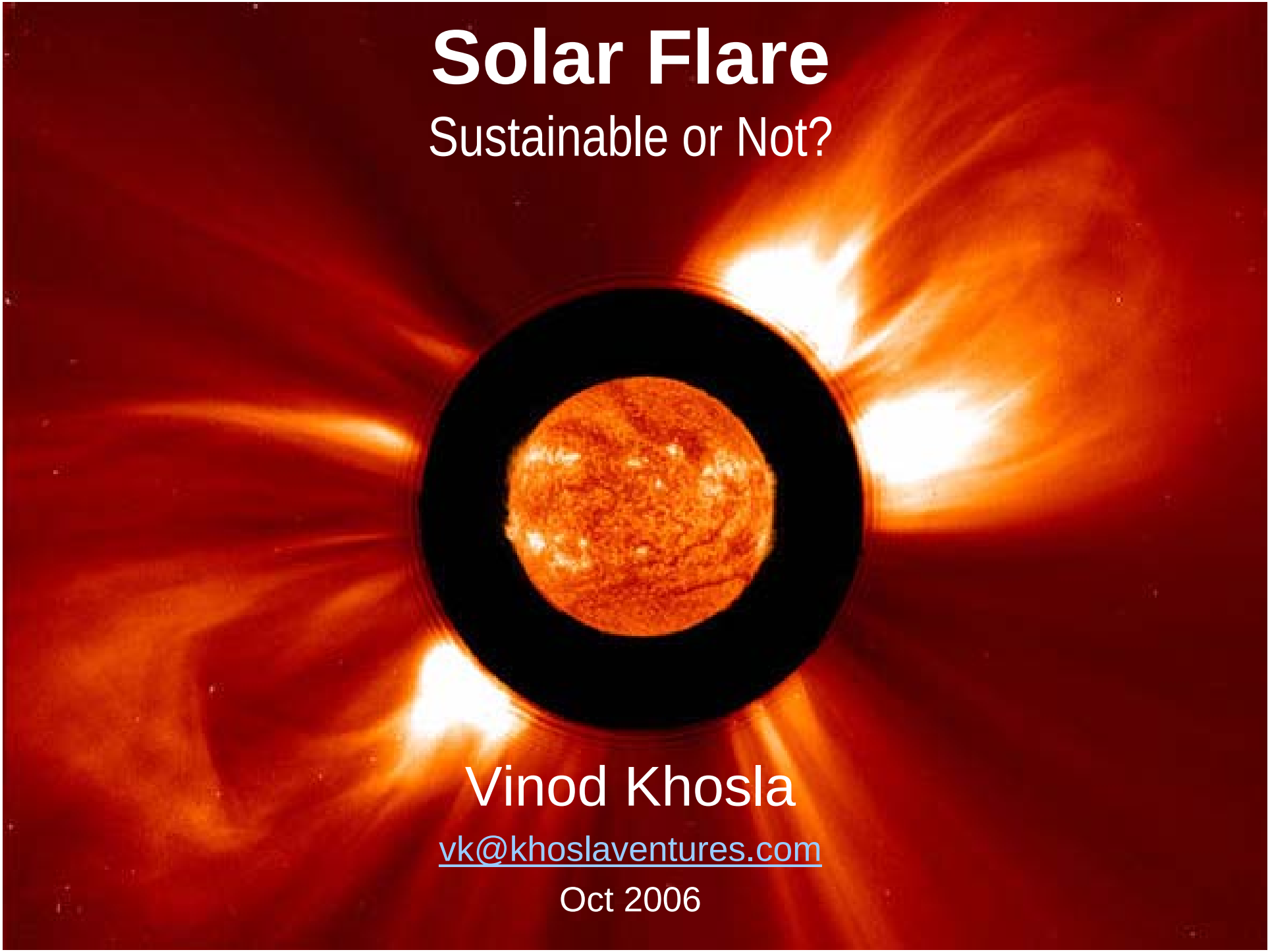
Solar Flare

Sustainable or Not?

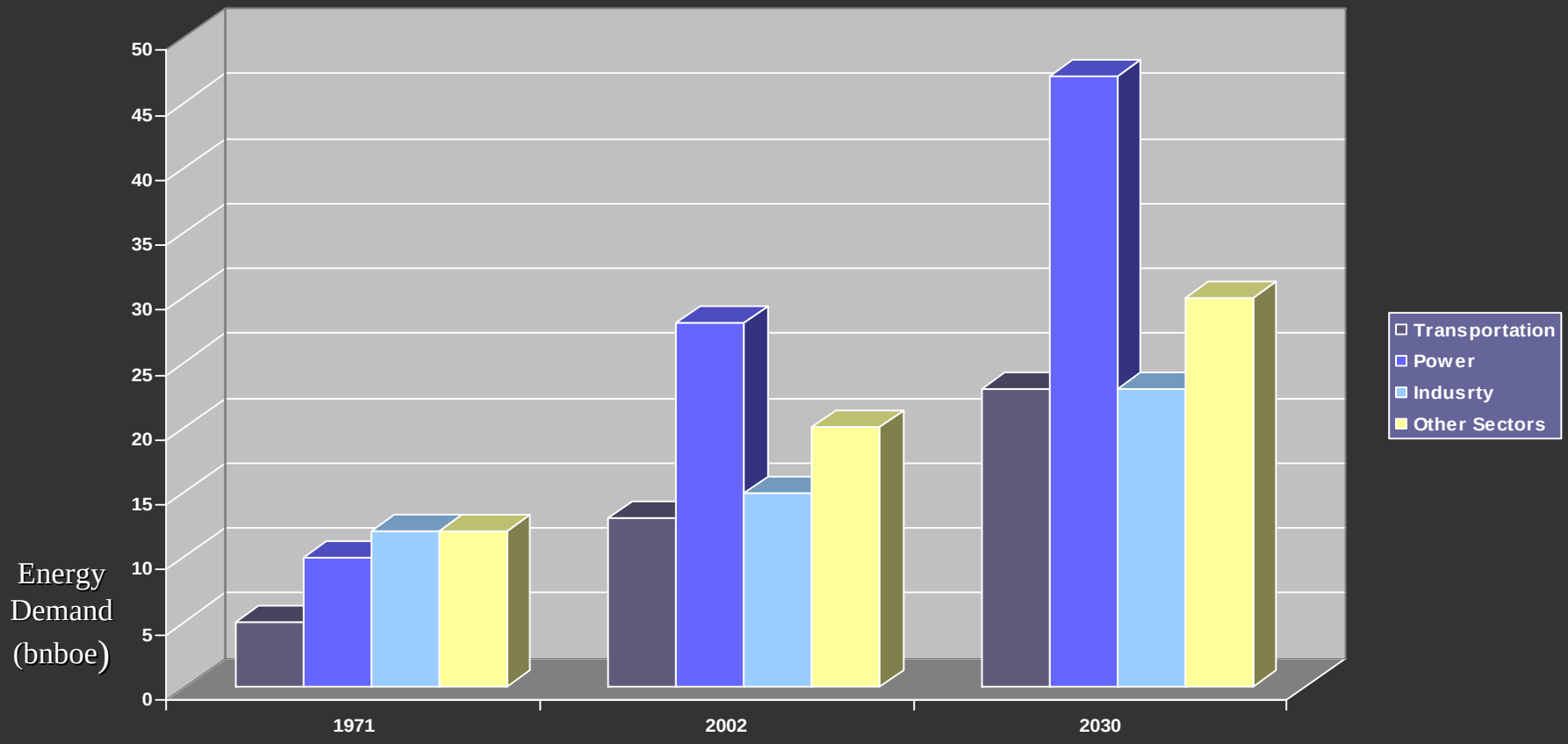


Vinod Khosla

vk@khoslaventures.com

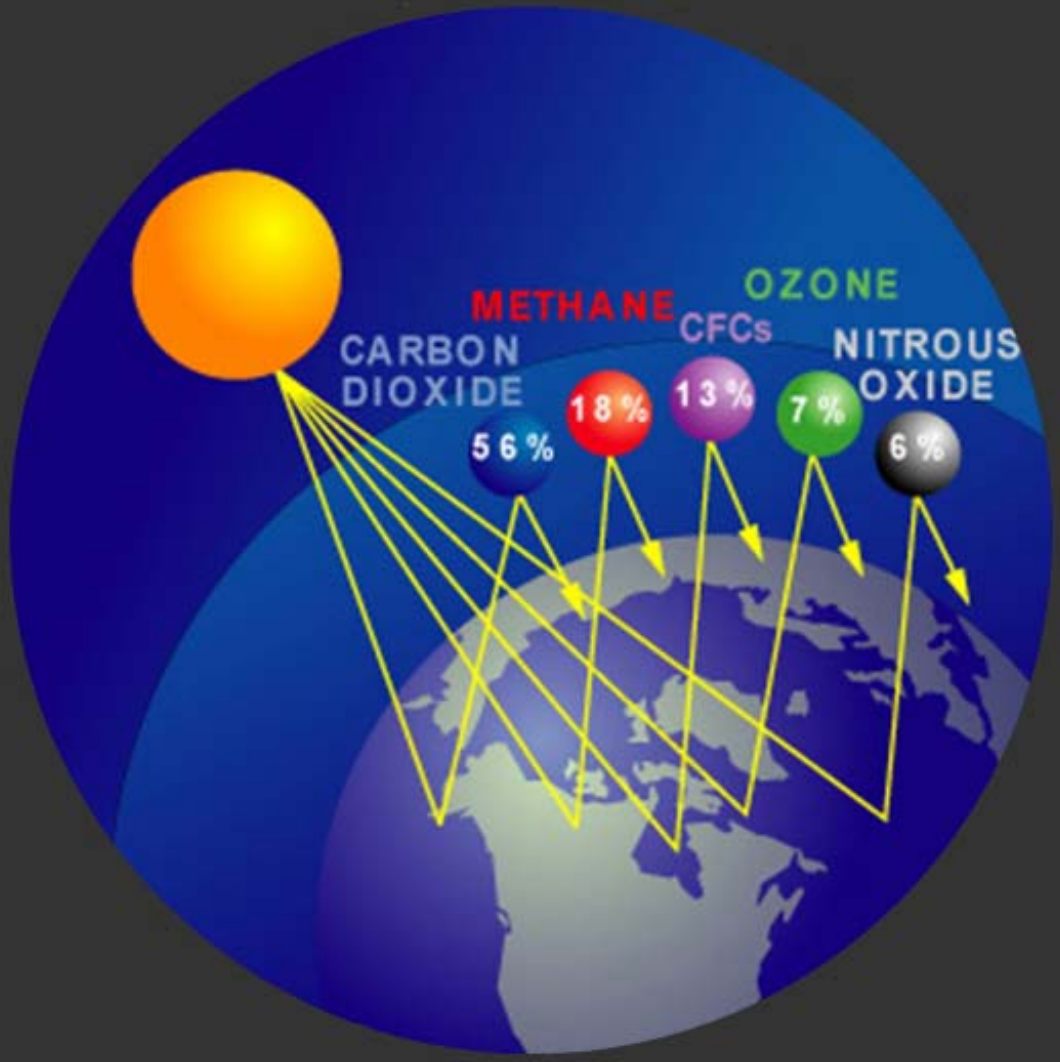
Oct 2006

Electricity = biggest & fastest growing carbon problem



Source: IEA WEO 2004

Greenhouse Gases



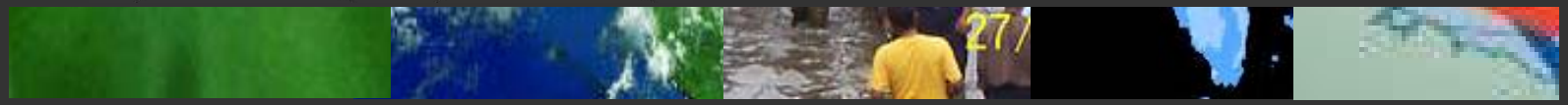
Brenda Ekwurzel, Union of Concerned Scientists, www.ucsusa.org

Safe or Not?

450ppm

550ppm

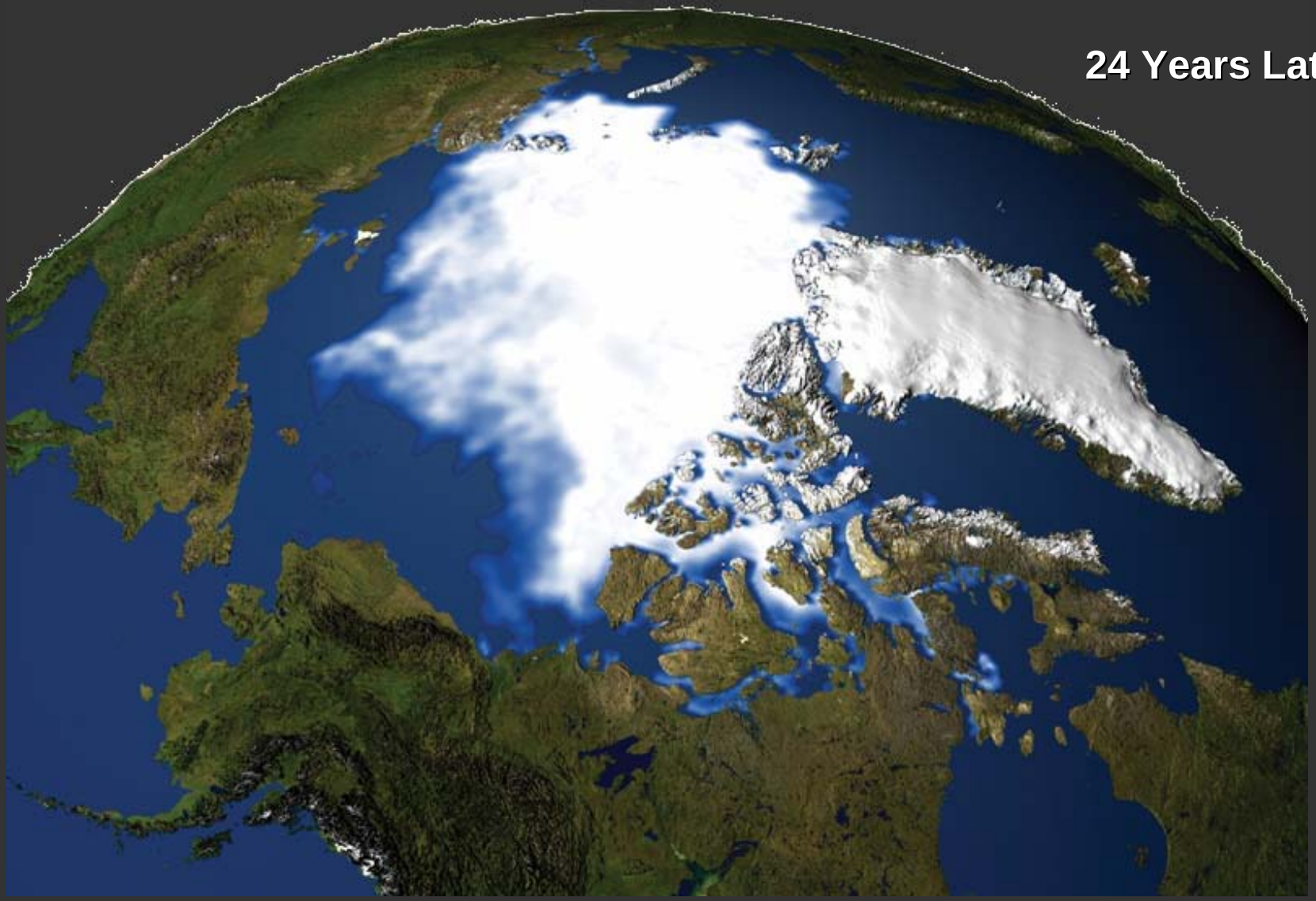
650ppm



Extinctions System Losses	Hurricanes Fires, Floods	Flooding NY Flooded	600 M Displaced	Catastrophe Planet Crash

