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An Economic Analysis of Photovoltaics versus Traditional Energy Sources: Where are We Now and Where Might We Be in the Near Future?

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Strategic Energy Analysis Center and [2]Electric Vehicles Program
The National Renewable Energy Laboratory

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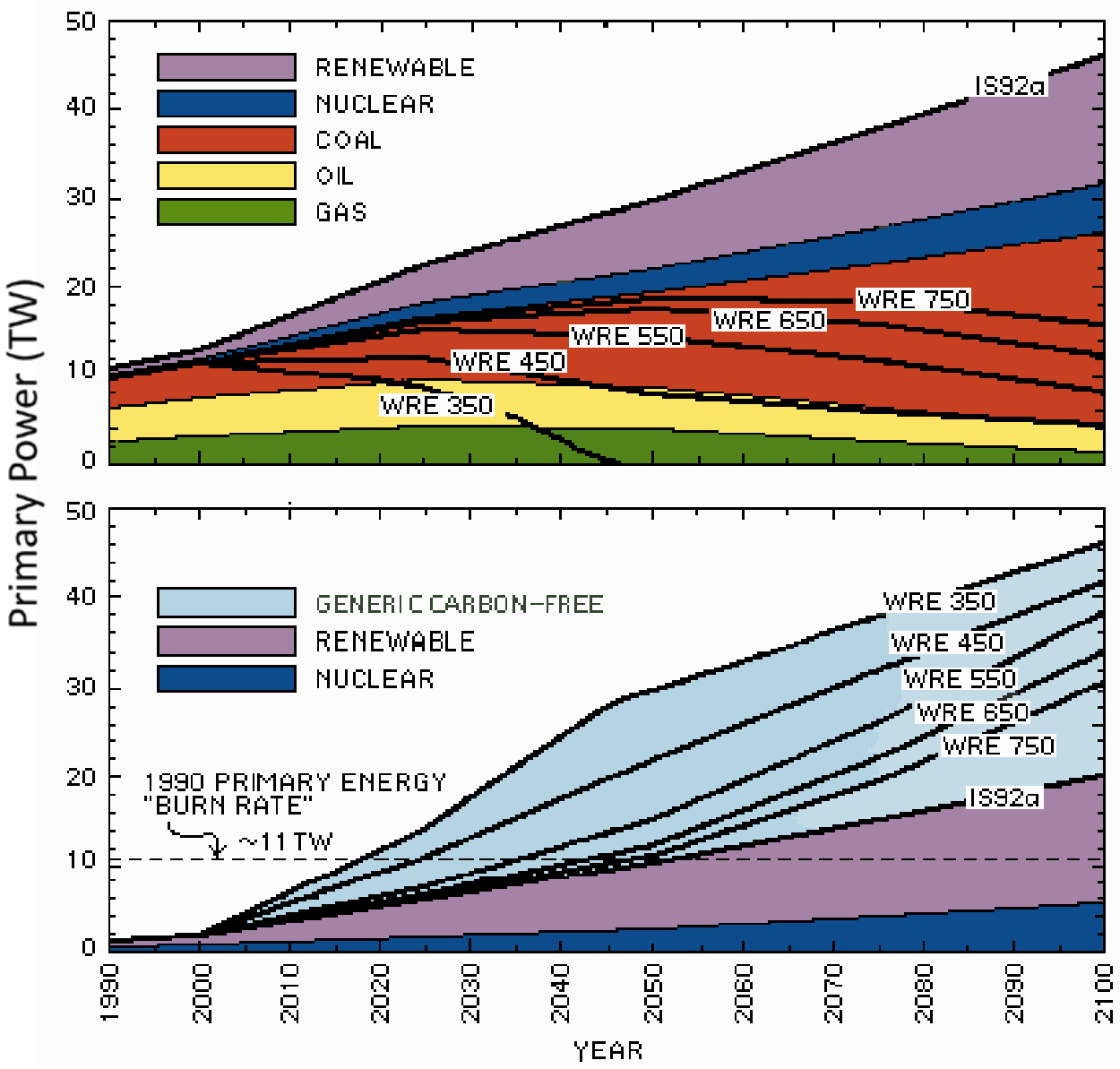
Overview: The Need for a Low Carbon Energy Future



*M. I. Hoffert et. al., Nature, **1998**, 395, 881*

Projected Trends in Primary Power Consumption:
≈15 TW in 2004; ≈30 TW in 2050

Pre-Industrial CO_2 concentration:
280 ppm

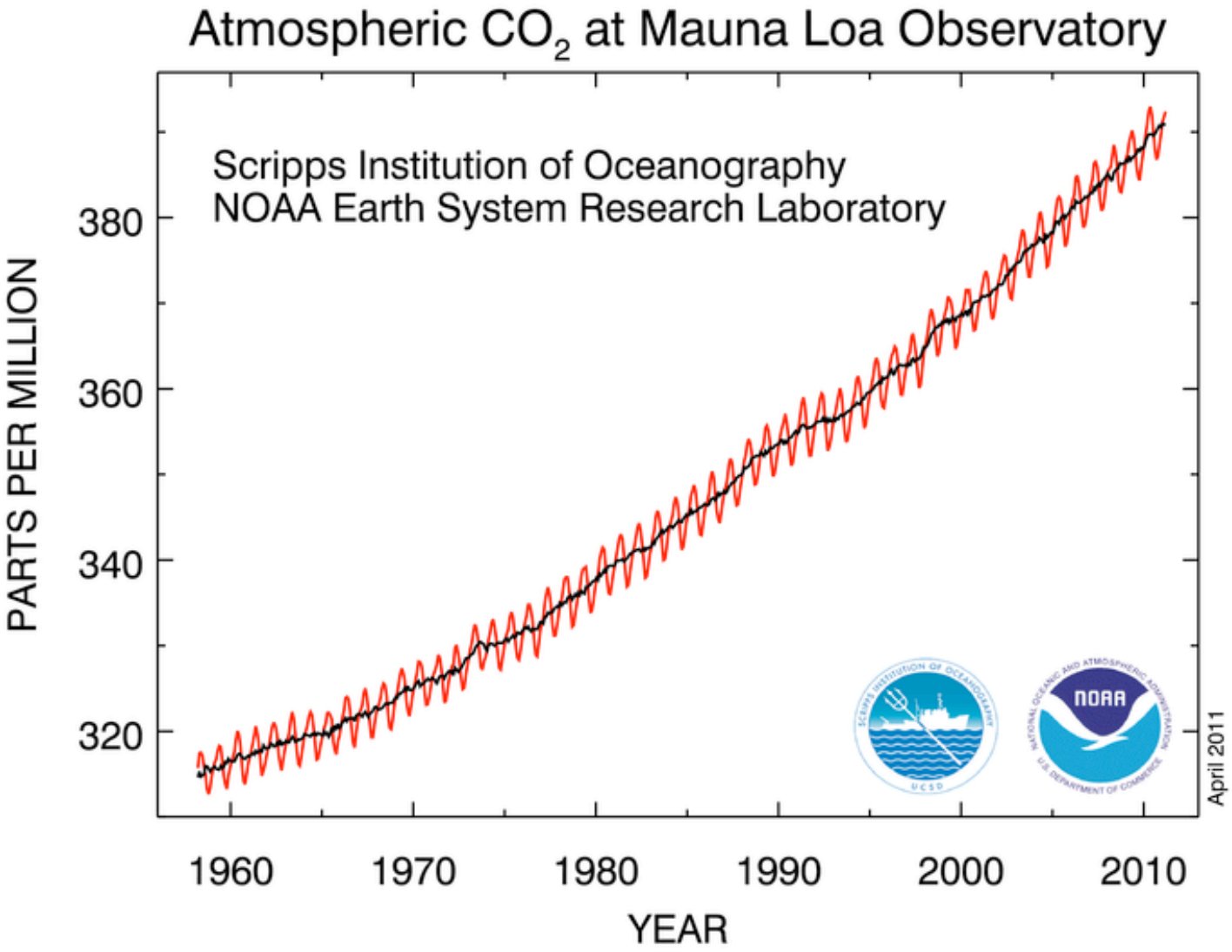
Carbon-Free Power Requirements
(including efficiency)
In 2035 to keep CO_2 <550 ppm:
≈10 TW
In 2050 to keep CO_2 <550 ppm:
A LOT!!!!

WRE= Wigley, Richels, and Edmonds

CO_2 Concentration (ppm)	Global Mean Temperature Increase Above Pre-Industrial Levels
445-490	2.0-2.4
490-535	2.4-2.8
535-590	**2.8-3.2** ('Dire Increase')
590-710	3.2-4.0
710-855	4.0-4.9
855-1130	4.9-6.1

(Table 3.5 in IPCC Fourth Assessment Report)

How Are We Doing?



Pre-Industrial CO_2 concentration: 280 ppm

Overcoming The Oil Conundrum: The *Other* Value Proposition of Renewables

	U. S. Crude Oil Trade Deficit ($ Billion)	Oil Price ($/ bbl, Weekly Averages)
2005	$180	$49
2006	$220	$60
2007	$250	$69
2008	**$340**	**$96**
2009	$190	$60
2010	$251	$81
2011 (to 5/31/11)	---	**$98**

2010 U. S. Crude Oil Trade Balance:

Imports – Exports

= $252.06 Billion – $1.32 Billion

= **50.4% of the 2010 U. S. Trade Deficit**

Data Sources:

U. S. Bureau of Economic Analysis, *U. S. International Trade in Goods and Services Reports* & DOE (EIA)

Lets Start Here: What are the costs for a PV Installation?

Materials:

- Module ($1.50 – $2.00/ W)
- Inverter (<$0.50/ W)
- Racking, Roof Mounts, Wiring, Frames, Combiner Boxes, etc.

