Carnegie Mellon Electricity Industry Center

CEDM

Three Thoughts on
Renewables and Decarbonizing the Energy System

Remarks at the Peterson Institute, 2014 June 27

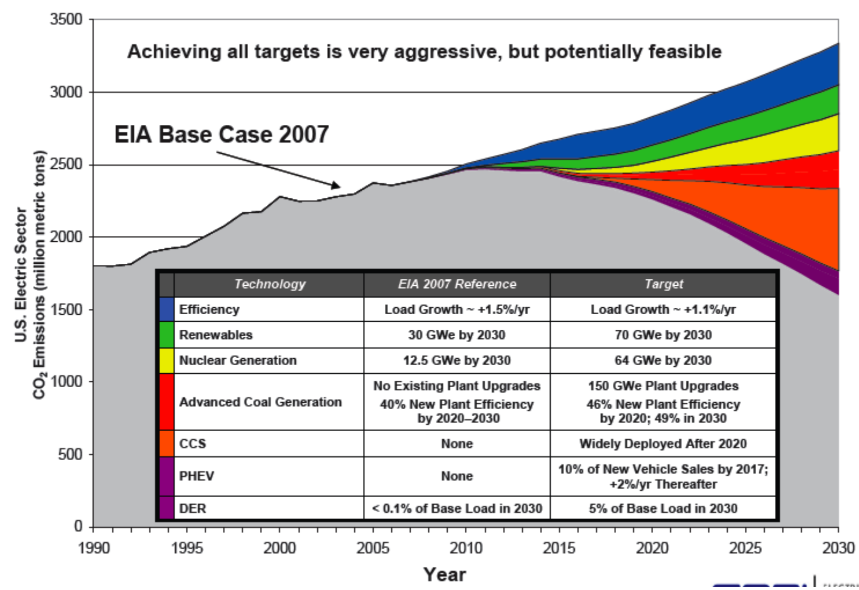
Prof. M. Granger Morgan
Department of Engineering
and Public Policy
Carnegie Mellon University
Pittsburgh, PA 15213
granger.morgan@andrew.cmu.edu
412-268-2672

Carnegie Mellon University
Scott Institute
for Energy Innovation

1. There are no silver bullets

While wind, solar, hydro and biomass can all play important roles, decarbonizing the energy system in an expeditious and cost-effective way will require a portfolio of everything we've got.

Here for example is output from a cost minimizing EPRI model.

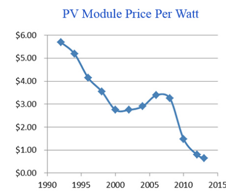


Technology	EIA 2007 Reference	Target
Efficiency	Load Growth ~ +1.5%/yr	Load Growth ~ +1.1%/yr
Renewables	30 GWe by 2030	70 GWe by 2030
Nuclear Generation	12.5 GWe by 2030	64 GWe by 2030
Advanced Coal Generation	No Existing Plant Upgrades 40% New Plant Efficiency by 2020–2030	150 GWe Plant Upgrades 46% 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

Source: EPRI

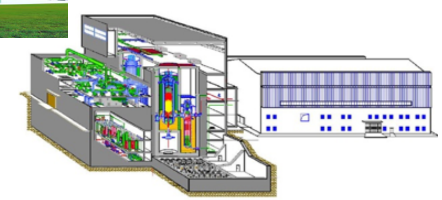
China has important activities in several "wedges"

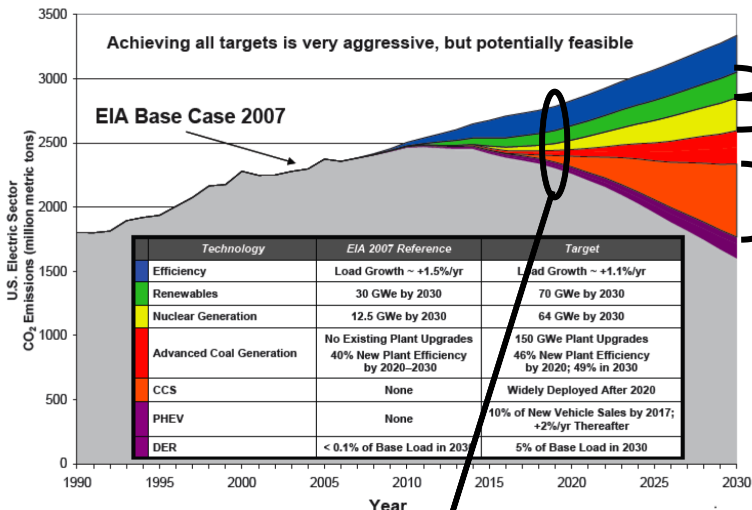
Sources:solarcellcentral and PVMagazine



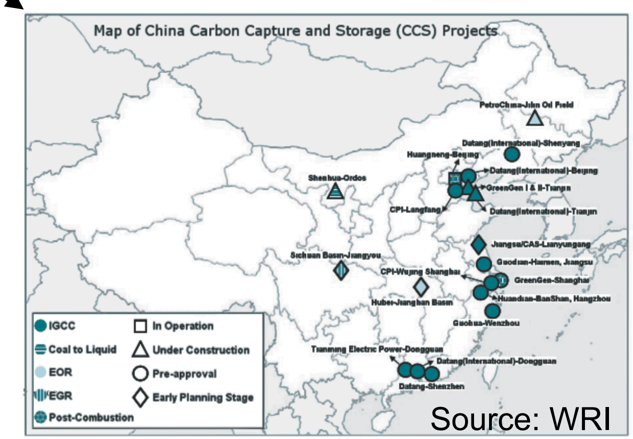
PV is important but be careful

Source: Westinghouse and UXC

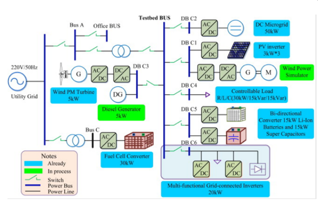




	Technology	EIA 2007 Reference	Target
	Efficiency	Load Growth ~ +1.5%/yr	Load Growth ~ +1.1%/yr
	Renewables	30 GWe by 2030	70 GWe by 2030
	Nuclear Generation	12.5 GWe by 2030	64 GWe by 2030
	Advanced Coal Generation	No Existing Plant Upgrades 40% New Plant Efficiency by 2020–2030	150 GWe Plant Upgrades 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



