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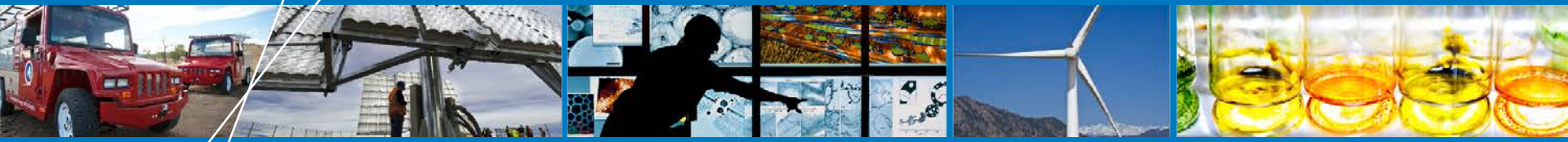
Solar PV Manufacturing Cost Analysis: U.S. Competitiveness in a Global Industry



Stanford University: Precourt Institute for Energy

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October 10, 2011

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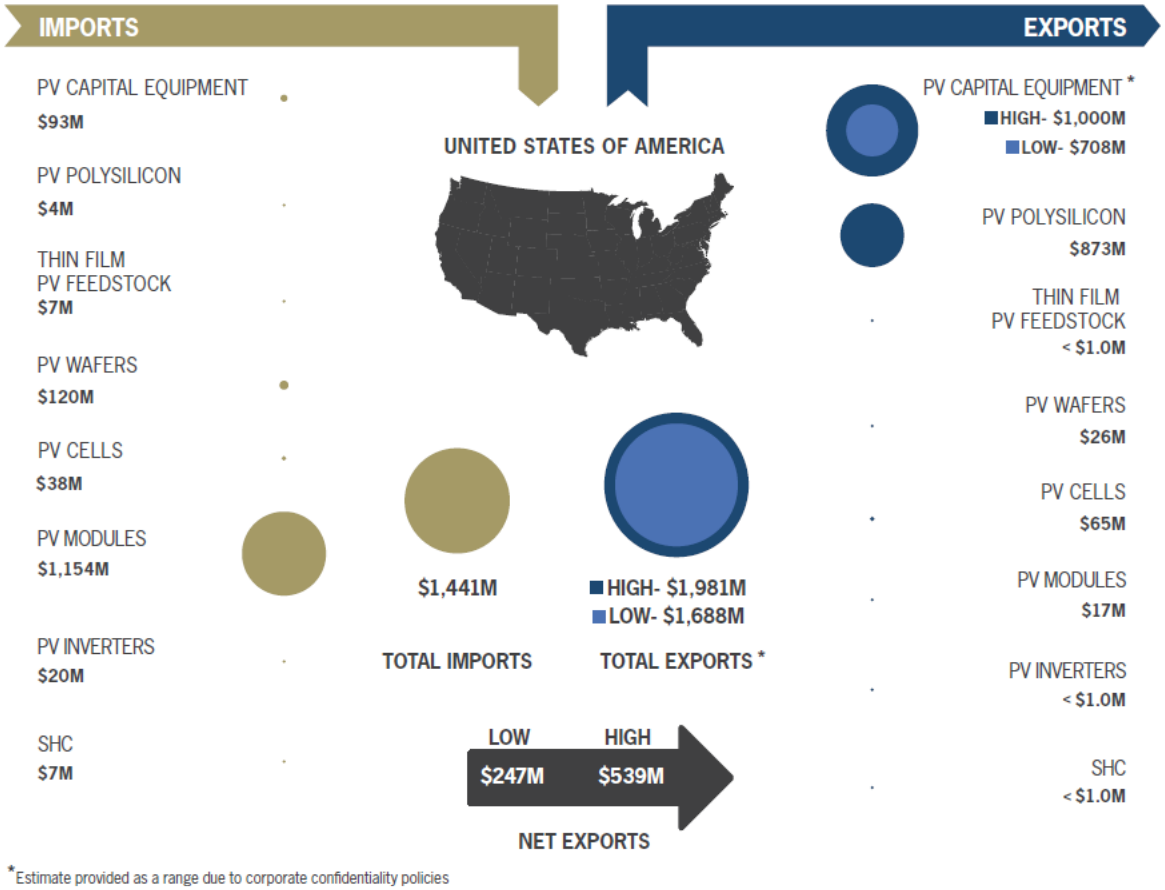
Si Solar Manufacturing Supply Chain

Also…

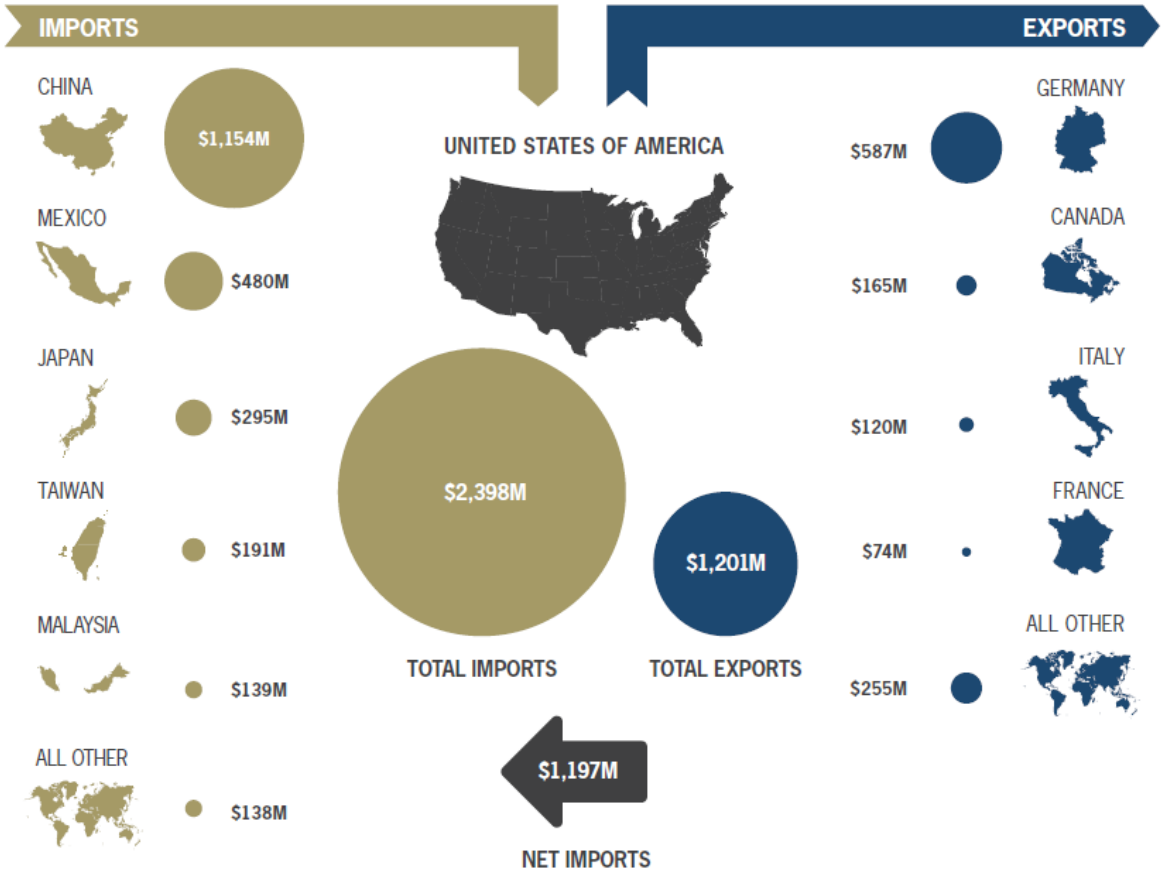
- **Capital equipment**
- **Raw materials**
- **Intermediate products**

US-China Solar Energy-Related Trade Flows



Source: GTM Research and International Trade Commission. (2011). "U.S. International Trade Assessment 2011: Trade Flows and Domestic Content for Solar energy-related Goods in the United States."

PV Module Trade Flows



Source: GTM Research and International Trade Commission. (2011). "U.S. International Trade Assessment 2011: Trade Flows and Domestic Content for Solar energy-related Goods in the United States."

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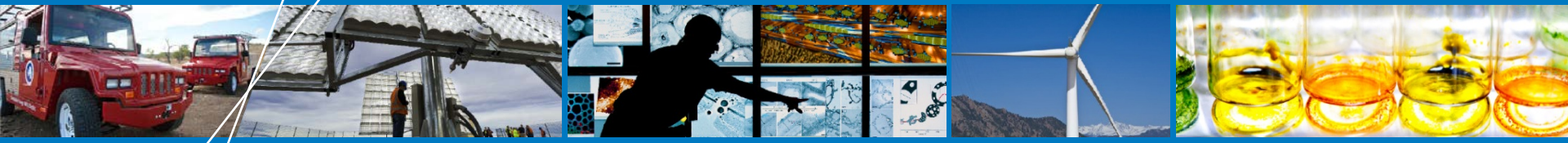
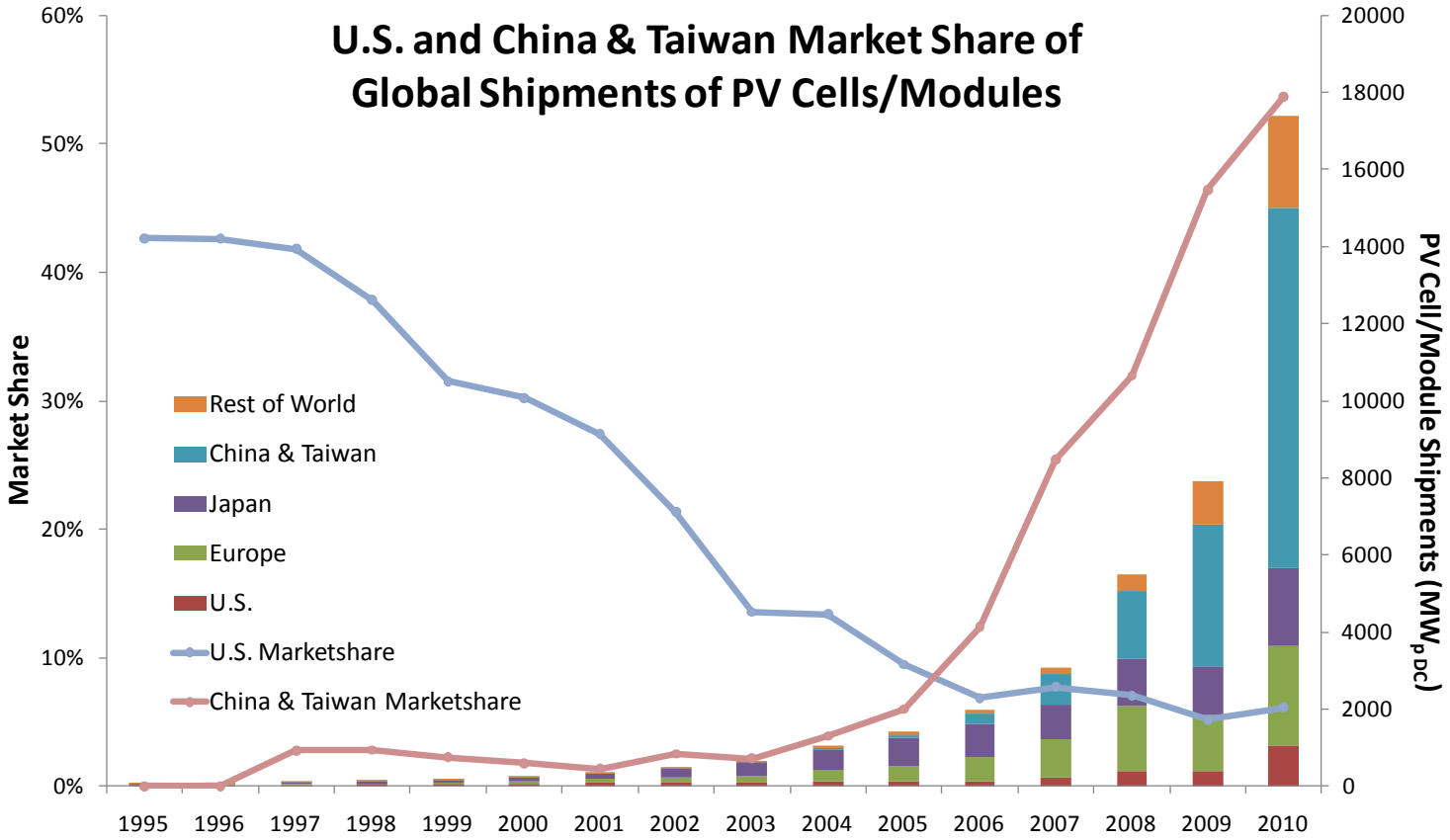


Solar PV Market Developments

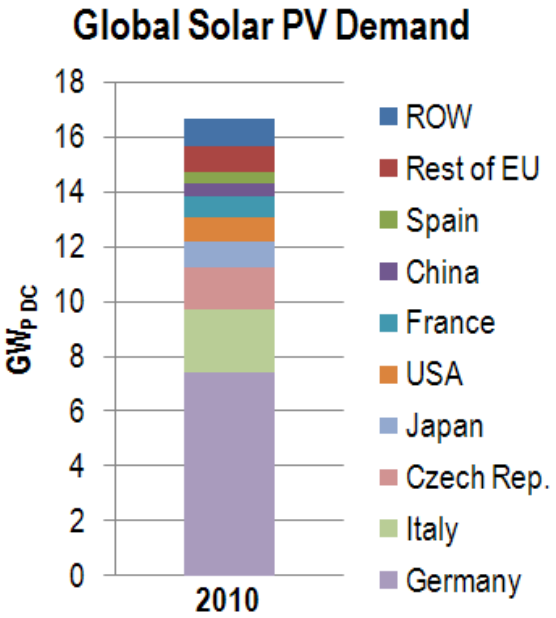
Global U.S. Position Ceded to China & Taiwan

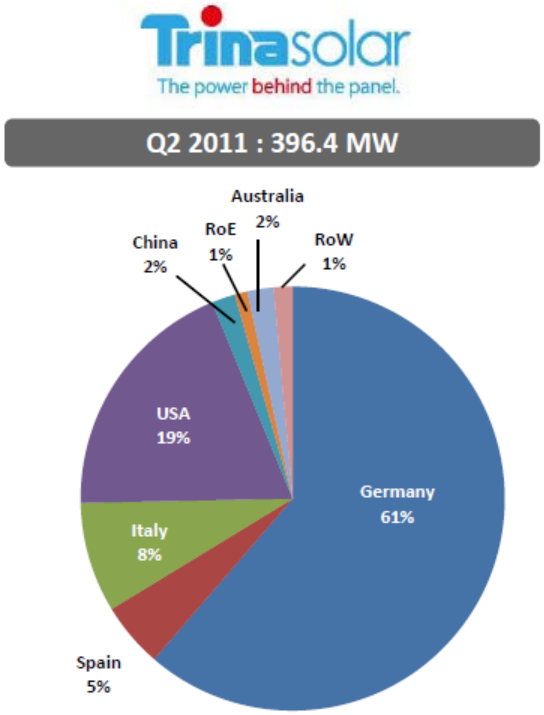
- Between 2000 and 2010 global shipments grew 53% (CAGR)
- U.S. market share slipped from 30% to 7% (30% CAGR)
- China/Taiwan grew from <2% to 54% (115% CAGR)



Sources: NREL chart using data from Mints, P.; Donnelly, J. (2011). "Photovoltaic Manufacturer Shipments, Capacity and Competitive Analysis 2010/2011." Report NPS-Supply 6, Navigant Solar Services Program. Palo Alto, CA.