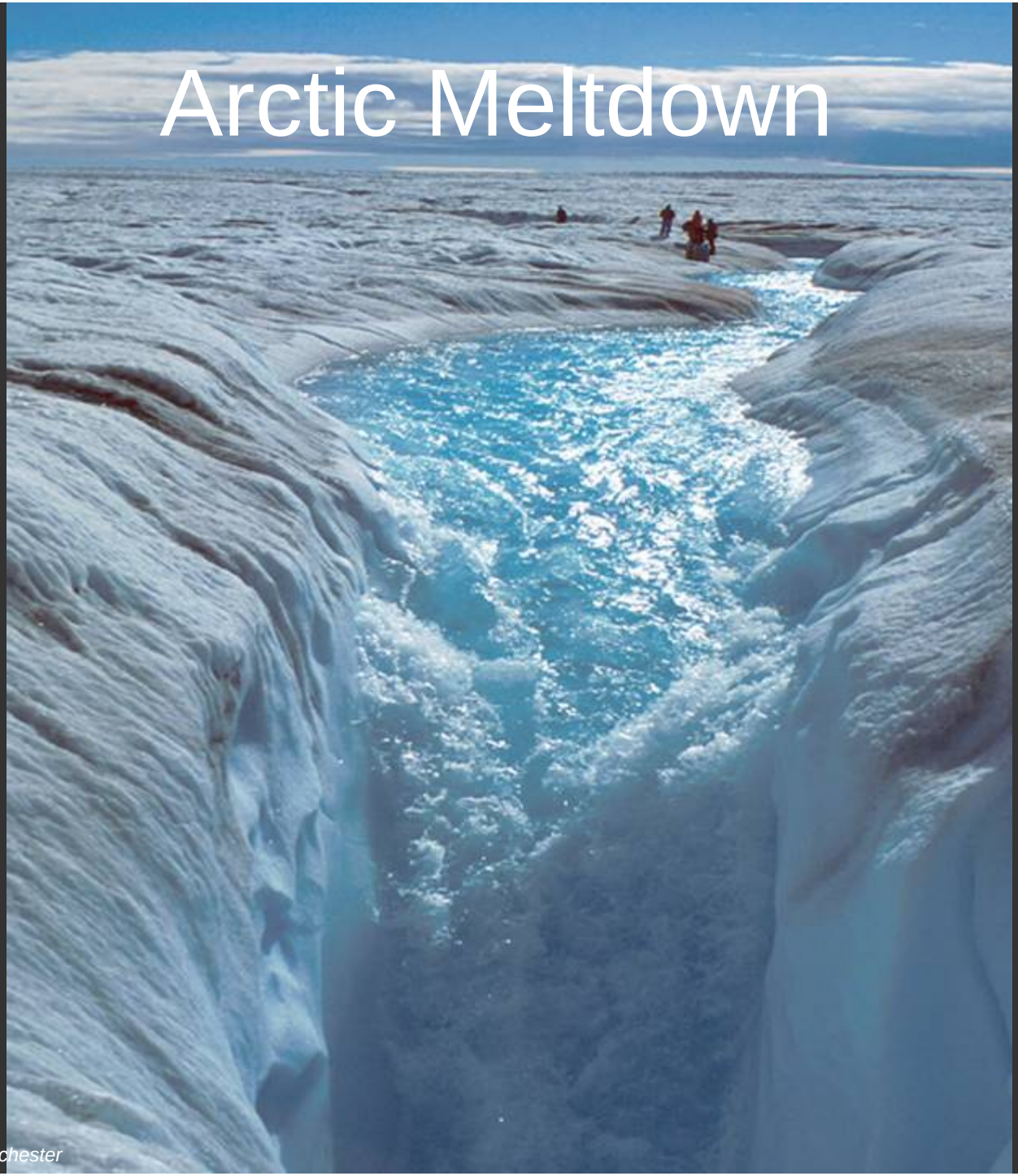
Source: IPCC

Arctic Meltdown

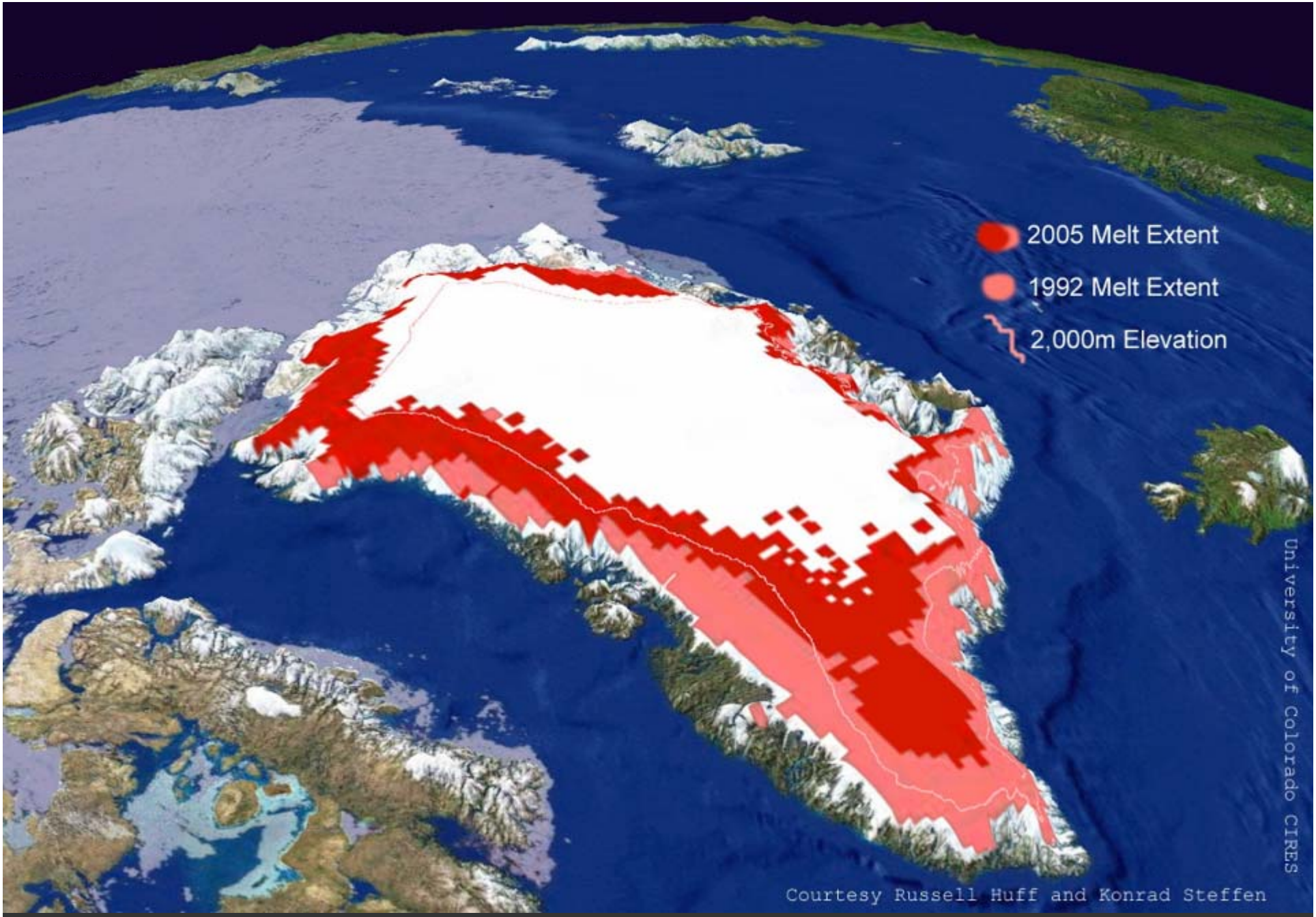


www.usgcrp.gov

Arctic Meltdown



Roger Braithwaite, University of Manchester

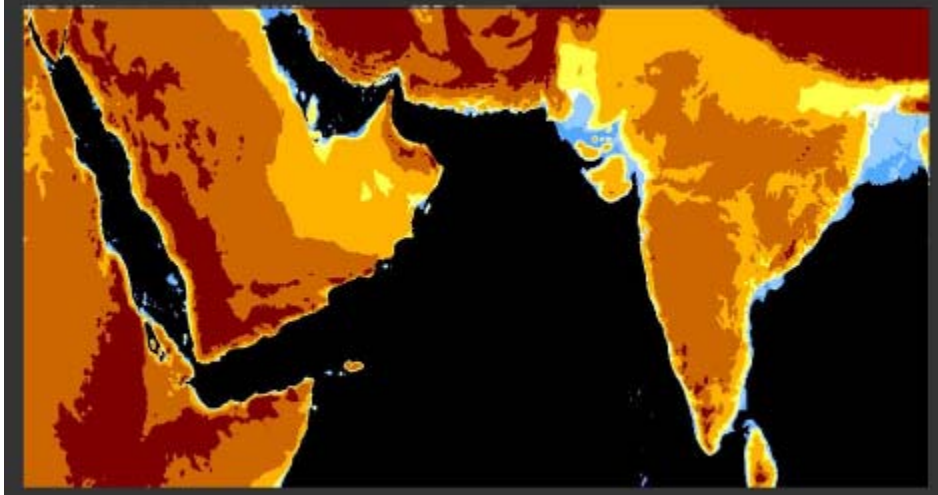


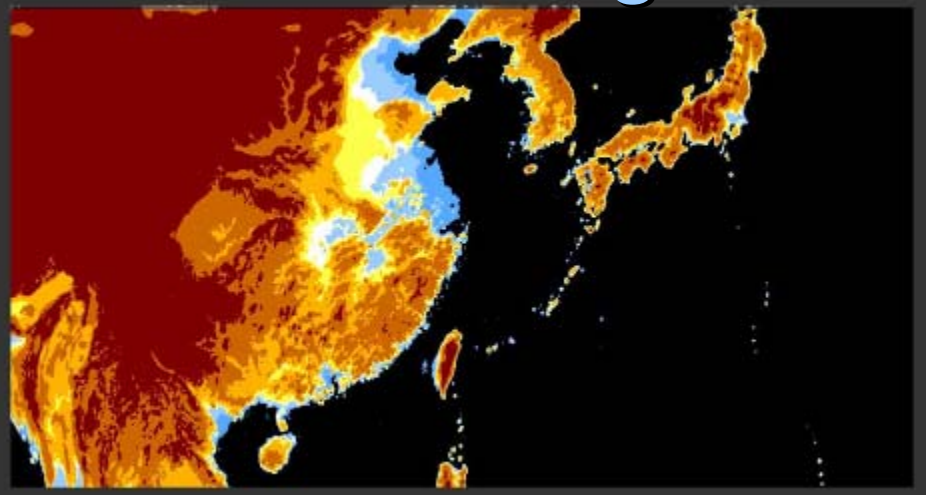
All melt records were exceeded in 2005.

Waleed Abdalati, Goddard Space Flight Center

Greenland Takes Out FL, NJ, NYC

Greenland is 22 Feet of Ocean Height





http://www.solar2006.org/presentations/plenaries/p02-hansen.pdf

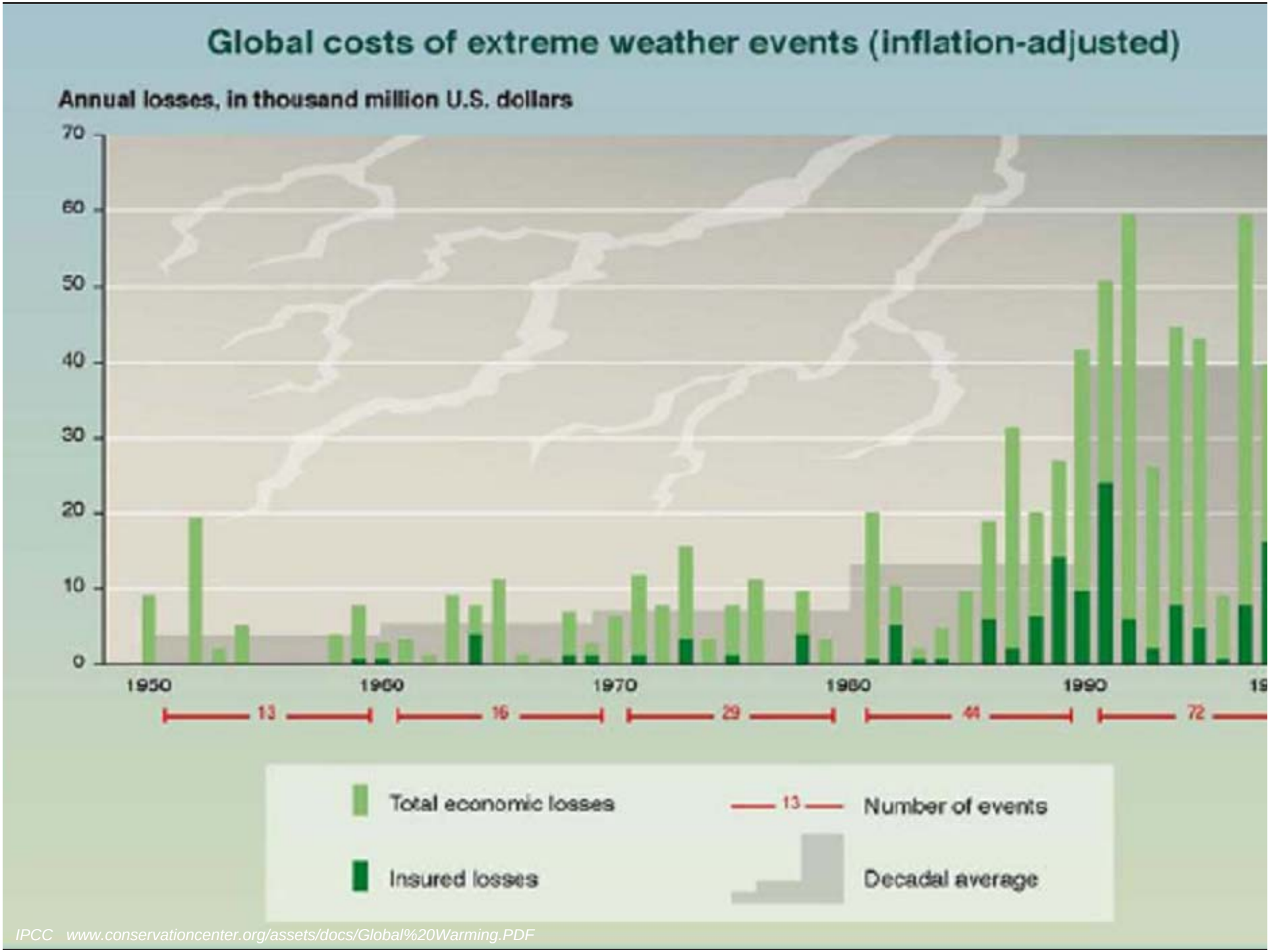
2004

http://science.nasa.gov/headlines/y2004/images/bluemoon/elkbath.jpg

2005

It's Happening Now

- **Within Our Lifetimes**
- **RUNAWAY Within Our Kids' Lifetimes**
- **Models appear too conservative**



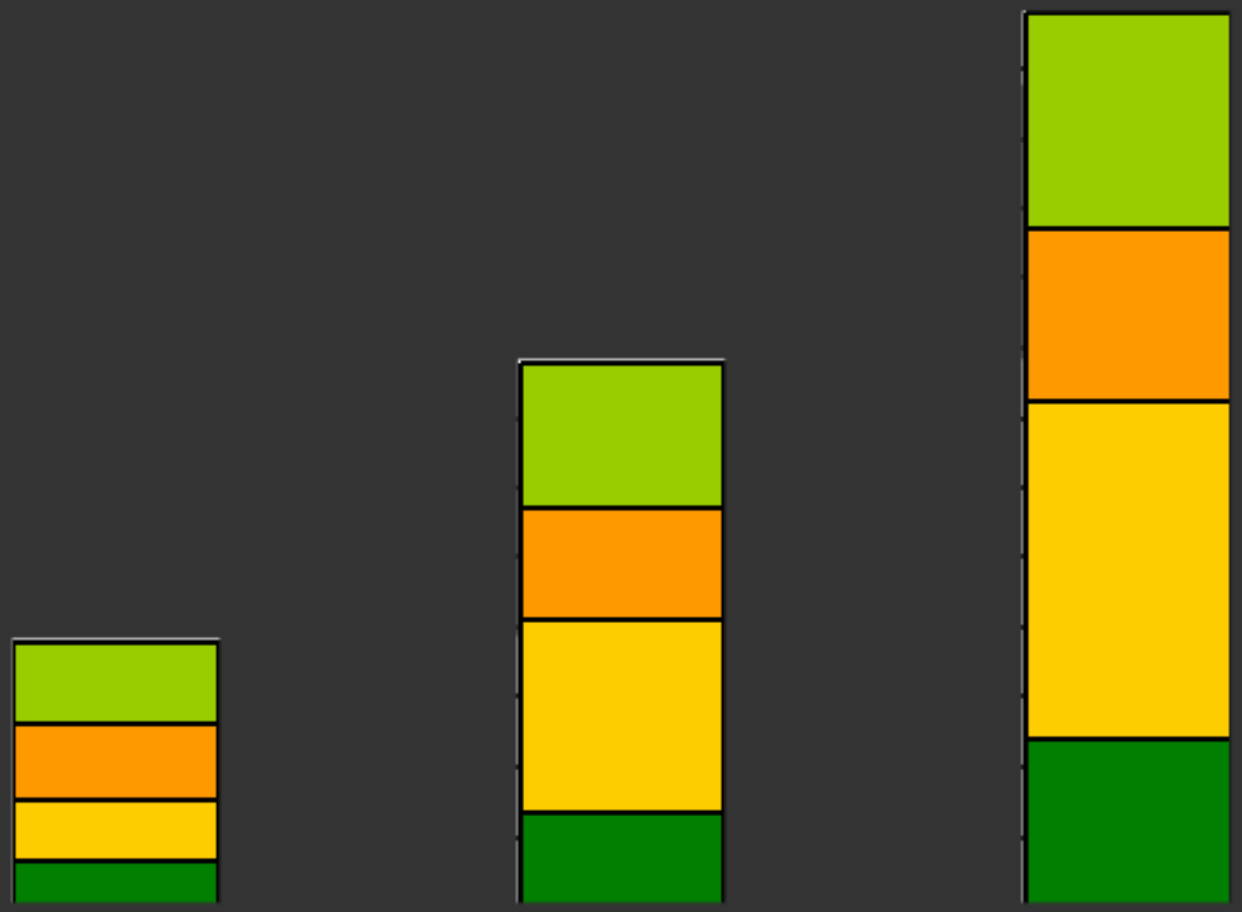
IPCC www.conservationcenter.org/assets/docs/Global%20Warming.PDF

Defeatism or Action?

We insure our homes

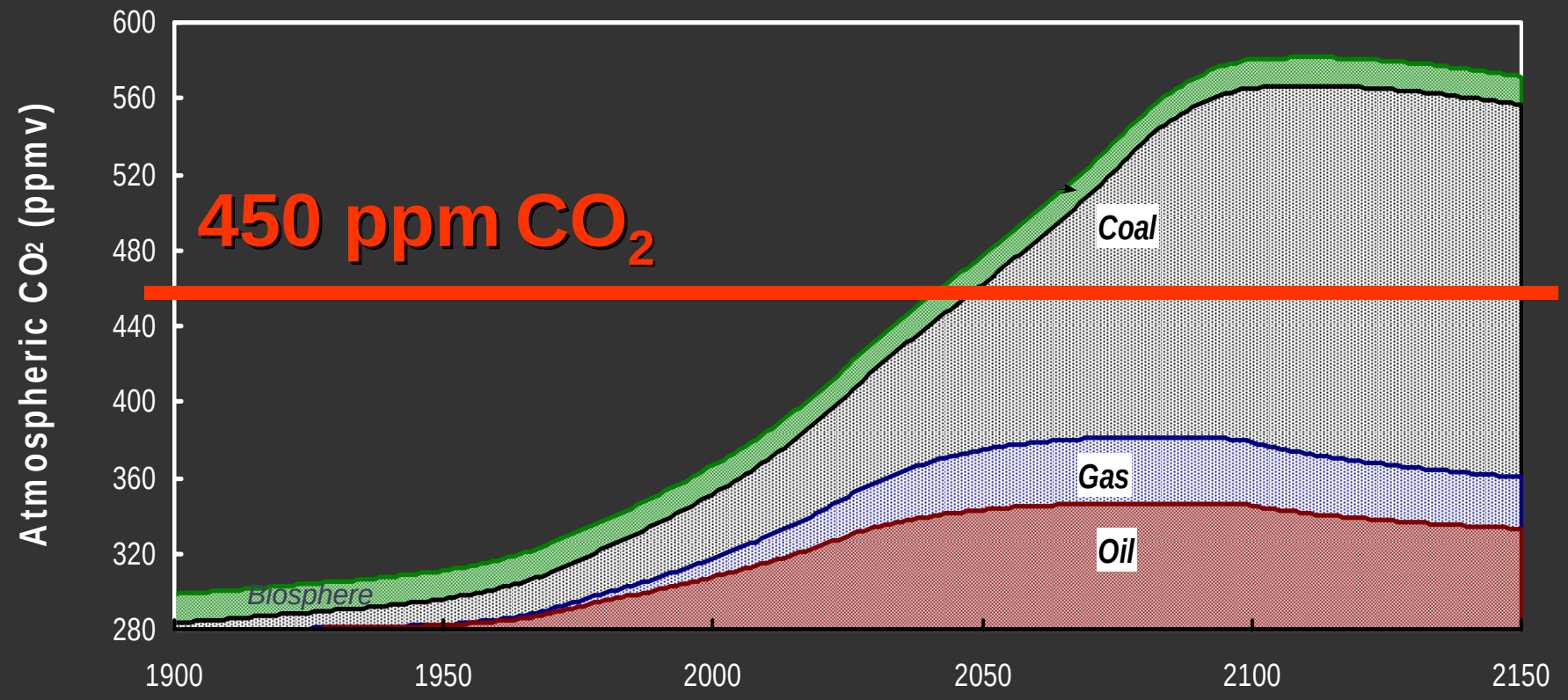
Why not our planet?

