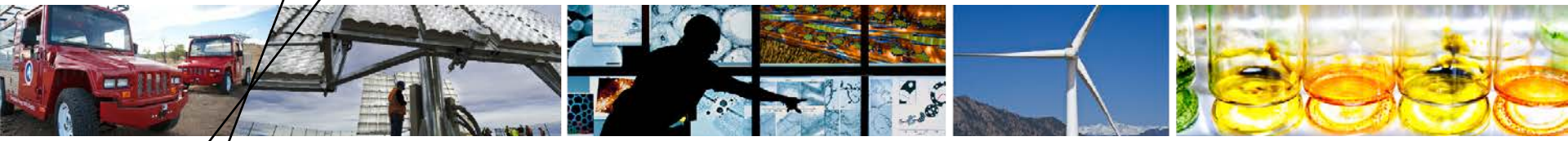
NREL
NATIONAL RENEWABLE ENERGY LABORATORY

Economics of Future Growth in Photovoltaics Manufacturing



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IEEE Photovoltaic Specialists Conference

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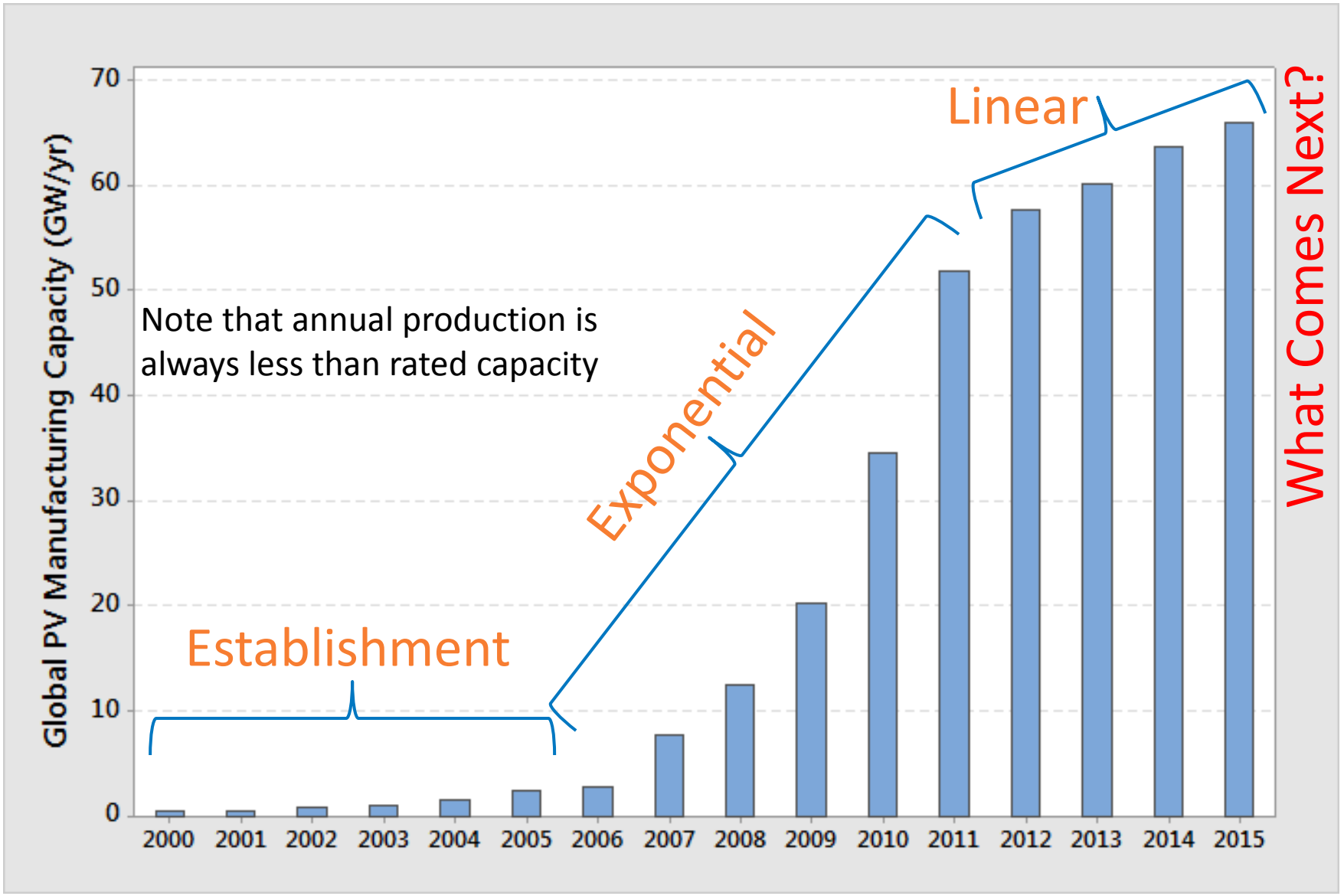
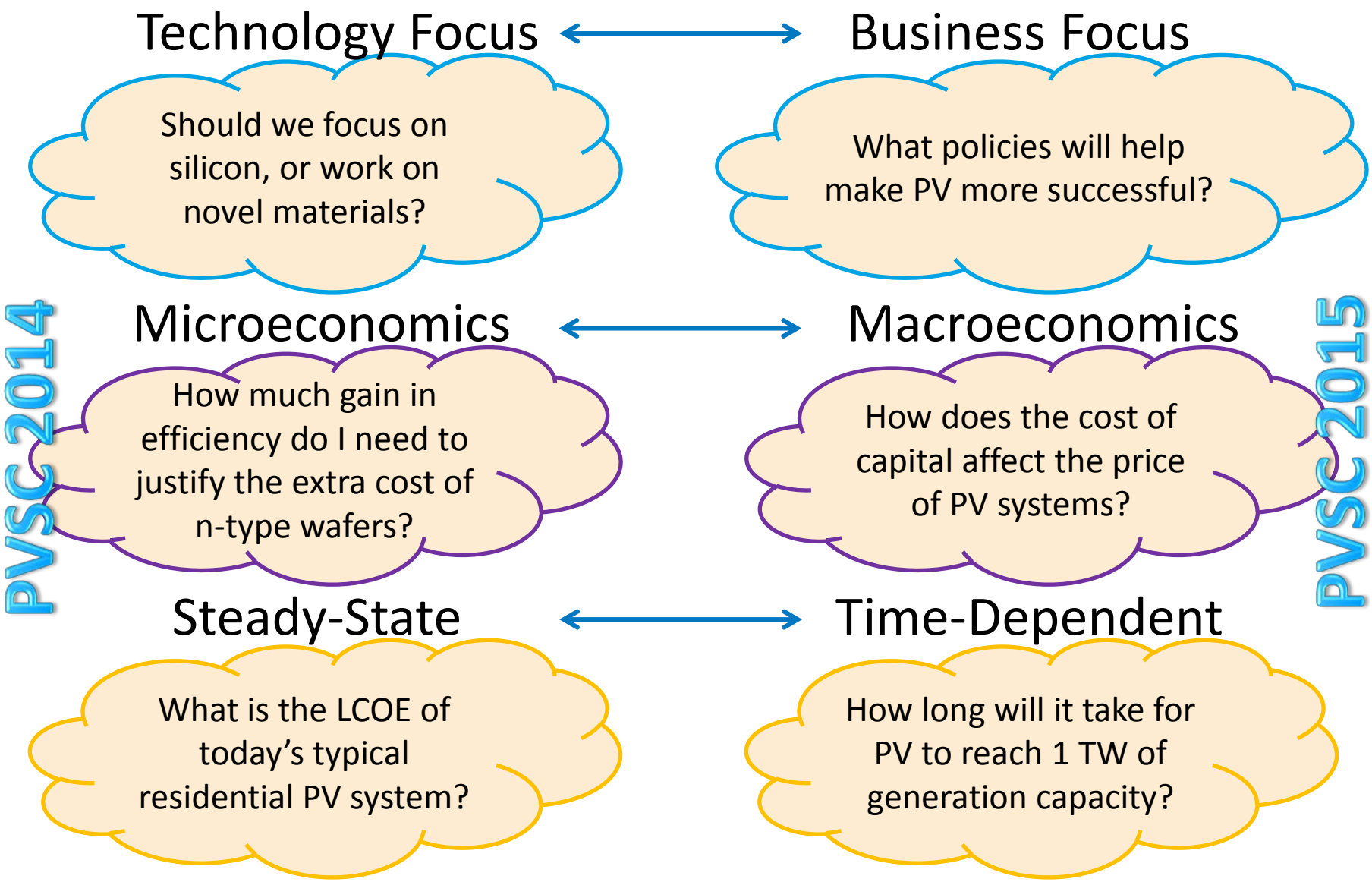
Global PV Manufacturing Capacity



Predicting the Future of PV



The Simple Basis for this Presentation

The future of PV manufacturing is determined by:

- **How much is invested**
  - Capital Investment Rate: *CapIR*

- **How much it costs**
  - Capital Demand Rate: *CapDR*

Basic Assumptions

- **Global PV manufacturing can be treated as an *integrated* value chain from polysilicon production through module assembly**
  - The size of the global PV manufacturing industry can be characterized by the nominal ("nameplate") manufacturing capacity of this value chain

