

U.S. Department of Energy
Energy Efficiency and Renewable Energy

Photovoltaics Recycling and Sustainability

Vasilis Fthenakis

PV Environmental Research Center
Brookhaven National Laboratory
and

Center for Life Cycle Analysis
Columbia University

Recycling Scoping Workshop, IEEE PVSC, Philadelphia, June 11, 2009

email: vmf@bnl.gov

web: www.pv.bnl.gov



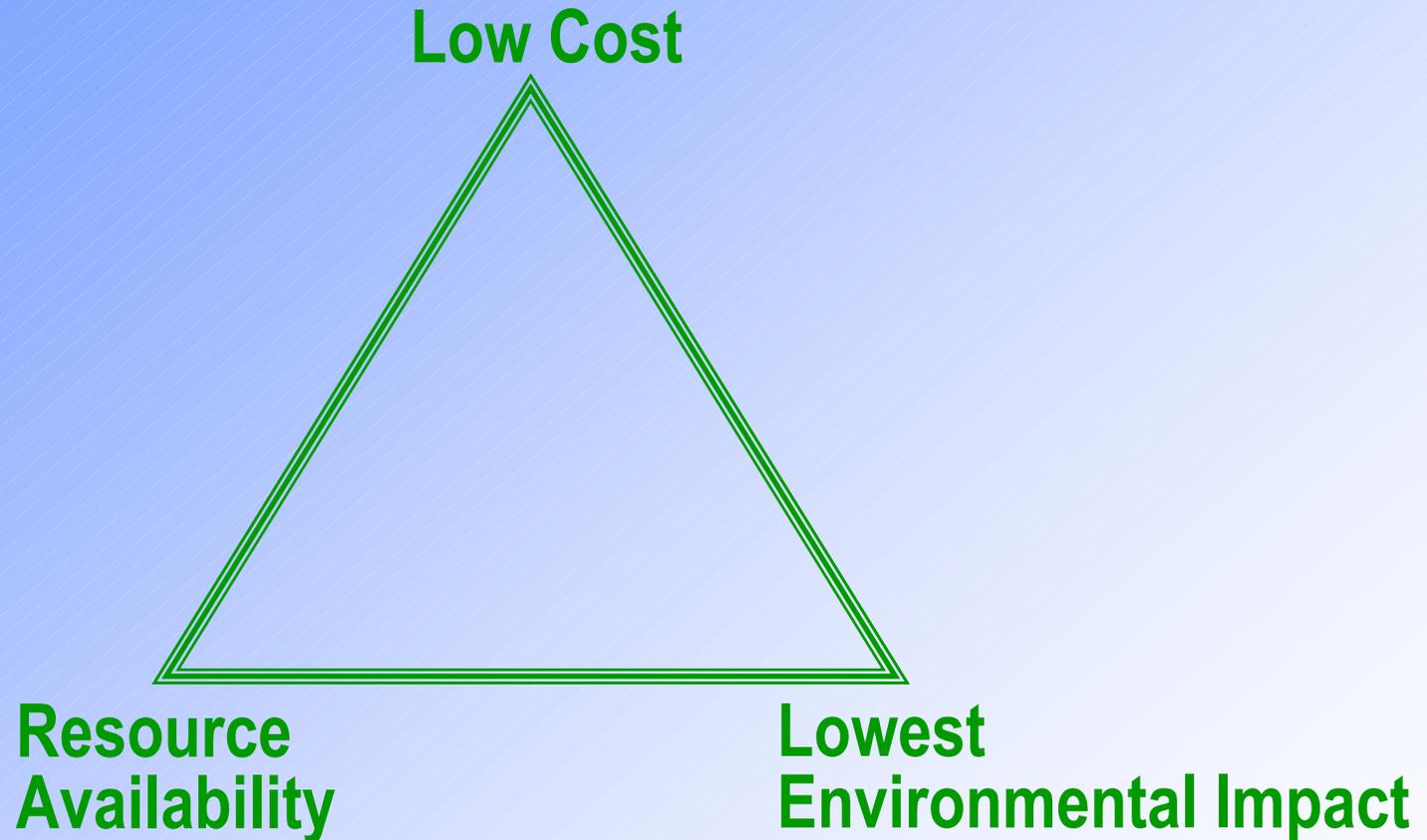
PV Sustainability Criteria

- Photovoltaics are required to meet the need for abundant electricity generation at competitive costs, whilst conserving resources for future generations, and having environmental impacts lower than those of alternative future energy-options