Electricity = biggest & fastest growing carbon problem



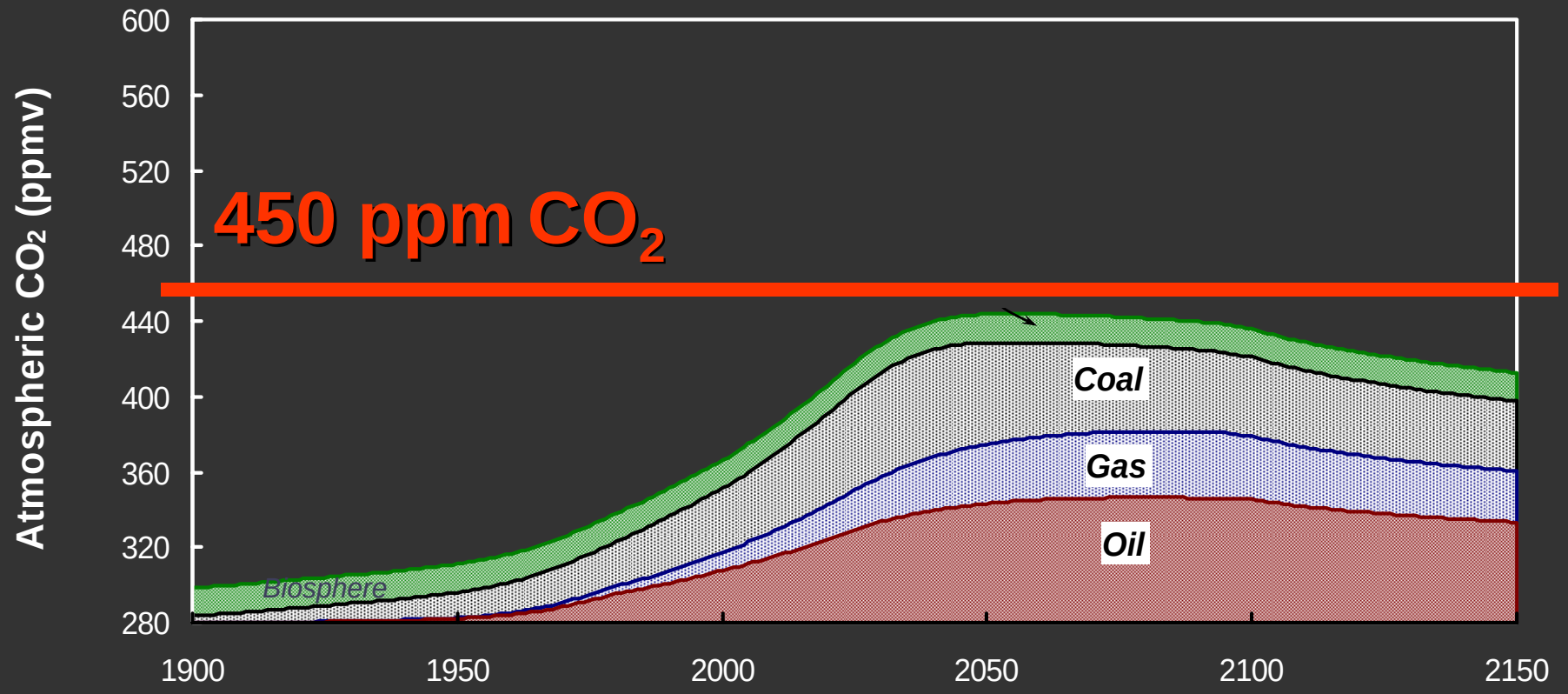
IEA WEO 2004 Courtesy Steve Koonin, BP

Our Current Course



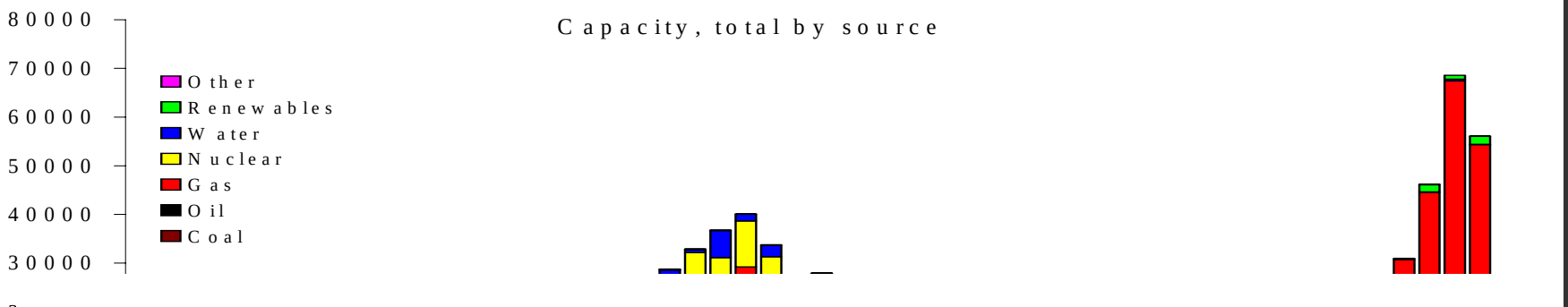
http://www.solar2006.org/presentations/plenaries/p02-hansen.pdf

Phase Out Coal



http://www.solar2006.org/presentations/plenaries/p02-hansen.pdf

US Electric Power: Coal Is Back

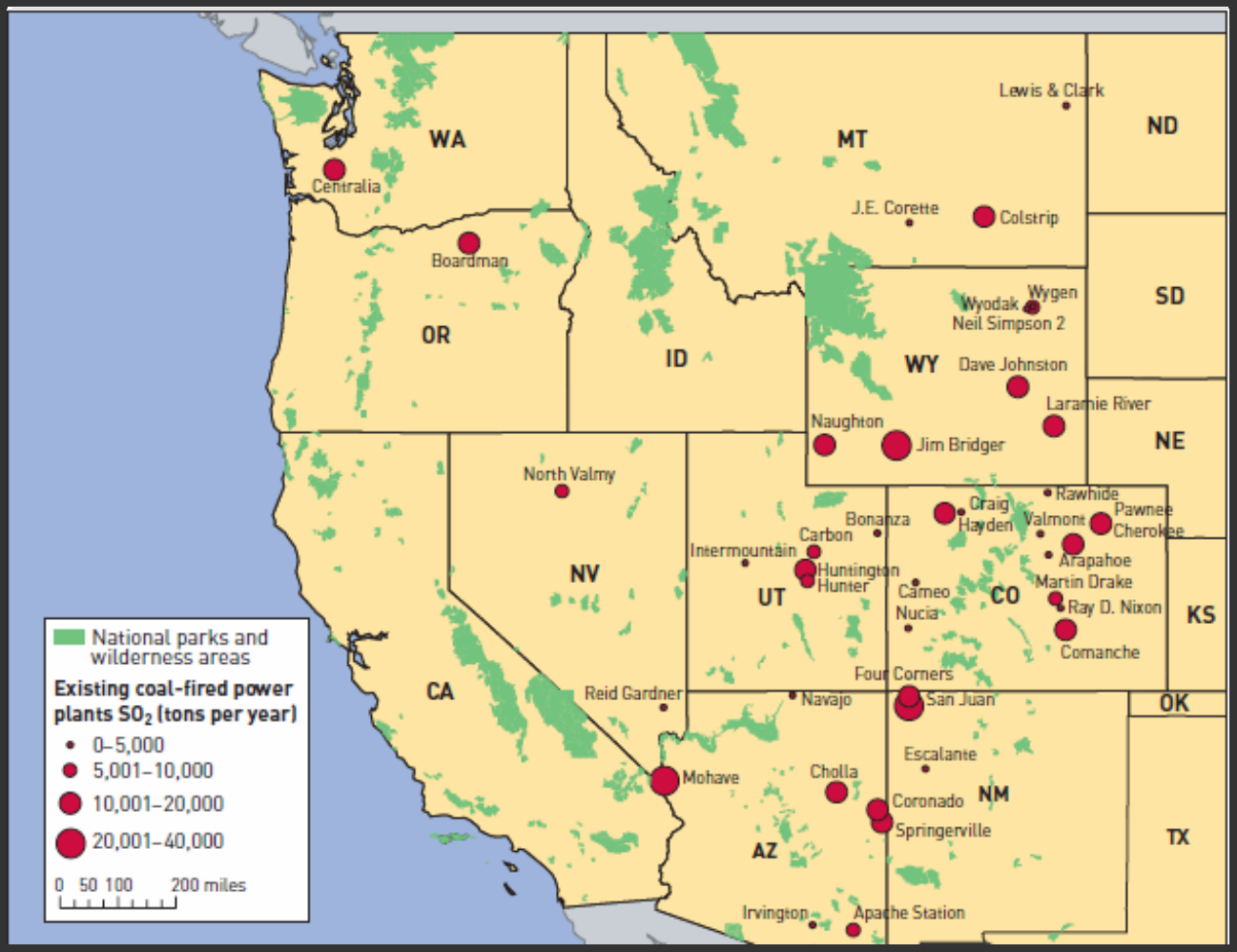


"As natural-gas supplies and prices have become a problem the power industry is shifting to coal in a big way, with plans to build more than 100 coal-fired power plants in coming years at a potential cost of more than $100 billion"

-"As Utilities Seek More Coal, Railroads Struggle to Deliver " **Wall Street Journal** - ***March 15, 2006***

www.eia.doe.gov
www.oilnergy.com

Western US



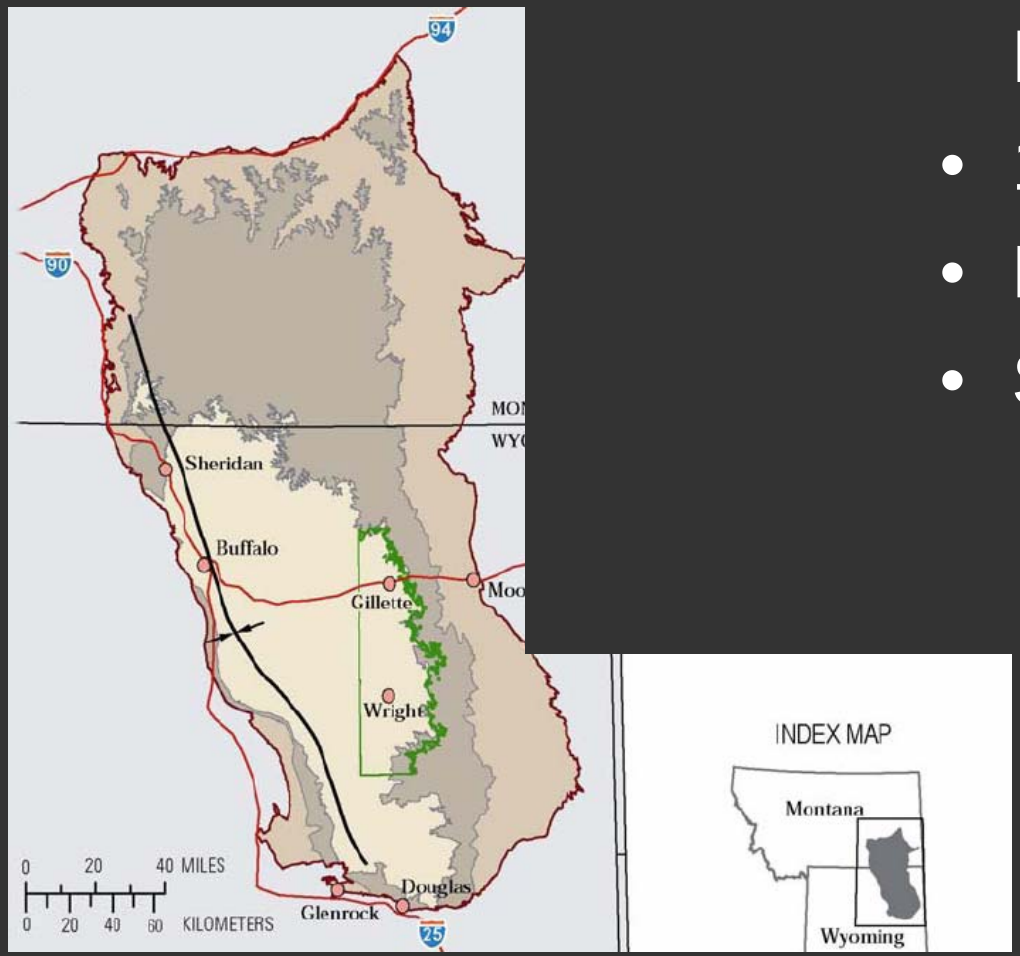
http://www.westernresourceadvocates.org/media/pdf/CA%20Coal%20Shadow.pdf

Coal Issues

- Availability
- Cost
- Transportation
- Emissions Costs

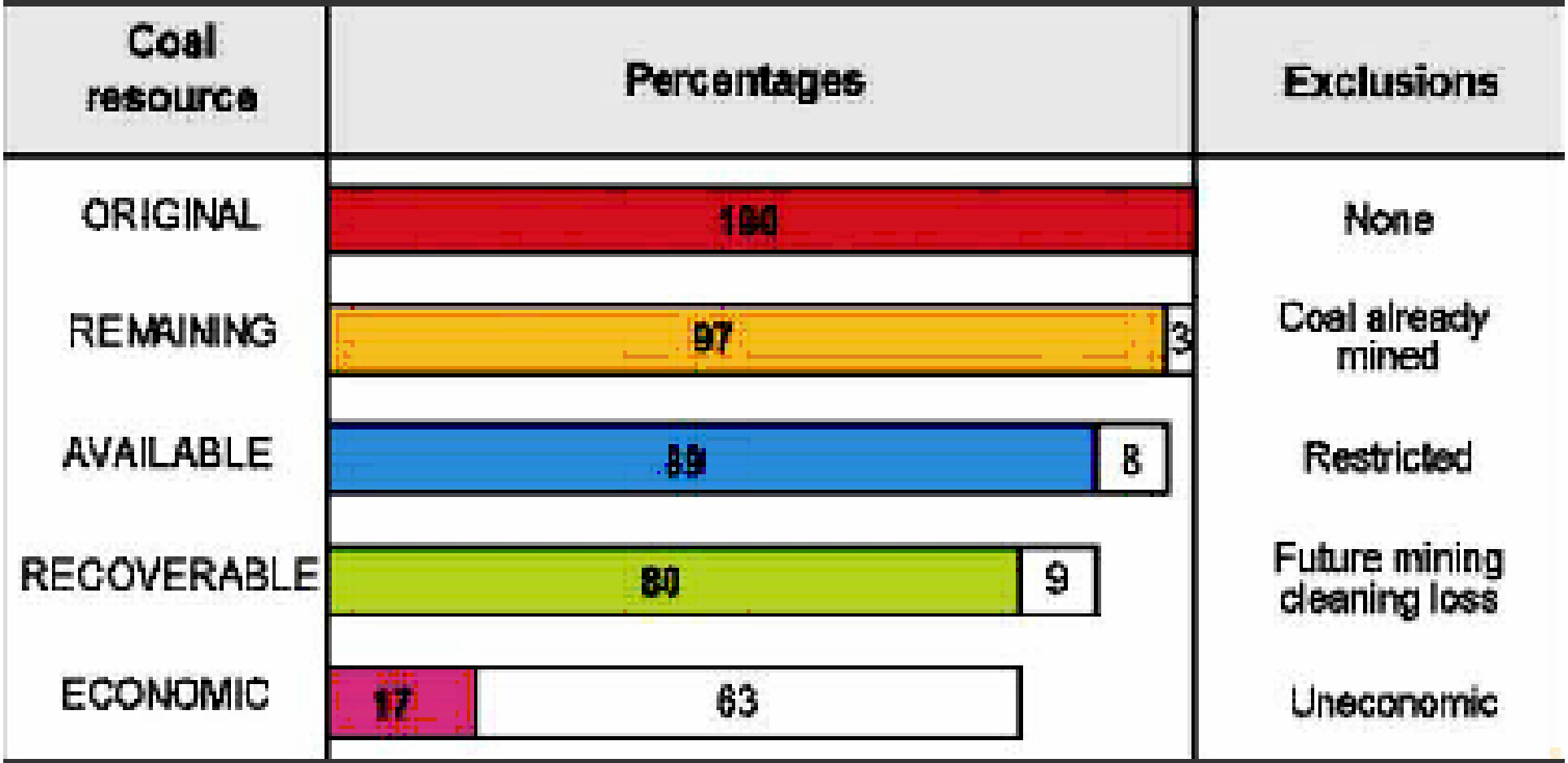
Conventional Wisdom:“200 Years of Coal”

- 1/2 US 2005 Coal from Powder River Basin
- 136 Gtons, Dug out 4
- Now Burning 1/ yr
- Some blocked; 109 left



USGS, Evaluation of Economically Extractable Coal Resources in the Gillette Coal Field, Powder River Basin, Wyoming 02-180 2002

200 Years of Coal?



USGS, Evaluation of Economically Extractable Coal Resources in the Gillette Coal Field, Powder River Basin, Wyoming 02-180 2002

How Much At What Price?

10 Years of Coal Left

New Plants Will Raise Burn Rate

and / or

Greatly Increased Prices

17% of PRB left economically recoverable?

