The Energy Balance of the Photovoltaic (PV) Industry:

Is the PV industry a net electricity producer?

Michael Dale

GCEP Symposium 2012

October 11th

Outline:

- Background
- Energy inputs to PV manufacturing
- Dynamic net energy analysis
- Results
- Conclusions

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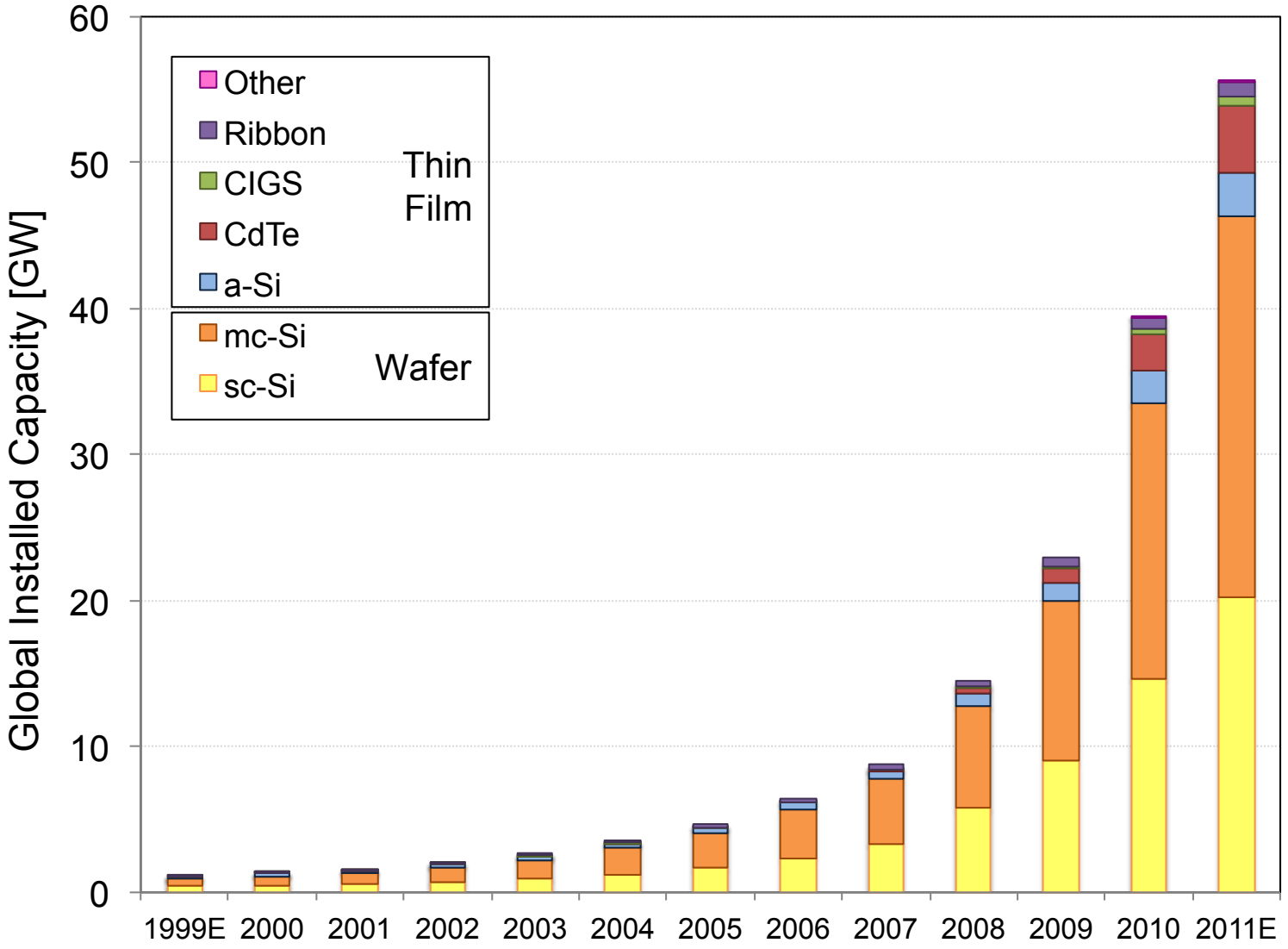
PV industry is growing rapidly



DOE (2008), EPIA (2011), EIA (2012), UN (2012)

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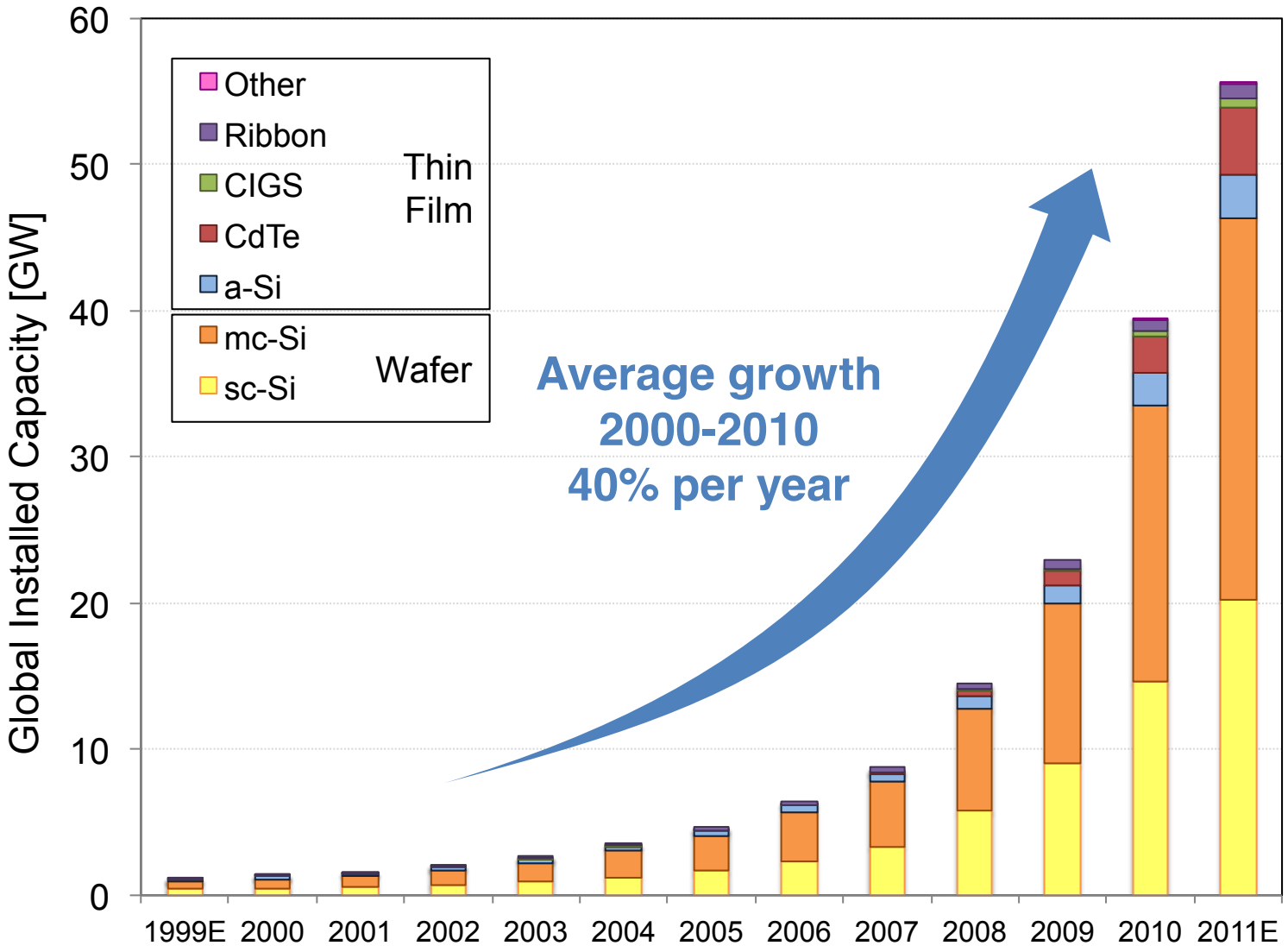

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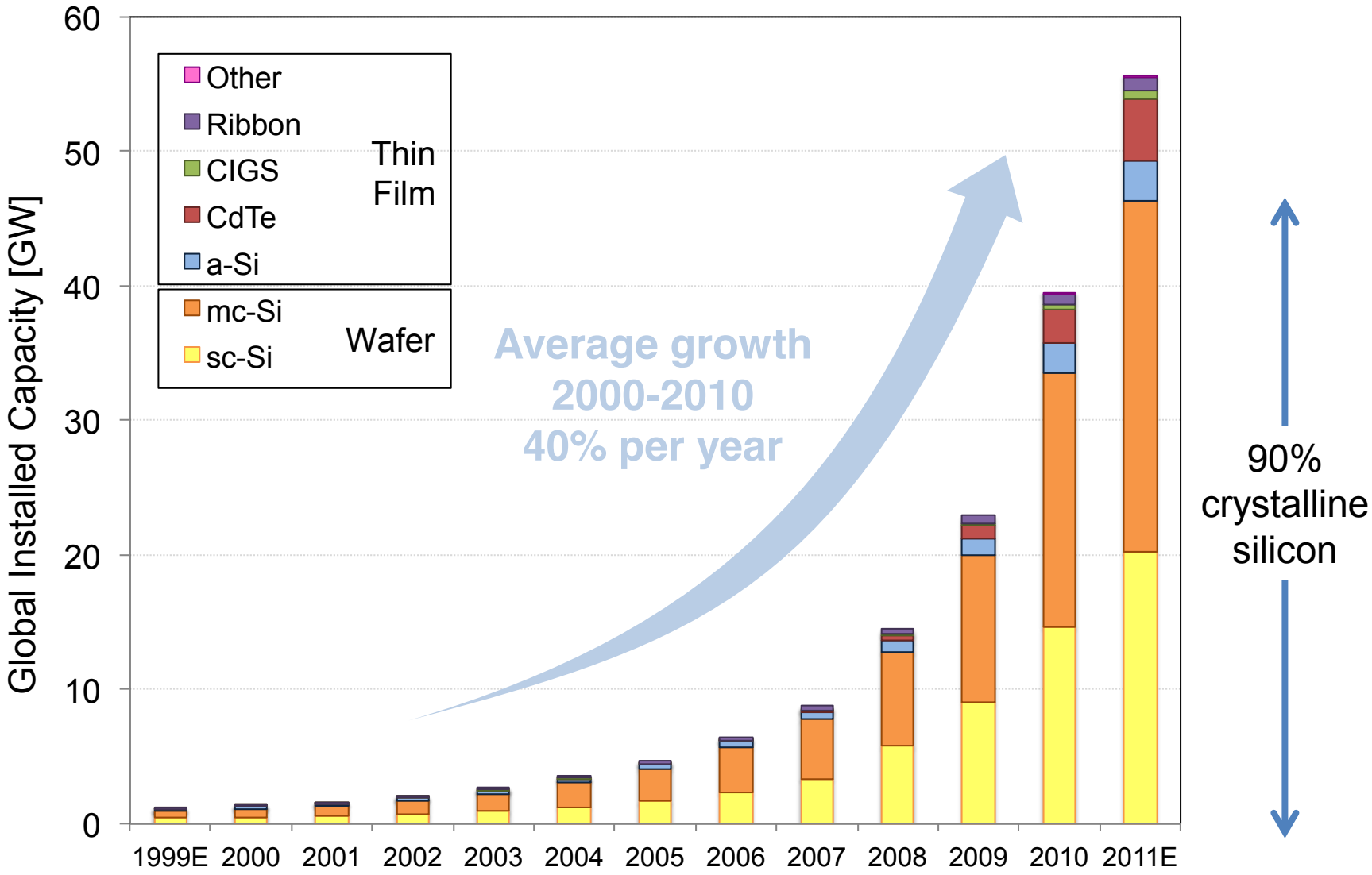

