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Technology Tools: The Importance of a Full Tool Box

Wednesday, November 7, 2007
Chicago Botanic Garden, Glencoe, Illinois

Thomas Key

EPRI Renewable

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Context

- Growing scientific findings and public opinion that GHG emissions contribute to climate change…
- U.S. responsible for 1/4 of worldwide CO_2 emissions…
- Electric utilities responsible for 1/3 of U.S. CO_2 emissions…
- Agreement that technology solutions are needed…

…But What is Feasible???

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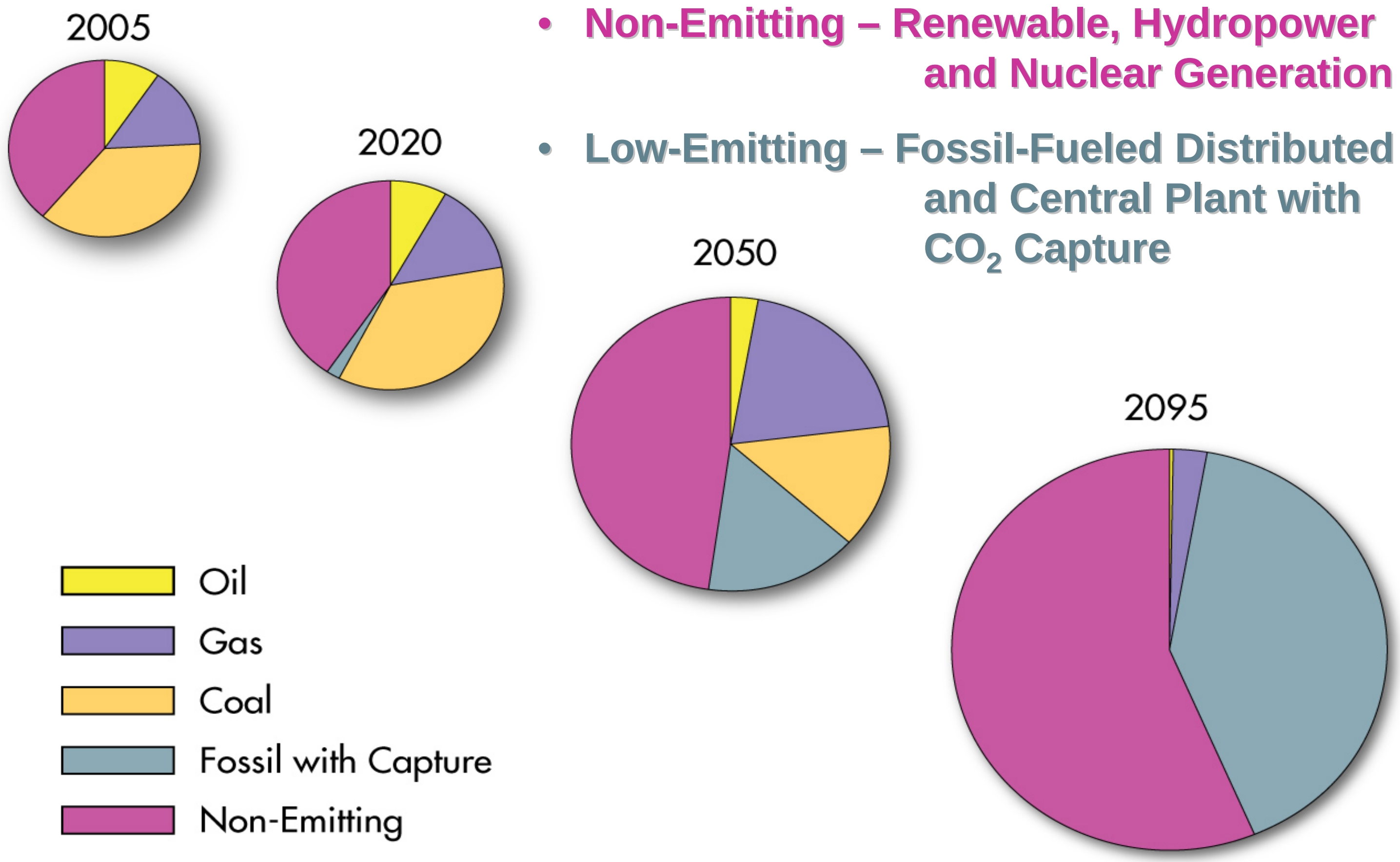
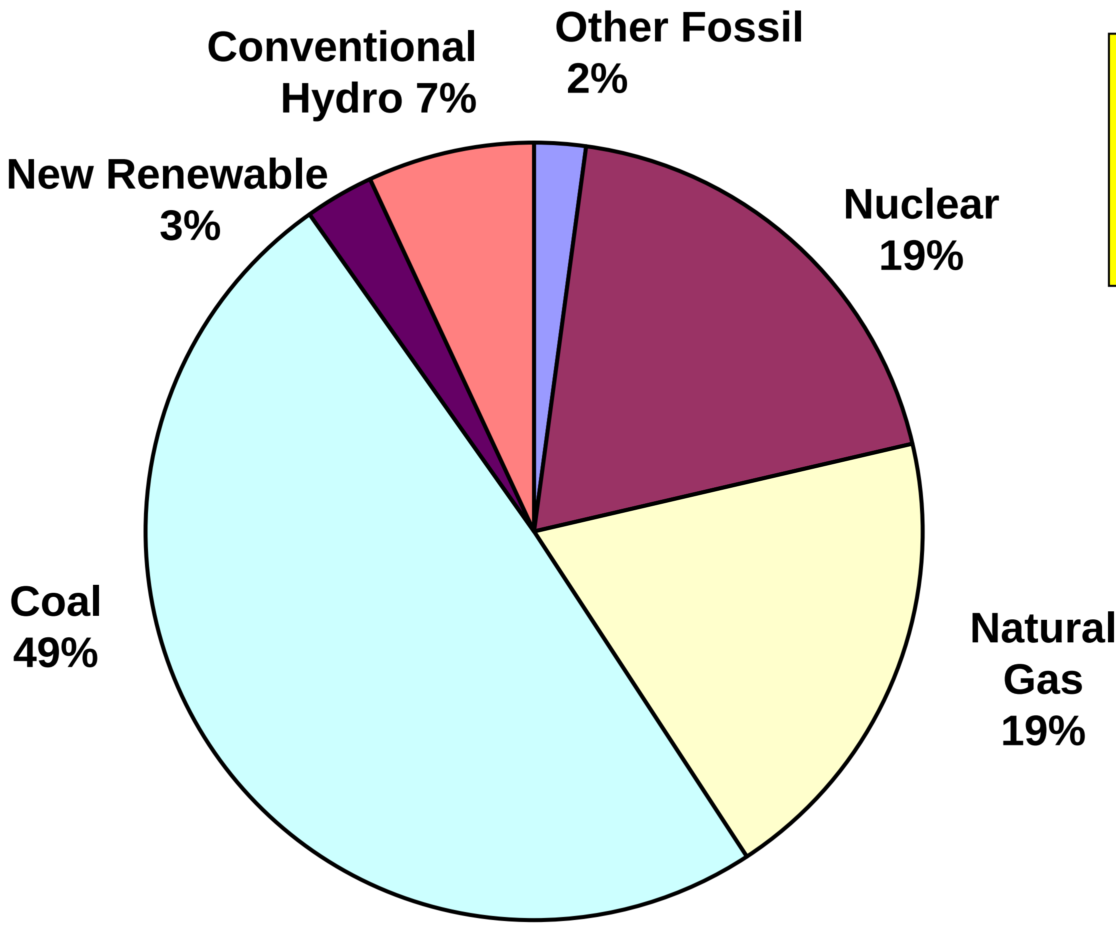
World Electrification Growth and Mix to Stabilize CO_2 Concentrations at 550 ppm

- **Non-Emitting – Renewable, Hydropower and Nuclear Generation**
- **Low-Emitting – Fossil-Fueled Distributed and Central Plant with CO_2 Capture**



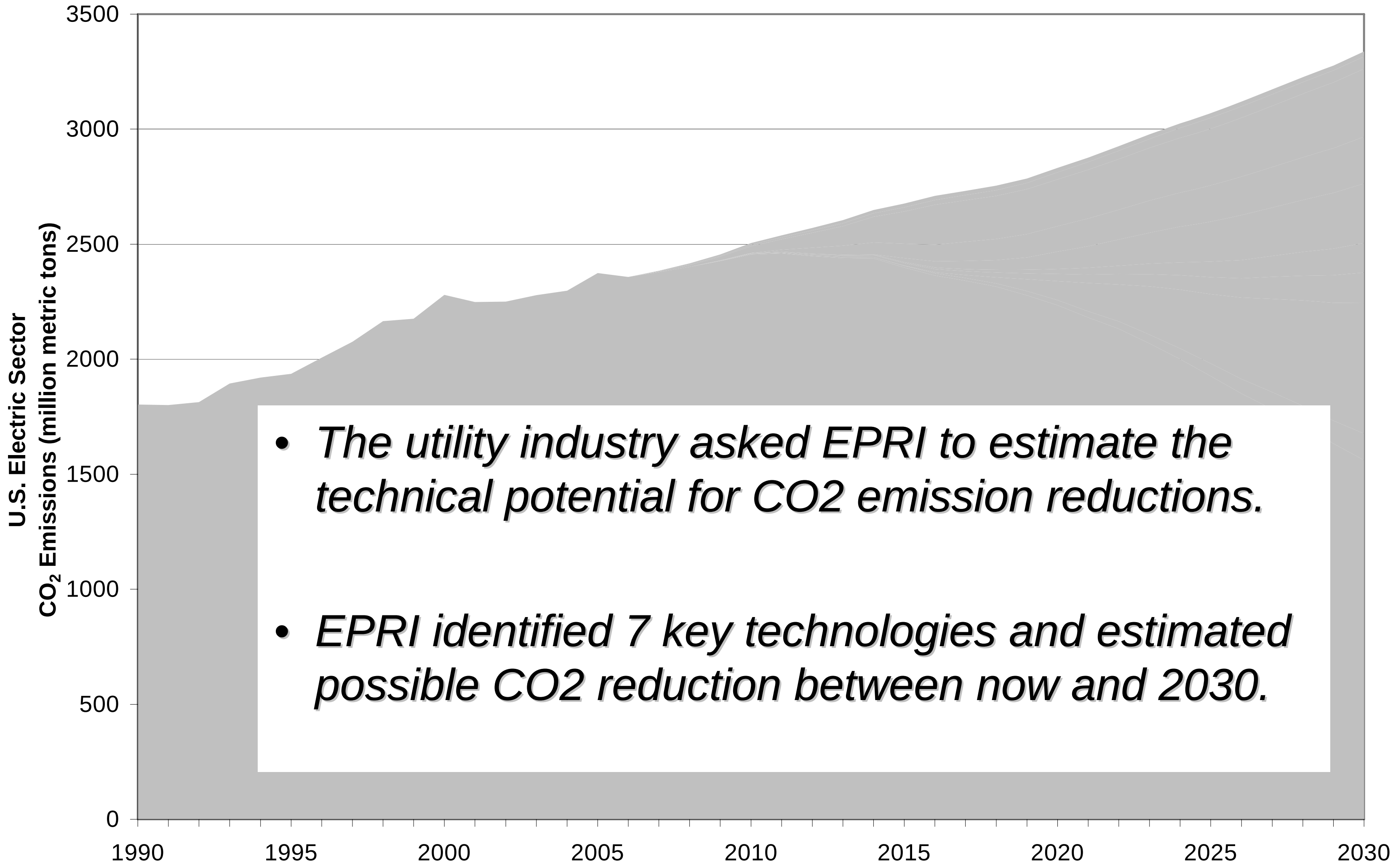
From T. Wilson, EPRI, etal, "Electrification of the Economy and CO2 Emissions Mitigation," ***Journal of Environmental Economics and Policy Studies*****, Vol. 7/No. 5, 2005**

U.S. Electricity Generation 2006 from Energy Information Agency (EIA)



Electric energy generation = 4097 TWh

Anticipated U.S. Electricity Sector CO_2 Emissions based on EIA 2007 Annual Energy Outlook



- *The utility industry asked EPRI to estimate the technical potential for CO2 emission reductions.*
- *EPRI identified 7 key technologies and estimated possible CO2 reduction between now and 2030.*

