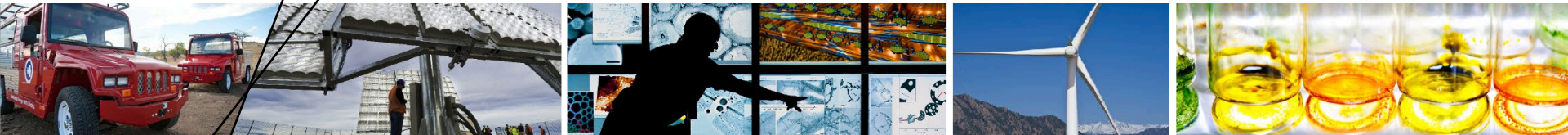


# The Capital Intensity of Photovoltaics Manufacturing

Barrier to Scale and Opportunity for Innovation\*

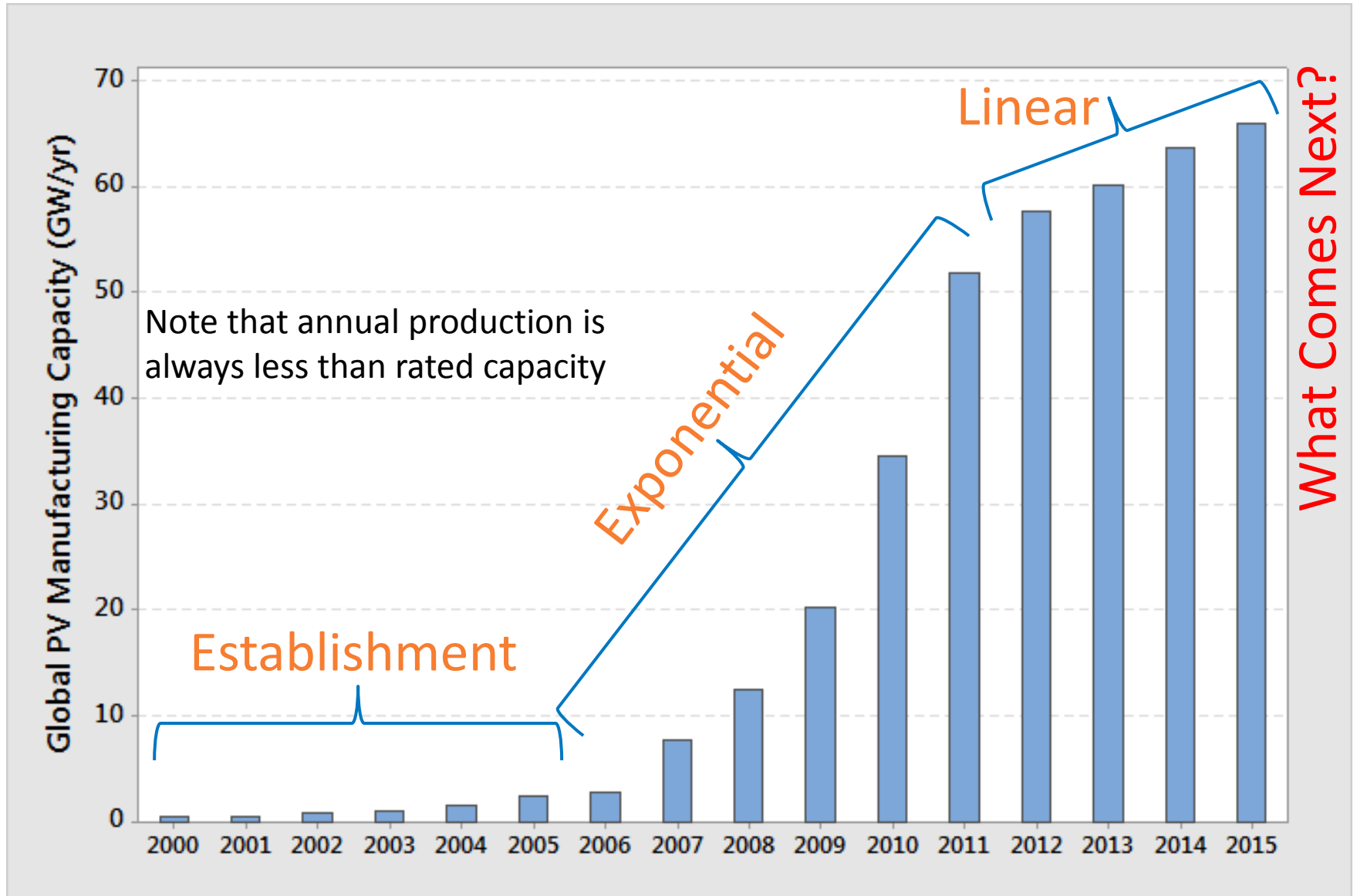


**Paul Basore**  
**National Renewable Energy Laboratory**  
**Golden, Colorado**  
**19 October 