- **Annual global investment in PV manufacturing tends to scale approximately in *proportion* to the size of the industry**
  - Internal investment depends on sector's earnings
  - External investment depends on size of market
  - Availability of capital depends on perceived risk

  } Bigger fares better

- **Time-dependency details**
  - There is a delay of 6 to 24 months between a decision to invest in capacity expansion and its subsequent commissioning (nominal average 1 *year*)
  - Manufacturing assets are useful for 5 to 15 years (nominal average *10 years*)
  - PV systems survive for 15 to 25 years (nominal average *20 years*)

Capital Cost of Manufacturing Capacity

PV-Critical Manufacturing	Capex ($yr/W)
Polysilicon Production	0.33
Ingot Casting/Wafer Slicing	0.25
Cell Fabrication	0.30
Module Assembly	0.13
TOTAL	**1.01**

- **Capital expense (Capex) normalized to nominal manufacturing capacity**
  - Scientifically correct unit is $ per (W/yr) = $yr/W
  - Capex increases sublinearly with manufacturing capacity of each plant, but…
    - Capex is similar for additional plants of similar scale, thus linear on global scale
  - Figures in table above assume 2 GW/yr plant scale located in the USA*
    - These figures are lower in Asia, but add values there for glass, backsheets, etc.
  - Net result is a globally nominal 1 $yr/W
    - Plant utilization is treated separately
    - Cost of capital treated separately

*D. Powell, R. Fu, K. Horowitz, P. Basore, M. Woodhouse, and T. Buonassisi, "The capital intensity of crystalline silicon photovoltaics: Barriers to scale and opportunity for innovation," publication pending

Annualized Capital Requirement

- **Capital Demand Rate (*CapDR*)**

Capital expense normalized to manufacturing capacity (Capex, $yr/W)

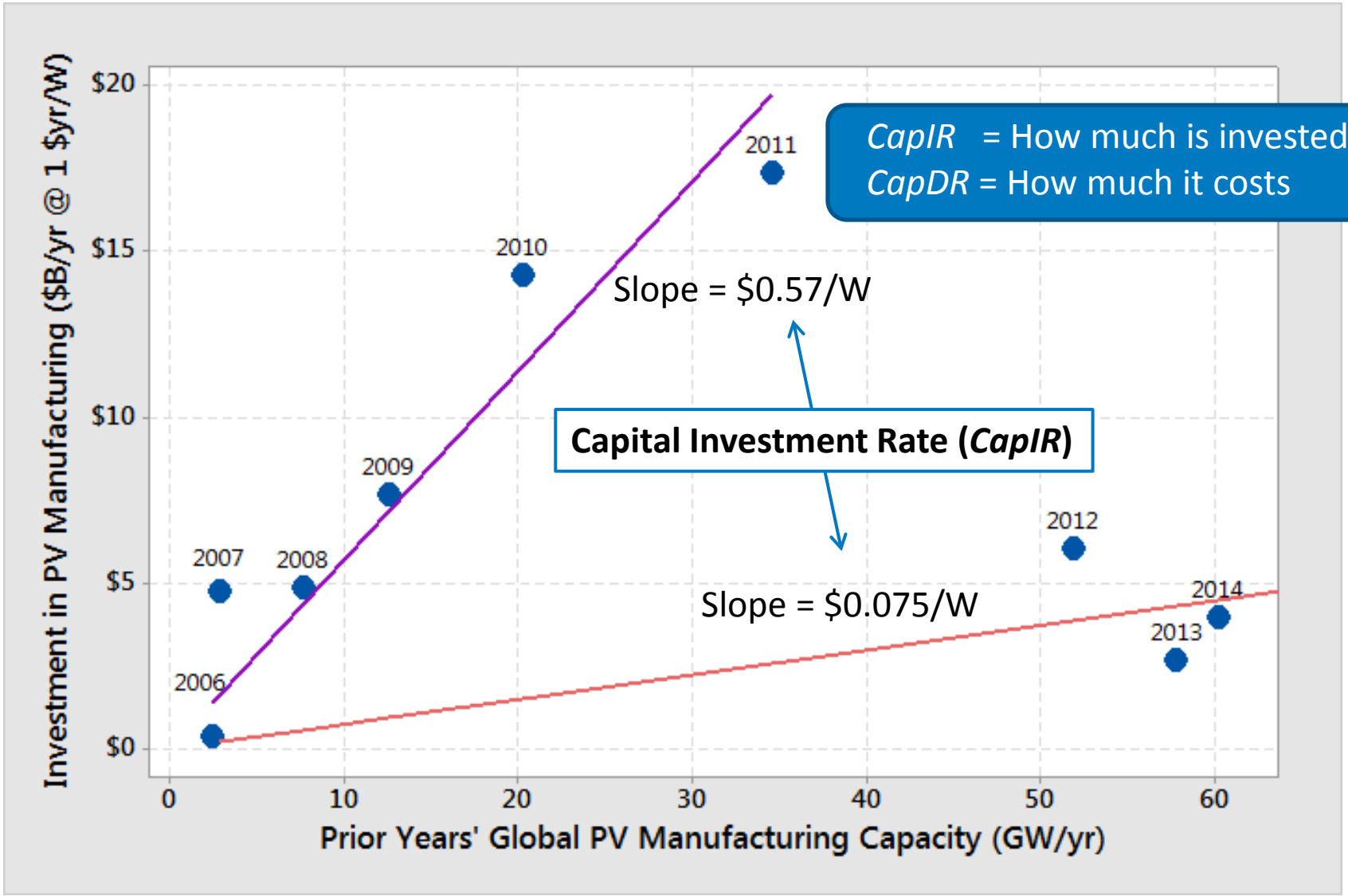
Divided by the average life of the manufacturing assets (yr)