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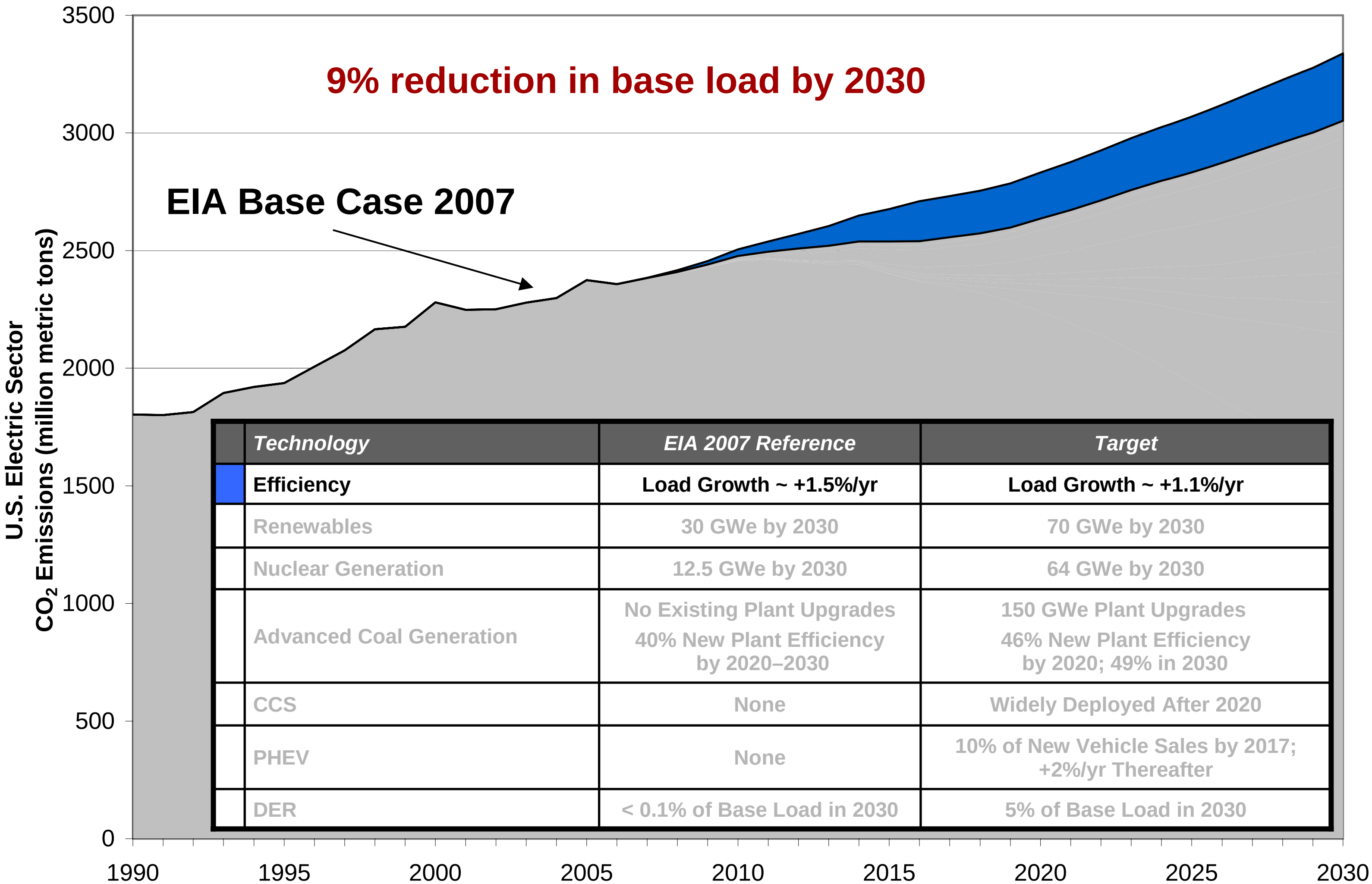
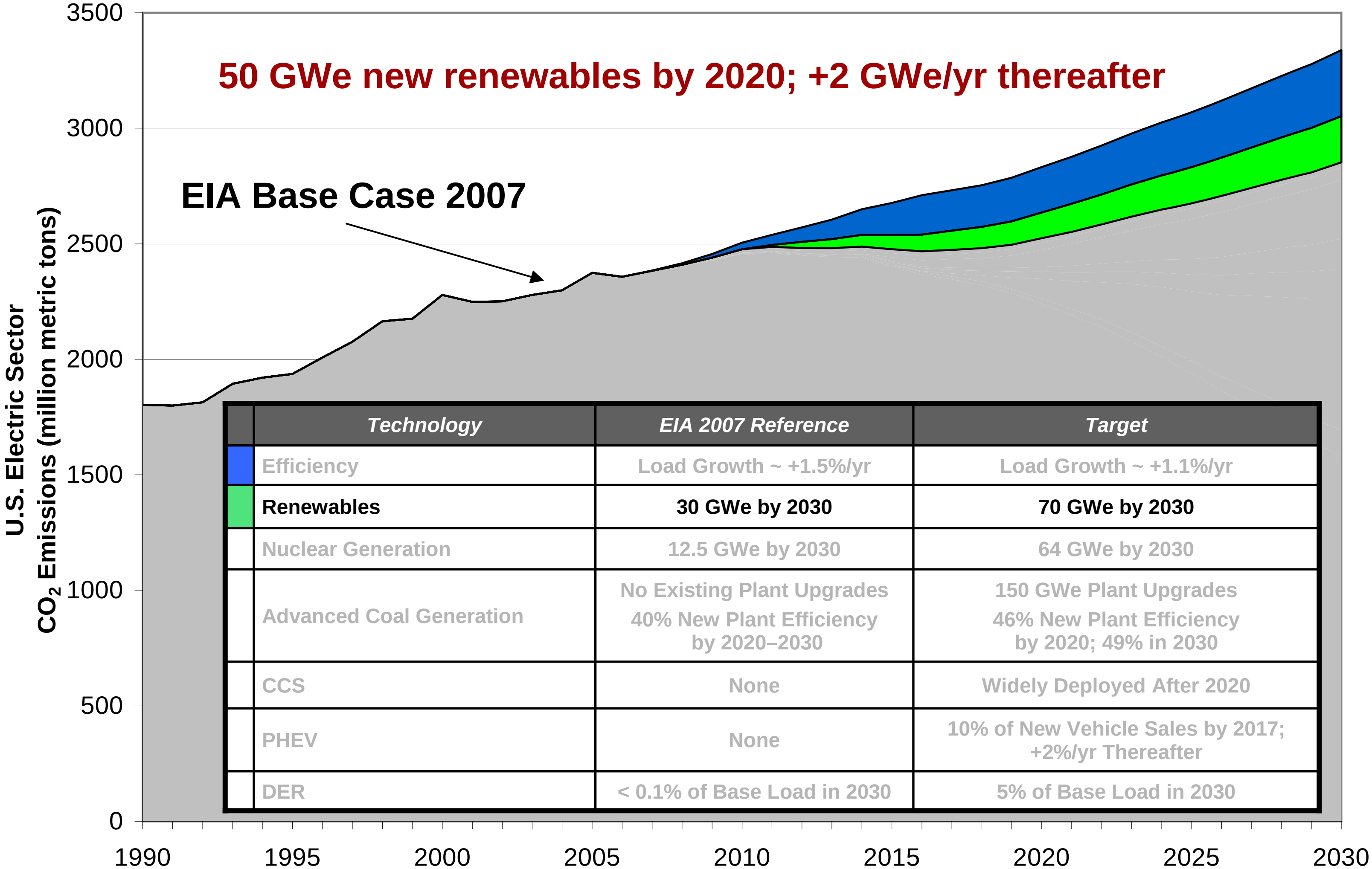
Benefits of Achieving Efficiency Target



	Technology	*EIA 2007 Reference*	*Target*
	Efficiency	**Load Growth ~ +1.5%/yr**	**Load Growth ~ +1.1%/yr**
	Renewables	30 GWe by 2030	70 GWe by 2030
	Nuclear Generation	12.5 GWe by 2030	64 GWe by 2030
	Advanced Coal Generation	No Existing Plant Upgrades 40% New Plant Efficiency by 2020–2030	150 GWe Plant Upgrades 46% New Plant Efficiency by 2020; 49% in 2030
	CCS	None	Widely Deployed After 2020
	PHEV	None	10% of New Vehicle Sales by 2017; +2%/yr Thereafter
	DER	< 0.1% of Base Load in 2030	5% of Base Load in 2030

Benefits of Achieving Renewables Target



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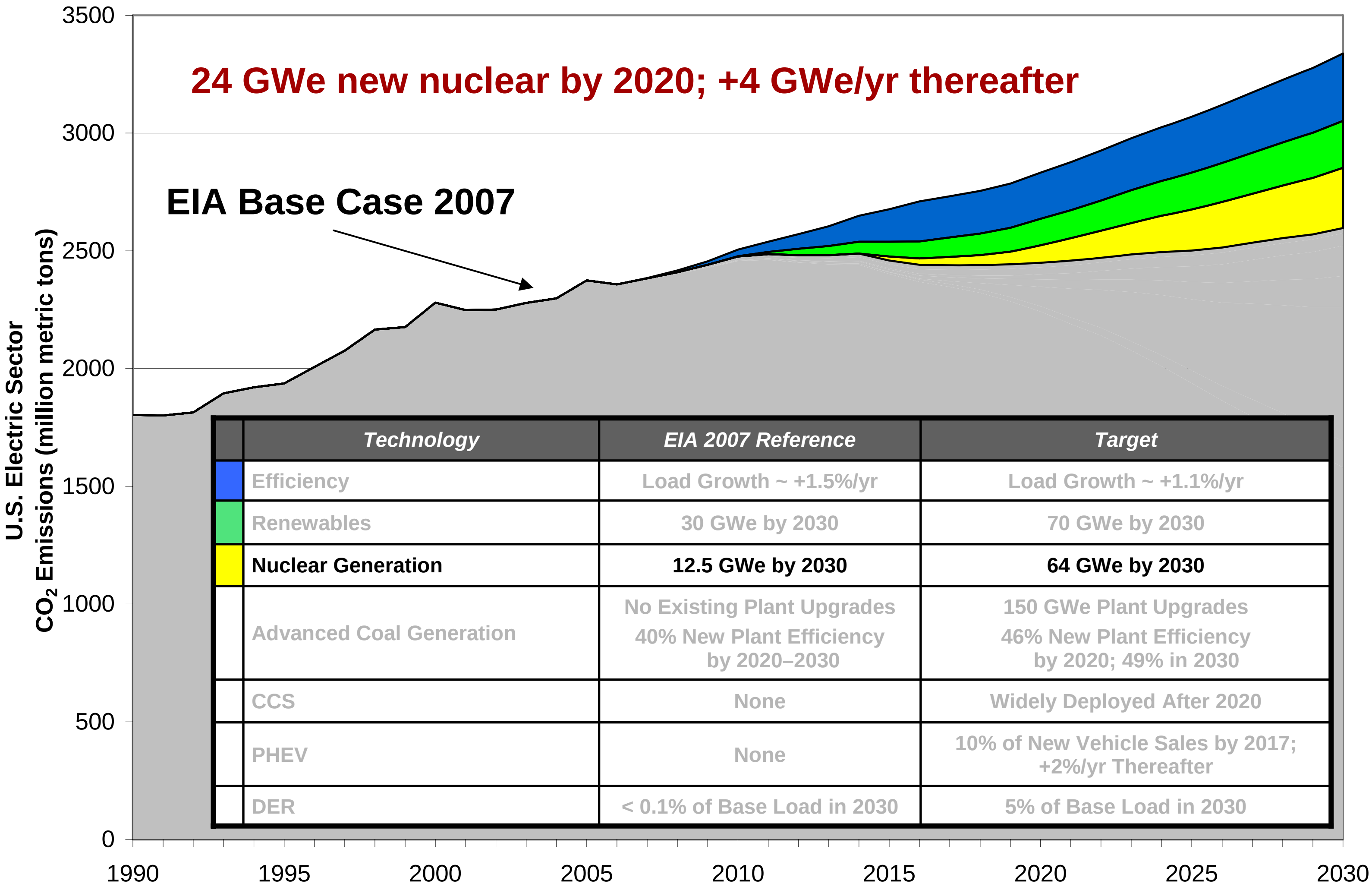
Benefit of Achieving Nuclear Generation Target



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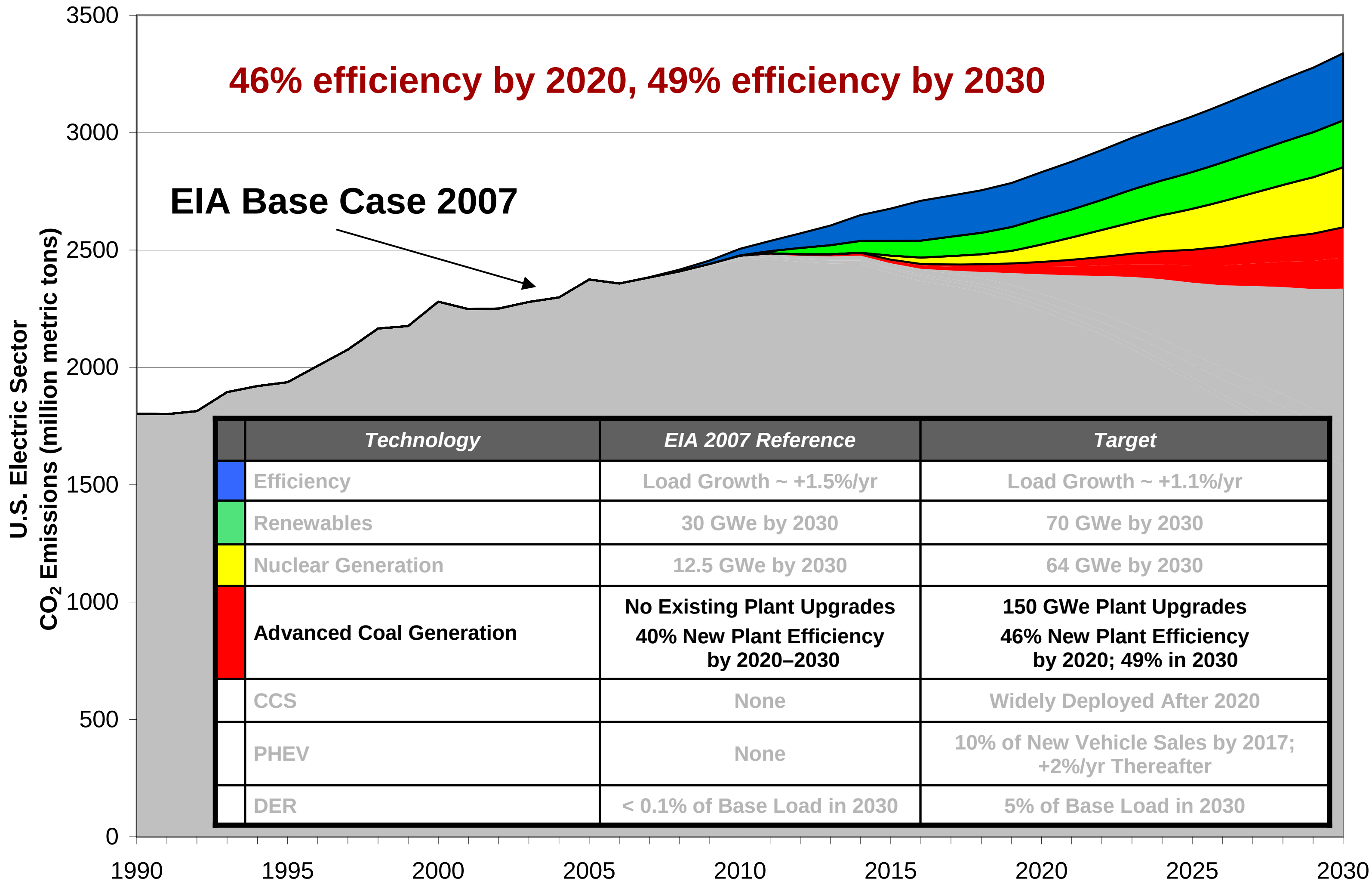
Benefit of Achieving Advanced Coal Generation Target



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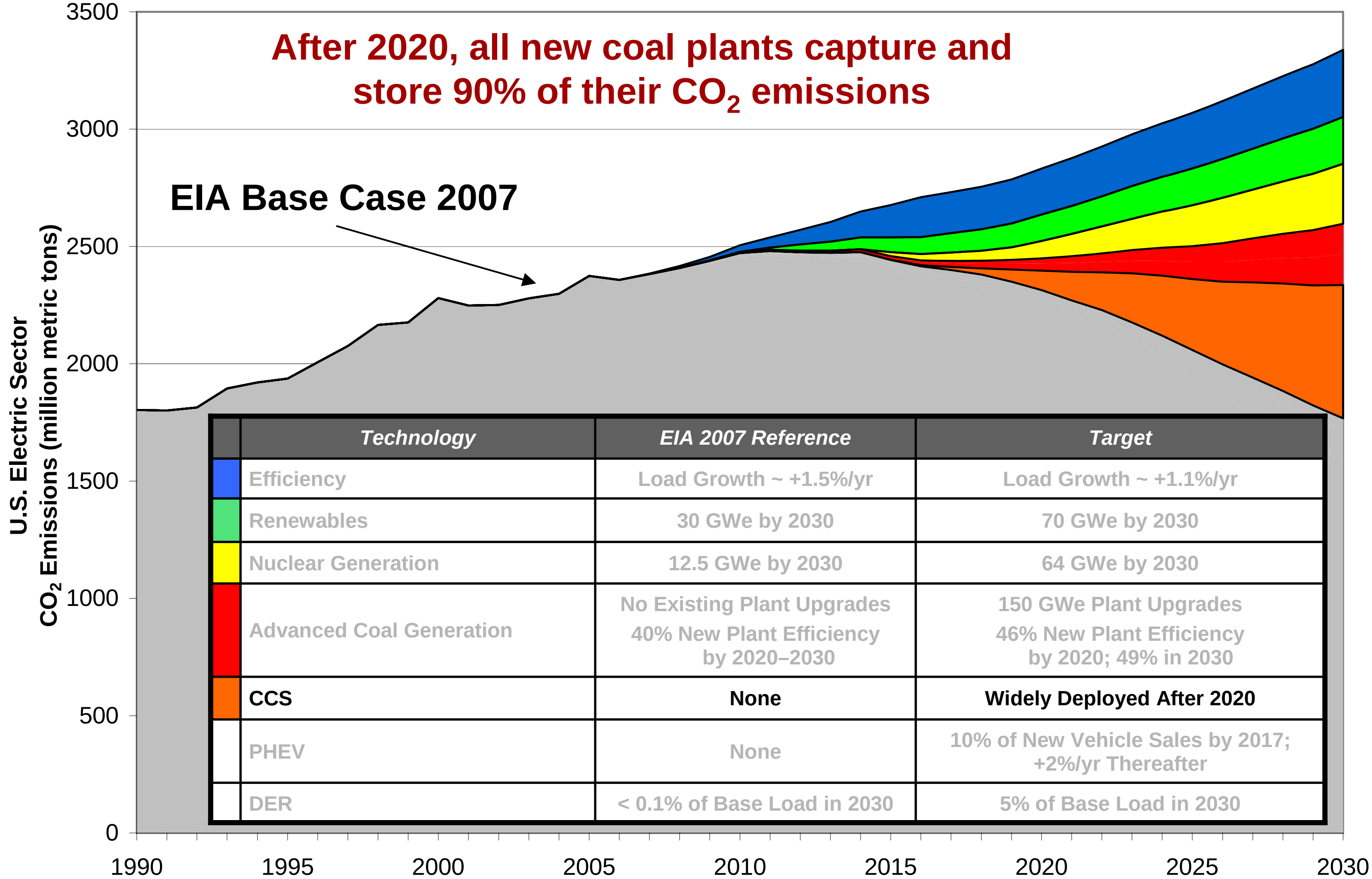
Benefit of Achieving the CCS Target