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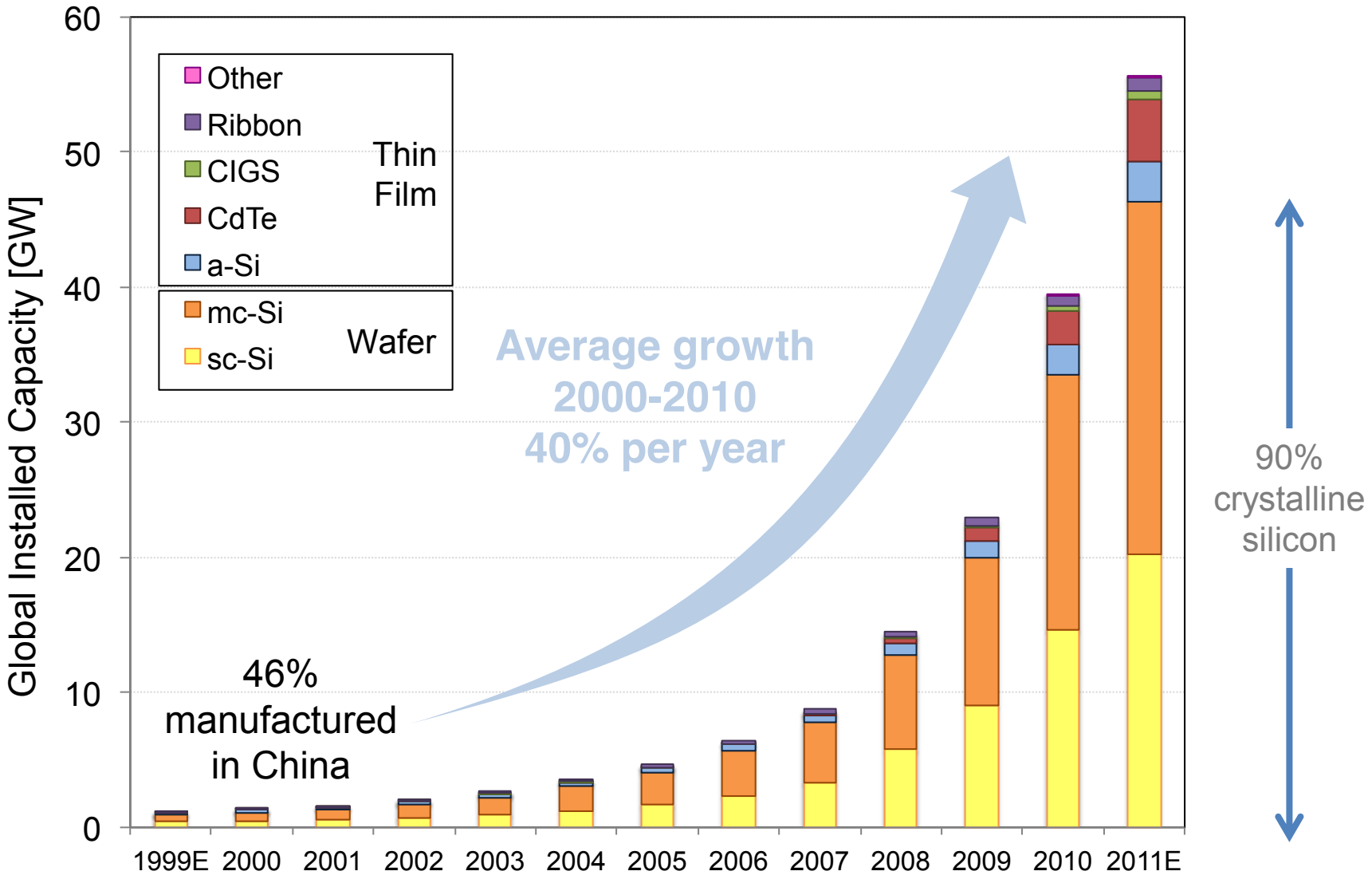

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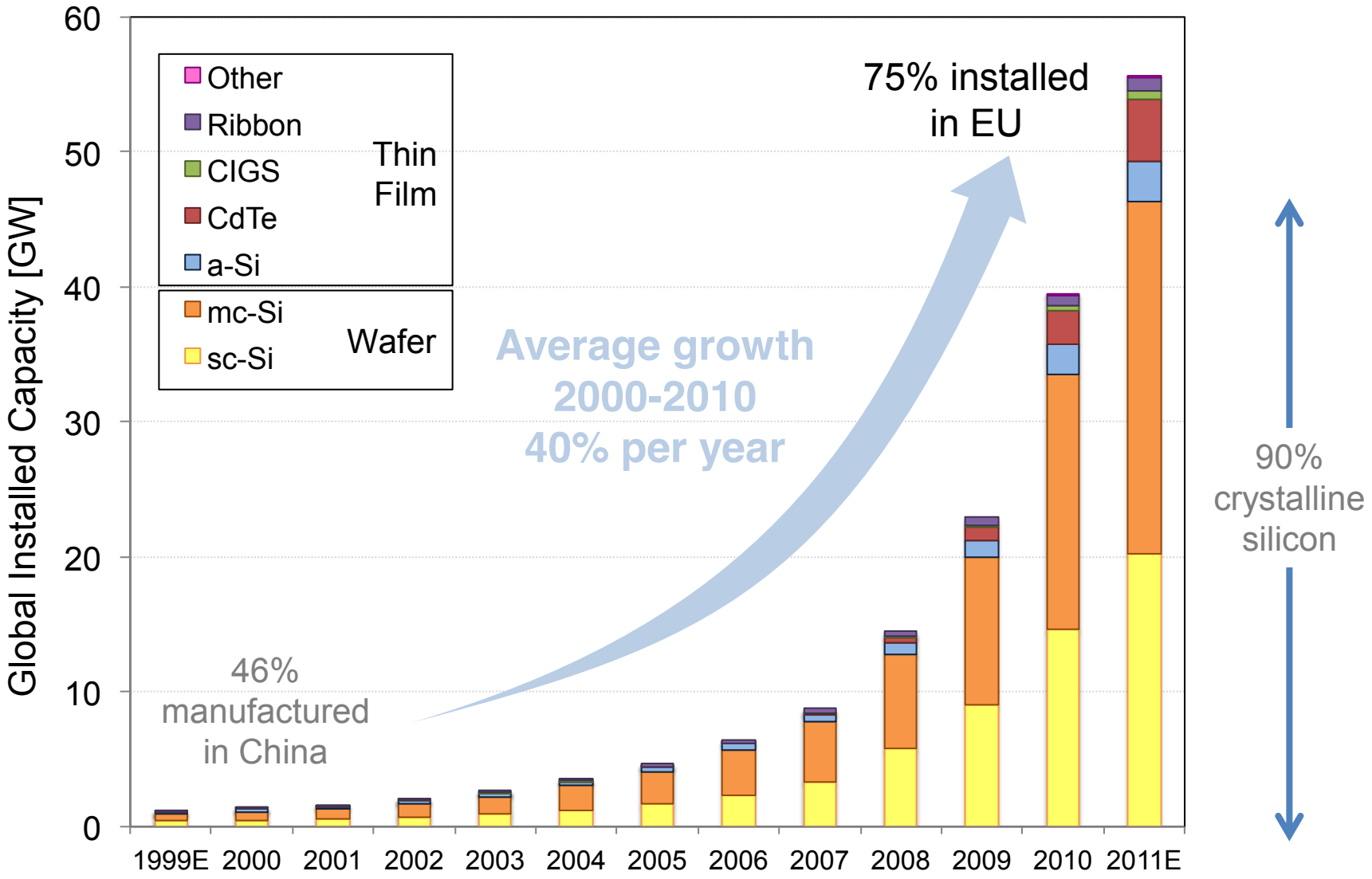

DOE (2008), EPIA (2011), EIA (2012), UN (2012)

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Silicon production is very energy intensive…

Silicium Kazakhstan LLP – source: http://www.thyssenkrupp.com

…and that's just the first step!

Poly-Si

…and that's just the first step!

Poly-Si

Ingot

…and that's just the first step!


Poly-Si


Ingot


Wafer

…and that's just the first step!


Poly-Si


Ingot


Wafer


Cell

…and that's just the first step!


Poly-Si


Ingot


Wafer


Cell


Module

…and that's just the first step!


Poly-Si


Ingot


Wafer


Cell


Module


System

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Poly-Si


Ingot


Wafer


Cell

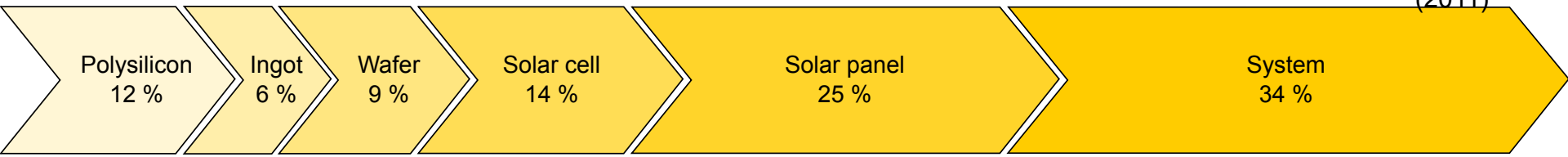

Panel


System

Financial costs ≠ energy costs

FINANCIAL COST

Swanson (2011)