Labor:

- Electrical and Manual

  (Varies regionally, we use RS Means)
- System Design and Engineering
- Grid Connection

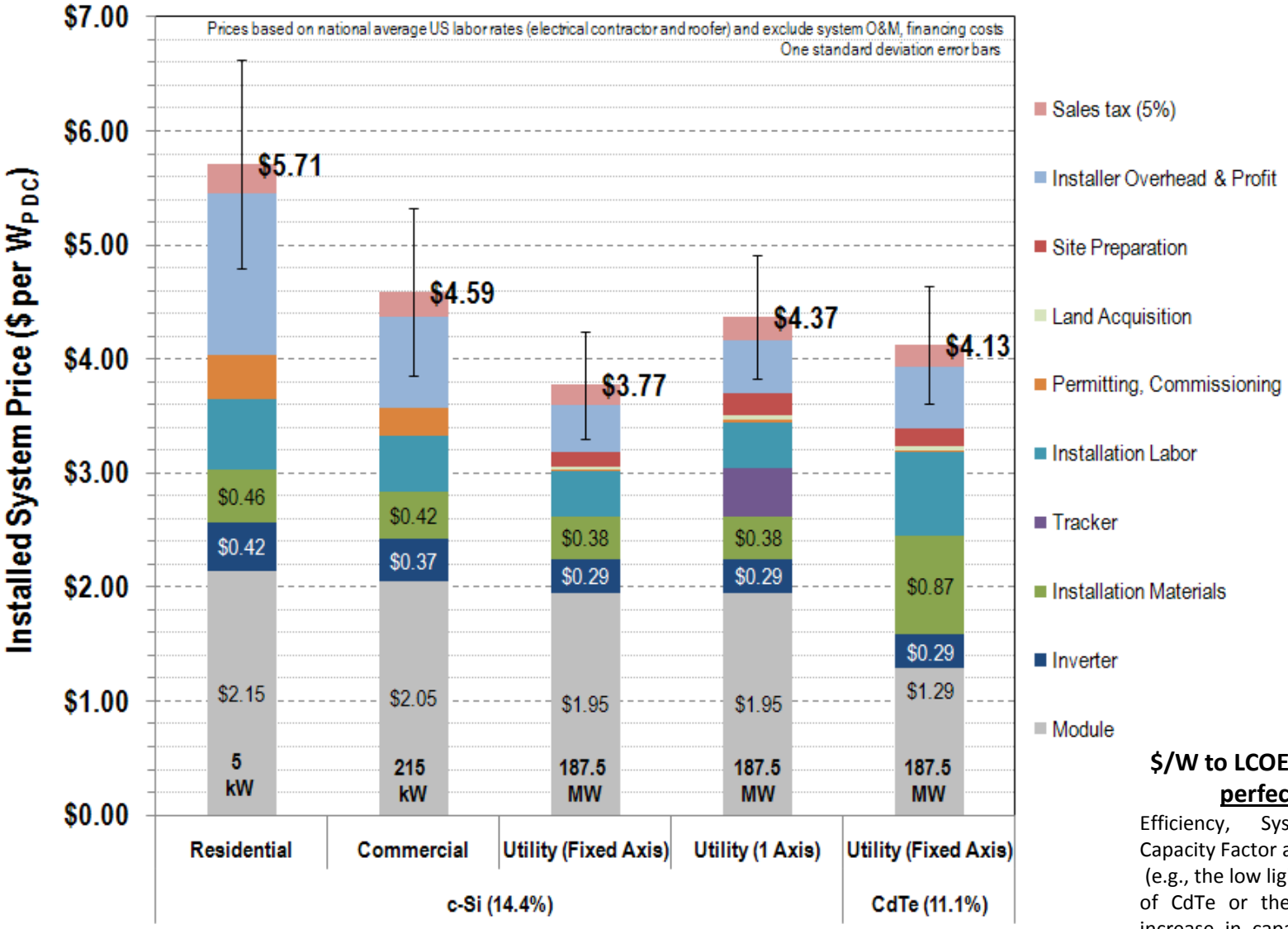
Margins:

- Manufacturing
- Distribution
- Installation

Soft Costs:

- Permitting (Estimated $500 for 5 kW)
- Sales Tax (5% in this analysis (CO))

System Costs

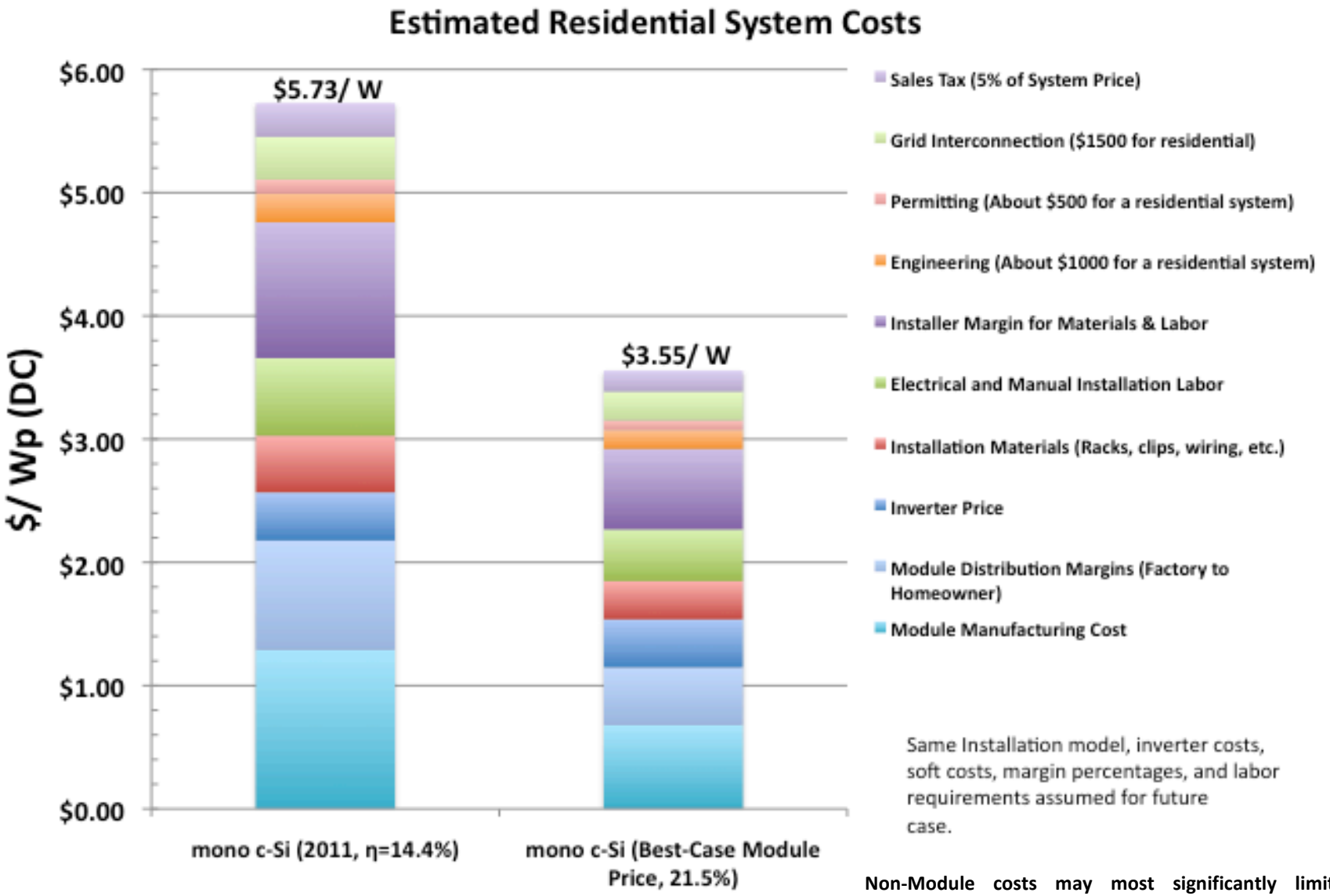


$/W to LCOE is not necessarily a <u>perfect correlation:</u>

Efficiency, System Reliability, and Capacity Factor are additional factors (e.g., the low light level efficiency benefit of CdTe or the approximately 25-30% increase in capacity factor, kWh/ kWp, for 1-axis tracking).

Goodrich, A.; Feldman, D.; James, T.; Woodhouse, M. Installed Cost of U.S.-Based Solar Photovoltaic Systems. ; NREL Report No. TP-6A20-52225.

Estimated Residential System Costs Along the c-Si Roadmap



Non-Module costs may most significantly limit the downward trajectory of system costs; reaching the SunShot $2/W residential equivalent goal will certainly require new innovations in BOS as well as modules.

