10,000 Feet through 1,000 Feet: Linking an IAM (GCAM) with a Detailed U.S. Electricity Model (ReEDS)

Snowmass

August 6, 2009

Snowmass, CO

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Introduction

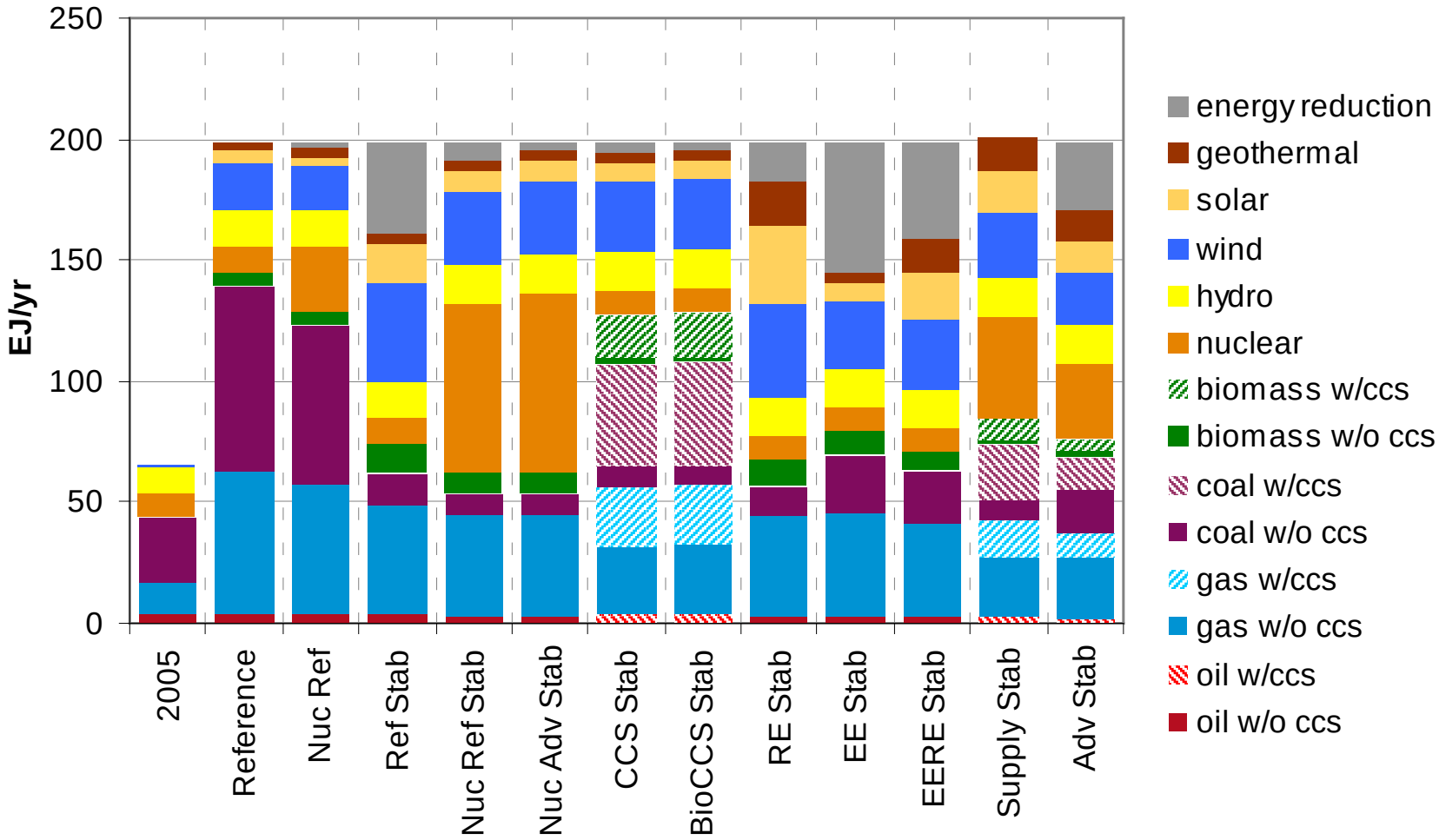
(To a Work in Progress!)

The Use of IAMs for Strategic Technology Planning

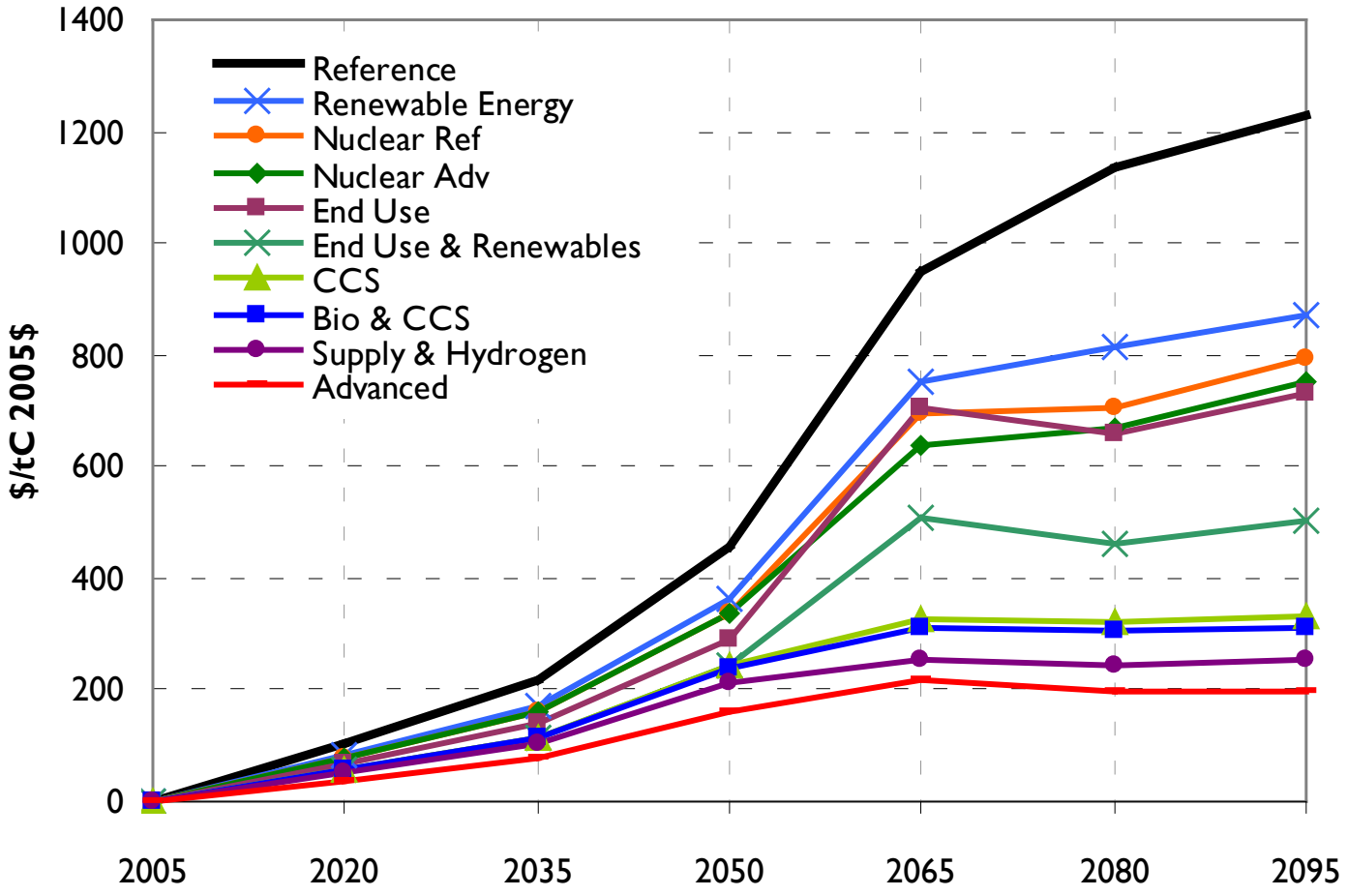
The U.S. Climate Change Technology Program (CCTP) uses integrated assessment analysis to inform strategic technology decision making.

Scenario & Naming Convention	Reference (Ref)	Nuclear Reference (Nuc Ref)	Nuclear Advanced (Nuc Adv)	CCS (CCS)	Bio and CCS (BioCCS)	Renewables (RE)	End Use (EE)	End Use & Renewables (EERE)	Hydrogen & Supply (Supply)	Advanced (Adv)
Transportation: Electric Vehicles	Reference	Reference	Reference	Reference	Reference	Reference	Advanced	Advanced	Reference	Advanced
Transportation: Fuel Cell Vehicles	Reference	Reference	Reference	Reference	Reference	Reference	Advanced	Advanced	Advanced	Advanced
Transportation: Other	Reference	Reference	Reference	Reference	Reference	Reference	Advanced	Advanced	Reference	Advanced
Buildings	Reference	Reference	Reference	Reference	Reference	Reference	Advanced	Advanced	Reference	Advanced
Industry	Reference	Reference	Reference	Reference	Reference	Reference	Advanced	Advanced	Reference	Advanced
Electricity and Hydrogen CCS	No CCS	No CCS	No CCS	Advanced	Advanced	No CCS	No CCS	No CCS	Advanced	Advanced
Agricultural Productivity	Reference	Reference	Reference	Reference	Advanced	Advanced	Reference	Advanced	Advanced	Advanced
Hydrogen Production	Reference	Reference	Reference	Reference	Reference	Reference	Reference	Reference	Advanced	Advanced
Wind Power	Reference	Reference	Reference	Reference	Reference	Advanced	Reference	Advanced	Advanced	Advanced
Solar Power	Reference	Reference	Reference	Reference	Reference	Advanced	Reference	Advanced	Advanced	Advanced
Nuclear Fission	No New Nuclear	Reference	Advanced	No New Nuclear	No New Nuclear	No New Nuclear	No New Nuclear	No New Nuclear	Advanced	Advanced
Geothermal	Reference	Reference	Reference	Reference	Reference	Advanced	Reference	Advanced	Advanced	Advanced

Global Electricity Deployment Levels in 2050 from the CCTP Scenarios



Carbon Prices across the CCTP Scenarios



Strengths and Weaknesses of IAMs in Strategic Technology Planning

- Integrated assessment models focus on a broad view of mitigation and technological interactions.
  - They capture a range of technology interactions that would not be possible with more focused models.
- However, IAMs do not necessarily capture all the details that might be important influences on deployment of renewable energy, nor can they explain many of the details of these deployments (e.g., subregional deployment levels).

The PNNL/NREL Collaboration for CCTP

- By “combining” a global IAM with a detailed U.S. electricity capacity expansion model, we hope to:

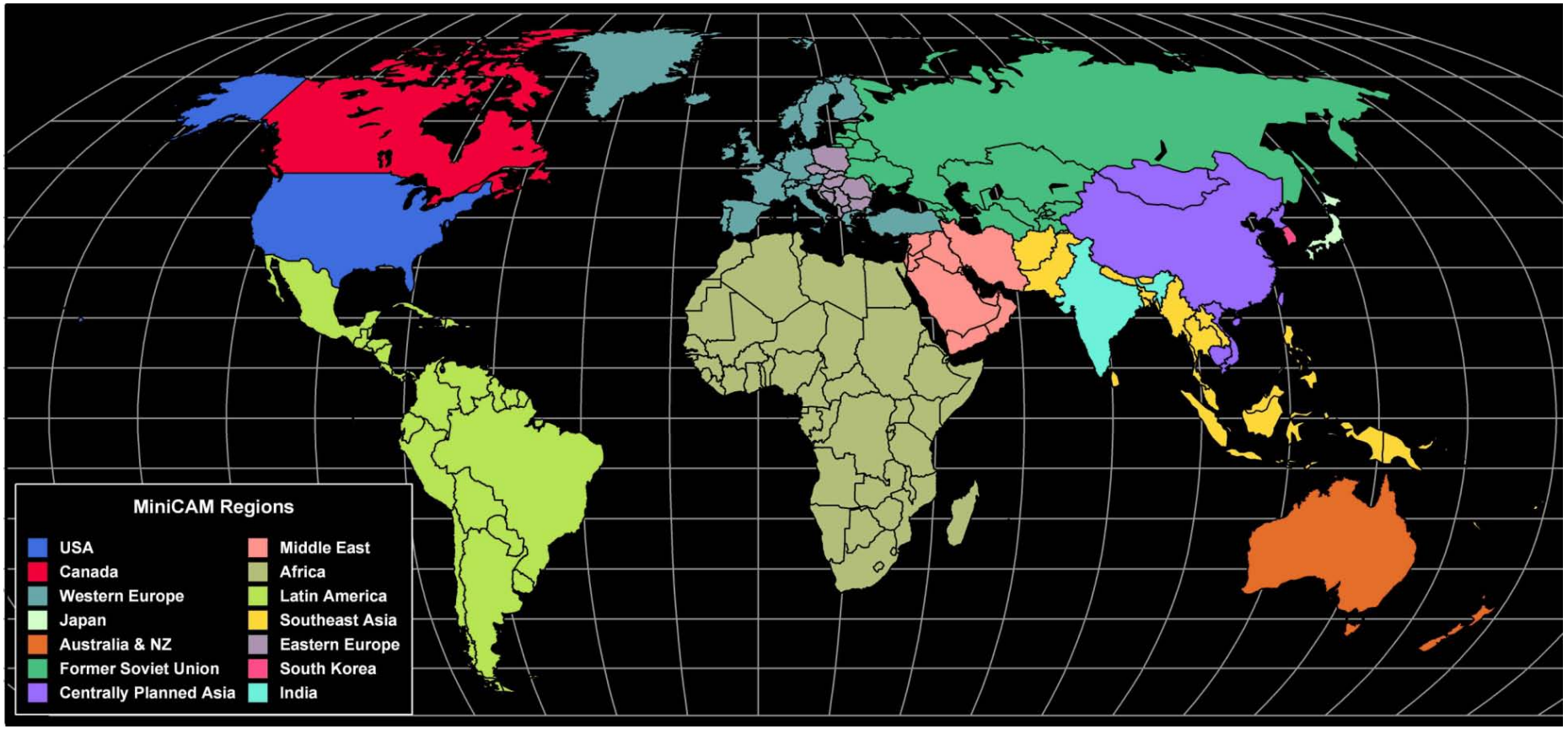
- Obtain an ability to go from 10,000 feet to 1,000 feet.
- Evolve capabilities and assumptions for both models through interactions.