Source: WRI

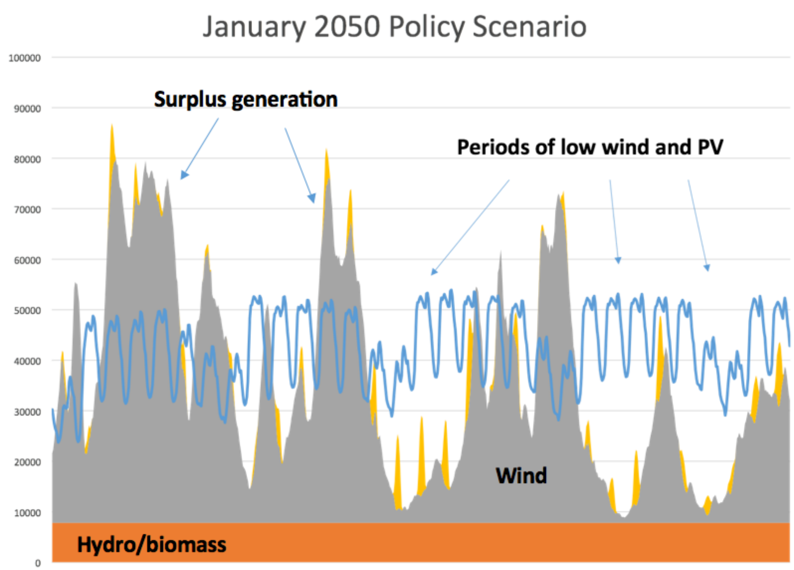


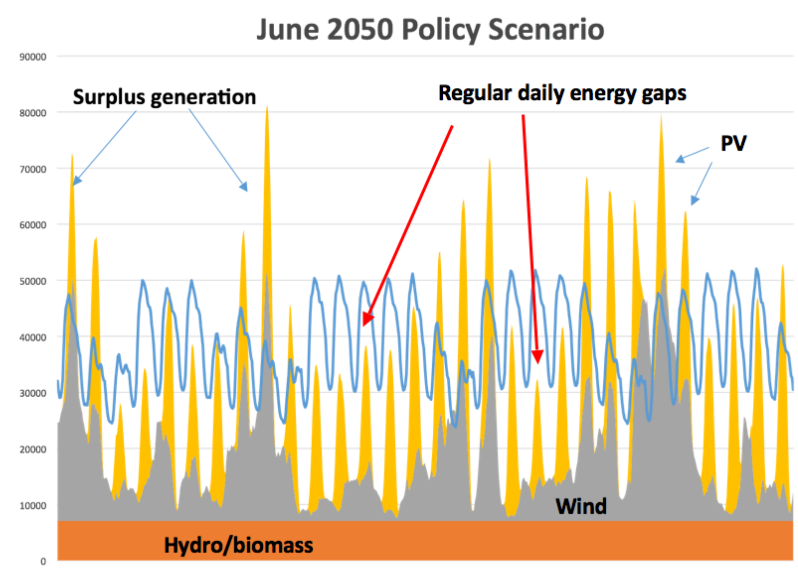
Source: ABB and Zeng et al.

We should study early adopters

Steve Brick of CATF has been examining the German Energiewende. When he does a simple extrapolation to 2050 there appear to be big problems:

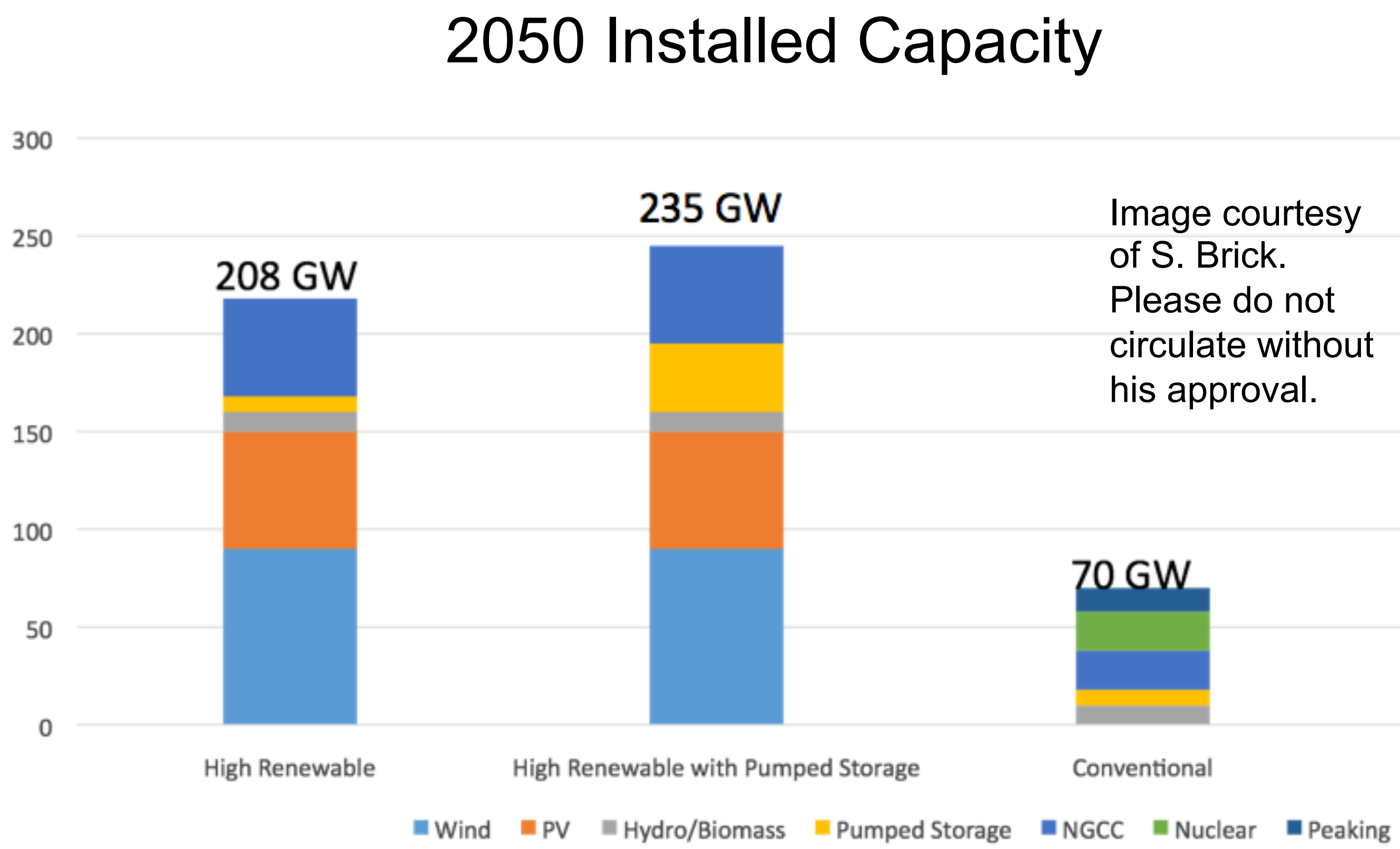
MW_e





Images courtesy of S. Brick. Please do not circulate without his approval.