Calculating The Levelized Cost of Electricity (LCOE) for PV

$$\text{LCOE (\$/ kWh)} = \frac{\text{Total Life Cycle Cost (\$)}}{\text{Total Lifetime Energy Production (kWh)}}$$

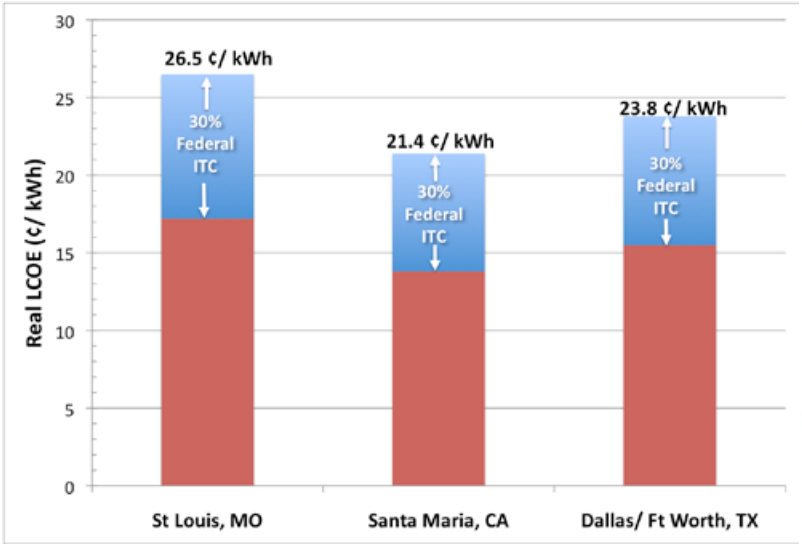
Cost — **Stability/ Reliability** — **Financing** (Standard Deductions from Tax Liability)

$$= \frac{\text{Initial Investment} + \sum_{n=1}^{N} \frac{\text{Annual O \& M Costs}_n}{(1 + \text{Discount Rate})^n} - \sum_{n=1}^{N} \frac{\text{Depreciation}_n}{(1 + \text{Discount Rate})^n} \text{x(Tax Rate)}}{\sum_{n=1}^{N} \frac{\text{Rated kWh/ kW}_p \text{ x Capacity Factor}}{(1 + \text{Discount Rate})^n} \text{x}(1 - \text{System Degradation Rate})^n}$$

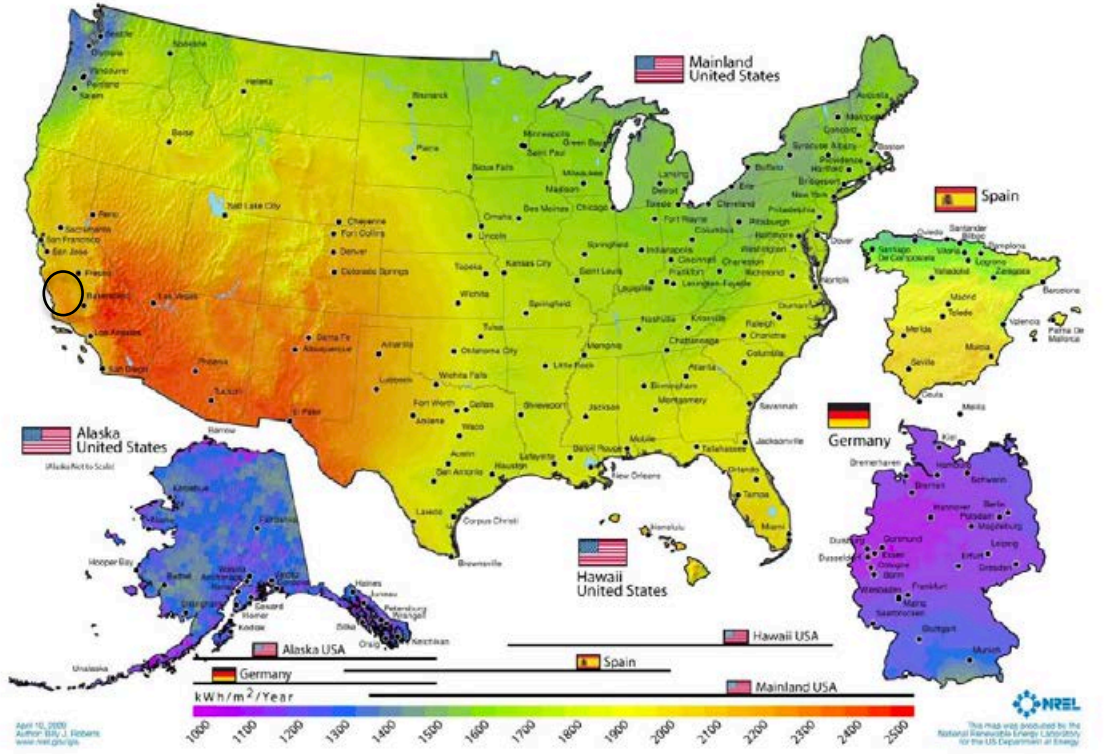
Efficiency (AND SYSTEM LOCATION)

The Estimated LCOE for the Residential System

2011 Residential PV LCOE Estimates



Assuming Same System Cost for All Locations.
LCOE Differences shown are Solely Due to Different Irradiation Levels.



$$\text{LCOE (\$/ kWh)} = \frac{\text{Total Life Cycle Cost}}{\text{Total Lifetime Energy Production}}$$

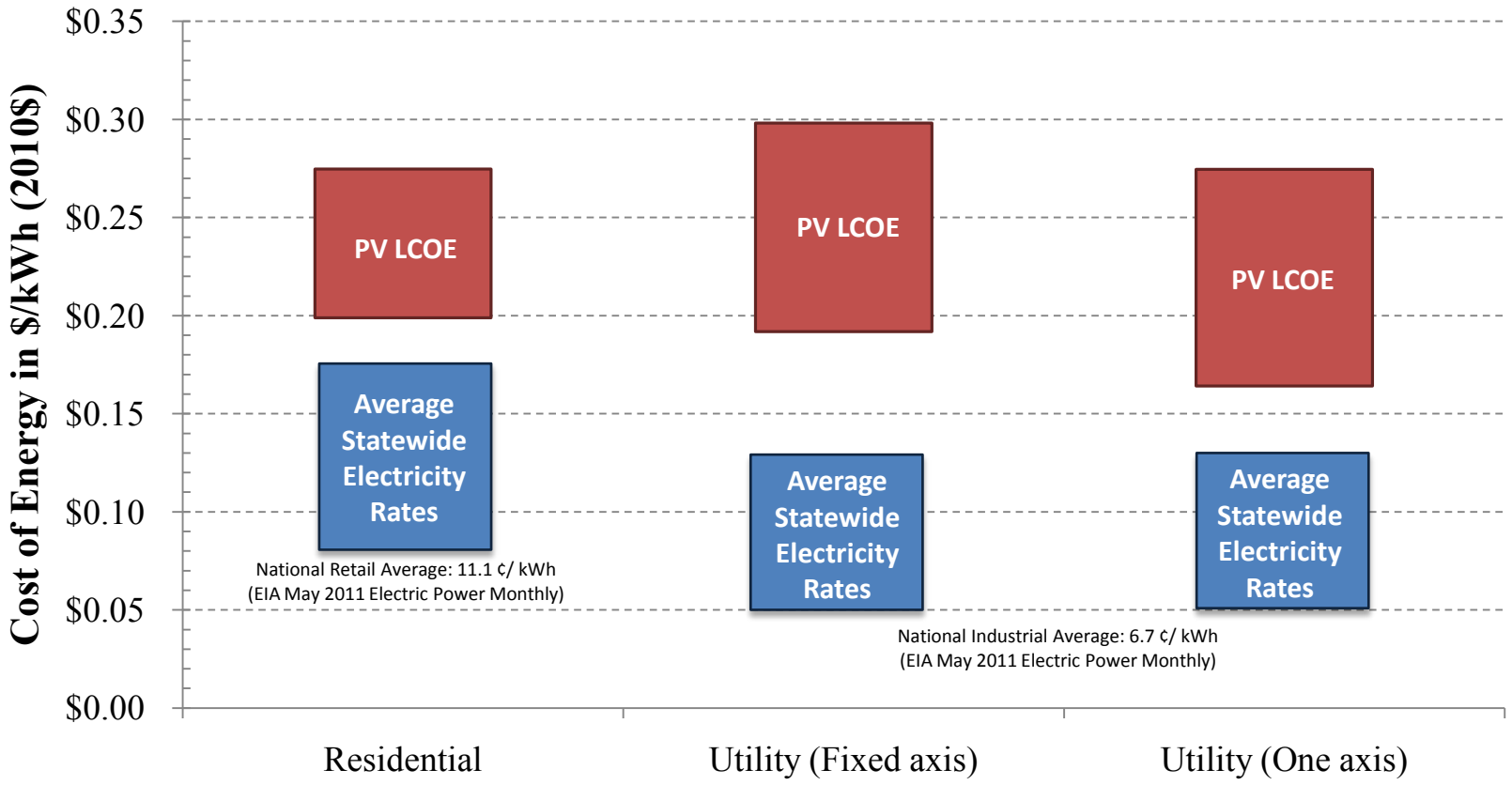
NREL Solar Advisory Model (SAM) Input Assumptions

PV System Lifetime of 30 years
Module degradation: 0.5%/yr; Temperature coefficient: -0.38%/ C

Financing assumptions (John Bartlett, formerly DOE, and David Feldman, NREL):
2.5% Inflation Rate
Mortgage Loan (80% Debt, 30 years, 7% Discount Rate)
28% Federal Tax Rate for Interest Expense Deductions
Lease (100% Cash, But Leases are not yet a SAM functionality)
35% Federal Tax Rate for 5 Year MACRS Depreciation

The LCOE for PV Against Traditional Power Rates in the U. S.: A Range of Considerations

UNsubsidized Continental U.S. Installed Solar PV System LCOE Against Current Statewide Average Electricity Rates



LCOE Assumptions:

Incentives: No federal, state, local or utility incentives are included.

Taxes: Residential PV segment assumes host ownership, therefore no taxes are paid on electricity. Mortgage payments in residential sector are tax-deductable. Utility PV Assumes IPP or IOU ownership, and thus the LCOE includes the taxes paid on the profit from electricity generated and sold. LCOE includes 5-year MACRS in the Utility PV segment.

Financing: Residential PV assumes a high financing scenario of a nominal 6% Weighted Average Capacity Cost (WACC). The low financing scenario assumes 80% of system cost is paid through a mortgage loan, with a 7% interest rate. Utility PV assumes a high financing scenario with a nominal 9.89% WACC, with a 50% debt level. The low financing scenario assumes a nominal 8.15% WACC, with a 60% debt level.

Location: LCOE calculations were performed assuming a range of solar insolation. New York and Phoenix were used as proxies.