Increased to account for the weighted average cost of capital (WACC, %/yr)

$$\frac{1\ \$yr/W}{10\ yr} \times \left[1 + \frac{10\%/yr \times 10yr}{2}\right] = \$0.15/W$$

- **WACC**
  - Range for subsidized/guaranteed loans 0-10%/yr
  - Range for conventional loans 10-15%/yr
  - Range for equity investments 15-25%/yr
  - Assume a mix of types averaging 10%/yr

Global Investment in PV Manufacturing



Baseline Scenario

- ***CapIR* stays near its current level**
  - Price competition limits profits available to increase investment
  - Companies with declining investment will lose market share
  - Baseline Scenario: Assume *CapIR* will stay in the range $0.05/W - $0.10/W

- ***CapDR* stays near its current level**
  - The size of the PV industry has already achieved most of the benefits of scale
  - Improvements require real innovation on a massive scale, which is slow
  - Baseline Scenario: Assume *CapDR* will stay in the range $0.10W - $0.20/W

- **What will happen if *CapIR* and *CapDR* stay near their current levels?**
  - *CapIR* < *CapDR* is not sustainable in the long term!
  - Not enough investment to replace manufacturing assets as they are retired

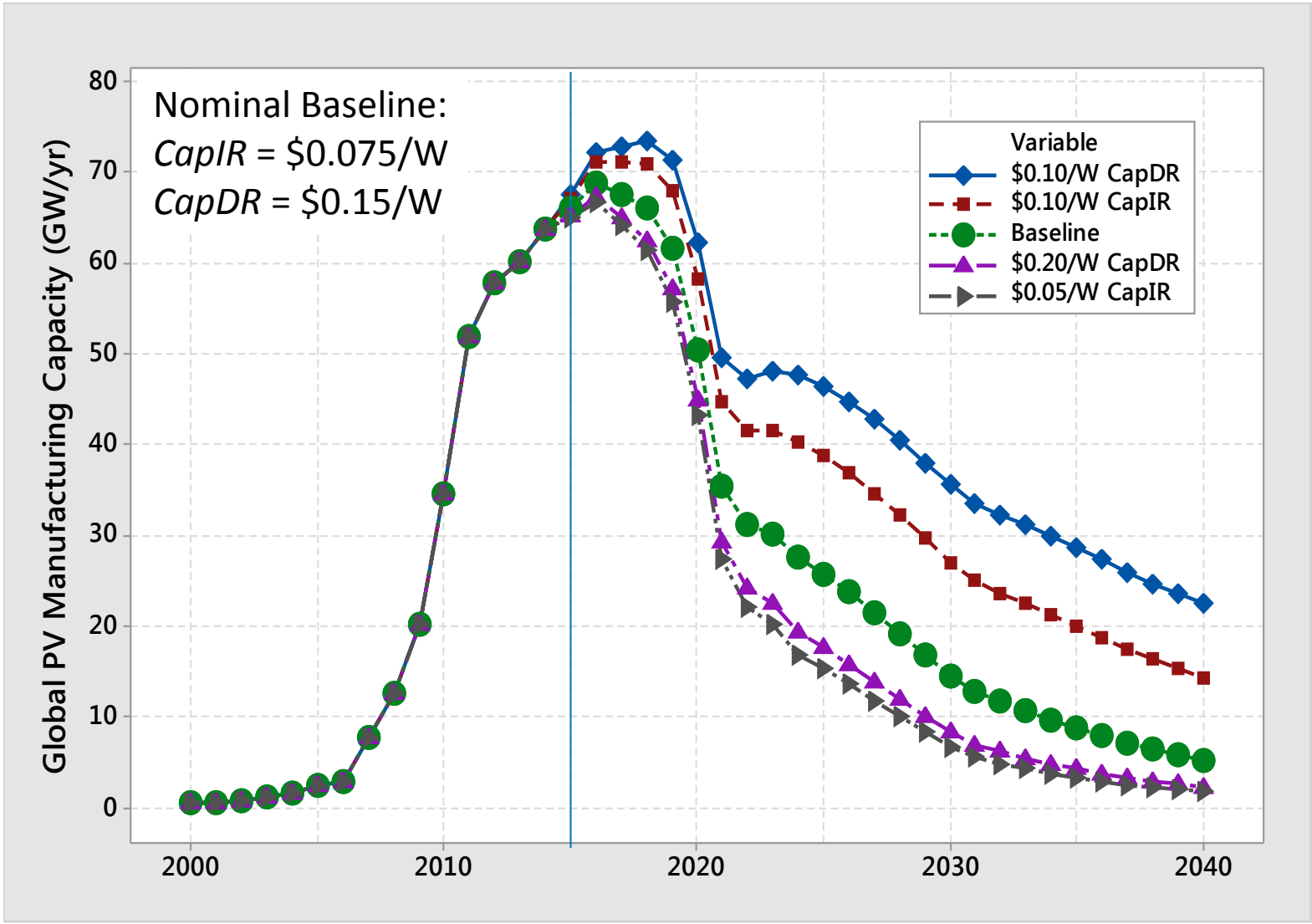
PV Futures Spreadsheet Calculator

PV Futures Calculator	Paul Basore	21-Jan-15	Version 5		Based on "Economics of Future Growth in Photovoltaics Manufacturing", IEEE PVSC42, P. Basore, D. Chung, T. Buonassisi									
						CapDR ($/W)		WACC=0		Plant		WACC		
Year	CapIR ($/W)	Expansion Capex ($yr/W)	Renewal Capex ($yr/W)	Asset Lifetime (yrs)	PV System Lifetime (yrs)	Expansion	Upgrades	Capex ($yr/W)		Utilization				
2015	$0.075	$1.50	$1.50	10	20	0.15	0.15	$1.00		80%		10%	Baseline	
2020	$0.075	$1.50	$1.50	10	20	0.15	0.15	$1.00		80%		10%	Expansion	
2030	$0.075	$1.50	$1.50	10	20	0.15	0.15	$1.00		80%		10%	Renewal	
