Overview of Renewable Energy Representations in GCAM

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Snowmass

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Renewable Sources Covered in this Talk

- Bioenergy (only briefly)

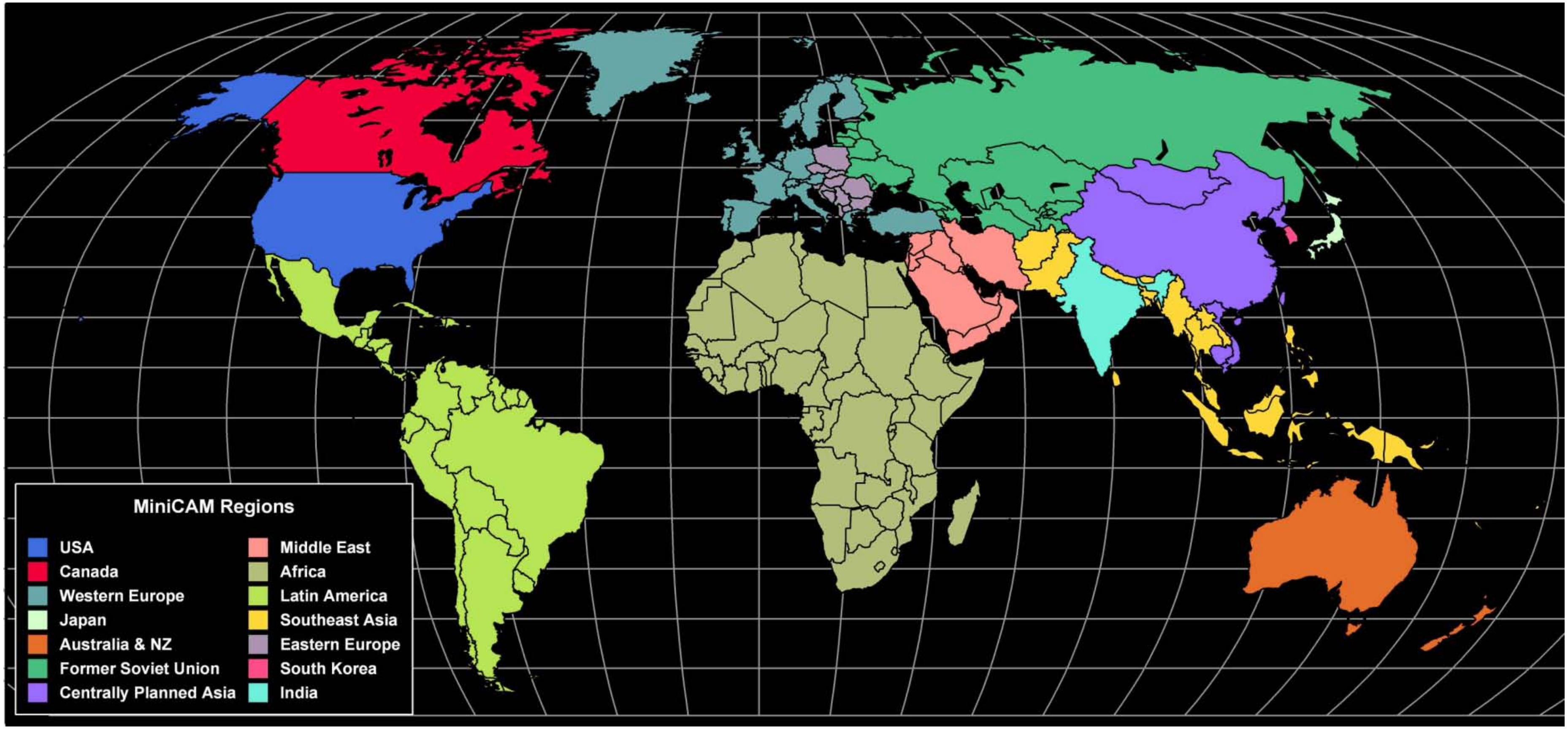
- Solar Power
- Wind Power
- Geothermal Power

- Big issues are:
  - Transmission expansion costs
  - Resource gradation
  - International data and analysis
  - Intermittency/grid connection