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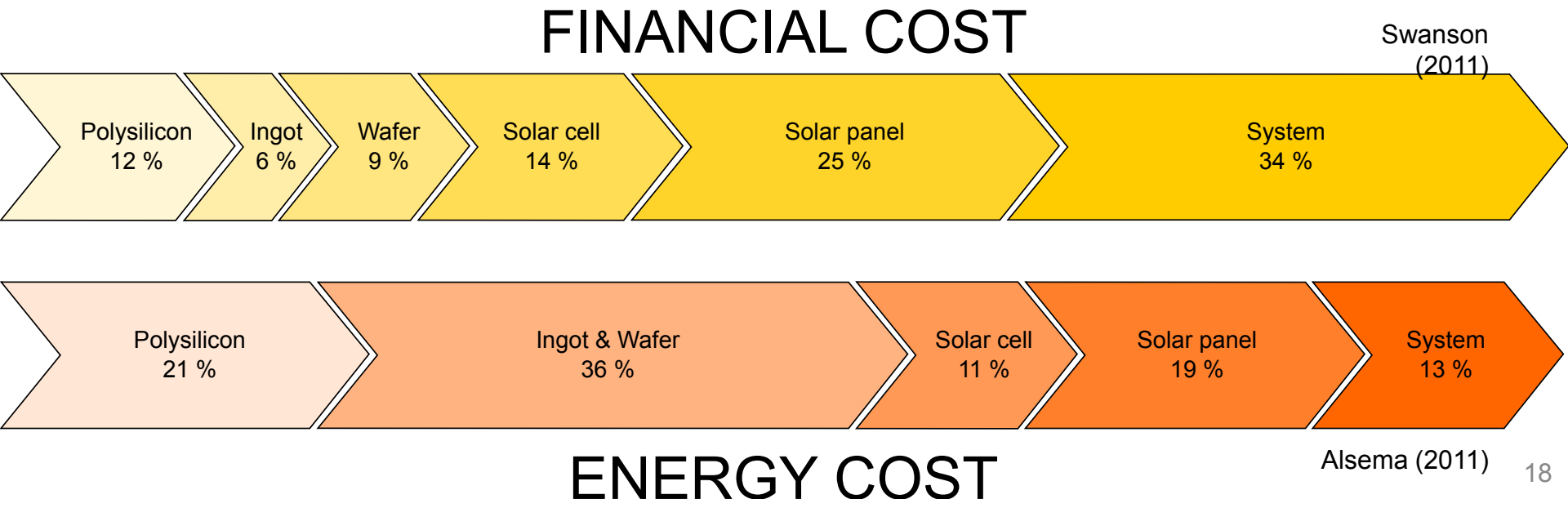
Cell


Panel

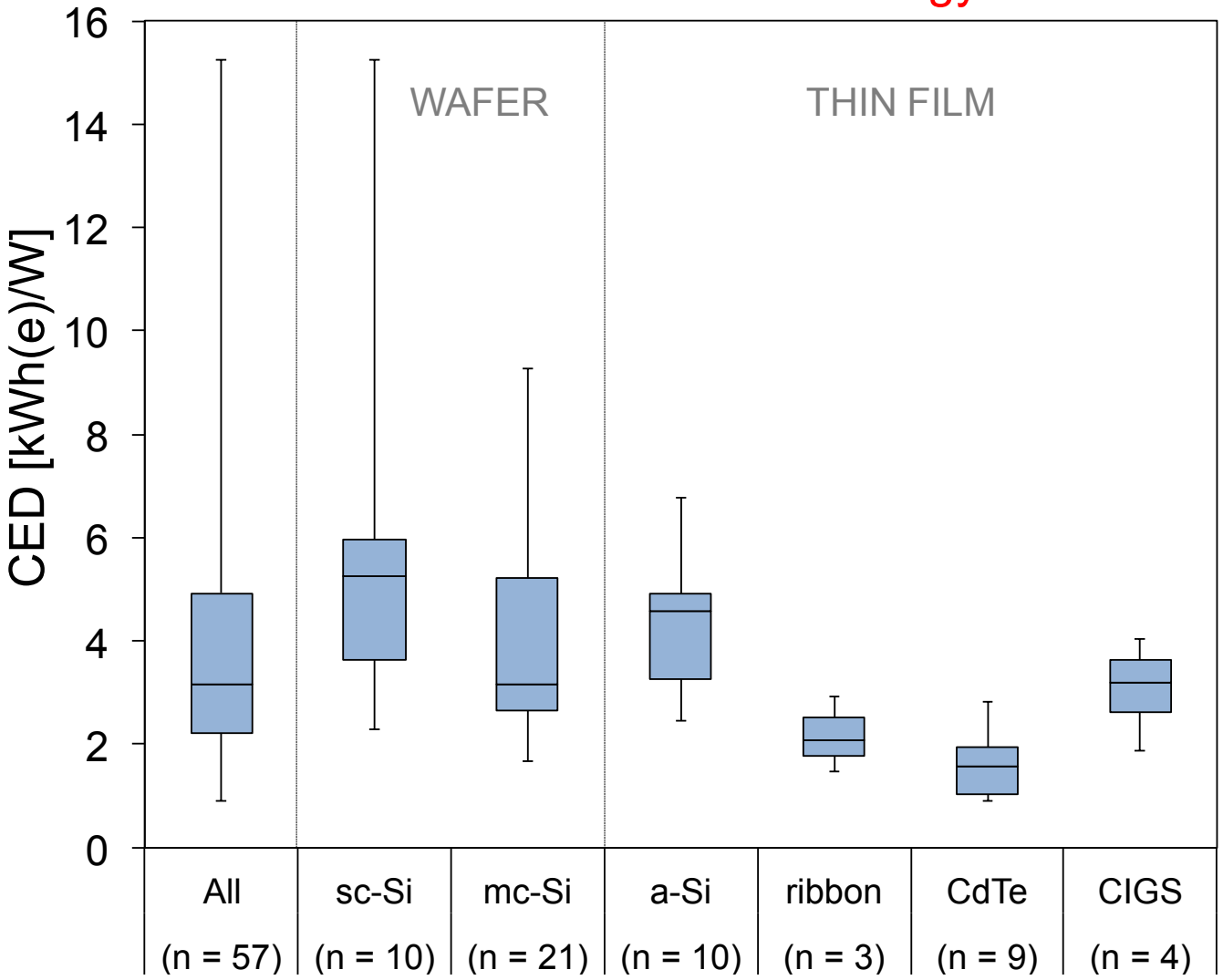

System

Financial costs ≠ energy costs



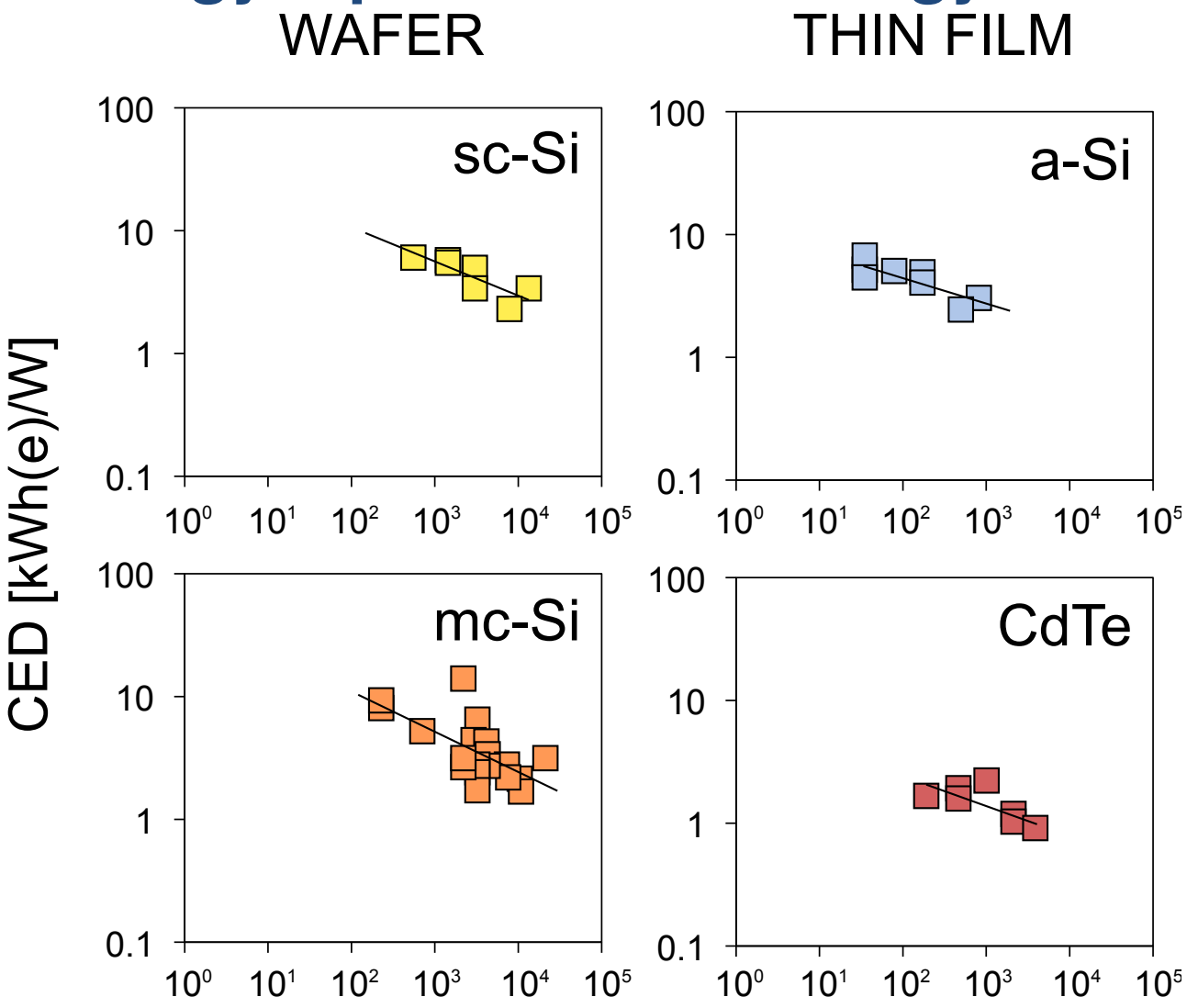
Cumulative energy demand – meta-analysis

Lower value is better – less energy intensive



Kreith (1990)
Prakash (1995)
Kato (1997)
Keolian (1997)
Alsema (2000)
Frankl (2001)
Knapp (2001)
Mathur (2002)
GEMIS (2002)
Gürzenich (2004)
Krauter (2004)
Battisti (2005)
Fthenakis (2006)
Muneer (2006)
Mason (2006)
Kannan (2006)
Mohr (2007)
Pacca (2007)
Raugei (2007)
Ito (2008)
Stoppato (2008)
Roes (2009)
Fthenakis (2009)
Raugei (2009)
Zhai (2010)
Nishimura (2010)
Held (2011)
Laleman (2011)