Introduction to Study

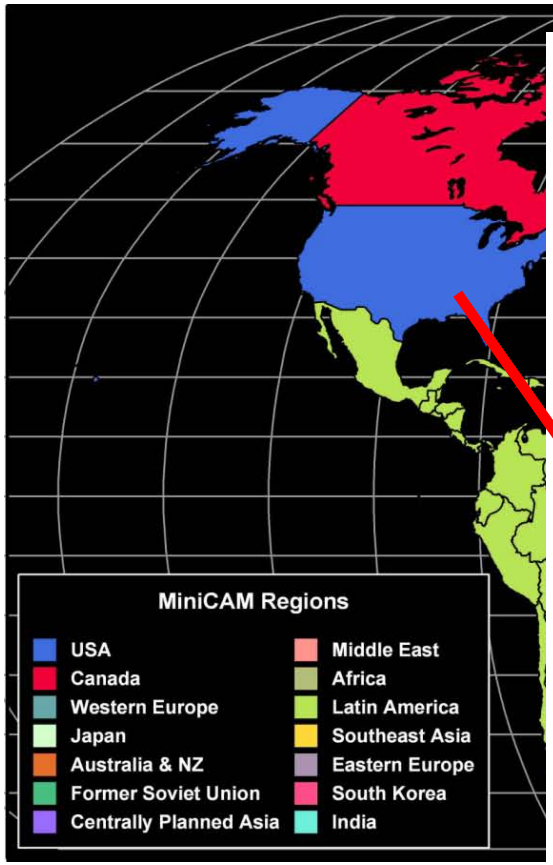
A General Outline of the Exercise

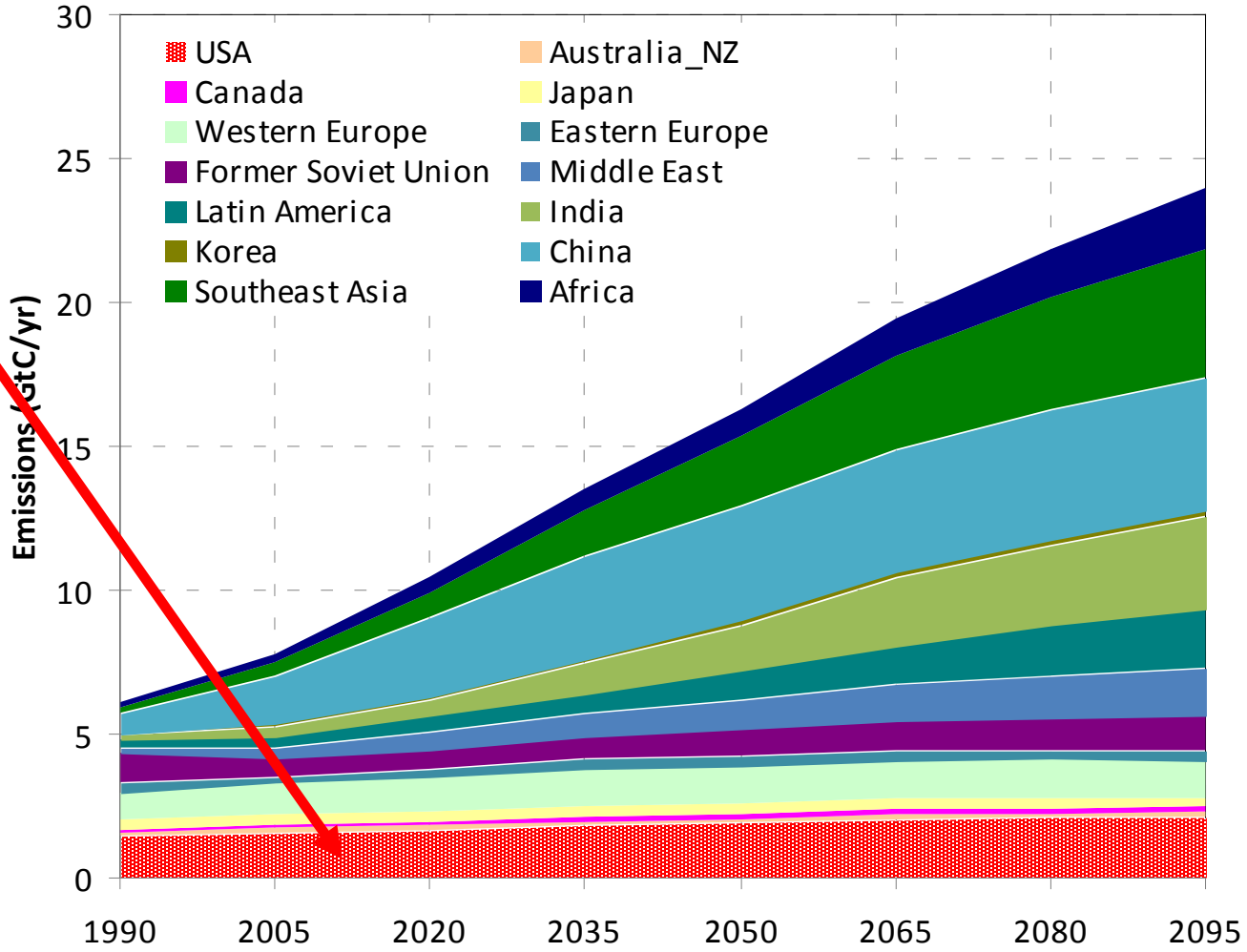
- Posit global and U.S. emissions pathways.
- Pick two technology futures, one with many competing electricity options and one with limitations on competing electricity options.
- Run the models, make adjustments, run models, make adjustments,…….
- Give presentation at Snowmass
- Run the models, make adjustments, run models, make adjustments,…….

Beginning with GCAM: A Global Perspective on Energy, Agriculture, and Climate

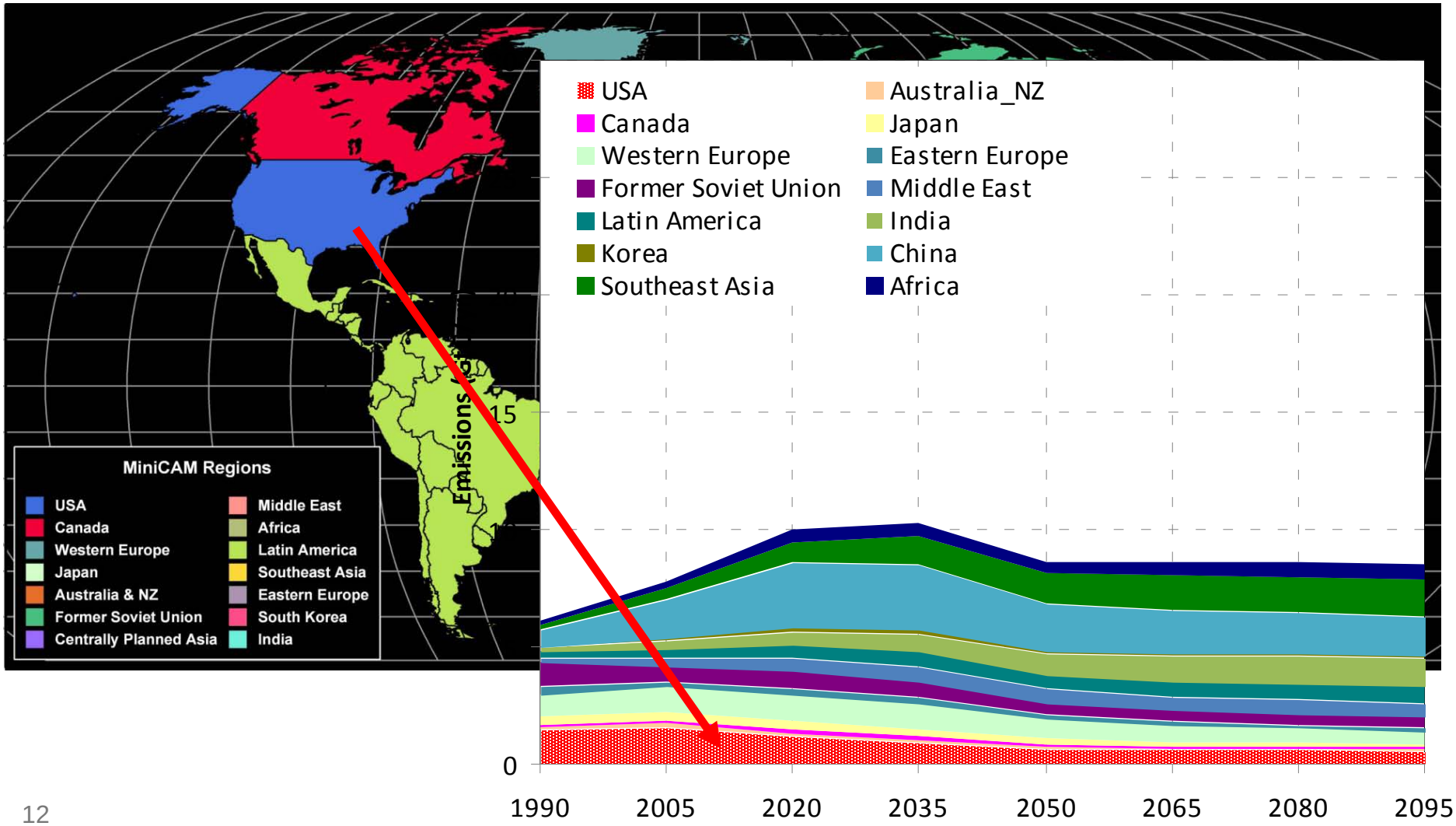


Global Emissions in the Reference Scenario

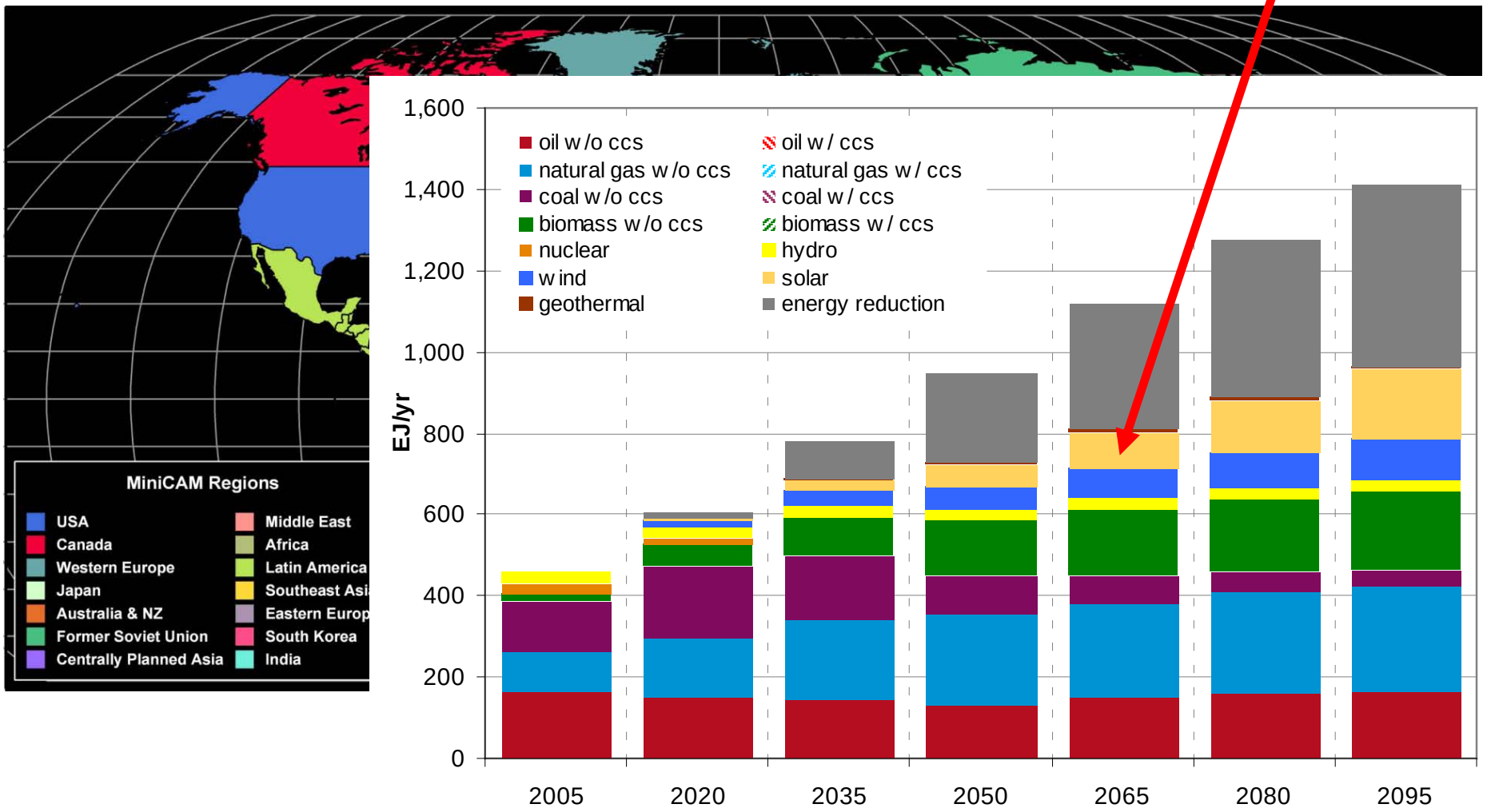




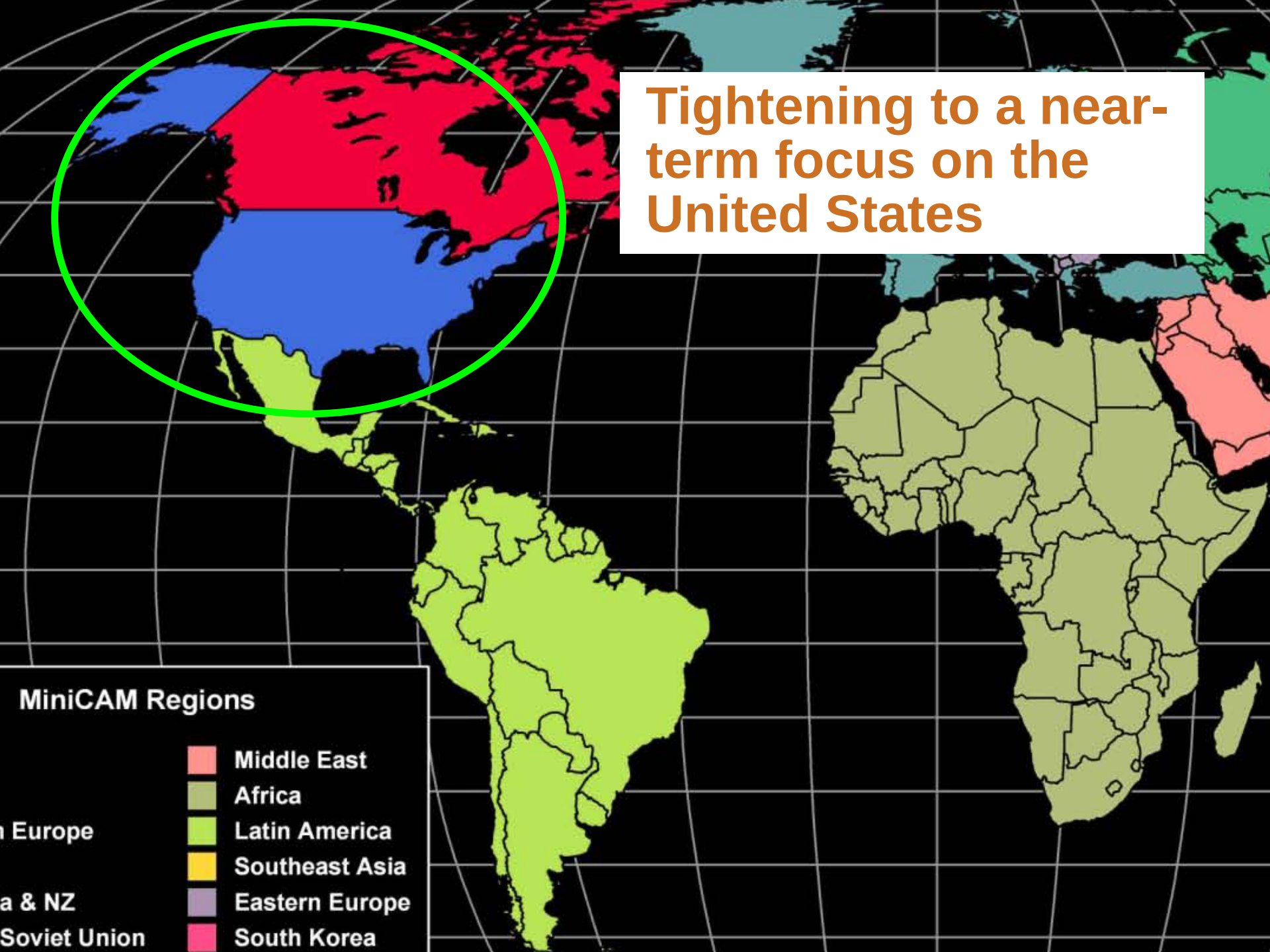
Applying a CO2 constraint alters global emissions patterns.