Caveat:

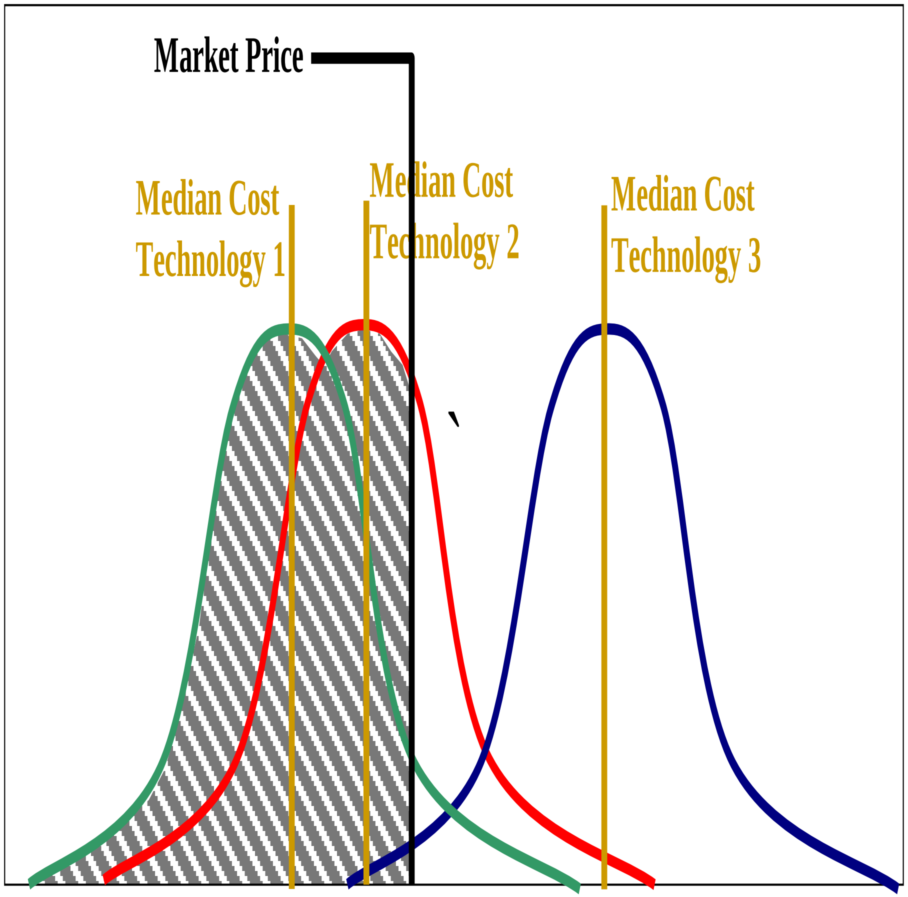
This discussion is based on the CCTP scenarios from late 2008. There have been some adjustments to assumptions and formulation over the last year.

GCAM (not MiniCAM) is a global model with 14 regions.



GCAM Technology Competition – Based on Economics

A Probabilistic Approach



- Economic competition among technologies takes place at many sectors and levels.
- Assumes a distribution of realized costs due to heterogeneous conditions.
- Market share based on probability that a technology has the least cost for an application.
  - Avoids a “winner take all” result.
  - “Logit” specification.