For a complete list of LCOE assumptions, see "Levelized Cost of solar Electronic Technologies," Bartlett et. al. Publication forthcoming. Figure courtesy of David Feldman, NREL.

Let's Examine the U. S. Market Even More Closely

¢/ kWh	Missouri	California	Texas	National
Residential	8.2	15.1	11.0	11.1
Commercial	7.0	12.6	8.9	10.0
Industrial	5.4	9.7	6.1	6.7
Weighted Avg	7.3	13.0	9.1	**9.7**

Tiered Rate Structure for California's SCE and P G & E

Baseline	Tier 2	Tier 3	Tier 4
12 ¢/ kWh	0 - 30% Above Baseline 14 ¢/ kWh	31 -100% Above Baseline 29 ¢/ kWh	>100% Above Baseline 40 ¢/ kWh

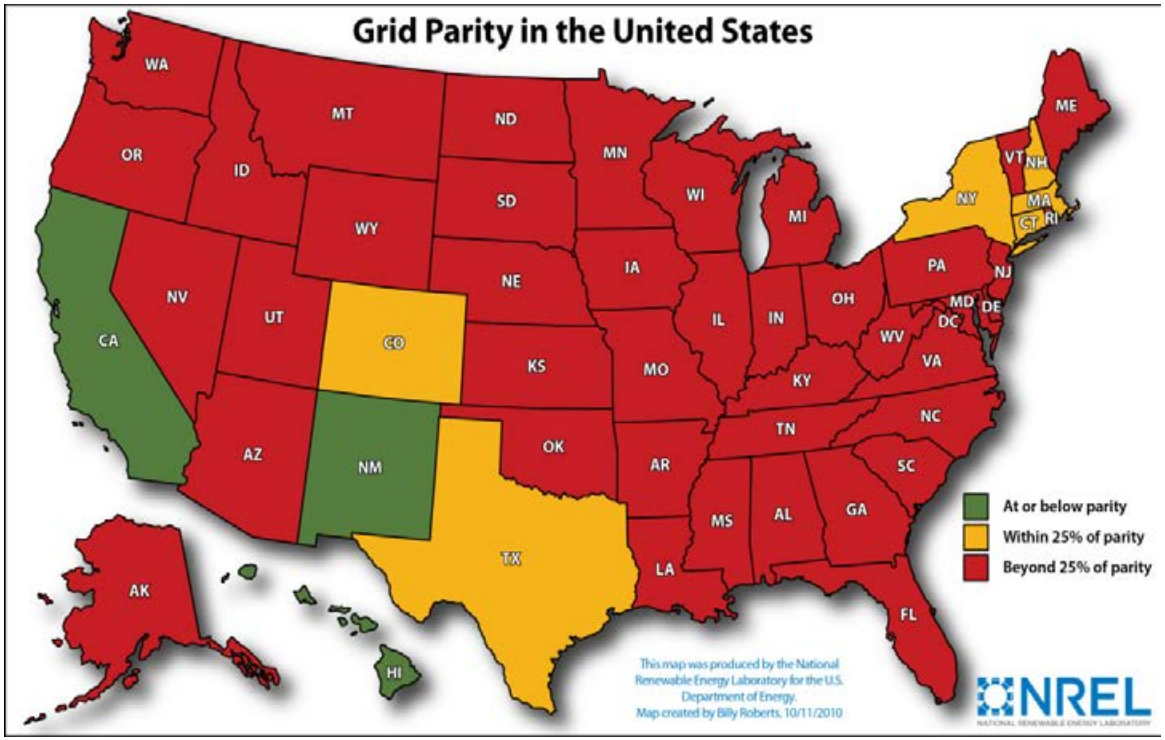
Rates Source: DOE (EIA): May 15, 2011 Release of Electric Power Monthly.

Note: California alone is the eighth largest economy in the world (EconPost.com., 2009).

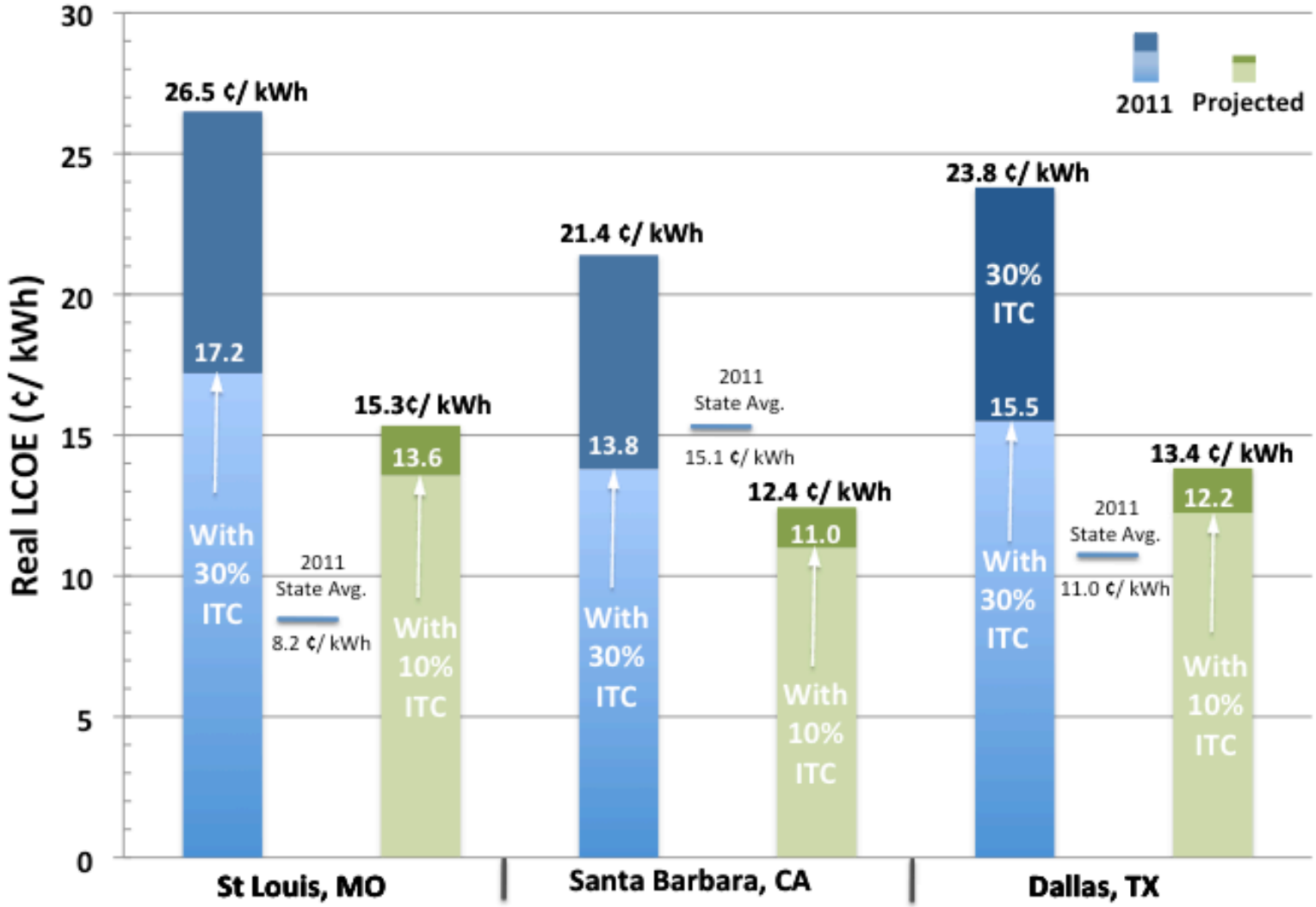
While sizable 'transition markets' are available, the costs of PV will have to continue their downward trend in order to meet broader 'Grid Parity'.

2010 Costs and Incentives

- Includes 30% Federal ITC. (Guaranteed until 2016; 10% thereafter). State incentives not included.
- $\$6.50/W_{DC}$ Residential system (4.4 kW); however, more recent costs are lower.
- Electricity rate source: EIA



Current and Projected LCOE for Residential PV Compared to State-by-State Electricity Rates



Notes:

-- Unsubsidized LCOE shown at the top of each bar. The White numbers estimate the LCOE with the current and post-2016 ITC benefit.

-- 2011 average residential rates for each state (May 2011 EIA Electric Power Monthly data) is indicated with blue horizontal bar.

-- Grid Parity in 'transitional markets' is clearly possible with wafer-Si; however, new technologies will be needed for the cost of PV to arrive at NATIONAL Grid Parity. The DOE SunShot Initiative specifically addresses this challenge.