2015**

**BAPVC Fall Meeting, Berkeley, California**

\*D. Powell, R. Fu, K. Horowitz, P. Basore, M. Woodhouse and  
T. Buonassisi, *Energy and Environmental Science* 2015.

# Global PV Manufacturing Capacity



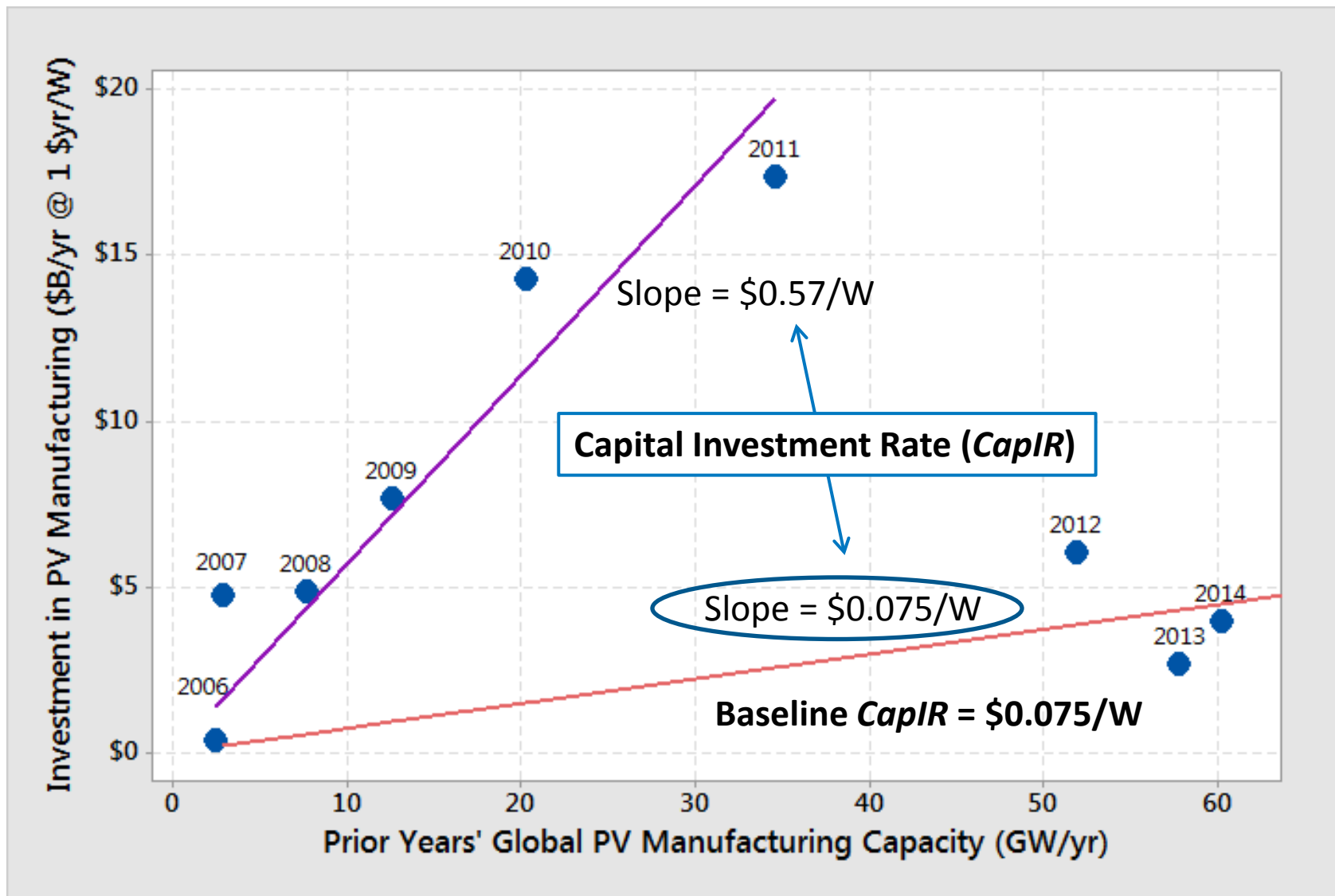
# Predictions are Hard, so Keep it Simple