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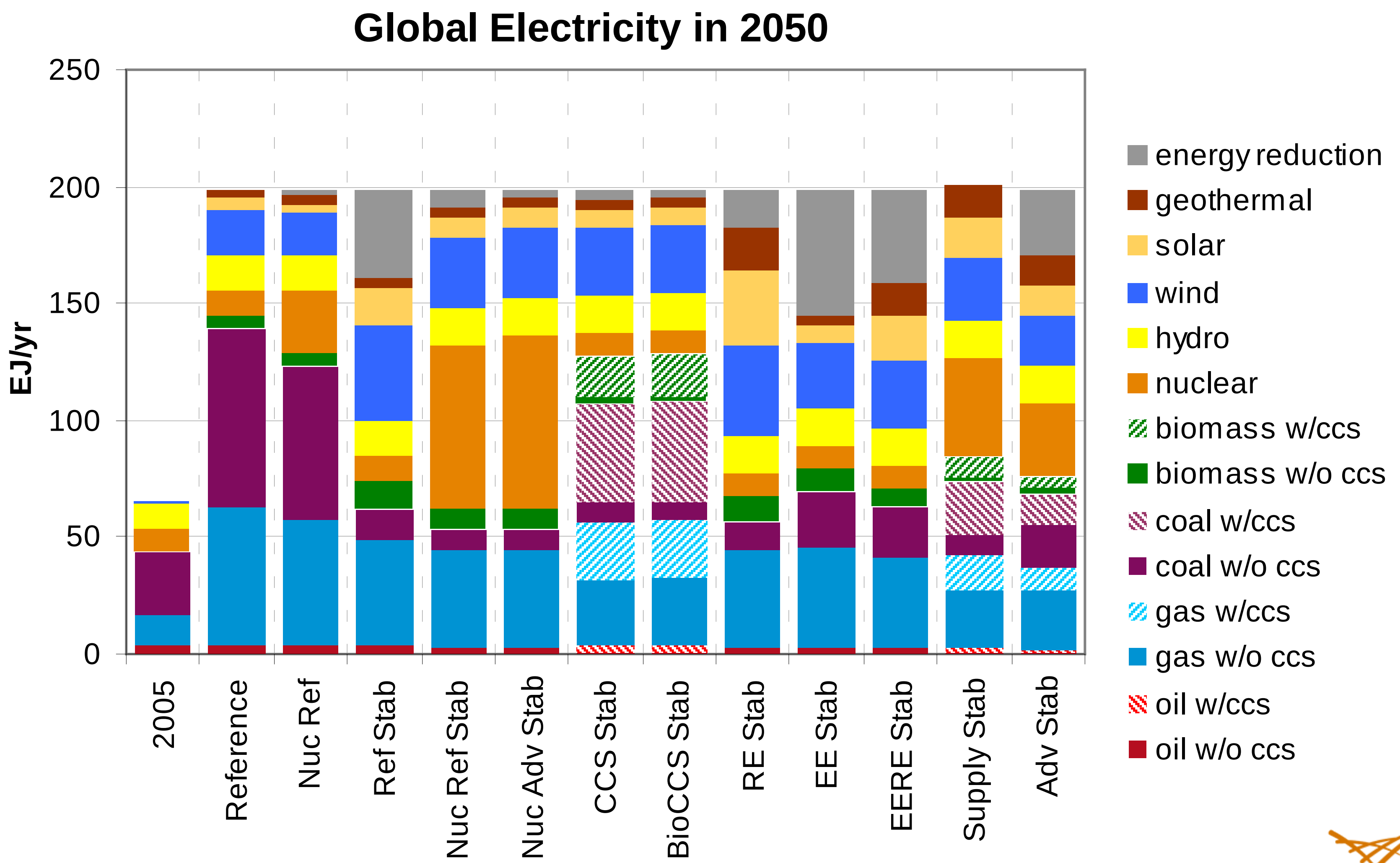
How much renewable energy does GCAM get?



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Bioenergy

Commercial Bioenergy: A Quick Summary

- Integrated land use model that includes production of bioenergy crops
  - Dedicated bioenergy must compete with other uses of land
- Supplies include
  - Municipal solid waste
  - Crop Resides (crop and forest waste, e.g., corn stover)
  - Dedicated bioenergy crops
- Bioenergy can be used for
  - Electricity production
  - Liquid fuels production
  - Hydrogen
  - Direct use (e.g., buildings and industry)
- Simple representation of traditional bioenergy supplies