China Solar PV: Export Driven



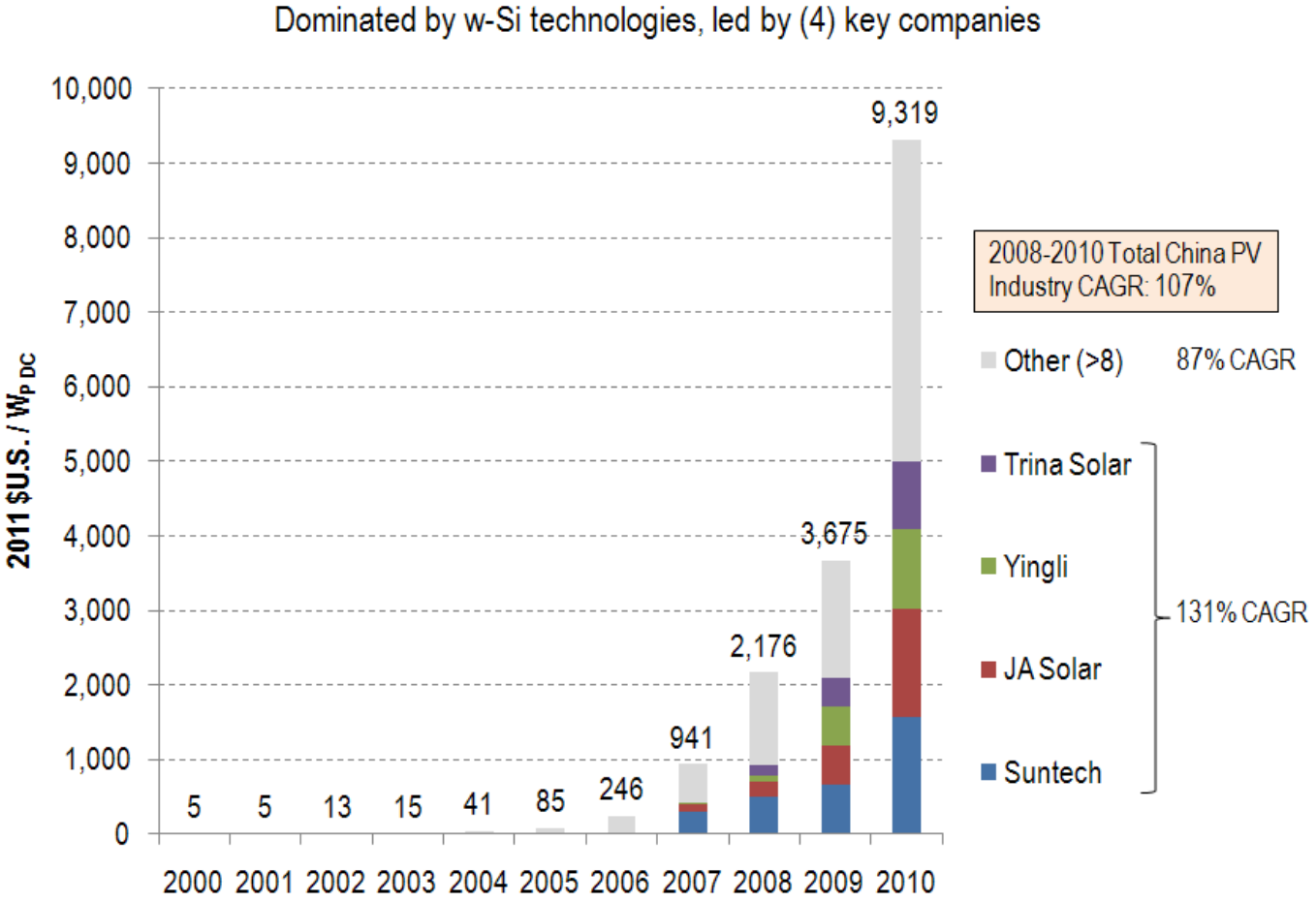


- Meager domestic demand belies China's dominant production
- 9.3 $GW_{P\ DC}$ shipments vs. 0.5 $GW_{P\ DC}$ installed

Sources: NREL chart using data from European Photovoltaics Industry Association (EPIA). "Global Market Outlook for PV until 2015." http://www.epia.org
Trina Solar (August 23, 2011). "Q2 2011 Supplemental Earnings Presentation."

China's Focused Growth: (4) Key Players, All Si

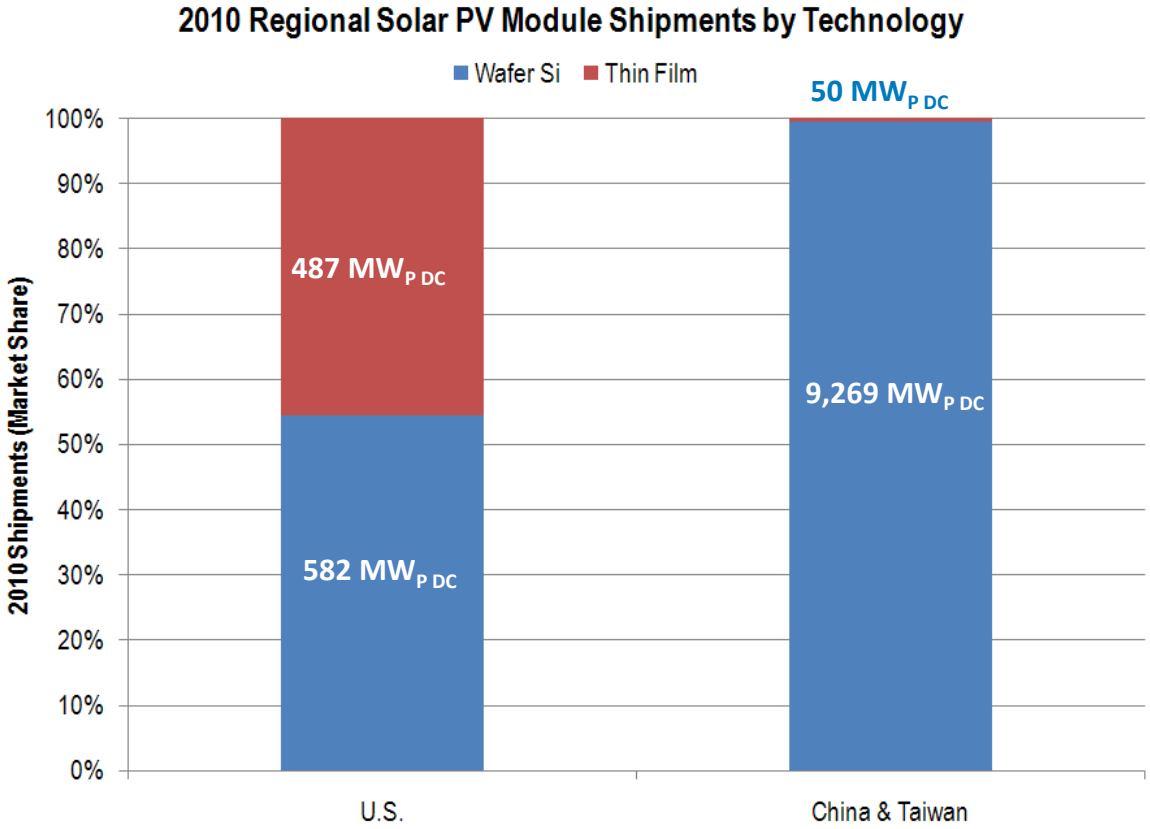
Growth enabled by access to low cost debt, technology diffusion

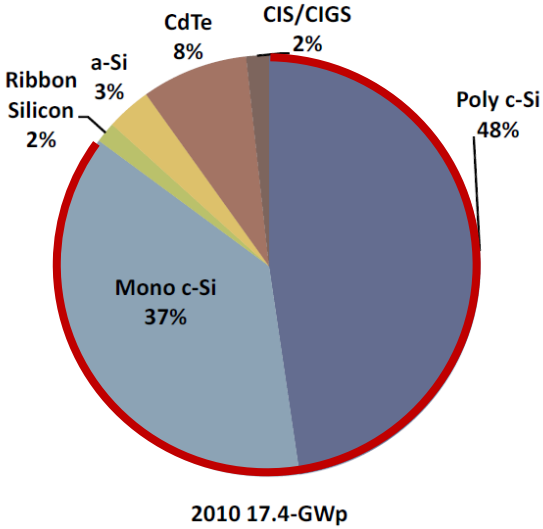


Sources: Mints, P.; Donnelly, J. (2011). "Photovoltaic Manufacturer Shipments, Capacity and Competitive Analysis 2010/2011." Report NPS-Supply 6, Navigant Solar Services Program. Palo Alto, CA.
de la Tour et al. (2011). "Innovation and international technology transfer: The case of the Chinese PV industry," *Energy Policy* 39 (2011) 761-770.

U.S. Diversity vs. China Manufacturing Scale

- U.S. private investors encourage technology differentiation – opportunities for producers of innovative Thin Film PV technologies
- China's government-backed investors fund more mature technologies – opportunities for w-Si technologies (quick scale-up; wages, exports)

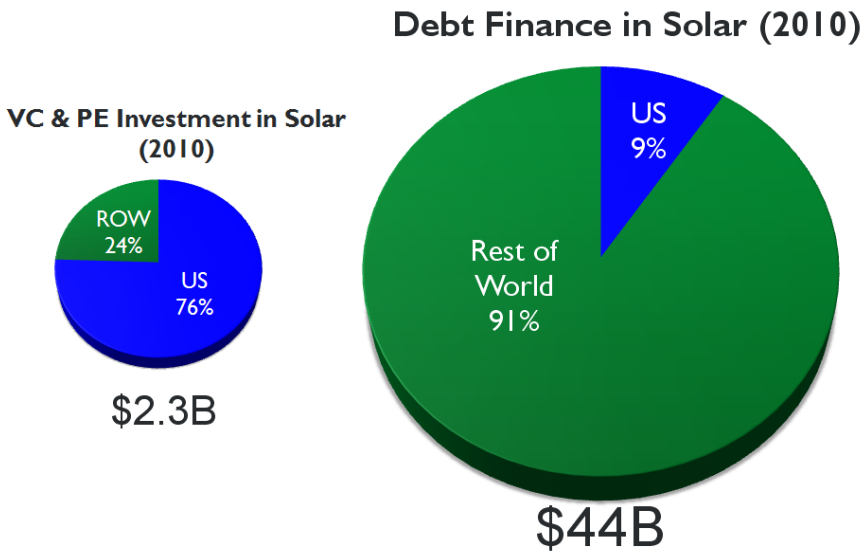




Wafer silicon is >85% of the global market

Sources: Mints, P.; Donnelly, J. (2011). "Photovoltaic Manufacturer Shipments, Capacity and Competitive Analysis 2010/2011." Navigant Solar Services Program. Palo Alto, CA.