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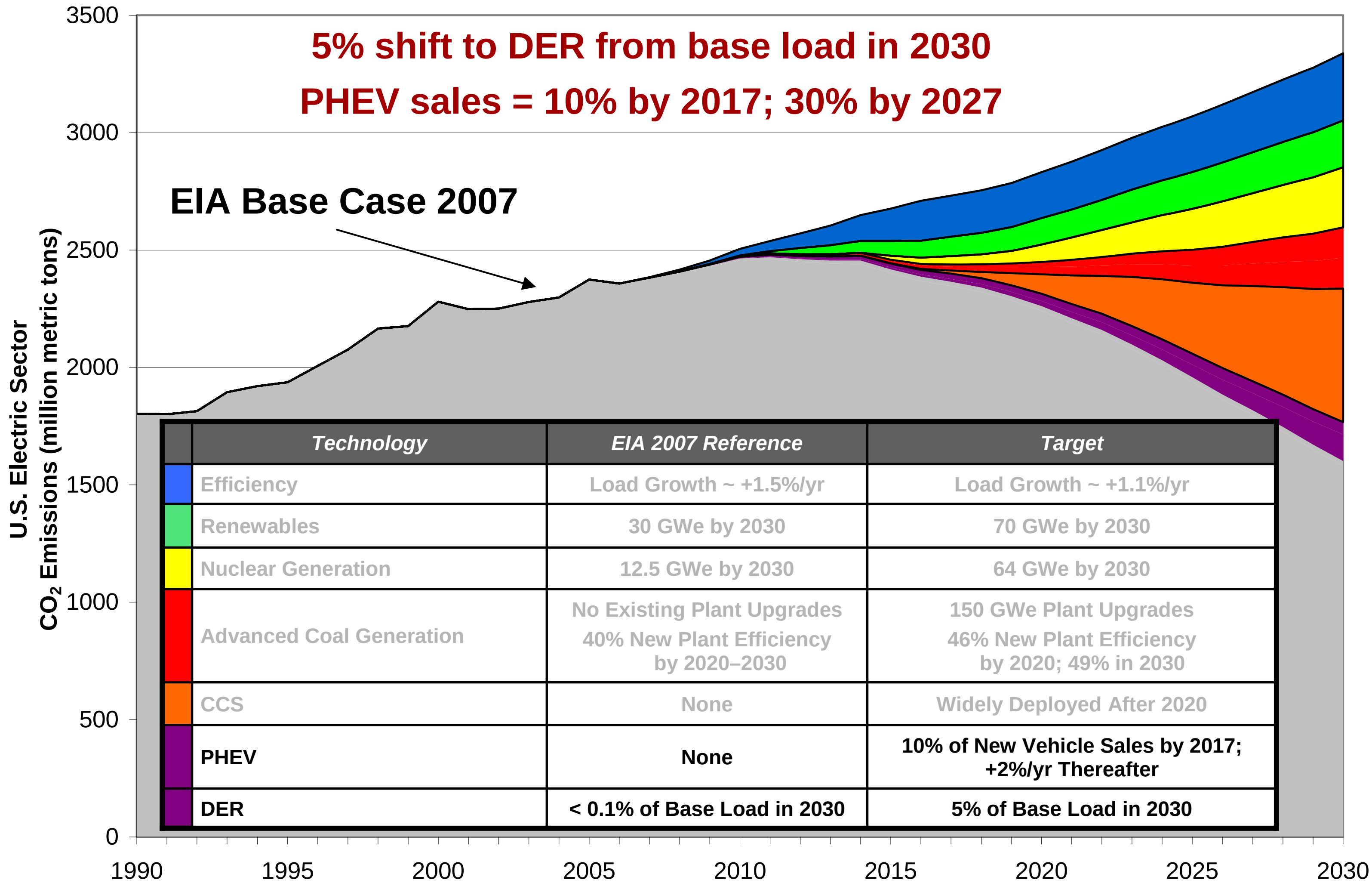
Benefits of Achieving PHEV and DER Targets



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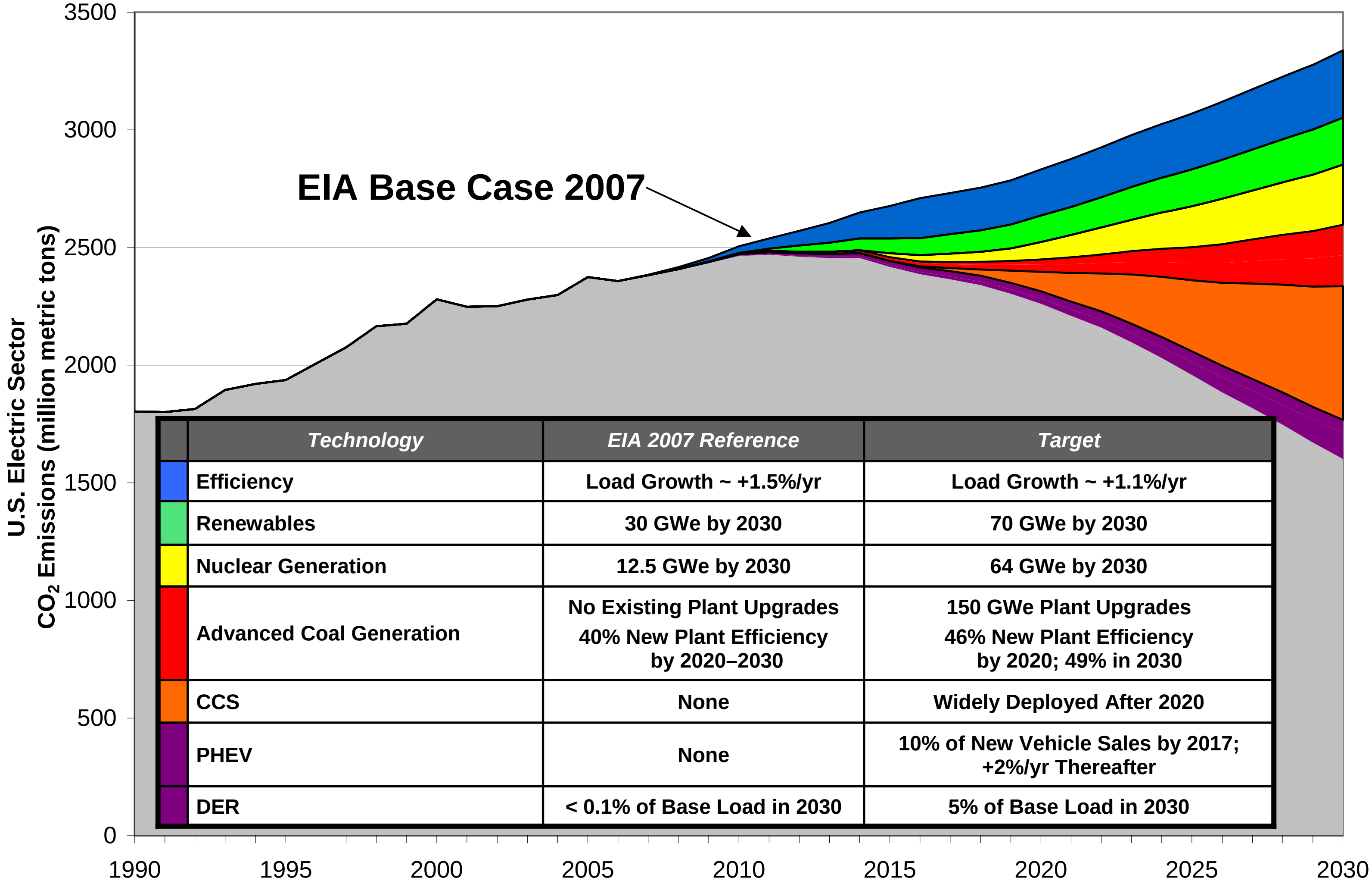
CO_2 Reductions…What's Technically Feasible



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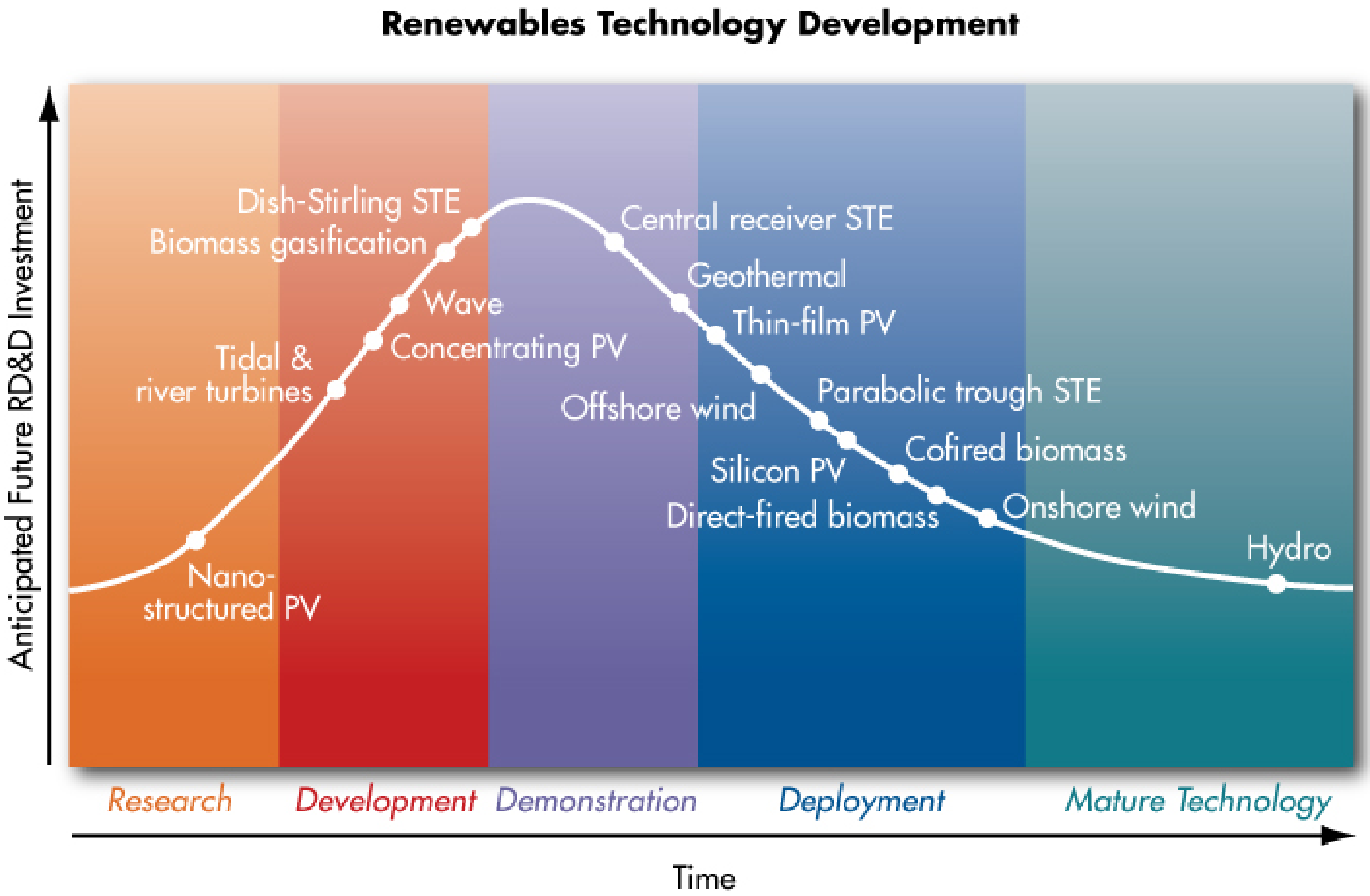
Conclusions

- It is technically feasible for the electricity sector to significantly reduce CO_2 emissions over the coming decades.
- No one technology will be a silver bullet – a portfolio of technologies will be needed.
- Much of the needed technology isn't available yet – substantial R&D and demonstration are required.

Where Renewable Technologies are Today



Estimates on how much renewable energy, by when?

Source of Estimate	Description of Estimate	Target Year	Renewable Capacity (GW)	Renewable Energy (TW-hr)	Different Methods, Assumptions and Conditions
EIA AEO 2007	NEMS model	2030	40	177	Detailed economic model Business-as-usual scenario
EPRI CO2 Prism	Technical Feasibility	2030	70	307	Estimated technical potential to reduce CO_2
EPRI RE Scenarios	NESSIE model	2030	155	737	Detailed economic model High Natural Gas and High CO_2 cost scenario
EIA AEO 2007	Federal RPS 20%	2030	236	1034	RPS (20%) times estimated metered electricity sales
ACORE Outlook	Resource Availability	2025	635	1947	Assumes significant renewable deployment, with incentives to bridge cost gaps

Status of Renewable Generation Capacity

Technology for Electric Generation	Status	2006 Installed World (US) MW	Main Issues
Wind	Commercial	73,900 (11,603)	Cost, Grid Integration
Biomass Combustion	Commercial	22,400 (9,700)	High Fuel Cost, Emissions
Geothermal	Commercial	8,933 (2,828)	Cost and Risk
Solar PV	Commercial	5,000 (550)	Capital Cost, Efficiency
Solar Thermal	Demo & Pre-Commercial	365 (355)	Capital Cost, Resources
Biomass Gasification	Pilot & Demo	<20 (n/a)	Fuel Cost, Hot Gas Cleanup
Ocean Energy (Wave and Tidal)	Pilot & Demo	<5 (<1.1)	Cost, Durability, Reliability

Source: EPRI *Renewable Energy Technical Assessment Guide: TAG-RE 2006* (1012722, 3/07), and data available 10/5/07