Energy inputs to PV – energy learning curves



Learning is reducing energy cost of PV systems

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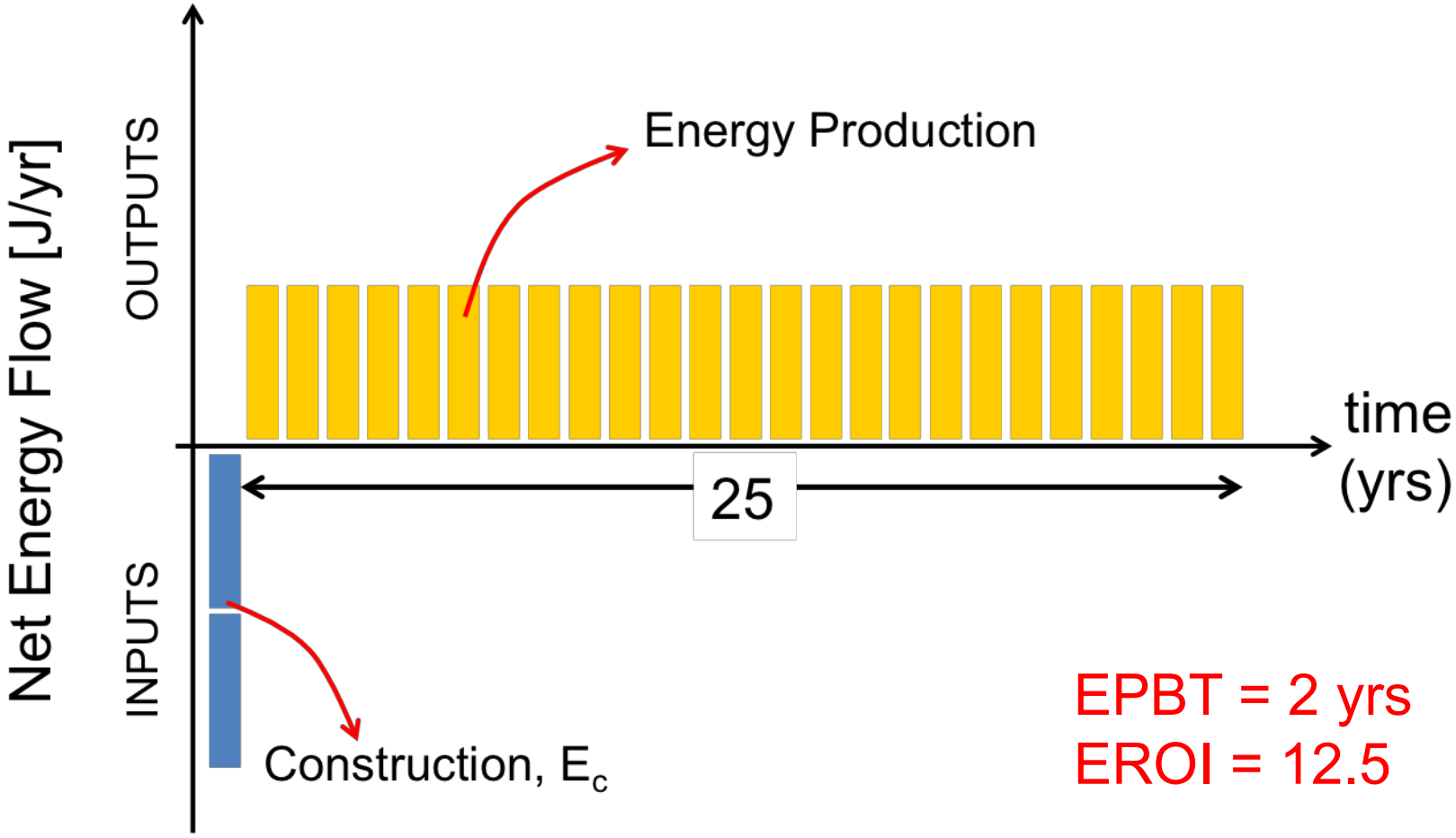
Energy flows: single plant



Energy flows for PV industry – 100% growth rate

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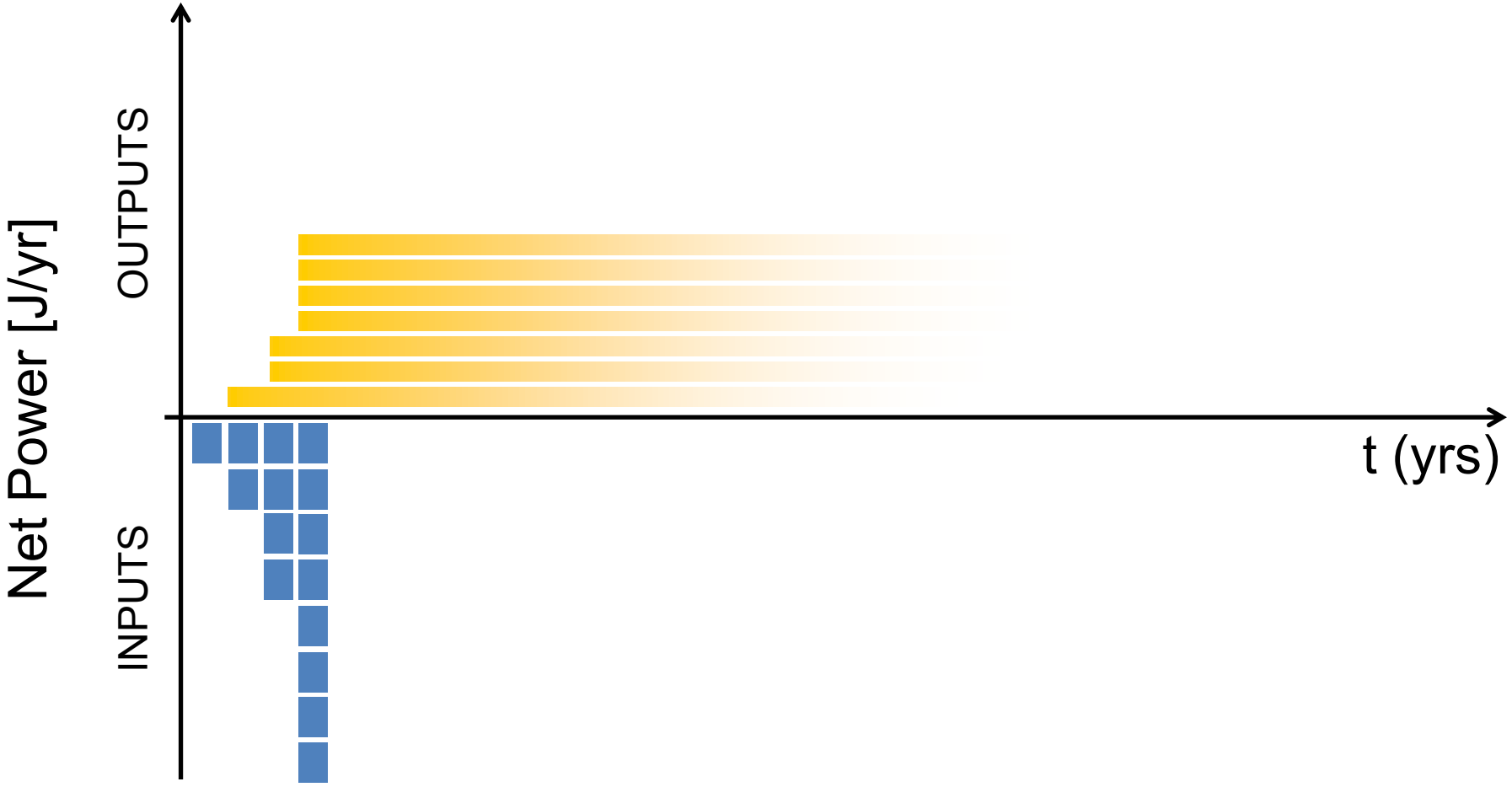
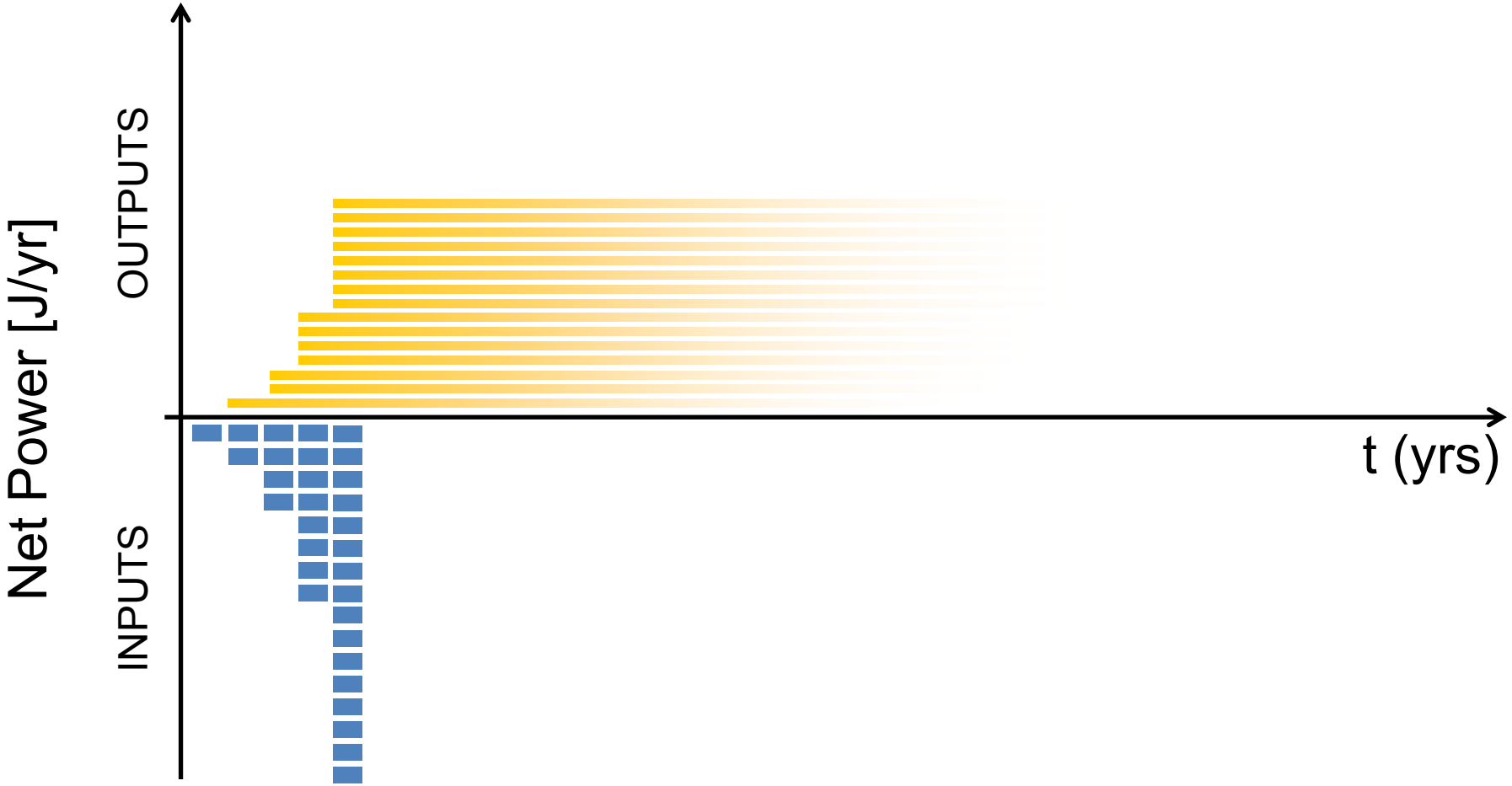
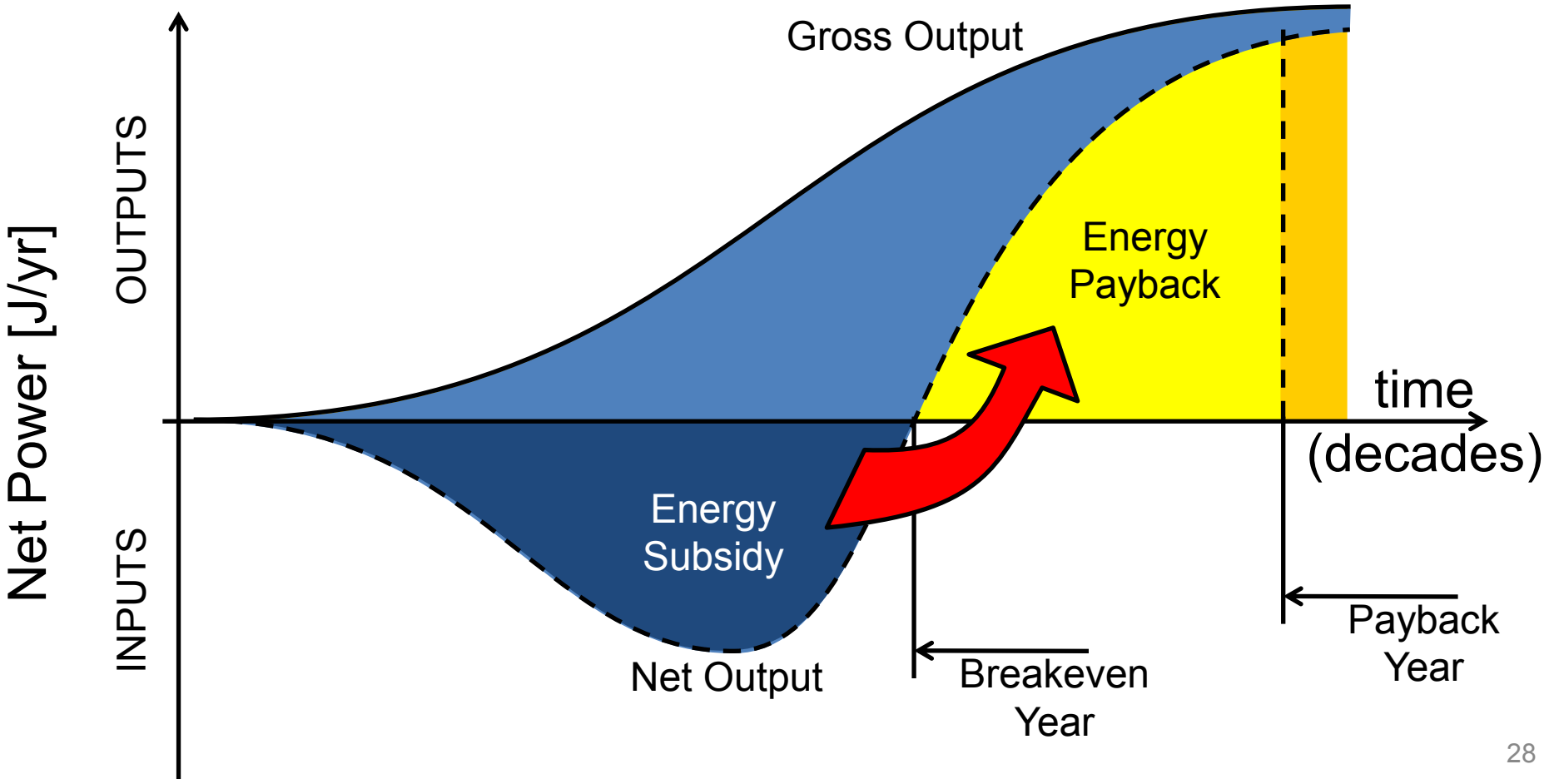