Capital Sources Drive Solar Technology Mix



2009 ARRA Manufacturing Tax Credit (section 48C):

- *"...have the greatest potential for technological innovation and commercial deployment."*

Energy Policy Act of 2005 (§1703 – Innovative Technology LG Program):

- *"...employ new or significantly improved technologies as compared to commercial technologies."*

Recovery Act of 2009 (§1705 – Temporary LG Program for Deployment of Renewable Energy)

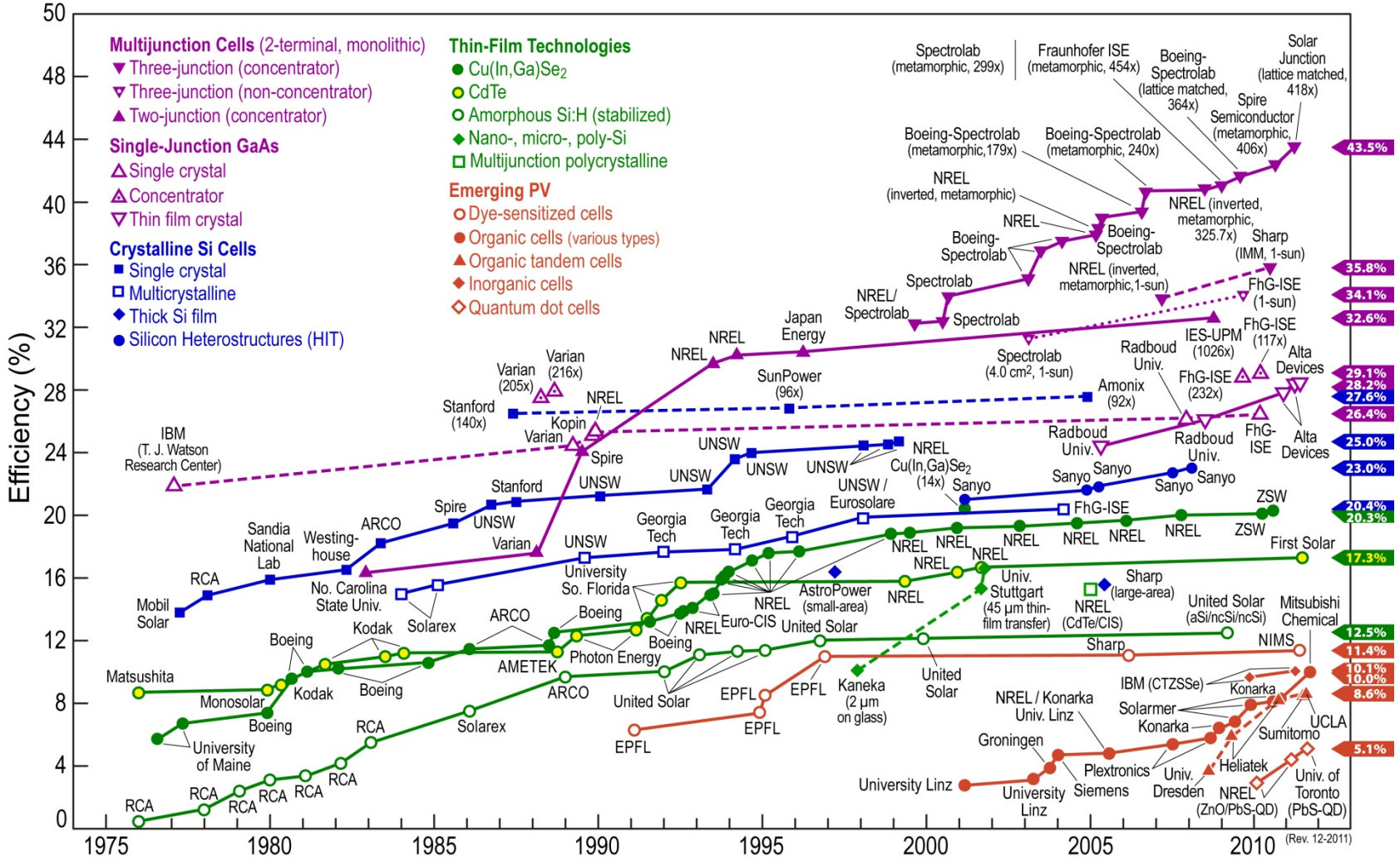
- Amended EPAct §1703; Expired September 30, 2011.

"The (Loan Guarantee) program was designed to provide support to these cutting edge industries, which have great potential to create jobs in whatever country wins the clean energy race, but also involve technology and market risks that private sector lenders often cannot or will not underwrite."

– Jonathan Silver, Executive Director LPO, U.S. DOE

Sources: Graphic – Bloomberg NEF (4/9/10, 4/16/10, 11/8/10, & 3/16/11); J. Silver Testimony before the Subcommittee on Oversight and Investigations Committee on Energy and Commerce, U.S. House of Representatives (September 14, 2011)

Best Research (Laboratory) Cell Efficiencies

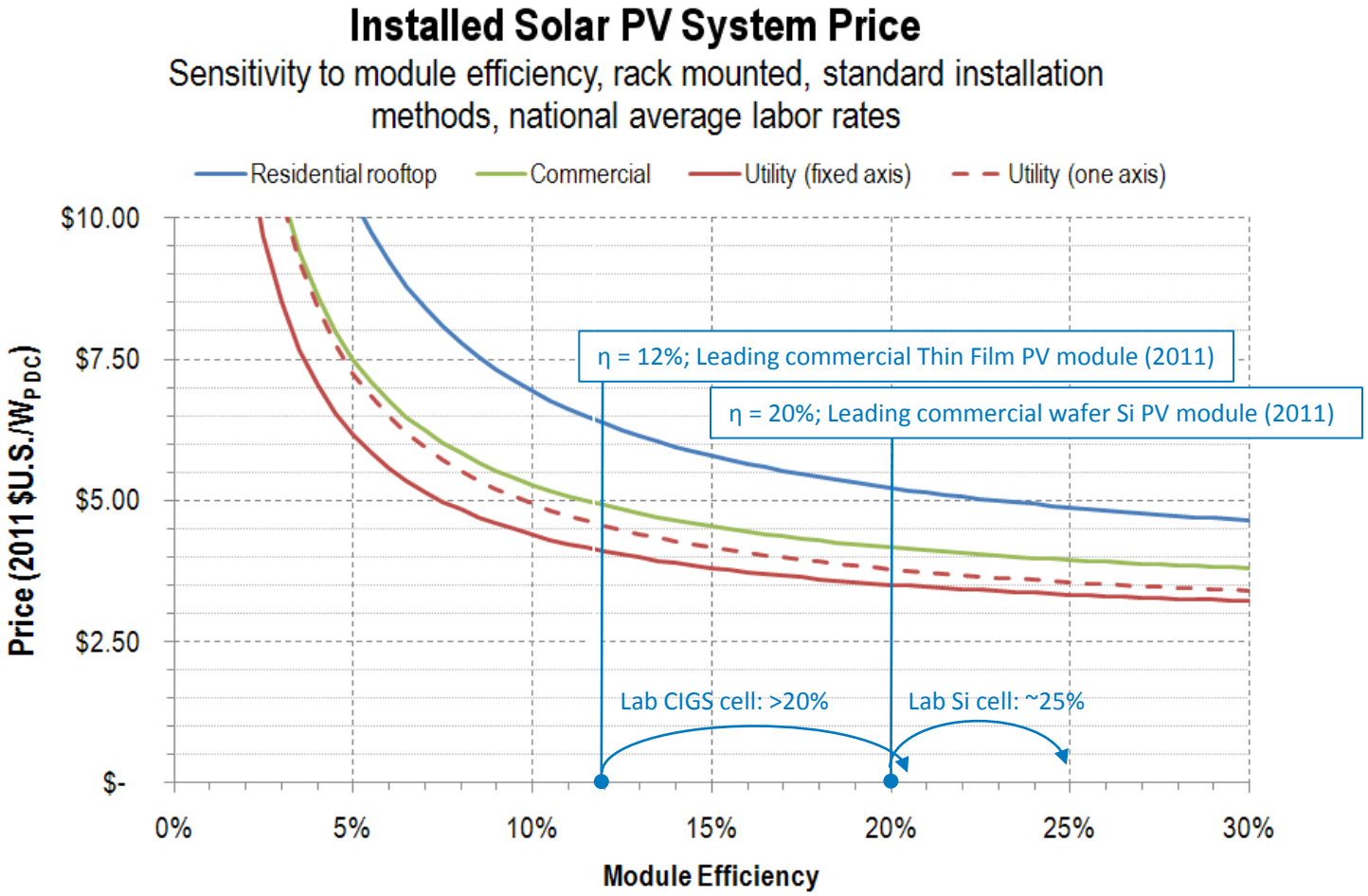


- Single junction wafer Si approaching practical performance limit
- Challenge facing thin films: closing the gap between laboratory and production devices

Private Investors Value Thin Film PV Potential

Thin Film PV technologies seek to close the gap: innovative, disruptive

- Startups raise capital based on defensible, disruptive IP position



Sources: Goodrich, A.; James, T.; Woodhouse, M. (2011). "Drivers of Residential and Utility Scale Solar Photovoltaic (PV) System Price. in the U.S." NREL Technical Report. Golden, CO: National Renewable Energy Laboratory (NREL).

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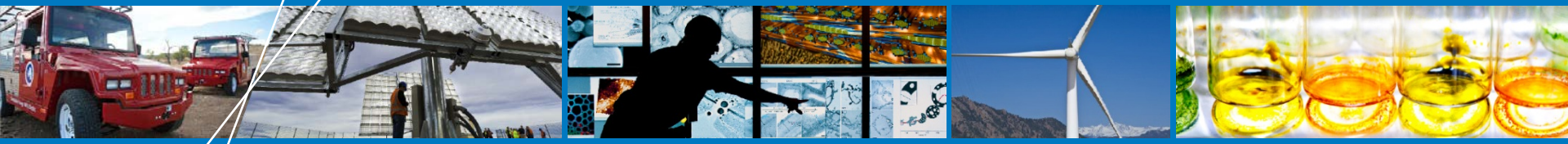


International Investment Risk

Other Investment Risk Considerations

Country	Political and economic stability Status, procedures, and maturity of legal system Transparency of business dealings
Economic	Expected inflation Local regulation
Currency	High cost and reliability of derivatives and other hedging instruments, particularly in emerging markets
Security	IP protection Property ownership, including the ability of creditors to repossess assets
Financial	Interest rates Insurance (business interruption)

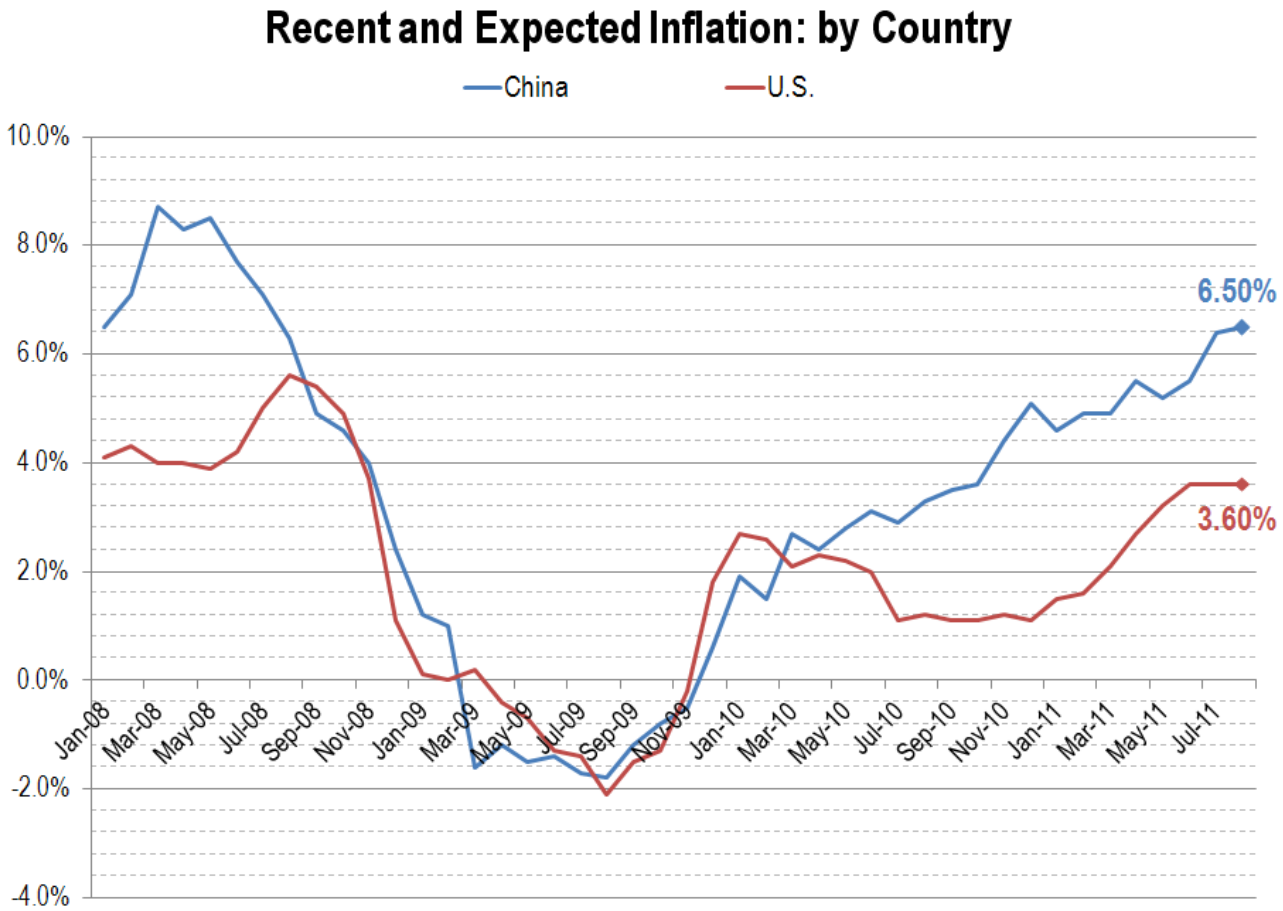
Only *Economic*, *Financial* risks quantified in this analysis

Other factors partially considered by Global K_E approach

- *Security* risk factors related to IP, property ownership particularly important (innovative startup); binary considerations
- Access to subsidized China debt generally limits foreign ownership to minority stake, e.g., Evergreen-Jiawei JV

Expected Inflation by Country

- Delta between U.S. and China as high as 470 bps
- China labor rates rose nearly 50% in 2010. Some expect 2011 $China_{inflation}$ 20%.



