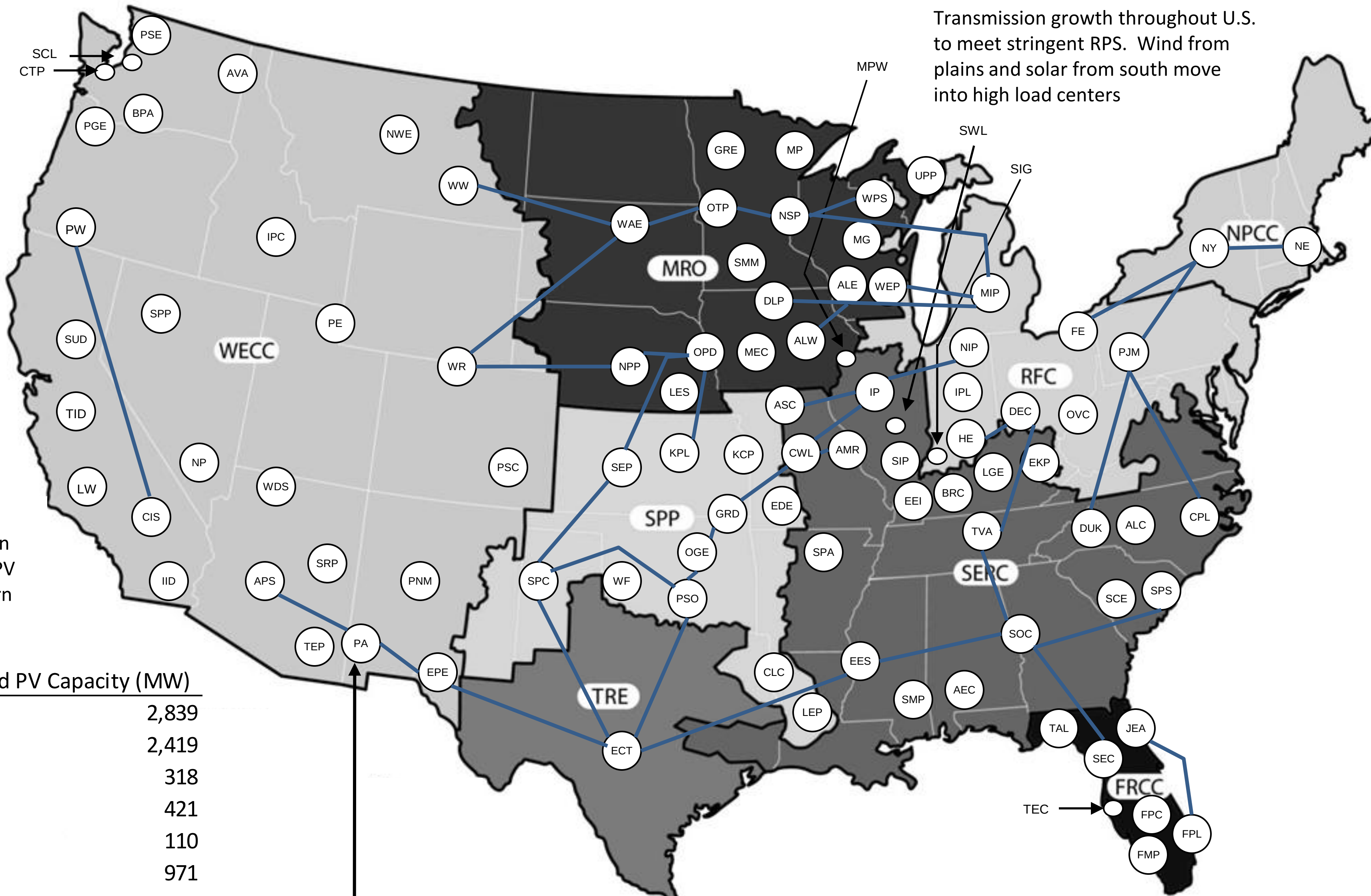
Installed PV Capacity (MW)	
ERCOT	178
FRCC	40
MRO	246
NPCC	44
RFC	8
SERC	329
SPP	83
WECC	5,172
Total	**6,099**

Project area installed PV capacity: 500 MW

Southern and Central United States continue to remain self sufficient with respect to solar power. SERC begins PV buildout

Power and Transportation Scenario – Years 15-20

Transmission growth throughout U.S. to meet stringent RPS. Wind from plains and solar from south move into high load centers



Large expansion of Solar PV in western U.S.

Installed PV Capacity (MW)	
ERCOT	2,839
FRCC	2,419
MRO	318
NPCC	421
RFC	110
SERC	971
SPP	1,584
WECC	6,429
Total	**15,092**

Project area installed PV capacity: 1200 MW

Southern U.S. becomes renewable energy source.