Energy flows for PV industry – 100% growth rate

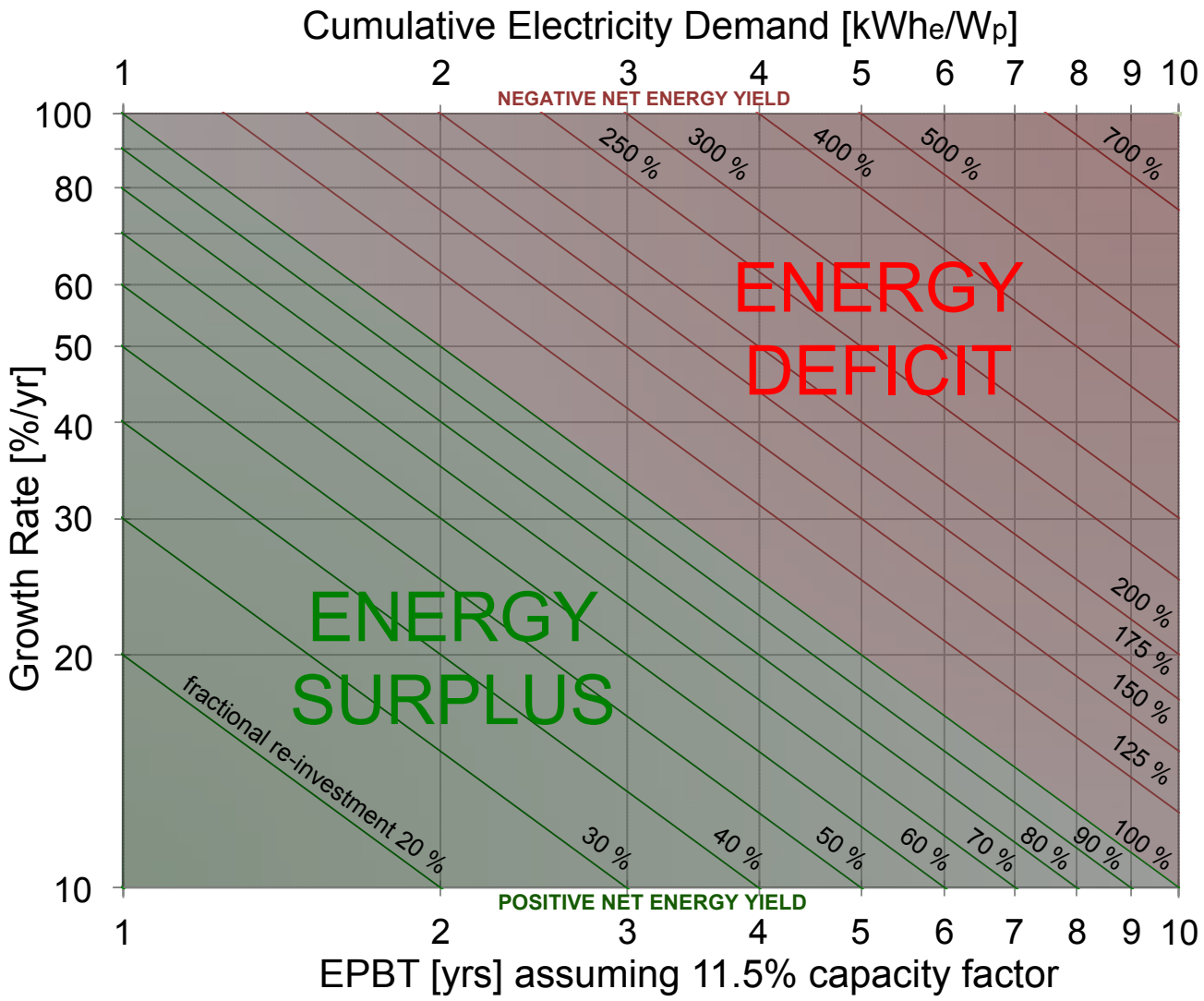


Energy flows for growing industry

Growing industry requires '**start-up capital**'