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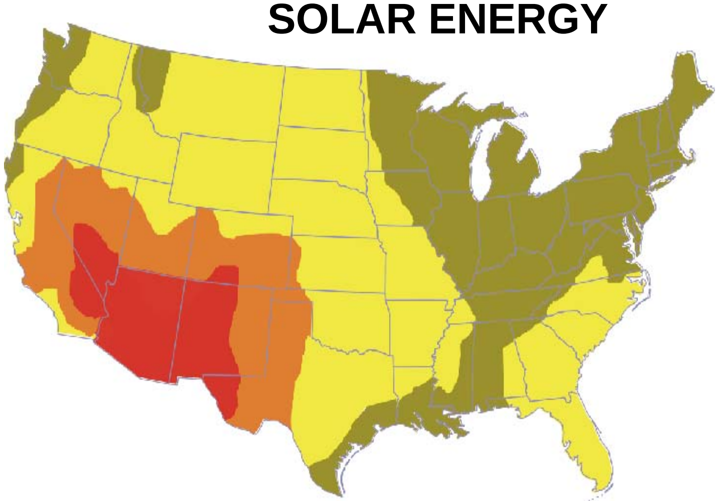
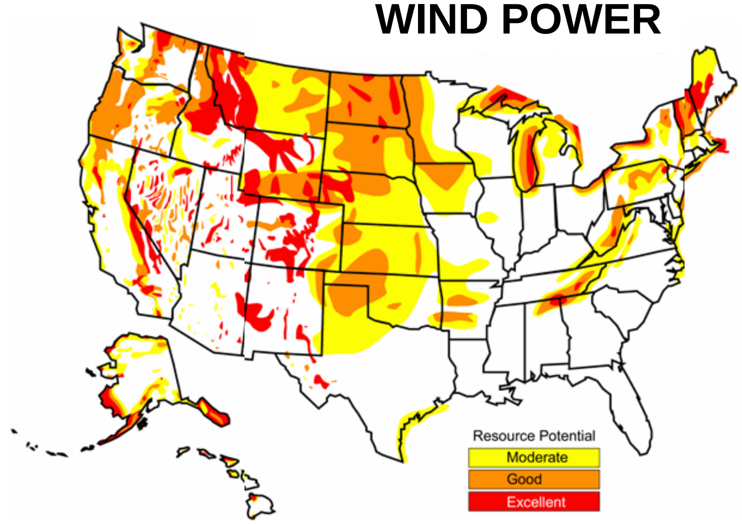
U.S. Renewable Energy Resource Availability

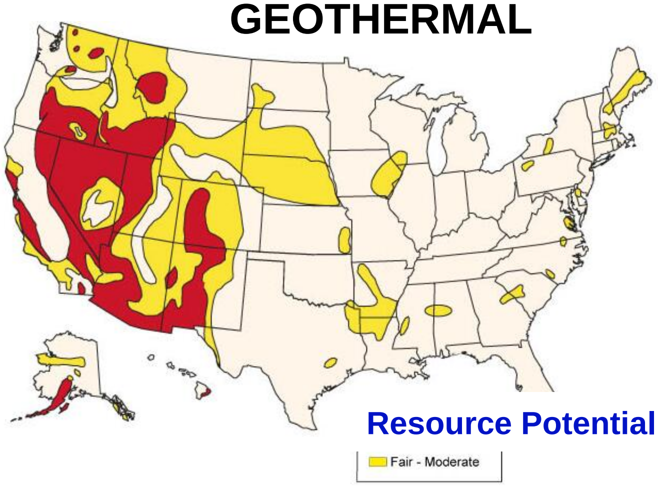
SOLAR ENERGY



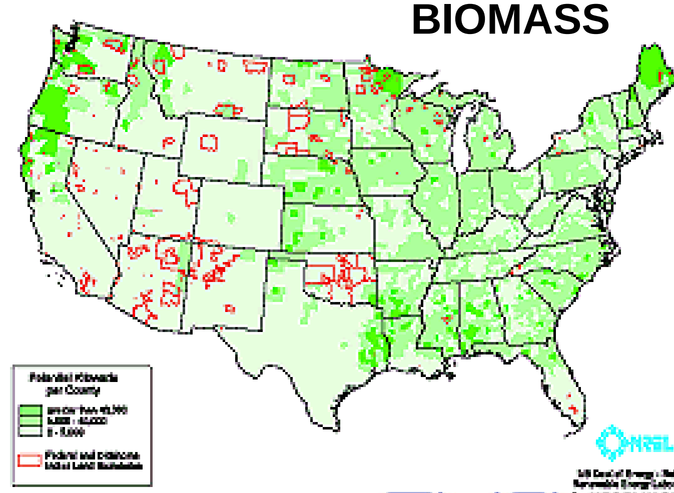
WIND POWER



GEOTHERMAL



BIOMASS

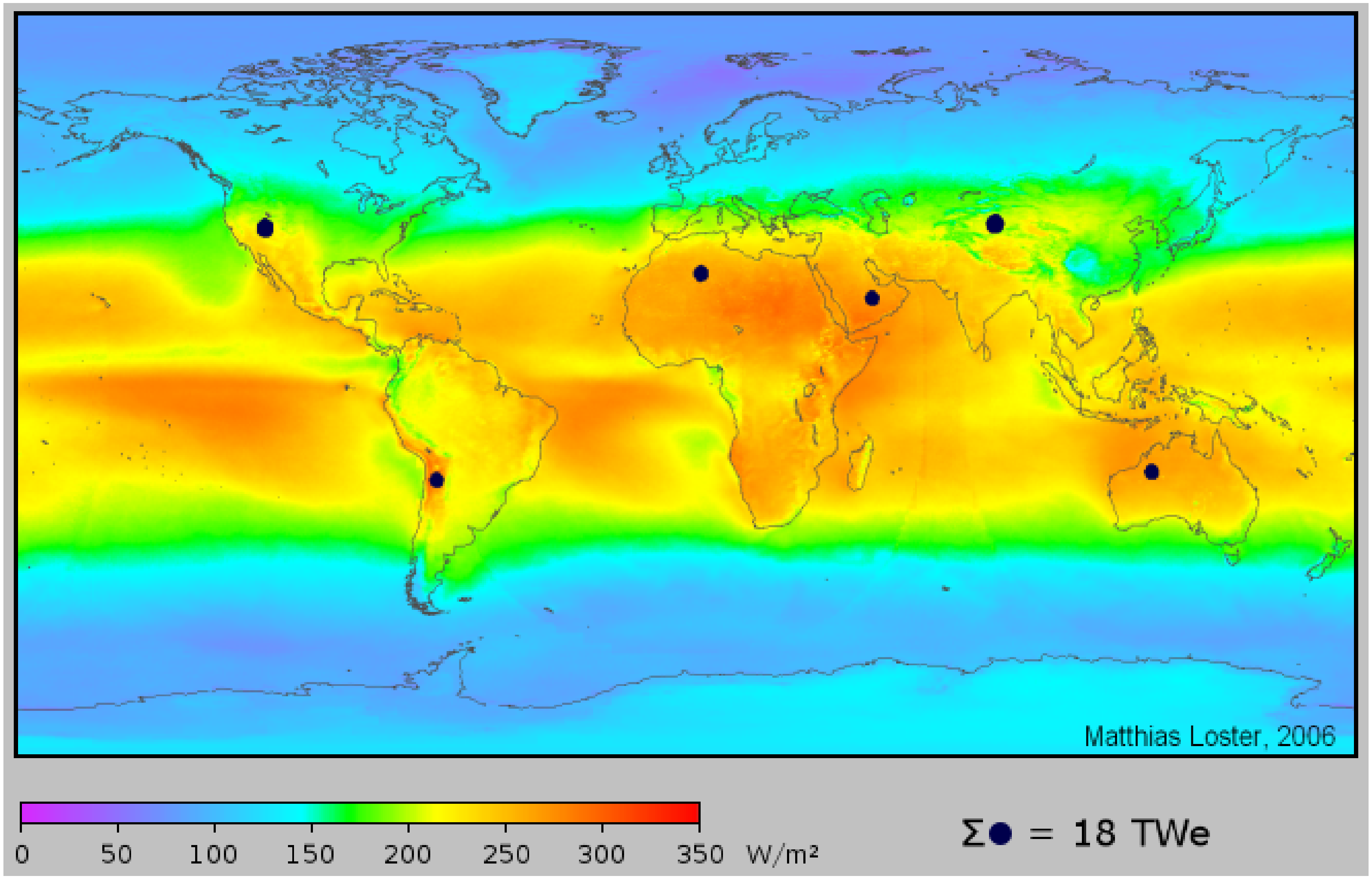


Cost estimates for current renewable energy technologies (in 2006 $)

Updated 10/6/07	Biomass CFBC	Geo-thermal	Solar PV Flat Plate	Solar Thermal Trough	Wind Class 3 to 6 No PTC
Rated MW	50 MW	50 MW	10 x 5 MW	80 MW	25 x 2 MW
Capital Cost $/kW	$3,495	$2,470 – 3,470	$7,000	$4,390	$1,932
O&M Cost $/kW-yr	$122	$125	$14	$58	$40
Fuel Cost $/GJ	$1.00 – 4.00	-	-	-	-
Capacity Factor	85%	90%	17 – 25%	28 – 32%	32 – 42%
LCOE $/MWh (no PTC)	$77 – 116	$55 – 71	$406 – 597	$216 – 247	$81 – 104

Source: *Renewable Energy Technical Assessment Guide – TAG-RE: 2006* (EPRI 1012722, March 2007), Note that LCOE depends on site-specific resources, labor and financing costs.

Daily Average Worldwide Insolation



Source: M. Loster, U.C. Berkeley, www.ez2c.de/ml/solar_land_area/

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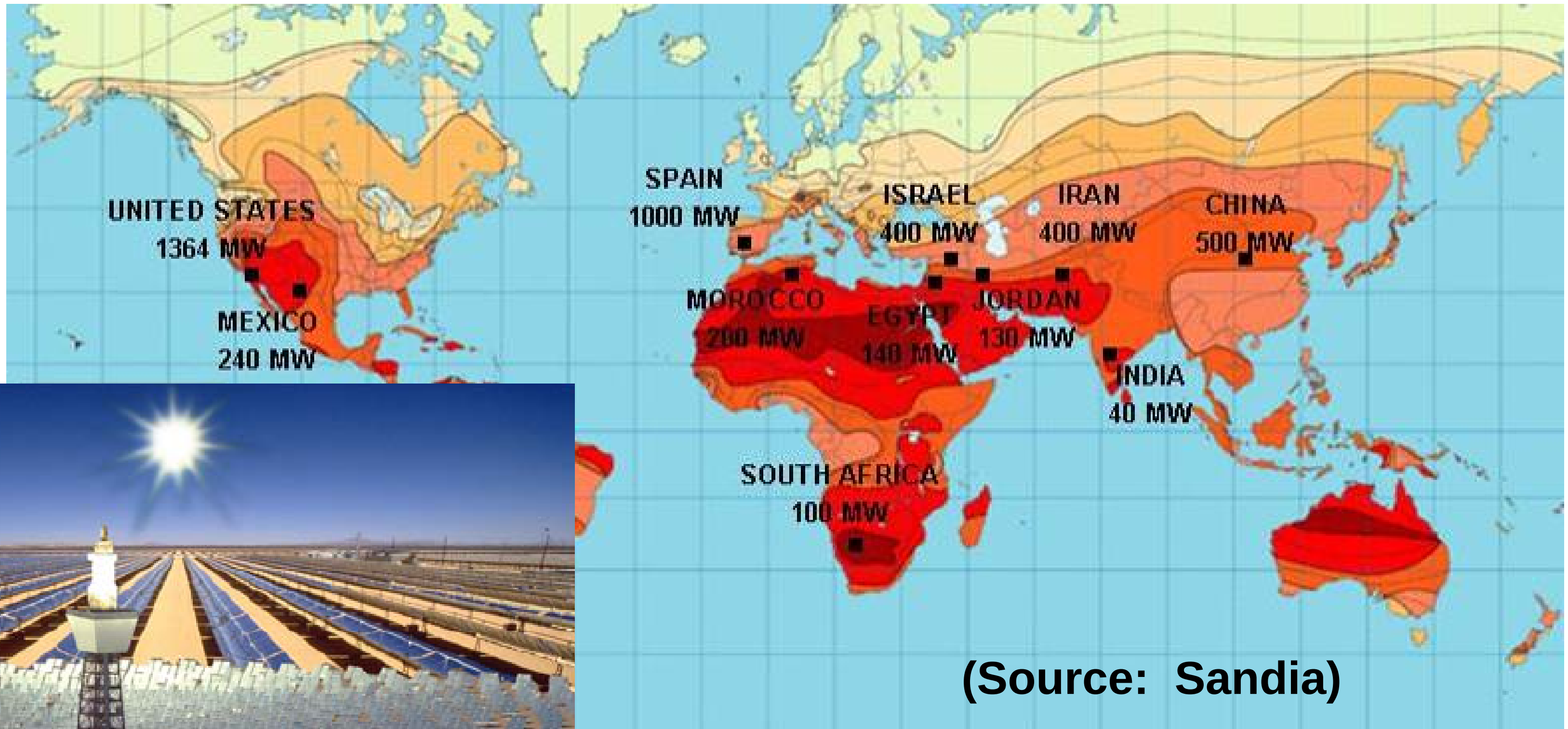
Concentrating solar thermal plants planned Total ~4.5 GW



(Source: Sandia)

- **Simple learning curve analysis for solar trough shows potential to cut the cost in half by 2015**

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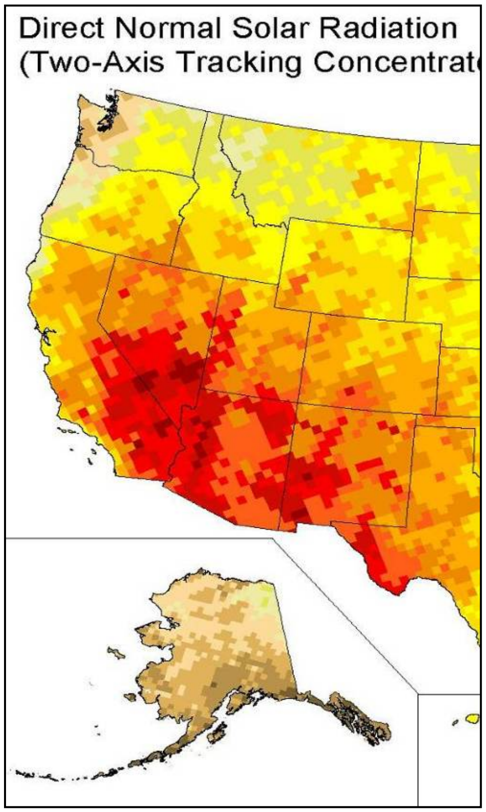
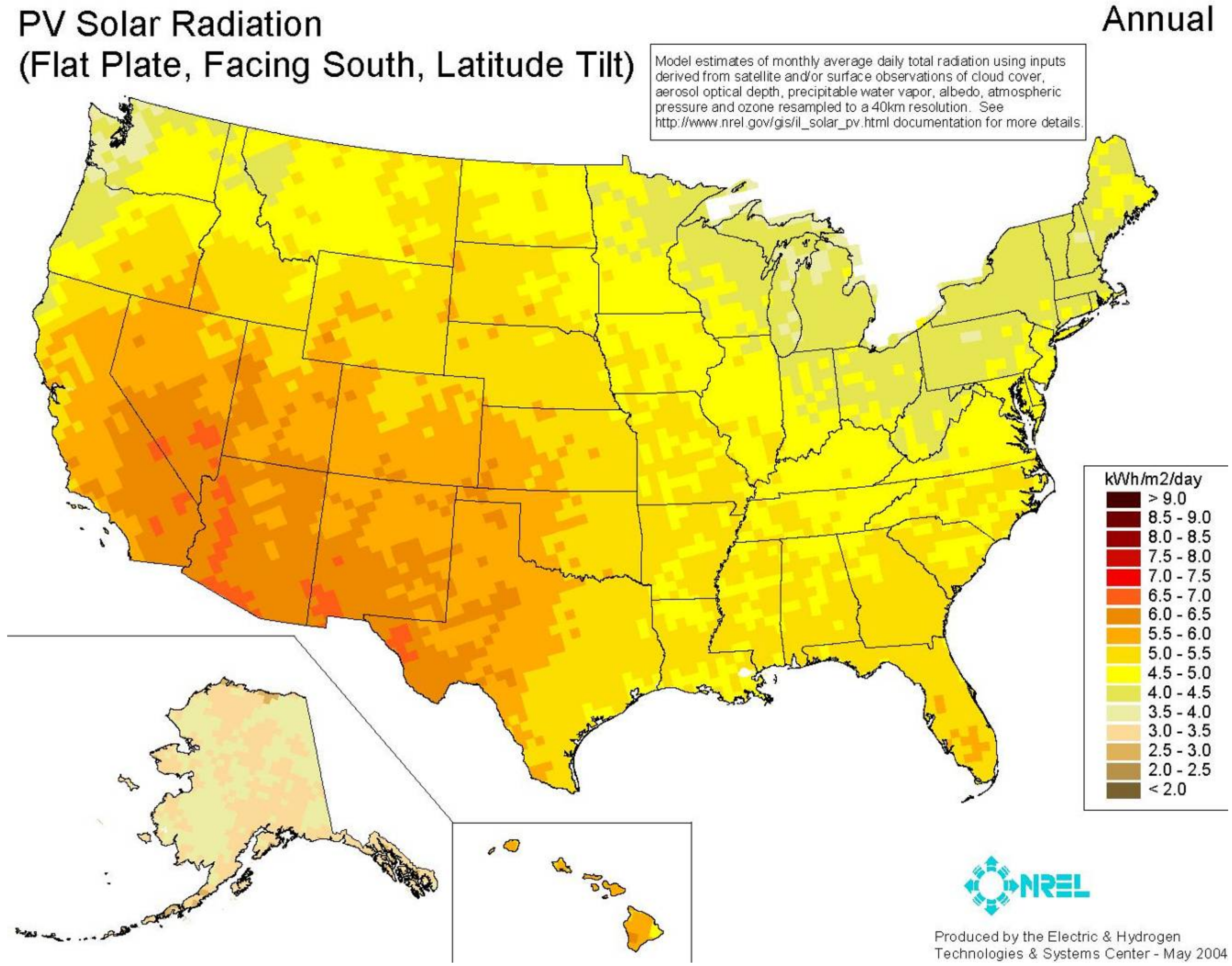
Diffuse solar radiation varies by a factor of ~ 2 to 1, Direct normal (concentrating thermal) ~ 4 to 1