Impact of Inflation on capital budgeting decisions [2]:

- Revenues
- Costs (non-depreciation)
- Cost of debt capital ($K_{D\ Nominal}$)
  - Increased demand *Investments in non-financial assets.*
  - Decreased supply *Regulators seek to limit growth*

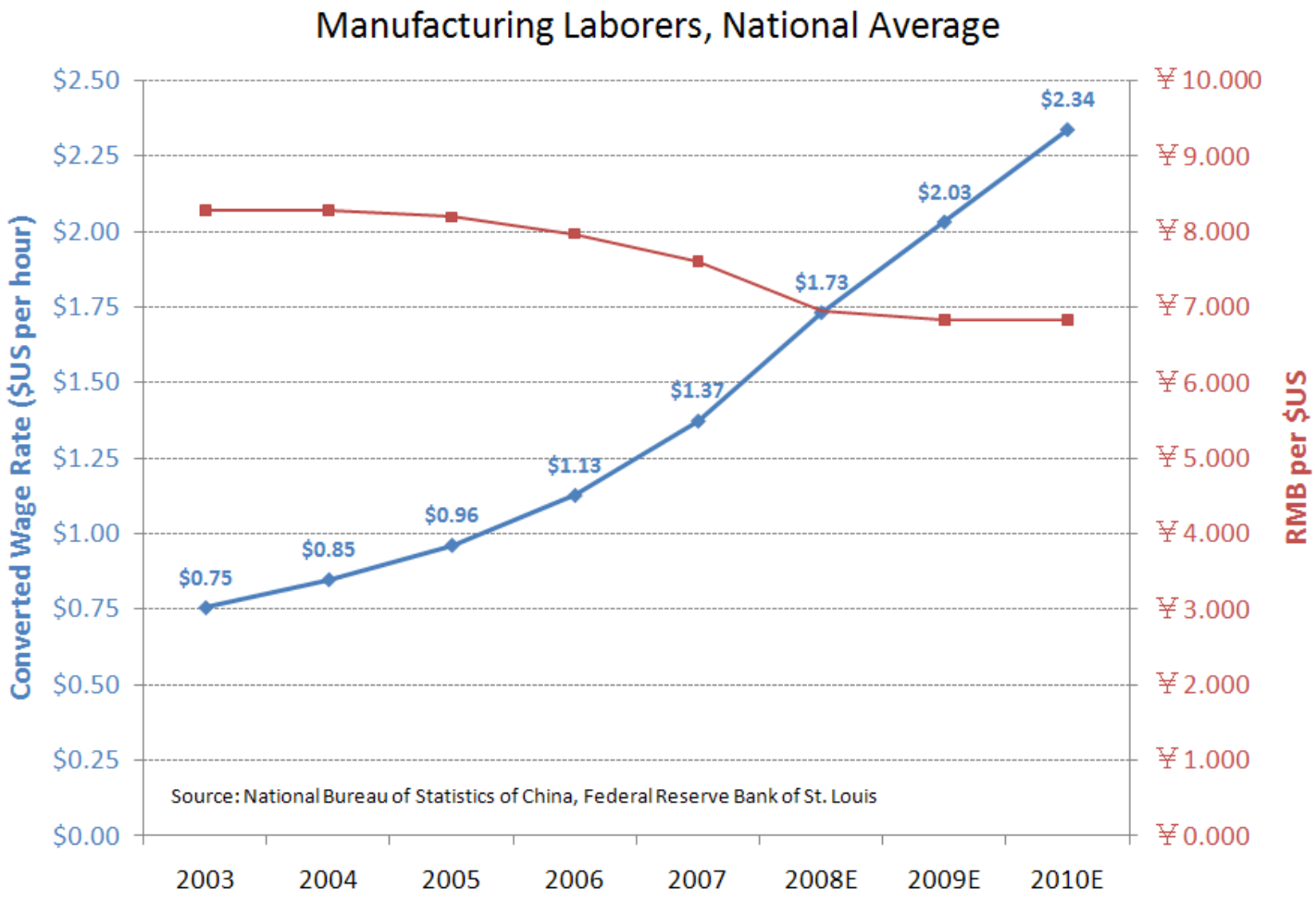
Sources: www.tradingeconomics.com

Gregory T. Mills, "The Impact of Inflation on Capital Budgeting and Working Capital," *Journal of Financial And Strategic Decisions*, 1996

NREL private conversations with agent from leading Chinese Si PV manufacturer, January 2011

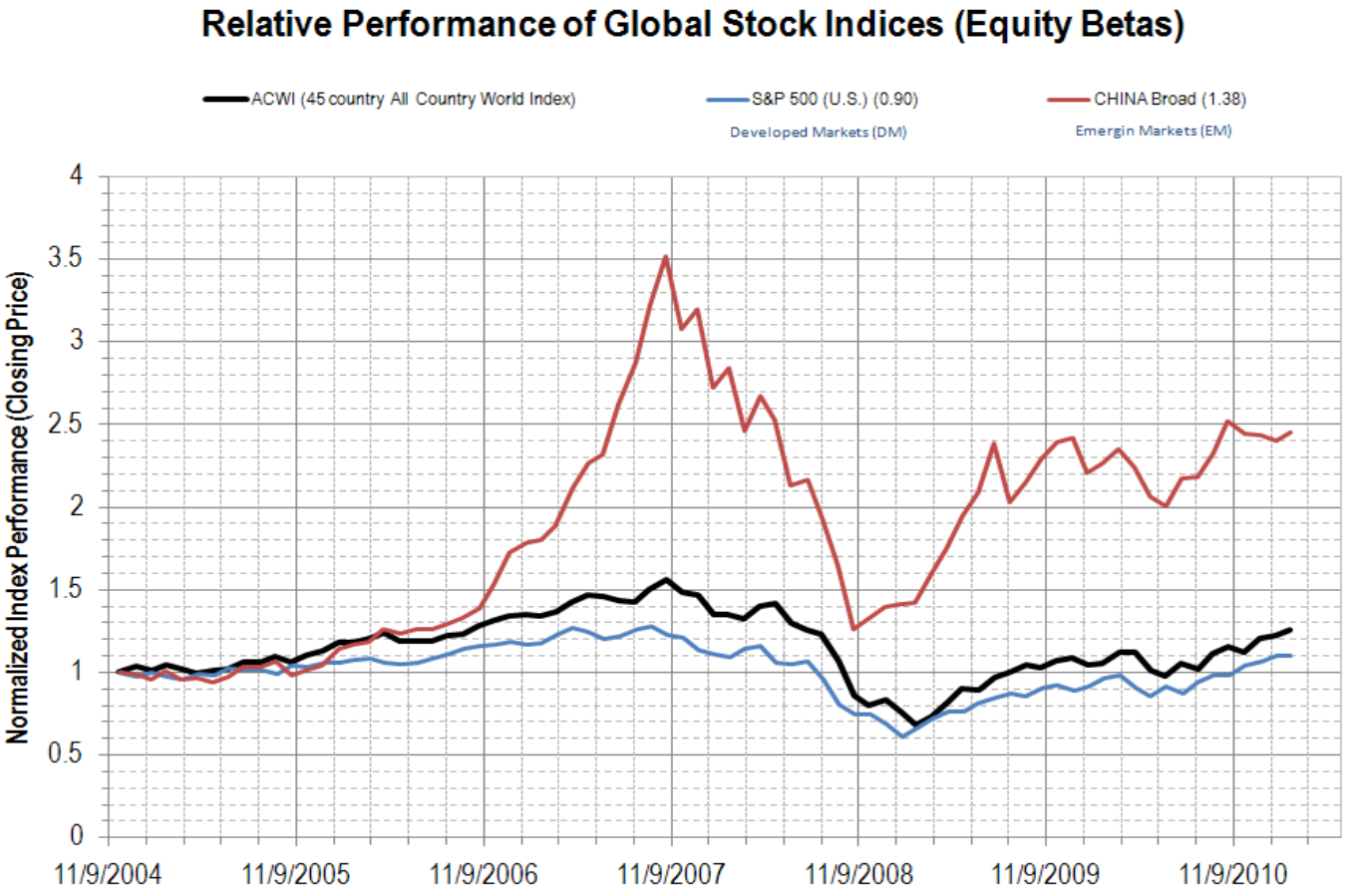
Inflation and Chinese Wages

Jiangsu province (Suntech) +5%, Jiangxi province (LDK) -26%



Source: National Bureau of Statistics of China, Federal Reserve Bank of St. Louis

Market Volatility in the Global Equity Market



$\beta_{U.S.} = 0.90$

$\beta_{China} = 1.34$

Specific market volatility measured as $\beta_{Country}$

- Covariance of target country index & ACWI, divided by variance of ACWI

Source: Goodrich, A.; Woodhouse, M.; Hsu, D. (2011) Si Solar Manufacturing Cost Models. In preparation. Golden, CO: NREL
MSCI website (www.mscibarra.com). Accessed September 9, 2011.

Global CAPM Overview

W.A.C.C. = $[(D/V) * K_D * (1 - \tau_C)] + [(E/V) * K_E]$

Levered, Nominal Cost of Debt (K_D):

$K_D = [(1 + Rf) * (1 + i) - 1]$ + levered corporate bond spread

Levered Cost of Equity (K_E):

$K_E = K_{E\ Unlevered} + [(D/E) * (K_{E\ Unlevered} - K_D)]$

Where, unlevered K_E is determined by unlevering R_E:

$$R_E = (K_D \ \& \ CRP) + (\beta_{Equity} * EMRP_{Global})$$

Country Risk Premium (CRP):

$$CRP = R_{F\ Country} - R_{F\ Global}$$

Equity Market Risk Premium (EMRP):

$$EMRP_{\ Global} = EMRP_{\ Country} / \beta_{Country}$$

- Levered corporate bond spread estimated based on current (Q3 2011) U.S. bond spreads, estimate of best (unlevered) Solar PV bond rating (B for established player, low gearing)
- β_{Equity} estimated based on private conversations wit hVCs, PE firms, banks. Solar PV industry: 2.0. Startup, e.g., company profiled in the following case study: 3.5

Source: Ogier, T.; Rugman, J.; Spicer, L. (2004). "The Real Cost of Capital." Prentice Hall, Financial Times. Pearson Education Limited, 2004. Edinburgh Gate, U.K.

Manufacturing Subsidies by Country

	U.S. Loan Guarantee, Manufacturing Tax Credit	U.S. State Subsidies	China
Domestic proprietorship required?			Yes
Sales/Value Added Tax waiver?	Yes	Yes	
Property tax credits	100%	100%	N/A
Subsidized cost of debt	4.0%	3.0%	3.0-4.5%
Subsidized debt limit (D/ D+E)	60%	60%	80%
delay in processing subsidized debt	2 years	<1 year	<1 year
Facilities grant		100%	100%
Land grant			Discount purchase (land use rights)
Training grant (millions USD)	$0.5-4.5	$0.5-4.5	
Effective Corporate income tax rate	28%	28%	21%
Income tax credits	30% MTC *Cash Grant in lieu*	State: 5-7 year holiday	20 year holiday

Sources: Private conversations with solar PV manufacturers who are investigating potential production sites in U.S. and non-U.S. locations.
United States Bureau of Labor Statistics, 2011
U.S. Energy Information Administration
The World Bank. International Finance Corporation. (www.doingbusiness.org)

Solar PV Module Technologies

Disaggregate supply chain

- Multiple players, some vertically integrated
- Intermediate products are relatively cheap to ship
- Wide range of automation levels
- Relatively mature, less tech. differentiation than TF PV

Many flavors of TF PV

- Many opportunities for tech. differentiation
- Monolithically integrated
- Single factory: glass & gas in, modules out
- No intermediate products (shipping costs)
- Automation does not vary, regionally

Photos left to right: NREL/PIX 19248; NREL/PIX 15377; NREL/PIX 13859; NREL/PIX 13569

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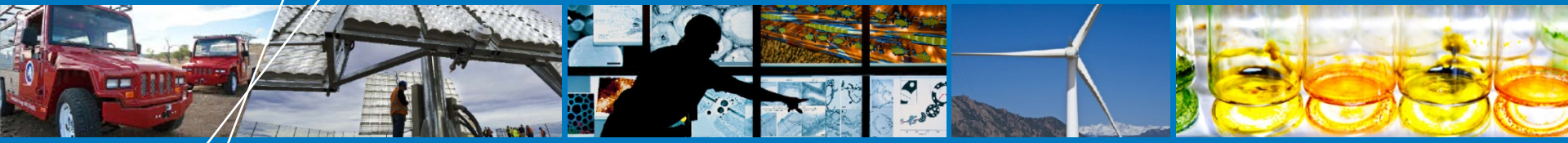


The Case for Foreign Direct Investment

China based c-Si PV manufacturer, U.S. customer (end market)