Growing industry may be a net energy sink



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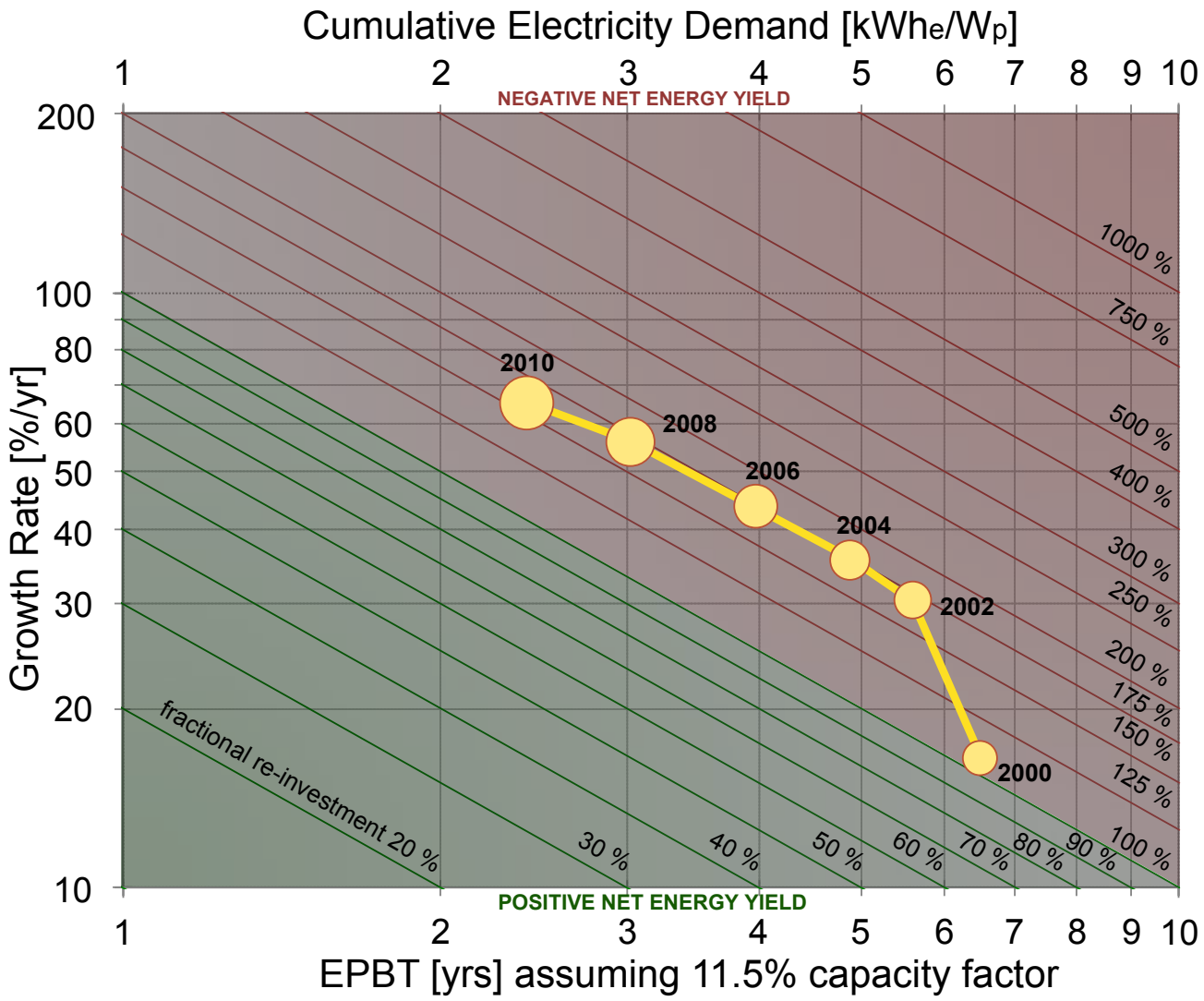
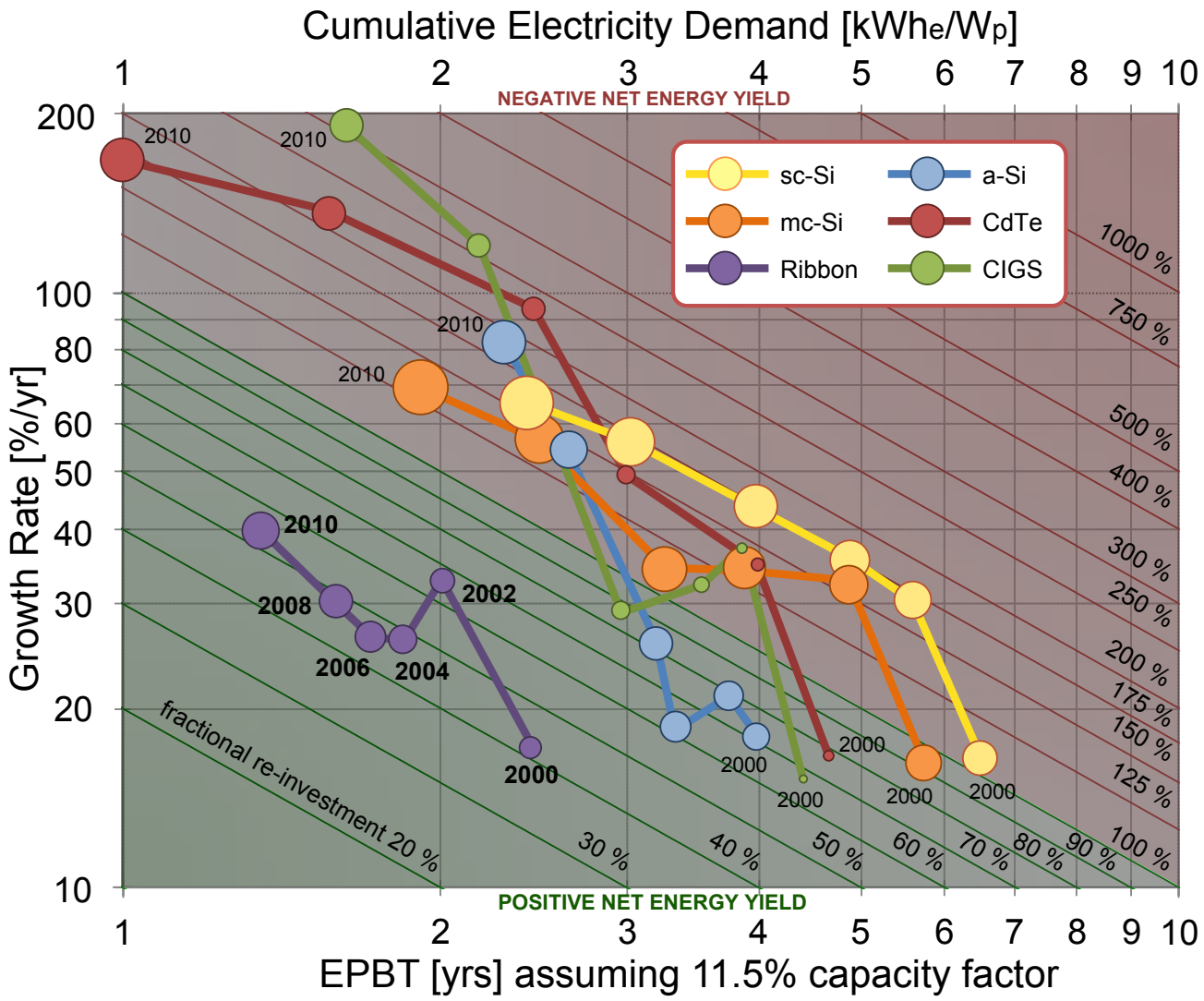
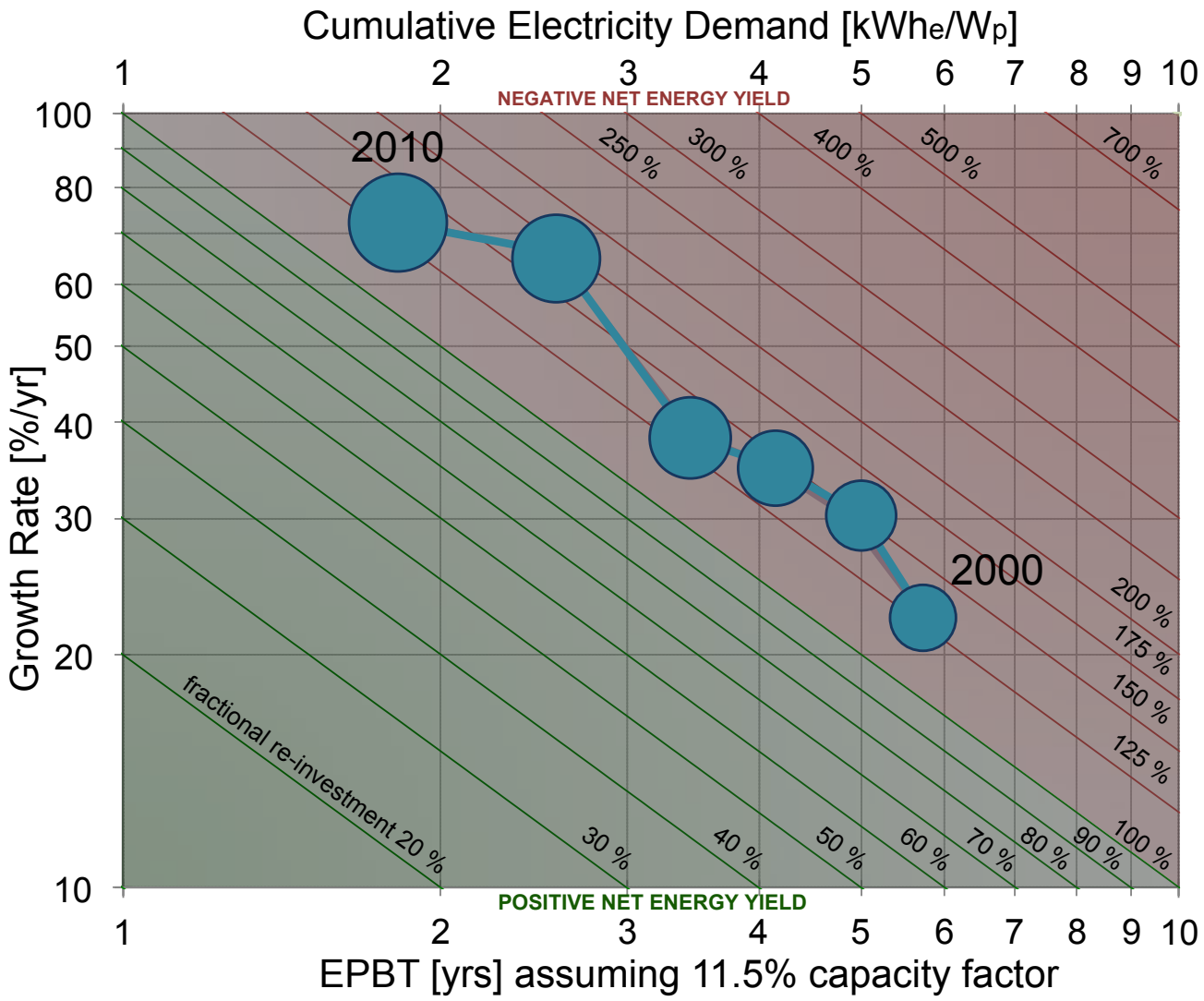
Growth trajectory for sc-Si



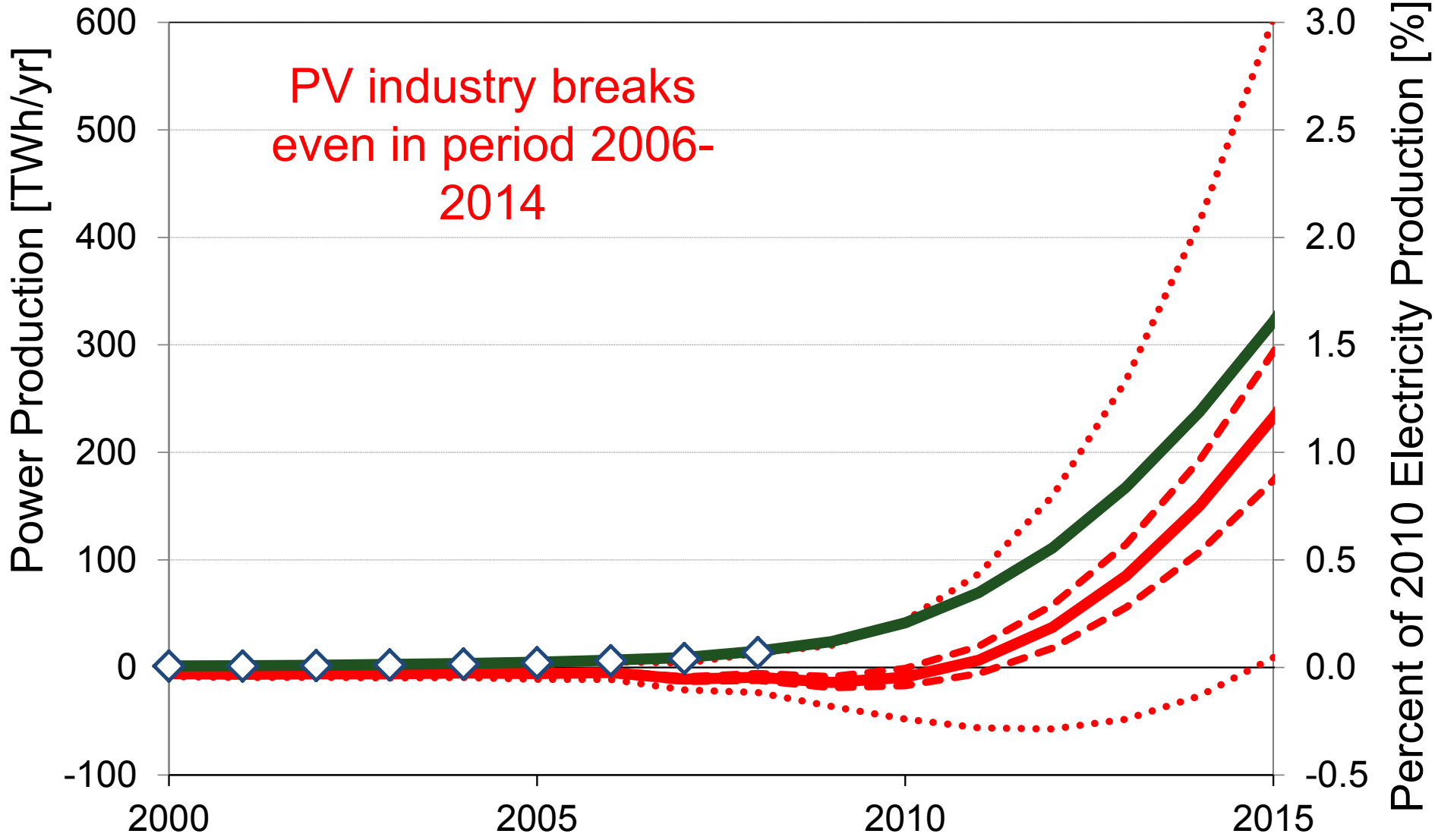
Trajectories for all PV technologies



Growth trajectory for the PV industry



Results:


PV industry breaks even in period 2006-2014
Power Production [TWh/yr]
600
500
400
300
200
100
0
-100
2000
2005
2010
2015
3.0
2.5
2.0
1.5
1.0
0.5
0.0
-0.5
Percent of 2010 Electricity Production [%]

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Conclusions

- The PV industry is **now likely** (>50%) to be a **net electricity provider**.
- The PV industry almost certainly **become** a net power provider by **2015**.
- The industry will '**pay back**' the electricity consumed in its early growth between by **2018**.
- Even in our 'worst-case' scenario, GHG emissions breakeven lags electricity breakeven by 3 years.