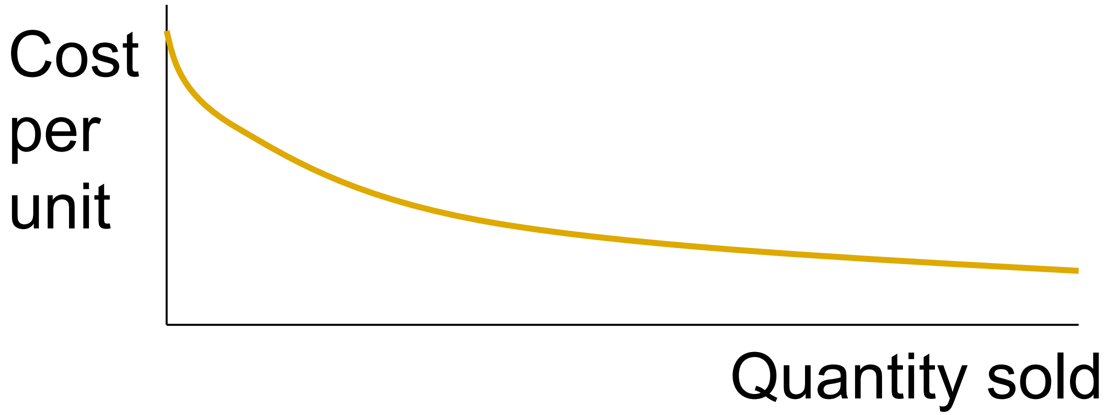
Steve Brick…(Cont.)



This is a first-order "back of the envelope" assessment.
We have a new student who will do a more refined analysis, but these results certainly suggest there may be a problem.

2. One needs to be careful about the use of subsidies and incentives

There is good historical evidence that as the quantity of a technology that is sold goes up, the cost per unit usually goes down:

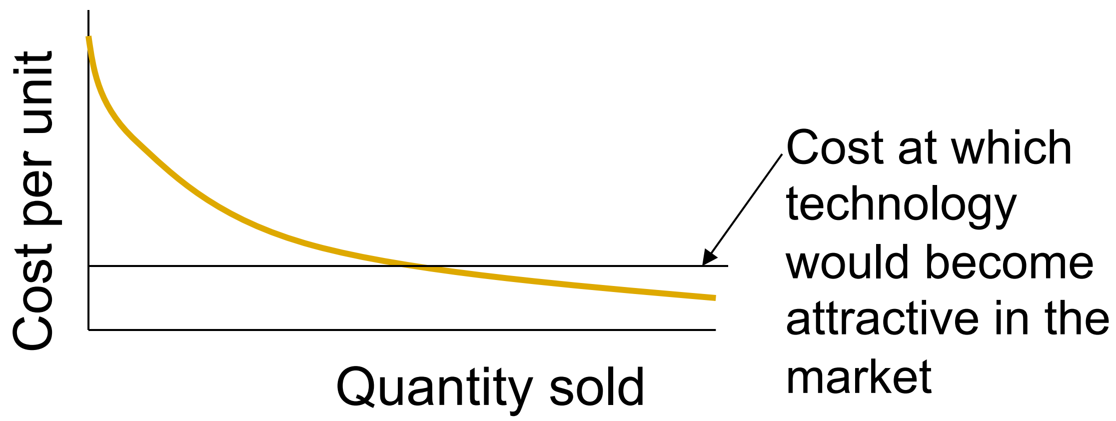


So, if the technology is socially desirable, there may be a case to subsidize early deployment to "get down the curve."

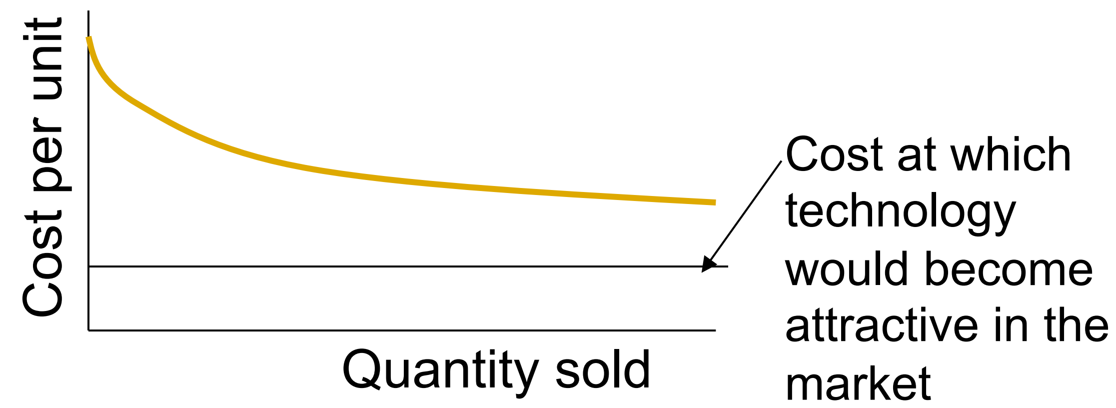
BUT again, be careful…

The technical details matter

In some cases, technical assessment suggests that for large enough Q, the technology will become competitive…



BUT…in other cases, assessment suggests it will never get there.