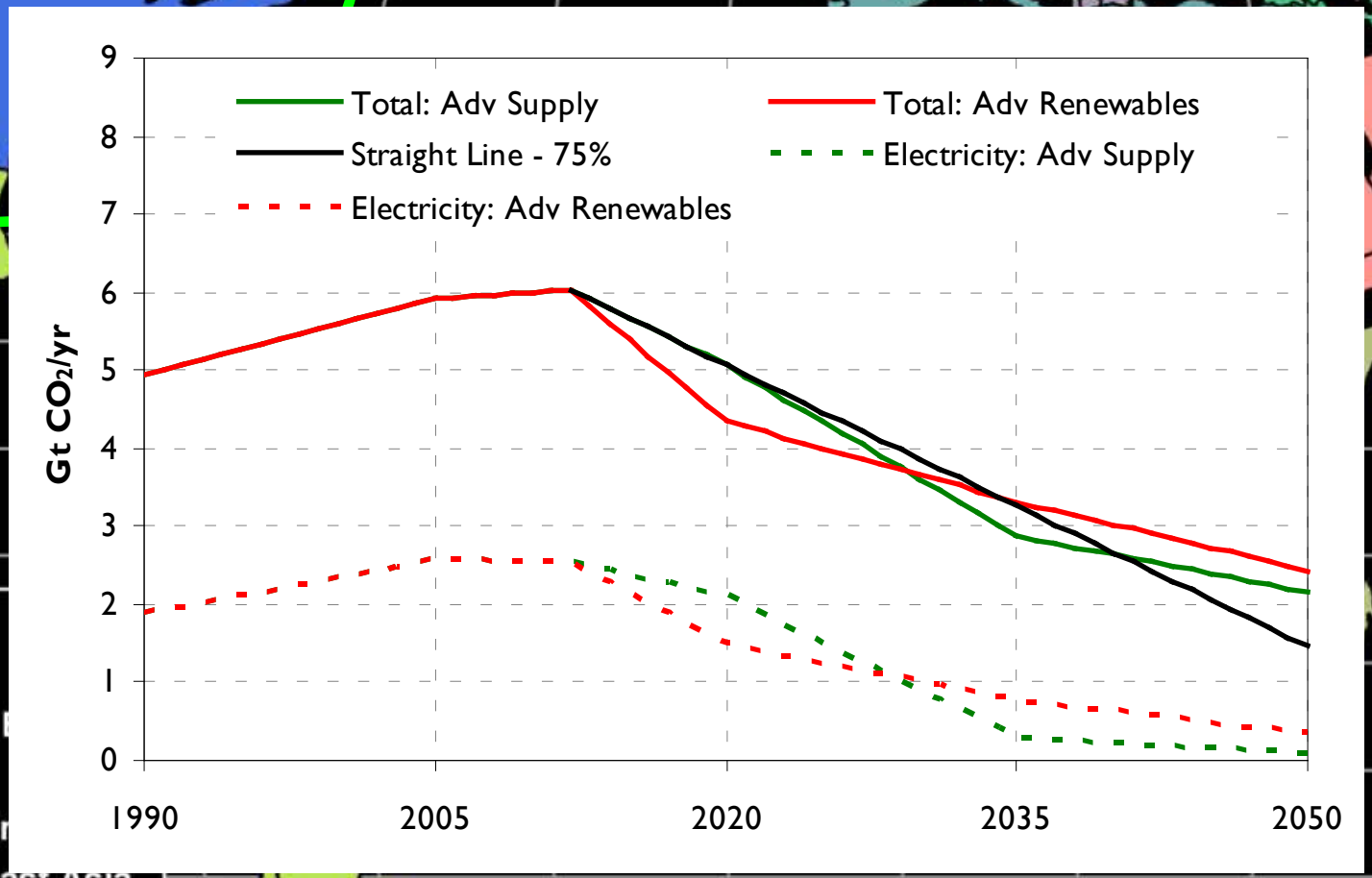
and global energy primary energy production.



Tightening to a near-term focus on the United States



The U.S. undertakes emissions reductions in the global context.



MiniCAM Regions

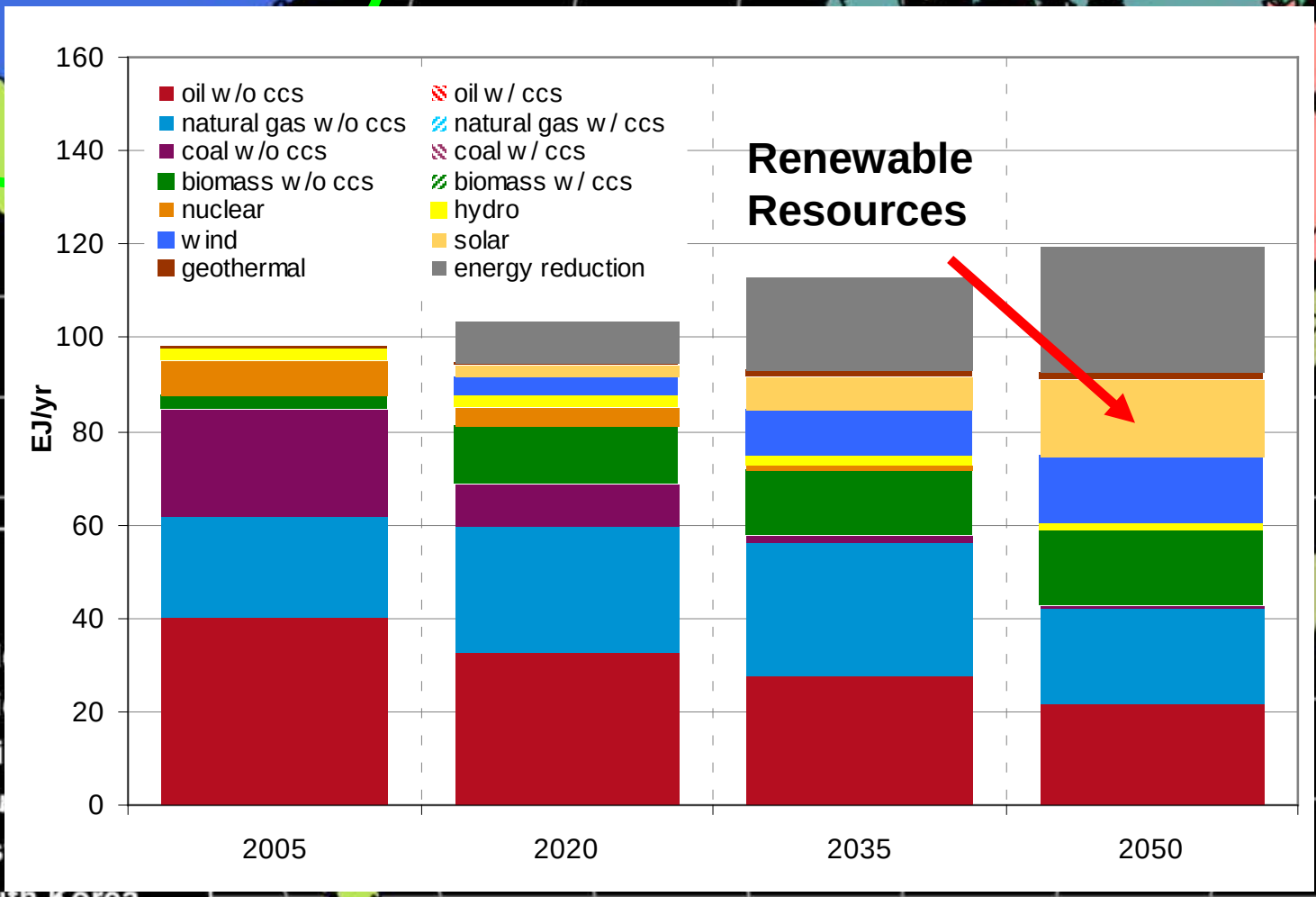
Middle E
Africa
Latin Ar
Southeast Asia
Eastern Europe
South Korea

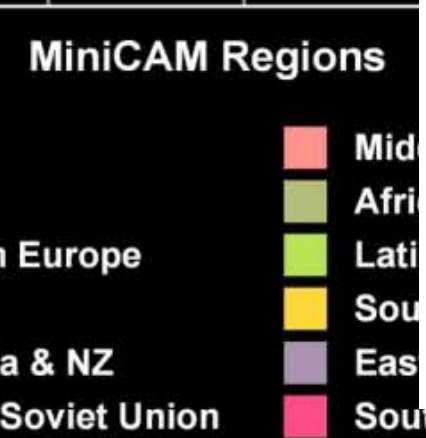
Europe

a & NZ

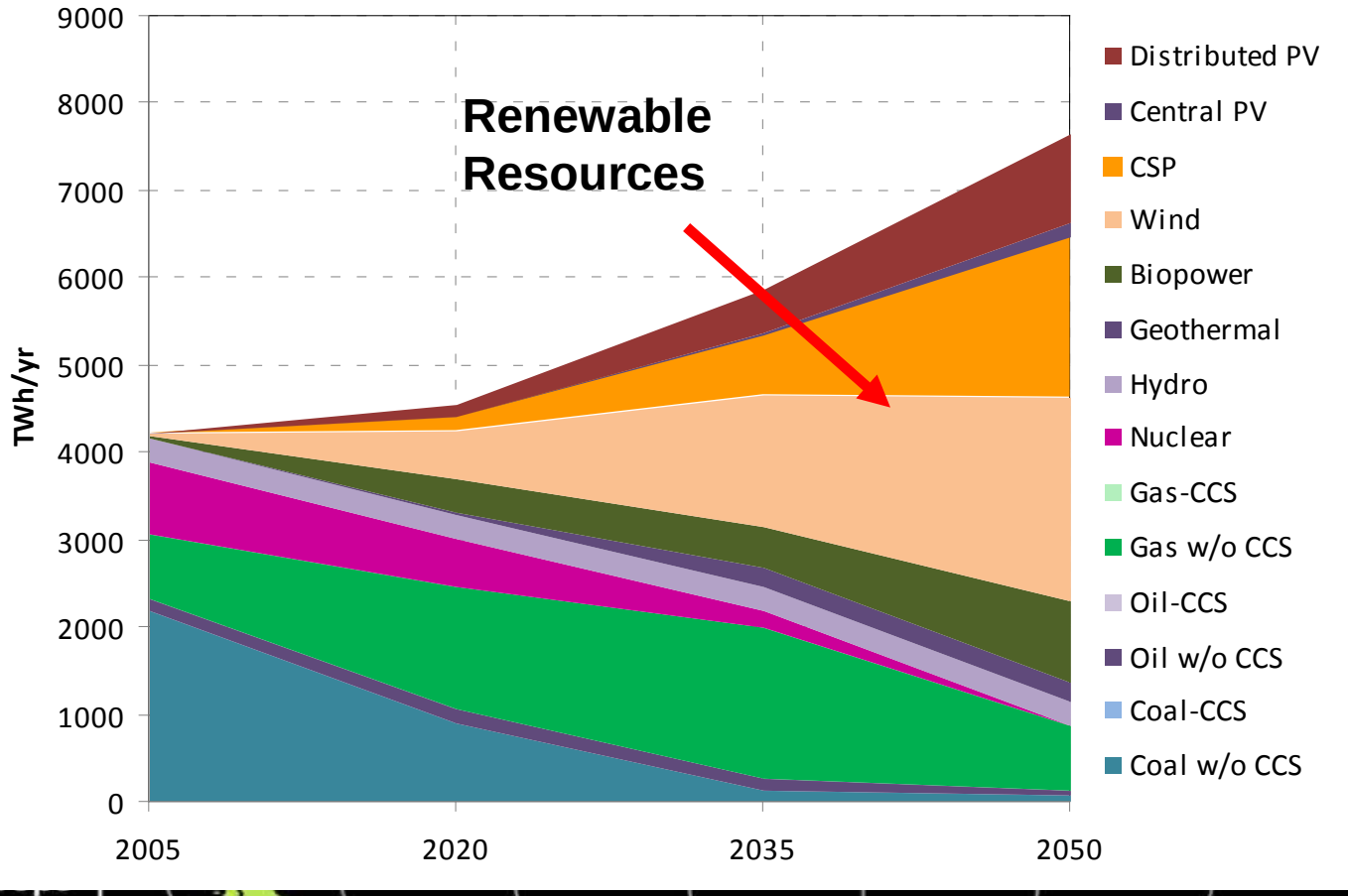
Soviet Union

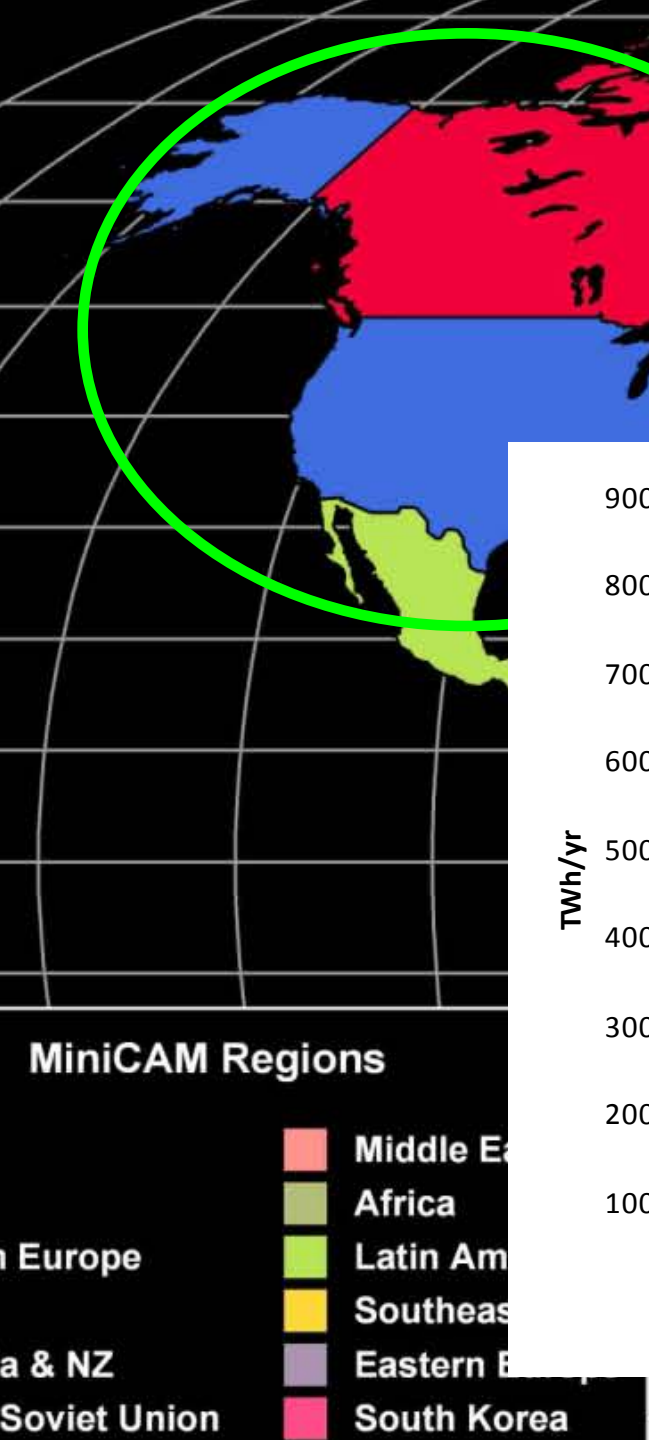
U.S. emissions constraints alter U.S. primary energy.





