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PRIMA:
Platform for Regional Integrated Modeling and Analysis

Insights From Coupling GCAM-USA with a High-Resolution Siting Model

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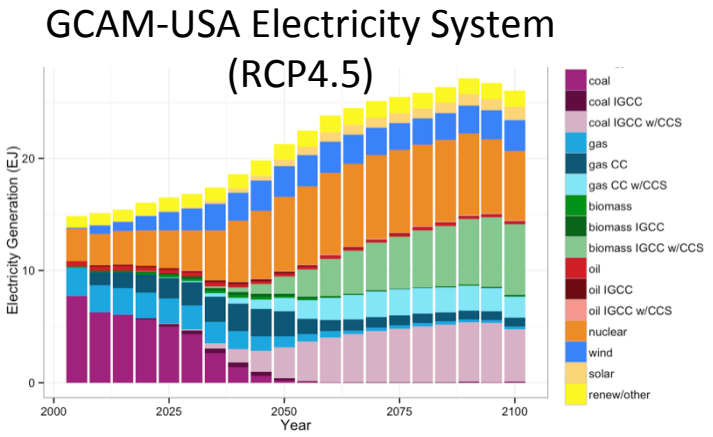
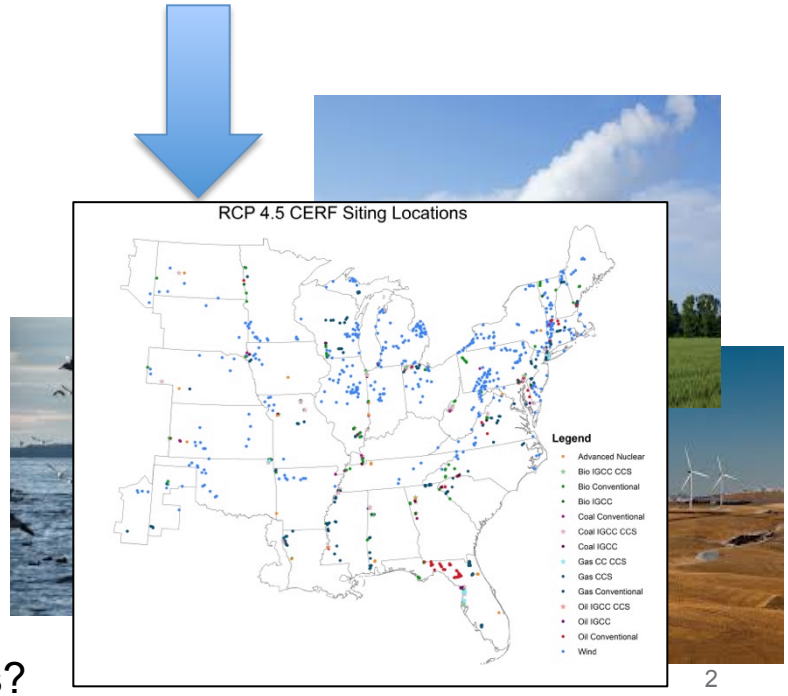
Motivating Questions

- Integrated assessment models project the future for alternative scenarios of policy, socioeconomics, climate, etc., but how viable or realistic are those futures?
  - What do these futures look like "on the ground" and how can they inform impact, vulnerability, and resilience analyses?
  - Are there barriers to mitigation or adaptation that are revealed at higher resolution?
- This effort couples GCAM-USA to a high resolution power plant siting model to address:
  - How might GCAM-USA's energy-based electricity system expansion be experienced on the landscape?
  - Can we site all the power plants?
  - Are there transmission constraints?
  - Are there operational constraints?
  - What are the implications for water?
  - Do certain scenarios pose specific challenges?

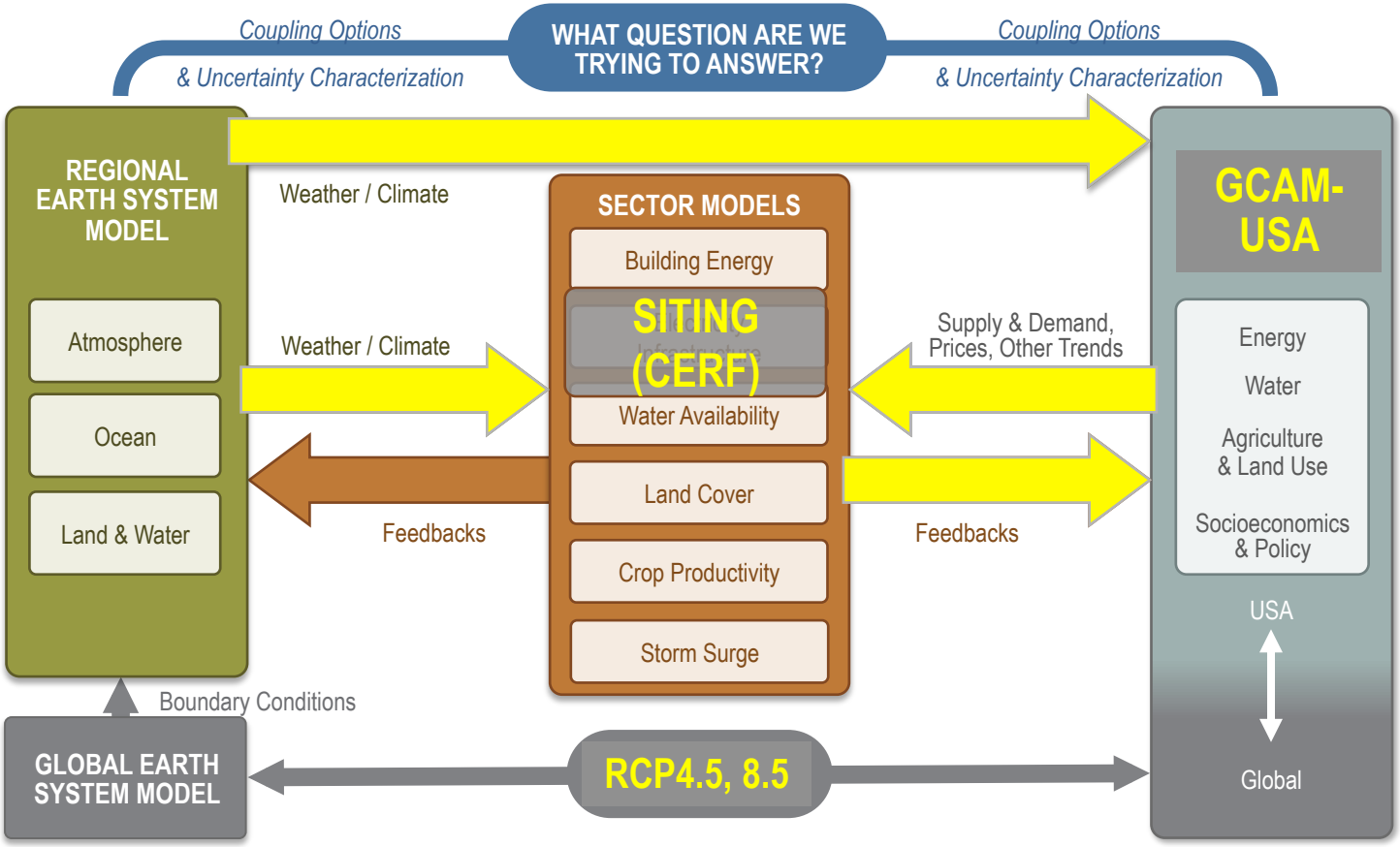




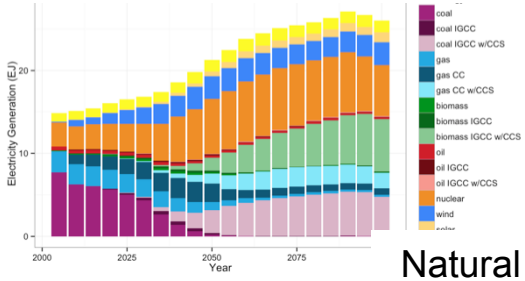
Platform for Regional Integrated Modeling and Analysis (PRIMA)

- PNNL initiative (2010-2014) to address climate-energy-water-land nexus
- Unique local to global coupling of human (e.g., macroeconomic) and natural systems (e.g., climate) models. New models developed and regionalization added to existing models.
- Stakeholder engagement used to define applications and select appropriate couplings

PRIMA leveraged and extended by:
DOE SC
DOE EPSA
DHS OCIA
NGA

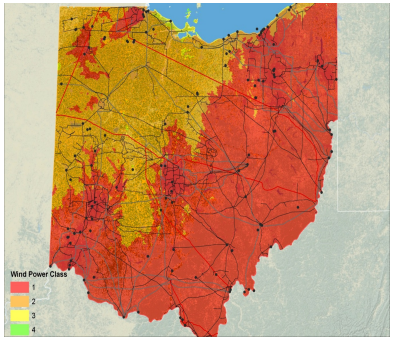


Overview of CERF (Capacity Expansion Regional Feasibility) Model



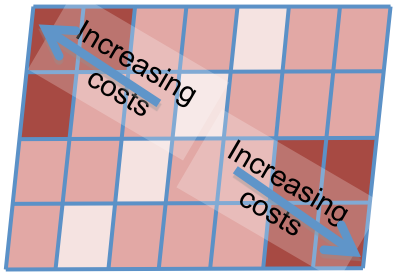
GCAM-USA Electricity Expansion

Natural resource constraints due to climate, land use, water availability, etc.



