



PrimeStar Solar
Making It Happen



Solar Grand Plan

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- **A Proper Skepticism, but...**
- **120,000 terawatts of power**
 - **“The only big number out there” (Lewis and Smalley)**
 - **Solution to CO₂ build up**
- **Nearly economical approaches in comparison to traditional energy sources (which themselves are getting more costly)**
- **Distributed availability instead of geographic concentration**
 - **Reduced global tensions**
 - **Increased local jobs**

But...

- **Intermittency**
- **Cost**
- **Transportation?**
- **Solar NIMBY!**
 - **Transmission Lines**
 - **Large Arrays**
 - **Roofs**

- **Scientific American, January 2008, Grand Solar Plan**
 - **Zweibel, Mason, Fthenakis**
 - **<http://www.sciam.com/article.cfm?id=a-solar-grand-plan>**

- **What is a “Grand Plan” (besides possibly being pretentious)?**
 - **Addresses both climate change and energy availability**
 - **Has reasonable level of practicality – definitely not blue sky (or outer space)**
 - **Economically and technically feasible**
 - **Passes laugh test**

- **Nuclear**
- **Carbon sequestration**
- **Solar (and renewables)**
- **Hybrid combinations**
- **“Business as usual” (in China and India)**
 - **Which means, burn a lot of coal, build some nuclear plants, look to new hydrocarbons like oil shale and tar sands, do some renewables, try to save more energy, and produce a lot of CO₂**

- Southwest has a significant amount of *reliable* sunlight
- Amount of sunlight is large enough to offset transmission losses to other continental locations
- Other locations have greater land use value
 - And may be better for biomass and wind
- Solar on rooftops, parking lots, etc., can make a good contribution, but more like the “10%” level than the “100%” level

- **Economical Solar**
 - PV and CSP
 - Mostly from the southwest (great sunlight)
- **Economical Storage**
 - Compressed air energy storage (CAES)
 - Thermal
- **Electric Distribution**
 - High voltage DC
- **Hybrid Vehicles for Transportation**
 - 80% electric, 20% fuel for distance
- **Wind, geothermal, geothermal (solar) heat pumps, solar hot water, energy efficiency, biomass for fuel and for gasification into hydrogen, solar electrolytic hydrogen**

- **Direct conversion of sunlight into DC electricity**
- **Cookie-cutter systems of any size – MWs to GWs, with little price impact**
- **Thin film cadmium telluride (CdTe) first successful thin film in the sense of achieving the lowest system prices**
 - **First Solar with various system integrators installing at about \$4/Wp (fixed flat plate large, ground-mounted systems)**
 - **Equivalent to about 15 ¢/kWh in US Southwest location (30 year levelized)**
 - **Technical roadmap to \$2/Wp installed (8 ¢/kWh)**
 - **Potential for even lower price, in fullness of resources (time and money)**
 - **Other PV technologies trailing but fighting for competitive success**
- **Intermittent daytime electricity “feedstock”**
- **New Paradigm: High capital, negligible O&M, possible 60-year life**

Inside a CdTe PV Factory



First Solar, Perrysburg, OH

CdTe 2-MW Array at Ft Carson, CO



- **Troughs proven and being installed**
- **Large systems to be cost-effective**
- **Requires desert location, dependent on direct sunlight for concentration**
- **Heats fluid, produces steam, turns turbine, makes electricity**
- **Versatile: Can be combined with thermal storage and natural gas fuel**
- **Higher O&M than PV, shorter intrinsic durability**
- **Similar economics to PV for desert locations (horse race)**