The emissions constraints alter U.S. electricity production.

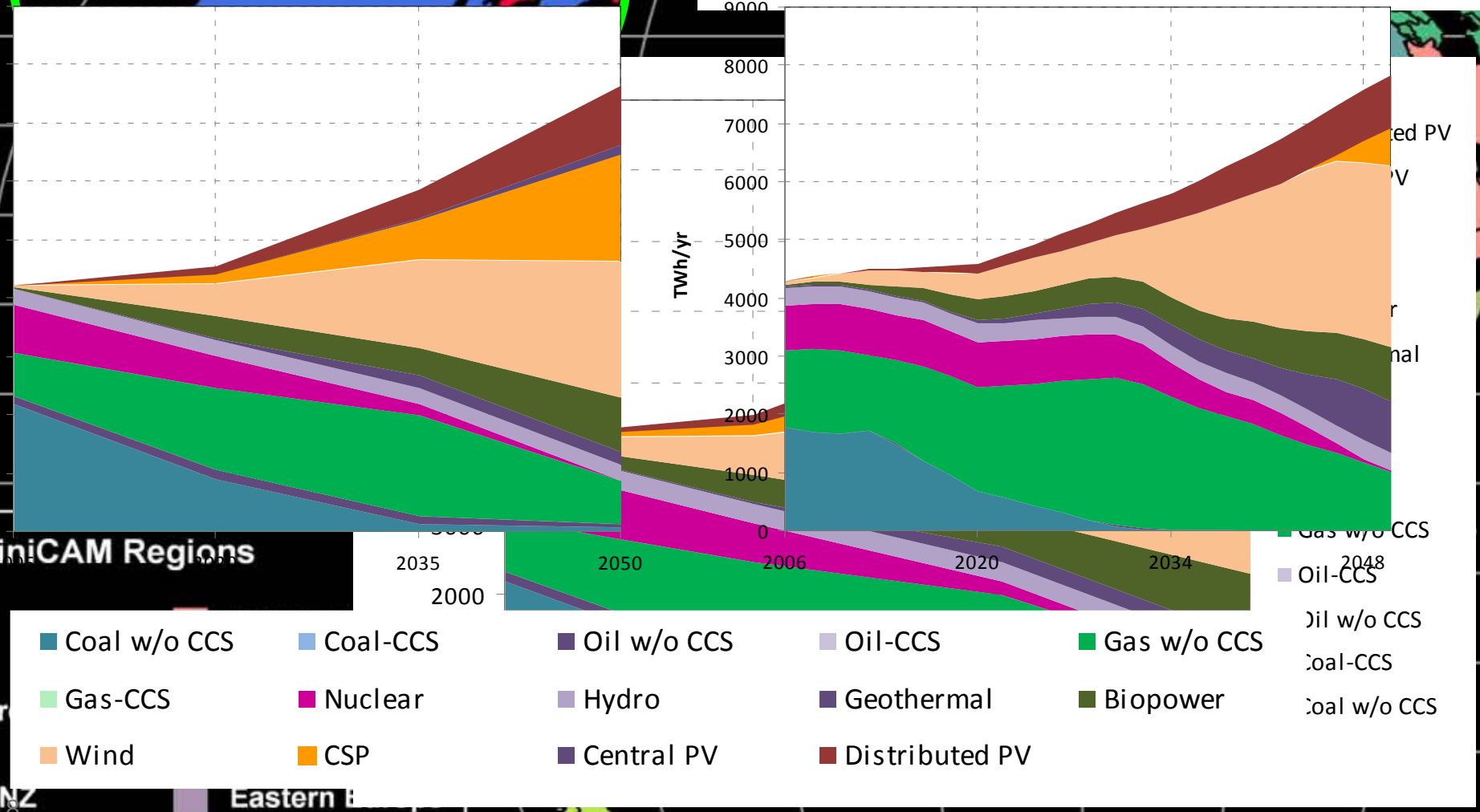


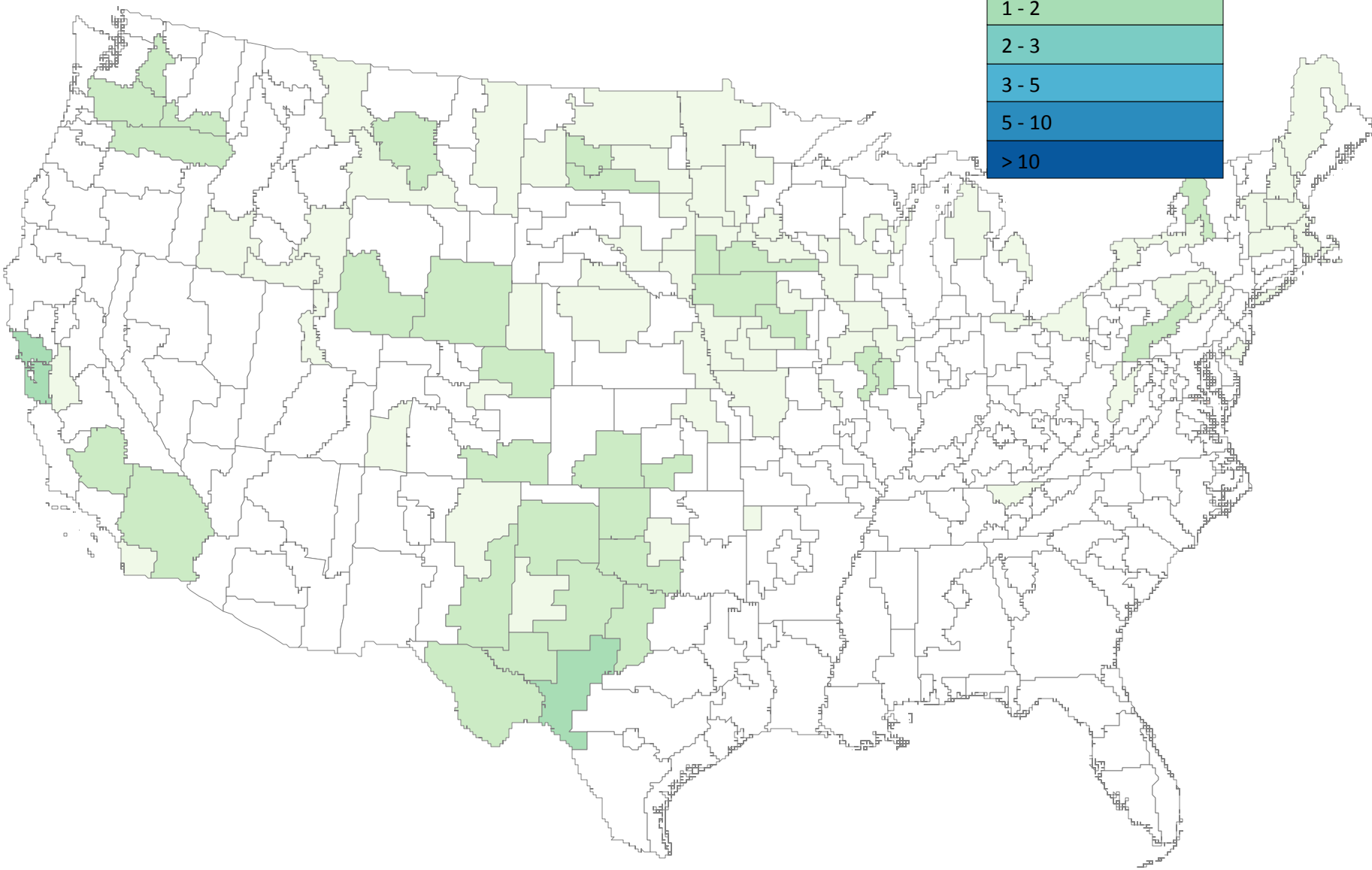


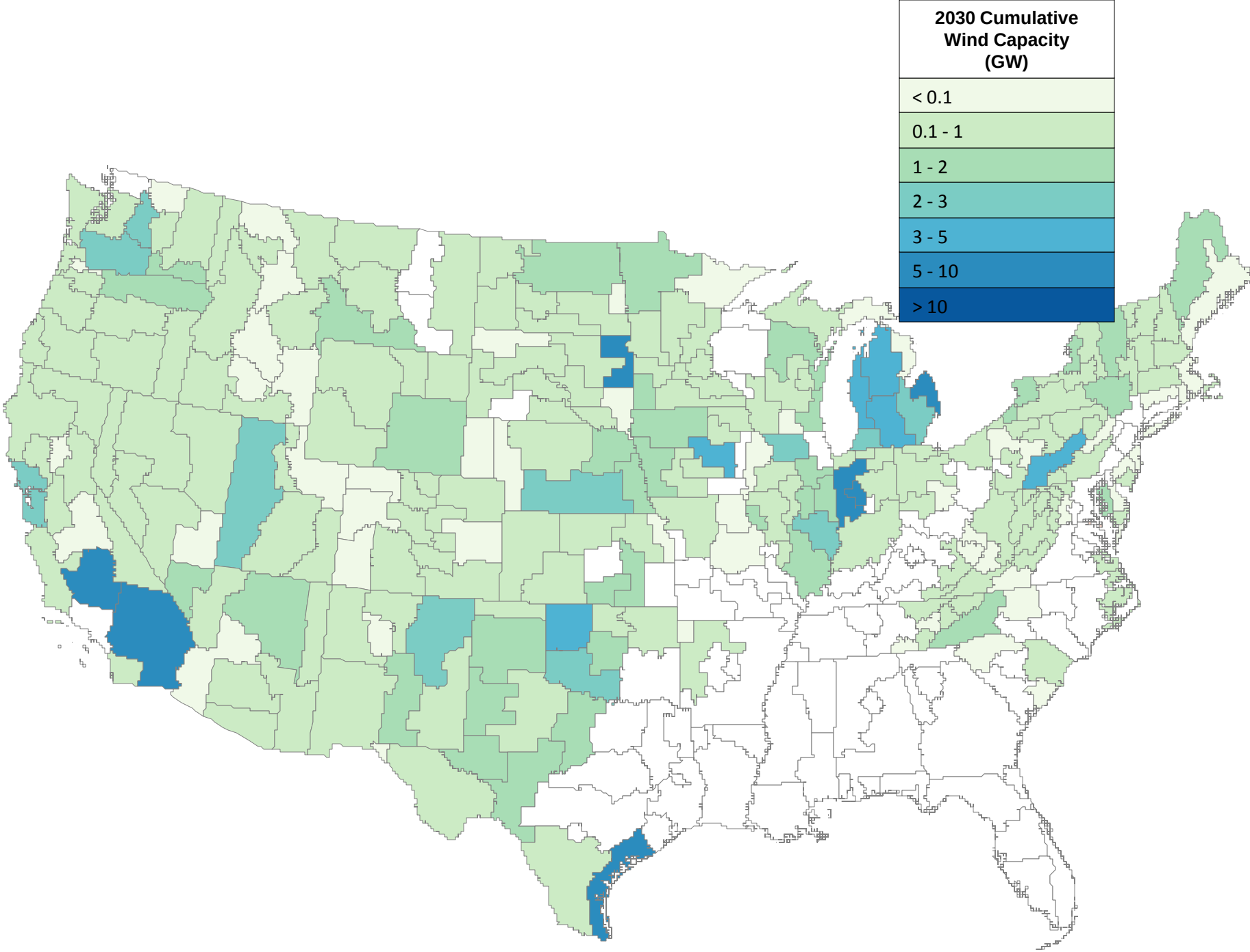
Global, long-term, fully integrated model

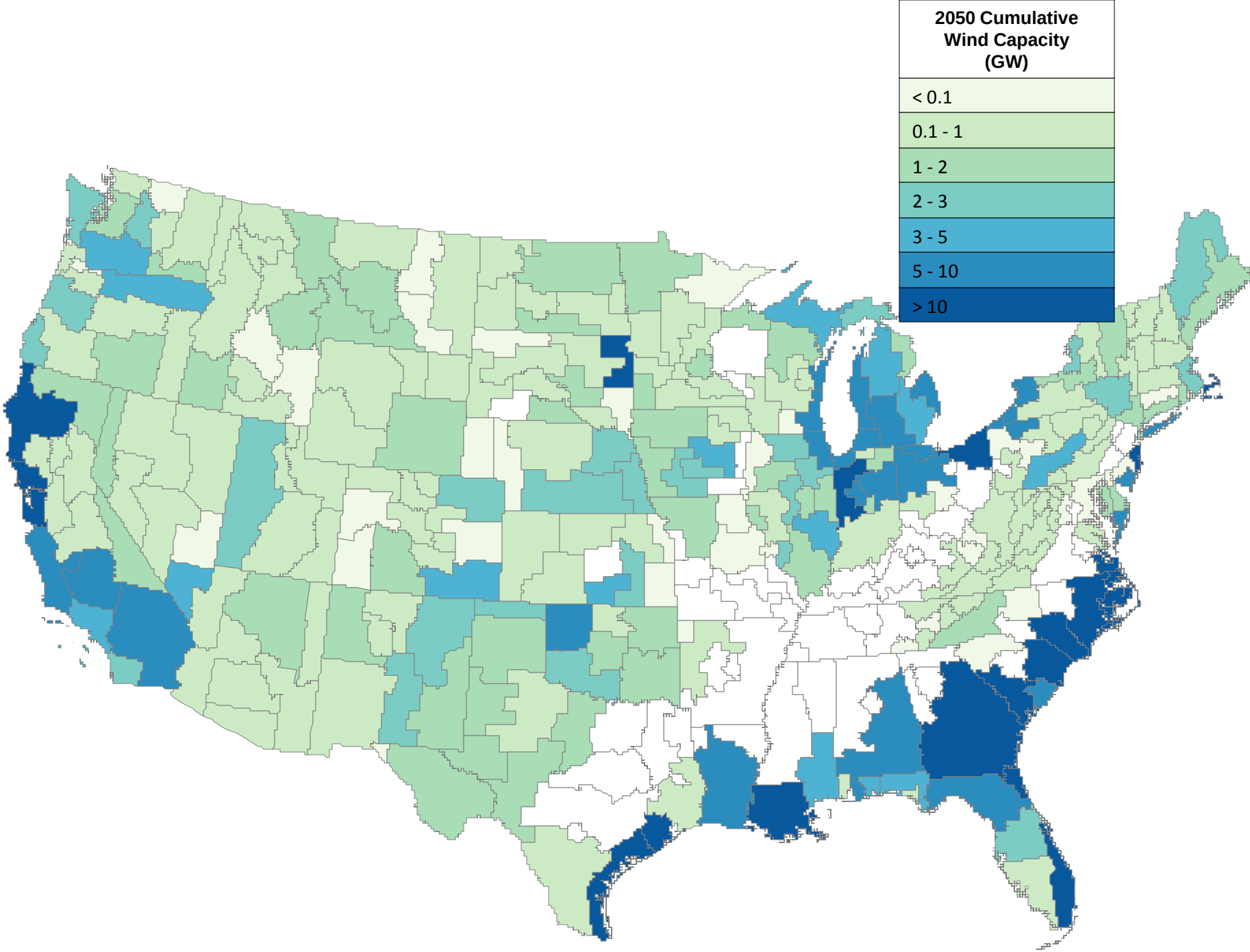
handoff to U.S. detailed, electricity modeling