The future of PV manufacturing is determined by:

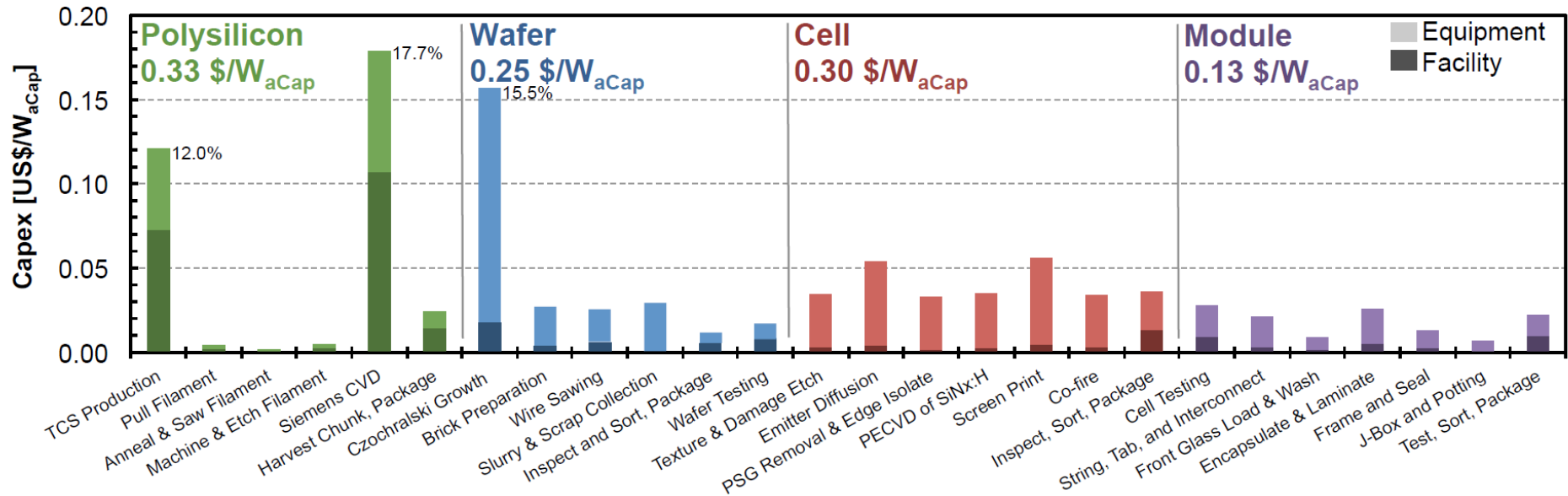
- **How much is invested**
  - Capital Investment Rate: *CapIR*
- **How much it costs**
  - Capital Demand Rate: *CapDR*