Silicon Cell & Module Manufacturing

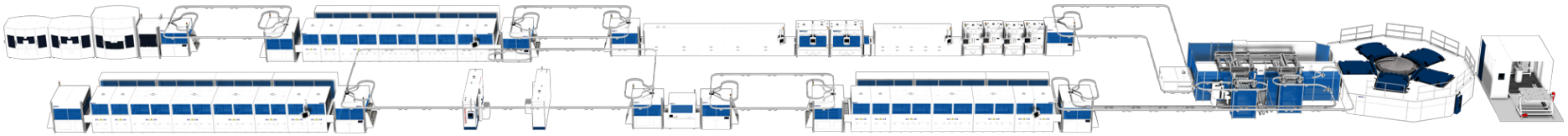


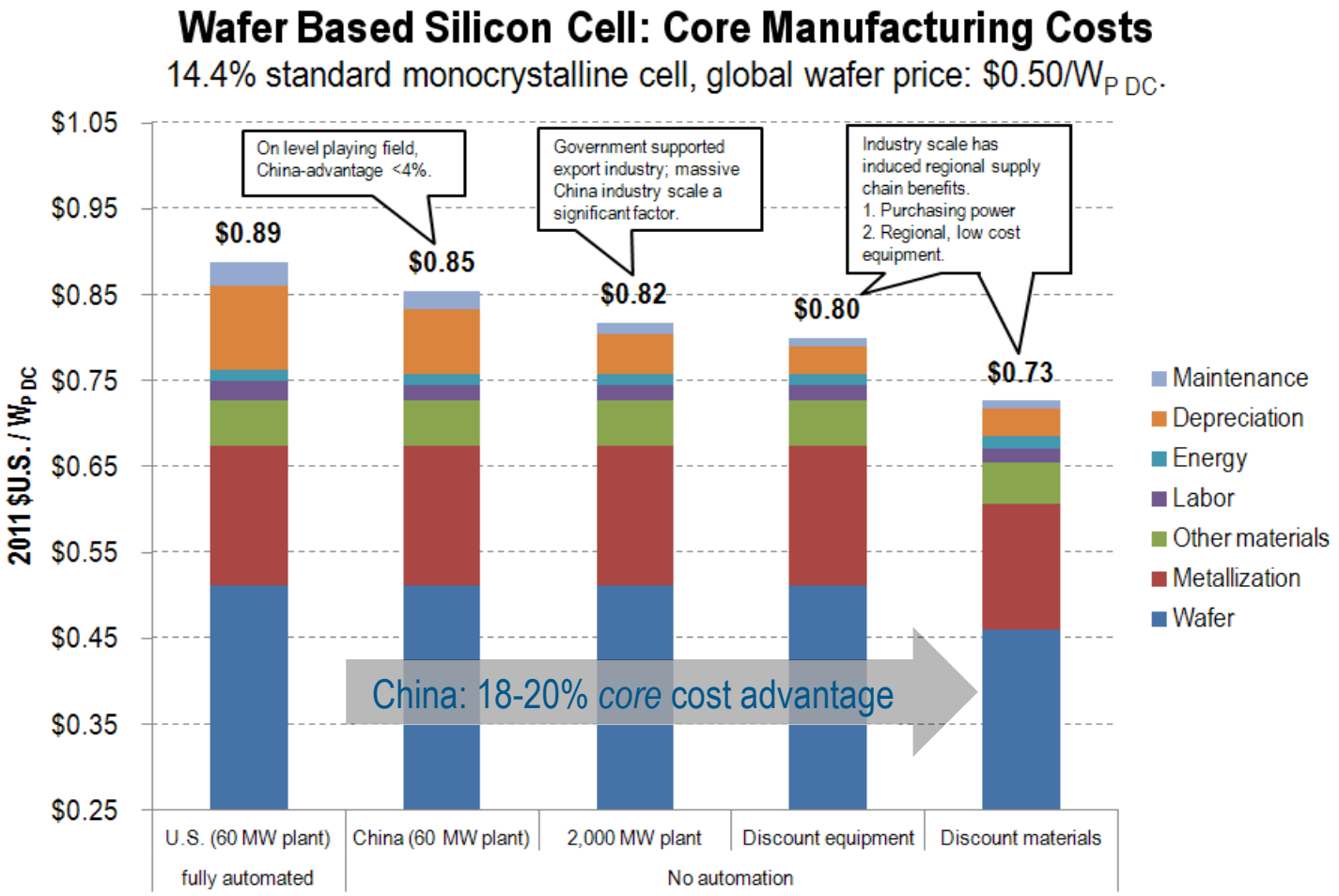
Illustration of a silicon cell line from the SCHMID Group | Gebr. SCHMID GmbH

- **Direct labor content varies from <1.0 job/MWP DC to 4.0 jobs/MWP DC**
  - Suntech automation strategy (~1.4 jobs/MWP DC) reflects inflation risk, not cost benefits
- **Relative to low cost labor regions, automation requires:**
  - 80% less direct labor content, 33% additional investment (automation)

500 $MW_{P\ DC}$ c-Si Cell & Module Facility	US			China		
	Cells	Modules	**Total**	Cells	Modules	**Total**
No. of Direct Laborers (all shifts)	296	104	**400**	1492	508	**2,000**
Unskilled Labor rate ($ per hour)	$13.33			$2.13		
Manufacturing Engineer ($ per year)	$75,110			$8,171		
Total facility Capex ($/$W_p$)	$0.49	$0.19	**$0.68**	$0.35	$0.16	**$0.51**

Sources: Goodrich, A.; Woodhouse, M.; Hsu, D. (2011) Si Solar Manufacturing Cost Models. In preparation. Golden, CO: NREL
Wenham, S. (2011) "Multigigawatt Manufacturing in China." IEEE PV Specialists Conference. Seattle, WA. June 20,2011
Bullis, K. (2011) "Chinese Solar Companies Thrive on Manufacturing Innovations." *Technology Review* published by MIT. July 6, 2011.

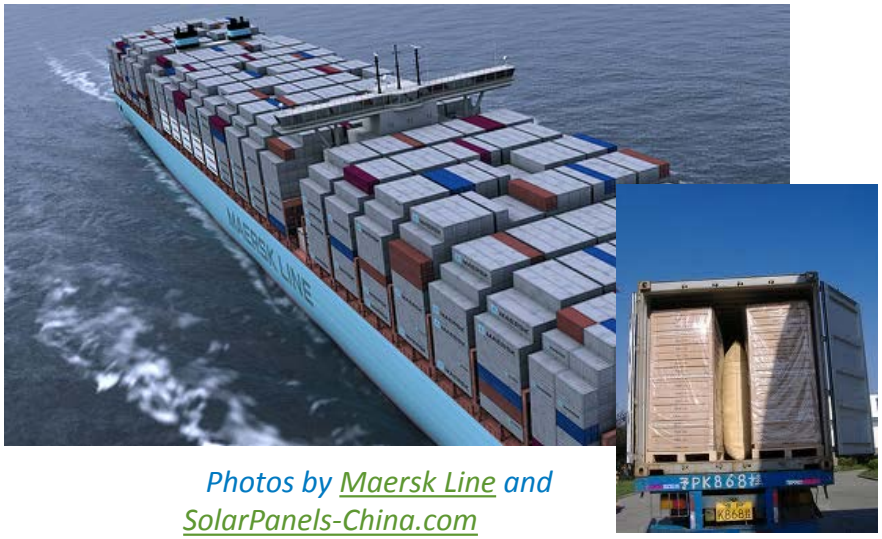
China's Comparative Advantage: Si Cells



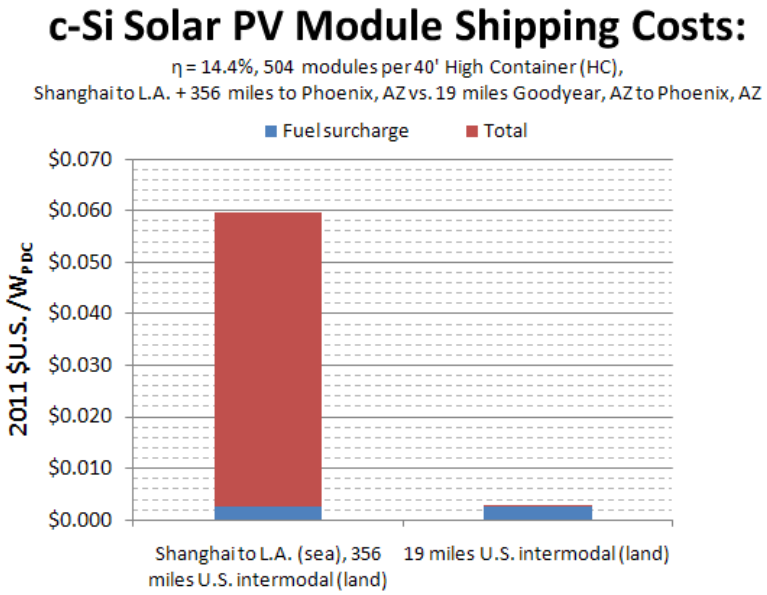
Is China's comparative advantage sustainable?

Sources: Goodrich, A.; Woodhouse, M.; Hsu, D. (2011) Si Solar Manufacturing Cost Models. In preparation. Golden, CO: NREL
National average labor rates assumed for U.S., China scenarios. "Discount materials": 10%.
"Discount equipment": 50% for wet benches, screen printer lines, co-firing furnace operations only.
"Core Costs" include direct labor, materials, energy, depreciation expenses, but exclude: shipping costs, cost of capital, taxes.

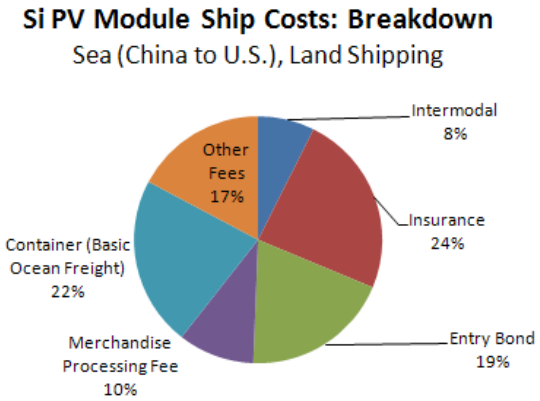
Si Module Shipping Costs



Photos by Maersk Line and SolarPanels-China.com



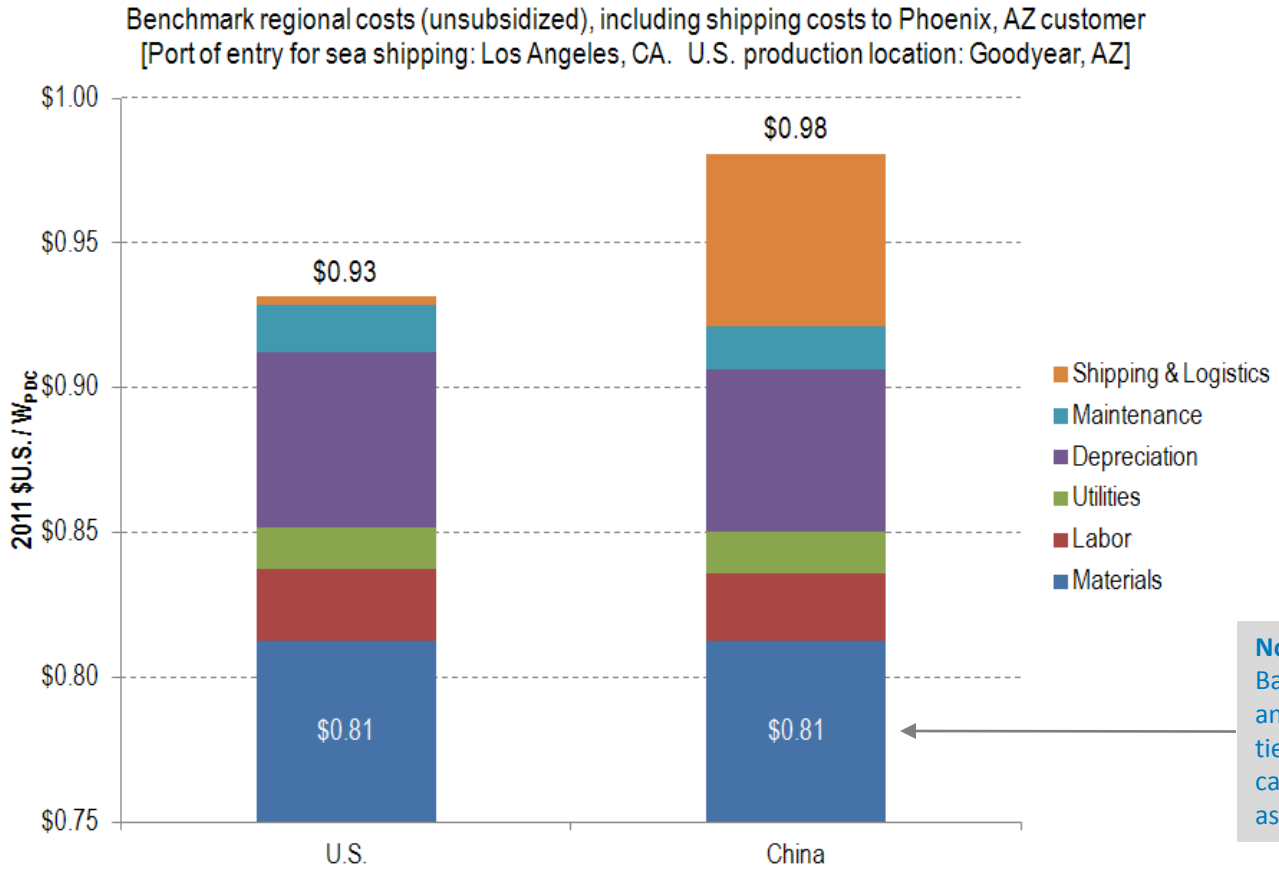
- Costs including fees, insurance are significant, total: ~$0.05/$W_{P\ DC}$
- Cost of capital excluded (Shanghai to Los Angeles: 30 day transit time)
- Cost of breakage excluded
- Shanghai to Hamburg, Newark to Hamburg costs roughly the same



Sources: (504) 27 kg modules/40 HC, STP280-24/Vd module datasheet. Suntech. EN-NA-STD-Vd-NO1.01-Rev 2010.
Maersk online shipping calculator, NREL private conversation with Maersk sales representatives. 2011
Bunker Adjustment Factor as of (March 31, 2011)
Fuel surcharge based on $3.96-$3.99/gallon gas price. Average DOE diesel fuel surcharge. (March 2011)

Regional Benchmarking Analysis:

Direct Si PV Module Core Costs



Note 1:
Cost structures that are heavily comprised of variable costs, including shipping costs are more sensitive to inflation.