An Oil Alternative: Electric Vehicle Charging with Solar Energy

4 - 5 miles/ kWh

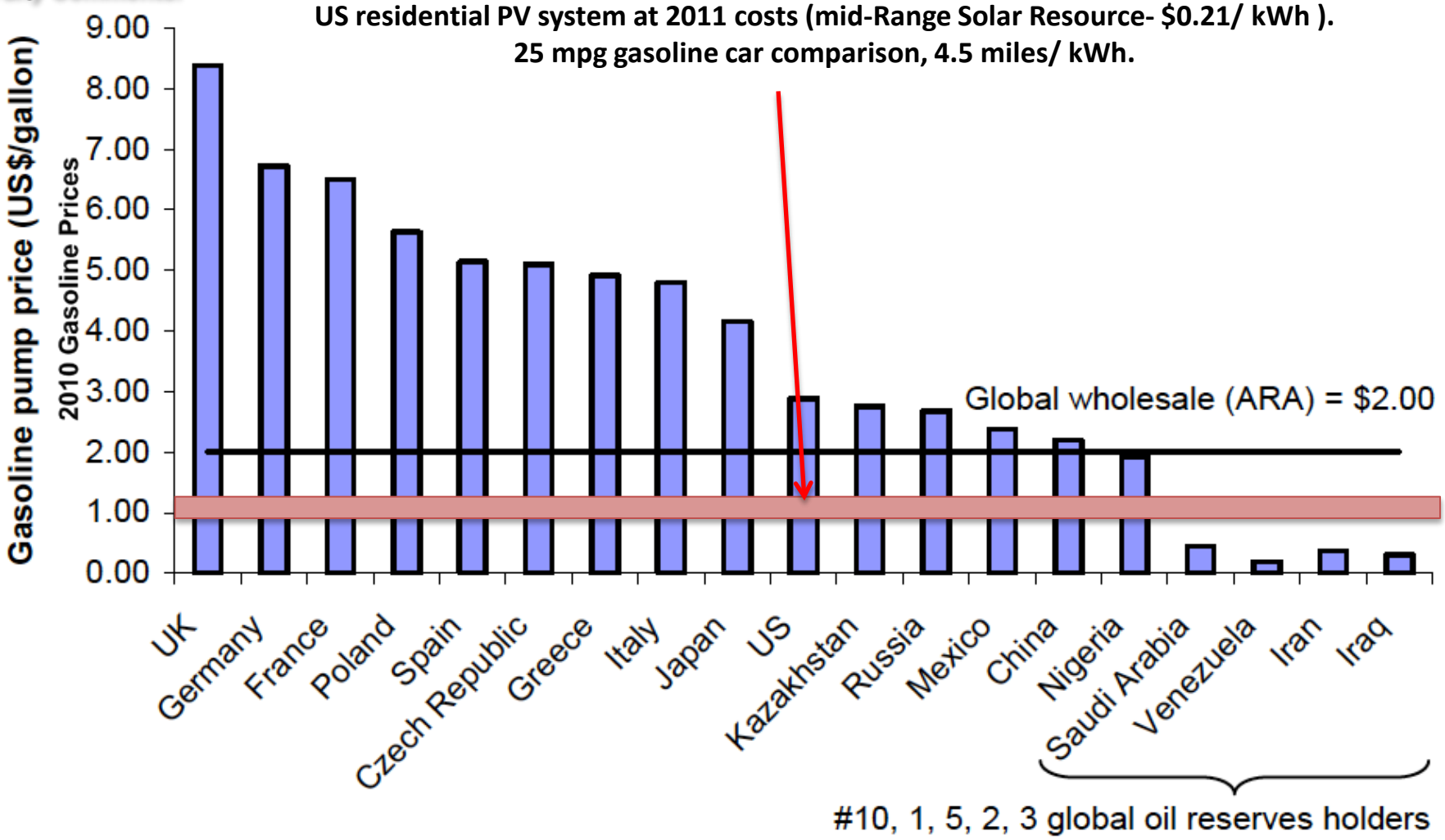
Chevy, Nissan, Toyota, Tesla, et al; Duetsche Bank, & Tony Markel (NREL Electric Vehicle Team).

And Why it Makes Economic Sense

DRAFT
Analysis.
Please respond to authors with any Comments.

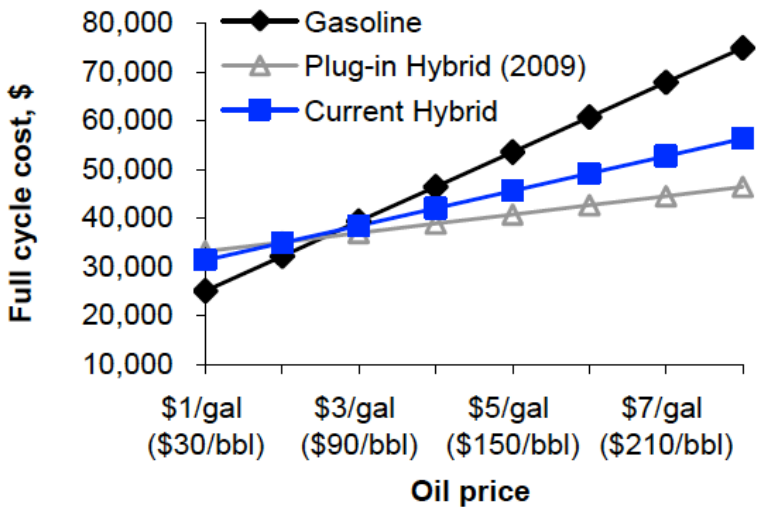
≈$1.15/ Gallon

ENERGY Price Per Gallon Equivalent for Electric Vehicle Charging with an UNsubsidized US residential PV system at 2011 costs (mid-Range Solar Resource- $0.21/ kWh). 25 mpg gasoline car comparison, 4.5 miles/ kWh.



Source: IMF, DOE, EIA, World Bank, PIW, Bloomberg, Deutsche Bank

EV Battery and Related Components: The Additional Cost Considerations



Source: Deutsche Bank

Assumes 15,000 miles per year (over 9.5 years vehicle life) at 20 mpg for gasoline car, 40 mpg for plug-in and current hybrids, and 5 miles per kWh for plug-in. Vehicle cost: $18,000 gasoline car vs $25,000 current hybrid vs $32,000 plug-in hybrid. Battery cost: $2,850 current hybrid vs $8,000 plug-in.

Estimated Battery Costs:

2011: ≈ $700/ kWh capacity;

70% Battery Capacity Utilization

-- About 12 kWh total capacity needed for 40-mile range

-- About $9000 for EV Battery & Additional Components[1]

-- Typical 2011 Charging Parameters: 120 V, 16 A

= 4.7 hours with 2.26 kW_{DC} of PV[2]

(A typical residential PV System is around 5 $kW_{p\ DC}$)

-- 240 V, 80 A in the near future: Much shorter charging times

[1]One can research the costs for an EV car versus a comparable all-gasoline car to check; we are not here to mention or endorse specific brands. EV price depicted here includes federal tax credits.

[2] Active Capacity: 9 kWh of charging; 0.85 DC-to-AC derate.

Projected Near- Term Costs: ≈$300/ kWh

Electric Vehicles Are A Valuable Hedge Against Ever-Increasing Oil Prices

Fossil Fuel Based Vehicles: Low CapEx, High OpEx

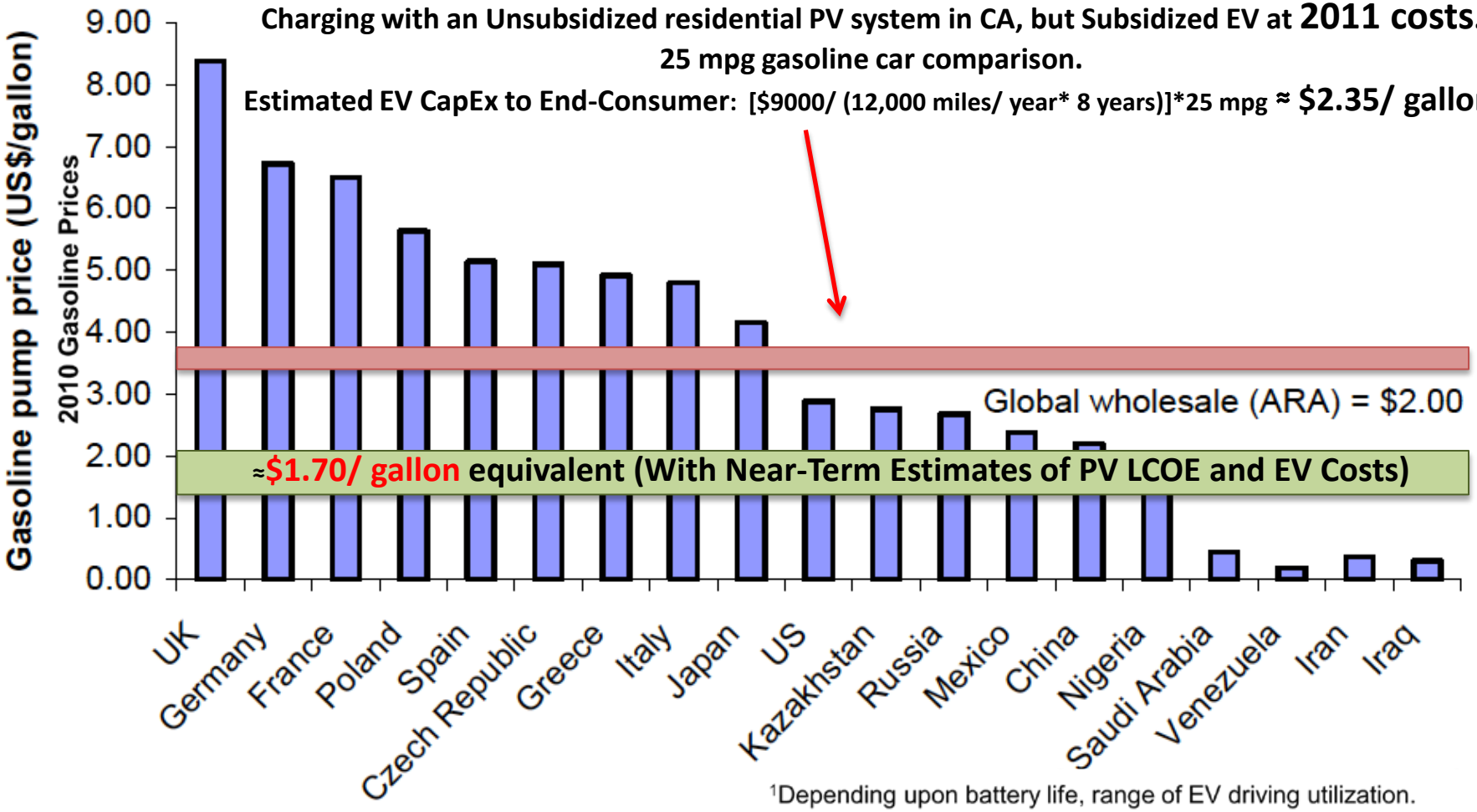
Electric and Hybrid Vehicles: **High CapEx**, Low OpEx

And Why it Makes Economic Sense

DRAFT Analysis.
Please respond to authors with any Comments.