Implications

- Not all financial cost reductions lead to reductions in embodied energy
  - Economic analysis should be supplemented with energy analysis

- PV systems with lower energy costs provide more net energy
  - These systems will also cost less money
  - Have lower associated GHG emissions

Implications

- We must continue reducing embodied energy of PV systems:
  - Currently the PV industry consumes around 90% of its own production
  - IF current growth continues, by 2025 this would represent consumption of 2900 TWh/yr
  - IF learning continues, this consumption would be greatly reduced 300 TWh/yr or 8% of gross output.

- Reducing energy costs of PV system production should be an explicit goal of technology development

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- Thanks to Prof. Sally Benson, Dr. Richard Sassoon, Prof. Adam Brandt and Dr. Charles Barnhart for very fruitful and enlivening discussions;
- Thanks to Prof. Mike McGehee, Dr. Jenny Milne, Patricia Carbajales, Leigh Johnson, Mark Golden and Maxine Lym for very helpful comments;
- Thanks to you for listening…

… any questions?

References:

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- Swanson, R. (2011) The Silicon Photovoltaic Roadmap ,Stanford Energy Seminar Nov 14, 2011, http://energyseminar.stanford.edu/
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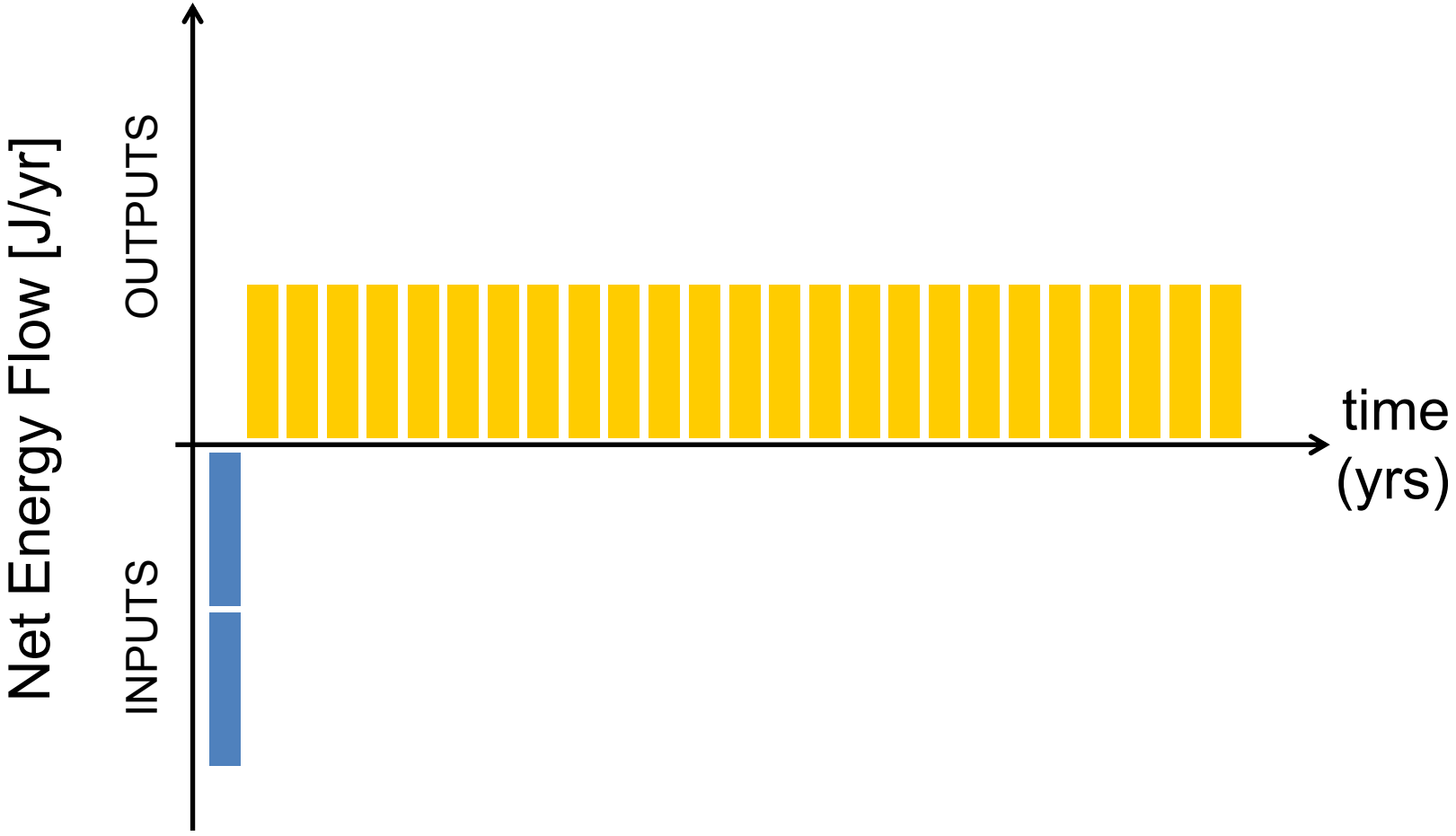
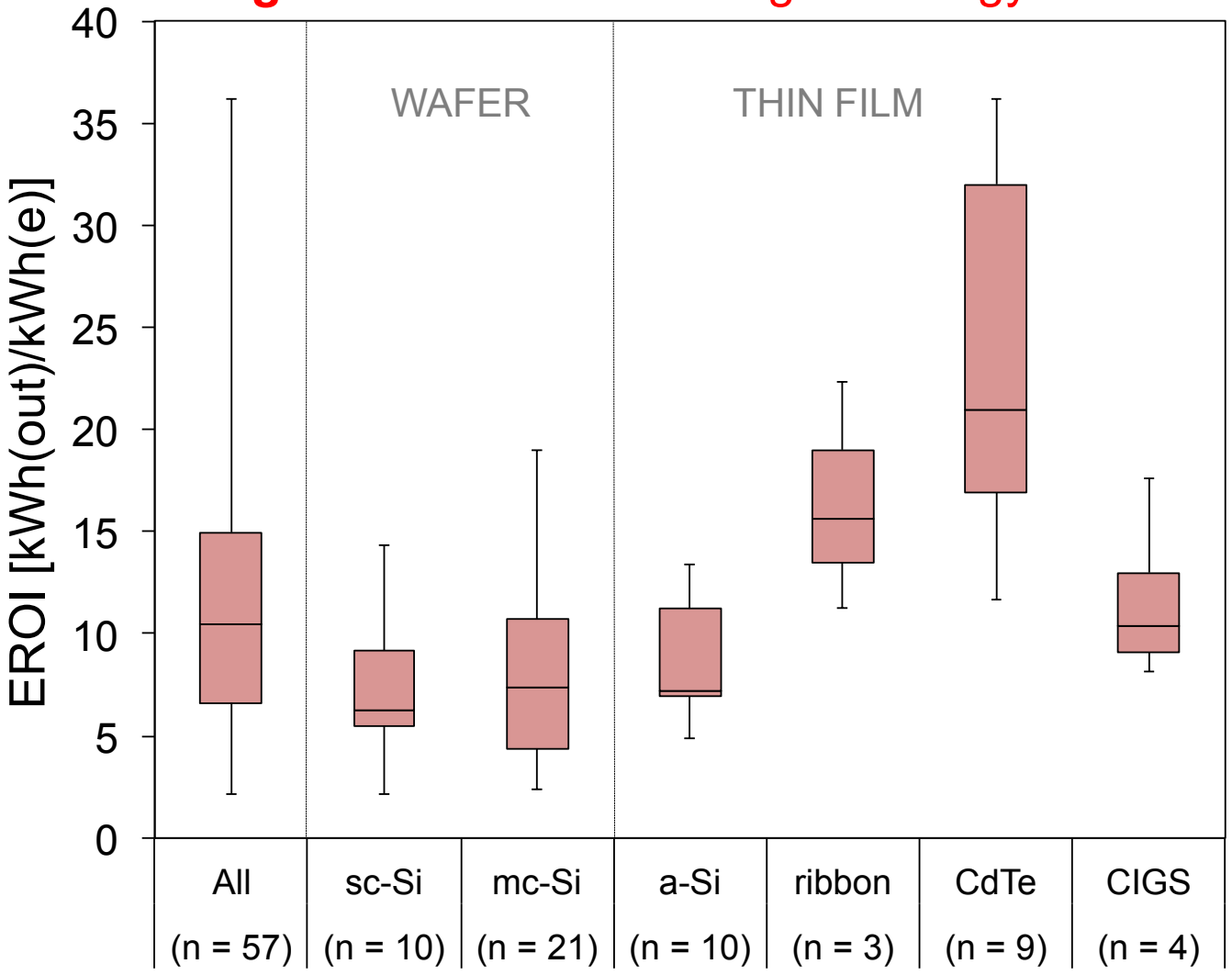
- UN, UN Energy Statistics Database (2012).