Expected inflation:
- China: 6.5%
- U.S.: 3.6%

Note 2:
Based on one global wafer and cell prices (e.g. Chinese tier 1 module manufacturer can ship cells to U.S. module-assembly location for little cost).

- **China-direct (module) manufacturing cost benefits, excluding shipping: 1-2%**
- **Including shipping to U.S., China suffers a 5% cost disadvantage**
  - Above *Direct Costs* analysis excludes other regional factors: direct government subsidies, income taxes, global economic instability (inflation), and investment risk factors

Sources: Goodrich, A.; Woodhouse, M.; Hsu, D. (2011) Si Solar Manufacturing Cost Models. In preparation. Golden, CO: NREL
Maersk online cost estimating tool (accessed March 2011). NREL internal shipping cost model.

Cost of Capital (Global CAPM): Tier 1 Si company

Facility location **Subsidy program, if any.**	**U.S.**	**U.S.** **Loan Guarantee (LG)**	**U.S.** **LG, 30% MTC grant[2]**	**U.S.** **State Subsidies**	**China**	**China** **Subsidized**
Debt percent (book D / book V)[1]	60%	60%	60%	60%	60%	60%
Nominal Cost of Debt ($K_{D\ Nominal}$)[6]	6.4%[13]	4.0%	4.0%	3.0%	10.2%	4.5%[13]
Loan Terms[4]		2 year delay, $2.5 million application costs	2 year delay, $2.5 million application costs			Foreign ownership limited to minority stake
Expected Inflation (i)[5]	3.6%				6.5%	
Real Cost of Debt ($K_{D\ Real}$)[3]	**2.7%**	**0.4%**	**0.4%**	**-0.6%**	**3.8%**	**-1.9%**
Expected Market Return(R_m)	10.8%[7]				18.1%[8]	
Country Beta ($\beta_{country}$)[9]	0.91				1.34	
Nominal $EMRP_{Global}$[10]	11.0%				10.1%	
Country Risk Premium (CRP)	0%				3.8%	
Company's Equity Beta ($\beta_{E\ Company}$)	3.4[11]					
Levered (Global) Cost of Equity ($K_{E\ Levered}$)[12]	**38.1%**				**42.7%**	
Effective Corporate Tax Rate (T_C)[15]	**28%**				**21%**	**0%[14]**
Global CAPM (WACC) or Hurdle Rate:[16]	**16.4%**	**15.4%**	**15.4%**	**15.0%**	**22.0%**	**19.8%**

See next slide for footnotes

Cost of Capital (Global CAPM): Tier 1 Si company

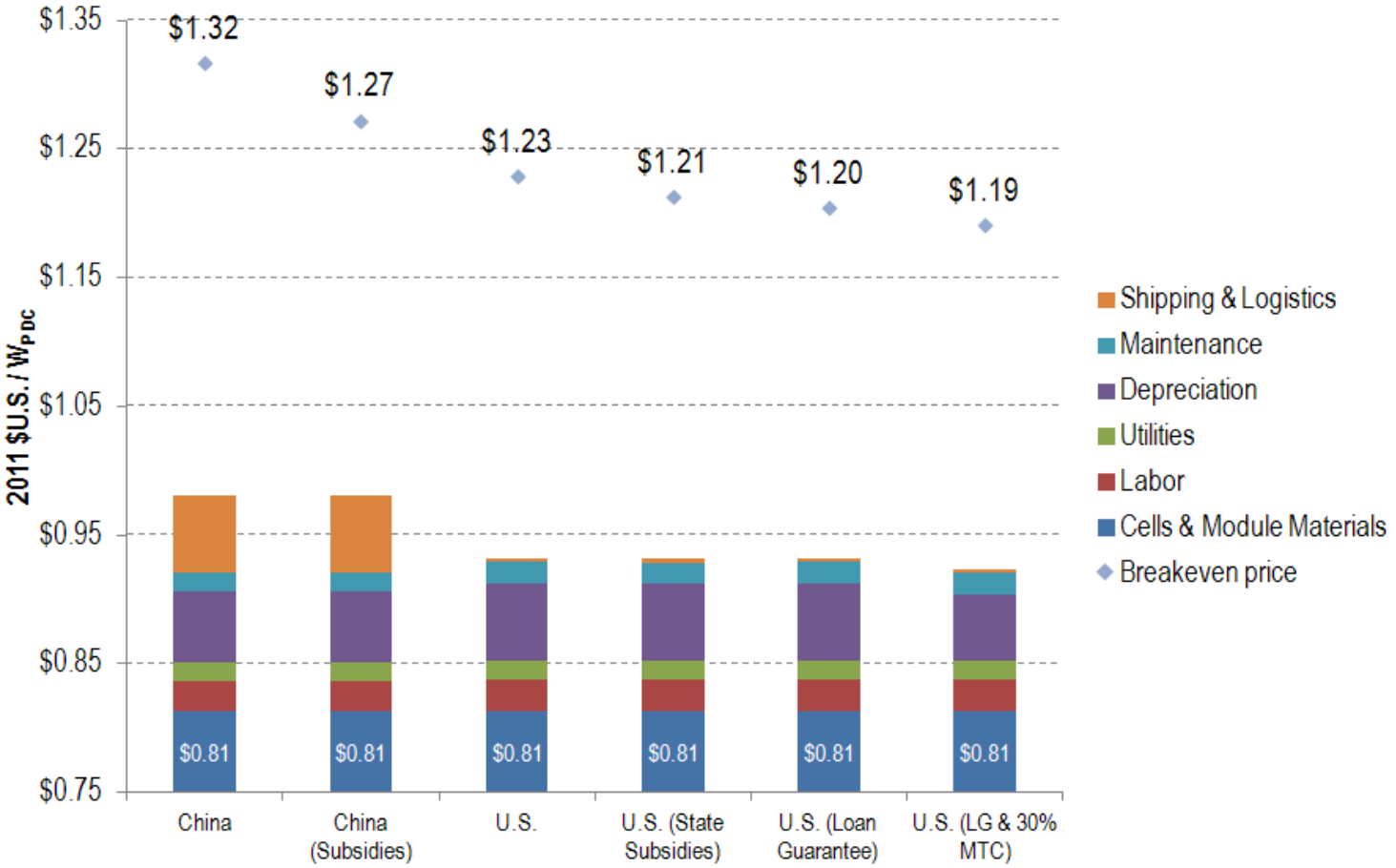
Footnotes

1. Based on Suntech Corporation book value of total debt divided by book value of total assets (as of 10/06/11).
2. 30% Manufacturing Tax Credit (MTC) monetized in year 1, effectively reducing depreciation expenses.
3. $K_{D\ real} = R_f$ + Debt Margin; R_f = Global risk free rate (10 year U.S. T-bill), Debt Margin = corporate bond spread estimated based on company leverage
4. U.S. LG award delay: 2 years, application cost: $2.5 million); Low cost China debt subsidized based on condition that foreign ownership is limited to minority stake (≤49%)
5. Average rate of inflation (i) since Jan-2008 for U.S. and China, as reported by "Trading Economics" (www.tradingeconomics.com)
6. Based on Fisher equation: $K_{D\ nominal} = (1 + K_{D\ real})*(1 + i) - 1$
7. Expected market return ($R_{m\ U.S.}$): S&P 500. 50 years: 1961 to present (September 2011).
8. Expected market return ($R_{m\ China}$): MSCI AWCI Broad China
9. Country Beta ($\beta_{Country}$) = Covariance (Country Index, MSCI AWCI) / Variance (MSCI AWCI)
10. Nominal Equity Market Risk Premium (EMRP) = $(R_m - K_{D\ nominal})/B_{Country}$
11. Company's Equity Beta ($B_{E\ Company}$) based on Suntech Corporation, as reported by yahoo.finance.com (10/6/11)
12. $K_{E\ Levered} = K_{E\ Unlevered} + [(D/E)*(K_{E\ Unlevered} - K_{D\ nominal})]$
13. Source: Interest rates on debt, Suntech Corporation, BNEF (2008-2011)
14. 20 year China corporate tax holiday
15. U.S. Mean Effective Tax Rate (ETR): 28%; China 21%: . Markle, S.; Shackelford, D. (2009). " Do Multinationals of Domestic Firms Face Higher Effective Tax Rates?" NBER Working Paper Series. NBER Cambridge, MA.
16. WACC = $[(E/V)*K_{E\ Levered}] + [(D/V)*K_{D\ nominal}*(1 - T_C)]$

Regional Benchmarking Analysis:

Minimum Sustainable Si PV Module Price

- Chinese Si PV manufacturers should consider regional module production strategy
- Regional module manufacturing facilities located near end markets reduce glass shipping costs and mitigate impact of China's inflation on product costs



Sources: Goodrich, A.; Woodhouse, M.; Hsu, D. (2011) Si Solar Manufacturing Cost Models. In preparation. Golden, CO: NREL
NREL internal DCF (2011), including Global CAPM analysis and country based incentives (private conversations with PV companies)

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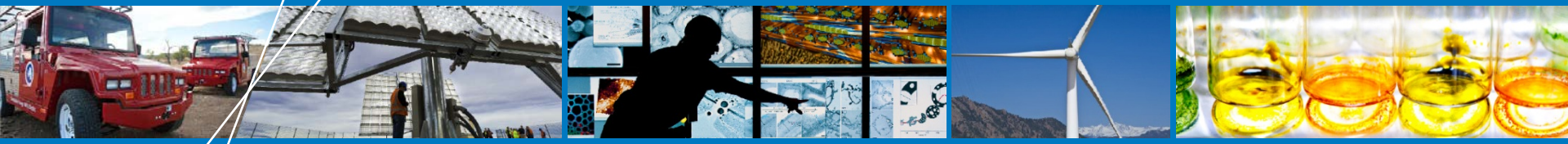
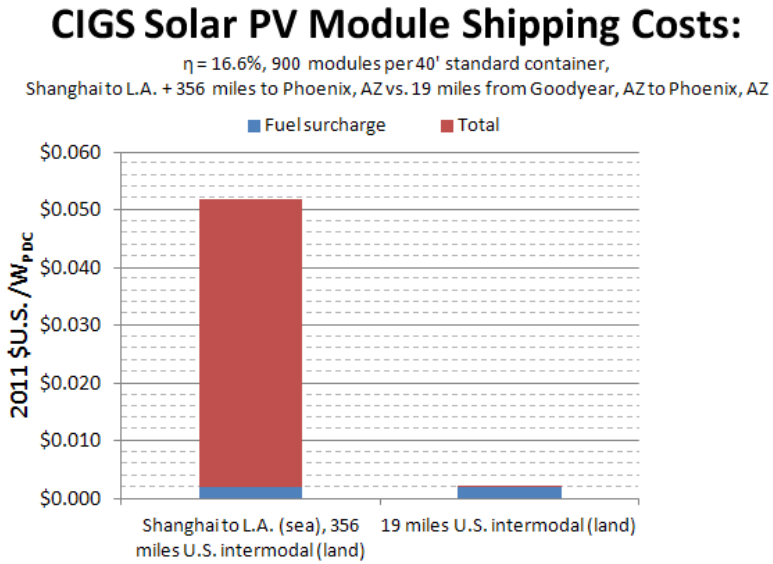


Capitalizing on U.S. Innovation

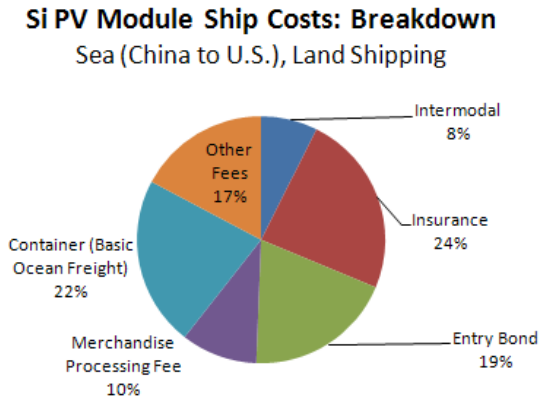
U.S.–based thin film (CIGS) PV startup, U.S. customer (end market)

CIGS Module Shipping Costs

Photos by Maersk Line and SolarPanels-China.com



- Costs including fees, insurance are significant, total: ~$0.05/$W_{P\ DC}$
- Cost of capital excluded (Shanghai to Los Angeles: 30 day transit time)
- Cost of breakage excluded
- Shanghai to Hamburg, Newark to Hamburg costs roughly the same



Sources: (900) 20 kg modules/SF140-L module datasheet. Solar Frontier. 20110722_Datasheet_SF140-155 Letter. 2010.
Maersk online shipping calculator, NREL private conversation with Maersk sales representatives. 2011
Bunker Adjustment Factor as of (March 31, 2011)
Fuel surcharge based on $3.96-$3.99/gallon gas price. Average DOE diesel fuel surcharge. (March 2011)