Wind & Solar Power

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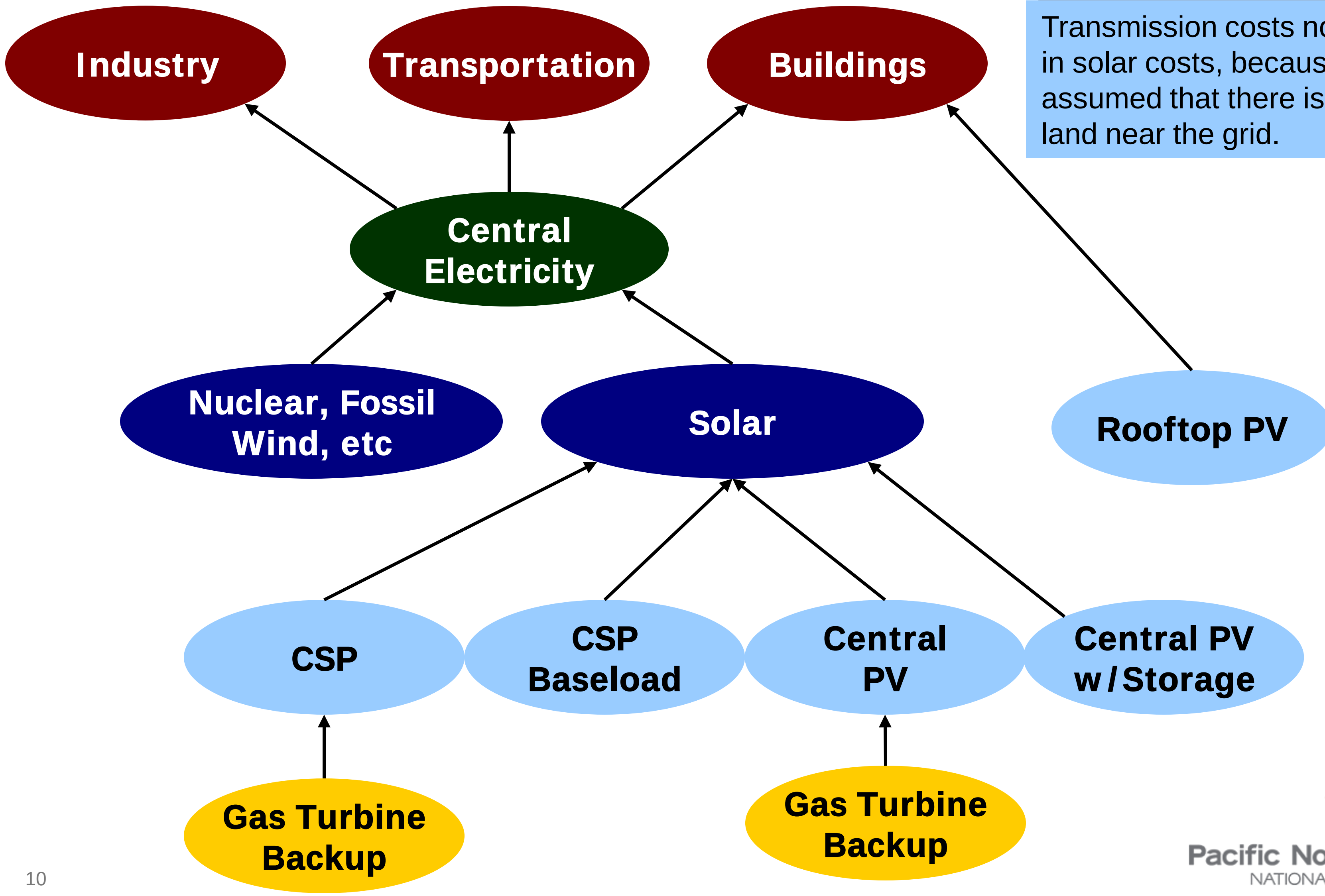
Five Sources of Solar Electricity

Transmission costs not included in solar costs, because it is assumed that there is ample land near the grid.