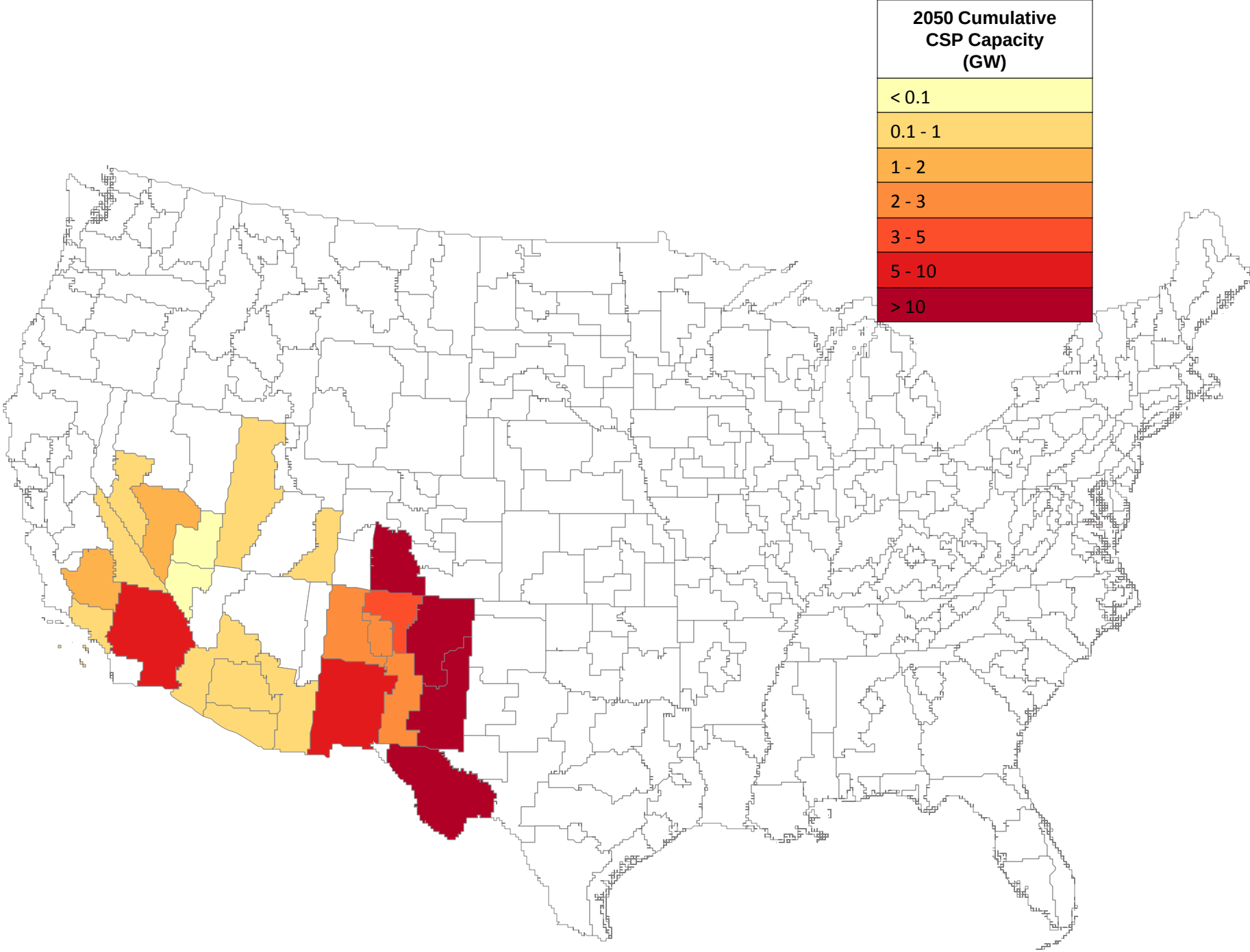
The emissions constraints alter U.S. electricity production.

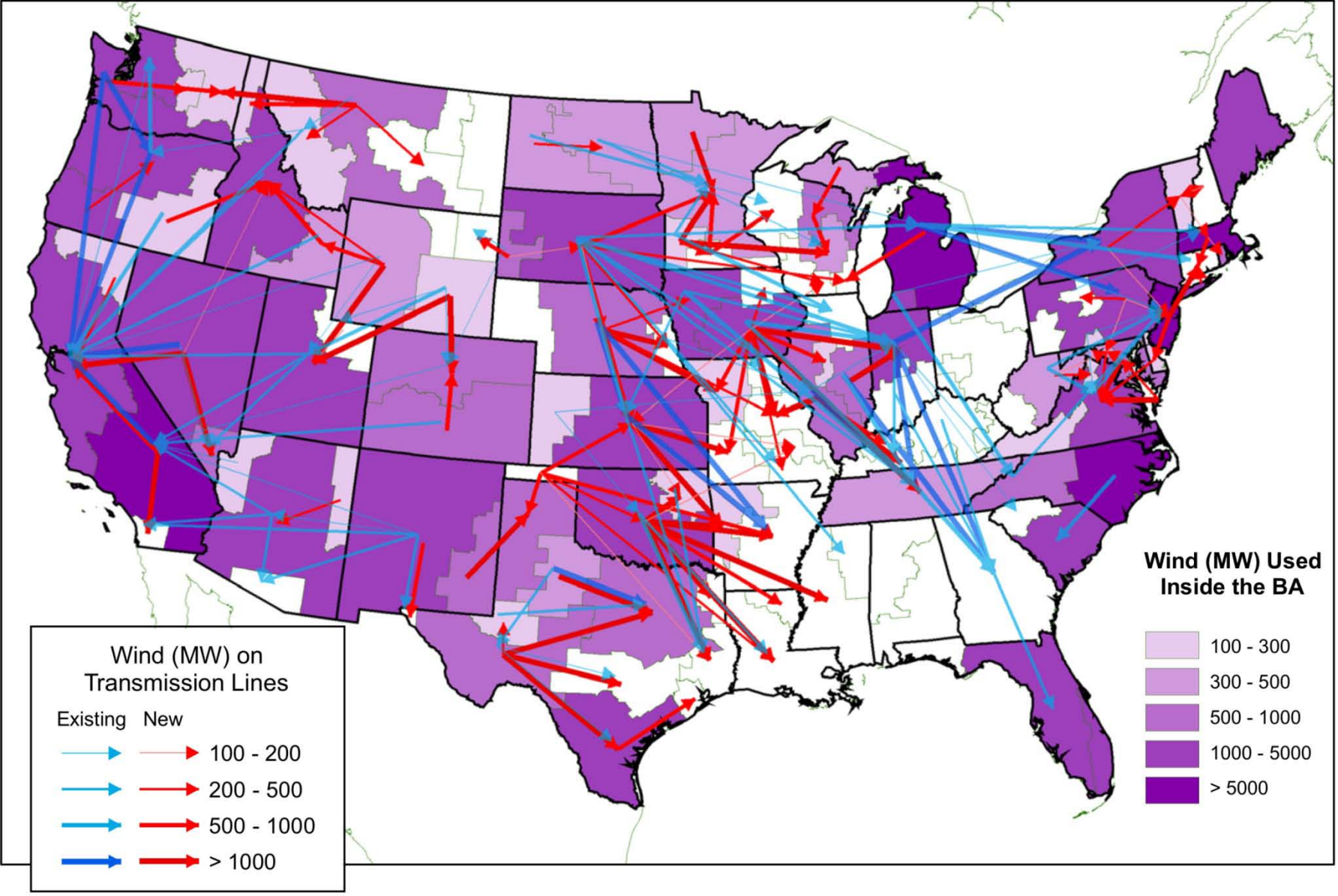



2006 Cumulative Wind Capacity (GW)
< 0.1
0.1 - 1
1 - 2
2 - 3
3 - 5
5 - 10
> 10


2030 Cumulative Wind Capacity (GW)
< 0.1
0.1 - 1
1 - 2
2 - 3
3 - 5
5 - 10
> 10


2050 Cumulative Wind Capacity (GW)
< 0.1
0.1 - 1
1 - 2
2 - 3
3 - 5
5 - 10
> 10


2050 Cumulative CSP Capacity (GW)
< 0.1
0.1 - 1
1 - 2
2 - 3
3 - 5
5 - 10
> 10



Total Between BA Transfer >= 100 MW (all power classes, land-based and offshore) in 2030.
Arrows originate and terminate at the centroid of the BA for visualization purposes; they do not represent physical locations of transmission lines.

20% Wind 06-19-2007

Results Here From NREL 20% Study

Fig 1-7; A-1

Key Differences Between the Models

Brief Comparison of ReEDs and GCAM US Electric Sectors

	GCAM		ReEDS
Regional Coverage	Global model with 14 regions. U.S. is one region.	→	U.S. only; 358 subregions built from county data
Sectoral Coverage	Full agricultural and energy sector coverage	→	Electricity sector only
Solution Mechanism	Dynamic recursive, economic equilibrium	→	Linear Optimization sequentially through time with limited foresight
Technology Choice	Logit choice approach forces diversification	→	Optimization with regional variations in resource, prices
Capacity Expansion	New capacity is coupled with new generation	→	Explicit generation capacity expansion
Reserves	Not modeled.	→	Reserve margin and operating reserve requirements
Dispatch	Logit choice for investment, continued operation of capital stock vintages	→	Optimal dispatch in 16 timeslices
Transmission	Average transmission costs, no capacity constraints	→	Explicit transmission capacity expansion and transmission use

Brief Comparison of ReEDs and GCAM US Electric Sectors

	GCAM		REEDs
Wind Technologies	Representative Class 4-5 turbine	→	Onshore, offshore shallow, and offshore deep
Wind Supply Curve	For entire US; based on decreasing capacity factors, use of offshore wind, and transmission distances	→	Subregional resource constraints and supply curves
Wind Intermittency	Probabilistic treatment of backup or ancillary generation	→	Probabilistic treatment for determination of capacity value, reserve requirements, surplus
Solar Technologies	Rooftop PV, CSP and central PV with and without on-site storage	→	CSP-6hrs storage and limited treatment of distributed PV
Solar Supply Curve	Only for rooftop PV	→	Subregional resource constraints and supply curves
Geothermal Technologies	Hydrothermal supply curve; no EGS in this study	→	Hydrothermal and EGS with subregional supply curves
Storage	Directly coupled with wind and solar technology.	→	Explicit capacity expansion and dispatch of storage technologies

Study Design

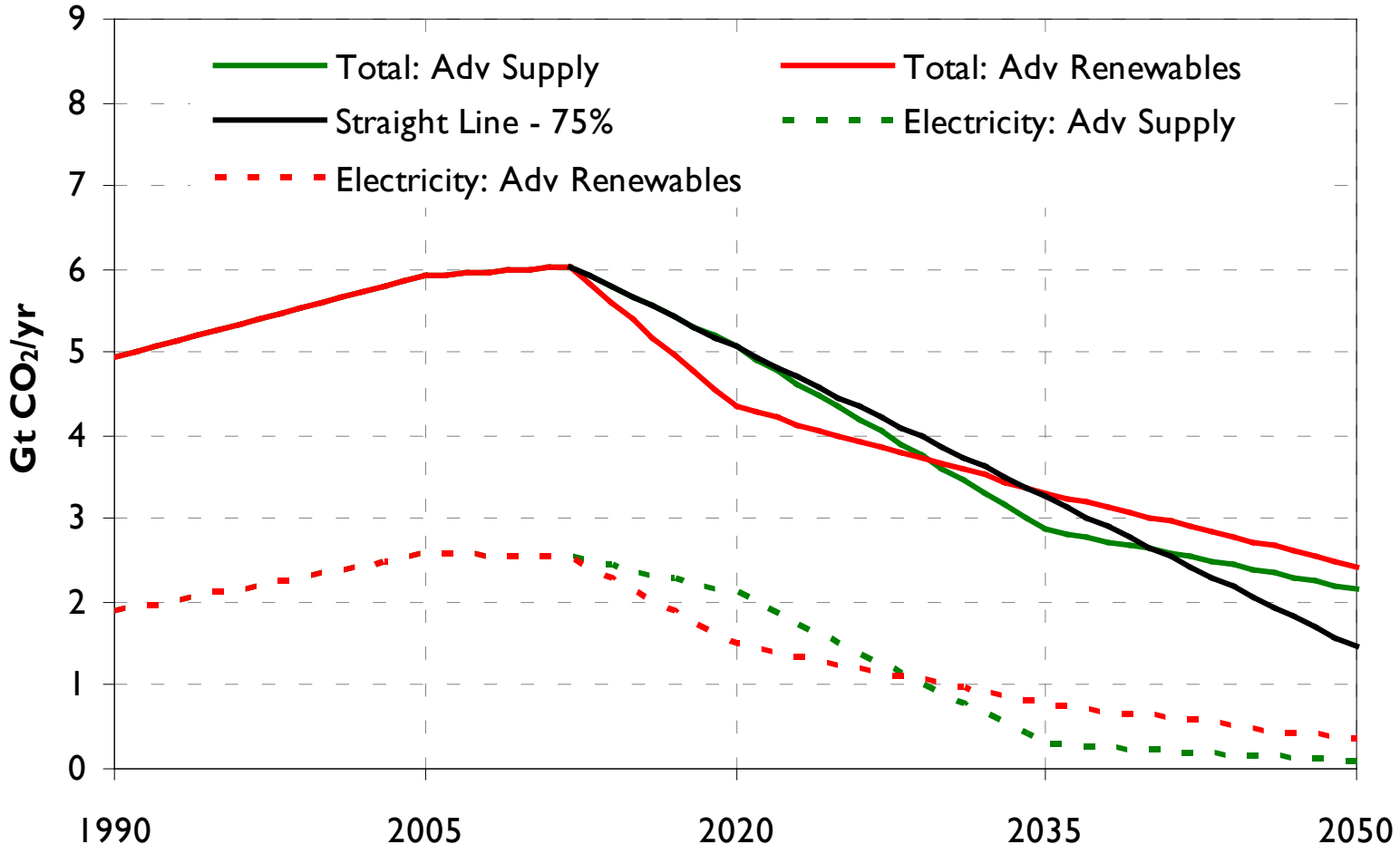
The study explores two sets of assumptions regarding technological advanced and availability

	CCS	Renewables	bioCCS	New Nuclear
Advanced Supply	**Yes**	**Adv**	**No**	**Yes**
Advanced Renewables	**No**	**Adv**	**No**	**No**