Wind *versus* Solar PV

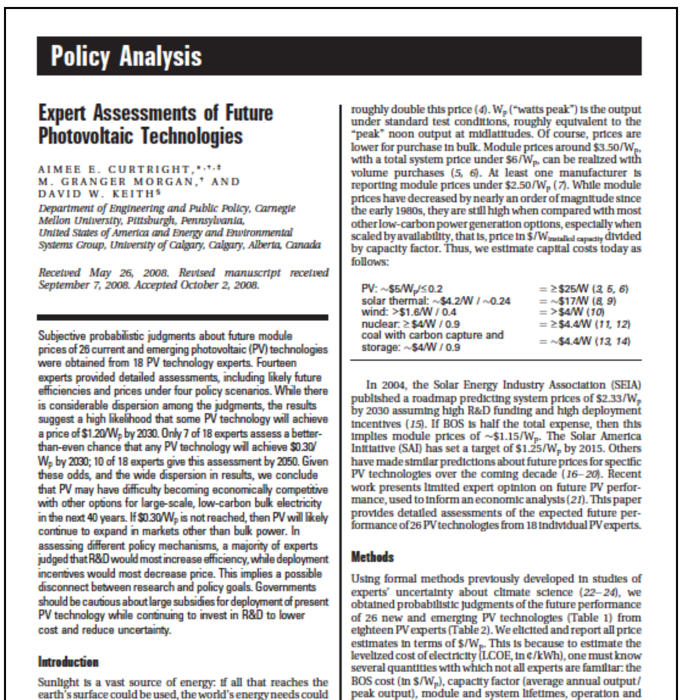
In my view, over the past couple of decades, wind was in that first category, solar PV was probably not.

For wind it was a matter of transferring and integrating a number of existing technologies:

Photo sources: Conrail, www.acronautic.com, CivilDB

BUT, if what you care about is affordable electricity, this has not been the case for current generation PV. For that we should be investing in R&D not promoting deployment.

Aimee Curtright, M. Granger Morgan and David Keith, "Expert Assessment of Future Photovoltaic Technology," *Environmental Science & Technology*, 42(24), 2008.



Policy Analysis

Expert Assessments of Future Photovoltaic Technologies

AIMEE E. CURTRIGHT,[*,†,‡]
M. GRANGER MORGAN,[†] AND
DAVID W. KEITH[§]
Department of Engineering and Public Policy, Carnegie Mellon University, Pittsburgh, Pennsylvania, United States of America and Energy and Environmental Systems Group, University of Calgary, Calgary, Alberta, Canada

Received May 26, 2008. Revised manuscript received September 7, 2008. Accepted October 2, 2008.

Subjective probabilistic judgments about future module prices of 26 current and emerging photovoltaic (PV) technologies were obtained from 18 PV technology experts. Fourteen experts provided detailed assessments, including likely future efficiencies and prices under four policy scenarios. While there is considerable dispersion among the judgments, the results suggest a high likelihood that some PV technology will achieve a price of \$1.20/W_p by 2030. Only 7 of 18 experts assess a better-than-even chance that any PV technology will achieve \$0.30/W_p by 2030; 10 of 18 experts give this assessment by 2050. Given these odds, and the wide dispersion in results, we conclude that PV may have difficulty becoming economically competitive with other options for large-scale, low-carbon bulk electricity in the next 40 years. If \$0.30/W_p is not reached, then PV will likely continue to expand in markets other than bulk power. In assessing different policy mechanisms, a majority of experts judged that R&D would most increase efficiency, while deployment incentives would most decrease price. This implies a possible disconnect between research and policy goals. Governments should be cautious about large subsidies for deployment of present PV technology while continuing to invest in R&D to lower cost and reduce uncertainty.

Introduction

Sunlight is a vast source of energy: if all that reaches the earth's surface could be used, the world's energy needs could

roughly double this price (*4*). W_p ("watts peak") is the output under standard test conditions, roughly equivalent to the "peak" noon output at midlatitudes. Of course, prices are lower for purchase in bulk. Module prices around \$3.50/W_p, with a total system price under \$6/W_p, can be realized with volume purchases (*5, 6*). At least one manufacturer is reporting module prices under \$2.50/W_p (*7*). While module prices have decreased by nearly an order of magnitude since the early 1980s, they are still high when compared with most other low-carbon power generation options, especially when scaled by availability, that is, price in \$/$W_{installed\ capacity}$ divided by capacity factor. Thus, we estimate capital costs today as follows:

PV: ~\$5/W_p/≤0.2	= ≥\$25/W (*3, 5, 6*)
solar thermal: ~\$4.2/W / ~0.24	= ~\$17/W (*8, 9*)
wind: >\$1.6/W / 0.4	= >\$4/W (*10*)
nuclear: ≥\$4/W / 0.9	= ≥\$4.4/W (*11, 12*)
coal with carbon capture and storage: ~\$4/W / 0.9	= ~\$4.4/W (*13, 14*)

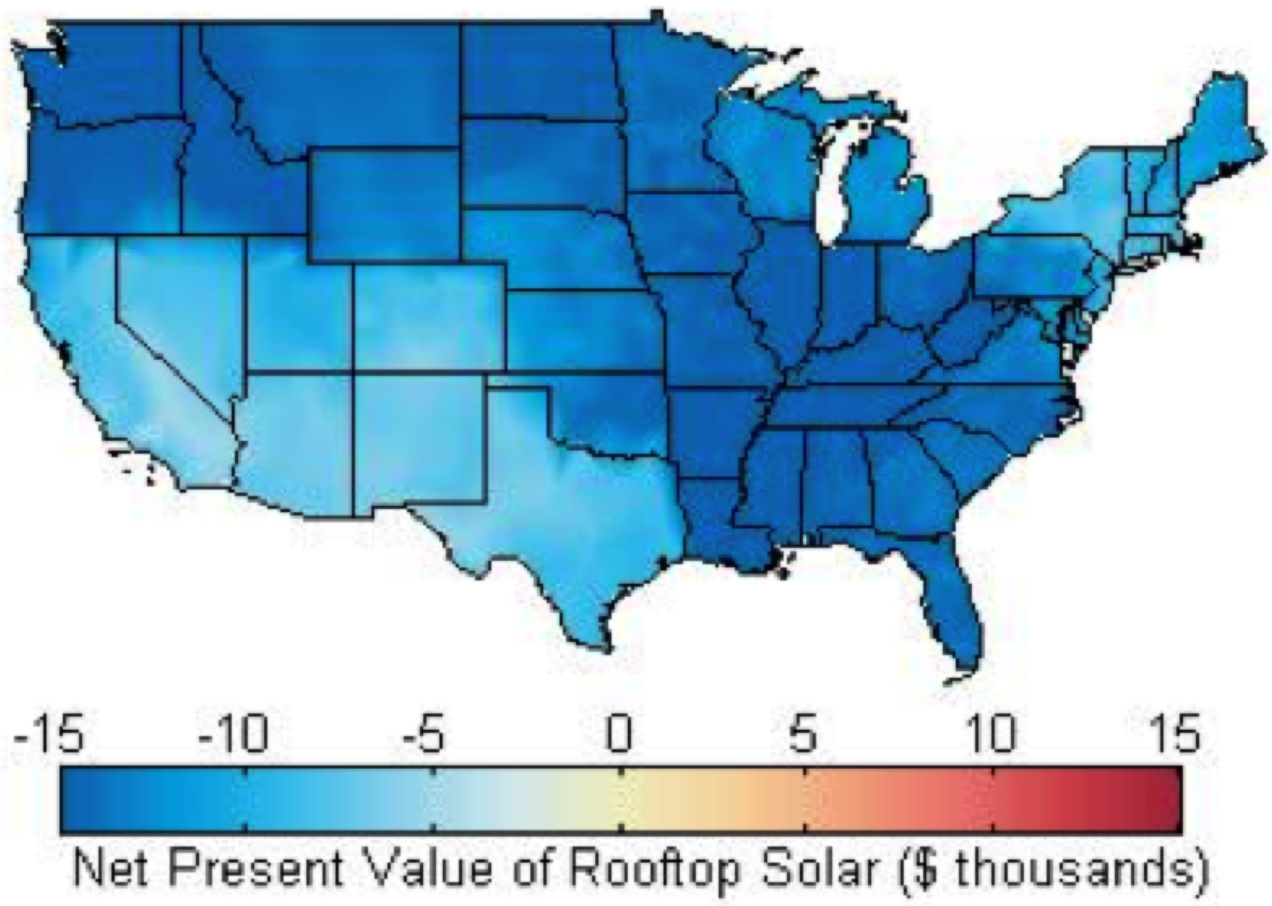
In 2004, the Solar Energy Industry Association (SEIA) published a roadmap predicting system prices of \$2.33/W_p by 2030 assuming high R&D funding and high deployment incentives (*15*). If BOS is half the total expense, then this implies module prices of ~\$1.15/W_p. The Solar America Initiative (SAI) has set a target of \$1.25/W_p by 2015. Others have made similar predictions about future prices for specific PV technologies over the coming decade (*16–20*). Recent work presents limited expert opinion on future PV performance, used to inform an economic analysis (*21*). This paper provides detailed assessments of the expected future performance of 26 PV technologies from 18 individual PV experts.