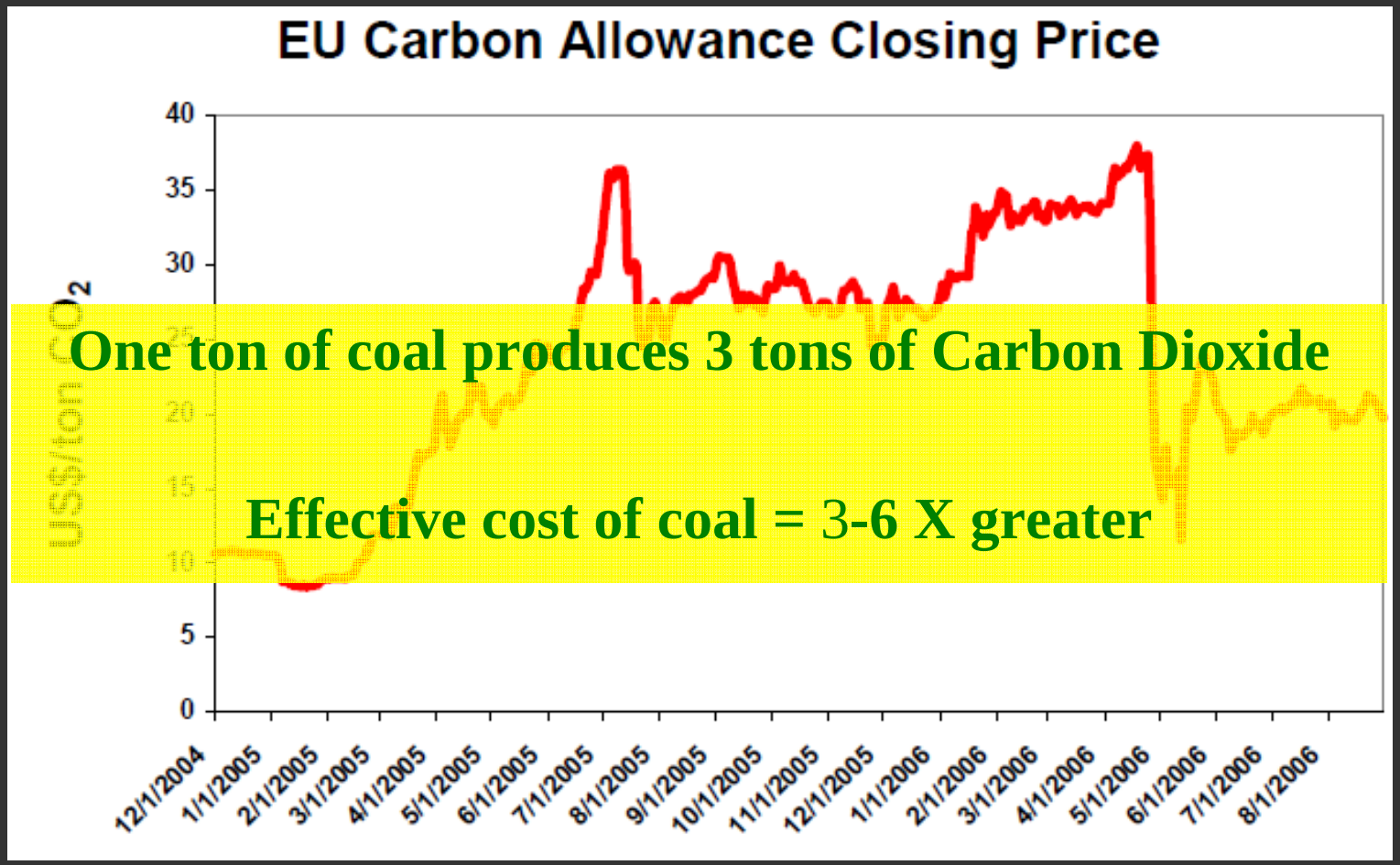
Coal Transport

- 70% of railroad traffic is coal
- Coal Rail Problems cost $3B in 2005
- Spot price doubled

Wall Street Journal 3/15/2006 As Utilities Seek More Coal, Railroads Struggle to Deliver

Testimony of David Wilks, President Energy Supply Xcel Energy, Senate Committee on Energy and Natural Resources, 5/25/2006

Carbon Credits KILL Coal



One ton of coal produces 3 tons of Carbon Dioxide

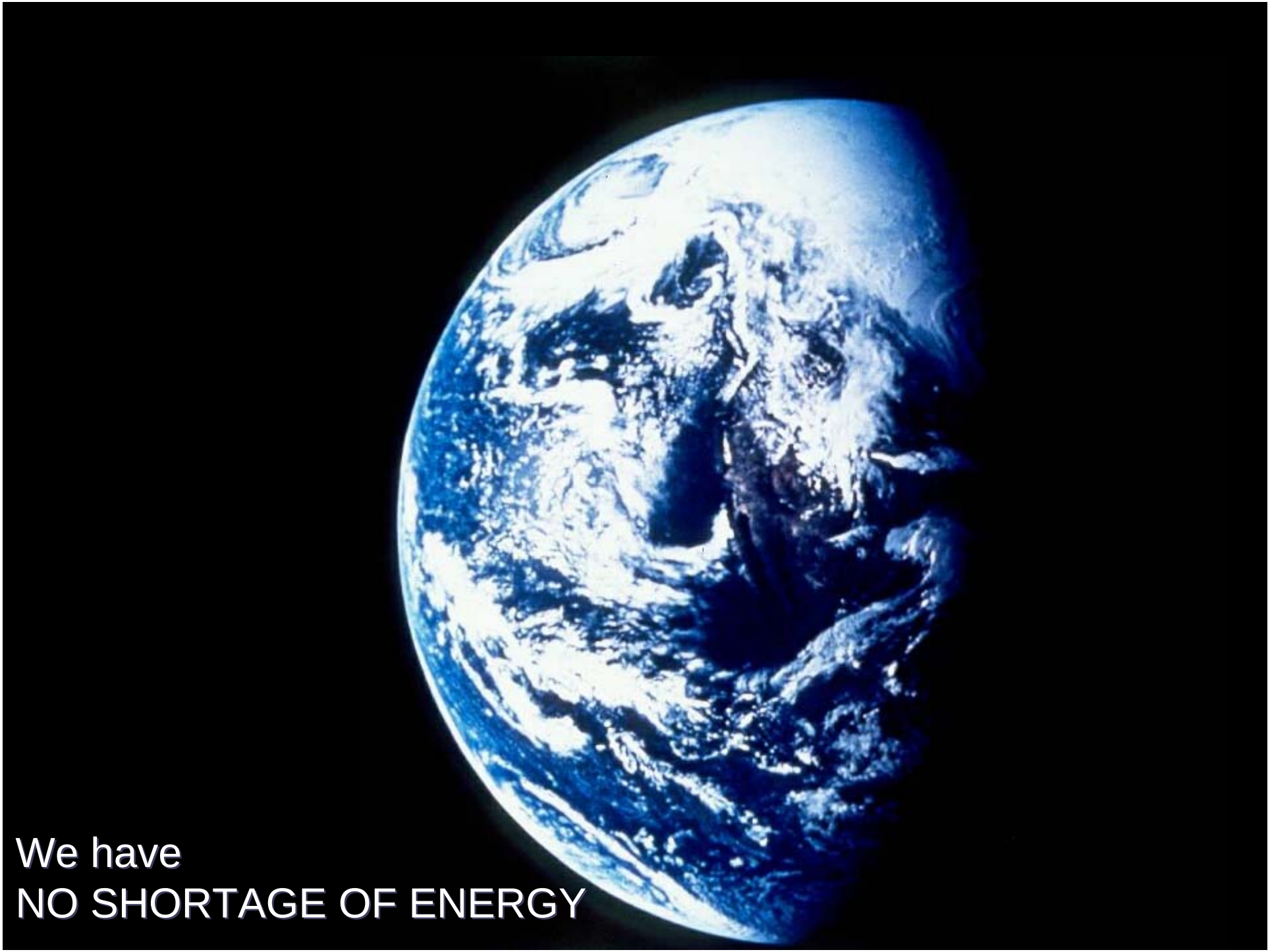
Effective cost of coal = 3-6 X greater

Steve Clemmer, Union of Concerned Scientists, "Gambling with Coal", 9/06

Coal's World is Changing

- 7 of 12 western utilities considered carbon risk
- 10 of 12 plans will consider in next round
- Calif. PUC requires utilities to include "adder
  - Initially $8 /ton
  - +5% per year ($27/ton by 2030)

Source: Union of Concerned Scientists


We have
NO SHORTAGE OF ENERGY

8 inch deep layer of oil annually

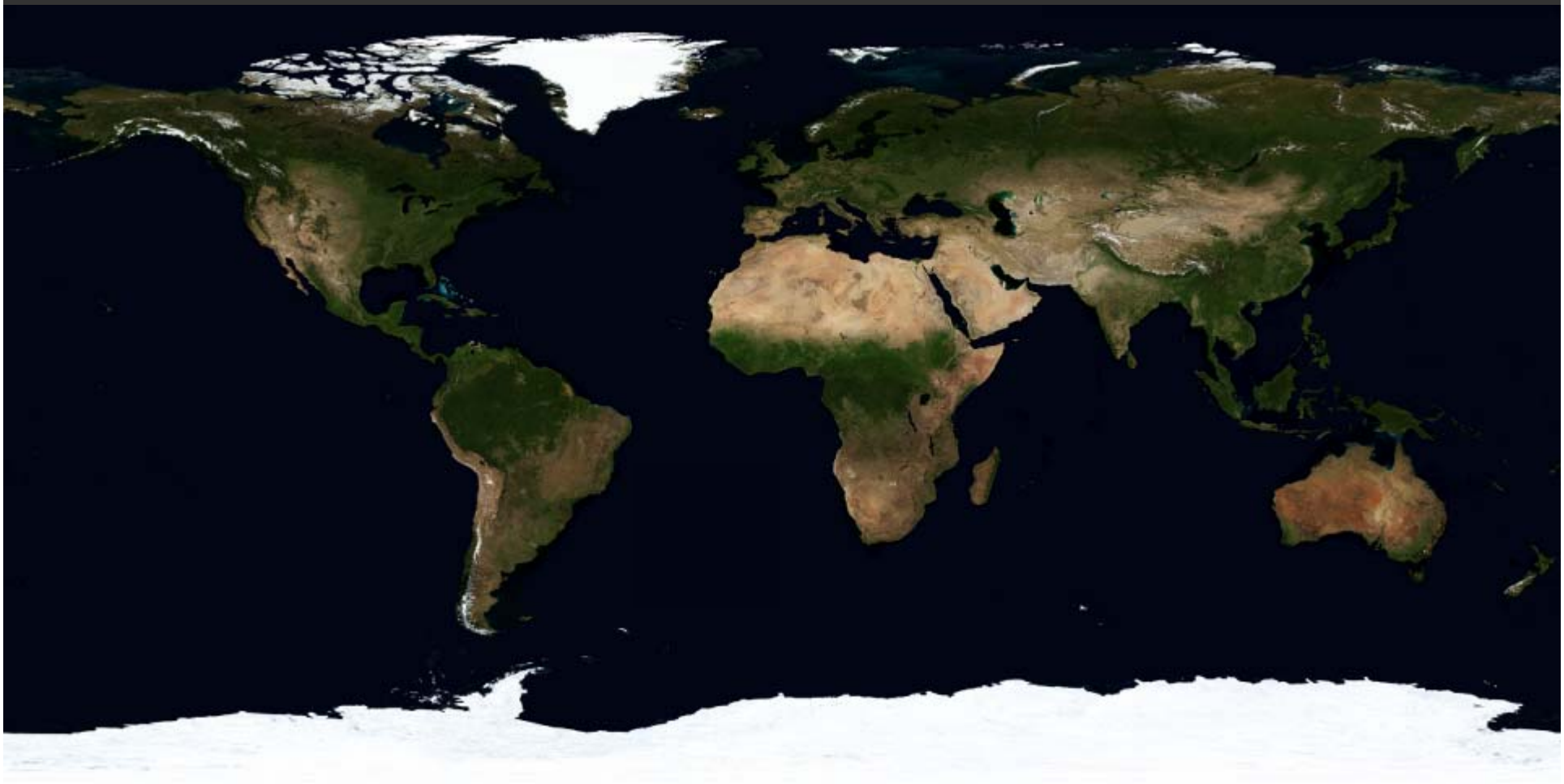
Humans will use 15 in 2050

100,000 Terawatts

A Technology Crisis, not a Resource Crisis!

- Scalability
- Cycle Time to Use
- Cost Competitiveness

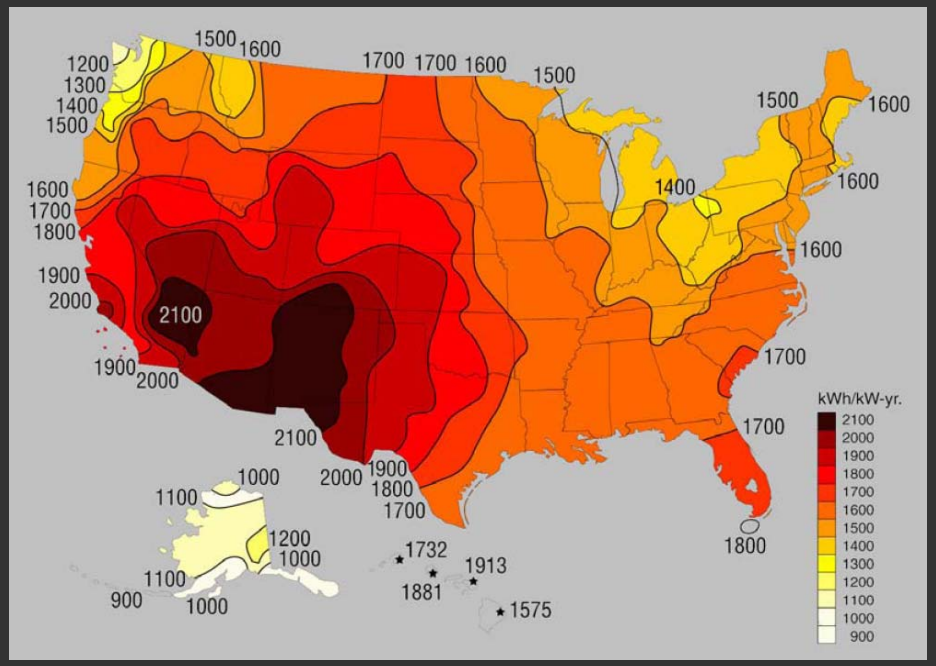
Scalability : Land For All Electricity



USA: Looking Good

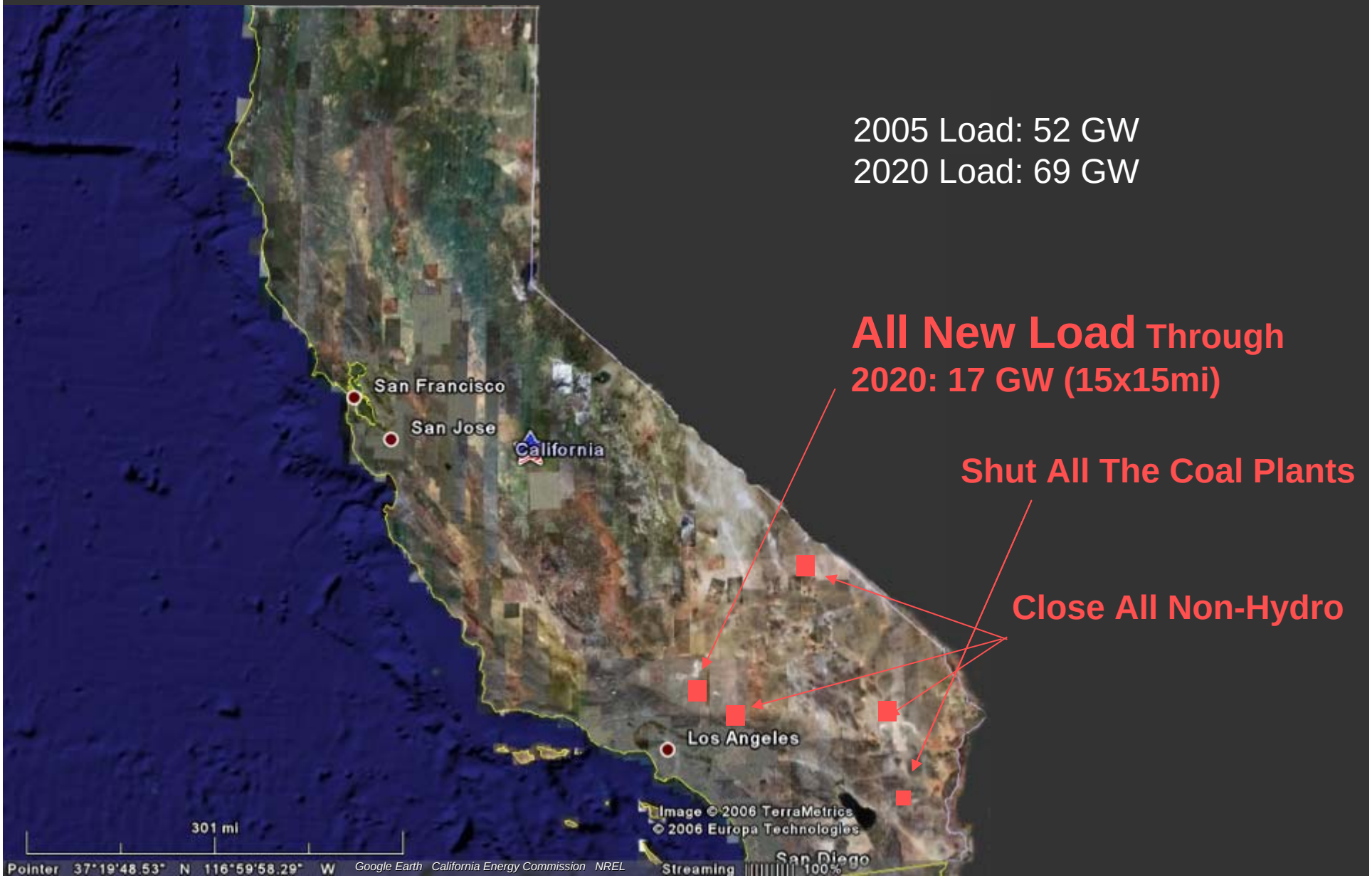
Germany: 57% world PV

US: 7% world PV



Creating a U.S. Market for Solar Energy, by Rhone Resch, President of the Solar Energy Industries Association.

How Much California Land?



2005 Load: 52 GW
2020 Load: 69 GW

All New Load Through 2020: 17 GW (15x15mi)

Shut All The Coal Plants

Close All Non-Hydro

Cycle Time to Use

- Oil & Coal – millions of years
- Gas & Clathrates –100,000’s?
- Biomass – 1 -10 years
- Thermal Solar – ?
- Photovoltaic Solar - instantaneous

Khosla’s Rules

- Attack Manageable but Material Pieces
- Unsubsidized Market Competitiveness <5 yrs
- Technologies that scale
- Declining cost with scale
- If It Ain’t cheaper, It Doesn’t Scale

How Soon Is Solar Competitive?