≈$3.50/ Gallon

Energy and Plug-In Battery Price Per Gallon Equivalent for Electric Vehicle
Charging with an Unsubsidized residential PV system in CA, but Subsidized EV at 2011 costs.
25 mpg gasoline car comparison.
Estimated EV CapEx to End-Consumer: [$9000/ (12,000 miles/ year* 8 years)]*25 mpg ≈ $2.35/ gallon[1]

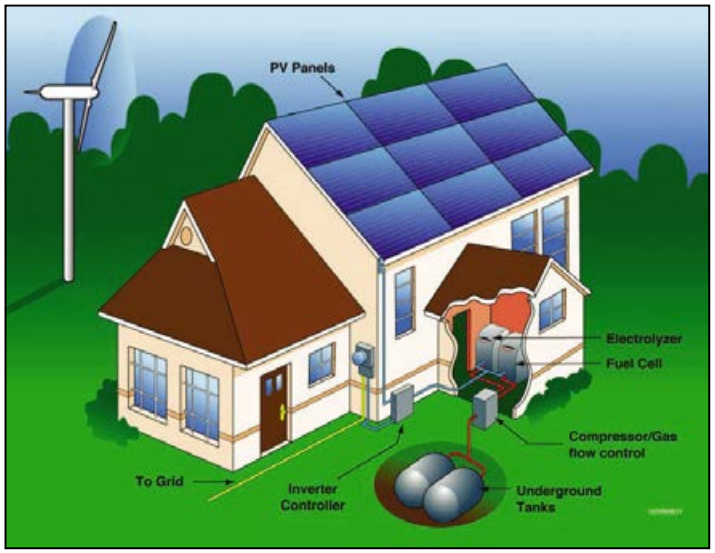


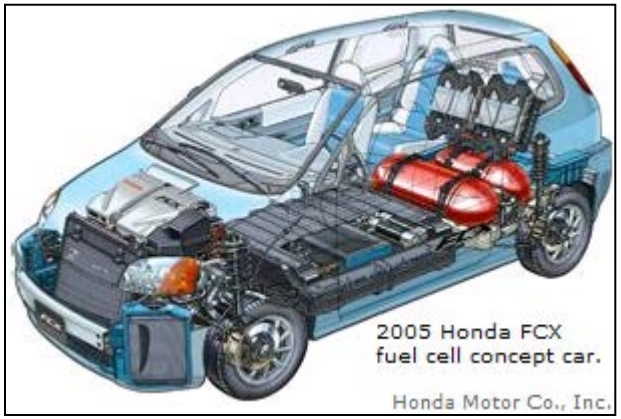
[1]Depending upon battery life, range of EV driving utilization. 8 years, 100,000 miles is a standard EV Battery Warranty offered for several vehicles, so cost shown here reflects coverage within factory warranty. Also, the typical battery warranty is now longer than the typical drivetrain warranty.

Source: IMF, DOE, EIA, World Bank, PIW, Bloomberg, Deutsche Bank

Conclusion

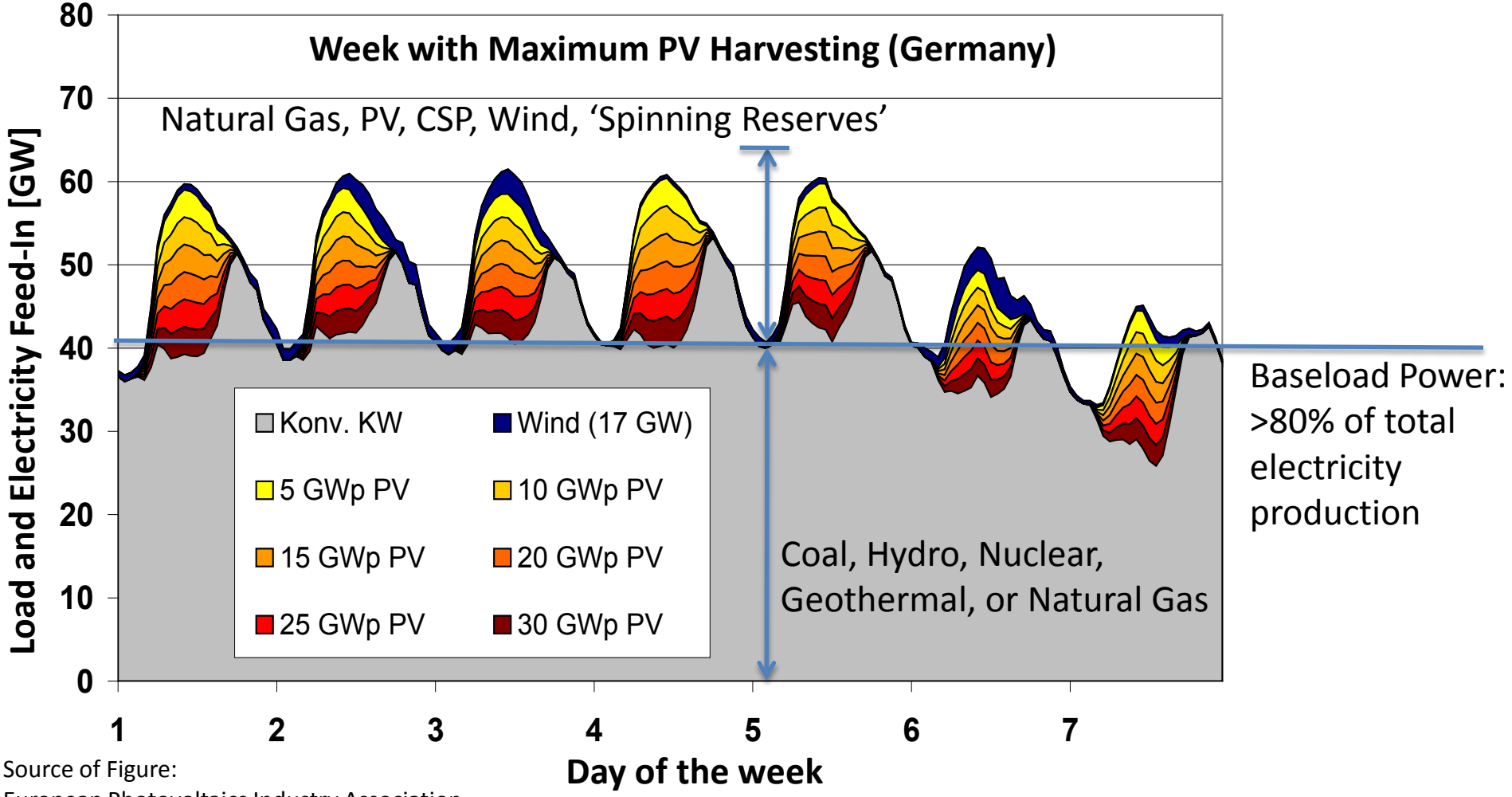
We CAN (and should) think about the economics of using PV to reduce oil consumption, as well as traditional electricity. To that end, storage costs need the biggest reductions; the energy price is already quite compelling.





Adoption dynamics must also be improved.
Is it enough to simply be at 'cost parity'?

Another reason why storage is critical



Source of Figure:
European Photovoltaics Industry Association

Energy storage solutions are needed for penetration >10-20%:
Denholm, P.; Margolis, R. M., *Energy Policy* **2007,** *35*, 2852-2861.

"I'd put my money on the sun and solar energy. What a source of power! I hope we don't have to wait until oil and coal run out before we tackle that."

Thomas Edison, 1931

M. I. Hoffert et. al., Nature, ***1998****, 395, 881*

Intergovernmental Panel on Climate Change (IPCC) *Fourth Assessment Report*

DOE, Energy Information Administration Website

Denholm, P.; Margolis, R. M., *Energy Policy* **2007,** *35*, 2852-2861.

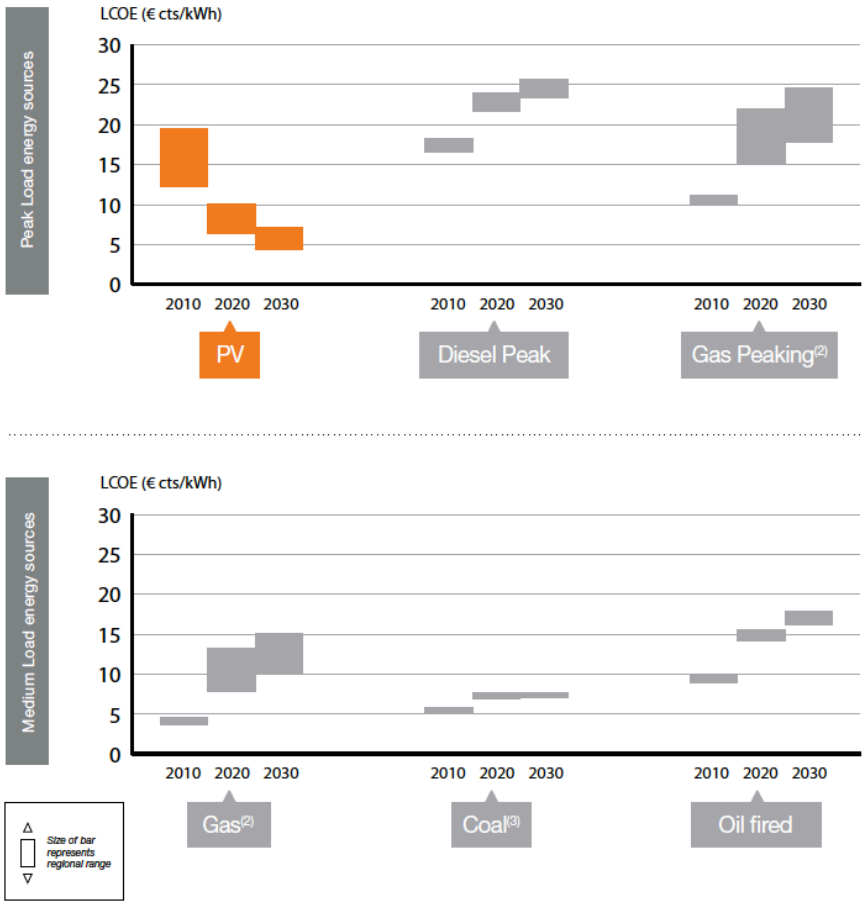
<u>Duetsche Bank Reports:</u>

- Price Dynamics at the End of the Oil Age
- Natural Gas and Renewables:
  A Secure Low Carbon Energy Future