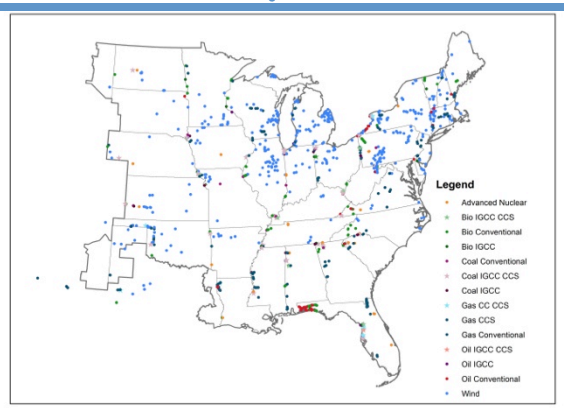
Other siting considerations, e.g., population, local policy

Locational economic considerations, e.g., grid interconnection costs and energy value



CERF Results

- Sited and un-sited power plants
- Siting constraints
- Interconnection cost supply curves



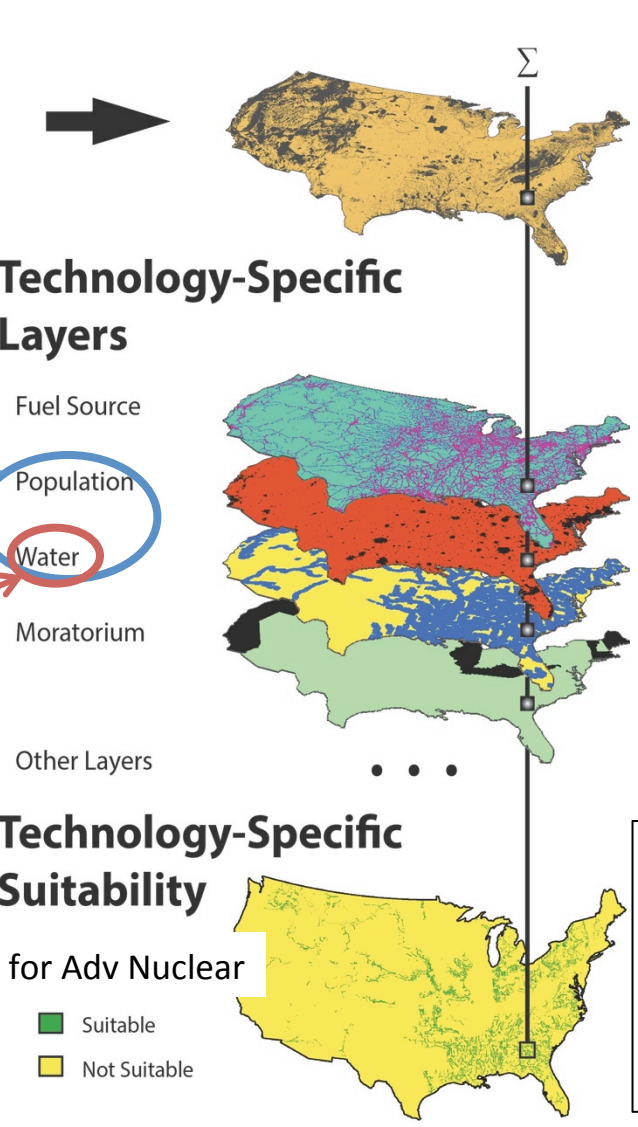
CERF Determines Siting Suitability for each GCAM-USA Thermal Technology

Common Layers

Layer	GIS Data Source
Wilderness Areas	BLM
Wilderness Study Areas	BLM
Wilderness Lands	National Atlas
Wilderness Areas	USFS
Wilderness Areas	WILDNET
TNC - Managed Lands	WDPA
State Protected Lands	WDPA
Protected Areas - Class 1 and 2	USGS
Natl. Forest Admin. Bndry.	USFS
USFS Lands	National Atlas
Class 1 Airsheds	NPS
Natl. Parks Admin. Bndry.	NPS
NPS Lands	National Atlas
Agricultural Research Service Lands	Nationa
Critical Habitat Areas	USFWS
FWS Land Interests	USFWS
Riparian Wetlands	USFWS
Wetlands	Nationa
National Wildlife Refuges	FWS
FWS Special Designation Areas	FWS
FWS Lands	National Atlas
Wild and Scenic Rivers	National Wild and Scenic Rivers
Scenic Rivers	BLM
Headwater Forest Reserves	BLM
National Conservation Areas	BLM
National Monuments	BLM
Outstanding Natural Areas	BLM
Steens Mountain CMPA	BLM
Historic Trails - West	BLM
Scenic Trails - East	BLM
Existing Wind Farm Footprints	Platts/PNNL
EWITS Potential Wind Sites	NREL/PNNL
Slope > 12%	PNNL

Dynamic

Coupled to PRIMA climate modeling



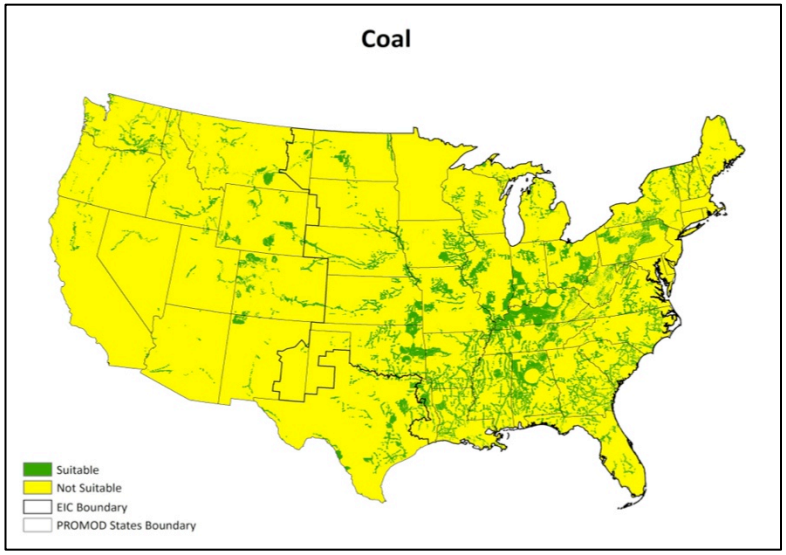
Example for Adv Nuclear

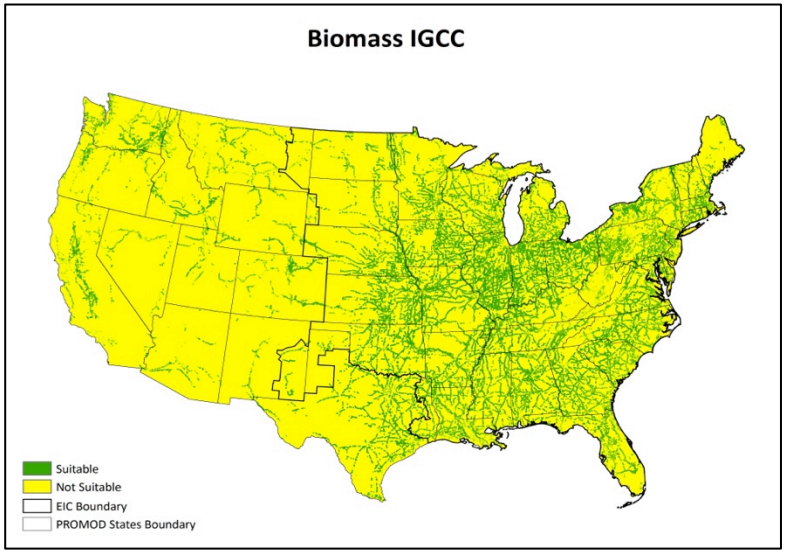
- Advanced Nuclear
- Bio IGCC CCS
- Bio Conventional
- Bio IGCC
- Coal Conventional
- Coal IGCC CCS
- Coal IGCC
- Gas CC CCS
- Gas CCS
- Gas Conventional
- Oil IGCC CCS
- Oil IGCC
- Oil Conventional
- Wind*

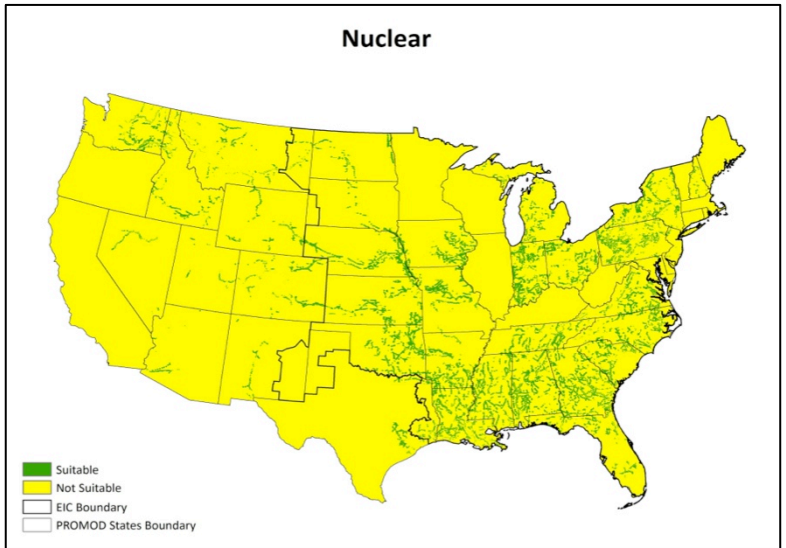
*CERF uses NREL's EWITS wind farms for its wind suitability layer (EWITS=Eastern Wind Integration and Transmission Study)

CERF Tech-Specific Suitability Results for 2020 (RCP8.5 water availability)

Selected suitability results reflecting common and tech-specific layers:

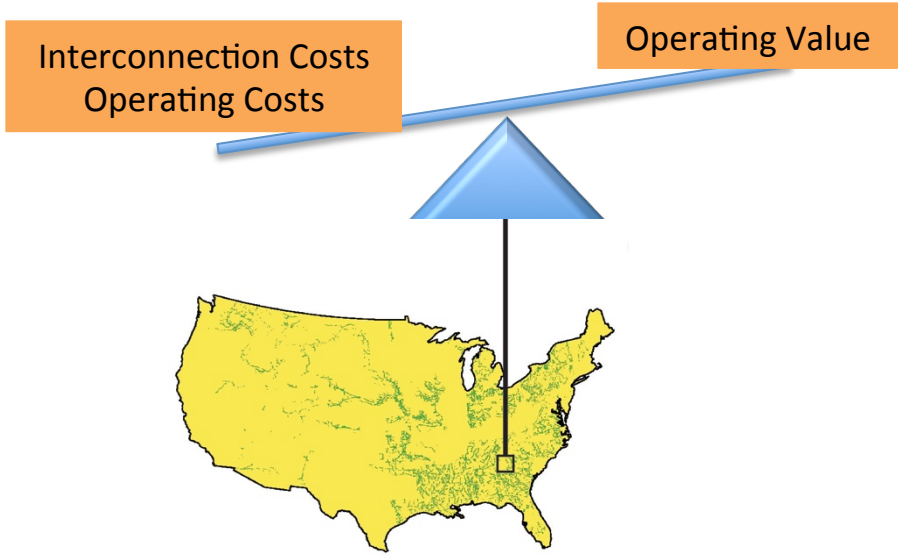




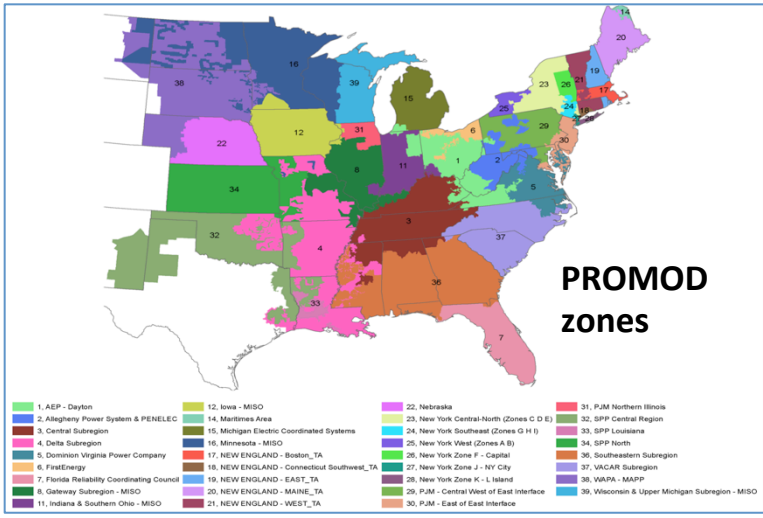


CERF Siting Algorithm Uses Locational Economic Considerations

- Suitability results are necessary but not sufficient to choose siting locations
- CERF places tech-specific units of capacity in grid cells according to:
  - Net Locational Cost = Interconnection Cost – Net Operating Value
  - Interconnection Cost = Distance to Nearest Suitable Transmission Line x Interconnection Unit Cost *(gas pipeline costs also calculated for gas plants)*
  - Net Operating Value = Locational Energy Value – Operating Costs



Locational Energy Value is based on zonal locational marginal prices (LMPs) with new demand but before new capacity is sited

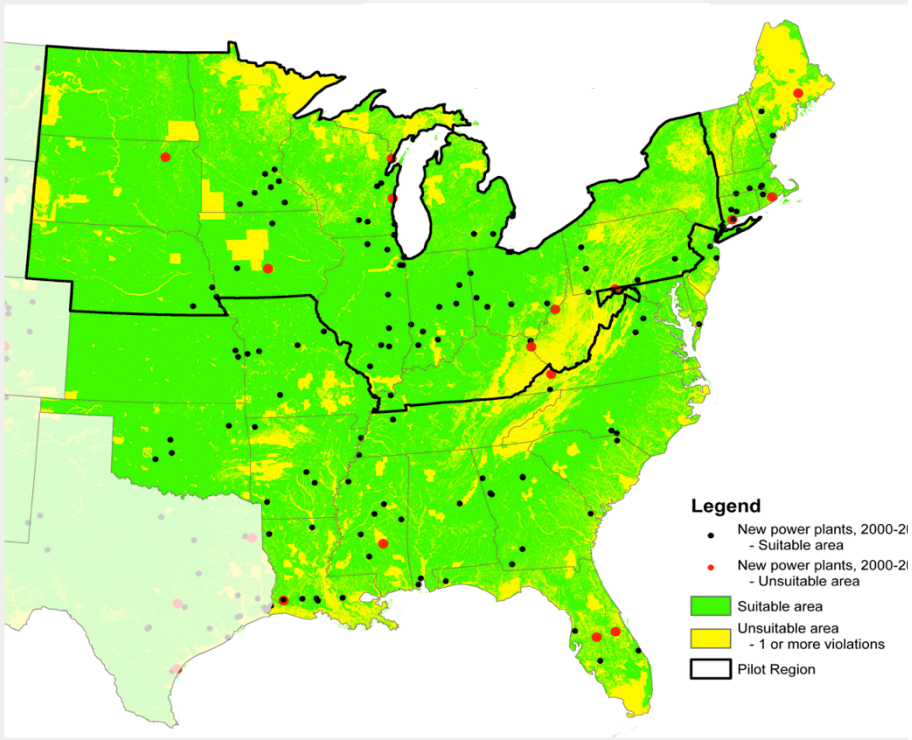


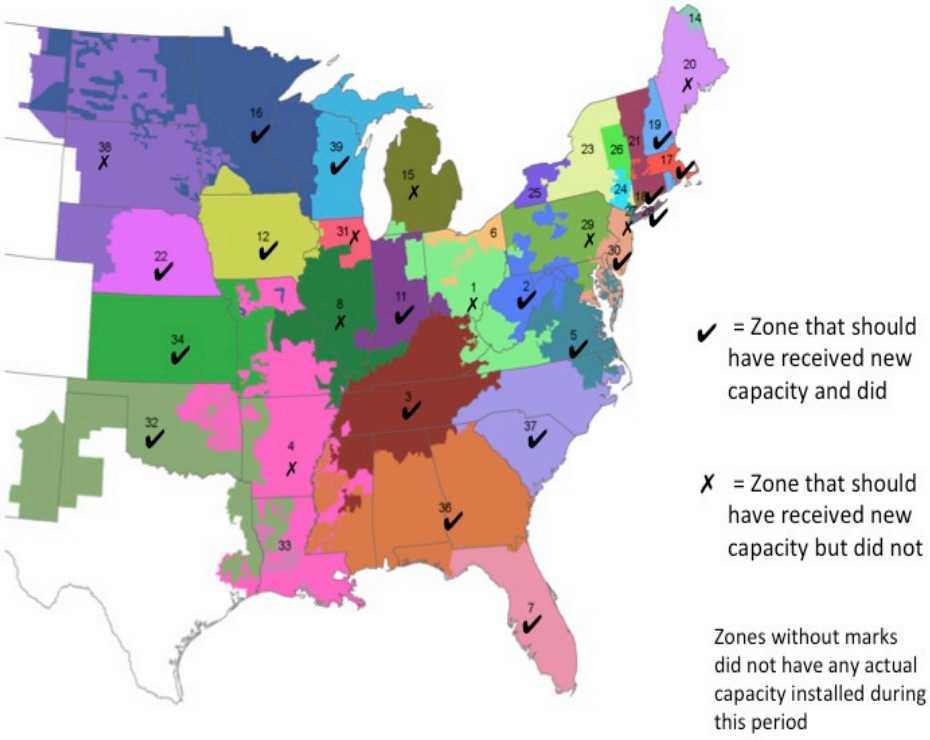
PROMOD zones

CERF Model Evaluation: Comparison to Historical Capacity Additions

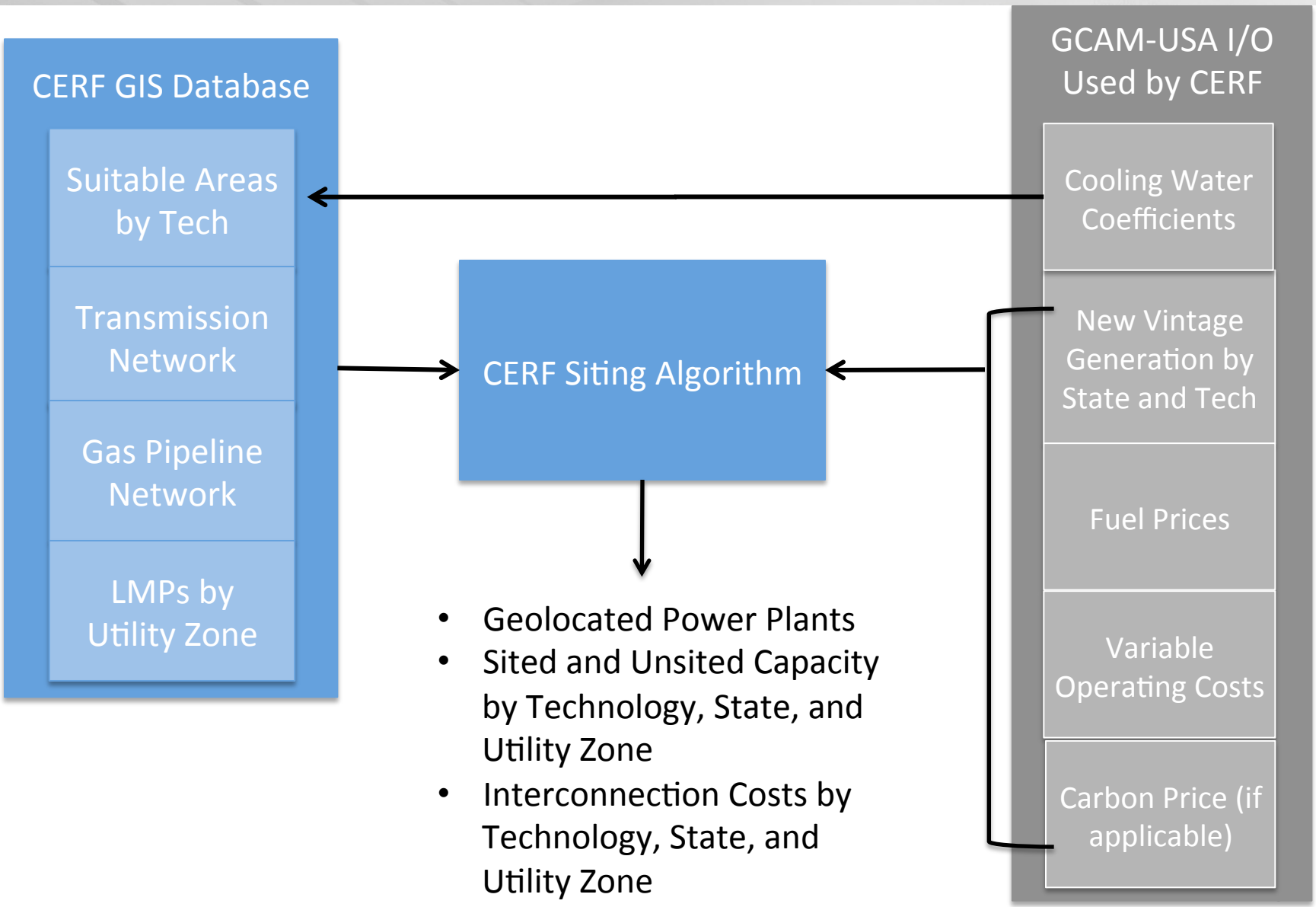
Over 90% of new plants (2000-2010) were located in CERF suitable areas