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Solar and Wind Technology Assumptions

Capital Cost

			Reference			Advanced		
		2005	**2020**	**2050**	**2095**	**2020**	**2050**	**2095**
Rooftop PV	2003$/kW	9500	6278	3583	2793	4258	2246	1654
Central PV	2003$/kW	5500	3620	1974	1407	2757	1105	758
Central PV with storage	2003$/kW	6100	4136	2402	1789	3200	1387	982
CSP	2003$/kW	3004	2786	2397	1913	2219	1770	1413
CSP with storage	2003$/kW	6008	5573	4795	3827	3731	2976	2375
Wind	2003$/kW	1167	1124	1043	932	1082	931	743
Wind with storage	2003$/kW	1825	1690	1511	1350	1568	1240	990

Capacity Factor

		Reference			Advanced		
	2005	**2020**	**2050**	**2095**	**2020**	**2050**	**2095**
Central PV	0.25	0.25	0.25	0.25	0.25	0.25	0.25
Central PV with storage	0.25	0.25	0.25	0.25	0.25	0.25	0.25
CSP	0.31	0.31	0.31	0.31	0.31	0.31	0.31
CSP with storage	0.73	0.73	0.73	0.73	0.73	0.73	0.73
Wind	0.40	0.45	0.47	0.50	0.45	0.49	0.52
Wind with storage	0.40	0.45	0.47	0.50	0.45	0.49	0.52

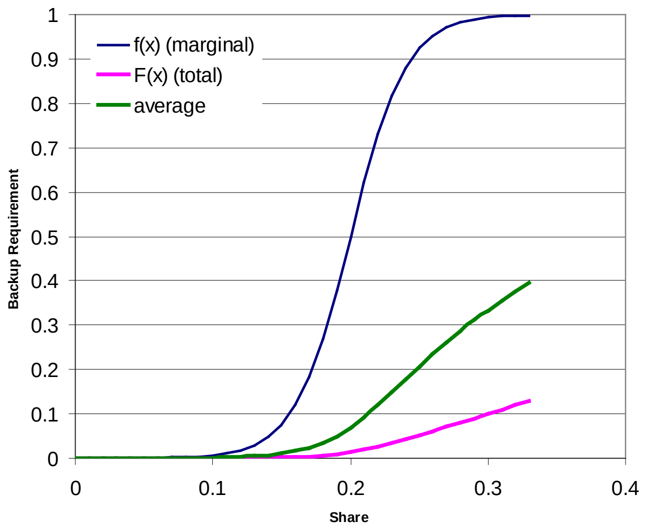
Levelized Energy Cost

			Reference			Advanced		
		2005	**2020**	**2050**	**2095**	**2020**	**2050**	**2095**
Central PV	2003$/kWh	0.41	0.27	0.15	0.11	0.21	0.09	0.06
Central PV with storage	2003$/kWh	0.44	0.30	0.17	0.13	0.23	0.10	0.07
CSP	2003$/kWh	0.16	0.15	0.13	0.10	0.12	0.09	0.08
CSP with storage	2003$/kWh	0.13	0.12	0.10	0.08	0.08	0.06	0.05
Wind	2003$/kWh	0.05	0.04	0.04	0.03	0.04	0.03	0.02
Wind with storage	2003$/kWh	0.07	0.06	0.05	0.04	0.05	0.04	0.03

There is a need to

- Backup capacity required =
  - 1 / [1 + e^(5 * (capacityLimit – elecShare) / 0.1)]
  - capacityLimit = 20%. When renewable elecShare gets to 20%, each additional unit of renewable capacity requires one unit of backup capacity.

Example of backup function shape – actual limits depend on scenario.



- Most of the backup costs are in the capacity, not the energy production
  - 5% capacity factor assumed for backup generators