Supplemental Slides

LCOEs from European PV Industries Association

COMPARISON OF LCOE 2010, 2020, 2030, HIGH CASE FUEL PROJECTION (1) (€cts/kWh)



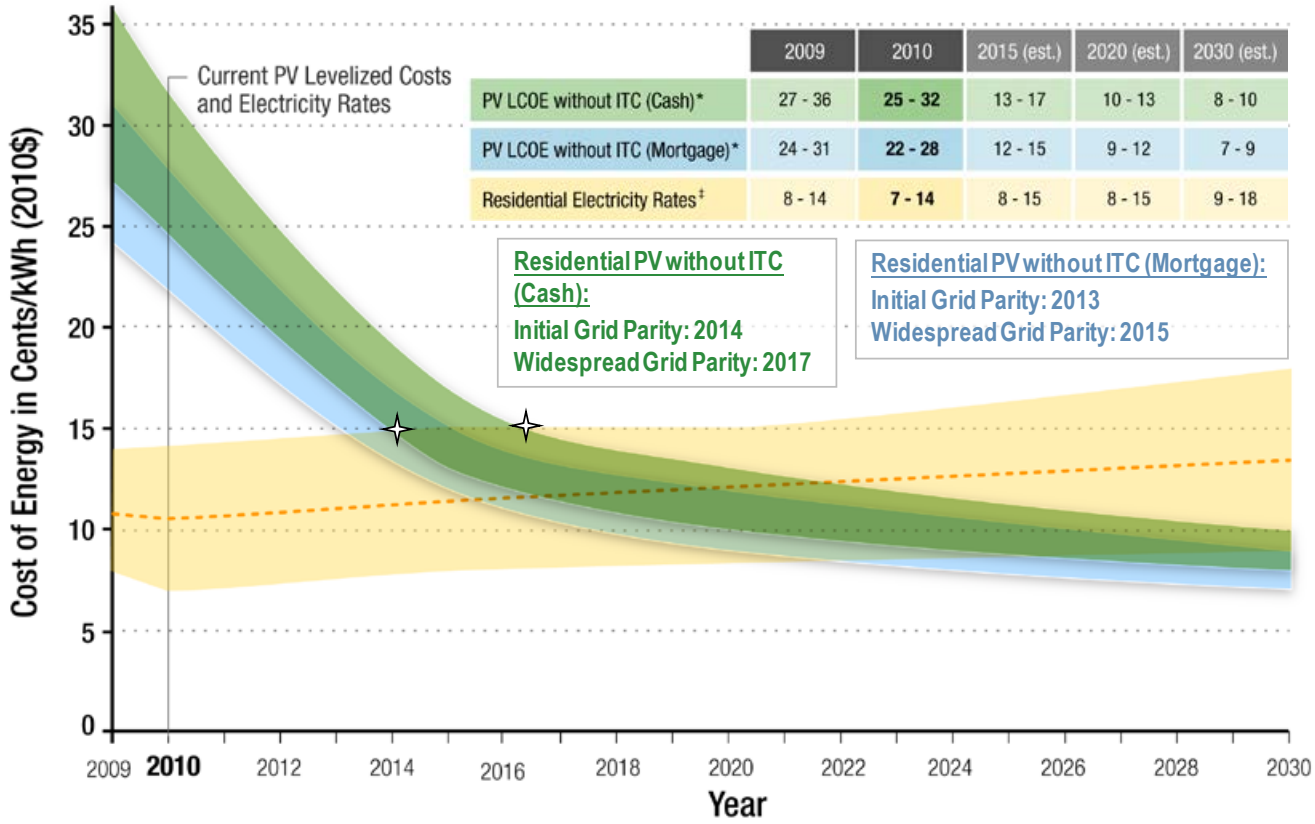
(1) WACC: 6.4%

(2) LCOE of Gas Peaking and Combined Cycle Gas Turbine (CCGT) in gas producing countries with very low gas prices are not displayed

(3) IGCC = Integrated Gasification Combined Cycle, a modern coal combustion technology

Source : National Renewable Energy Laboratory, National Energy Technology Laboratory, EPIA Set for 2020, World Bank, A.T. Kearney analysis

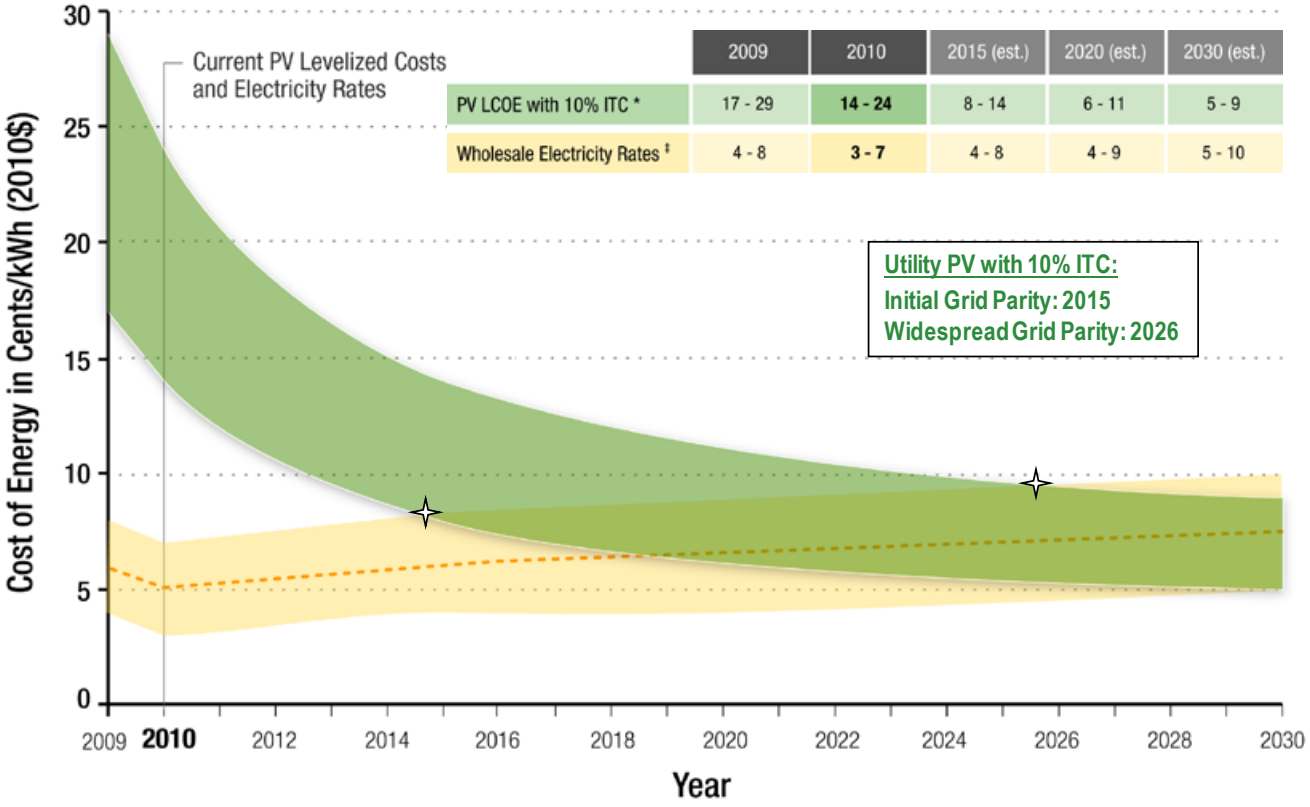
J E Bartlett, R M Margolis, A Goldstein.
"Levelized Costs of Solar Technologies Through 2030". Technical Report (2011)



* *No state, local or utility incentives are included. The range in residential PV LCOE values is due to different geographic locations. For a complete list of LCOE values, see Table A-1. The electricity rate range represents one standard deviation below and above the mean U.S. residential electricity prices.*

Figure shows the LCOE for residential PV systems without the ITC, as there is no permanent 10% ITC as is the case for commercial and utility systems. To illustrate the effect of financing, we show both cash purchase (with a 6.0% discount rate) and mortgage financing (with a 7.0% interest rate). Even without any incentives, residential PV is projected to be competitive with high residential electricity rates under above-average insolation conditions by 2014 for cash purchases (2013 for mortgage financing) and under below-average insolation conditions by 2017 for cash purchases (2015 for mortgage financing). As residential PV system costs continue to decline thereafter, so too does the LCOE range. By 2030, residential PV has expected levelized costs in all geographic cases and both financing assumptions that are lower than most residential electricity rates. The path of residential PV to grid parity and beyond is mostly due to PV cost reductions. From 2009 to 2030, the LCOE of PV is projected to decline by over 2.5 times whereas average electricity rates are expected to increase by only about one-fifth.