								GW/yr Manufacturing				GW PV Nameplate		
Year	Margin Invested ($/W)	Capital Expansion ($yr/W)	Capital Upgrade ($yr/W)	Plant Lifetime (yrs)	PV System Lifetime (yrs)	Investment ($B/yr)	Upgrades	Expansion	Decommission	Capacity	Plant Utilization	Installation	Decommission	Capacity
2000	$0.08	$1.50	$1.50	10	20	$0.0	0	0.0	0.0	0.5	60%	0.3	0.0	1.4
2001	$0.08	$1.50	$1.50	10	20	$0.2	0	0.1	0.0	0.6	67%	0.4	0.0	1.8
2002	$0.08	$1.50	$1.50	10	20	$0.3	0	0.2	0.0	0.8	50%	0.4	0.0	2.2
2003	$0.08	$1.50	$1.50	10	20	$0.5	0	0.3	0.0	1.1	55%	0.6	0.0	2.8
2004	$0.08	$1.50	$1.50	10	20	$0.8	0	0.5	0.0	1.6	75%	1.2	0.0	4.0
2005	$0.08	$1.50	$1.50	10	20	$1.4	0	0.9	0.0	2.5	60%	1.5	0.1	5.4
2006	$0.08	$1.50	$1.50	10	20	$0.6	0	0.4	0.0	2.9	66%	1.9	0.2	7.1
2007	$0.08	$1.50	$1.50	10	20	$7.2	0	4.8	0.0	7.7	49%	3.8	0.5	10.4
2008	$0.08	$1.50	$1.50	10	20	$7.4	0	4.9	0.0	12.6	53%	6.7	1.0	16.1
2009	$0.08	$1.50	$1.50	10	20	$11.6	0	7.7	0.0	20.3	55%	11.2	3.0	24.3
2010	$0.08	$1.50	$1.50	10	20	$21.5	0	14.3	0.0	34.6	62%	21.4	5.0	40.7
2011	$0.08	$1.50	$1.50	10	20	$26.1	0	17.4	0.1	51.9	70%	36.3	6.0	71.0
2012	$0.08	$1.50	$1.50	10	20	$9.2	0	6.1	0.2	57.8	63%	36.3	5.0	102.3
2013	$0.08	$1.50	$1.50	10	20	$4.1	0	2.7	0.3	60.2	66%	39.6	2.0	139.9
2014	$0.08	$1.50	$1.50	10	20	$6.0	0	4.0	0.5	63.7	82%	52.0	2.0	189.9
2015	$0.08	$1.50	$1.50	10	20	$4.8	0.9	2.3	0.9	66.0	80%	52.8	0.0	242.7
2016	$0.08	$1.50	$1.50	10	20	$4.9	0.4	2.9	0.4	68.9	80%	55.1	0.0	297.8
2017	$0.08	$1.50	$1.50	10	20	$5.2	3.4	0.0	4.8	67.5	80%	54.0	0.0	351.8
2018	$0.08	$1.50	$1.50	10	20	$5.1	3.4	0.0	4.9	66.0	80%	52.8	0.0	404.6
2019	$0.08	$1.50	$1.50	10	20	$5.0	3.3	0.0	7.7	61.6	80%	49.3	0.0	453.9
2020	$0.08	$1.50	$1.50	10	20	$4.6	3.1	0.0	14.3	50.4	80%	40.3	0.3	493.9
2021	$0.08	$1.50	$1.50	10	20	$3.8	2.5	0.0	17.4	35.5	80%	28.4	0.4	521.9