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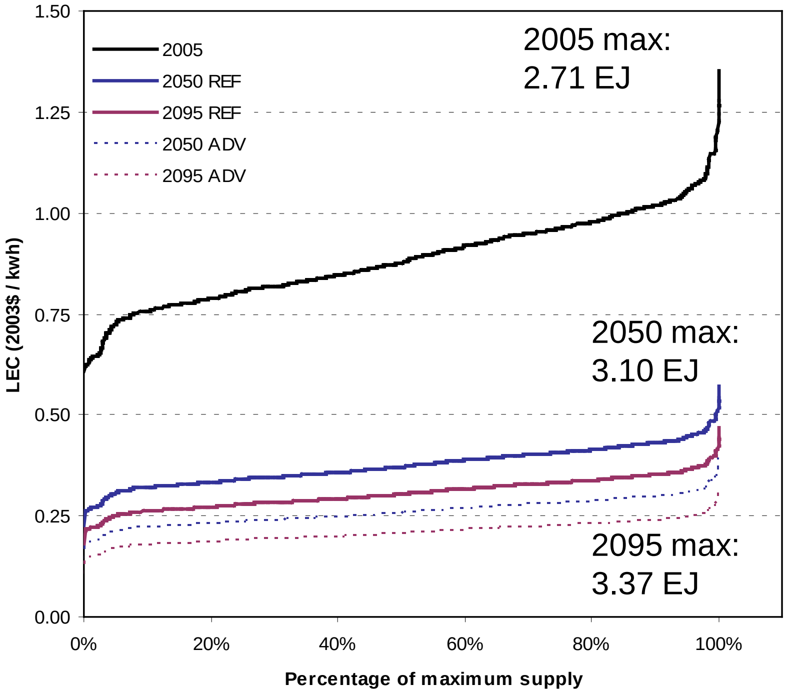
Rooftop Solar



Both commercial and residential and commercial rooftop PV are now included in GCAM

- Costs and max resources shown for U.S.
- A consistent distribution curve used globally. But totals and cost multipliers vary (discussed elsewhere).

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Adjustments or Solar Power Internationally

- Outside of U.S. costs are adjusted by a multiplier based on differences in solar irradiance.

Solar cost multipliers					
Regional differences in solar resources are represented in terms of technology costs (i.e. requiring more mirrors or PV cells to produce the same amount of power)					
MC Region	TotalIrradiance_Pop1_sum	area_Pop1_sum	area_weighted_pop1	Cost multiplier	
USA	4967040	1182645	4.20	1.00	
Canada	861324	252782	3.41	1.23	
Western Europe	2689289	767352	3.50	1.20	
Japan	383495	98269	3.90	1.08	
Australia_NZ	1106378	226363	4.89	0.86	
Former Soviet Union	7230950	2151284	3.36	1.25	
China	7636376	1846976	4.13	1.02	
Middle East	5487961	985805	5.57	0.75	
Africa	24379655	4339915	5.62	0.75	
Latin America	14828695	2894154	5.12	0.82	
Southeast Asia	6379156	1247618	5.11	0.82	
Eastern Europe	819461	241305	3.40	1.24	
Korea	112103	26831	4.18	1.01	
India	3054514	605381	5.05	0.83	

  - Obtain an average irradiance for non-populated land.
  - Cost multiplier for non-US regions = (US irradiance / US available land area) / (regional irradiance / regional available land area)

Overview of Approach to Wind in CCTP GCAM

- Modeled as a single technology with “fixed” cost based on Class 4/5 wind costs with variations in transmission costs.

$$c_{total} = c_{base\ energy} + c_{grid\ +\ resource\ variation} + c_{backup}$$

- Structure and transmission distances informed by detailed analysis based on NREL 20% by 2030 study
  - Outside U.S., distance to grid distribution based on U.S.
- Resource limits based on adjusted IEA wind supply functions in all regions – extended beyond NREL study based on internal PNNL analysis
- Backup capacity requirements increase with wind share of electricity generation.
  - Each additional unit of wind capacity requires one unit of backup capacity when wind accounts for greater than 20% of all electricity