Regional CIGS Module Costs

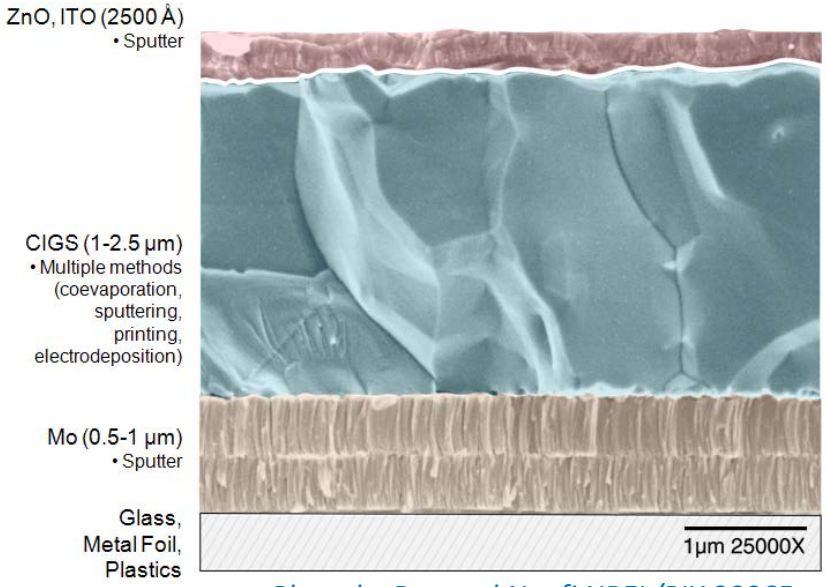


Photo by Rommel Noufi NREL/PIX 20065

- **CIGS direct labor content assumed not to vary by region: ~0.9 job/$MW_{P\ DC}$**

600 $MW_{P\ DC}$ CIGS Module Facility (near term target module efficiency = 16.6%)	**US**	**China**
No. of Direct Laborers (all shifts)	540	540
Unskilled Labor rate ($ per hour)	$13.33	$2.13
Manufacturing Engineer ($ per year)	$75,110	$8,171
Total facility Capex ($/$W_p$)	$0.40	$0.33

First Solar (Copy Smart™):
Vietnam (2H 2011) facility
$300MM, 600 jobs / 250 $MW_{P\ DC}$ capacity
http://compoundsemiconductor.net

Mesa, AZ U.S. (3Q 2012) facility
$300MM, 600 jobs / 250 $MW_{P\ DC}$ capacity
http://www.brighterenergy.org

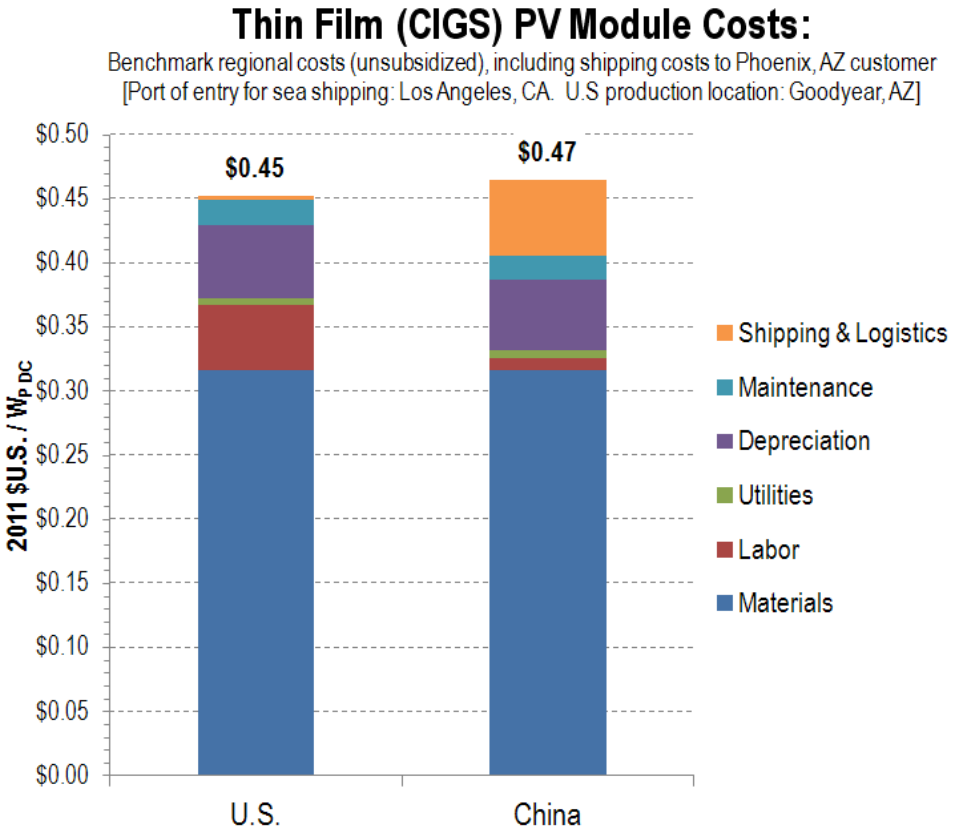
Sources: Goodrich, A.; Noufi, R.; Woodhouse, M. (2011) "CIGS Solar Manufacturing Cost Models." In preparation. NREL, Golden, CO

Regional Benchmarking Analysis:

Direct CIGS PV Module Core Costs

- China-direct manufacturing cost benefits, excluding shipping: 10%
- Including shipping to U.S., China advantage reduced to -3%

Direct Costs analysis excludes other regional factors: direct government subsidies, income taxes, global economic instability (inflation), investment risk factors



Sources: Goodrich, A.; Noufi, R.; Woodhouse, M.;(2011) CIGS Solar Manufacturing Cost Models. In preparation. Golden, CO: NREL
Maersk online cost estimating too (accessed March 2011). NREL internal shipping cost model.

Cost of Capital (Global CAPM): CIGS start-up

Facility location **Subsidy program, if any.**	**U.S.**	**U.S.** **Loan Guarantee (LG)**	**U.S.** **LG, 30% MTC grant[2]**	**U.S.** **State Subsidies**	**China**	**China** **Subsidized**
Debt percent (book D / book V)[1]	65%	60%	60%	60%	50%	80%
Nominal Cost of Debt ($K_{D\ Nominal}$)[6]	8.9%	4.0%	4.0%	3.0%	9.5%	3.0%[13]
Loan Terms[4]		2-year delay, $2.5 million application costs	2-year delay, $2.5 million application costs			Foreign ownership limited to minority stake
Expected Inflation (i)[5]	3.6%				6.5%	
Real Cost of Debt ($K_{D\ Real}$)[3]	**5.1%**	**0.4%**	**0.4%**	**-0.6%**	**3.1%**	**-3.3%**
Expected Market Return(R_m)	10.8%[7]				18.1%[8]	
Country Beta ($\beta_{country}$)[9]	0.91				1.34	
Nominal $EMRP_{Global}$[10]	11.0%				10.1%	
Country Risk Premium (CRP)	0%				3.8%	
Company's Equity Beta ($\beta_{E\ Company}$)	3.5[11]					
Levered (Global) Cost of Equity ($K_{E\ Levered}$)[12]	**39.2%**	**37.0%**	**37.0%**	**37.0%**	**43.7%**	**77.2%**
Effective Corporate Tax Rate (T_C)[15]	**28%**				**21%**	**0%[14]**
Global CAPM (WACC) or Hurdle Rate:[16]	**17.9%**	**16.6%**	**16.6%**	**16.1%**	**25.6%**	**17.8%**

See next slide for footnotes

Cost of Capital (Global CAPM): CIGS start-up

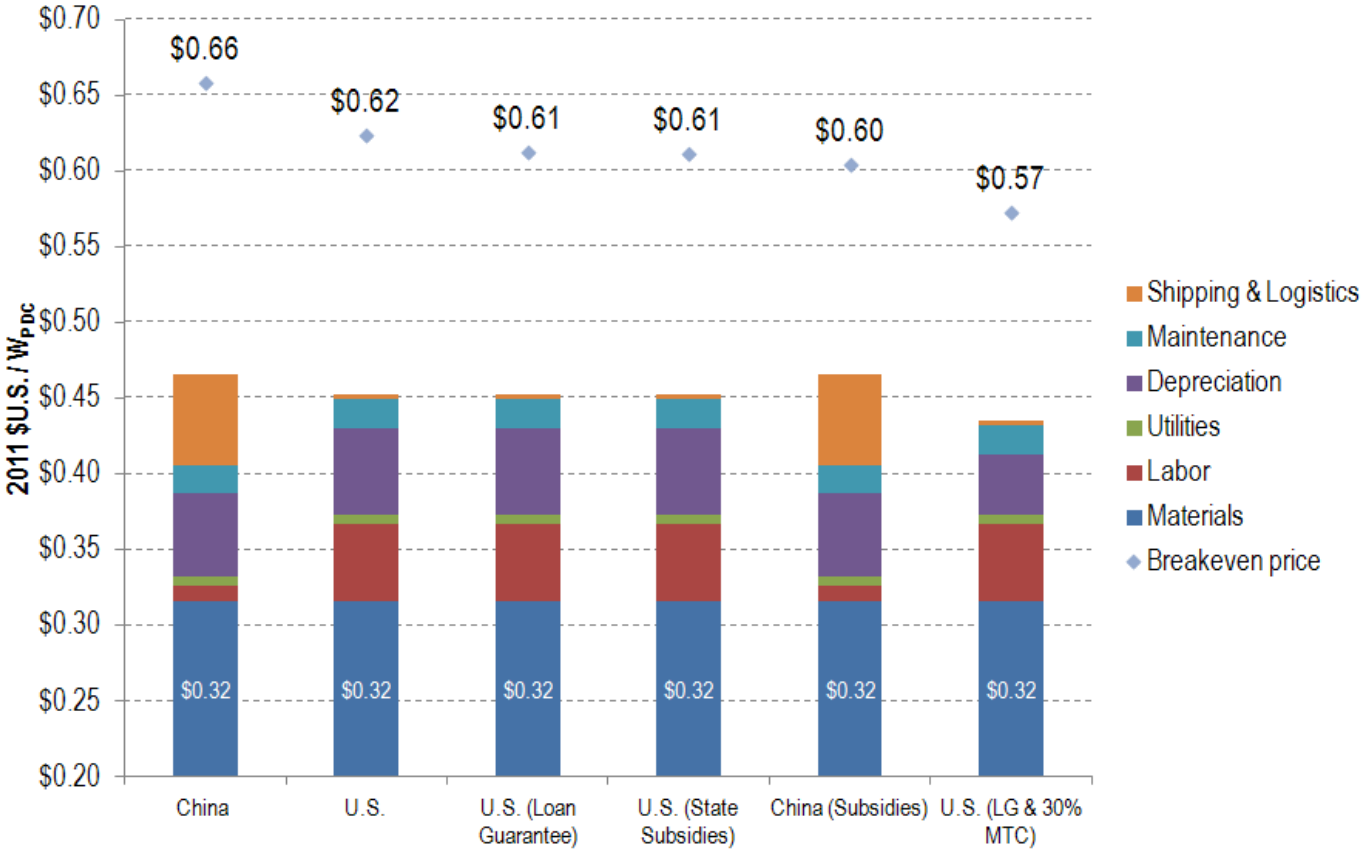
Footnotes

1. Based on Suntech Corporation book value of total debt divided by book value of total assets (as of 10/06/11).
2. 30% Manufacturing Tax Credit (MTC) monetized in year 1, effectively reducing depreciation expenses.
3. $K_{D\ real} = R_f$ + Debt Margin; R_f = Global risk free rate (10 year U.S. T-bill), Debt Margin = corporate bond spread estimated based on company leverage
4. U.S. LG award delay: 2 years, application cost: $2.5 million); Low cost China debt subsidized based on condition that foreign ownership is limited to minority stake (≤49%)
5. Average rate of inflation (i) since Jan-2008 for U.S. and China, as reported by "Trading Economics" (www.tradingeconomics.com)
6. Based on Fisher equation: $K_{D\ nominal} = (1 + K_{D\ real})*(1 + i) - 1$
7. Expected market return ($R_{m\ U.S.}$): S&P 500. 50 years: 1961 to present (September 2011).
8. Expected market return ($R_{m\ China}$): MSCI AWCI Broad China
9. Country Beta ($\beta_{Country}$) = Covariance (Country Index, MSCI AWCI) / Variance (MSCI AWCI)
10. Nominal Equity Market Risk Premium (EMRP) = $(R_m - K_{D\ nominal})/B_{Country}$
11. Hypothetical company beta based on conversations with firms that have experience investing in solar PV start-ups.
12. $K_{E\ Levered} = K_{E\ Unlevered} + [(D/E)*(K_{E\ Unlevered} - K_{D\ nominal})]$
13. As reported by PV start-ups investigating potential facility locations (2010).
14. 20 year China corporate tax holiday
15. U.S. Mean Effective Tax Rate (ETR): 28%; China 21%: . Markle, S.; Shackelford, D. (2009). " Do Multinationals of Domestic Firms Face Higher Effective Tax Rates?" NBER Working Paper Series. NBER Cambridge, MA.
16. WACC = $[(E/V)*K_{E\ Levered}] + [(D/V)*K_{D\ nominal}*(1 - T_C)]$

Regional Benchmarking Analysis

Minimum Sustainable CIGS PV Module Price

- The cost of China's subsidies (domestic proprietorship requirement, impact of significant government ownership on cost of equity) is largely left un-quantified in this analysis.
- Over past 2-3 years, the "U.S." (unsubsidized) case has largely been unavailable to innovative thin film startups. Unsubsidized access to capital in United States has been limited.