» Residential:
- $.15/kWh average
- Maximum scale limited to 10%
- Subsidy: function of carbon price

» Centralized:
- Gas Peaking $.16/kWh
- Gas CC $.10/kWh
- Coal $.06-$.12/kWh
- External Cost: function of carbon price

How Long Is Coal Competitive?

Photovoltaic Solar

- Expensive but improving
  - Doubling time has been 10 yrs not 2
  - This may be improving too
- Uses energy instantly as it is gathered
- $.20/kWh today (30% rebate)
- Economical as Distributed Power Today

Photovoltaic Cost Trajectory

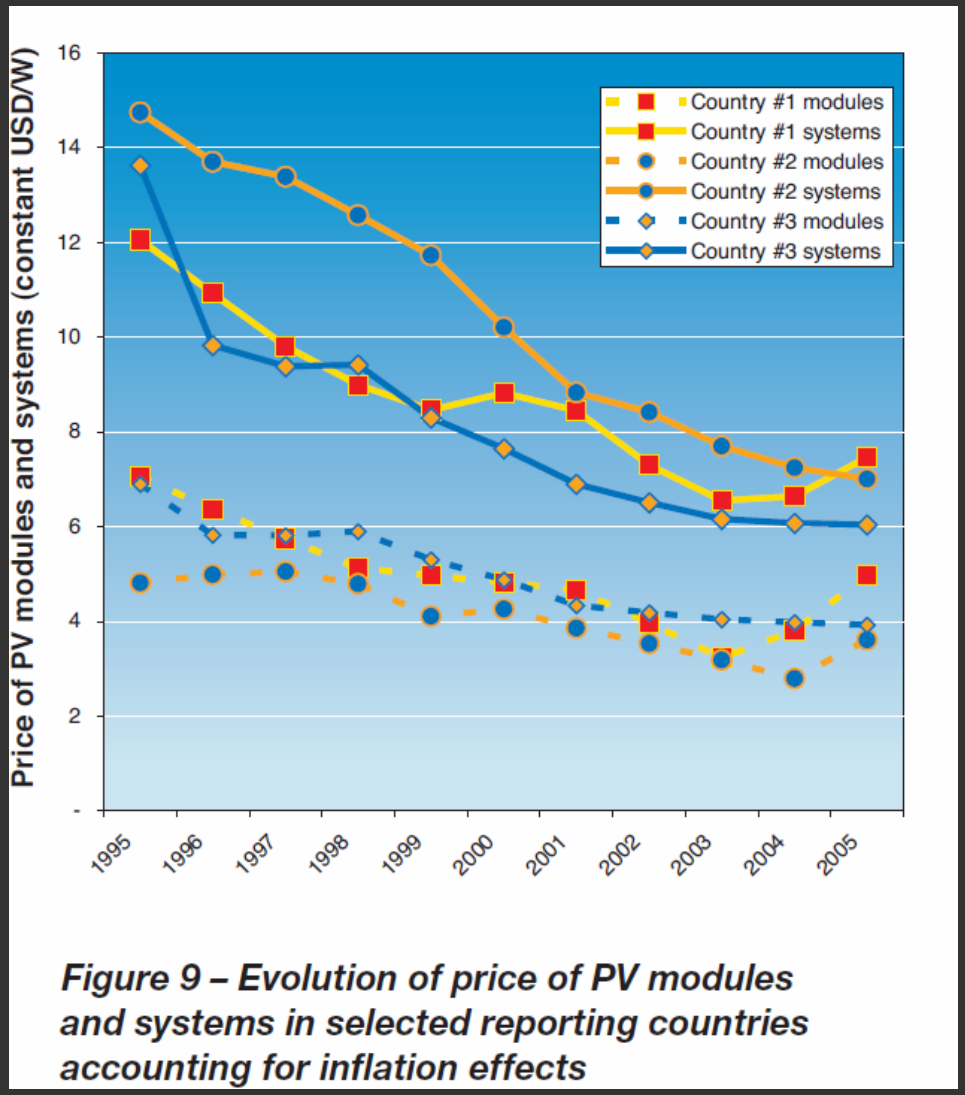


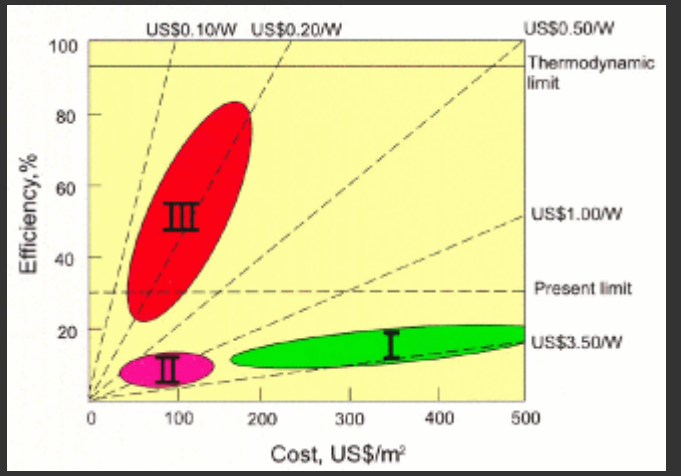
Figure 9 – Evolution of price of PV modules and systems in selected reporting countries accounting for inflation effects

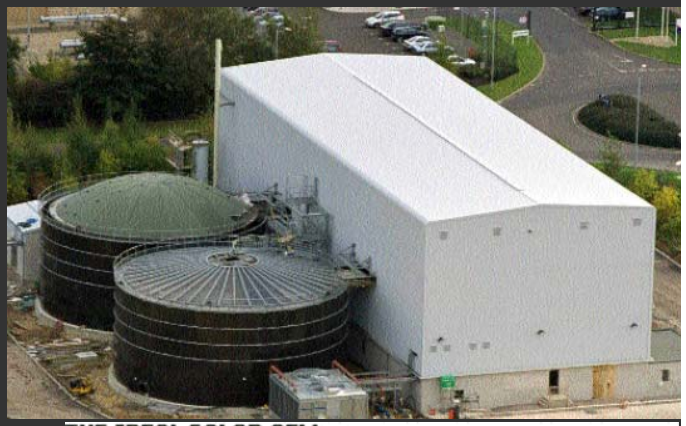
- Module Prices Falling
- System Share Of Cost Is Growing
- With zero cost modules Systems at $2/Wp
- Annual capacity equals China's weekly needs

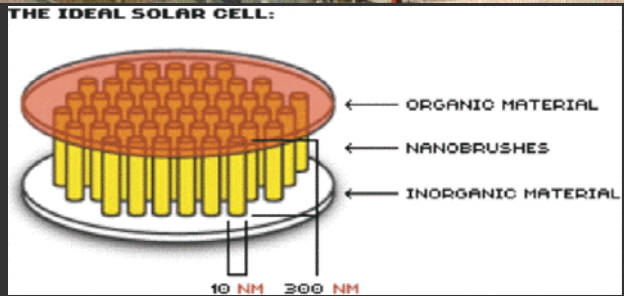
IEA http://www.iea-pvps.org/products/download/rep1_15.pdf

We Need To Work On

- Higher Efficiency Cells!
  - Leverage Systems/BOP Cost
- Manufacturing Scaleup!!
- Batteries and Storage
  - Beyond Vanadium Flow Cells, Li-Polymer, Beyond Lead-Acid, **$/kWh –** need 5x
- <u>Not</u> Concentrators
  - Adding BOP cost, reducing cell cost

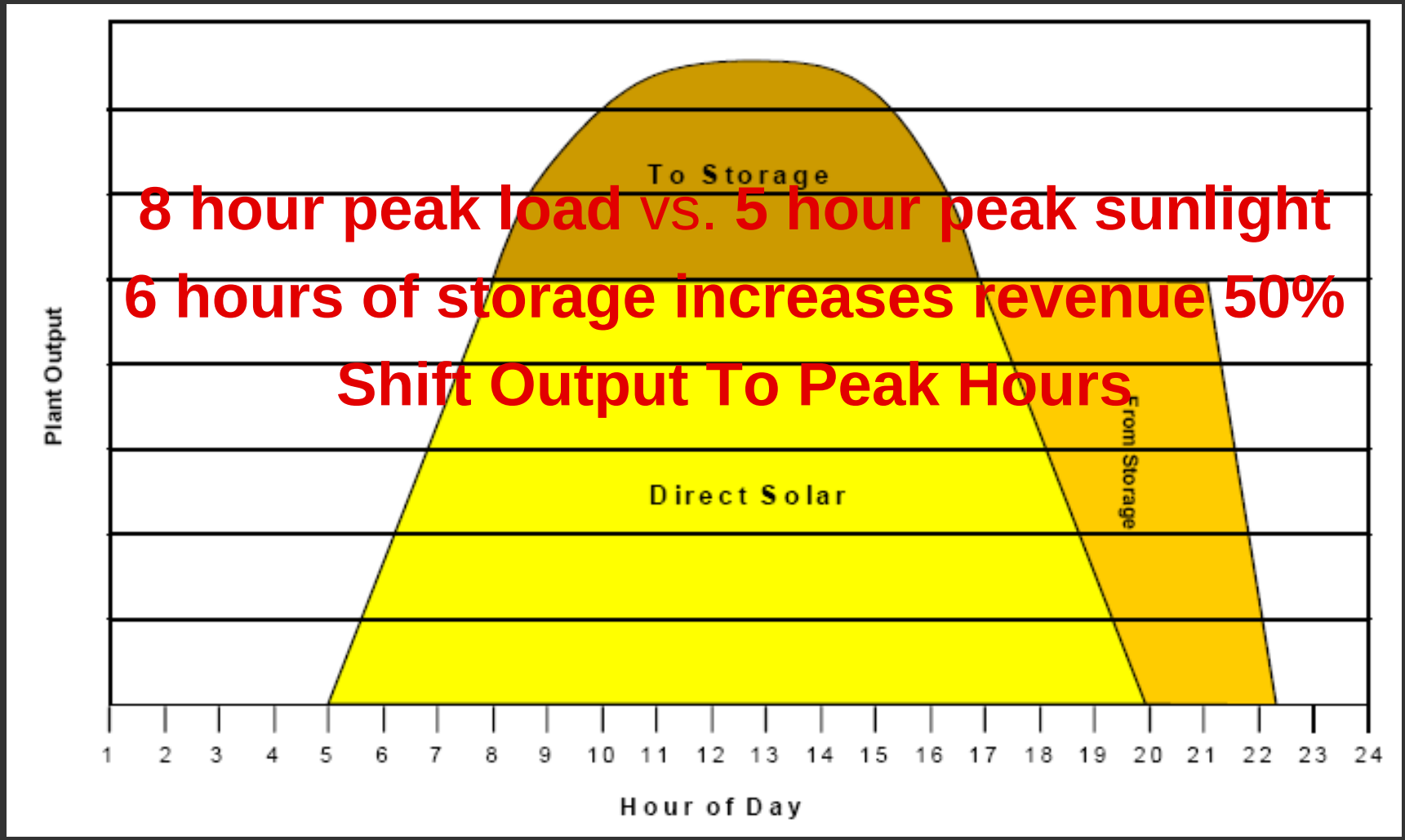






http://www.vrbpower.com/docs/media/energy%20storage.pdf

Storage For Timeshift



8 hour peak load vs. **5 hour peak sunlight**

6 hours of storage increases revenue 50%

Shift Output To Peak Hours

Time-Of-Day Pricing

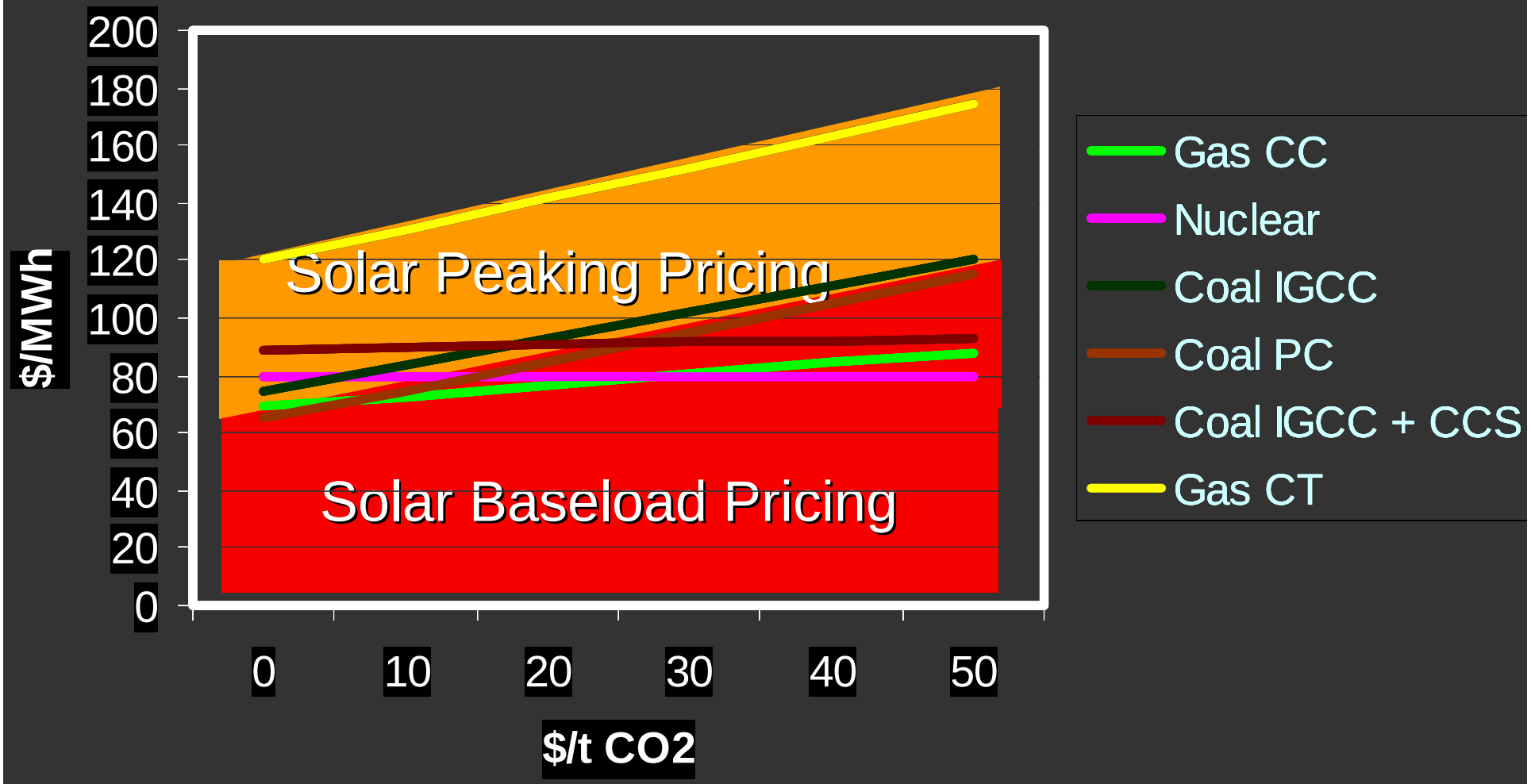
- PG&E (Northern CA) Summer
  - Noon – 8pm : 1.95x “nameplate” $/kWh
- Coal, Wind get “nameplate” average price
- Solar gets 1.2x “nameplate” price
- Solar With Storage can get 1.5x

CA Electric Power

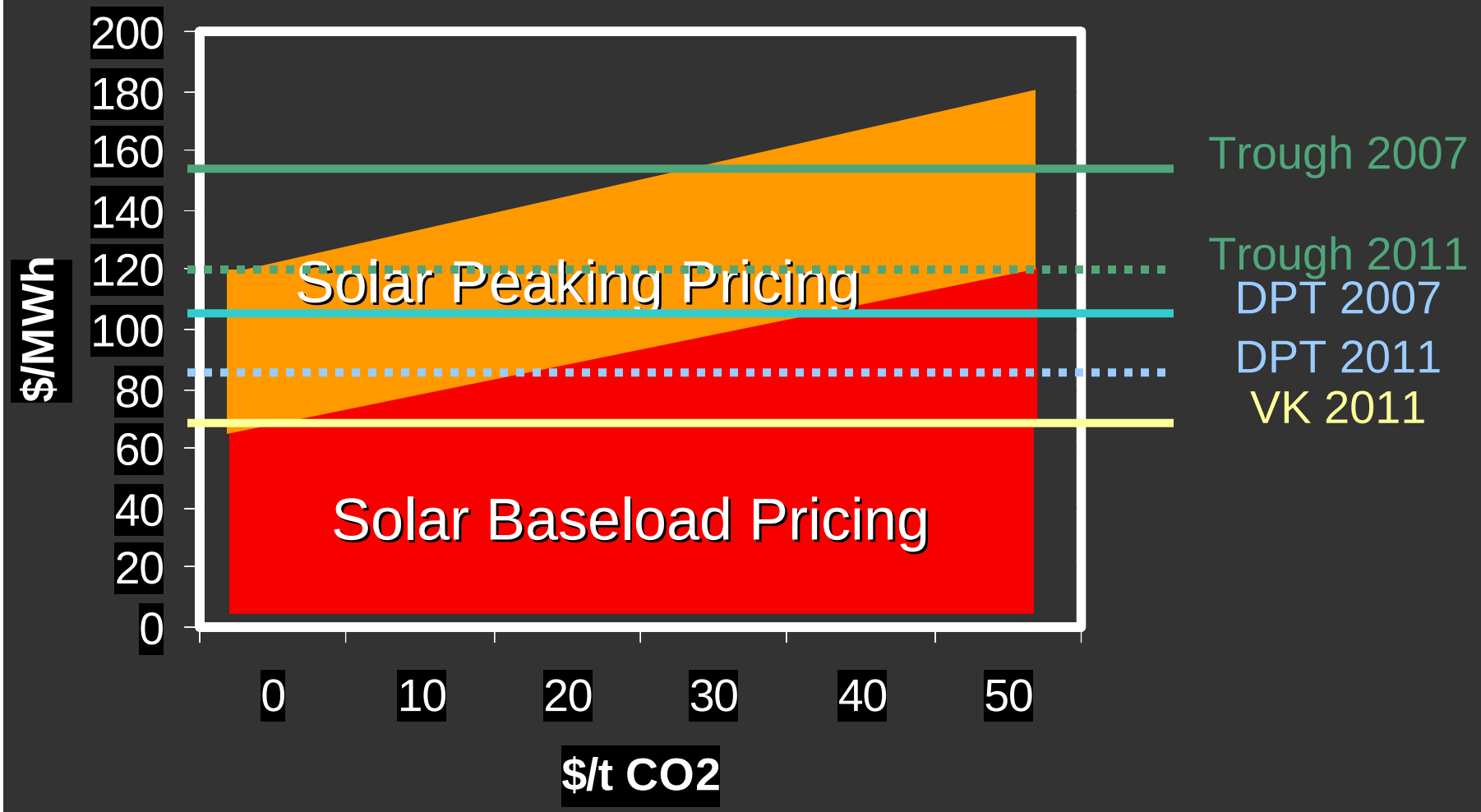
	Capacity, MW	Storage, hours	Capacity Factor	Nom LEC, 30%ITC	Nom LEC, 10%ITC
Simple Cycle Gas, PEAKING	85	n/a	10.0%	168.0	168.0
Combined Cycle Gas, INTERMEDIATE	500	n/a	40.0%	104.0	104.0
Pulverized Coal, BASE	1500	n/a	65%	45.0	45.0
PV, 2006	1	0	25%	200.	250.
Parabolic Trough	100	0	28.4%	154.0	173.0
Parabolic Trough 2011	150	6	40.4%	120.0	134.0
Luz2 DPT 150MW	150	0	25.0%	107	120