# Capital Investment Rate

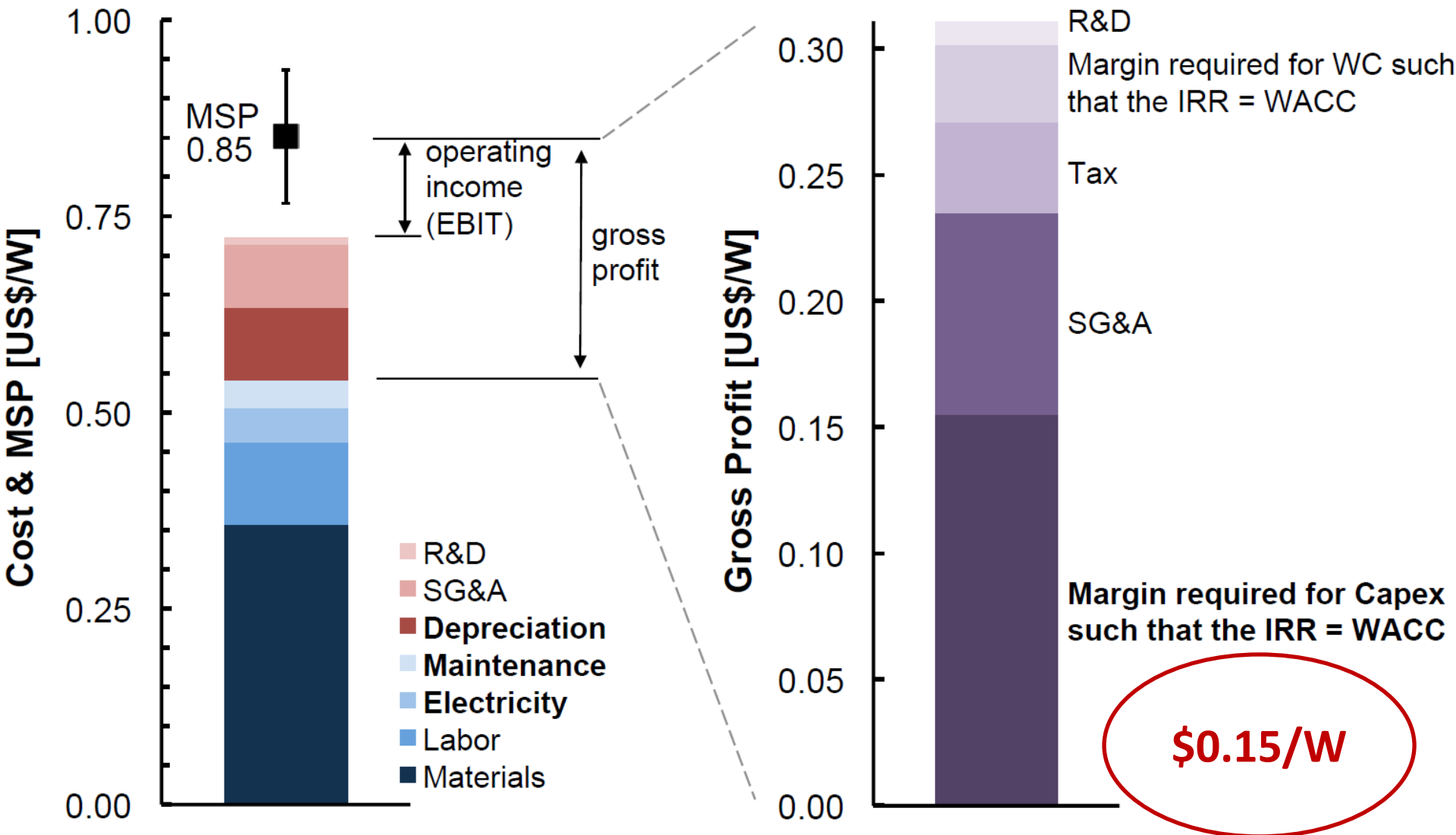


# Capex Components (US p-type mono Si)



- **Capital expense (Capex) of PV-specific manufacturing plants**
  - Normalized to production capacity expressed in rated module watts per year
- **The normalized Capex for each sector in the value chain is lower in Asia**
  - But more sectors need to be included: backsheet, EVA, frame, paste, etc.
  - More PV-specific sectors in Asia means similar Capex in Asia as in USA

# Capex-Related Cost Components



# Capital Demand Rate

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

- **Capital expense (Capex) normalized to nominal manufacturing capacity**
  - Within estimation and location error, assume a globally nominal 1 \$yr/W
- **Capital Demand Rate (*CapDR*)**
  - Capex normalized to nominal manufacturing capacity (1 \$yr/W)
  - Divided by the average life of the manufacturing assets (10 yr)
  - Increased to account for the weighted average cost of capital (WACC@10%/yr)
  - **Baseline *CapDR* = \$0.15/W**