Sources: Goodrich, A.; Noufi, R.; Woodhouse, M. (2011). "CIGS Solar Manufacturing Cost Models." In preparation. NREL, Golden, CO
NREL internal DCF (2011), including Global CAPM analysis and country based incentives (private conversations with PV companies)

Summary

- **China is the world's leader in global production (55% market share)**
  - 95% of production is exported; no domestic demand
- **The U.S. is a leader in early stage technology investments that have disruptive potential**
- **Shipping costs offset China's core cost advantage**
  - c-Si module advantage reduced from 1% to -5%
  - CIGS advantage reduced from 10% to -3%
- **Access to low cost capital is needed to offset investment risk in emerging markets**
  - Cost of capital: China (26%) $\xrightarrow{\text{with subsidy}}$ (18%), vs. U.S. (18%)
  - Inflation and changes in value of currency are significant

Conclusions

- **China advantage may not be sustainable**
  - Inflation
  - Growing importance of shipping costs
  - Reliance on massive government subsidies
  - Lack of technology diversification
    - Risk of being supplanted by disruptive non-Si technology

- **U.S. incentives can level the playing field**
  - The scale of Chinese incentives dwarf U.S. efforts
  - Access to capital is a critical compliment to the United States' capacity to innovate

U.S. Solar PV Opportunities and Challenges

Comparative advantages

- Low cost electricity (hydro power and poly Si)
- Complimentary industries
  - Specialty chemicals, non-woven films (Dow, DuPont, 3m, Eastman Chemical, etc.)
- Institutional capacity for R&D (innovation)
- Private capital
- Demand potential

Risk factors

- Material resource availability
- Policy uncertainty (R&D funding, industrial incentives)
- Inflation

Acknowledgements

Colleagues at NREL who have contributed through both formal and informal discussions. Special thanks to David Feldman, Robert Margolis, and Rommel Noufi.

Many industrial collaborators for their willingness to share data and provide invaluable external review.

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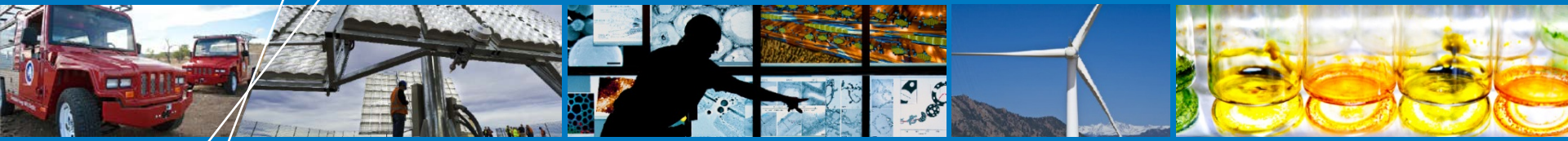
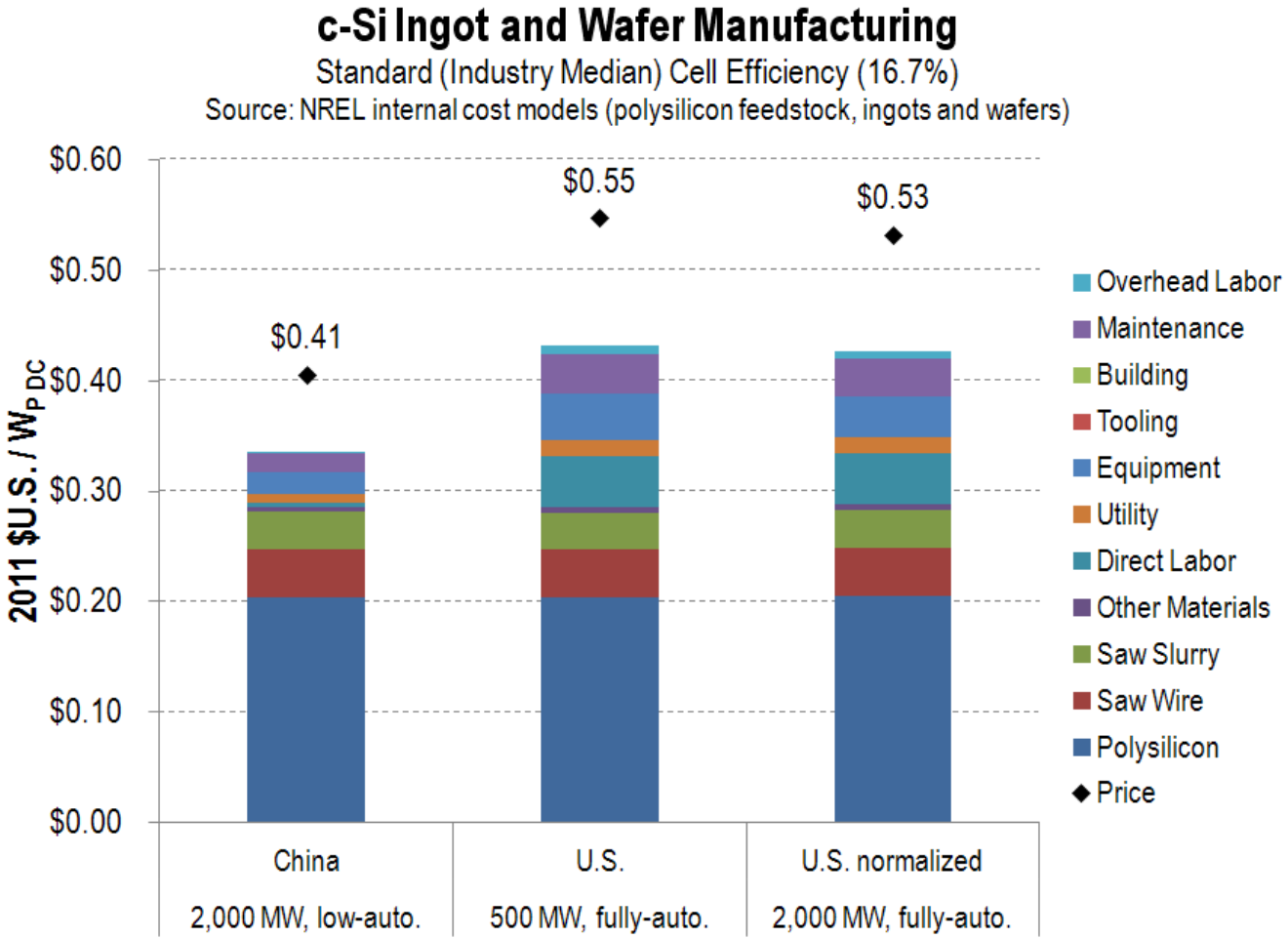


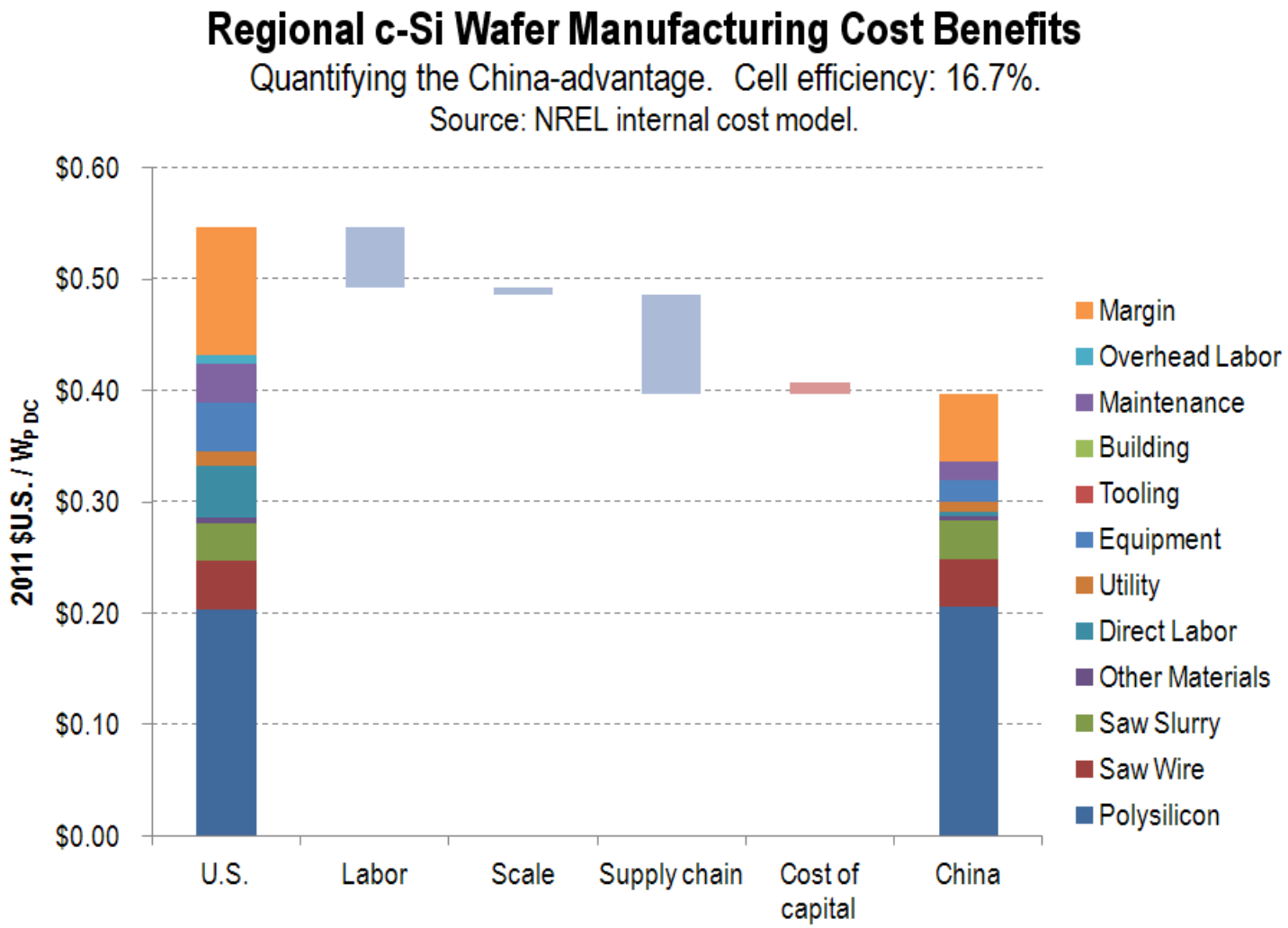
APPENDIX

c-Si Wafer Costs: 2011 Benchmark

- China's ingot and wafering advantage (~$0.14/WP DC)
- Labor intensive, and difficult to fully automate.

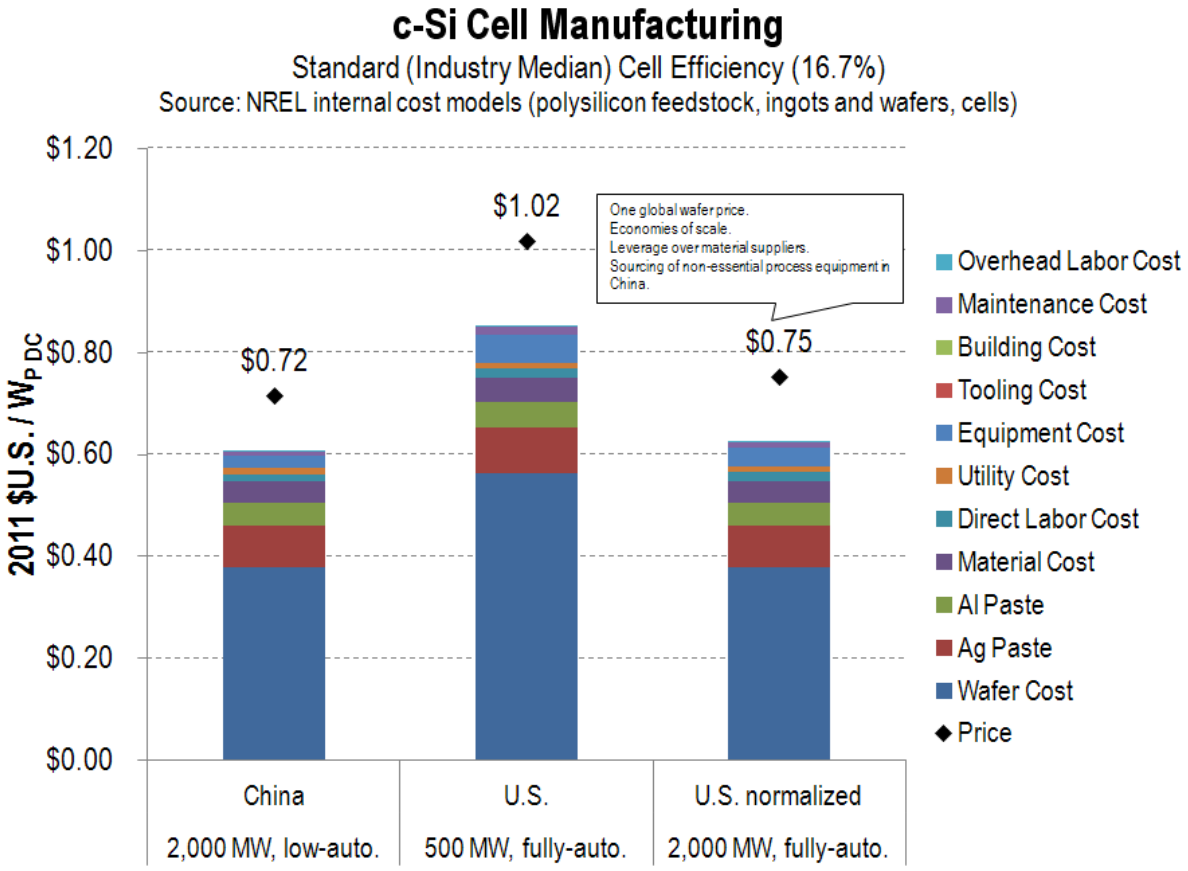


Regional Wafer Manufacturing



c-Si Cell Costs: 2011 Benchmark

- Little difference in regional costs, but negligible shipping costs and manufacturing scale benefits (regional supply chain)
- Low cost Chinese equipment vendors (wet-benches, screen-printers, firing)
- Regional-differences in automation



$U.S. 1/W$_{P\ DC}$ Chinese w-Si Panels: Unsustainable

- Recent module price reductions driven by poly price, manufacturer scale, and level of vertical integration
- Can U.S. w-Si manufacturers survive latest price wars?