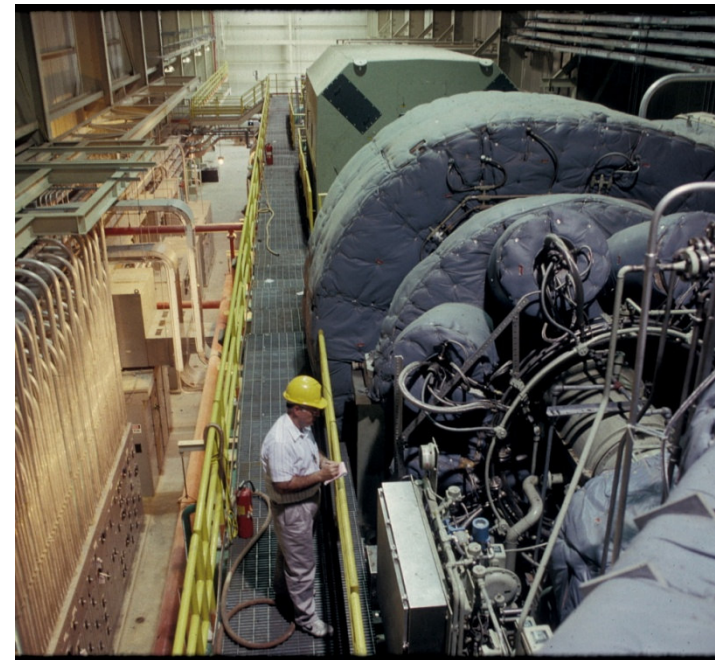
Nevada Solar One 64-MW



- **Location in US SW requires long distance transmission**
- **High voltage DC has significantly lower losses than AC transmission**
 - **PV is DC (avoids inverter cost)**
- **Orders of magnitude more lines and corridors needed than today**
 - **Another huge capital investment**
 - **NIMBY**
 - **Is SOLAR(N~N)IMBY possible???**

- **Proven technology – several existing facilities**
- **Pump air underground during day**
- **Store enough to smooth electricity & at night and in winter**
- **Distributed on the way to demand centers at the end of HVDC lines**
- **Caverns similar to those now used for storing natural gas (type and size)**
- **Turbines to extract energy**
- **Natural gas added to avoid ice formation in expanding air**
- **One of very few storage methods with good economics and necessary size**
 - **Turn around efficiency on solar electric about 75%**
 - **Good capital costs**

McIntosh, Alabama CAES power plant compressed air well-head for the turbo-train and the gas turbine power plant



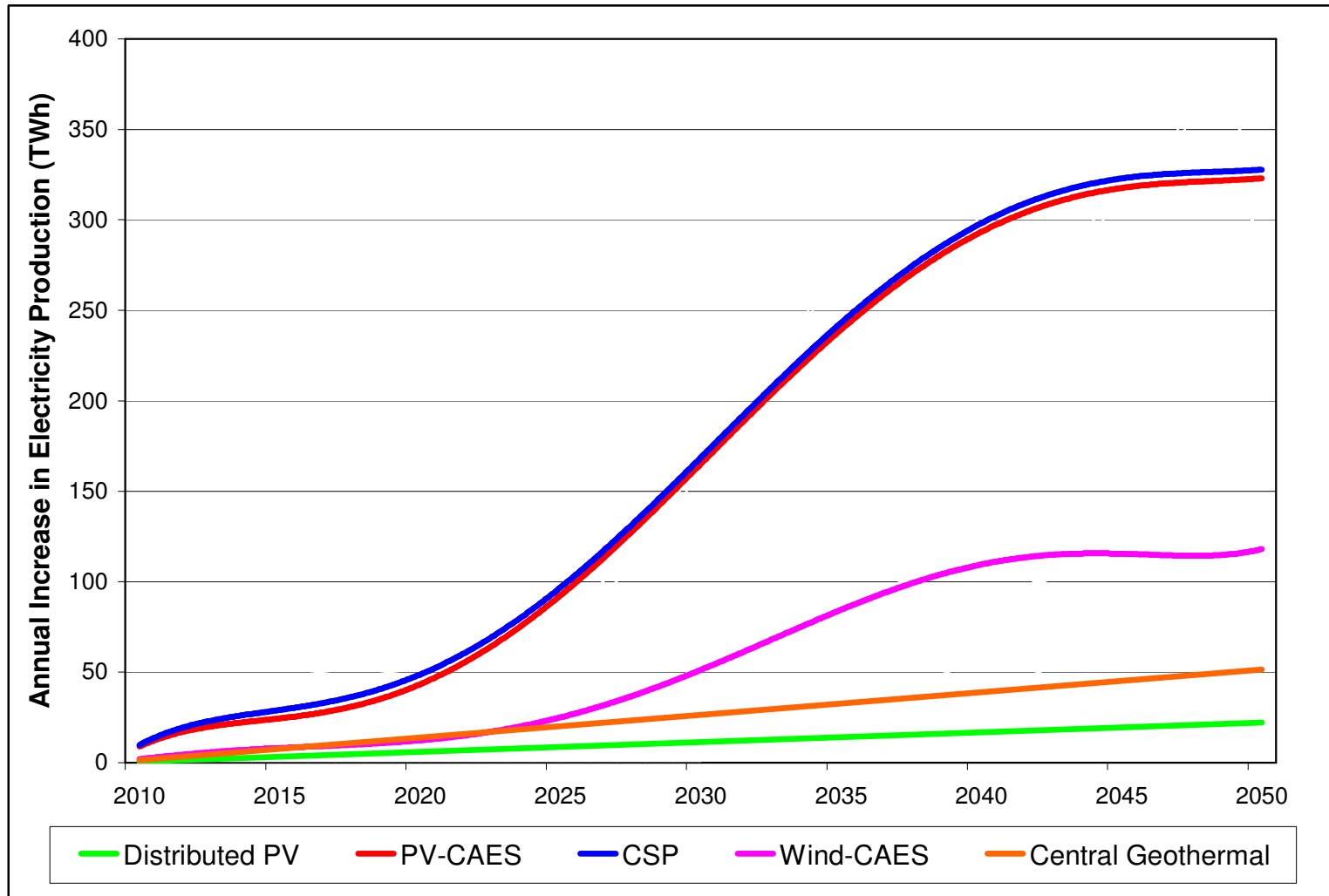
Alabama Electric Cooperative, owners and operators of the McIntosh, Alabama CAES plant