CERF sited almost 70% of power plants (2000-2010) in the correct PROMOD zone



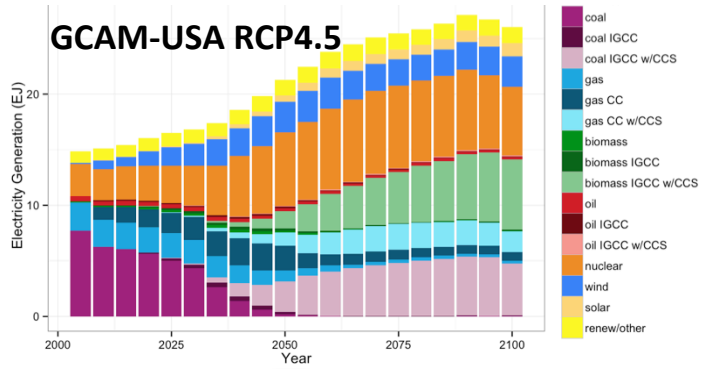


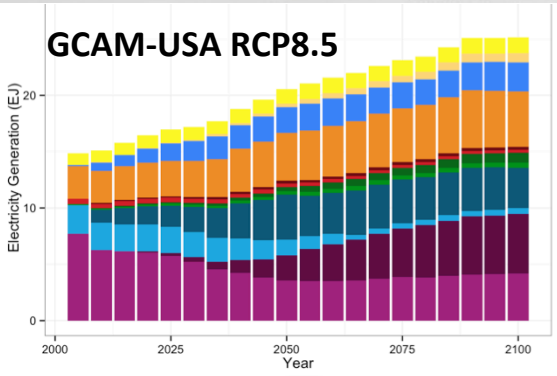
GCAM-USA -- CERF Coupling Process



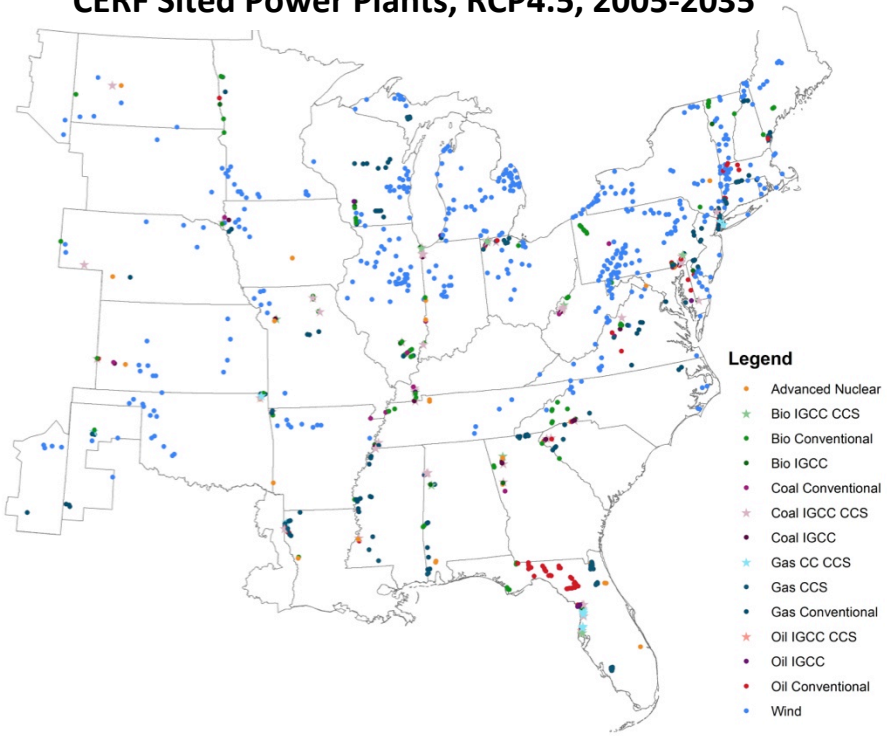
- Geolocated Power Plants
- Sited and Unsited Capacity by Technology, State, and Utility Zone
- Interconnection Costs by Technology, State, and Utility Zone

GCAM-USA – CERF Experiment Results

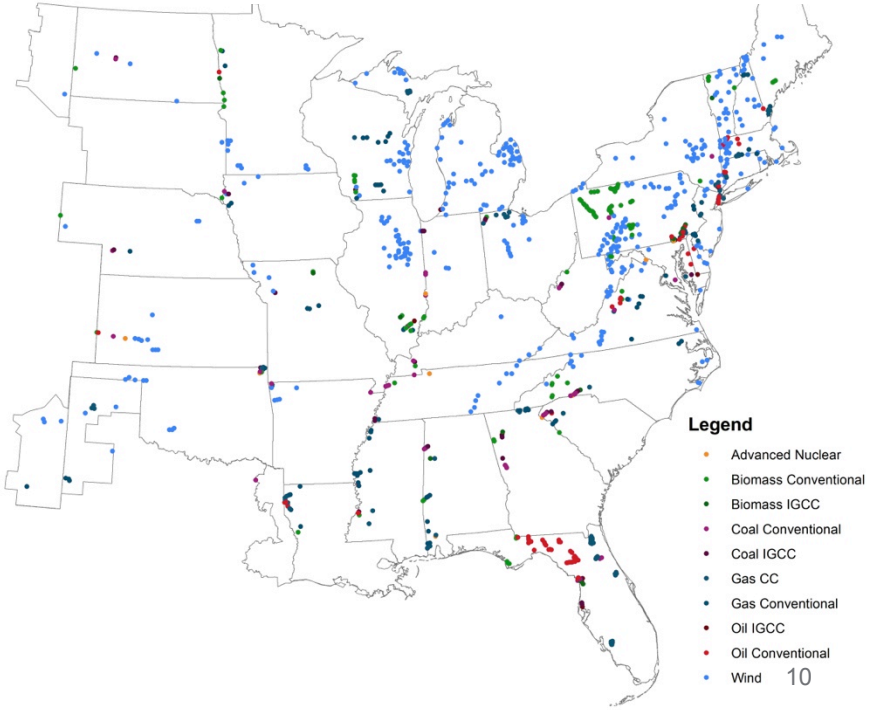




CERF Sited Power Plants, RCP4.5, 2005-2035

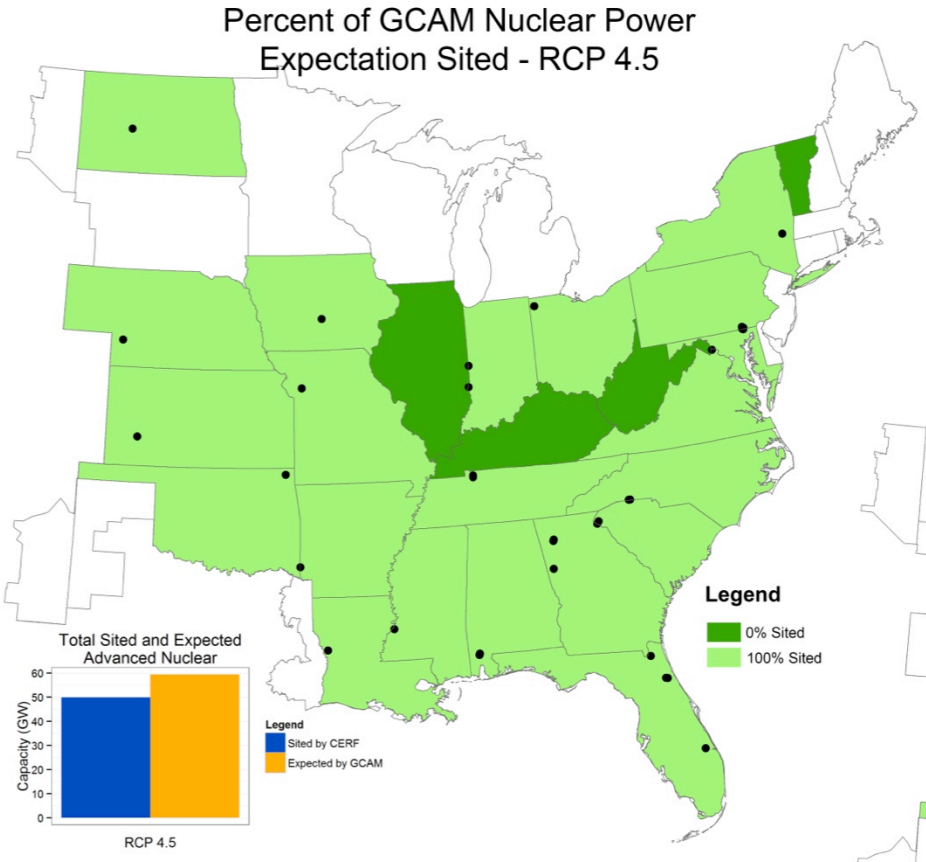


CERF Sited Power Plants, RCP8.5, 2005-2035

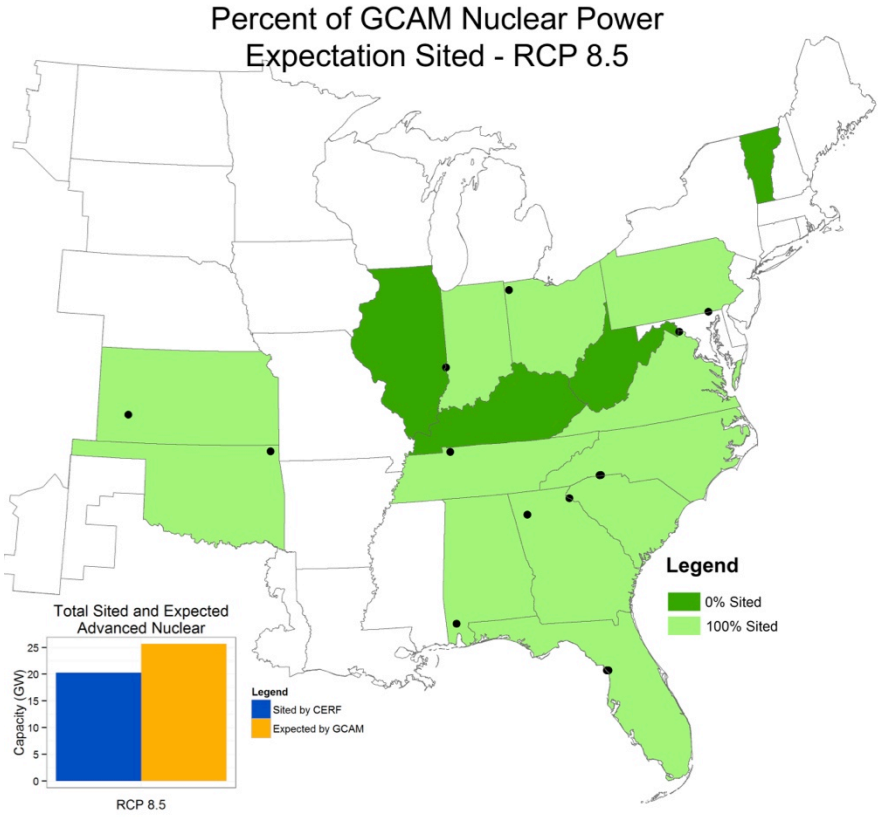


CERF Advanced Nuclear Siting (2005-2035)