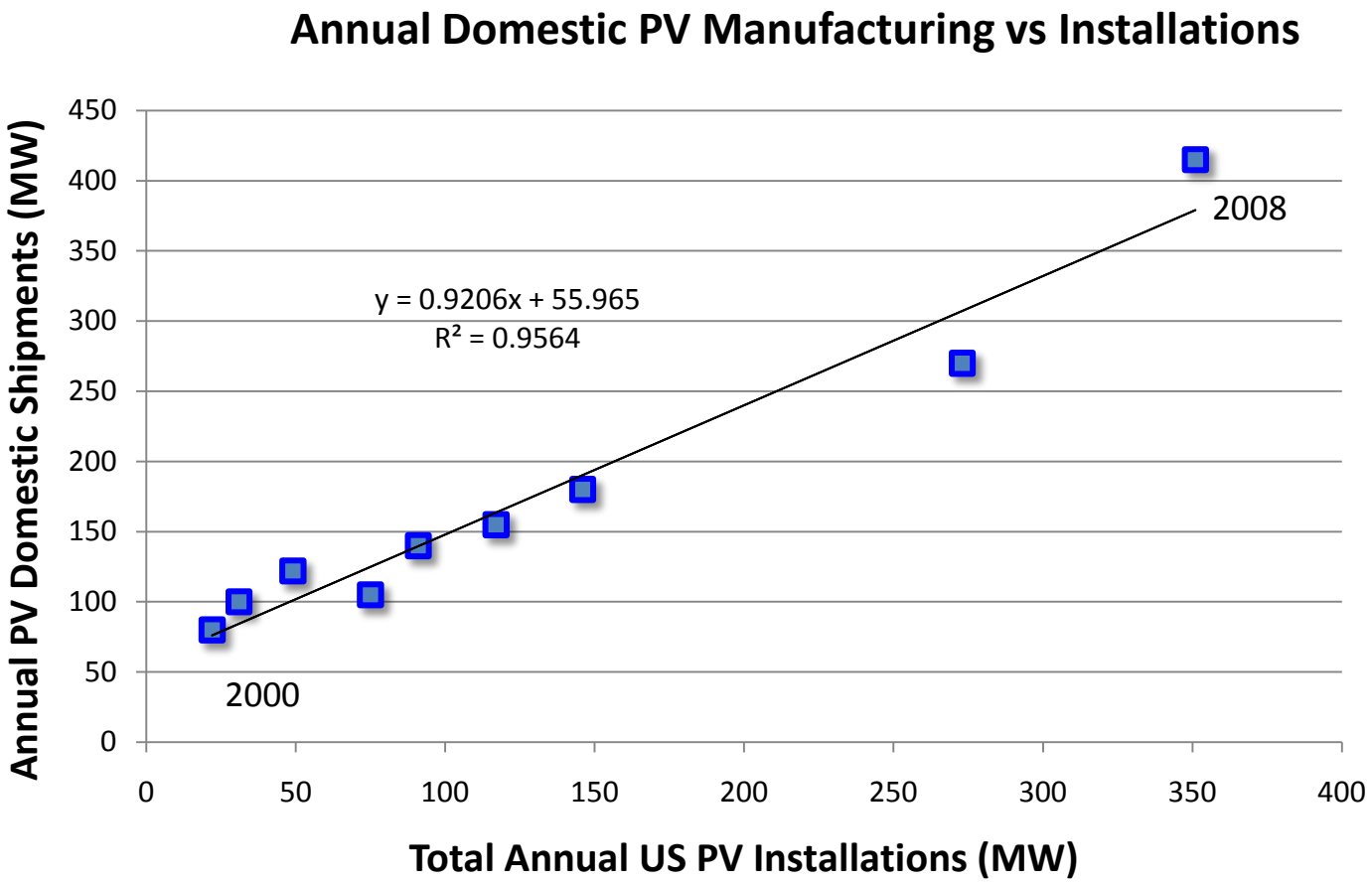
J E Bartlett, R M Margolis, A Goldstein.
"Levelized Costs of Solar Technologies Through 2030". Technical Report (2011)



* *Assumes IPP or IOU ownership of PV, and thus the LCOE includes the taxes paid on the profit from electricity generated and sold. Includes 5-year MACRS but not state or local incentives. The range in utility PV LCOE values is due to different geographic locations and financing conditions. For a complete list of LCOE values, see Table A-3.*
The electricity rate range represents one standard deviation below and above the mean U.S. wholesale electricity prices.

Figure 3 shows the LCOE of utility PV systems with only the permanent 10% ITC and 5-year MACRS. By 2015, utility PV is forecasted to be competitive with high commercial electricity rates given above-average insolation conditions and good financing terms. Utility PV has proportionally similar differences as commercial PV between the upper and lower ends of the LCOE range, and it is not until 2026 that all utility cases modeled are within the same range as wholesale electricity prices.

The 2009 – 2030 trajectories of PV LCOE and electricity rates are somewhat different for utility residential compared to commercial and residential systems, with a projected LCOE decline of just over 2 1/3 times and average electricity rate increase of almost 30%. Similar to commercial systems, utility PV system costs (and LCOE) decline more sharply than residential systems in the early years but more modestly thereafter. Due to the larger project sizes and less fragmented market compared to residential PV, the utility PV market is expected to mature more rapidly but with less total headroom for cost reductions.


Annual Domestic PV Manufacturing vs Installations
Annual PV Domestic Shipments (MW)
Total Annual US PV Installations (MW)
y = 0.9206x + 55.965
R² = 0.9564
2000
2008
0
50
100
150
200
250
300
350
400
450

Sources: EIA

Remaining Crude Oil Reserves (Bn bbls, Conventional Sources[1])

Rank		Remaining Reserves	Share of Total	Oil Orthodoxy
1	Saudi Arabia	264.1	21.0%	OPEC
2	Iran	137.6	10.9%	OPEC
3	Iraq	115	9.1%	OPEC
4	Kuwait	101.5	8.1%	OPEC
5	Venezuela	99.4	7.9%	OPEC
6	United Arab Emirates	97.8	7.8%	OPEC
7	Russian Federation	79	6.3%	
8	Libya	43.7	3.5%	OPEC
9	Kazakhstan	39.8	3.2%	
10	Nigeria	36.2	2.9%	OPEC
	Top 10 Total	**1014.1**	**80.0%**	
14	**U. S. Total[2] (ANWR, Offshore, etc.)**	**19 - 21**	**1.8%**	

Sources: EIA, BP and Duetsche Bank

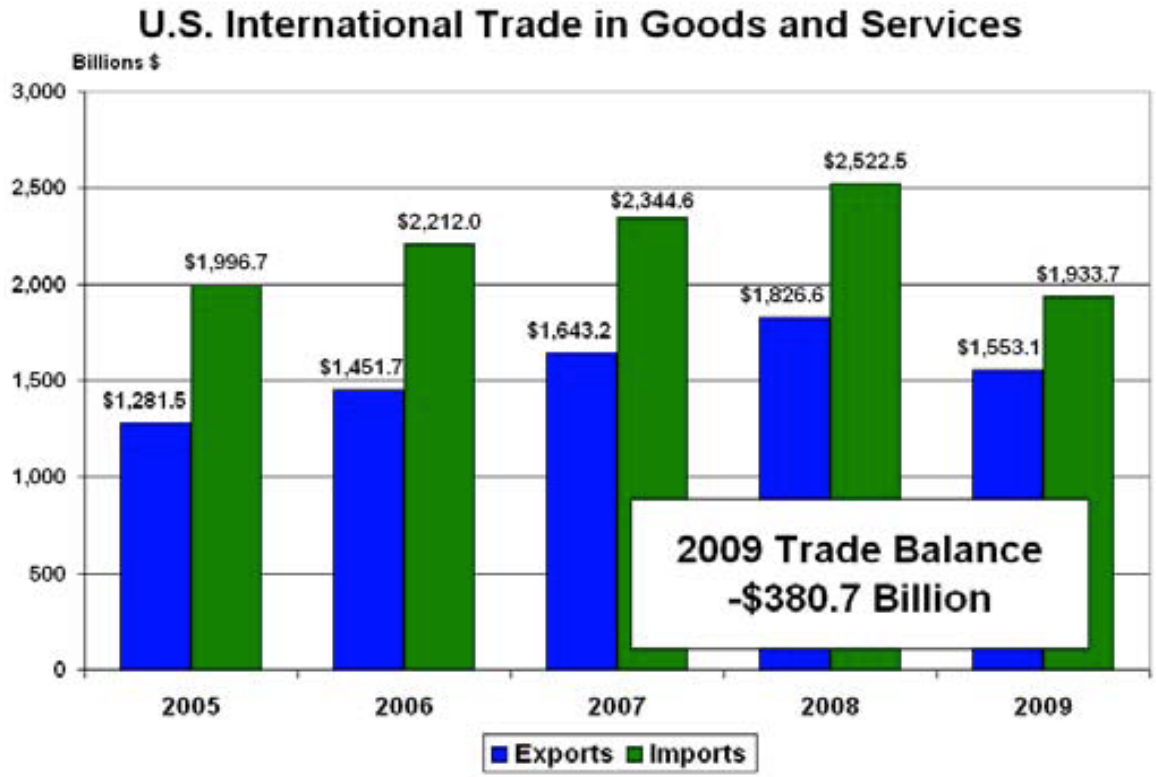
[1]Including Oil Sands puts Canada in the top two or three (with caveats surrounding increased CO_2 intensity & environmental damage).

[2]24% of Global Oil Consumption

U.S. Oil Consumption (from EIA Website):

- 6.5 - 7 Billion Barrels of Crude Consumed Annually
- Net Dependence on Imports: 60-70%

The Oil Conundrum: 2009



2009 U. S. Crude Oil Trade Balance:

Imports – Exports

= $188.57 Billion – $1.01 Billion

= **49.3% of the 2009 U. S. Trade Deficit**

Data Sources: U. S. Bureau of Economic Analysis, *U. S. International Trade in Goods and Services Reports* & DOE (EIA)