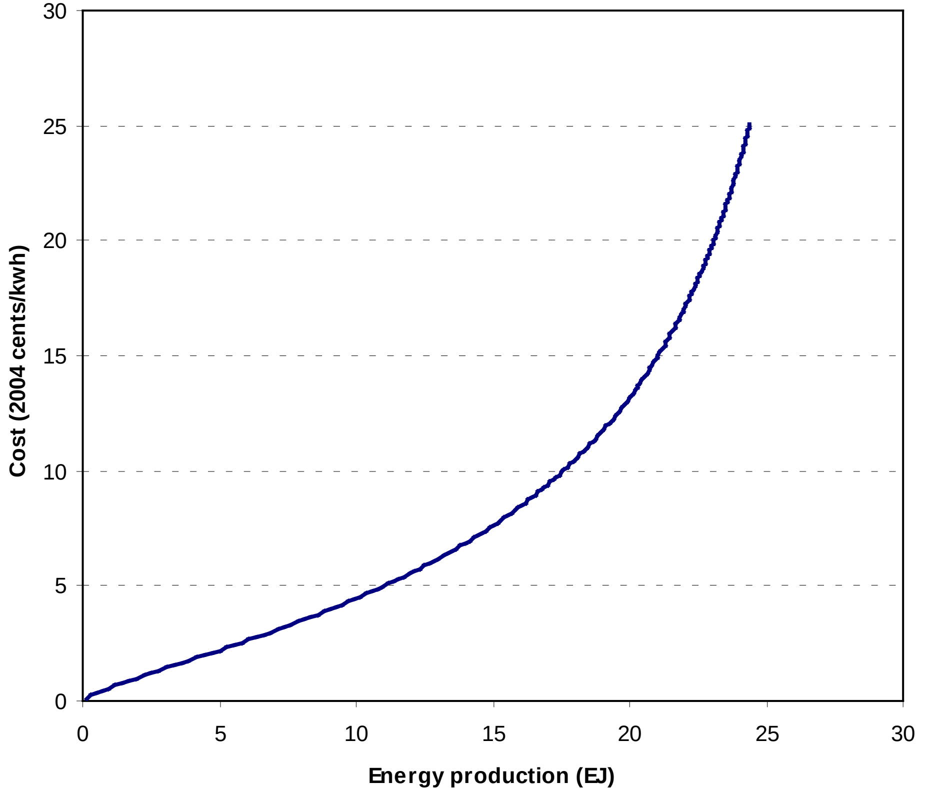
- Offshore and onshore not explicitly separated in the supply curve.

International Onshore Wind Resources in CCTP GCAM

	IEA max resource (EJ)	multiplier	new max resource
USA	8.06	3.62	29.2
Canada	4.68	3.62	17.0
Western Europe	4.8	1.38	6.6
Japan	0.32	3.20	1.0
Australia_NZ	7.17	1.77	12.7
Former Soviet Union	47.17	2.87	135.1
China	11.34	3.20	36.3
Middle East	11.4	4.04	46.0
Africa	34.07	3.98	135.6
Latin America	16.79	3.18	53.3
Southeast Asia	4.67	1.79	8.4
Eastern Europe	2.21	1.38	3.1
Korea	0.19	3.20	0.6
India	2.25	0.49	1.1

- IEA max resource adjusted to match maximum in detailed US spreadsheet model.
- Multiplier in non-US regions = U.S. multiplier * (Available land in region / Total land in region) / (Available land in US / Total land in US)
  - Assumes that IEA estimates scale with low turbine density over all land area. We are allowing higher turbine densities, but only on non-excluded land areas.