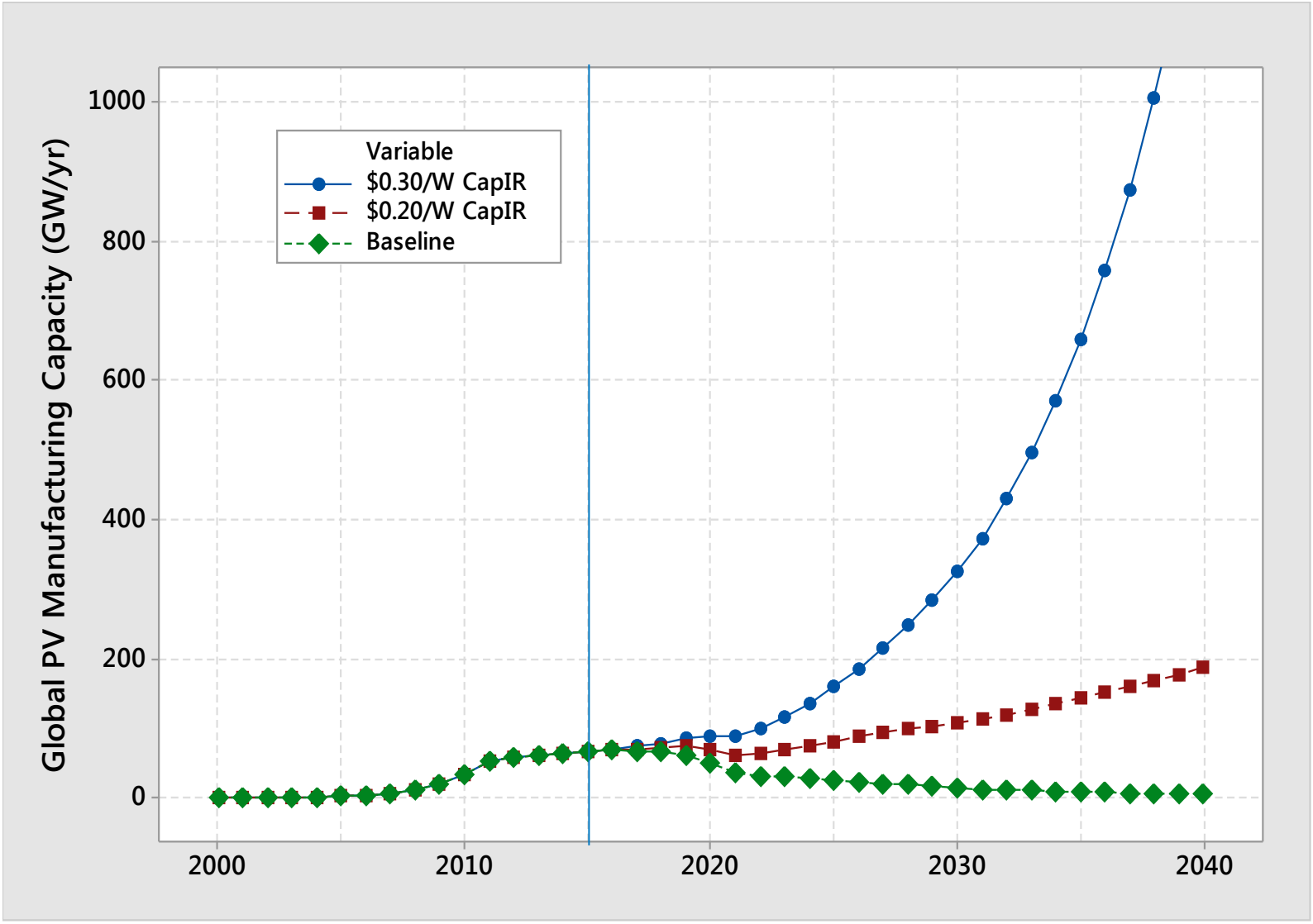
- Allows *CapIR* and *CapDR* to change with time (2015, 2020, 2030 values)
- Allows different *CapDR* for expansion or renewal of existing capacity
- Investment each year based on previous year's manufacturing capacity