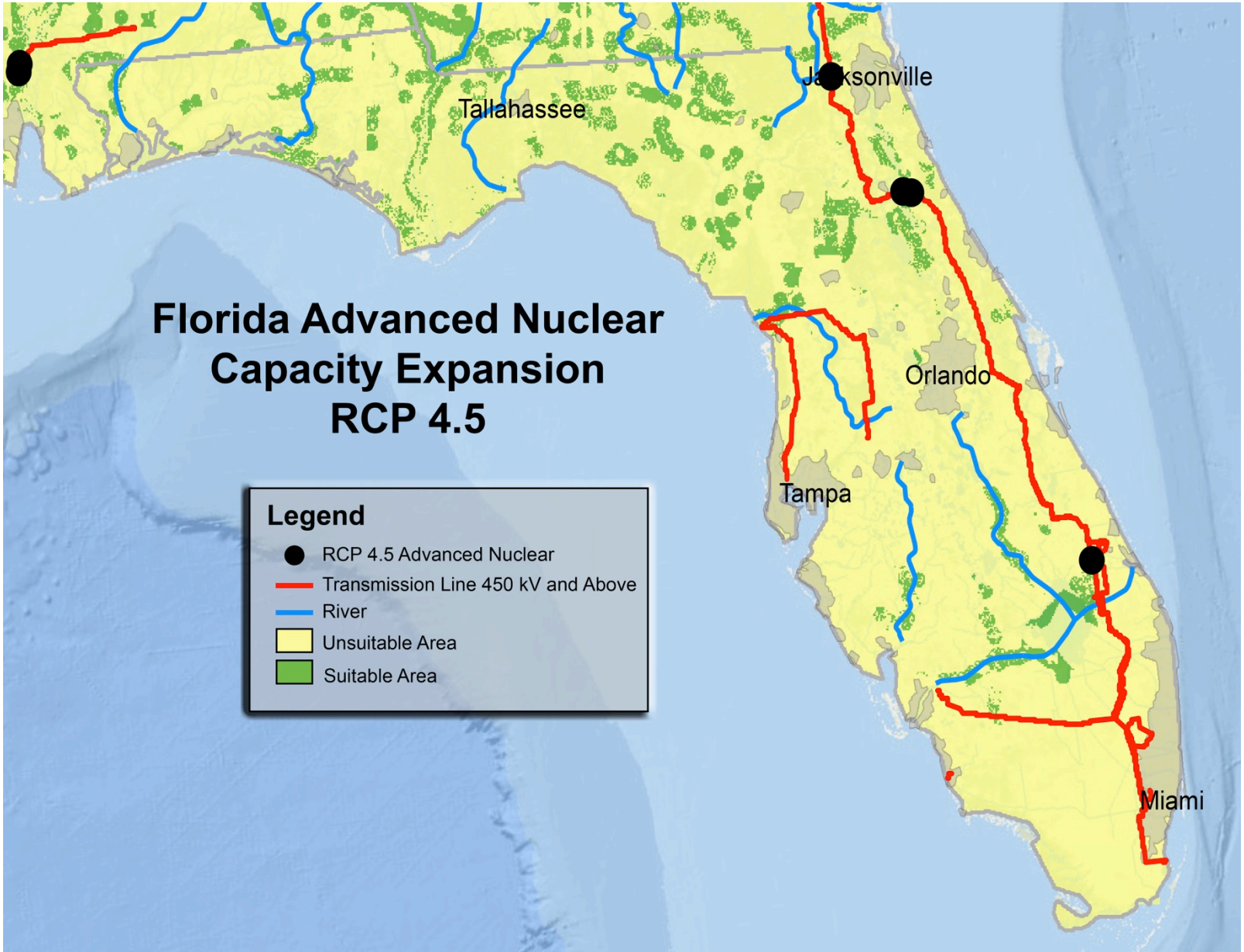
CERF Reveals Impact of Current Nuclear Moratoria