- **Easy to store volumes of heat with low losses**
- **Prior to conversion, so not storing converted energy (saves turnaround costs)**
- **Heat and heat conversion is part of the CSP system**
- **Economical to store a few hours, firming peaking power output**
- **More challenges with longer term storage using higher-temperature materials like molten salt**
- **Can easily integrate natural gas as secondary source of heat for steam turbines**

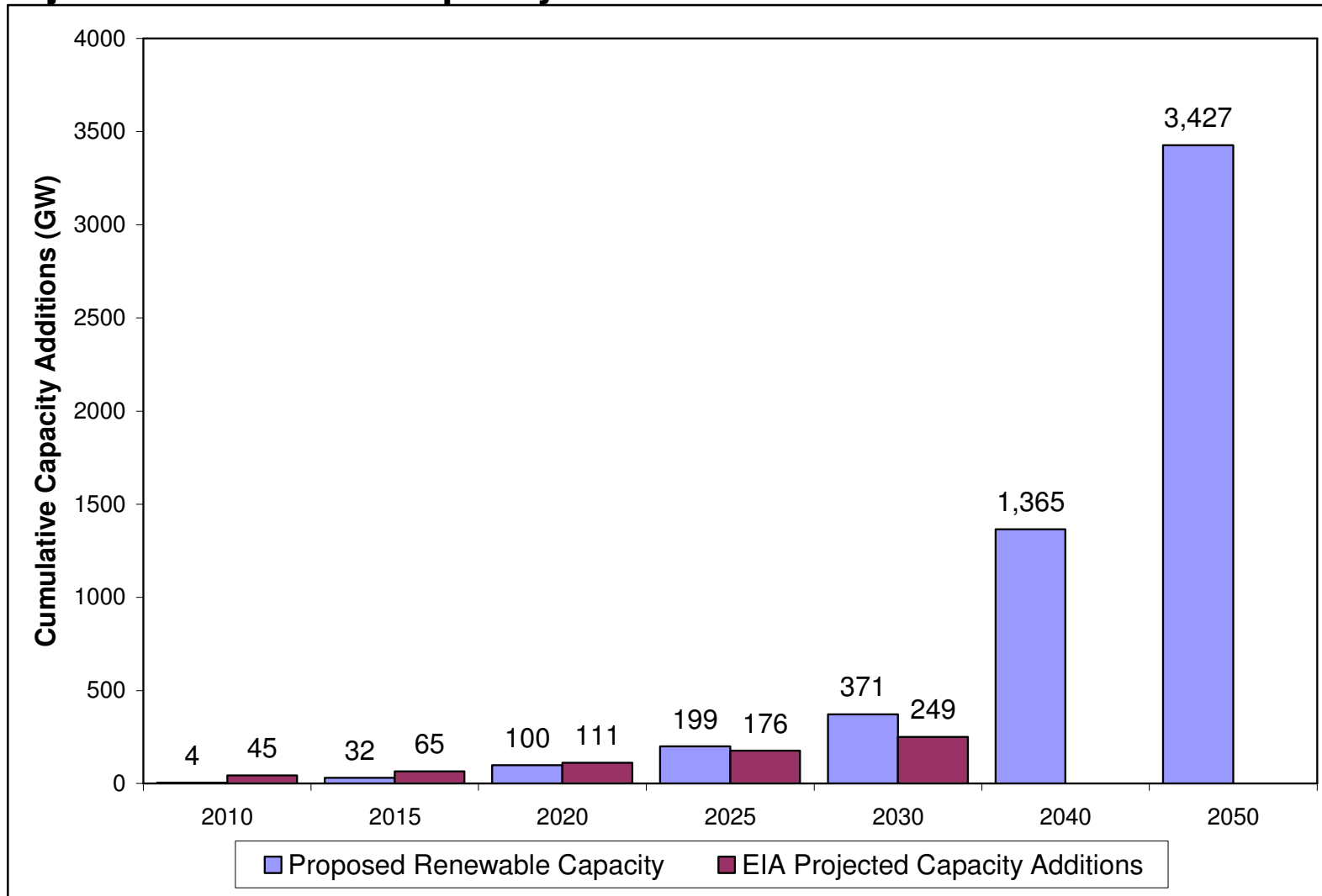
- **Path to converting to an electricity-based transportation system**
- **Need about 80% electricity, 20% fuel vehicle to offset CO₂ and fuel issues**
 - **Electricity for commuting, fuel for range extension**
 - **Need renewables as source of electricity**
- **Technical challenges**
- **Plug-in-specific issues**
- **Opportunity for US car companies???**