Spreadsheet available for download from *www.pvcolleagues.net* (Archives)

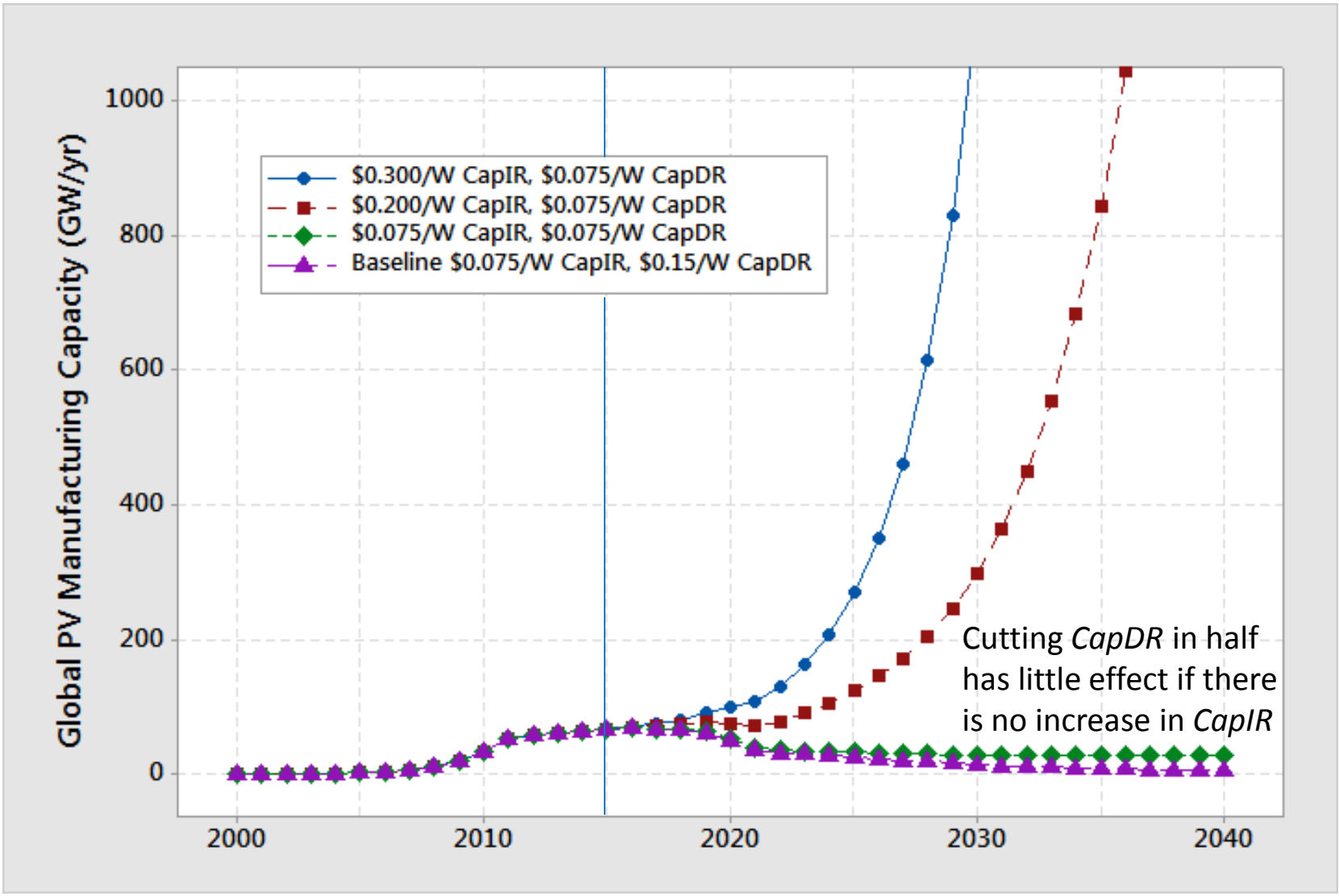
Baseline Sensitivity to *CapIR* and *CapDR*