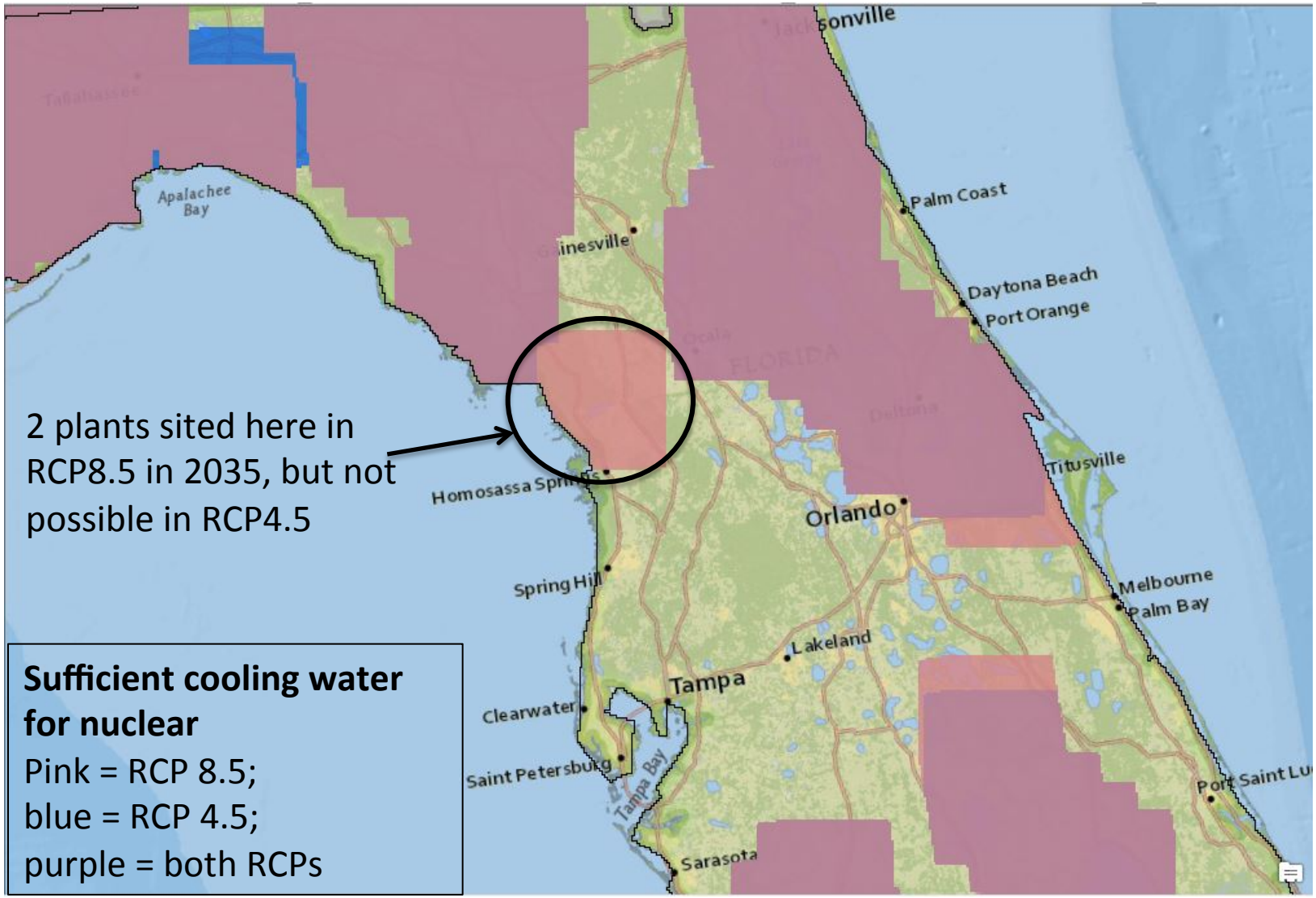
States with Nuclear Moratoria



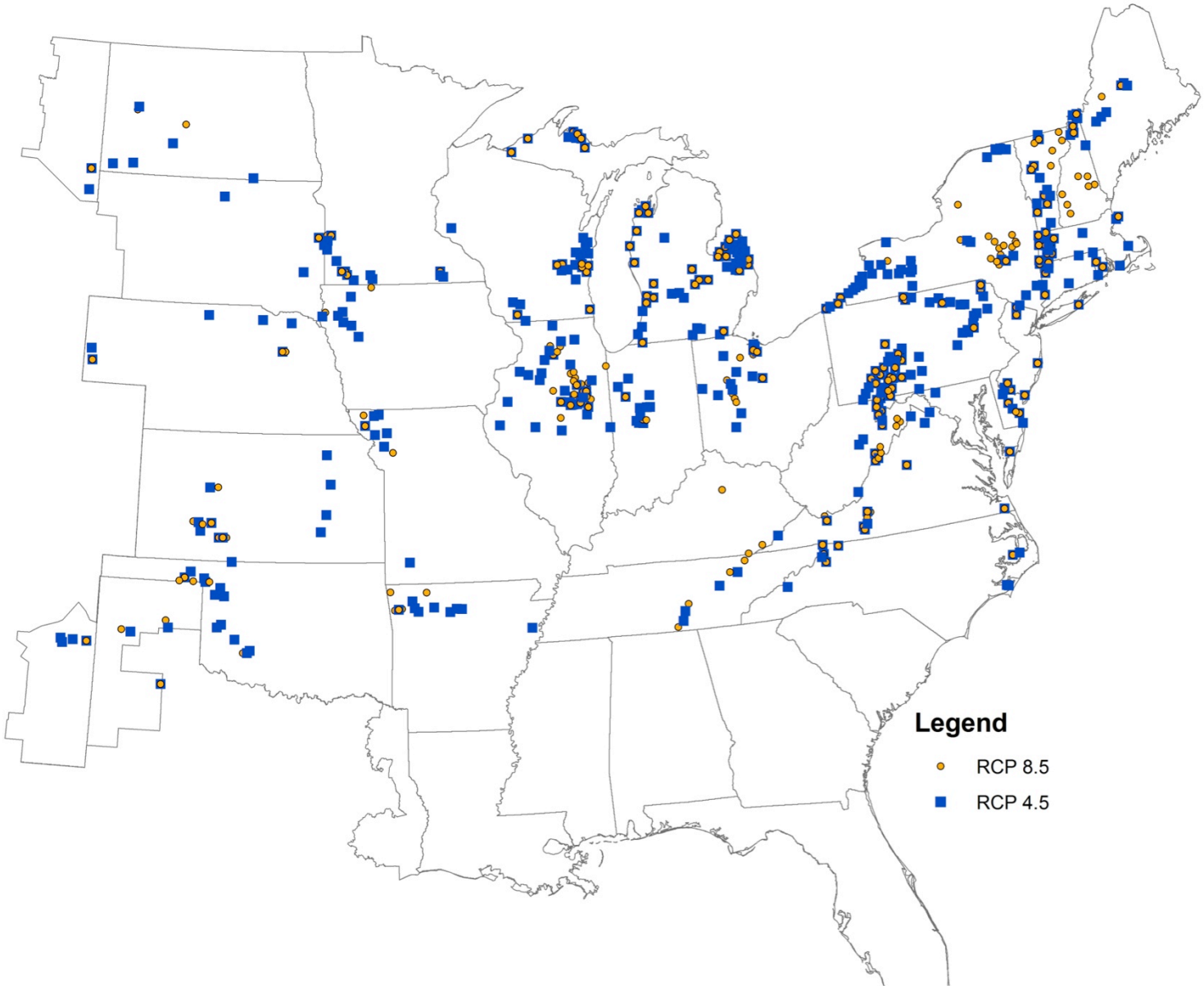
Example of CERF Siting Results Detail – Advanced Nuclear in Florida



Cooling Water Availability Affects Nuclear Plant Siting under RCP4.5

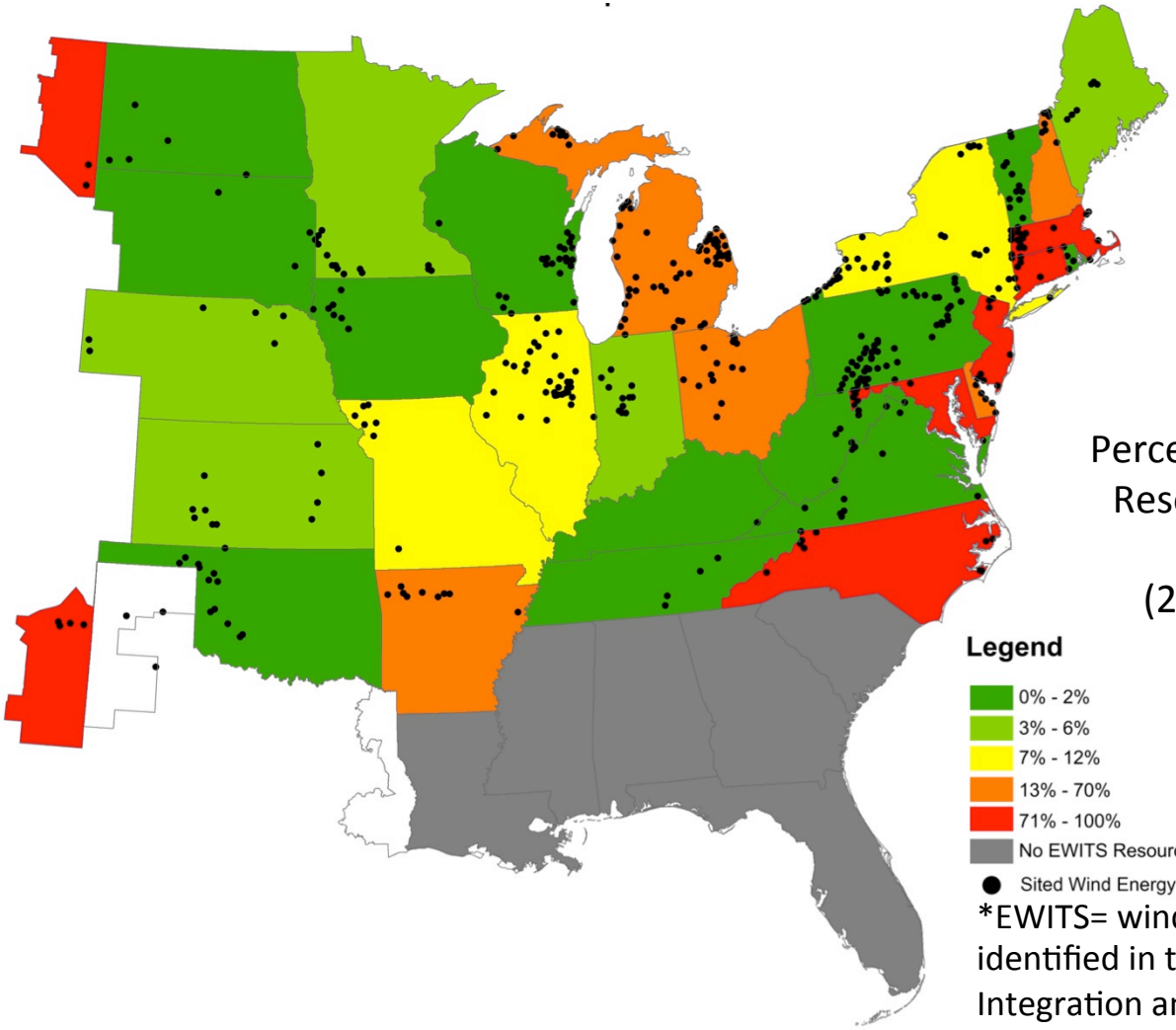


CERF Wind Farm Sitings 2005-2035



CERF Reveals Siting Constraints for Wind in Certain States

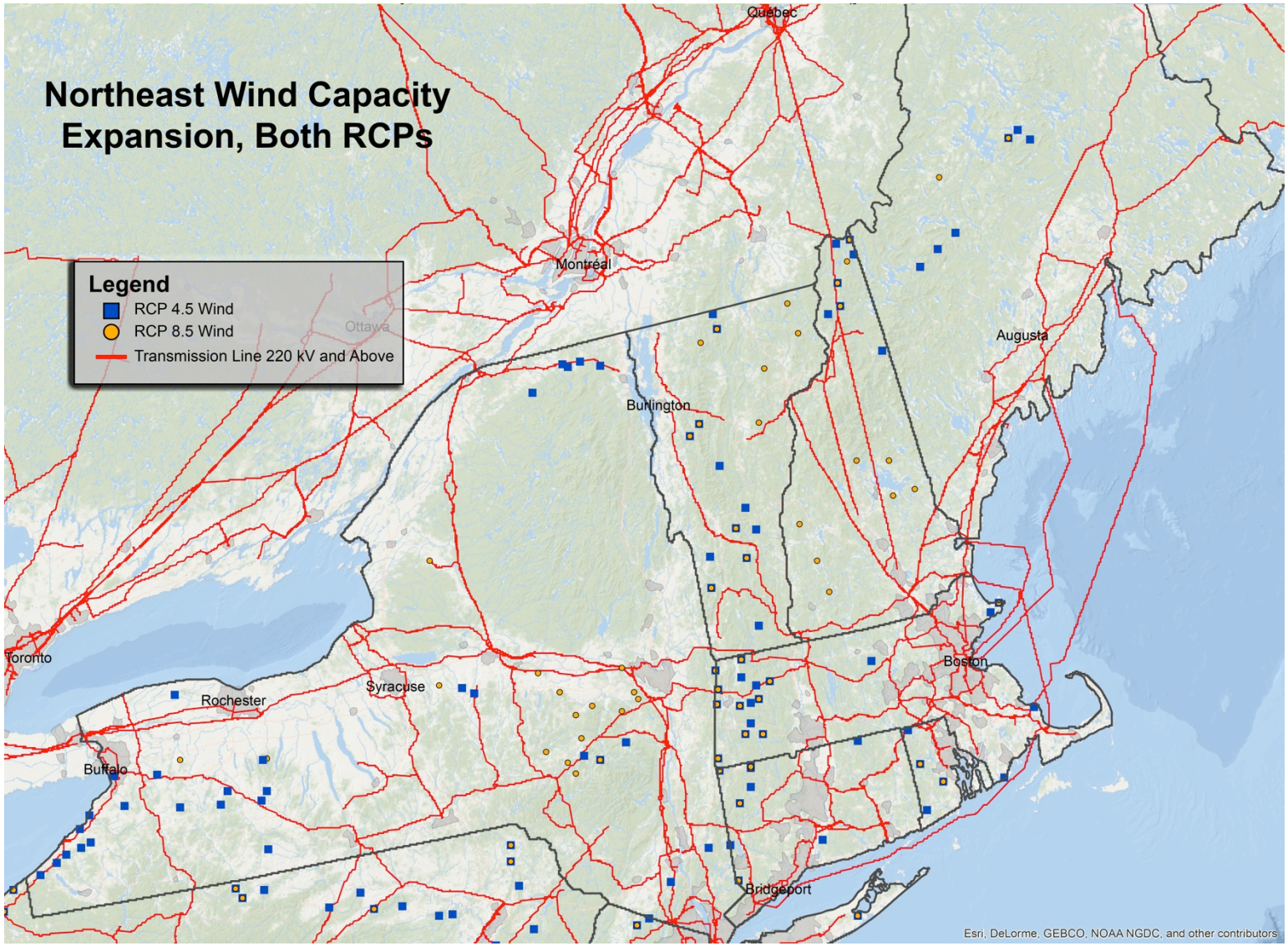
The wind energy requirements of the RCP4.5 mitigation strategy exceed the high quality wind resource available in certain states by 2035