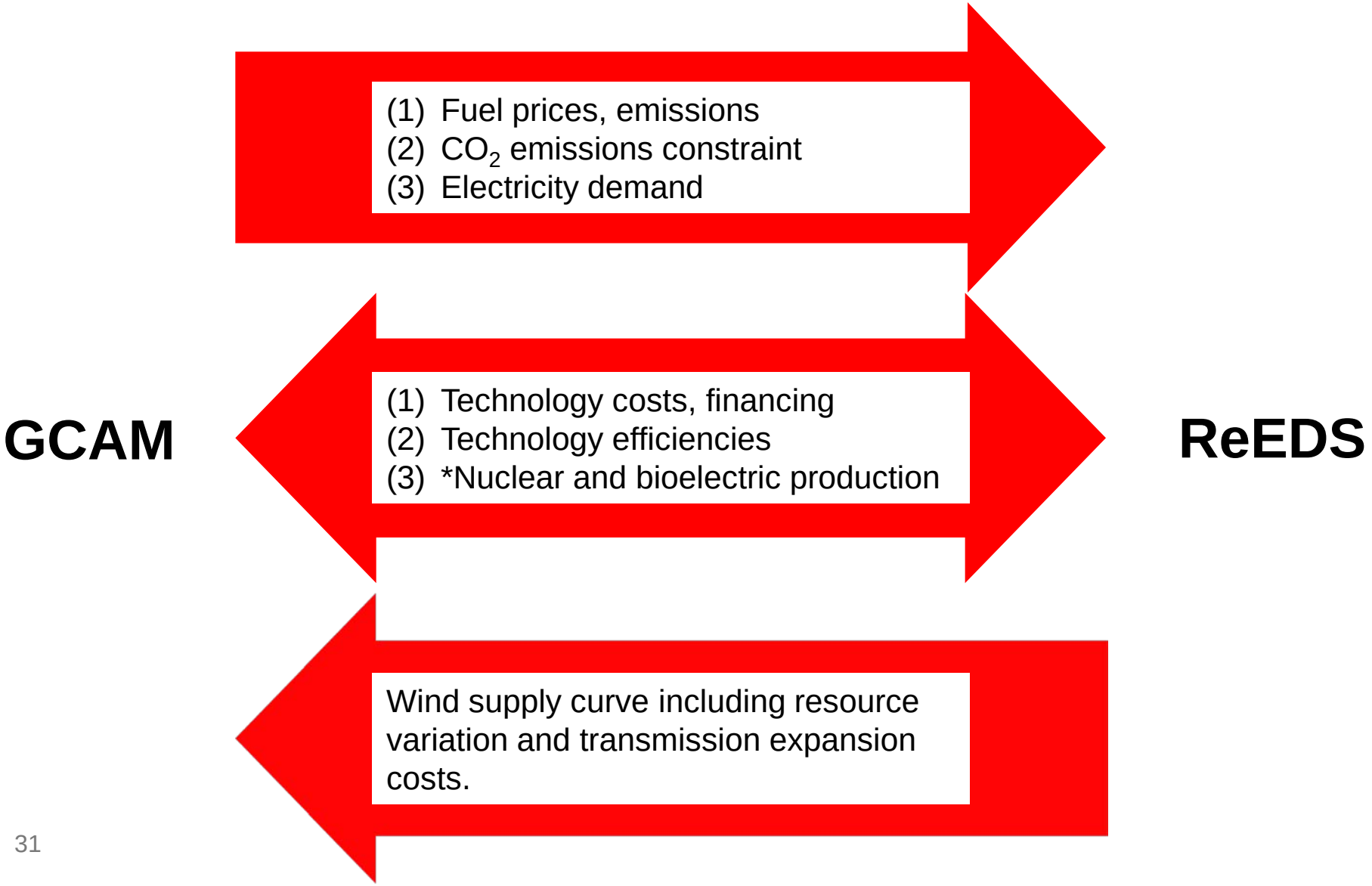
Defining the Electric Emissions Pathways from GCAM

- A global CO_2 regime is posited:
  - Action in the Annex-1 immediately, delays for non-Annex 1
- Posit a U.S. cumulative CO_2 emissions goal that corresponds to straight line emissions reduction path of 75% below 2005 emissions levels by 2050.
  - The is consistent with cumulative emissions of 146 $GtCO_2$ between 2005 and 2050.
- GCAM was then used to find an efficient emissions path to 146 GtCO2 for each technology future, based roughly on a Hotelling price rise.
- The electricity emissions pathway was then used as a constraint on ReEDS.

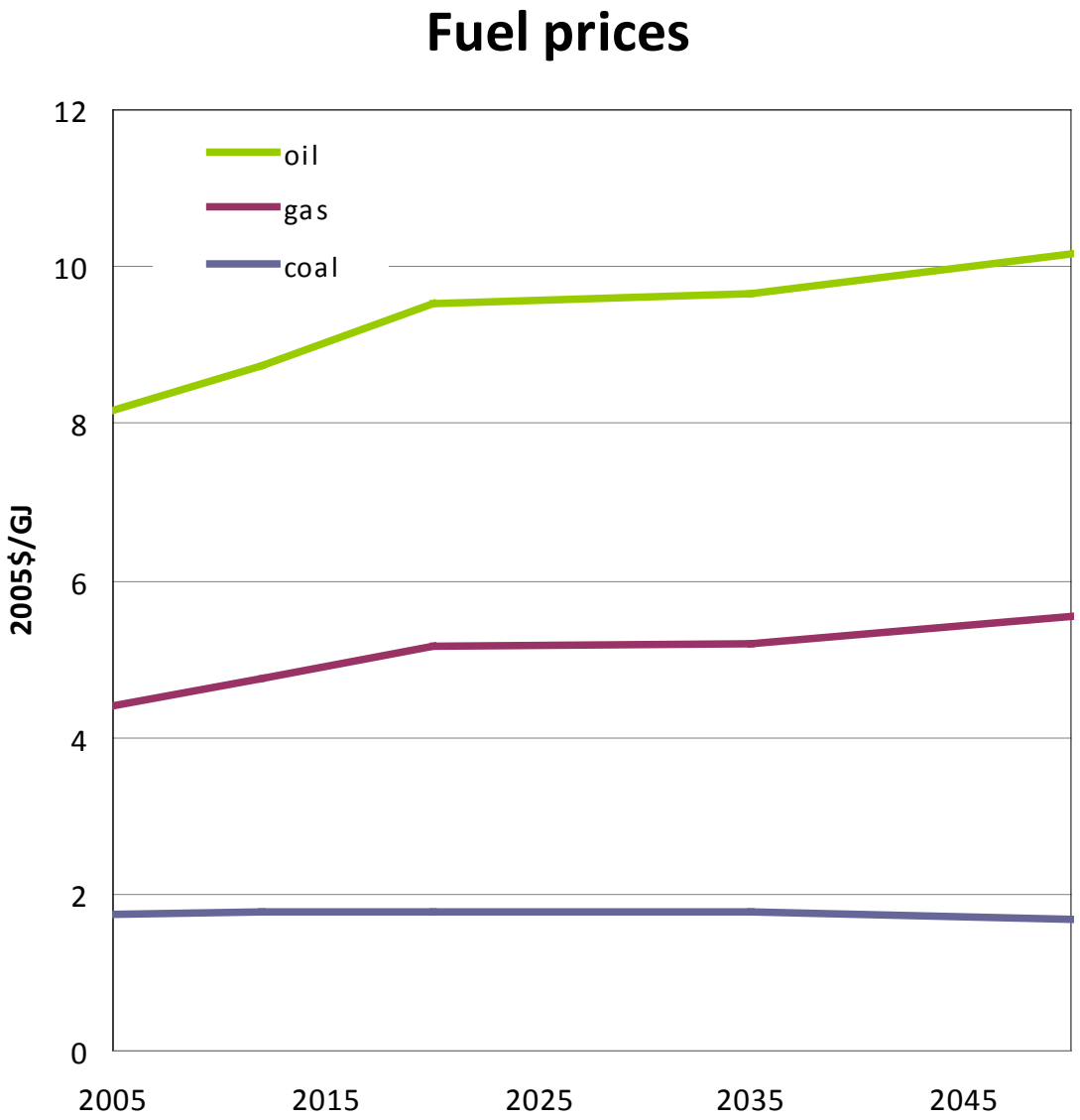
The 75 percent (146 $GtCO_2$) U.S. CO_2 Emissions Pathways.



The interface: what information needs to be passed back and forth between models?



Fuel Price Assumptions (US Average)



Coordinated Fossil Assumptions

Technology	Year	Capital Cost (2004$ / kW)	Fixed O&M cost (2004$ / kW / yr)	Variable O&M Cost (2004$ / MWh)	Efficiency (%)
Pulverized coal	2020	1545	27.50	4.58	39%
	2035	1455	25.89	4.32	40%
	2050	1370	24.38	4.06	41%
Coal IGCC	2020	1791	38.62	2.92	43%
	2035	1610	36.02	2.72	45%
	2050	1361	32.44	2.45	47%
Natural Gas CT	2020	509	11.68	3.48	38%
	2035	479	11.00	3.27	39%
	2050	451	10.36	3.08	40%
Natural Gas CC	2020	725	12.07	2.03	55%
	2035	632	11.04	1.86	60%
	2050	551	10.14	1.71	64%
Oil CT	2020	509	11.68	3.48	38%
	2035	479	11.00	3.27	39%
	2050	451	10.36	3.08	40%

Additional Coordinated Assumptions

Technology	Year	GCAM Capital Cost (2004$ / kW)	GCAM Fixed O&M cost (2004$ / kW / yr)	GCAM Variable O&M Cost (2004$ / MWh)	Output: SUPPLY (TWh / yr)	Output: RE (TWh / yr)
Nuclear	2005	2300	64.00	1.80	811	811
	2020	2266	64.00	1.80	847	540
	2035	2232	64.00	1.80	1643	180
	2050	2199	64.00	1.80	1961	0
Biomass	2005	1899	33.60	4.65	25	25
	2020	1899	33.60	4.65	196	380
	2035	1789	31.64	4.38	303	478
	2050	1684	29.79	4.12	439	934
Hydropower	2005	na	na	na	272	272
	2020	na	na	na	272	272
	2035	na	na	na	276	276
	2050	na	na	na	280	280
Rooftop PV	2005	9500	100.00	0.00	0	0
	2020	4258	30.00	0.00	90	129
	2035	2879	25.00	0.00	241	357
	2050	2246	20.00	0.00	418	616

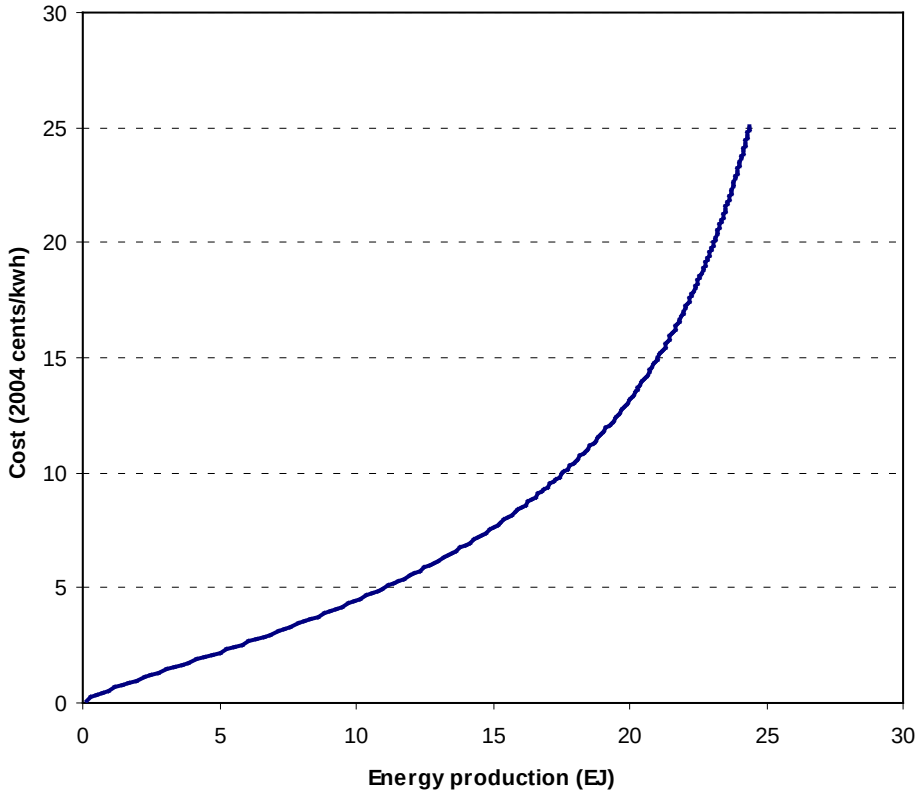
Renewable Assumptions.

Technology	Year	Capital Cost (2004$ / kW)	Fixed O&M cost (2004$ / kW / yr)	O&M cost (2004$ / MWh)
		GCAM	GCAM	GCAM
Wind (Onshore Class 5)	2020	1082	11.50	4.60
	2035	1004	10.67	4.27
	2050	931	9.89	3.96
Solar CSP	2020	3731	34.37	0.00
	2035	3209	29.56	0.00
	2050	2976	27.42	0.00
Geothermal	2020	2419	78.74	0.00
	2035	2220	72.25	0.00
	2050	2082	67.75	0.00
Storage	2020	---	---	---
	2035	---	---	---
	2050	---	---	---

Important difference in treatment of thermal storage options for CSP.

Partial harmonization on storage because of difference in treatment.

GCAM Wind Transmission and Resource Gradation Effects*



Build off base wind cost for class 4/5 production.