Black and Veatch, Economic, Environmental, and Energy Benefits of Concentrating Solar Power in California, April 2006; PV www.solarbuzz.com DPT Luz2

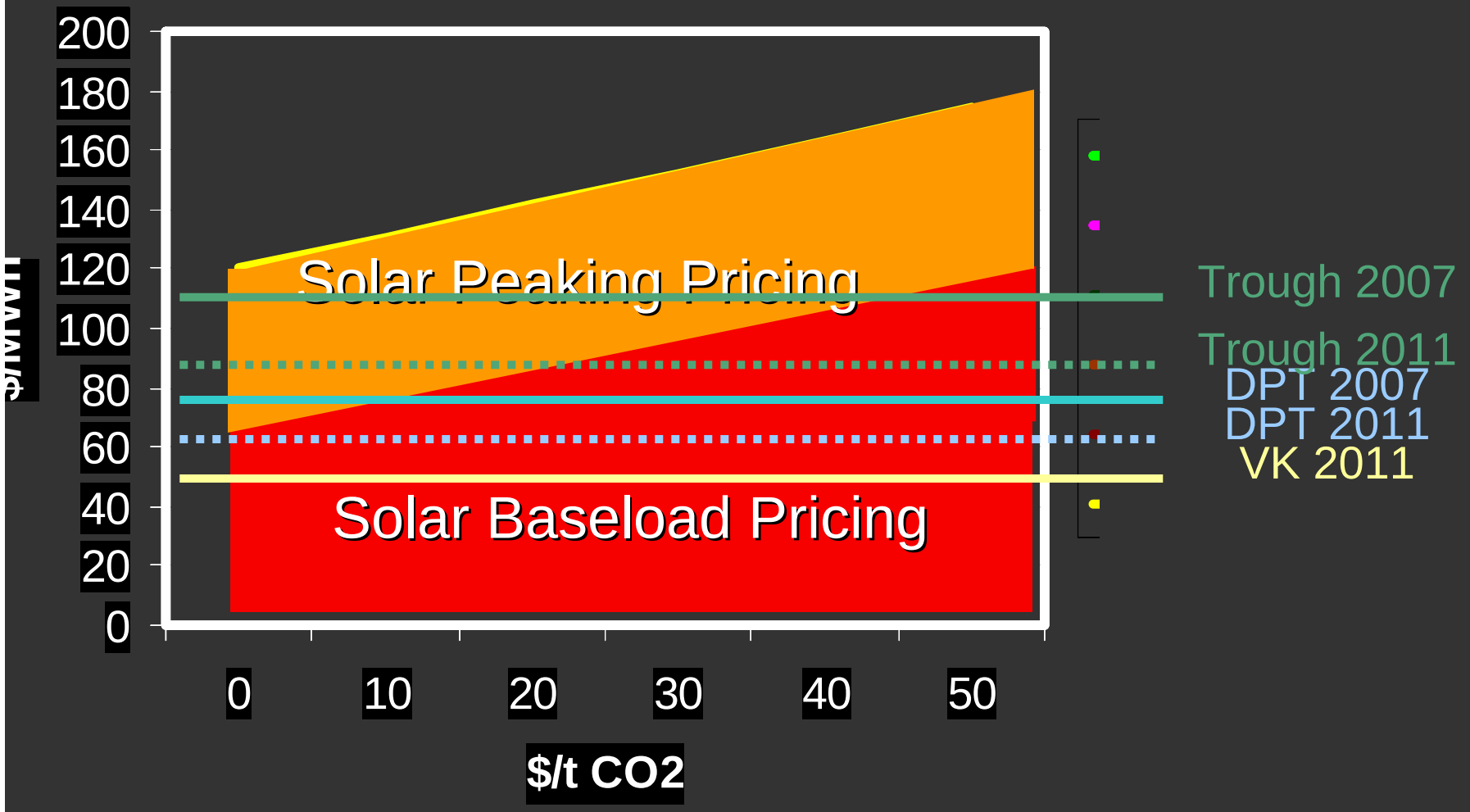
Cost of Power by Type



Cost of Power by Type



Net Impact of Time-Of-Day Including Thermal Storage

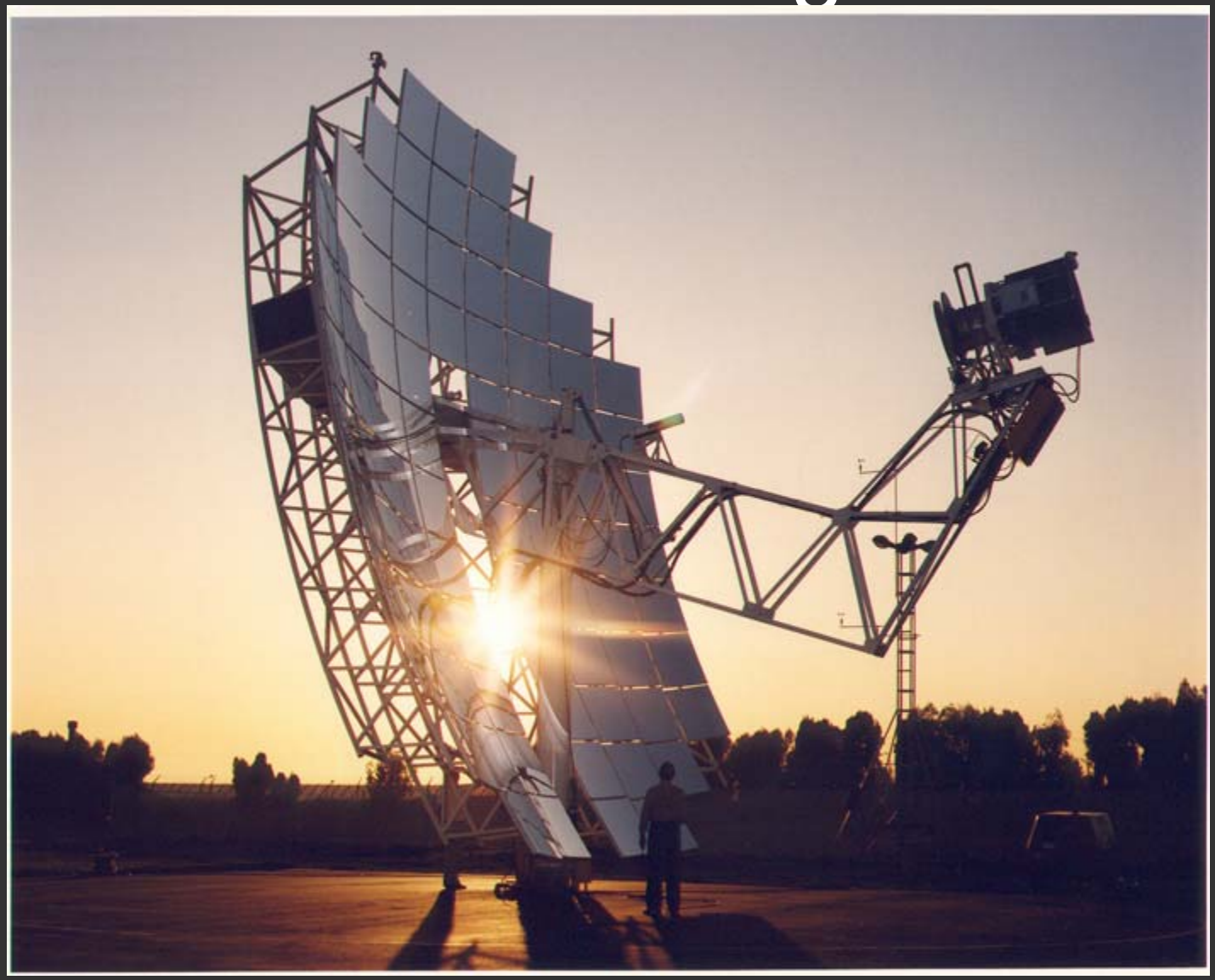


Costs Including Storage

- PV @ $4/Wp
  - $12 3x Wp energy capture for 60% CF
  - $20 $0.50/wh x 5 hrs x 2Wp (into storage)
- Total $32/W for 60% CF
- Thermal CSP $3-9/W for 60% CF
- Thermal CSP Is Key To Turning Off Coal

PV cost reduced from http://www.iea-pvps.org/products/download/rep1_15.pdf PV storage: ½ reported battery cost CSP: Black & Veatch, CA study 4/06

Dish-Engine



www.stirlingenergy.com

Power Towers

- **First commercial plants being built in Spain**

Solar Two, 10MW, Barstow, CA

Parabolic Troughs

Solar Electric Generating Stations, 354MW, Boron and Harper Lake, CA

Poised for Breakaway Growth?

- Crossing Gas Prices
- Meeting IGCC Prices (2008-09)
- Meeting Pulverized Coal Prices (2008-09)
- Large Capital Flows Will Follow Costs

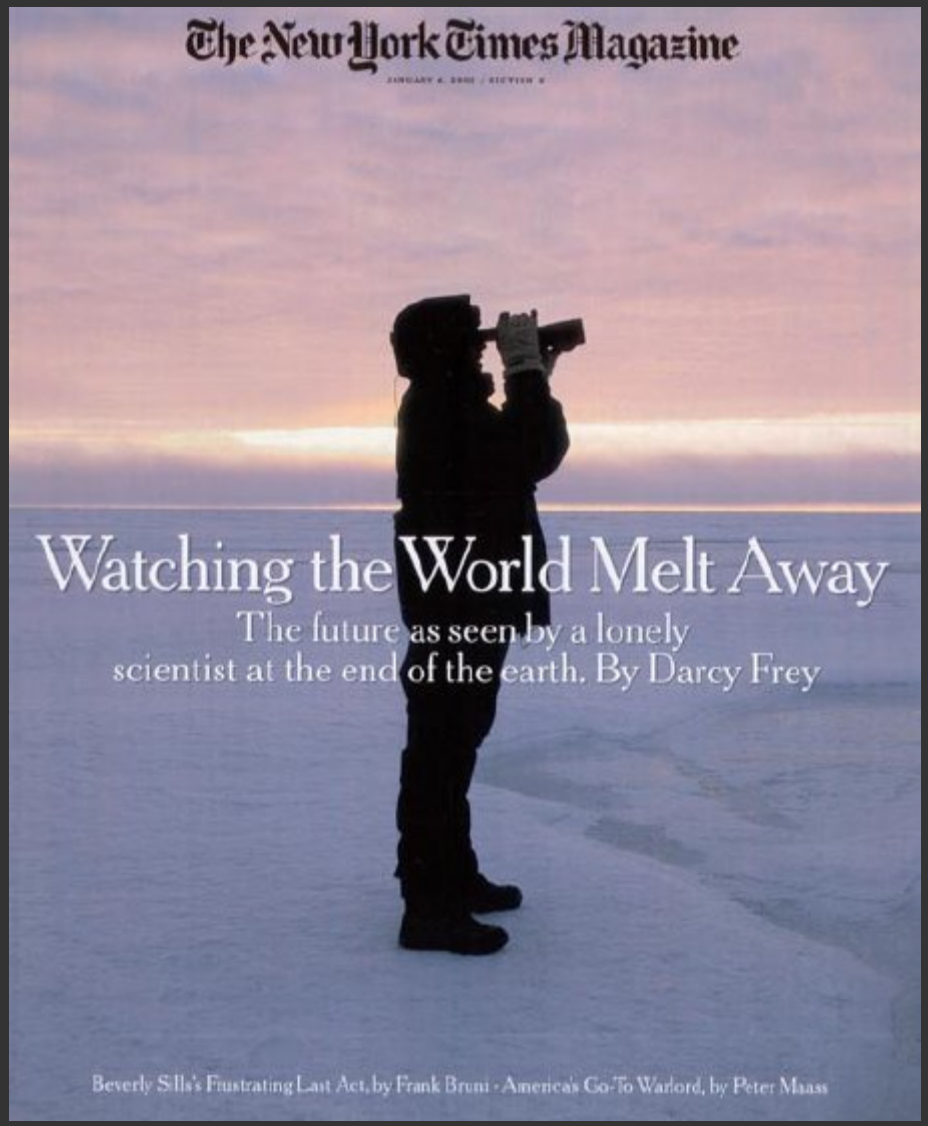
Policy Needs?

- Stable ITC
- Level tax playing field
- Transmission Priority and Grid Upgrades
- Startup loan guaranteed for initial plants

A New Federal Subsidy Program

- Farm Subsidies 2006: $26 B
  - » Stabilization, Preservation of Farms, Non-Production
- Total Coal Revenues: $12 B
  - » Profits $1.2B
- Let’s Subsidize COAL: $1.2 B
  - » Replace profits for NOT DIGGING COAL
  - » Lowest Cost, Highest Reliability Sequestration

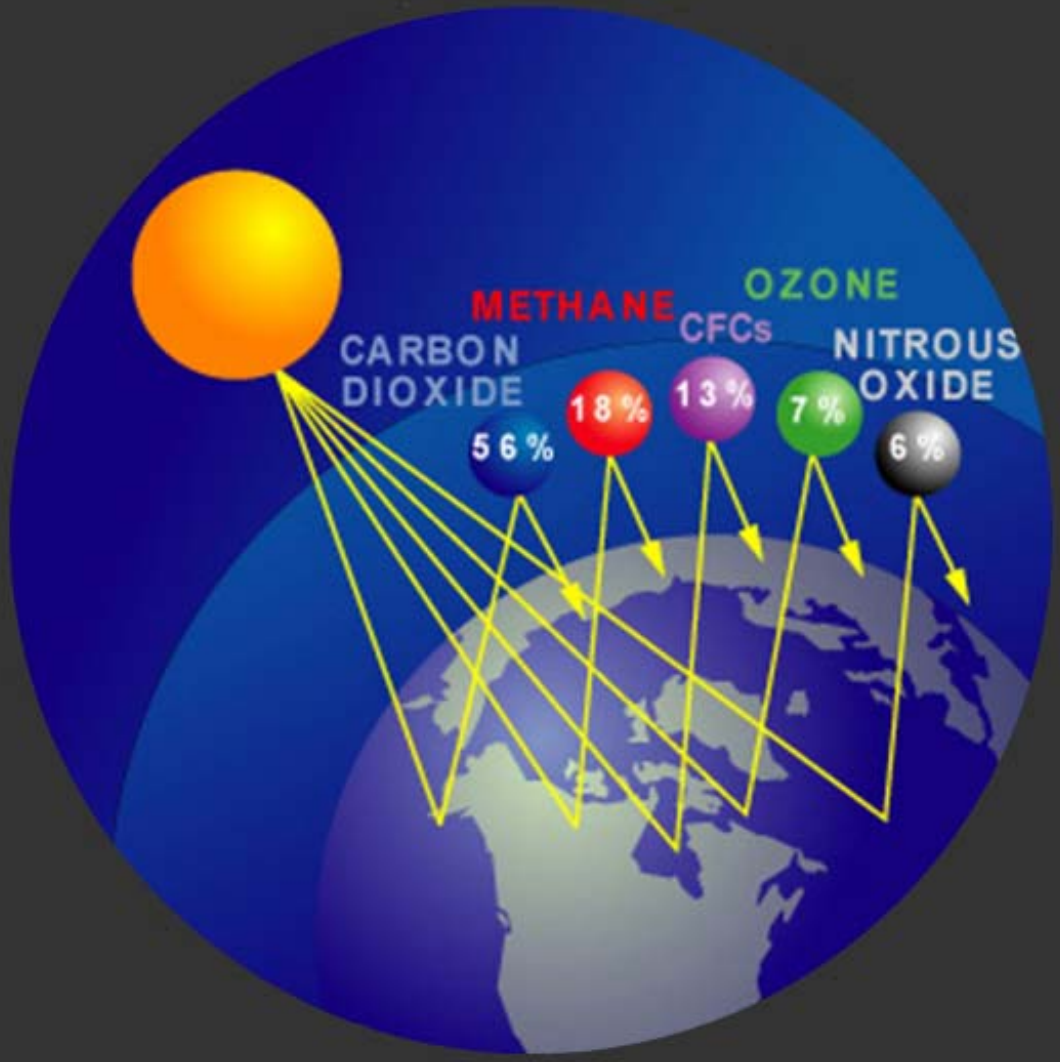
http://www.freetrade.org/pubs/pas/tpa-032es.html *http://www.mrm.mms.gov/Stats/pdfdocs/cr99.pdf*



…or get to work

vk@khoslaventures.com

Greenhouse Gases



Brenda Ekwurzel, Union of Concerned Scientists, www.ucsusa.org

Un Conventional Wisdom: "200 Years of Coal"