Percent of EWITS* Resources Sited RCP4.5, (2005-2035)

*EWITS= wind farms identified in the Eastern Wind Integration and Transmission Study (NREL)

Example of CERF Siting Results Detail – Wind Farm Sitings in the Northeast

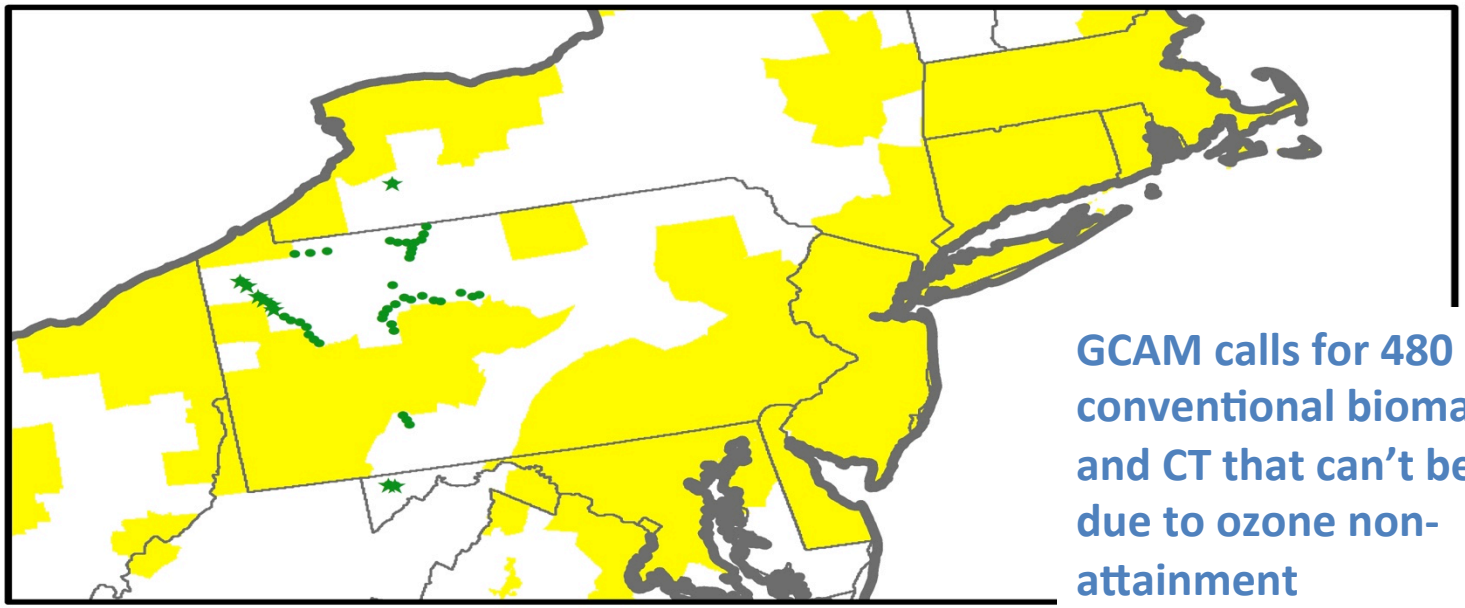


CERF Conventional Coal Sitings (2005-2035)

More coal plants are sited under the RCP8.5 no policy scenario

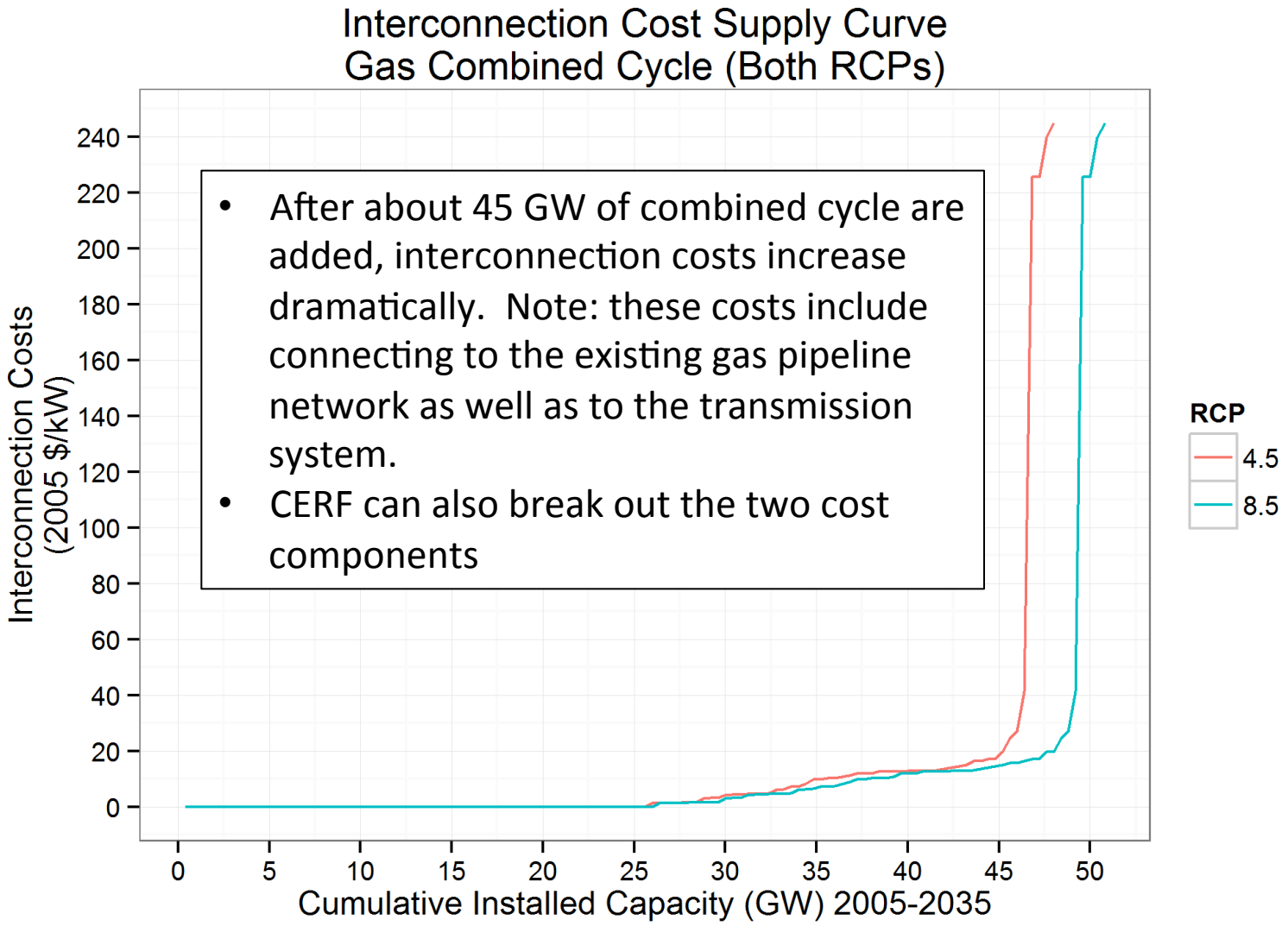
CERF Siting Constraints Revealed -- Biomass

Biomass Siting (RCP 8.5 and 4.5) Focused on Non-Attainment Areas 2005-2035



GCAM calls for 480 MW of conventional biomass in NJ and CT that can't be sited due to ozone non-attainment

CERF Interconnection Cost Results Reveal Constraints of Current Infrastructure



- After about 45 GW of combined cycle are added, interconnection costs increase dramatically. Note: these costs include connecting to the existing gas pipeline network as well as to the transmission system.
- CERF can also break out the two cost components

Potential Future Research Directions

- Explore the high resolution results for the RCPs in more detail
- Evaluate additional scenarios (e.g., no CCS (AGU paper), no nuclear, etc.)
- Implement feedbacks from CERF to GCAM-USA
  - Locations/techs with higher than average interconnection costs
  - Cooling water, land use, and air emissions-related constraints
- Address other water availability-based constraints in CERF and feedback to GCAM-USA
  - Water temperature, water deficit hotspots (part of AGU talk and paper)
- Integrate CERF with GCAM-USA/water management coupling
- Expand CERF to site solar and geothermal and produce results for Western U.S.
- Parameterize CERF to couple with GCAM-USA for other regions outside the US
- Couple GCAM-USA and CERF more tightly to facilitate scenario analysis

Backups

Net Locational Cost

$$Net\ Locational\ Cost\left(\frac{\$}{yr}\right) = Interconnection\ Cost\left(\frac{\$}{yr}\right) - Net\ Operating\ Value\left(\frac{\$}{yr}\right), \text{ where}$$

$$Interconnection\ Cost\left(\frac{\$}{yr}\right) = Distance\ to\ nearest\ suitable\ transmission\ line\ (km) \times Electric\ Grid\ Interconnection\ Capital\ Cost\left(\frac{\$}{km}\right) \times Annuity\ Factor\ + (\text{if gas-fired})\ Distance\ to\ nearest\ suitable\ gas\ pipeline\ (km) \times Gas\ Interconnection\ Capital\ Cost\left(\frac{\$}{km}\right) \times Annuity\ Factor$$