Methods

Using formal methods previously developed in studies of experts' uncertainty about climate science (*22–24*), we obtained probabilistic judgments of the future performance of 26 new and emerging PV technologies (Table 1) from eighteen PV experts (Table 2). We elicited and report all price estimates in terms of \$/W_p. This is because to estimate the levelized cost of electricity (LCOE, in ¢/kWh), one must know several quantities with which not all experts are familiar: the BOS cost (in \$/W_p), capacity factor (average annual output/peak output), module and system lifetimes, operation and

A paper about to go to *Energy Policy*

Shelly Hagerman, Paulina Jaramillo, Granger Morgan, "What is 'Socket' Parity and is Rooftop Solar PV There Yet Without Subsidies?"



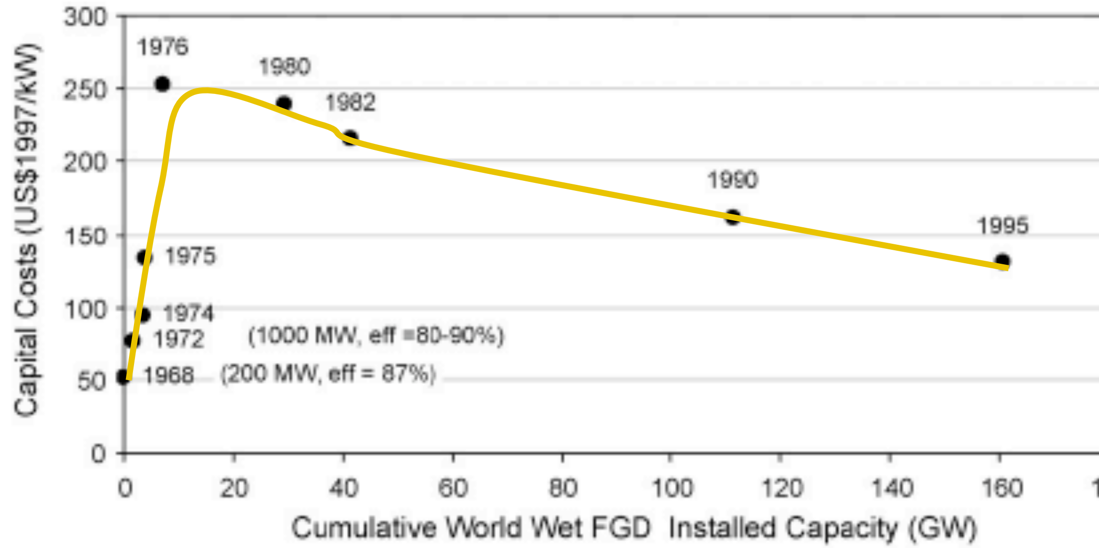
And…think about *what* technology to focus on

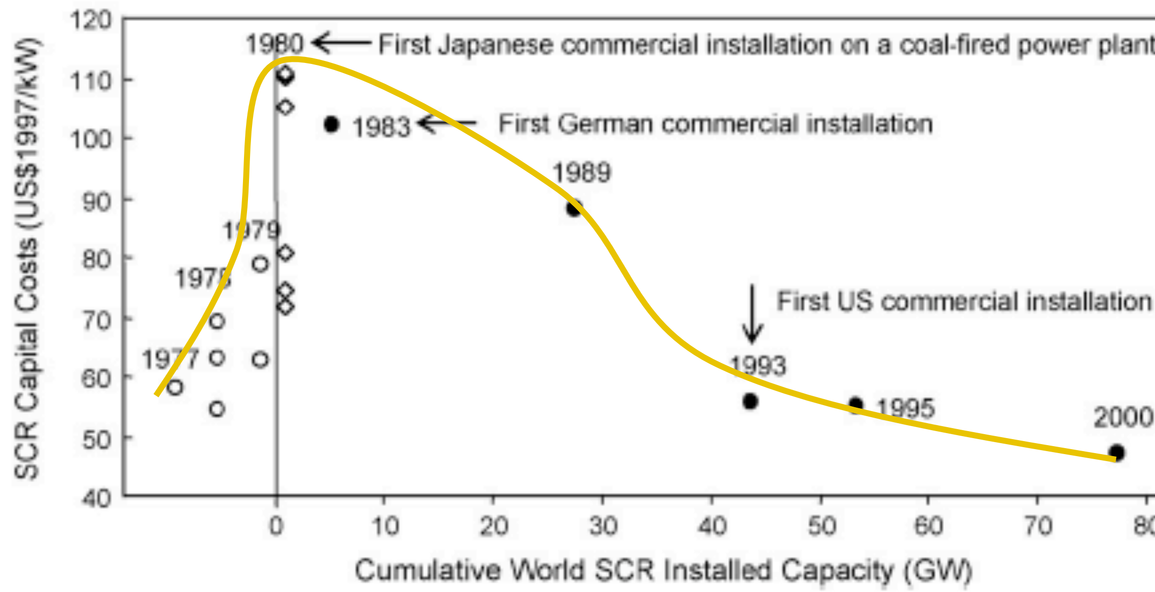
I think a strong argument can be made that solid state power electronics is as or more important as solar cells.