If We Build More Coal Plants We Get Either

10 Years Of Coal Left

Or

Greatly Increased Coal Prices

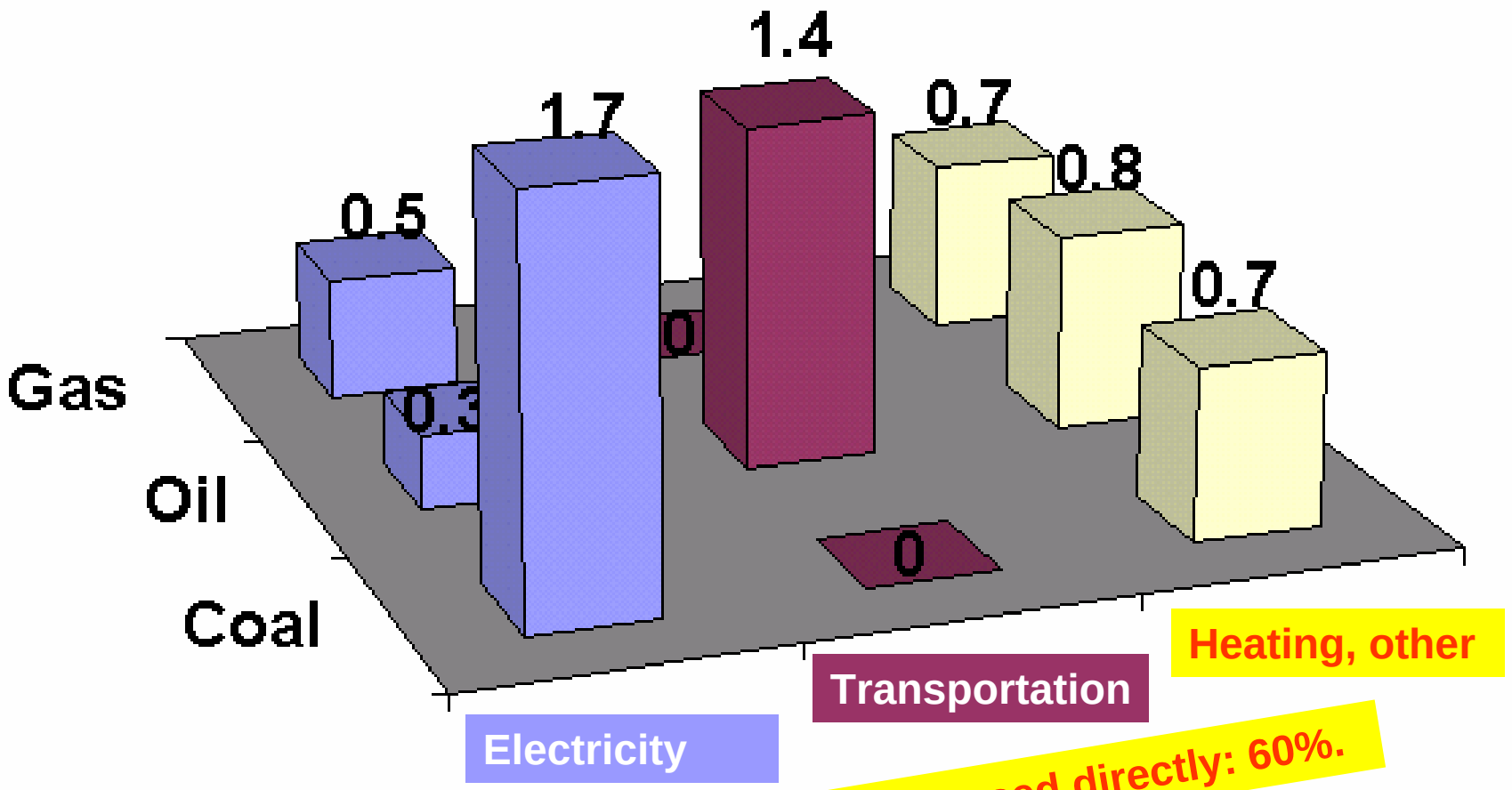
We can have cost or availability but not both!

Figure 24. Gillette coal field coal resource analysis results for the five coal mining units combined. Percentages of combined five coal units. Percent of original shownin red, percnt of previous resource category shown in white.

USGS, Evaluation of Economically Extractable Coal Resources in the Gillette Coal Field, Powder River Basin, Wyoming 02-180 2002

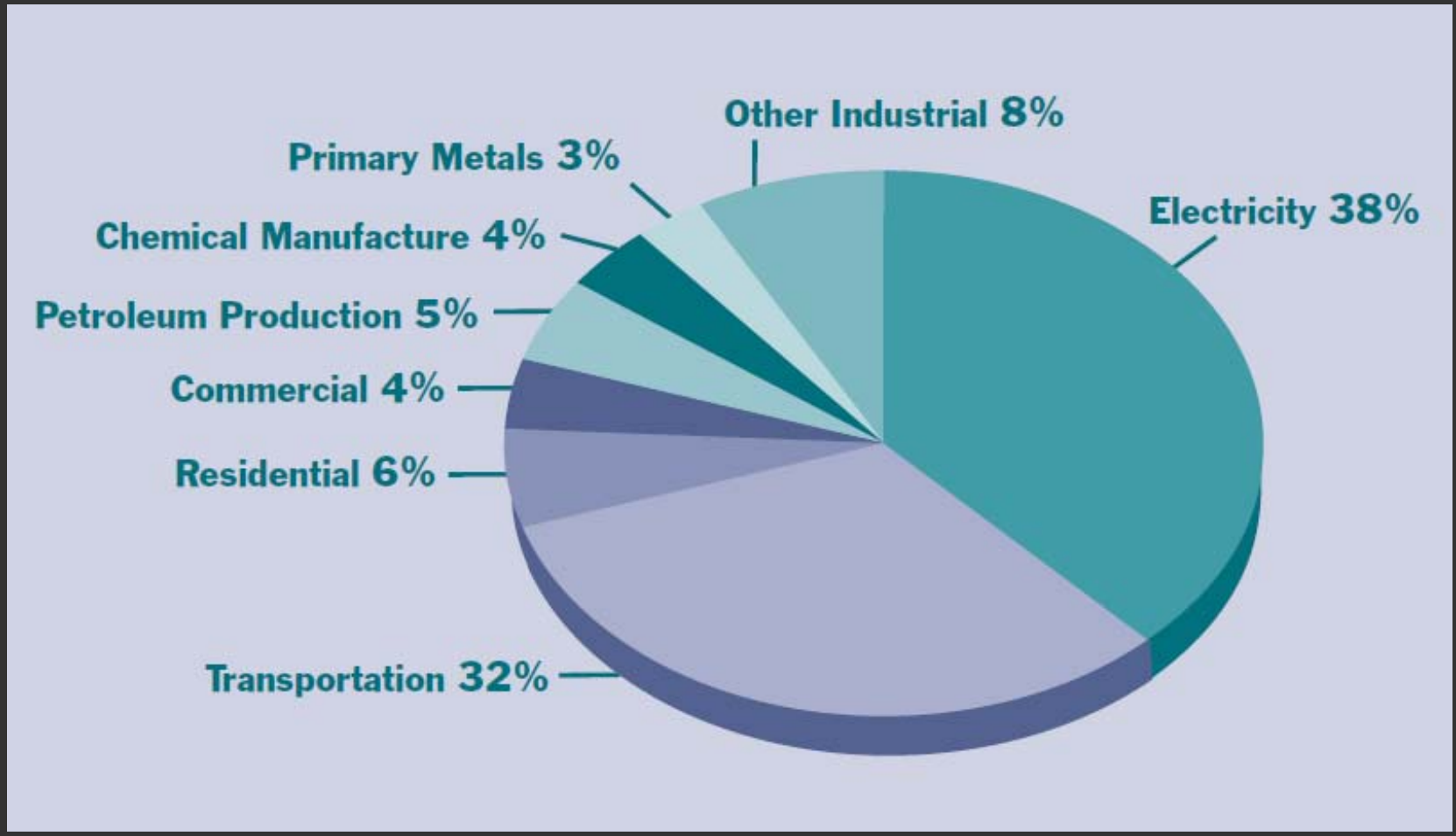
CO_2 Emissions by Sector and Fuel

Allocation of 6.2 GtC/yr 2000 global CO_2 emissions



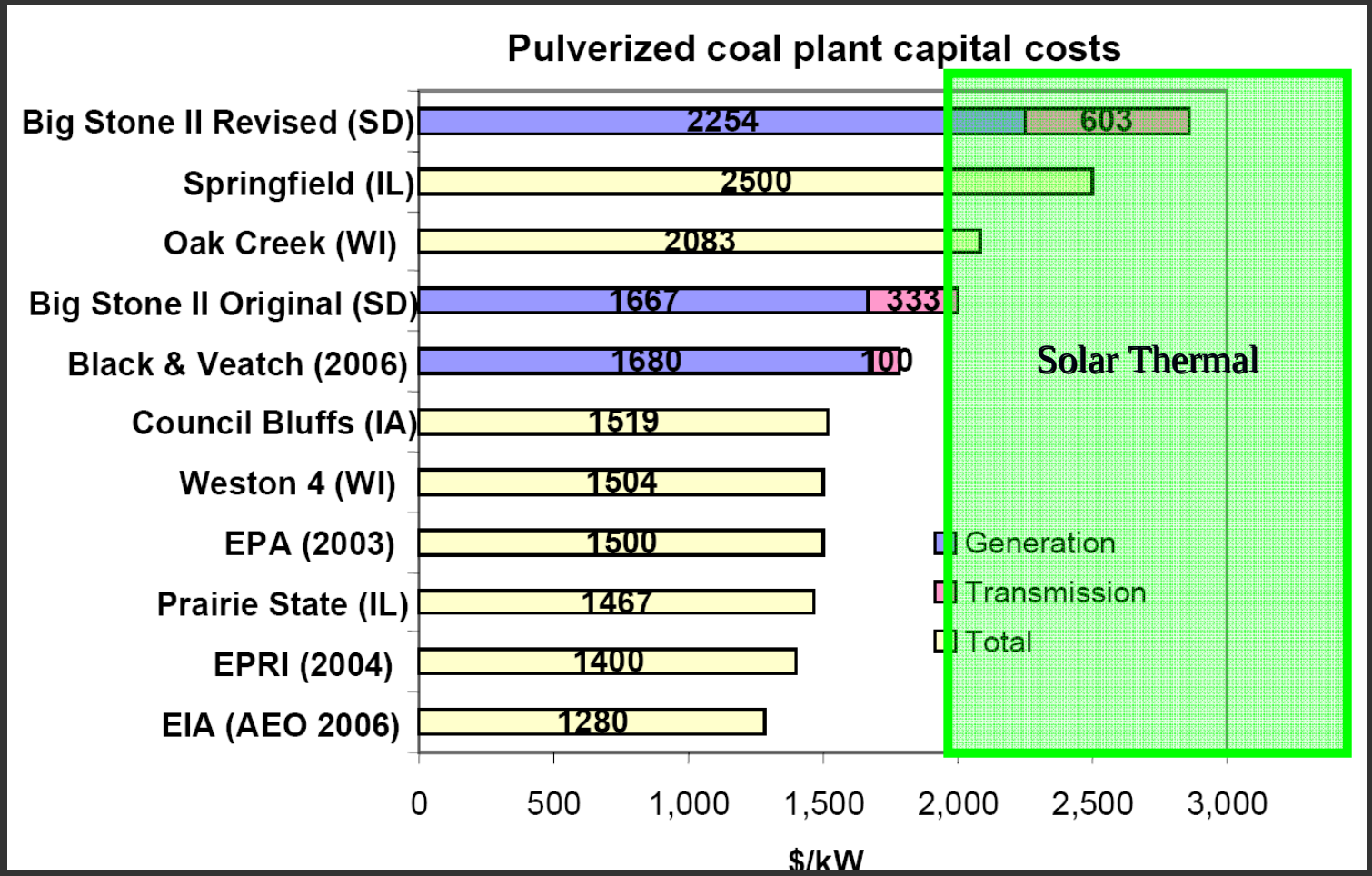
Electricity: 40%; fuels used directly: 60%.

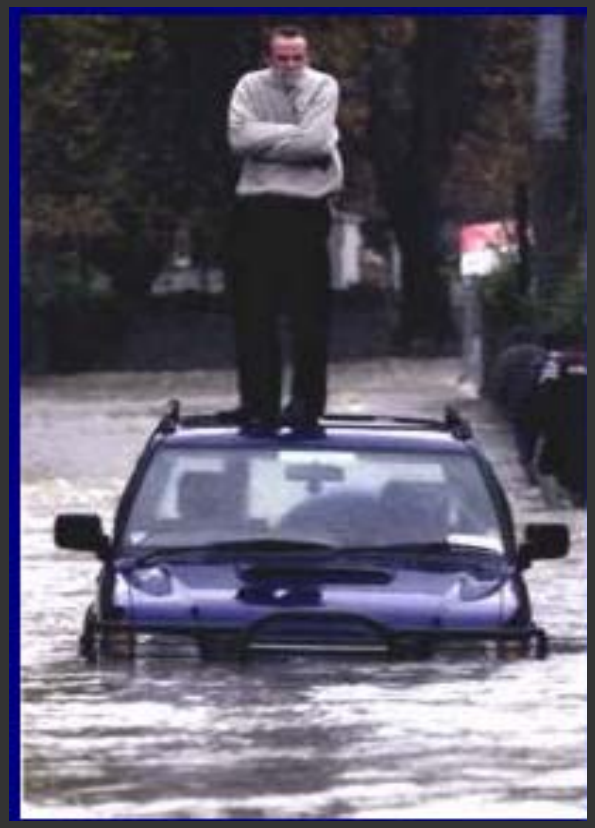
Electricity = Biggest Carbon problem



US Energy Information Administration and US Environmental Protection Administration
www.pewclimate.org/docUploads/Electricity_Final.pdf

Coal Capital Costs





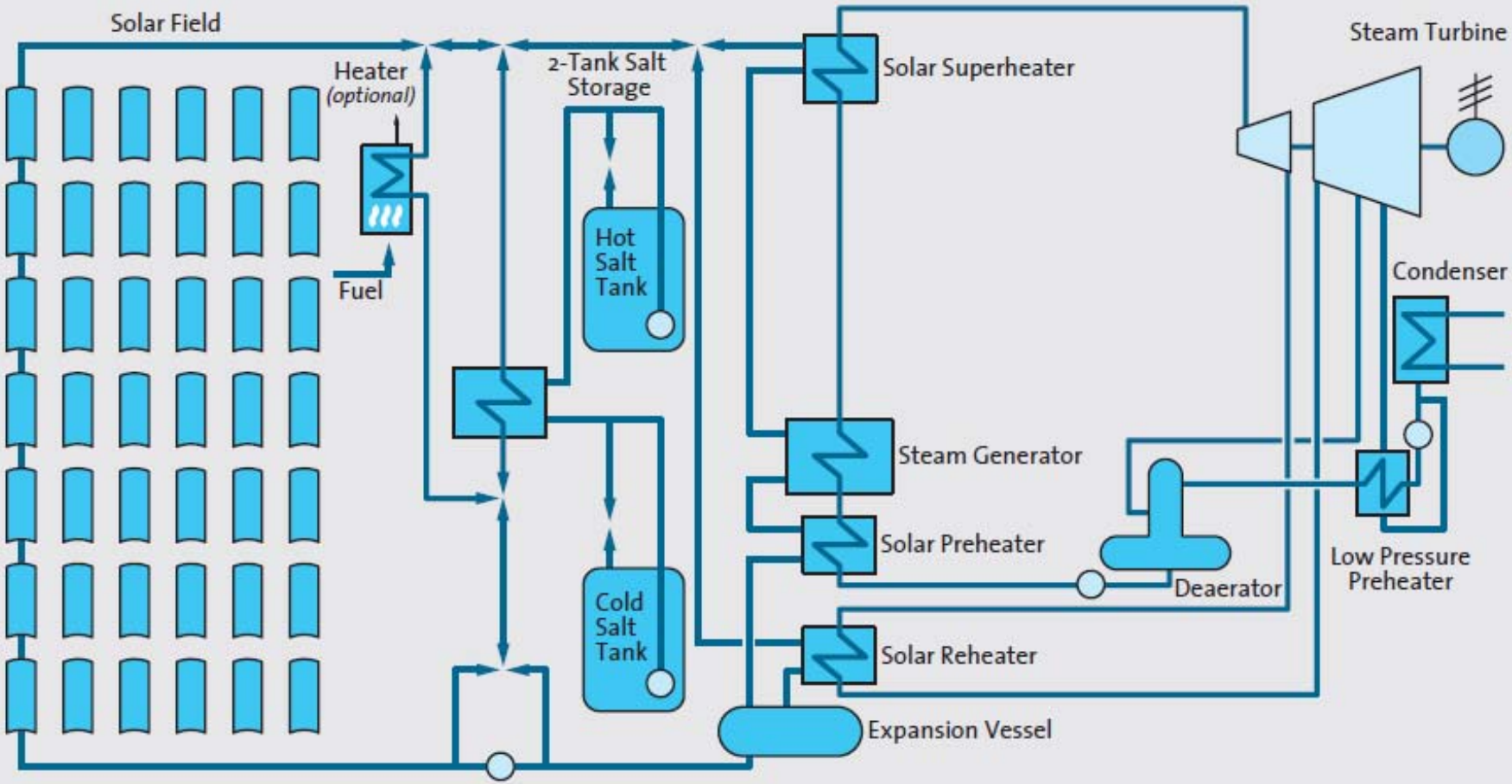
World Bank : <5 Years Left for Coal

Figure 9: Cost Reductions in Parabolic Trough Power Plants

	Near-Term (Next Plant Built)	Near-Term (Next Plant Built)	Near-Term (Next Plant Built)	Mid-Term (~ 5 Years)	Long-Term (~ 10 Years)	Long-Term (~ 10 Years)
Power Cycle	Rankine	Rankine	ISCC	Rankine	Rankine	Rankine
Solar Field (,000 m²)	193	1,210	183	1,151	1,046	1,939
Storage (hours)	0	0	0	0	0	0
Solar Capacity (MW)	30	200	30	200	200	200
Total Capacity (MW)	30	200	130	200	200	200
Solar Capacity Factor	25%	25%	25%	25%	25%	50%
Annual Solar Efficiency	12,5%	13.3%	13.7%	14.0%	16.2%	16.6%
Capital Cost ($/kW) US Plant International O& M Cost ($/kWh)	 3,500 3,000 0.023	 2,400 2,000 0.011	 3,100 2,600 0.011	 2,100 1,750 0.009	 1,800 1,600 0.007	 2,500 2,100 0.005
Solar LEC ($/kWh)	0.166	0.101	0.148	0.080	0.060	0.061