- **Other renewables critical to filling out the portfolio**
- **Wind at night and in winter**
 - **Wind CAES**
- **Distributed PV**
 - **Roofs, parking lots, small fields**
- **Biomass fuels for vehicles and CAES**
 - **Cellulosic ethanol**
 - **Gasified biomass, methane and hydrogen**
- **Eventually, PV hydrogen for vehicles and CAES**

Annual Increases (TWh)



Cumulative renewable energy capacity additions (GW) with EIA projected cumulative capacity additions



	2015	2020	2030	2050	2100
1. Concentrating Solar Plants (GW)^b					
a. Peak CSP Plants (GW)	9	28	90	1,130	2,790
b. Base Load CSP Plants (GW)	0	0	28	374	1,320
2. PV Compressed Air Energy Storage Plants (GW)^c					
a. Peak CAES Plants (GW)	9	28	90	880	3,484
* PV for Peak CAES Plants (GW) ^d	(12)	(40)	(130)	(1,280)	(5,067)
b. Base Load CAES Plants (GW)	0	0	28	307	1,234
* PV for Base Load CAES Plants (GW) ^d	(0)	(0)	(110)	(1,266)	(5,090)
3. Distributed PV Capacity (GW)	3	6	11	258	1,258
2. Wind Compressed Air Energy Storage Plants (GW)^e	4	11	47	279	400
* Wind Capacity for CAES Plants (GW) ^f	(9)	(28)	(118)	(698)	(1,000)
5. Central Geothermal Power Plants (GW)	9	28	78	200	200
Total Renewable Power Plant Capacity (GW)	34	101	372	3,428	10,686
6. EIA/DOE Projected Capacity Additions (GW)	65	111	249		

- **21st Century Demand: *Super-Sized* Energy**
- **Get used to land areas and NIMBY issues orders of magnitude beyond current concepts, no matter *what* energy source is involved**
 - **Exchange “IMBY” for unaffordable foreign trade imbalances, exported jobs, and CO₂ emissions**
- **2050: about 50,000 square miles of solar devoted to 35% of our total *energy* needs (70% of our electricity)**
- **2100: 165,000 square miles, essentially *all* of our expanded energy needs**
- **Hundreds of thousand of miles of individual HVDC distribution cables**
- **Massive reduction in CO₂ emissions versus even today’s levels**

- **Most aggregate world regions have similar solar availability, constrained by political challenges**
- **China and India have great solar**
- **Africa has great solar**
- **Northern Mexico is as good as the US SW**
- **Some regions need more help from wind**
- **Biomass will always be constrained and must be treated as a valuable niche product, e.g., as a liquid or gaseous fuel**
- **We believe that the Plan's economics will actually meet and surpass conventional prices and our demonstration of it will catalyze worldwide adoption**
 - **At minimum, it will cap the price of conventional energy**

- **Initial incentives for PV, CSP, CAES, and thermal storage**
- **Regulatory adjustment**
 - **Minimize property tax and insurance**
 - **Financially capture long useful life (60 years +)**
 - **Converting uncertain fuel costs to certain capital costs**
 - **Access to transmission and Federal land**
- **Incentives for plug-in hybrids**
 - **Electrify transportation**
- **Can be done incrementally, with interim assessments**