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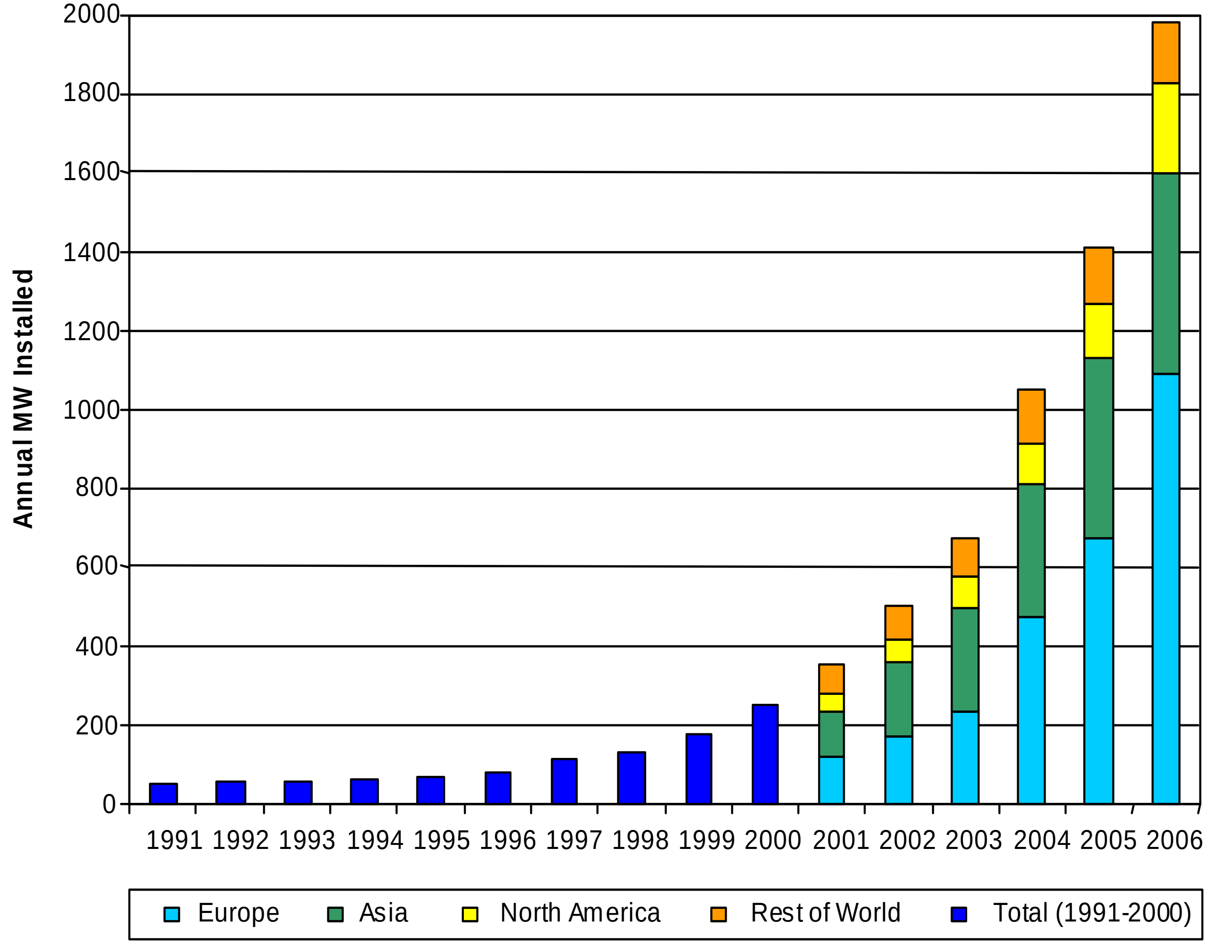
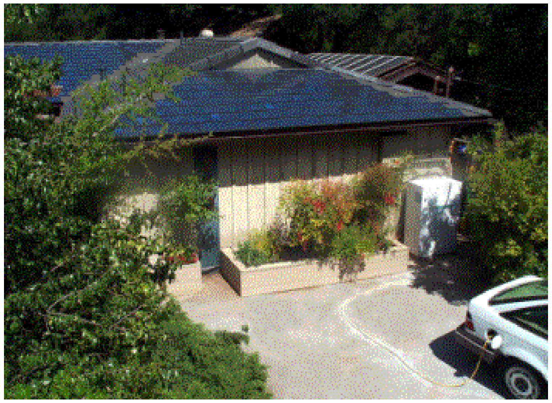
Photovoltaic – $8 billion/year Global Industry 90% will be Connected to Grid





Approximate 5,500 MW in place adding 1,500 MW/year globally

- Rooftop/building PV will emerge with cost/efficiency improvement.
- Solar thermal is better utility fit but unproven and less upside.

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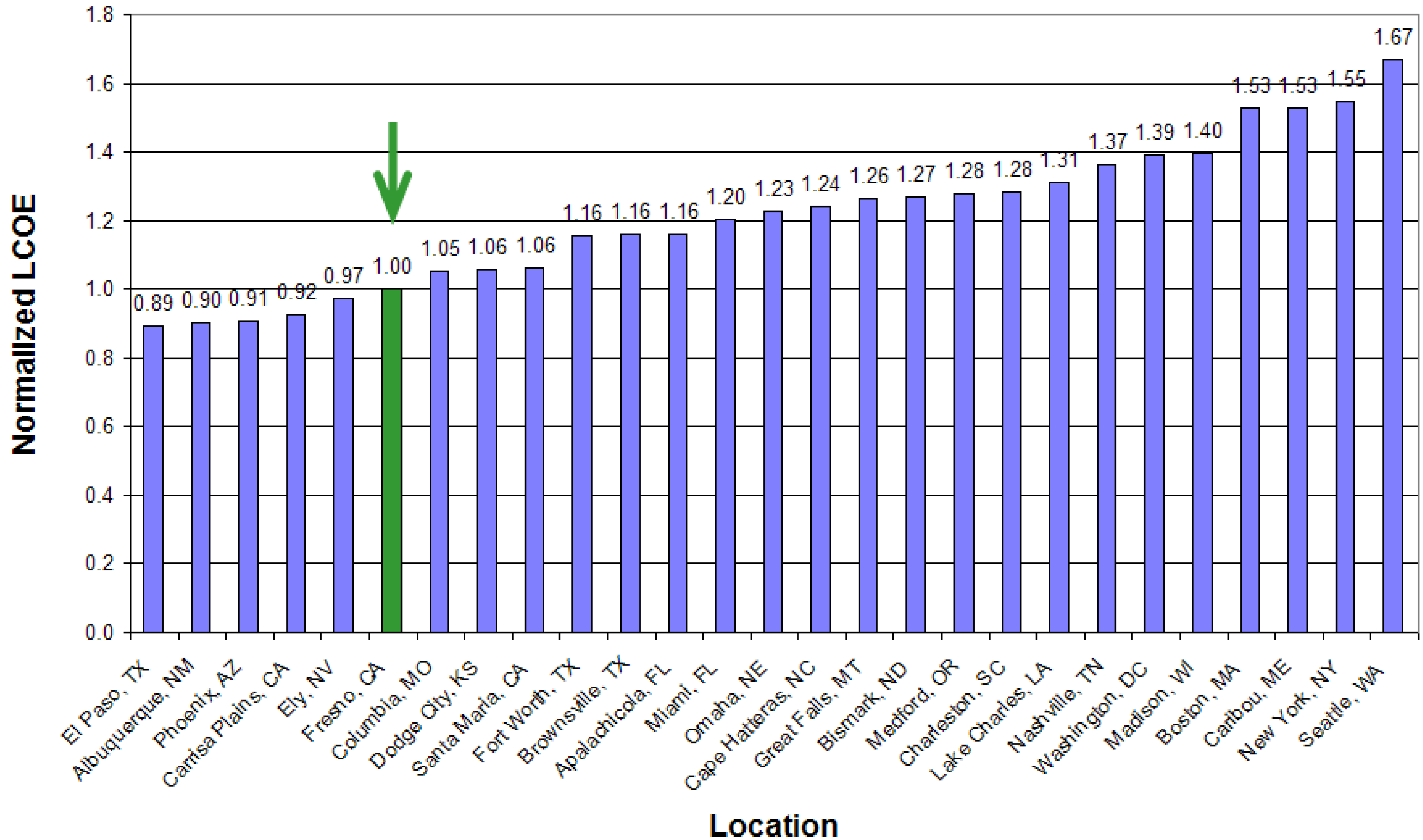
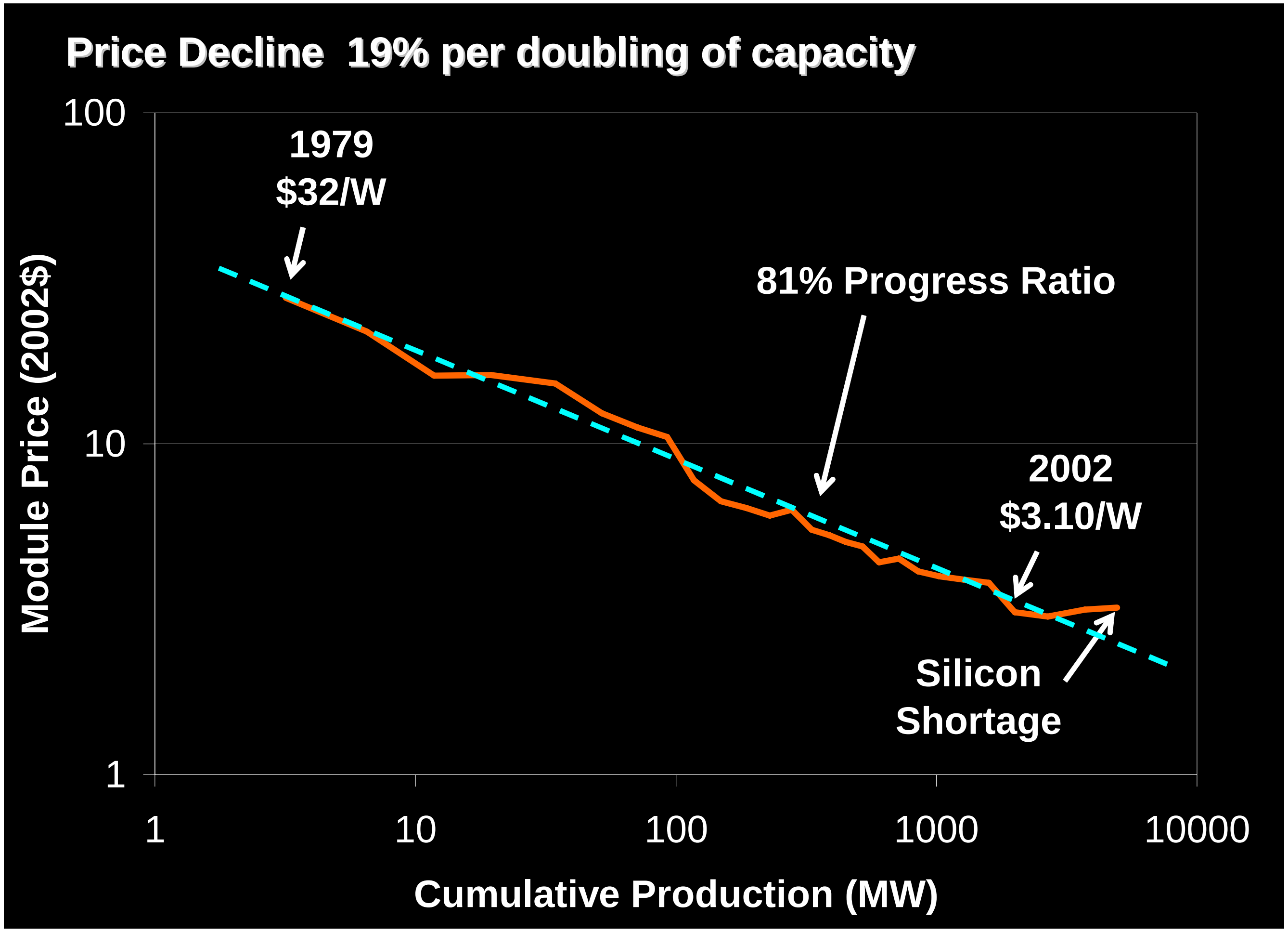
Relative Cost of PV Electricity Due to Resource Variability