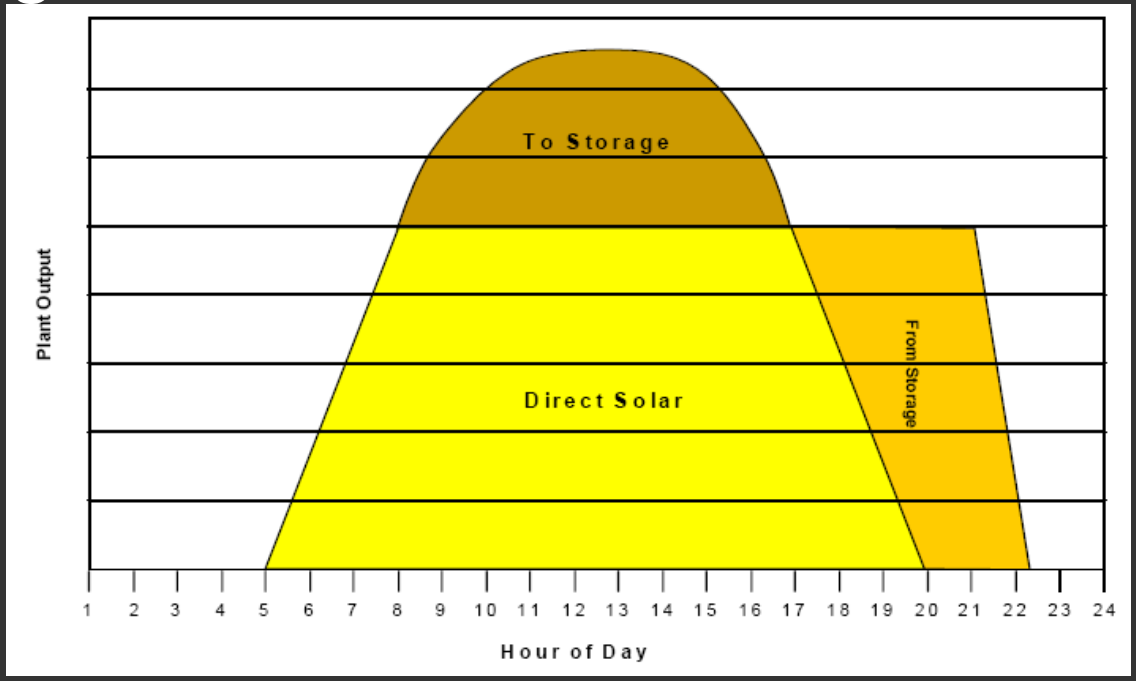
Source: World Bank

Thermal Storage



Storage is Essential

- **24 hour power** vs. **5 hour peak sunlight**
- Batteries, Flow Batteries, Compressed Air, Pumped Hydro, SMES: $300-1000/kWh
- Thermal Storage: $15/kWh demonstrated



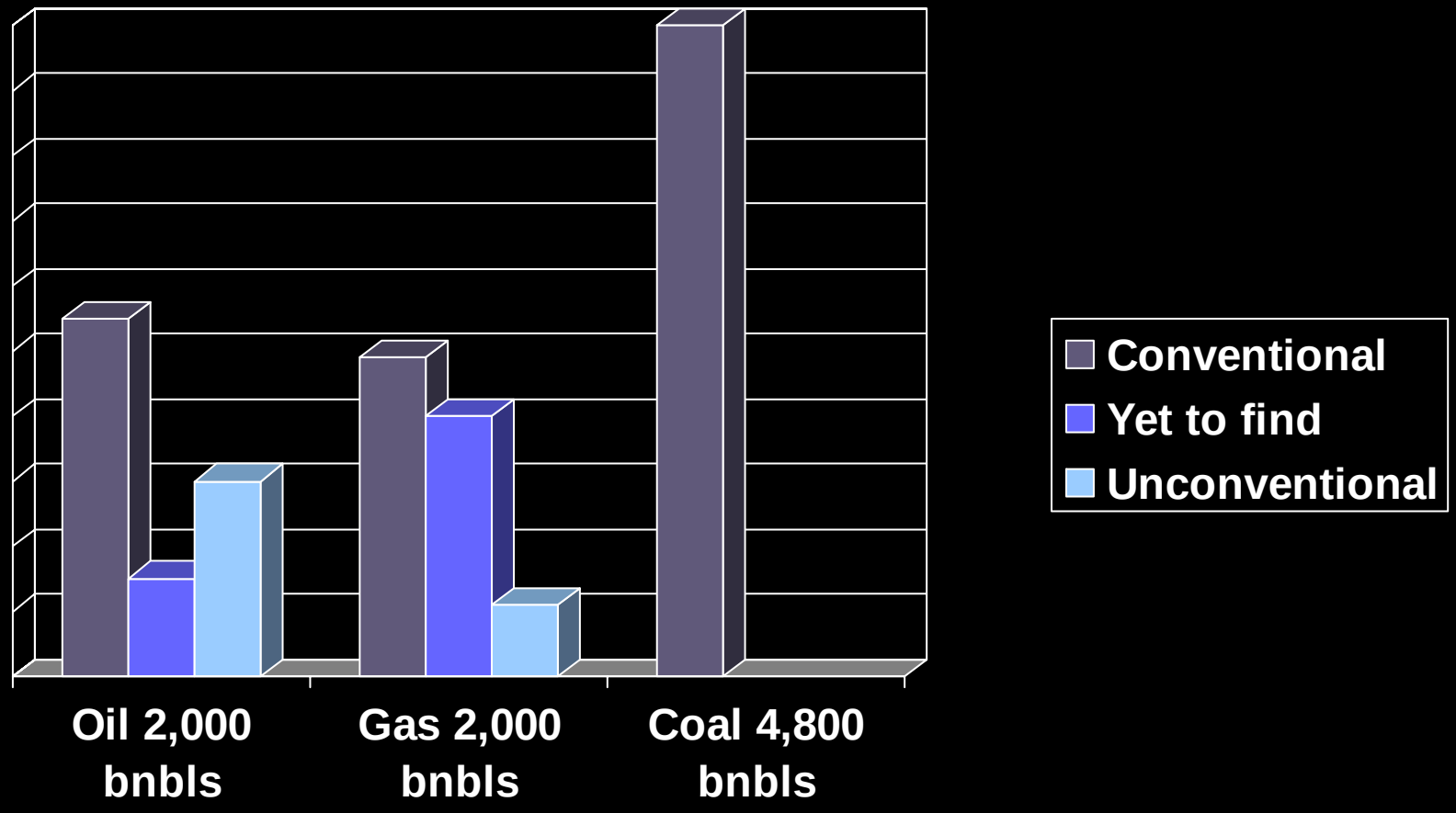
Area requirements to power the USA

$(150\ km)^2$ of Nevada covered with 15% efficient solar cells could provide the USA with electricity

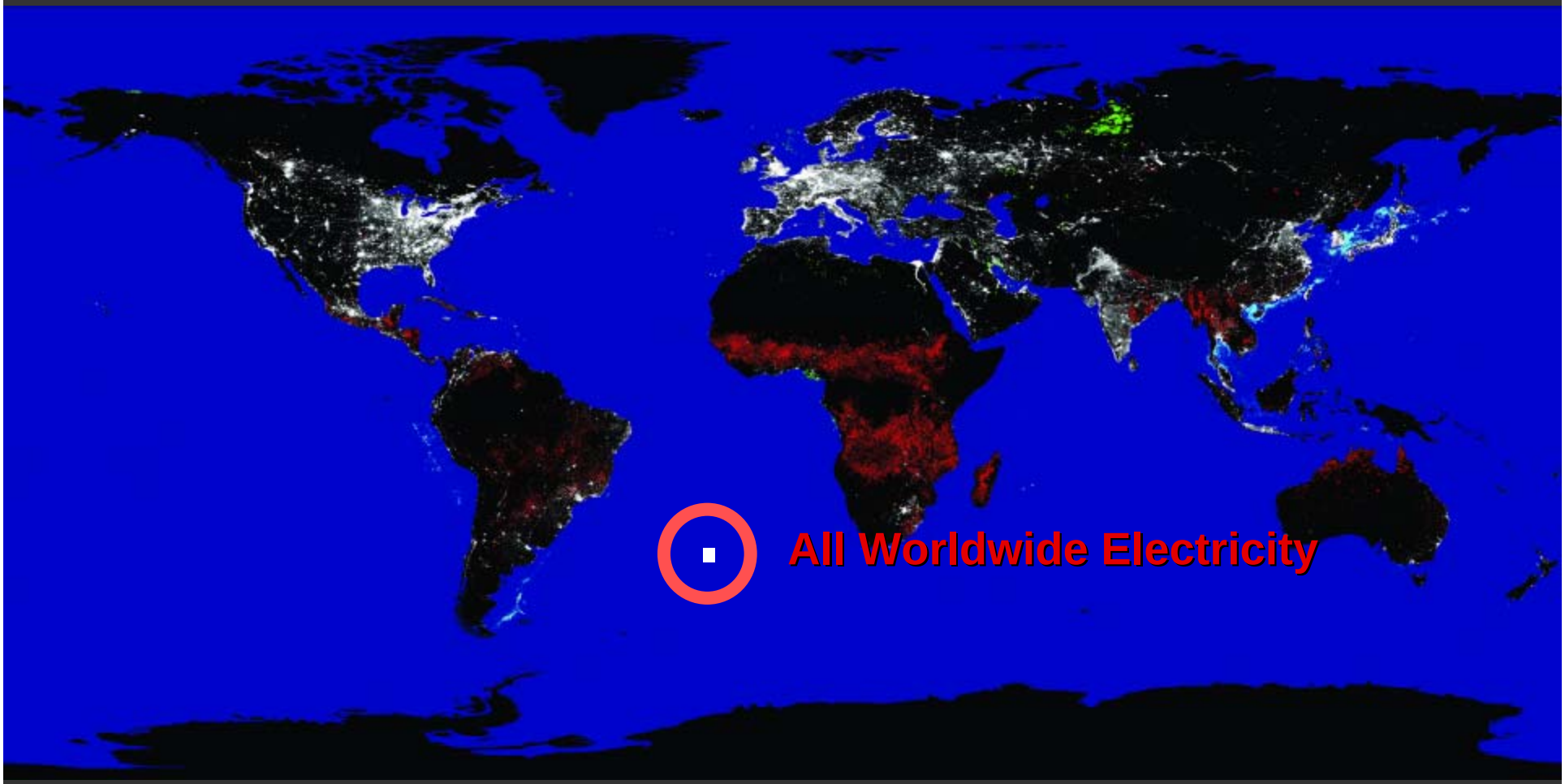
J.A. Turner, *Science* **285** 1999, p. 687.

Largest Reserve Is Worst Problem

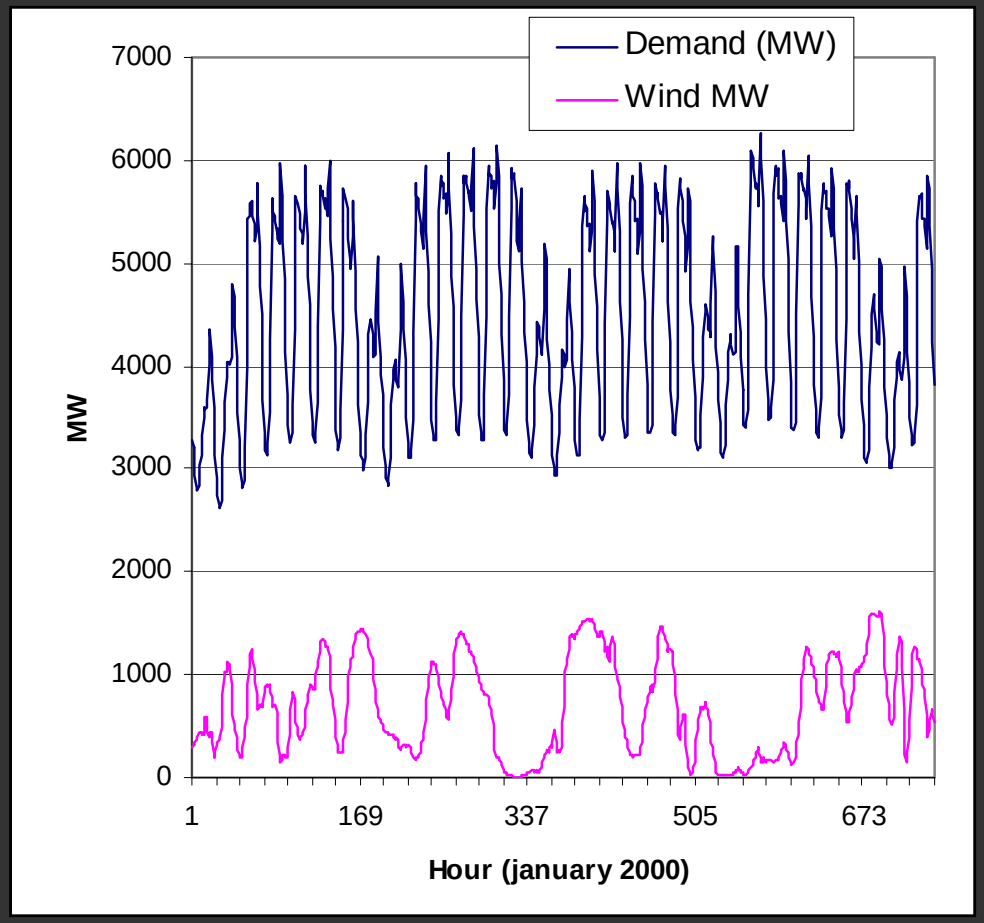
Substantial Global Fossil Resources



Scalability : Land For All Electricity



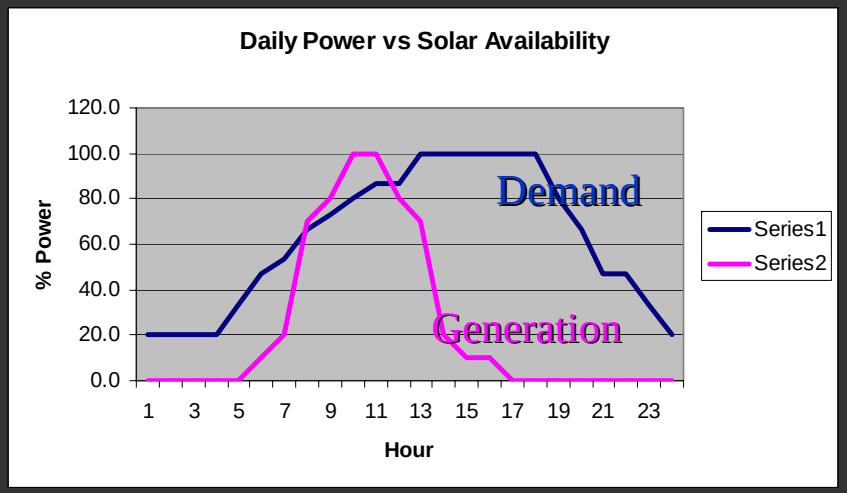
Wind vs. Load is Random

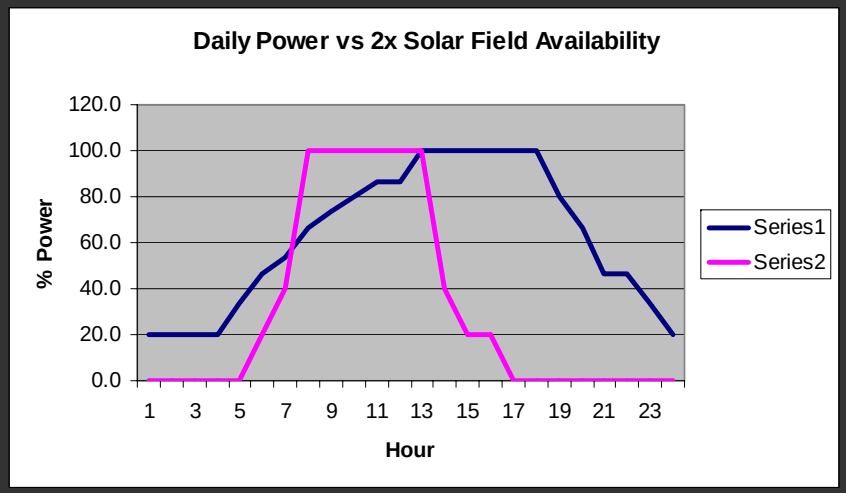


Wind Random vs. Load

- Lots of power at 2am
- Lots of Daily Variability (30%+)

Solar Correlates with the Load





Solar Highly Correlated with CA loads

Timeshifted a few hours

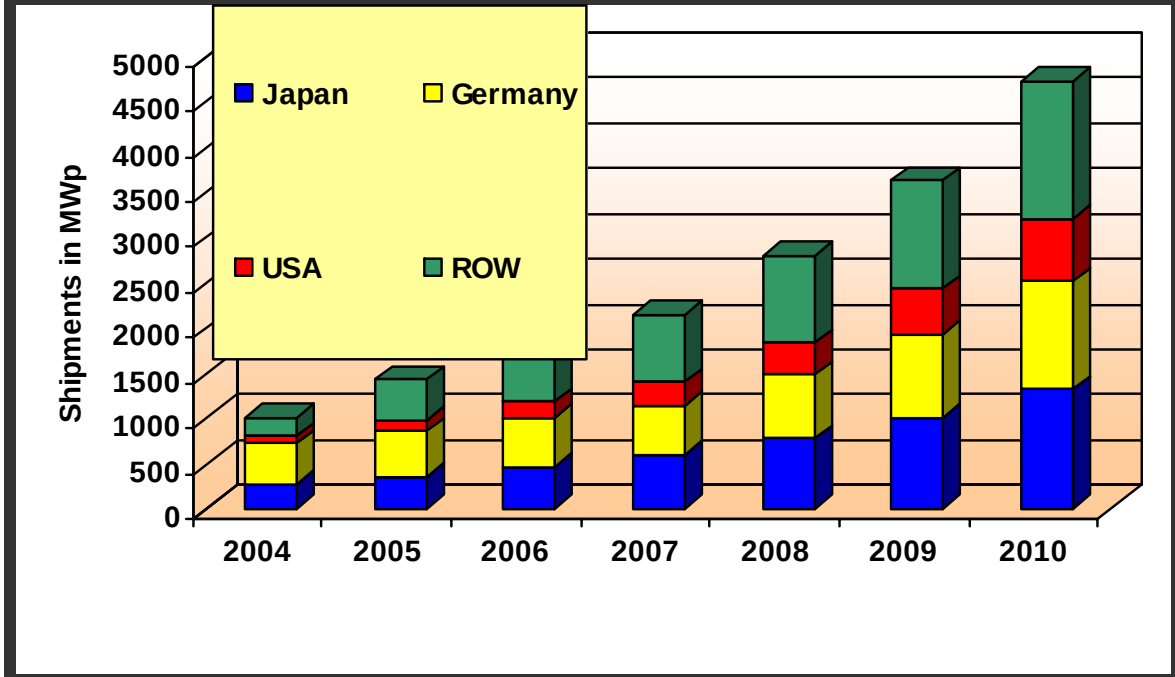
Very predictable and steady (10%)

Larger Solar Array
“Clipped” At Max Output Power
More Hours of Peak Load Served

Key Issues for Thermal CSP

- **Back End Power Block**
  - Turbine/Engine Efficiency
- **Concentrator and Receiver**
  - Mirror $ / m^2 dominates total system cost

PV Capacity Crisis: Temporary?



- 4.5 GW/yr by 2010
- **1 month** of China coal-fired power plant construction

http://www.iea-pvps.org/products/download/rep1_15.pdf