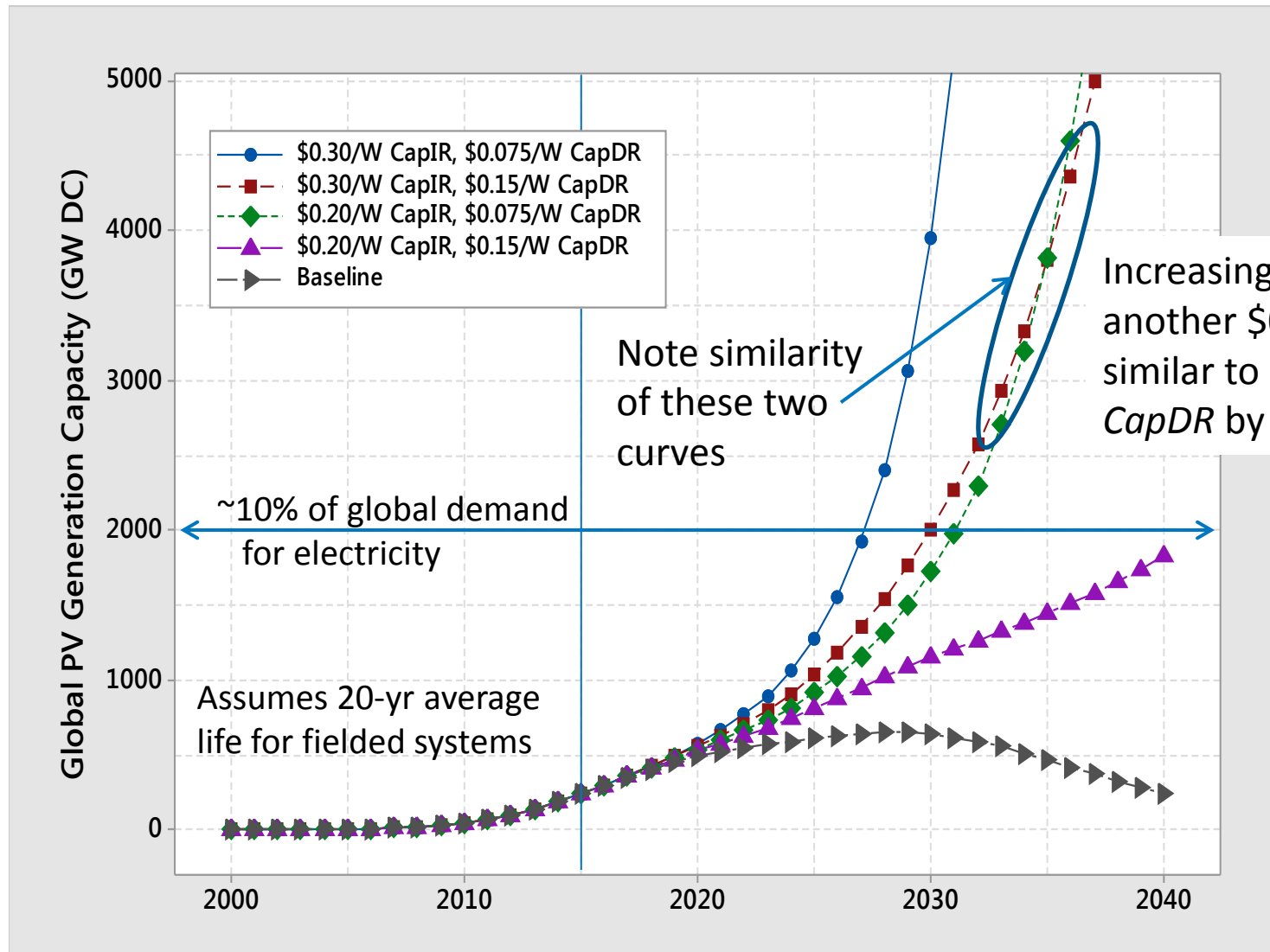
# Baseline Scenario\*

- **CapIR stays near its current level**
  - Price competition limits profits available to increase investment
  - Companies with declining investment will lose market share
- **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
- **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 Manufacturing will peak in the next few years and then decline!**

\*P. Basore, D. Chung and T. Buonassisi, "Economics of Future Growth in Photovoltaics Manufacturing," 42<sup>nd</sup> IEEE Photovoltaic Specialists Conference, New Orleans 2015.