Costs increases due to resource quality and transmission

Costs increase as longer transmission distances are required

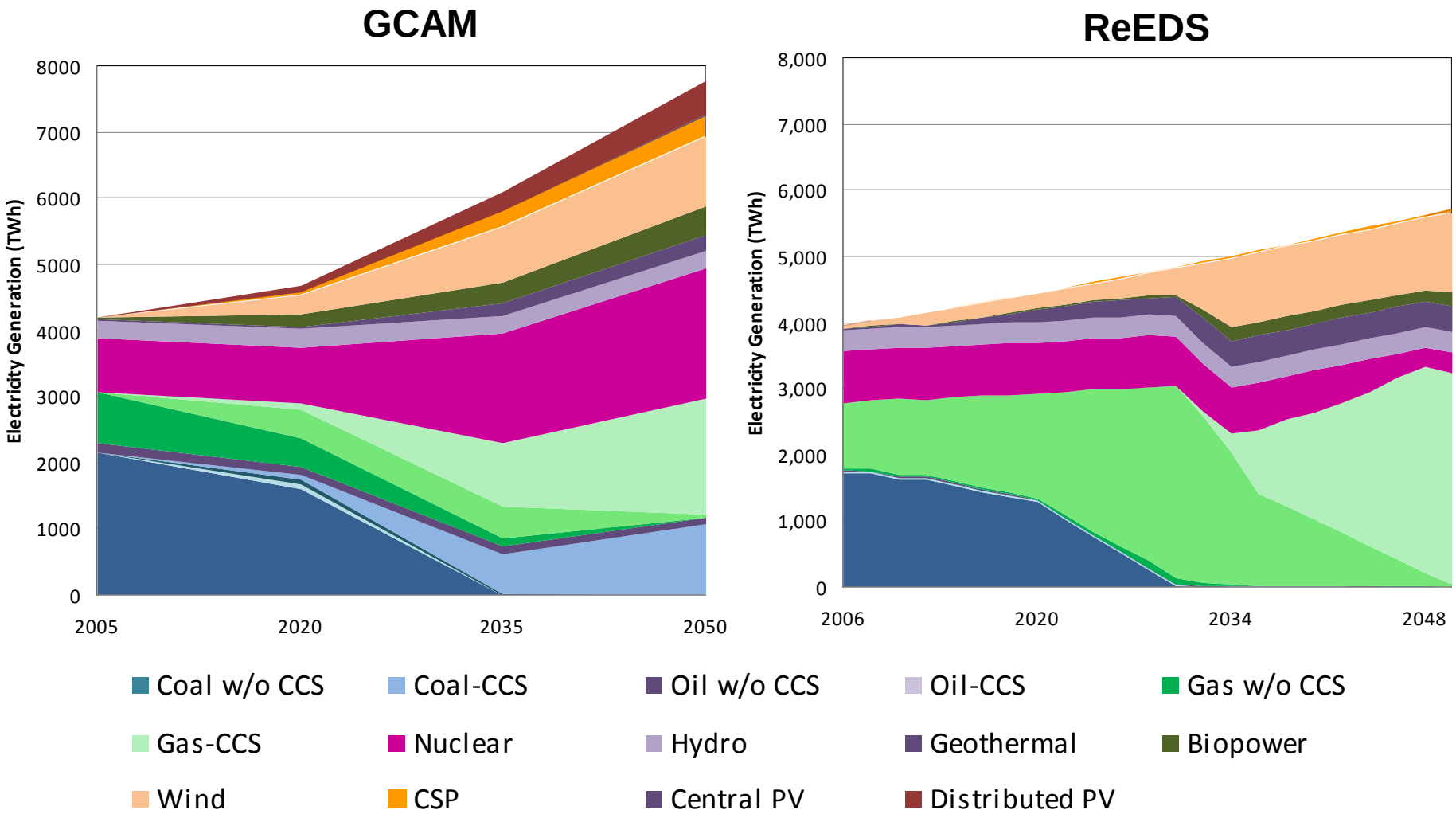
Based on NREL 20% by 2030 study

System integration costs due to wind intermittency are addressed at a different point in the model

* Costs are in addition to wind capital and operating costs

Results Comparison

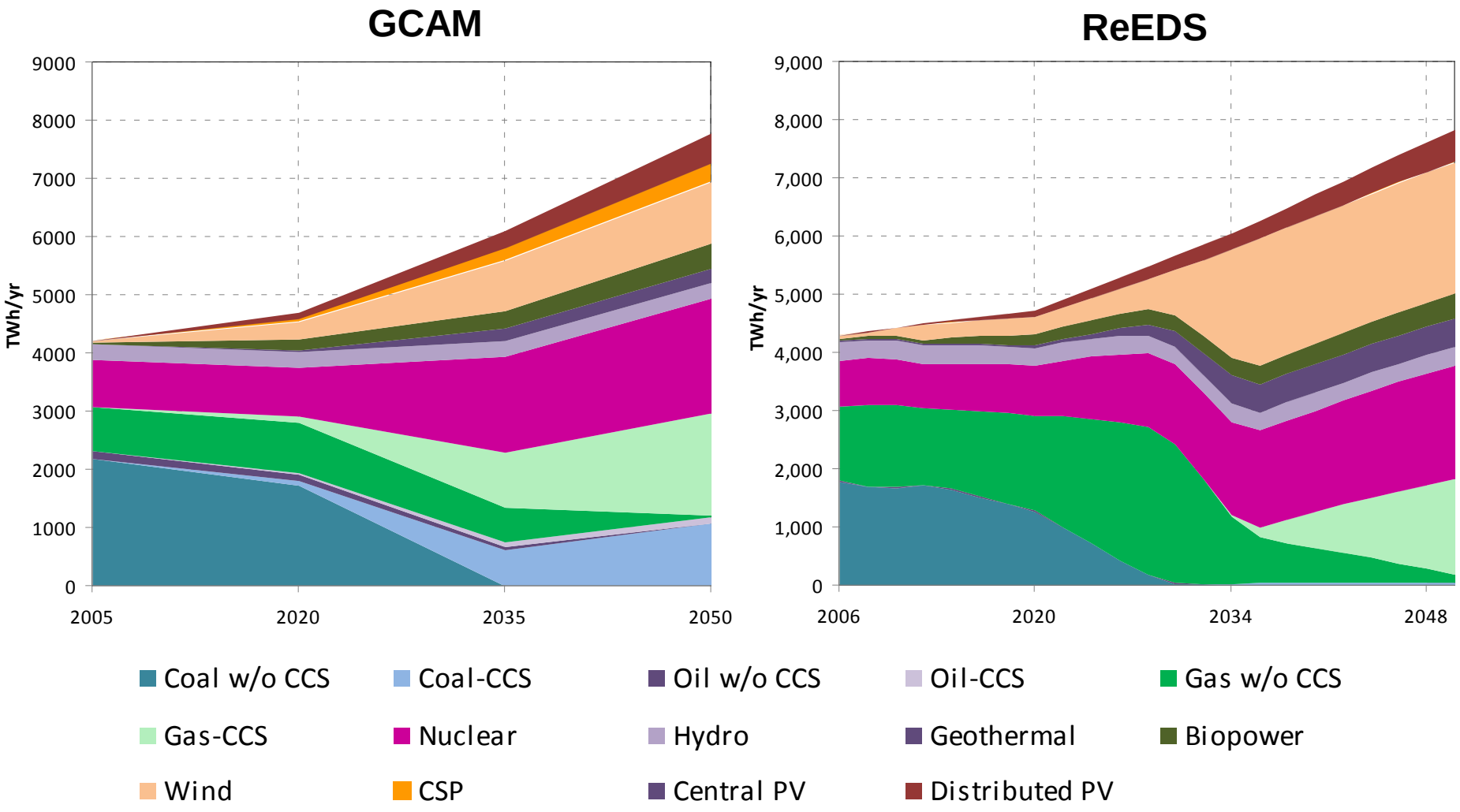
Electricity Generation: Advanced Supply Case – Early in Harmonization Process



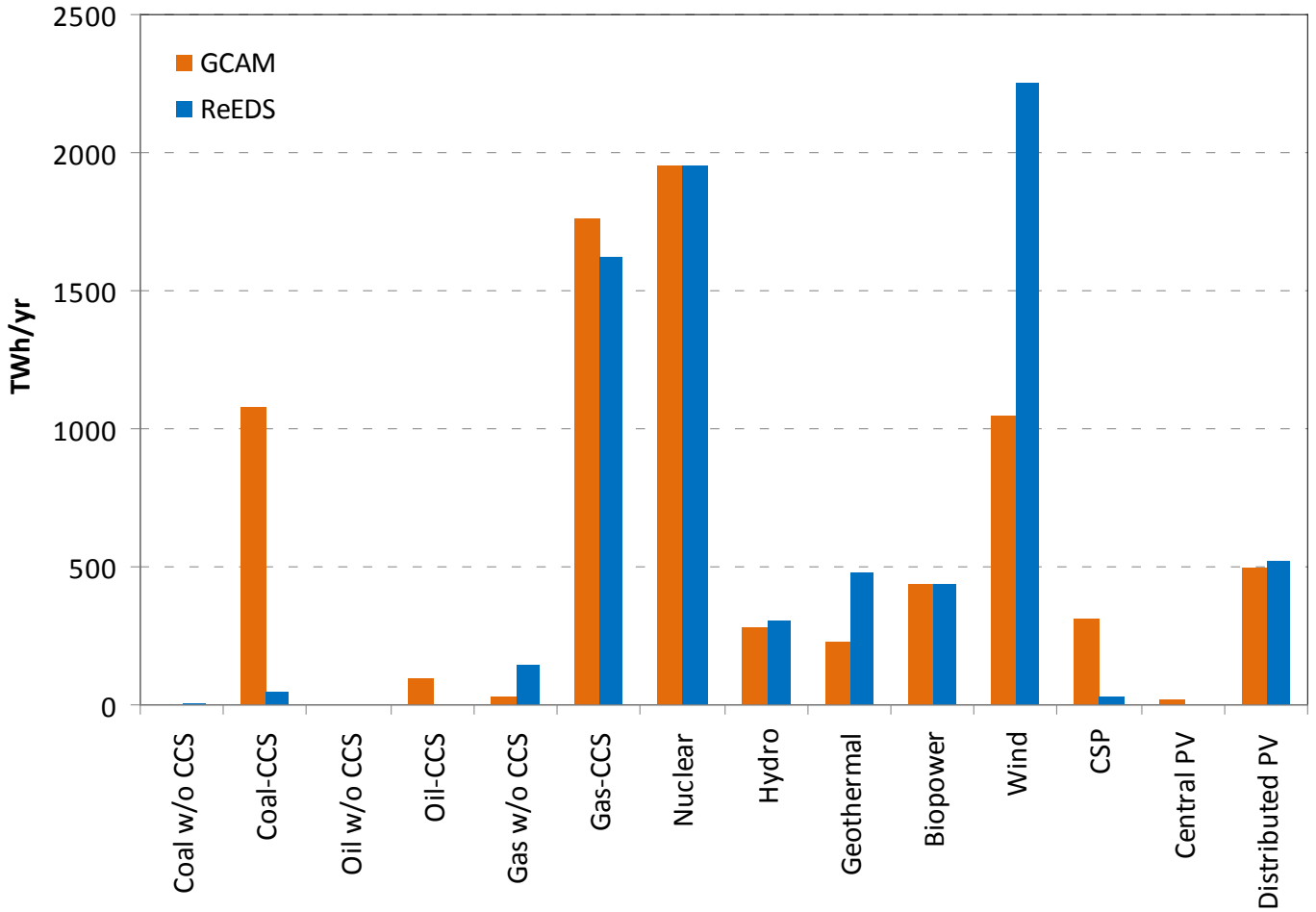
Differences in Renewables' Market Penetration Are Caused by Several Types of Factors

- General market algorithms
  - Equilibrium vs sequential optimization
  - Market share and regional detail
  - Financing and taxes
  - Adjustment costs (ReEDS uses algorithms to constrain rapid growth)
- Penetration of non-renewables
  - GCAM logit preferences for coal modified
  - ReEDS nuclear penetration constrained to equal that of GCAM
- Renewable technologies included
  - Biomass (ReEDS used GCAM bioelectricity production)
  - PV (PV in ReEDS based on GCAM production)
  - CSP (GCAM includes CSP with long-term thermal storage)
- Treatment of renewables
  - Variable resources (intermittency)
  - Transmission expansion

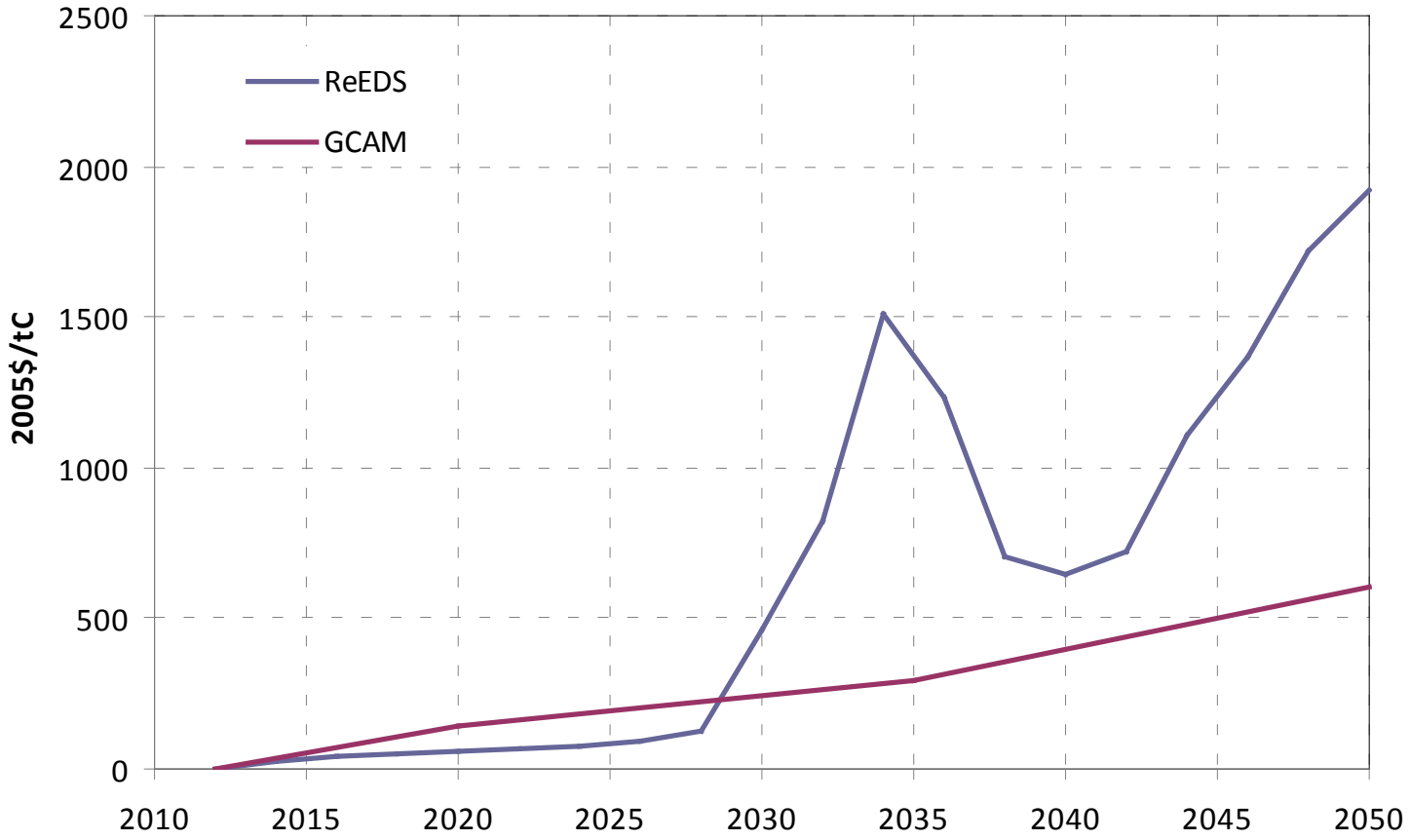
Electricity Generation: Advanced Supply Case