Power electronics plays a key role in determining the cost of many other energy technologies (e.g. transmission, storage, and end use) as well as PV.

Learning curves don't just go down

In the case of both SO_2 scrubber technology and in the case of NOx control technology, my colleague Ed Rubin and his co-workers show that costs rose significantly after problems were encountered with the design and performance of the first few plants.





Source: Rubin et al., IJGGC, 2007.

3. Many people do not realize…

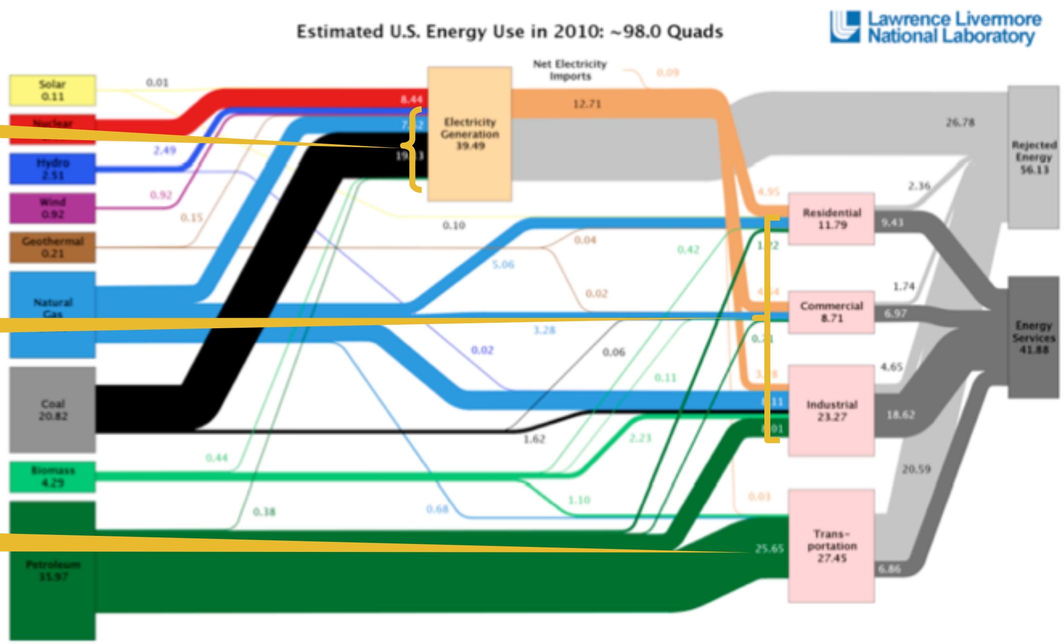
…just how major a transformation is involved in decarbonizing the energy system. I will illustrate with the the U.S., but the challenge is even greater for China.

Fossil fuel to:

Electricity

Heat

Transportation

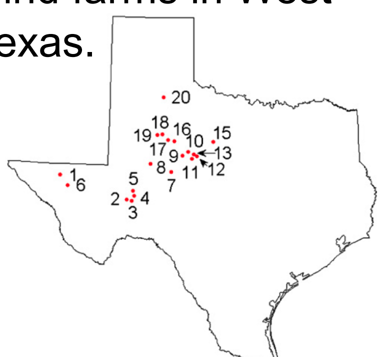


Producing 1×10^{12} kWhr would require roughly:

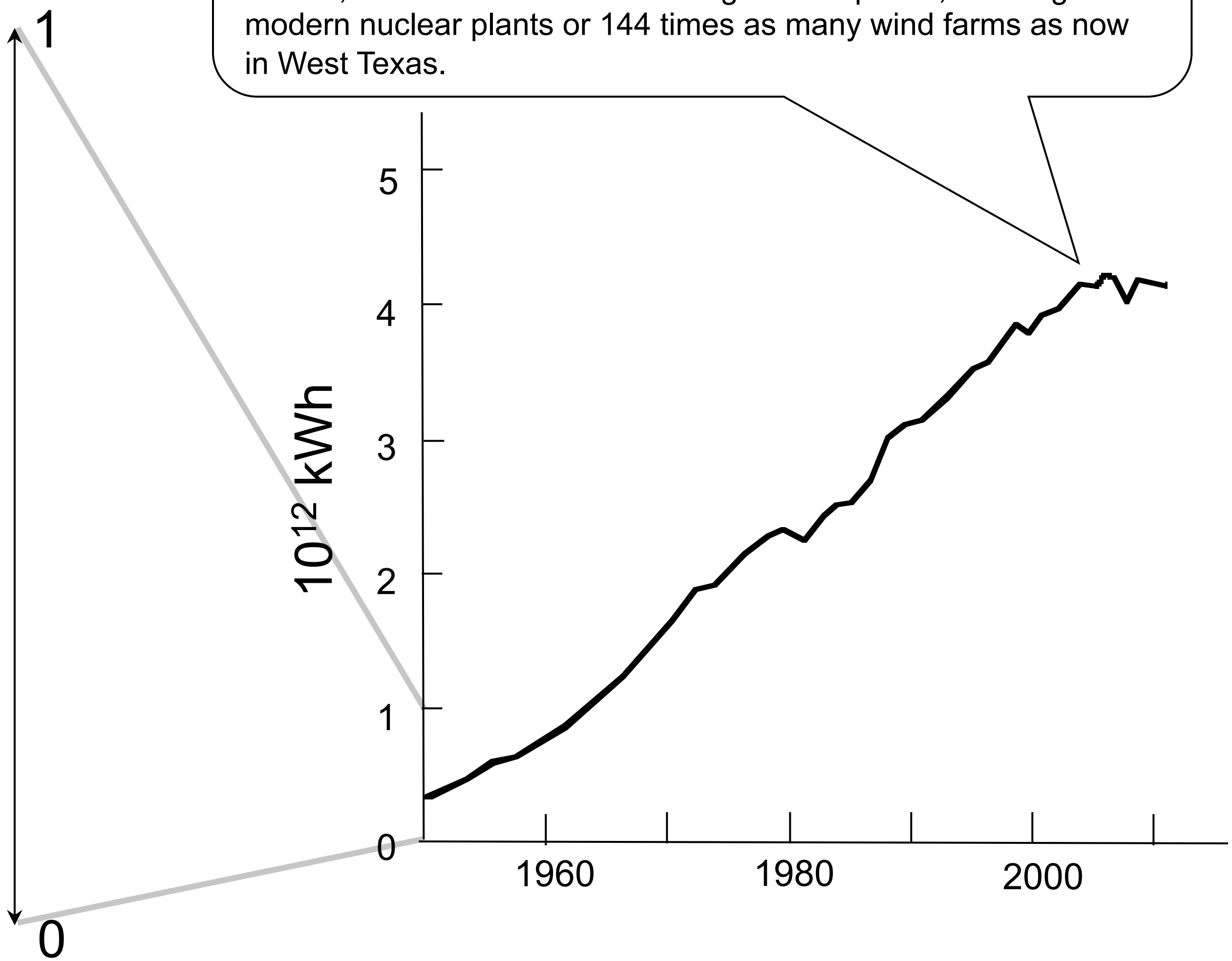
60 large coal plants like this one:

Or 120 of the newest nuclear power plants like this one:

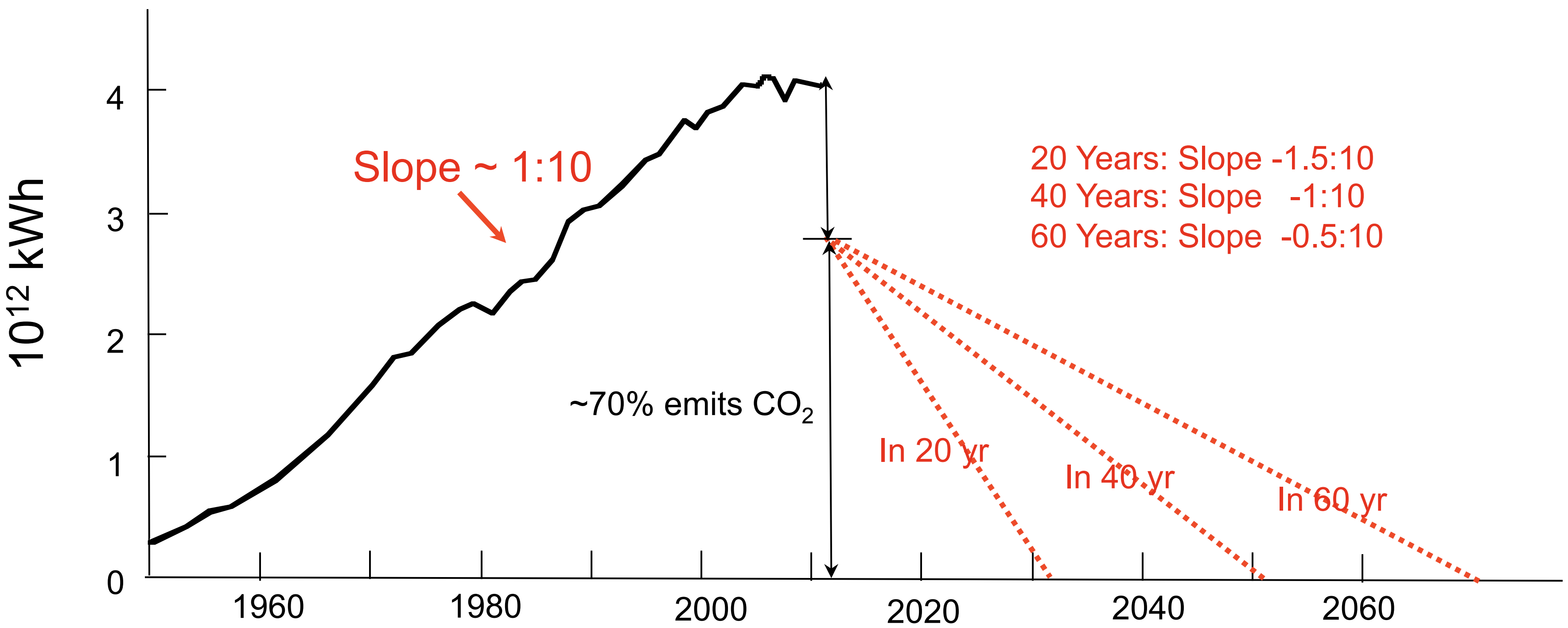
Or 36 times as many wind farms as twenty wind farms in West Texas.