PV Module Price Learning Curve



Note: Revenue in 2000, $2B, and expected in 2010, $20B

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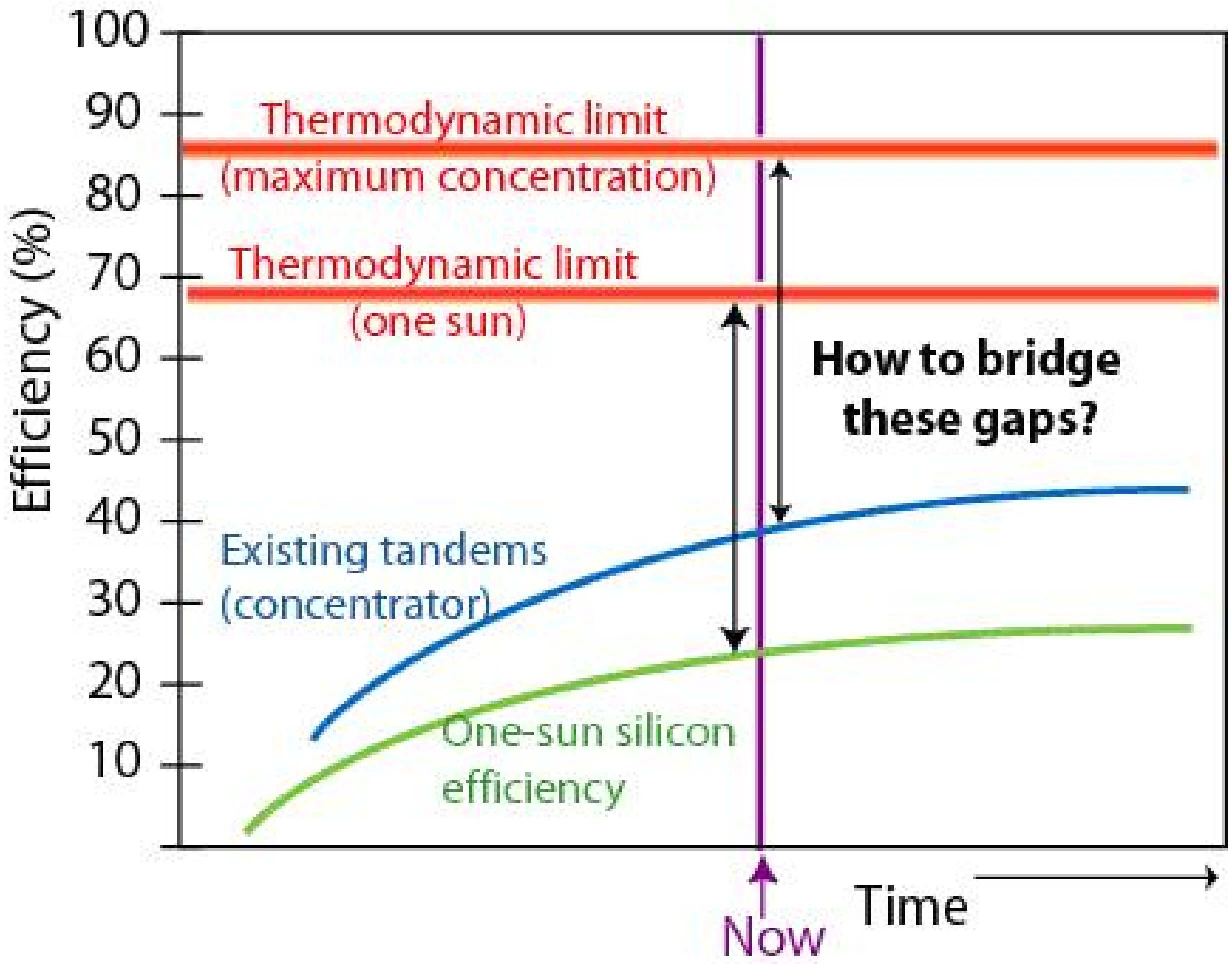
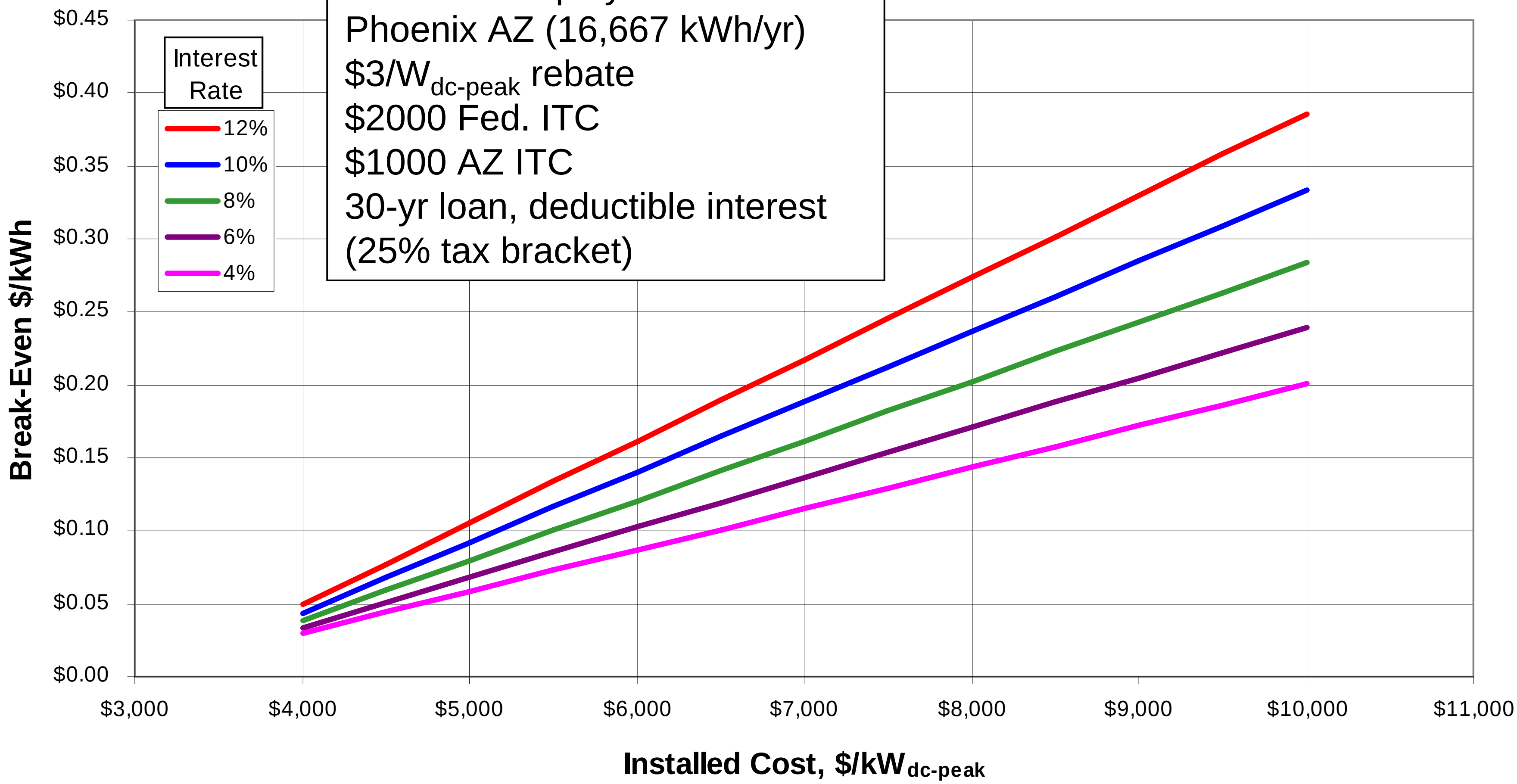
Opportunity Between Existing and Theoretical PV Efficiency



Source: U.S. Department of Energy

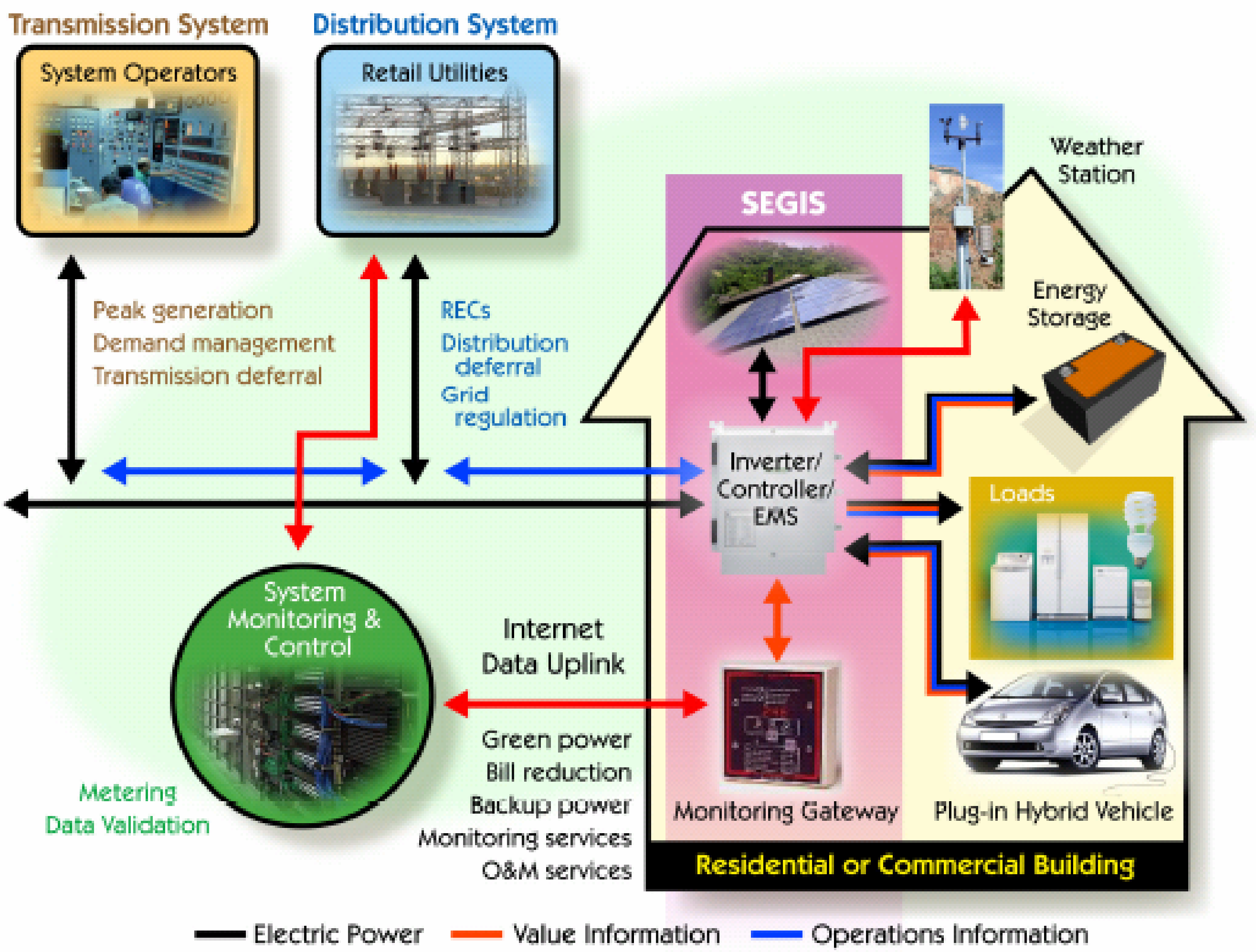
EPRI Break-Even Retail Electricity Prices with Home Mortgage Tax Deduction (first year)



Assumptions:

10-kW rooftop system
Phoenix AZ (16,667 kWh/yr)
$\$3/W_{dc\text{-}peak}$ rebate
$2000 Fed. ITC
$1000 AZ ITC
30-yr loan, deductible interest
(25% tax bracket)

Integration of Solar and Grid of the Future



Source: U.S. Department of Energy

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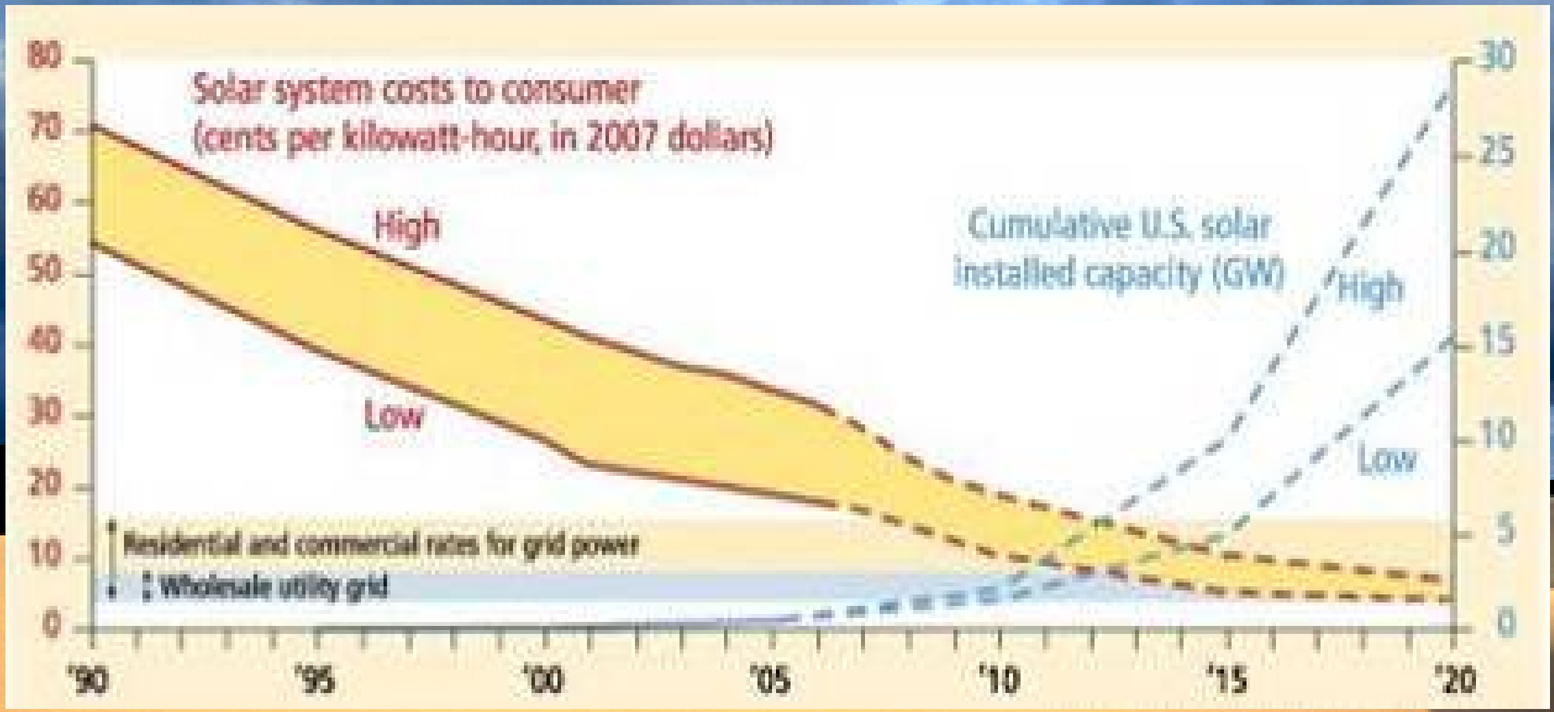
DOE Forecast by Year:
Cloudy With Strong Chance of Sun



Recent Projection from DOE Solar America

Biomass Energy Fuels

- **Wood and waste wood products**
- **Dedicated Feedstocks as Willow, Poplar, Alfalfa and Switchgrass**

Biomass Technologies

Three Options:

Direct-fired Combustion
Burning biomass to create hot flue gases that produce steam in conventional boilers

Cofiring
Mixing or injecting biomass with coal or other fuels for combustion in traditional steam turbine boilers

Gasification
Converting biomass to a gas used as fuel in a boiler or gas turbine

Biomass Direct-fired Combustion

- Average plant size: 20 MW
- Average biomass-to-electricity efficiency: 20%
- Average electricity cost: 8-15¢/kWh

Technologies include traveling-grate combustors and atmospheric fluidized-bed combustors.