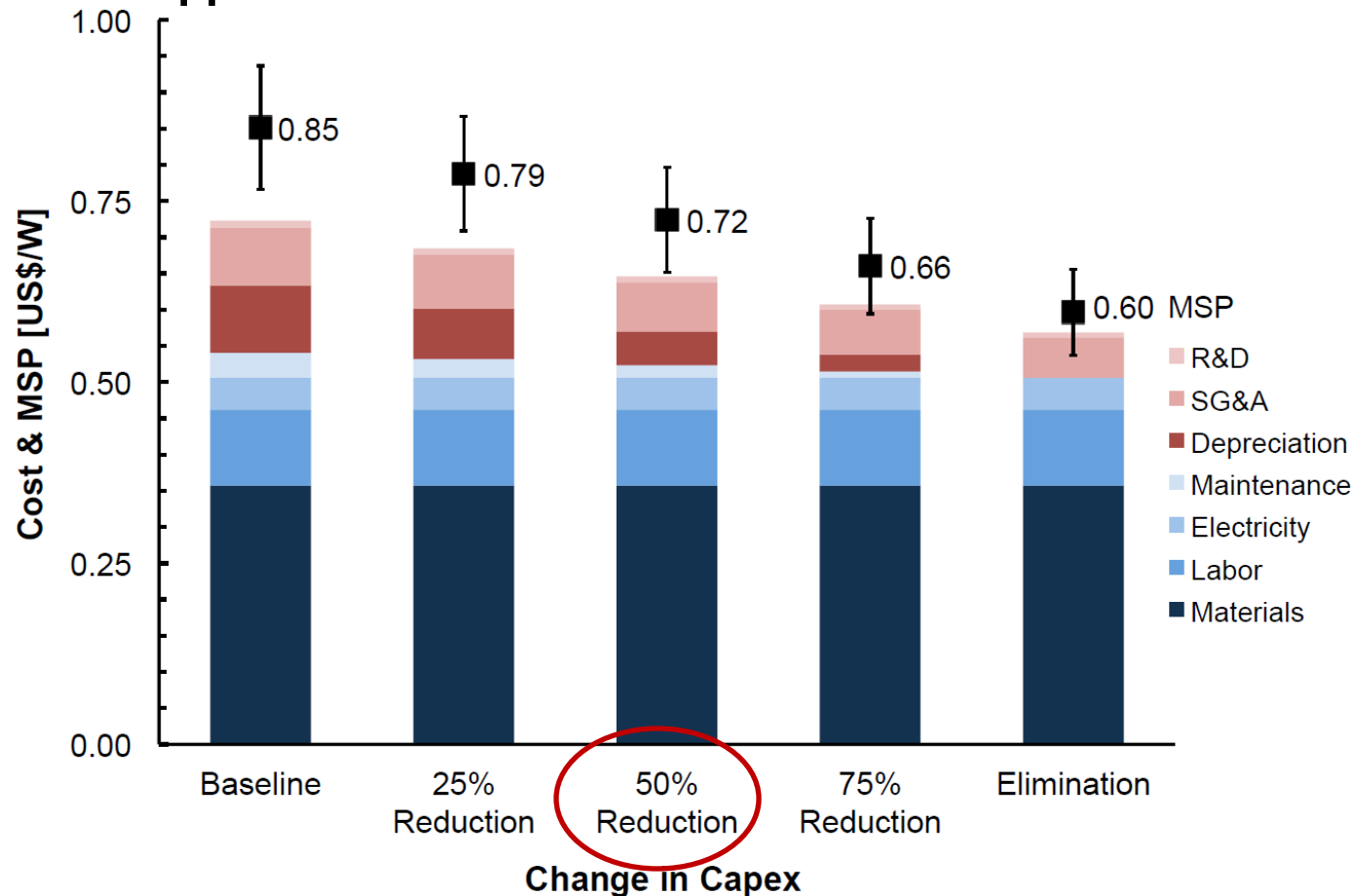


# Impact on Future PV Generation Capacity



# Opportunities for Capex Innovation

- Innovative Process Innovations
- Disruptive Process Innovations
- Platform Innovations
- Financial Approaches



# Incremental Process Innovation

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- **Increase tool throughput**
  - Grow faster (tolerance for defects, tolerance for nonuniformity)
  - Process faster (temperature optimization, reduce thermal mass, heat locally)
  - Assemble faster (fewer pieces, fewer movements, shorter distances)
- **Increase tool lifetime**
  - Avoid obsolescence (replaceable components, standardized interfaces)
  - Avoid wear-out (less corrosive processes, proper materials selection)
  - Avoid catastrophic failure (early-warning indicators, fault intervention)
- **Reduce facility cost**
  - Defect tolerance (airborne particulates, water impurities, gaseous impurities)
  - Timing tolerance (in process, between processes, maintenance schedules)
- **But don't increase tool cost, or adversely impact module quality!**

# Other Forms of Capex Innovation

- **Disruptive process innovation**
  - Process simplification (eliminate steps, combine steps, multi-purpose layers)
  - Non-PV examples: Float glass, razor blades
  - PV examples: UMG, kerfless wafers, epi cells, module-scale processing
- **Platform innovation**
  - Thin-film materials (earth-abundant, defect-tolerant, stable)
  - Solution-based deposition (uniform, consistent, low-hazard)
  - Optical concentration (low-concentration, high-concentration)
- **Financial approaches**
  - Leasing of capacity (tools, facilities)
  - Contract manufacturing (outsourcing, insourcing)
  - Downstream integration (installation, financing)

# Summary

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- **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
  - Profits are too low and capex is too high!
  - The industry must quickly transition to a state of  $CapIR > CapDR$
- **Capex reduction leverages both sides of this inequality**
  - Reduces the cost of manufacturing modules – increase  $CapIR$
  - Reduces the cost of manufacturing capacity – decrease  $CapDR$
- **There are numerous opportunities for Capex innovation**
  - Incremental process innovation
  - Disruptive process innovation
  - Platform innovation
  - Financial approaches