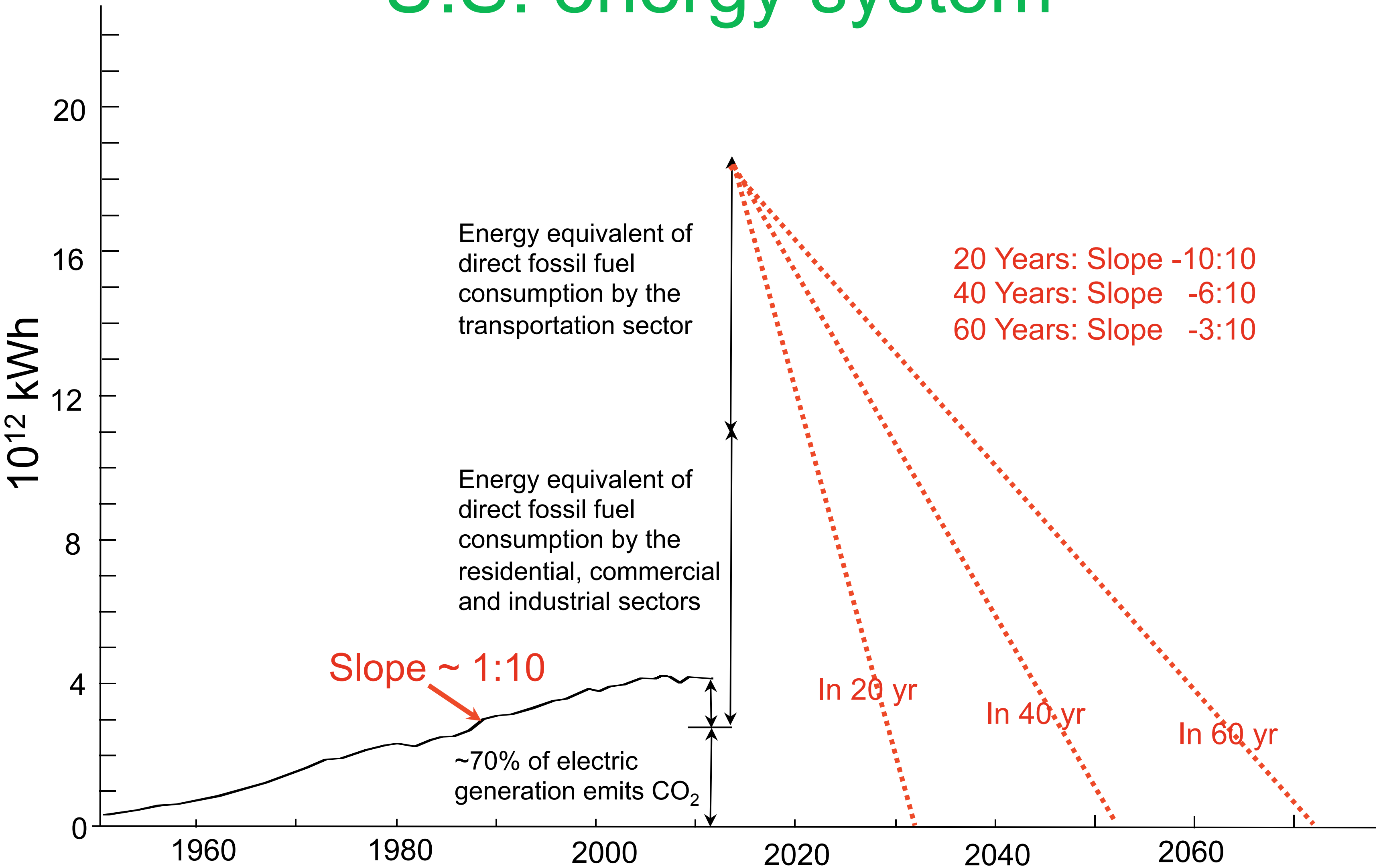
Today's U.S. power system involves a broad portfolio of generation technologies, However, if all of the 4×10^{12} kWh were (and could be) done with one of the three technologies shown to the left, it would take 240 of the largest coal plants, 480 large modern nuclear plants or 144 times as many wind farms as now in West Texas.



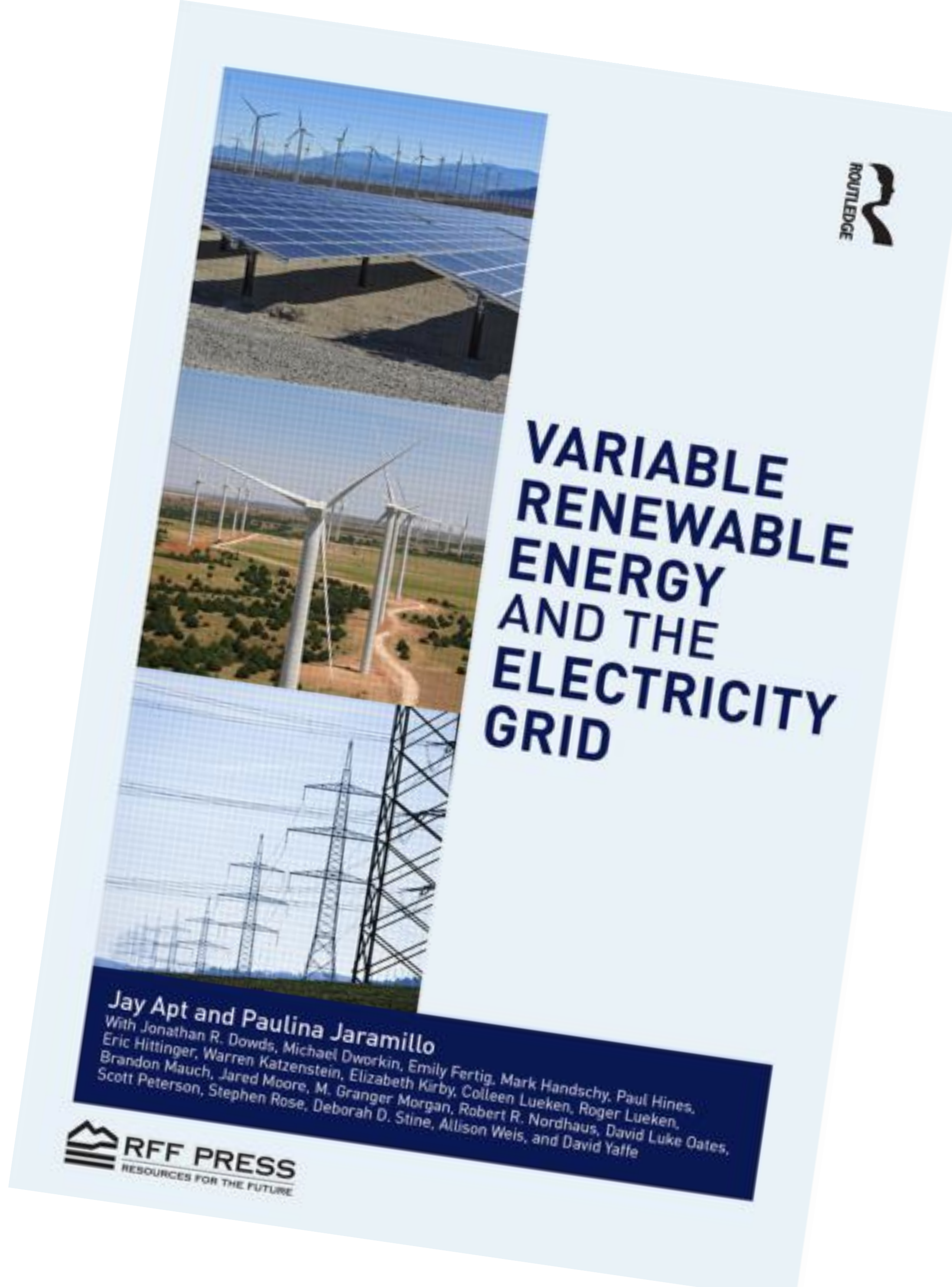
Decarbonizing *just* U.S. electricity



Decarbonizing *the entire* U.S. energy system



Finally… this just out through RFF Press



Thanks

Portions of the work reported have been supported by grants from the National Science Foundation (NSF) and the Electric Power Research Institute. Most recent support has been under NSF Cooperative Agreements SES-0345798 and SES-0949710.