49-MW Wheelabrator Shasta plant, California

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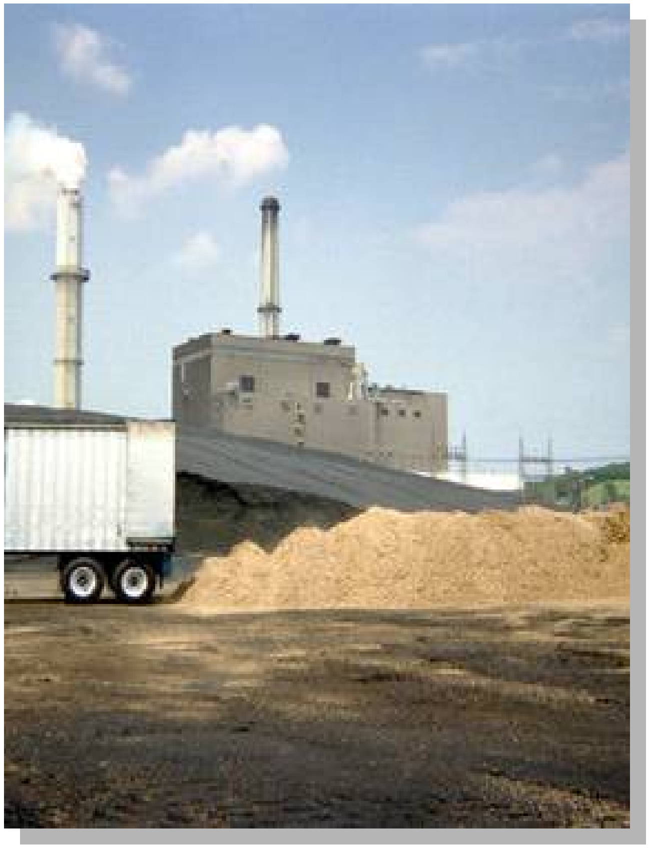
Biomass Cofiring with Coal



Most practical, and economical biomass option

- Biomass can be substituted for up to 10% of a boiler's coal input with minor modification of burner and feed intake
- Wood and most other biomass low sulfur and less ash than most coals
- Cofiring may yield NOx reductions of up to 20% in some cases
- Small decrease in boiler efficiency

EPRI studied biomass cofiring at NIPSCO's Bailey station in Indiana

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Biomass Gasification

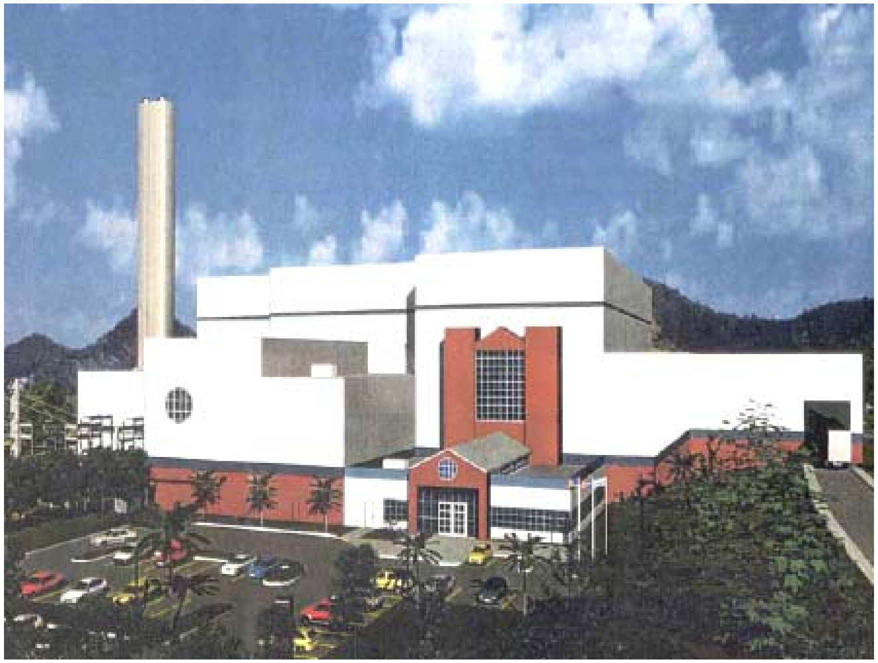
A promising future?

- Converting biomass to a synthesis gas used in a combined-cycle gas turbine
- New technique, not widespread 37% vs. 20% efficiency
- Potential advantages could make it a commercial workhorse of the future

Gasifier and loader, McNeil Station, Vermont

Municipal Solid Waste (MSW) or Waste to Energy (W-T-E) Generation

- ***W-T-E Generation is driven by increasing land fill costs, $50-75/ton in some areas…its not the cheapest source of electric energy***
- ***Up to 34% of Municipal Solid Waste in New England goes to energy, 27% recycled, 39% to land fill.****
- ***For the US 50 States average is 7% combusted, 32% recycled, and 61% to land fill.****



Modern W-T-E Facility includes recycling and power generation

***** From Columbia Univ. Earth Engineering Center, 2003 b

Biomass Digesters

- Manure Digestion
  - GHG and run-off mitigation
  - Plug-flow reactor most common
  - Produces CH_4 for combustion
  - Electricity produced by IC engine
- Landfill Gas
- Fermentation
  - Conventional vs cellulosic
    - Hydrolysis vs gasification
  - Integration opportunities?
  - Combustion turbine fuel?

Manure Digester, Chino, CA

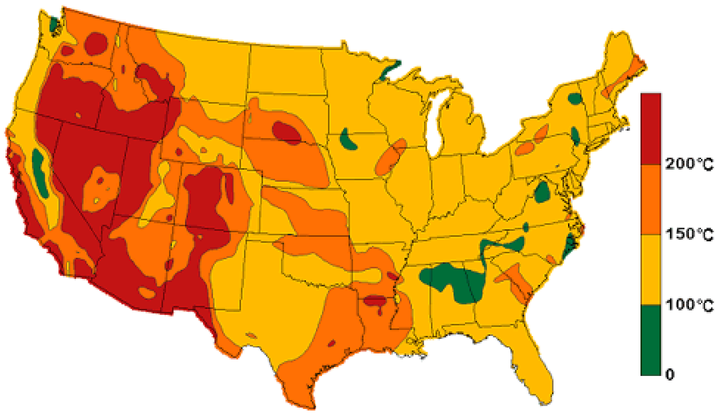
Unresolved issues in biomass utilization

- **Gasification**
  - How/when will biomass gasification play a role in the generation mix? Atmospheric? Pressurized?
  - "Utility Scale" gasification (>25 MW)
  - Gas cleanup/prime mover selection and integration
- **Resources**
  - Future tension between power station feedstock and cellulosic ethanol feedstock
  - Carbon neutrality of biomass
- **Generation**
  - How do you build biomass capability into the next generation of power stations?
  - From a risk-analysis perspective, how much biomass should be stored on site?
  - Definitive assessment of impact of biomass firing on deNOx catalyst life

Geothermal and ocean energy status

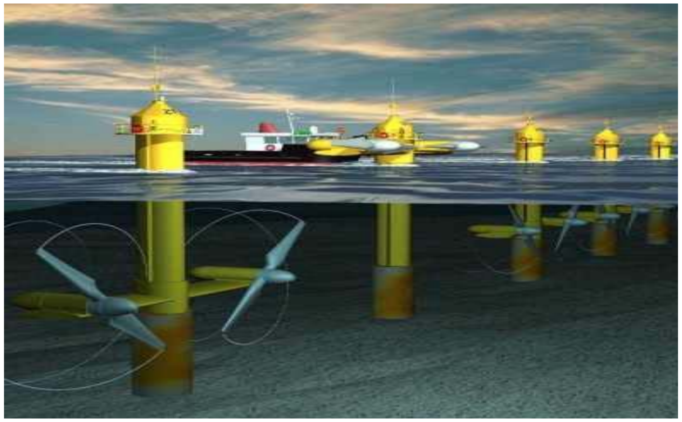
Geothermal energy

- 2500 MW in the U.S., mostly in California Nevada and Hawaii.
- Issues include finding reliable resources
- High cost of geothermal wells and potential decreased output over time
- Utility interest has waned



Subsurface temperatures

at 6-km depth (deg C)



Ocean energy

- A few hundred kW worldwide, ocean tidal and wave energy offers significant potential, 10-20 years out.
- North American assessment lead by EPRI collaborating with NREL…see rly demonstrations, including related wave, tidal and in-steam hydro-kinetic turbines.

Ocean and River Energy future?

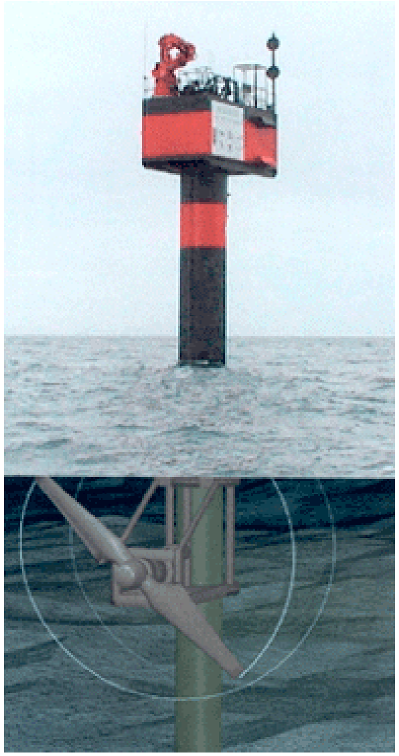
U.S. has significant resources:

Water Currents

Ocean Waves

Emerging technologies

Current machines



Courtesy: MCT

Wave machines

Courtesy: Pelamis WavePower

Courtesy: Ocean Power Technology

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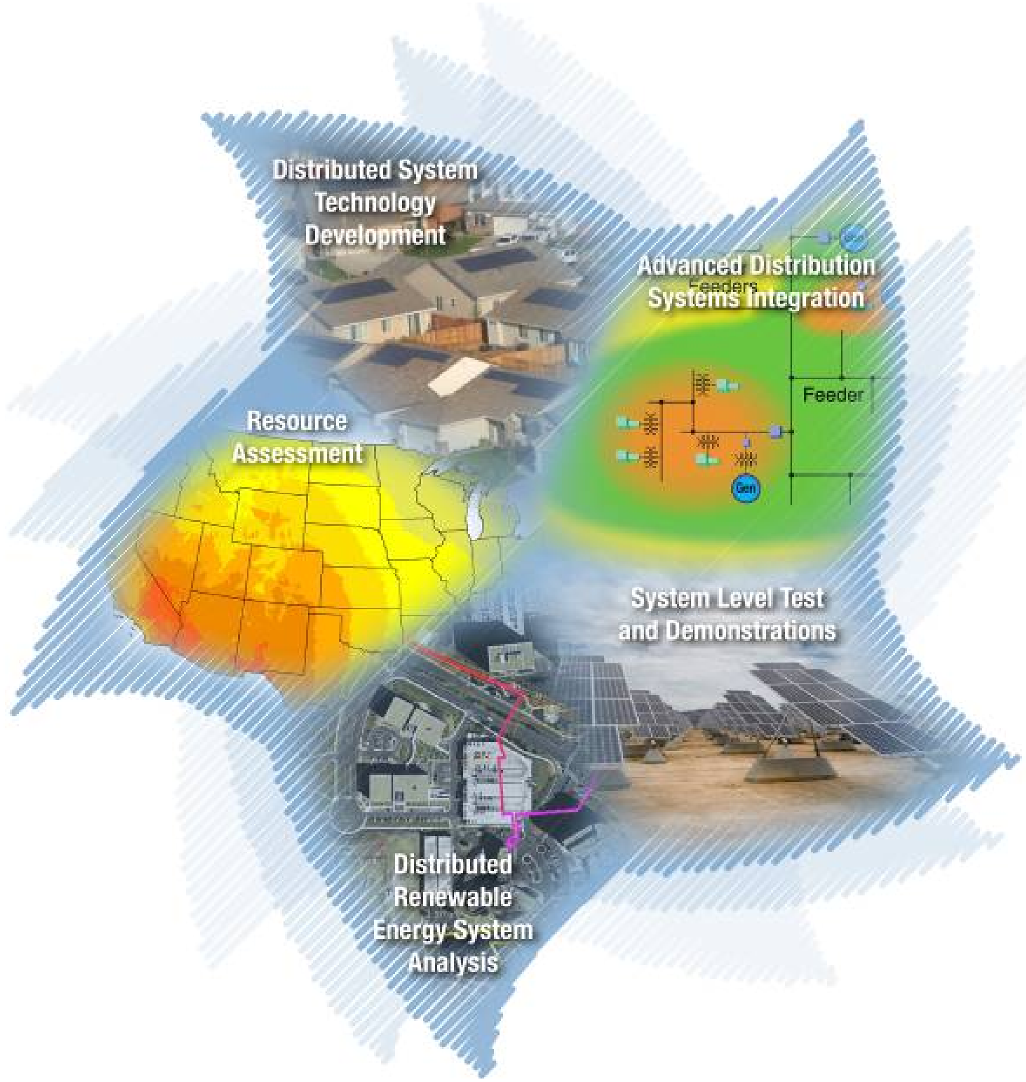
EPRI Joint Efforts with DOE on Distributed Renewable Integration in Electric Grids



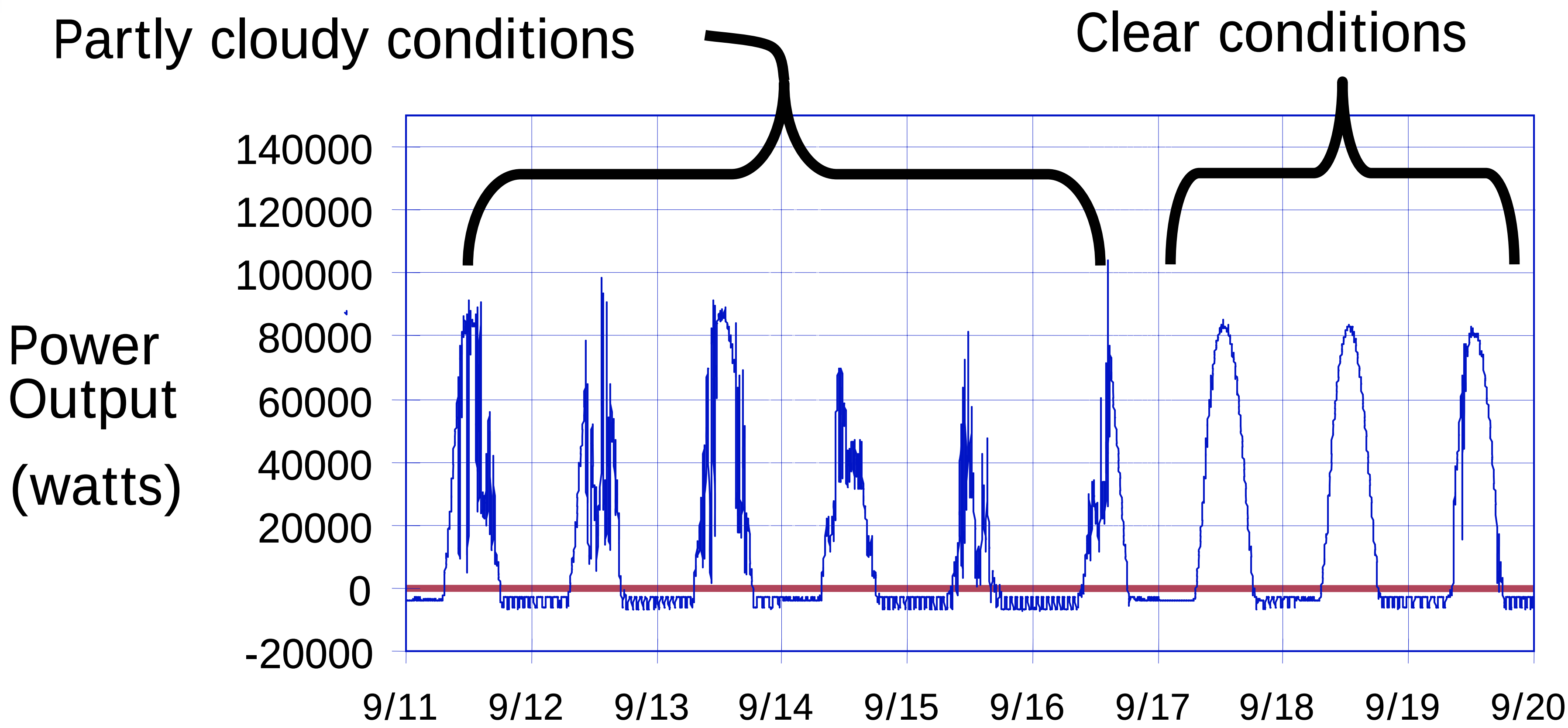
Study Efforts Looks at:

- Technology Development
- Advanced Distribution
- Test and Demonstration
- Distributed System Analysis (technical and economic)
- Solar Resources

Executive Summary and 14 reports available 1/08

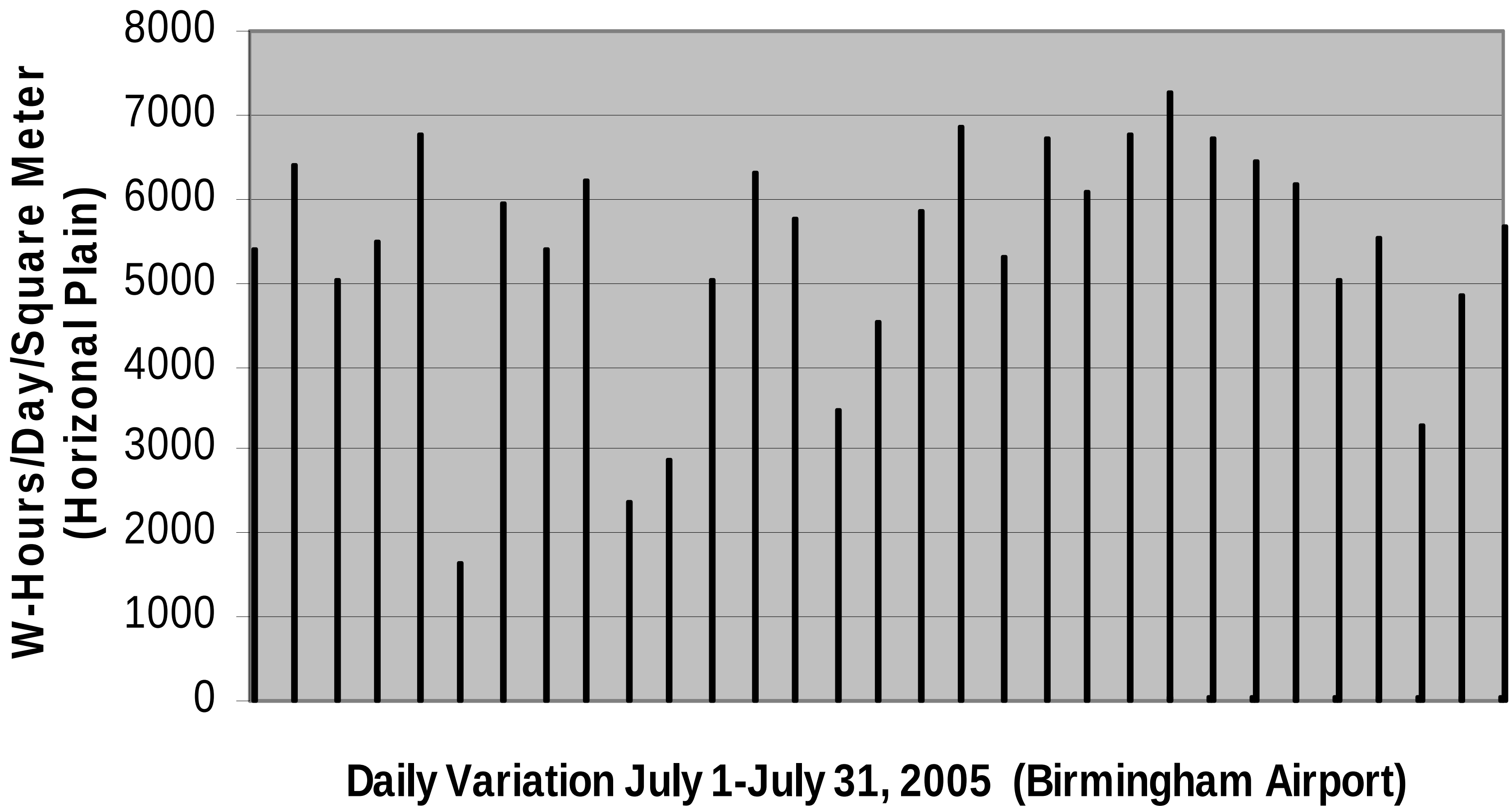
Ongoing Research Plans

Hourly variation of solar PV system output over a few days



Recorded Data for a 100 kW Site Near Albany, NY

Daily variation of solar over one month



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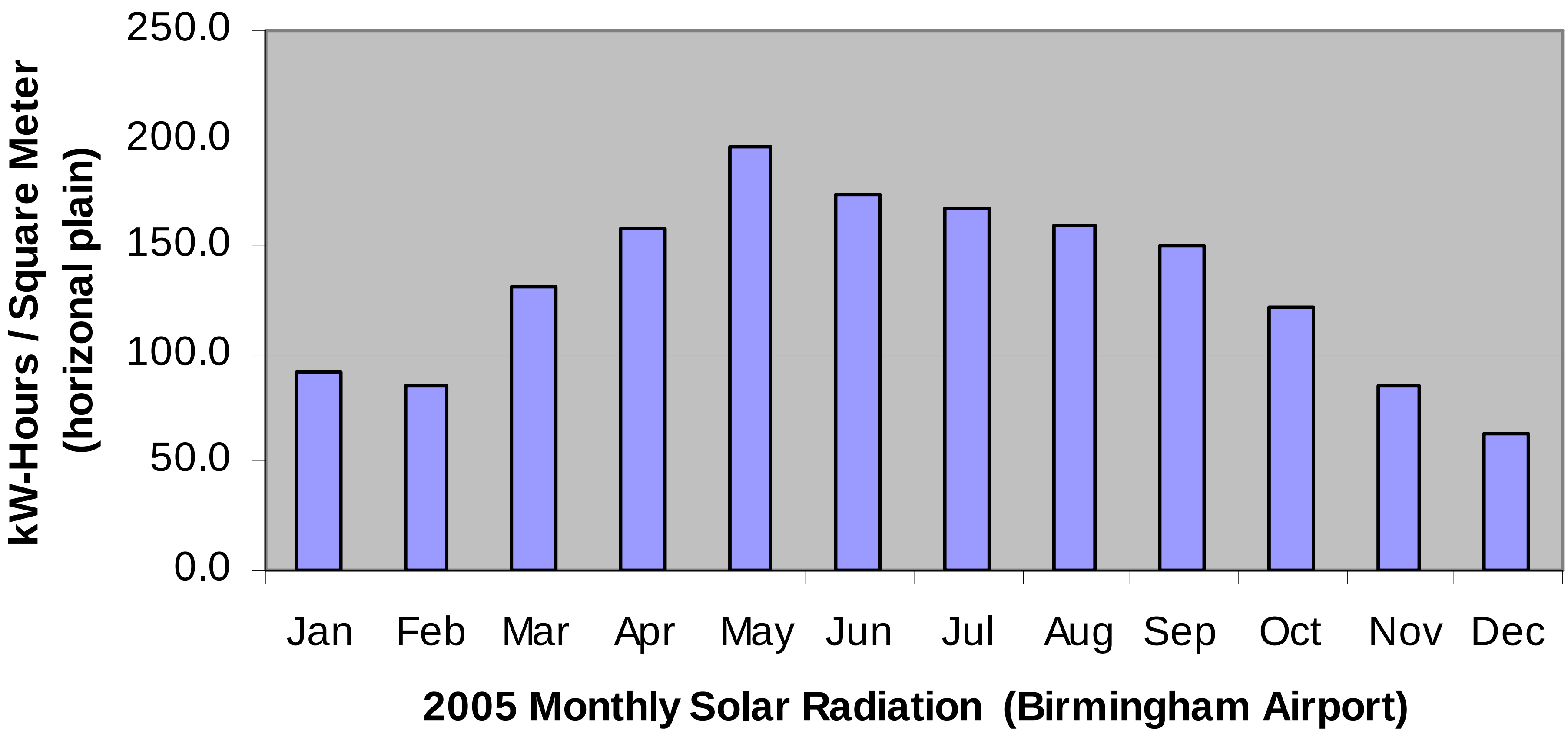
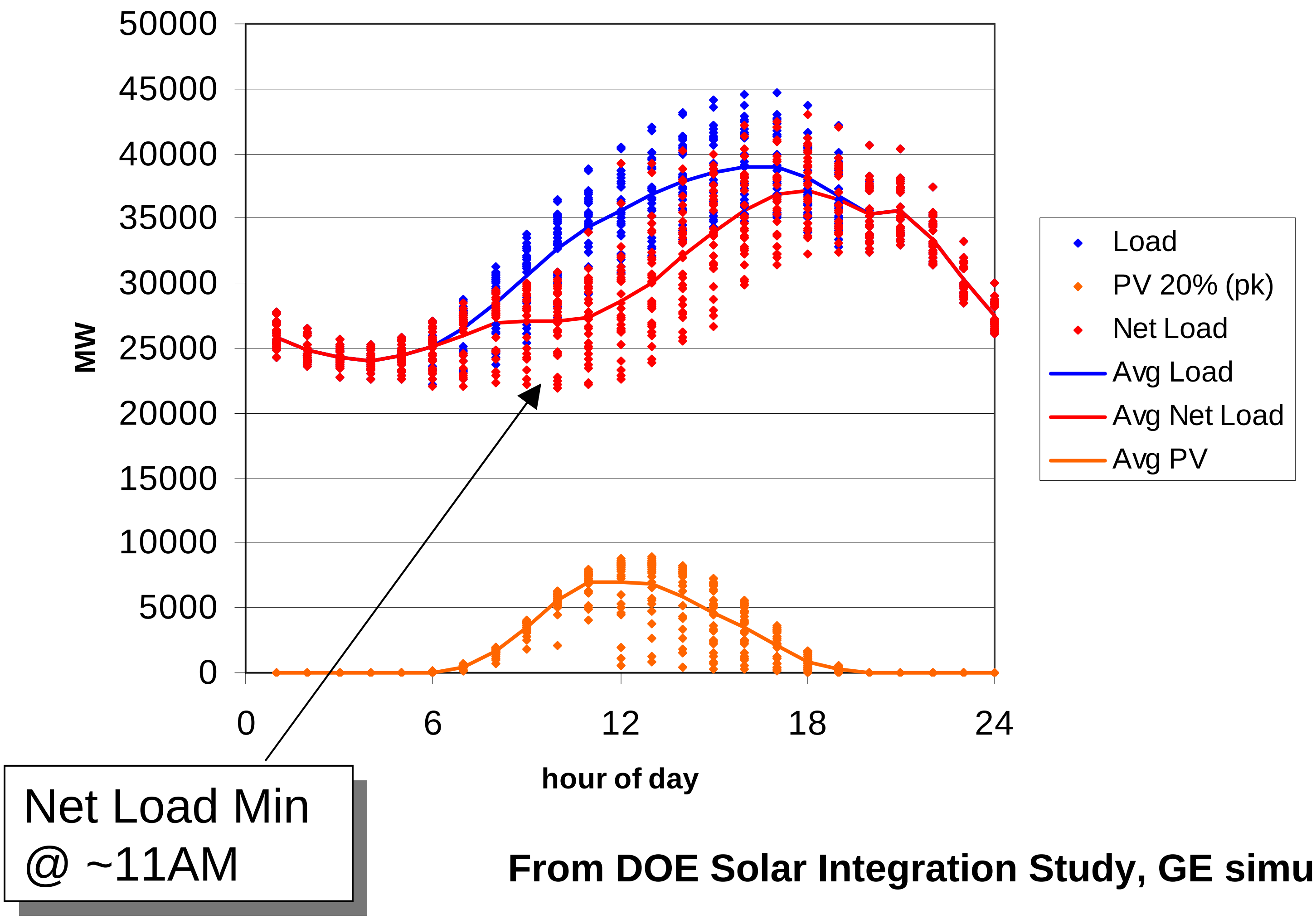
Monthly solar energy variation over one year



CAISO July 2007, 20% PV (% of capacity)



From DOE Solar Integration Study, GE simulation

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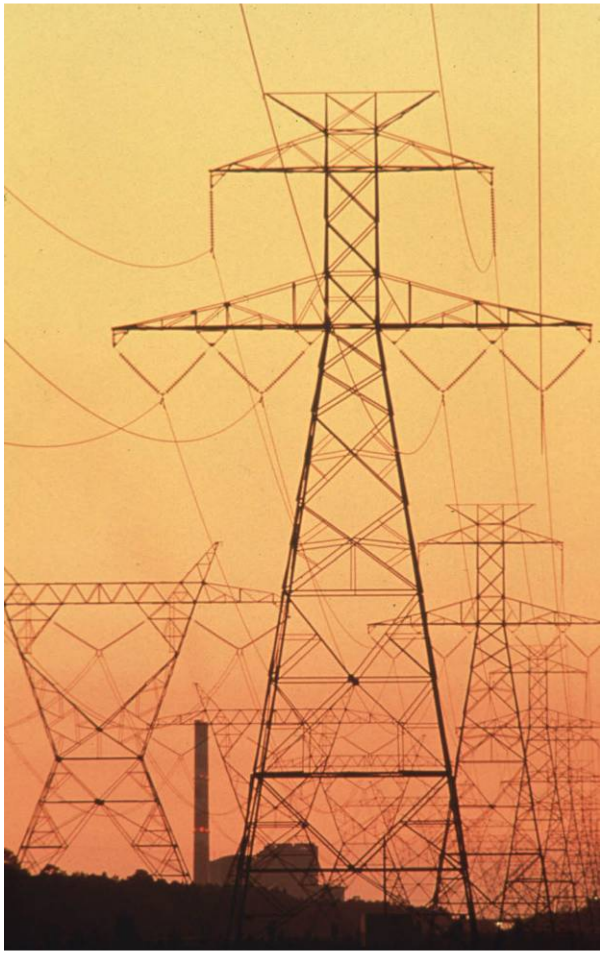
Wind power productivity and integration

- RPS uncertainty, how much by when?
- Siting and transmission
- Grid integration, regulation and load following with wind
- Need for contingency reserves

- Wind energy forecasting, condition monitoring, operation and maintenance issues as utility own more wind power

Renewable Integration Summary

- Uncontrolled resources like wind and solar require electric system integration investments
  - Other generation required to regulate energy, follow ramping and provide reserves to maintain grid reliability
- Most non emitting generation is less controllable than conventional
- Potential for distributed generation to integration with load control, PHEV, Smart Grid



What to expect in our electric energy future?

- The challenge of changing requirements,
- Extraordinary opportunity for new technology,
- Growing need for collaborations,
- Uncertainty and surprises.

Although the exact path for electricity is uncertain, there is clearly a renewable role that will benefit any sustainable generation portfolio