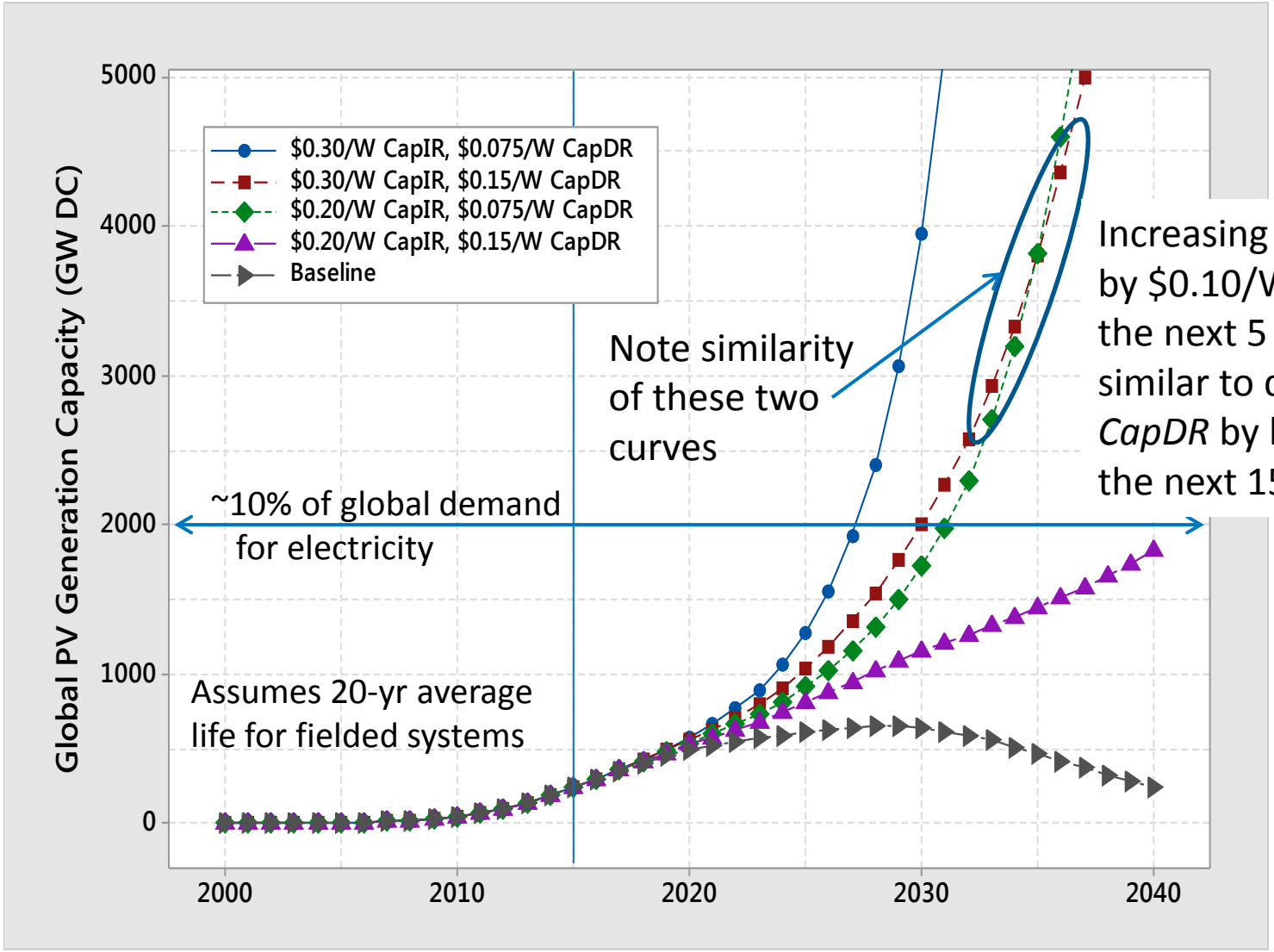
Increase in Capital Investment Rate



Decrease in Capital Demand Rate



Impact on Future PV Generation Capacity



Conclusions

- **The existing PV manufacturing capacity is sufficient to supply 5% of the world's electricity, *but only if capacity can be replaced as it is retired***
  - Maintaining the economic status quo is not enough!

- ***CapIR* needs to increase by $0.10/W for PV to grow**
  - Accelerate manufacturing cost reductions
  - Accelerate improvements in module efficiency
  - Accelerate reductions in balance of system and soft costs
  - Further increase the perceived value of PV systems
  - Expand government and utility incentives for renewable energy

- **Reducing *CapDR* will then accelerate that growth**
  - Reducing *CapDR* by half is similar to an additional $0.10/W increase in *CapIR*

- **Economic sustainability of the existing c-Si PV industry is tantalizingly close and absolutely necessary for the future success of PV**