GCAM Wind Supply Costs*



Based on NREL 20% by 2030 study

Costs increase due to resource quality and transmission

Costs increase as longer transmission distances are required

System integration costs due to wind intermittency are not included

* Costs are in addition to wind capital and operating costs

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Geothermal Energy

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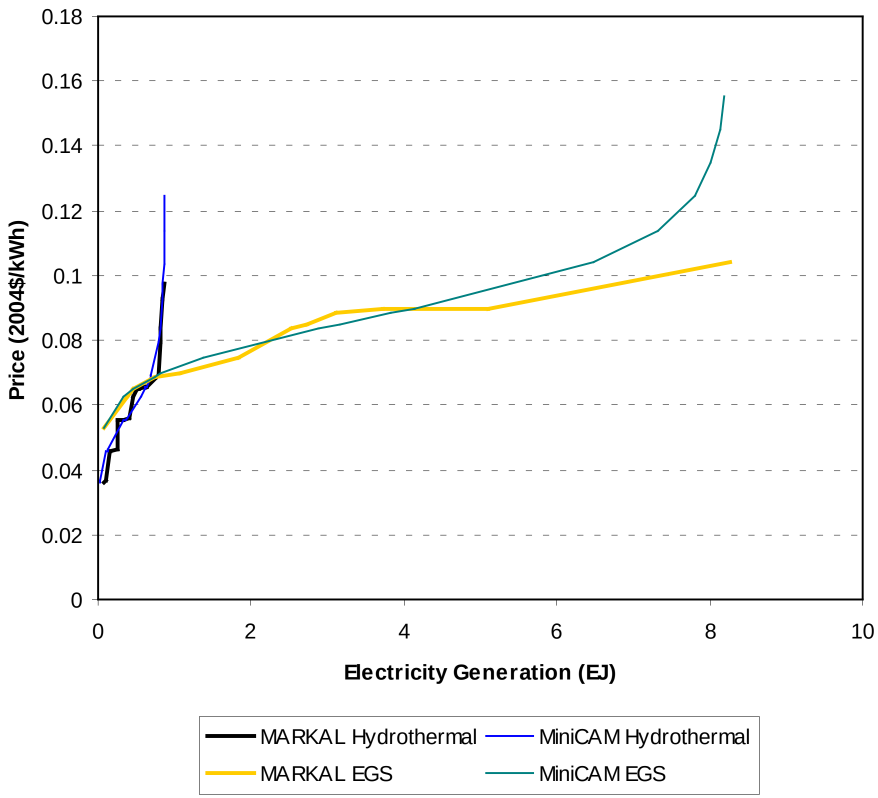
Modeling Geothermal Energy in GCAM

- Geothermal supply curves for US based on work by NREL
- Important question is availability and cost of EGS
- International supply curves based on NREL U.S. adjusted based on database of geothermal resources internationally (R. Bertani, International Geothermal Association)

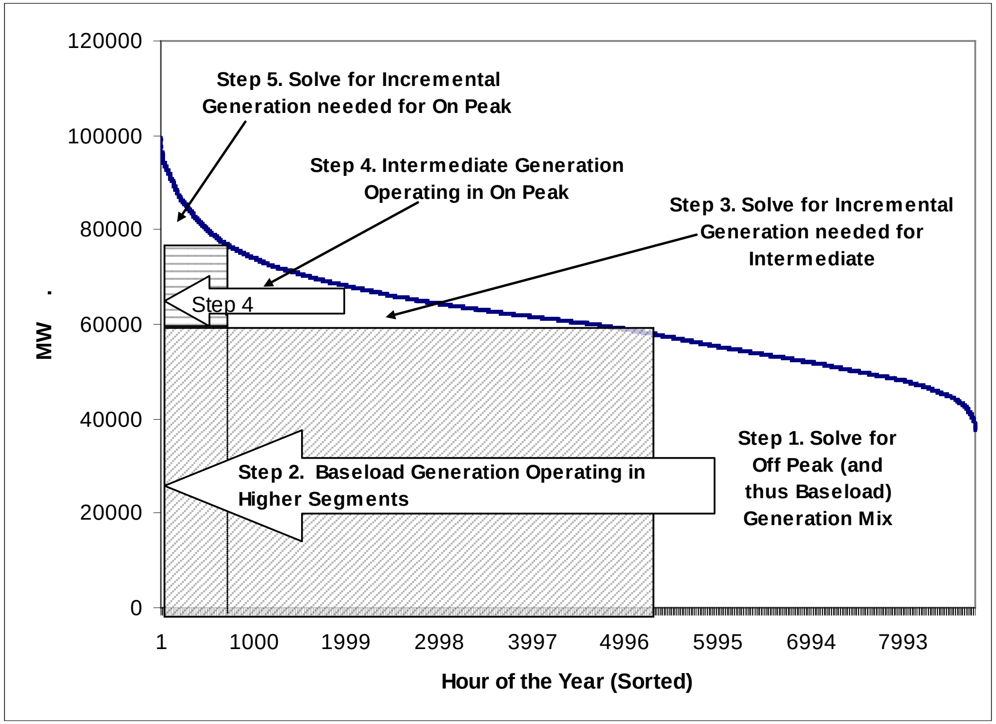
We have recently completed an update of the geothermal supply curves in the U.S. and globally.



Steps Moving Forward

Next Steps

- Explicit load duration curve.



- Interactions with NREL to better represent capacity expansion and integration issues.
- Continued revisions to cost numbers.
- Enhanced global supply numbers