and

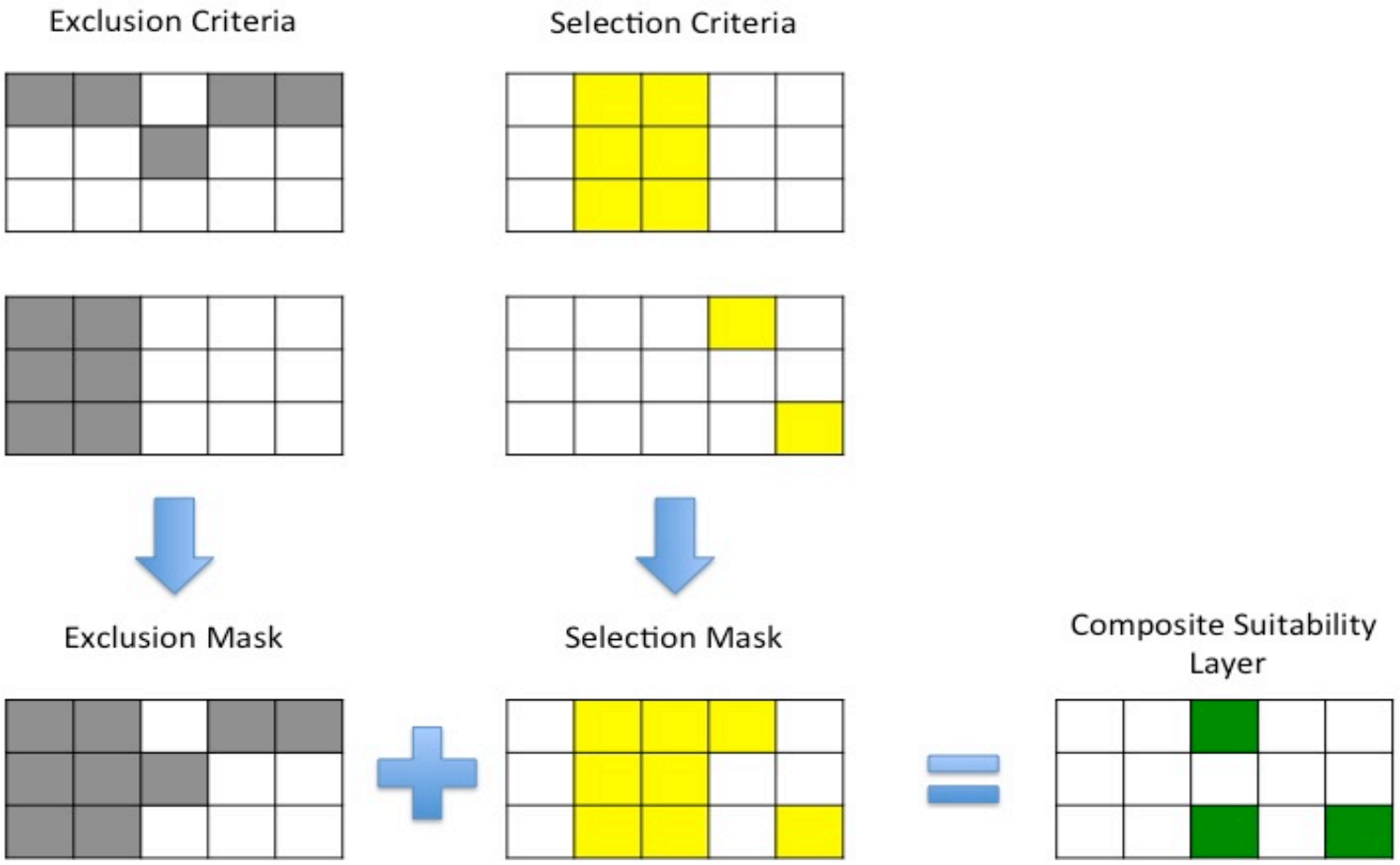
$$Net\ Operating\ Value\left(\frac{\$}{yr}\right) = Generation\left(\frac{MWh}{yr}\right) \times \left\{LMP\left(\frac{\$}{MWh}\right) - Operating\ Costs\left(\frac{\$}{MWh}\right)\right\} \times Levelization\ Factor$$

where,

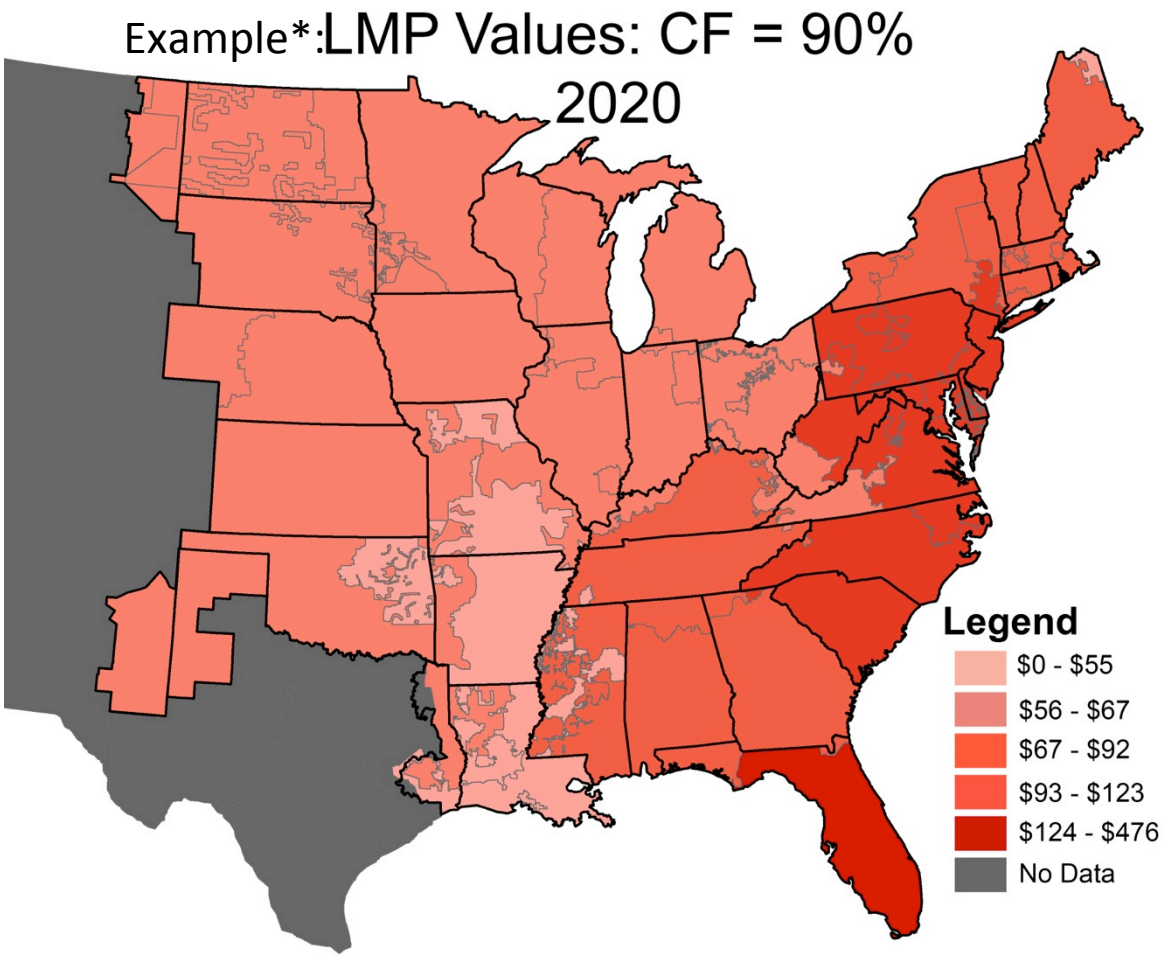
$$Operating\ Costs\left(\frac{\$}{MWh}\right) = Heat\ Rate\left(\frac{Btu}{kWh}\right) \times Fuel\ Price\left(\frac{\$}{MBtu}\right)\left(\frac{MBtu}{10^6\ Btu}\right)\left(\frac{10^3\ kWh}{MWh}\right) + Variable\ O\&M\ Cost\left(\frac{\$}{MWh}\right) + Carbon\ Price\left(\frac{\$}{ton}\right) \times Carbon\ Fuel\ Content\left(\frac{tons}{Btu}\right) \times Heat\ Rate\left(\frac{Btu}{kWh}\right)\left(\frac{10^3\ kWh}{MWh}\right) \times \left(1 - Carbon\ Capture\ Rate\ (\%)\right)$$

Note: Levelization factors are computed separately for each component of Net Operating Value

GIS process to determine suitability



Locational Marginal Prices are Averaged by Capacity Factor (CF)



*LMPs are calculated for 10, 30, 50, 80, and 90% capacity factors. LMPs are calculated by a production cost model (e.g., PROMOD).

Technology-Specific GIS Layers

Exclusions	Raw GIS Data Source	Buffer	Applied to these Technology Types
• Non-attainment areas for CO, SO_x, NO_x, ozone, lead, PM10, and PM 2.5	National Transportation Atlas Database (NTAD)	0	Conventional coal and biomass-fired
• Major airports (at least 30,000 operations per year, (Mays 2011))	Federal Aviation Administration	Variable	0 buffer for peaking gas and oil; 10 mile buffer for nuclear; 3 mile buffer all other technologies
• Earthquake risk (USGS Peak Ground Acceleration 0.3g, 2% probability in 50 years)	USGS	0	Nuclear
• Population density	U.S. Census, PNNL	Variable	All except peaking gas and oil; differential criteria based on technology type (assumptions described in text)
• State moratoria	NA	0	Nuclear (MN, WI, IL, KY, and WV in pilot region; 8 other states across U.S.[a]); Coal (MN) (Hemphill 2011)
Selections[b]			
• Proximity to coal mines	Platts	32 km (20 mi)	All coal-fired technologies
• Proximity to transportation infrastructure (railroad hubs, navigable waterways)	NTAD, USACE/National Atlas	5 km	All coal-fired, biomass-fired, oil-fired, and nuclear
• Cooling water availability	WM output	20 km	All; differential criteria based on intake requirements and Clean Water Act 316(b)

Current dynamic layers; straightforward to make other layers dynamic

Overview of PRIMA Couplings to Project Surface Water Supply, Demand, and Deficits

Regional Earth System Model (1/8th deg, hourly, 12 meteorological variables)

Daily temps for HDD/CDD

Integrated Assessment Model (energy & ag economy; state & national, annual)

Detailed technology characterization, policy, GDP, demography

Meteorological forcing

Land Surface Hydrology Model (1/8th degree, hourly)

Daily gridded surface and subsurface runoff

River Routing Model (1/8th degree, hourly)

Hourly natural streamflow

Simulations are from 1985-2100

Sector	Water Withdrawal	Water Consumption
Domestic		
Manufacturing		
Electricity Generation		
Resource Extraction		
Irrigated Crops		
Livestock		

Key: Spatial Resolution

US

Ag Zone

State

Spatial and temporal downscaling at 0.5 deg using geospatial data such as seasonal temperatures, gridded population, livestock density, power plant locations, crop locations, etc.

Power Plants

Population (1/8th deg)

Etc.

Water Management Model (1/8th degree, daily)

Regulated streamflow and deficits

Daily irrigation and non-irrigation water demands