Net Energy Flow [J/yr]
OUTPUTS
INPUTS
time
(yrs)

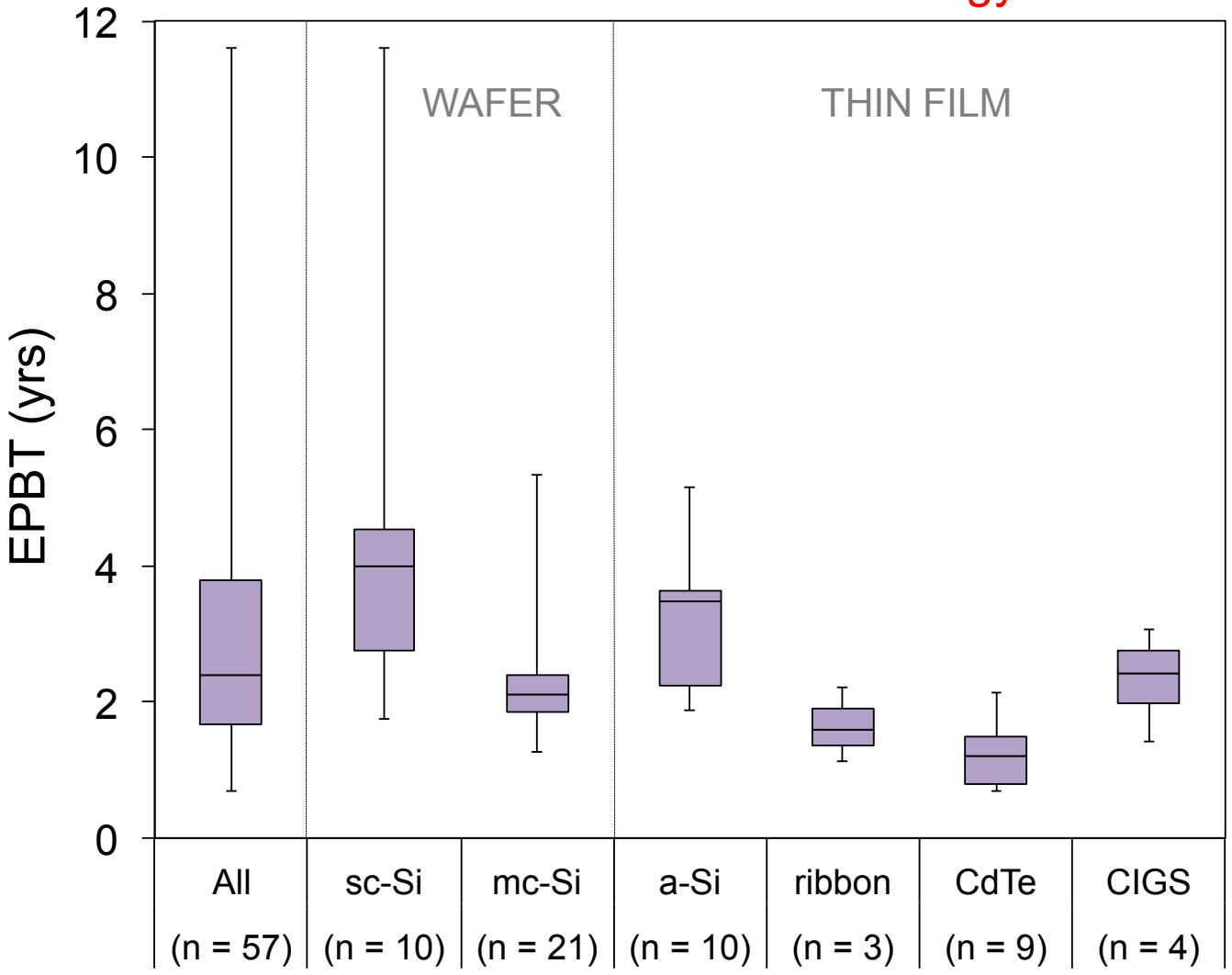
EROI for PV – meta-analysis

Higher value is better – higher energy return

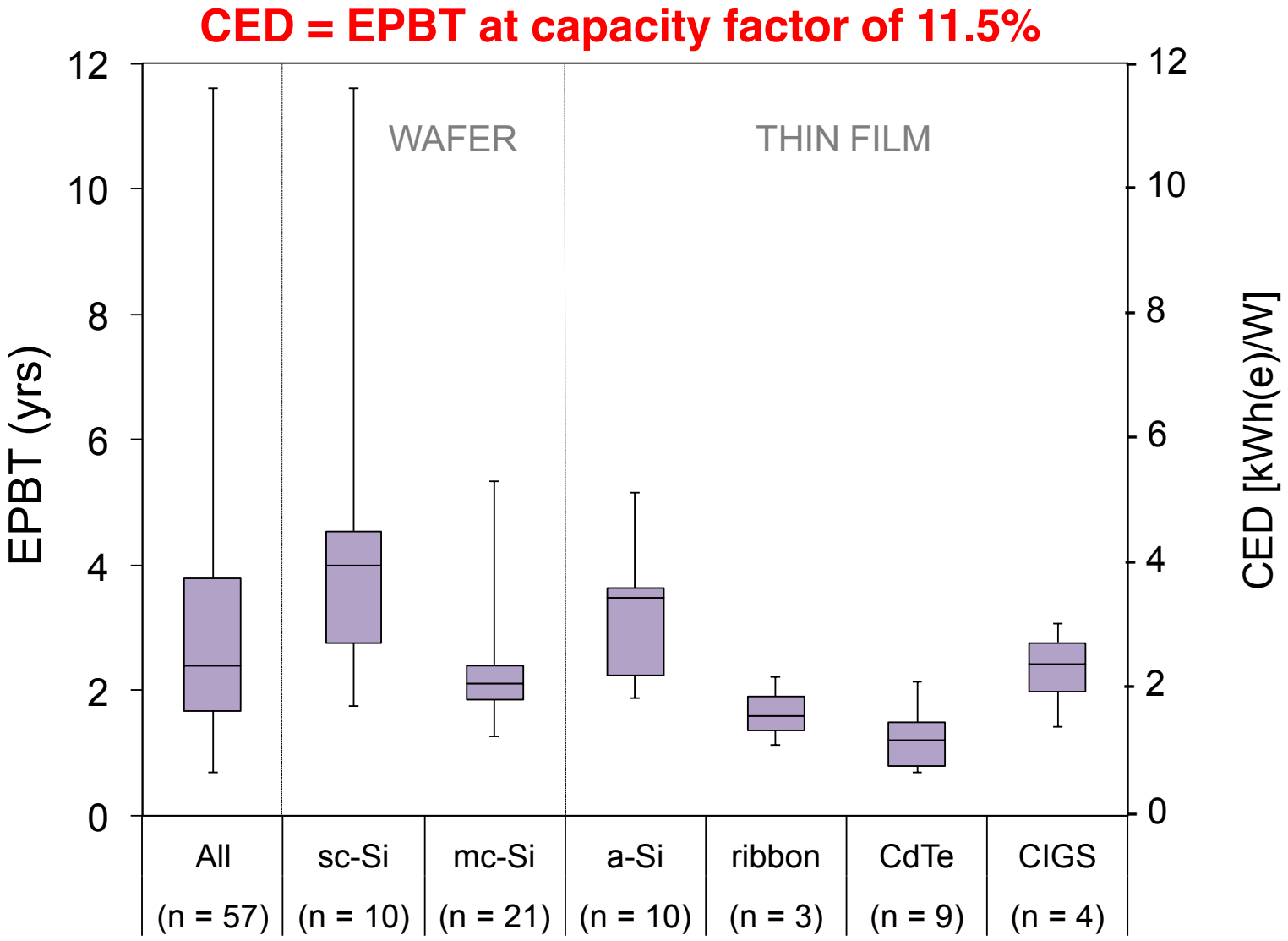


Energy payback time (EPBT) PV – meta-analysis

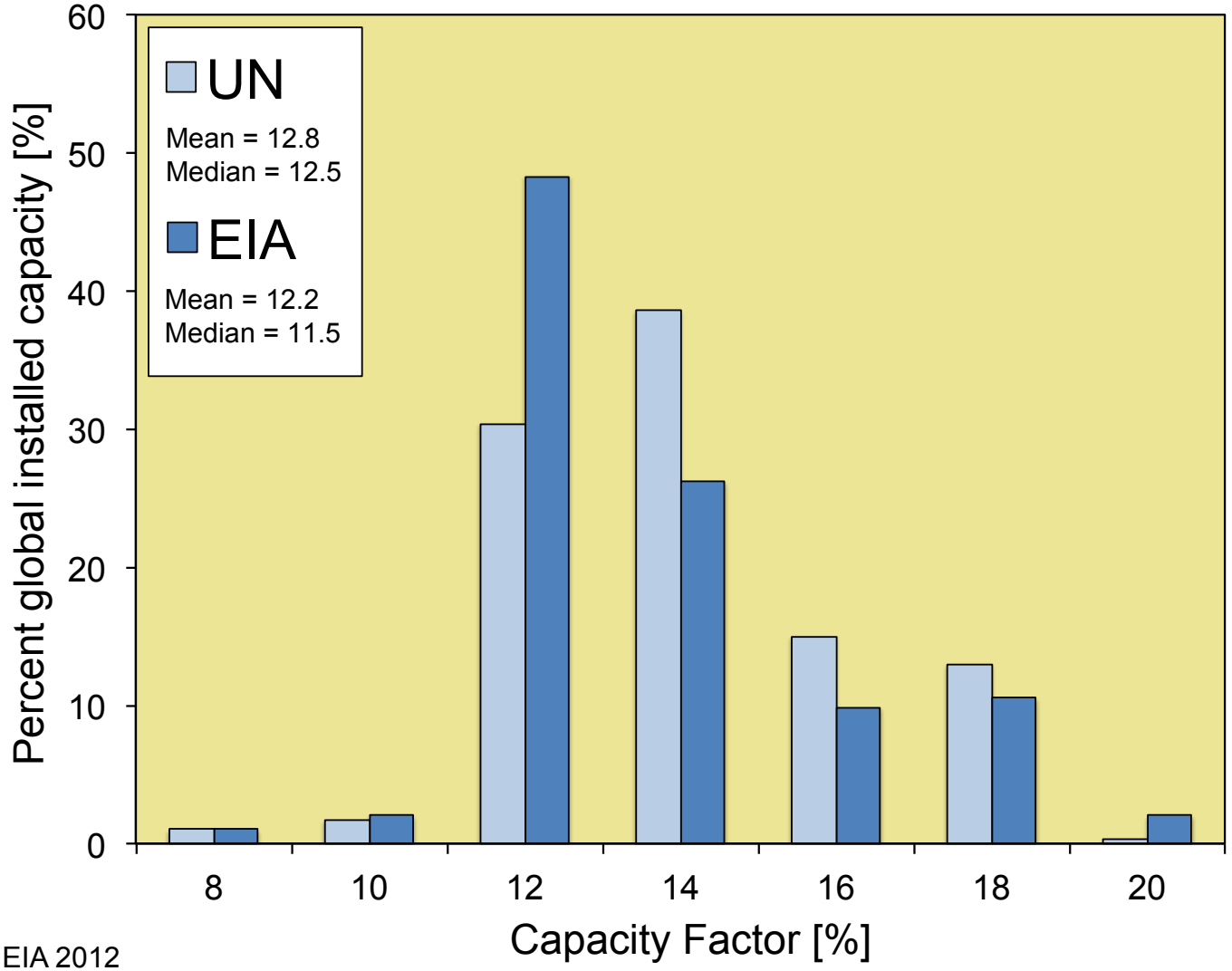
Lower value is better – faster energy return



Equivalence of CED and EPBT



Global PV capacity factor



UN (2011), EIA 2012