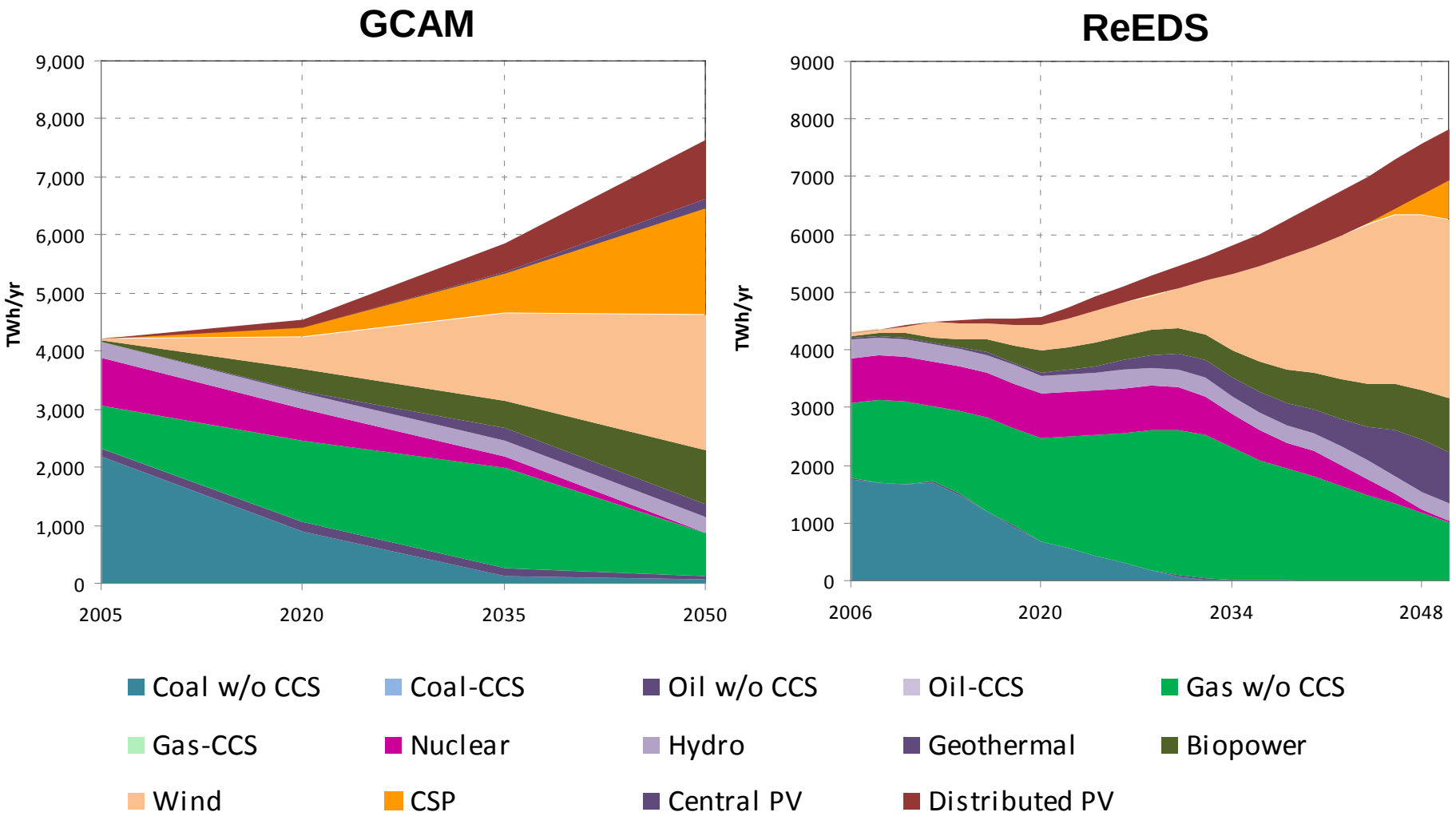
Comparison of Electricity Generation in 2050, Advanced Supply Case



Carbon prices: Advanced Supply Case



Electricity Generation: Advanced Renewables Case



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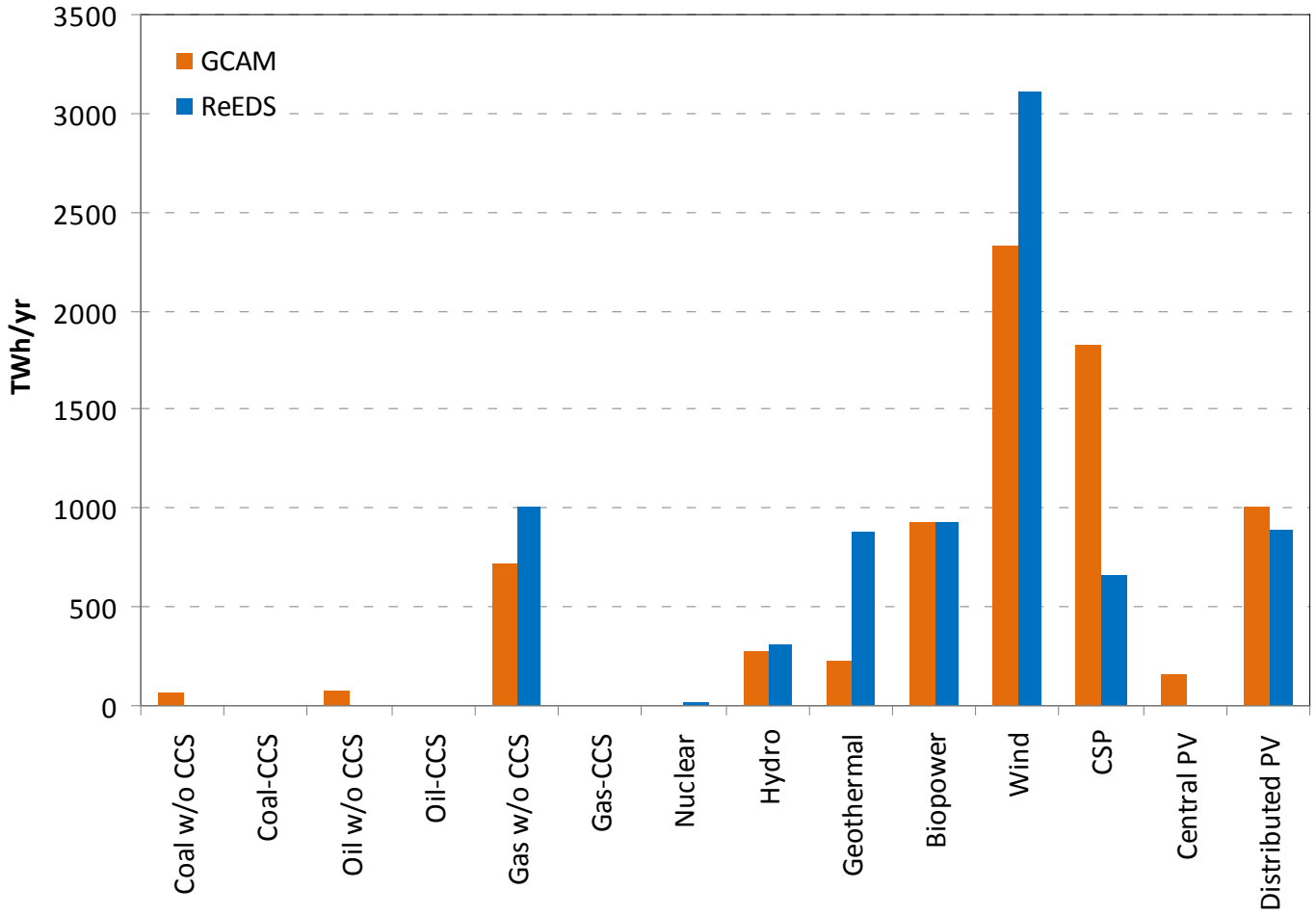

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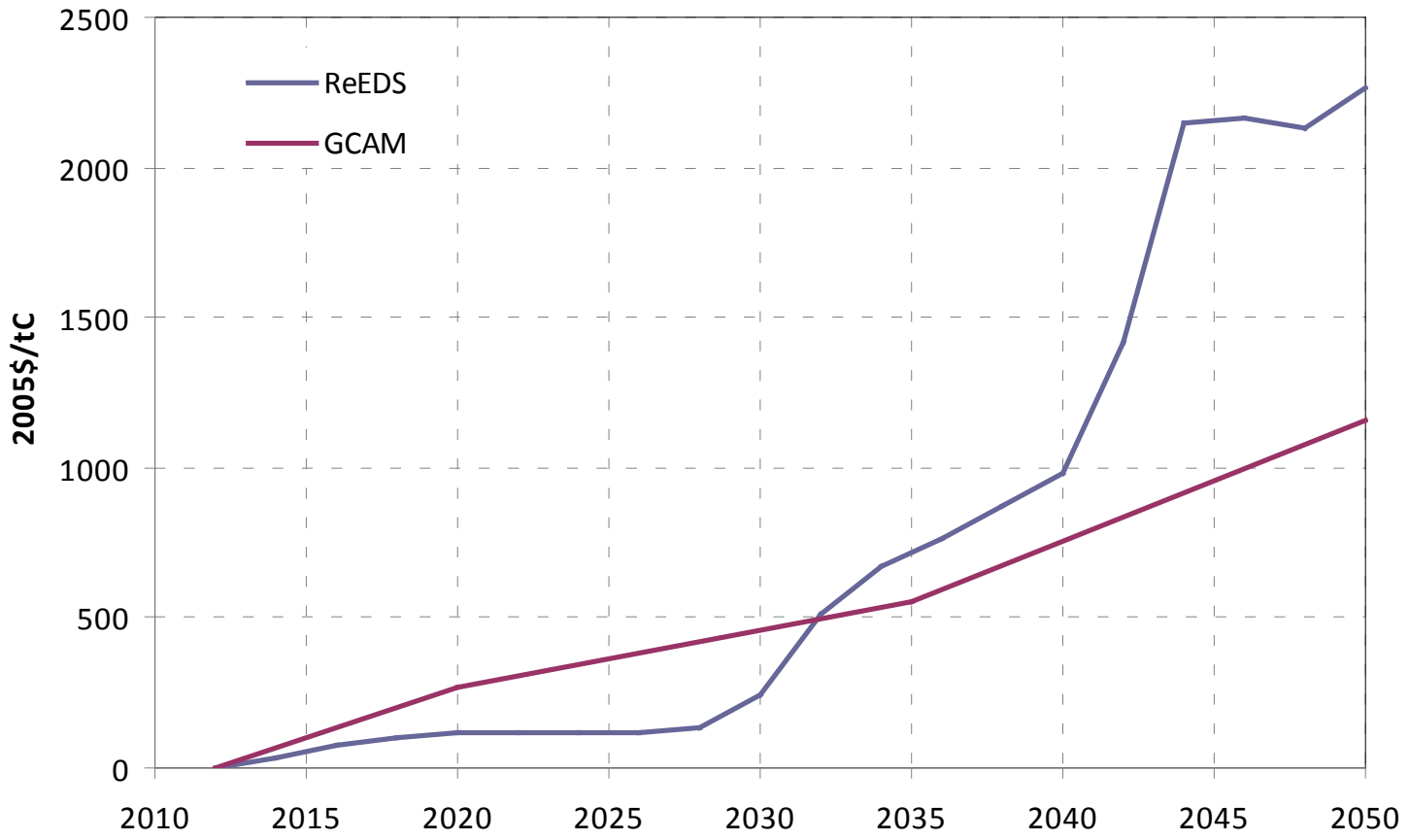


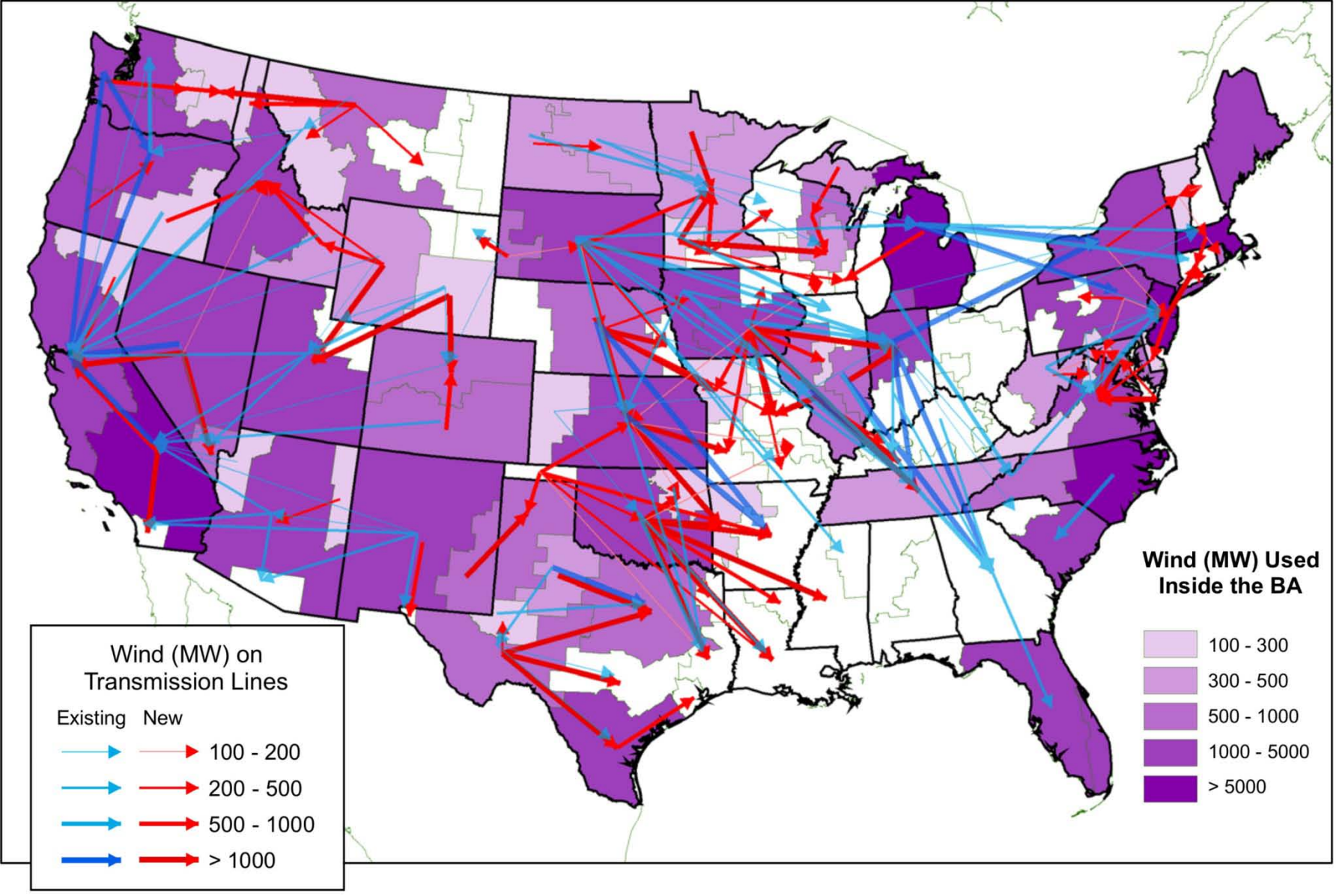
Summary and Next Steps

Some Summary Thoughts

- It is possible to link these diverse models to get a 10,000 to 1,000 foot perspective.
  - GCAM provides the context for ReEDS and ReEDS provides transmission constraints and supplies more generally to GCAM.
- Differences in methodological approaches, not just differences in granularity, drove many of the differences in results.
- In all cases, the deployments of renewables were impacted by the behavior of non-renewable technologies – given consistent renewable assumptions.

Possible Next Steps

- Adjustments to GCAM
  - Reexamine grid integration methodology
  - Reexamine logit preferences for coal et al
  - Reexamine wind supply curve for transmission, siting, system integration costs
  - Consider adding resource supply curves/caps for concentrating solar power
- Adjustments to ReEDS
  - Complete addition of PV
  - Consider competing biofuels with biopower for biomass resource
  - Examine fossil fuel price heterogeneity
  - Revise treatment of storage and its impact on reserves, wind, and CSP
- Possible Next coordinated steps
  - More scenarios (e.g., different technology assumptions, carbon constraints, etc.)
  - Formalize the interface.
  - Better implement feedbacks
  - Extrapolate lessons to international modeling



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