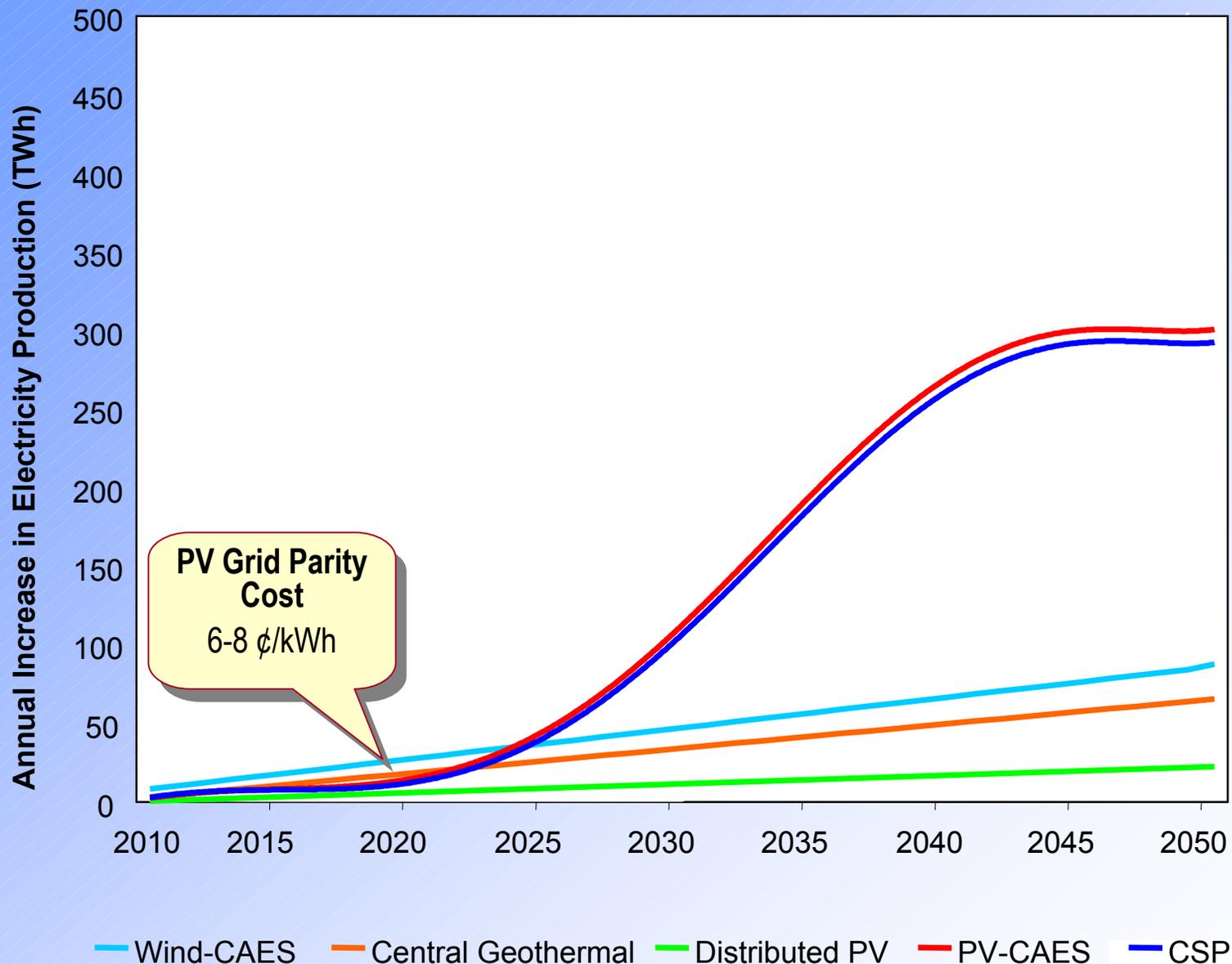
Sustainability Metrics:

- Cost
- Resource Availability
- Environmental Impact

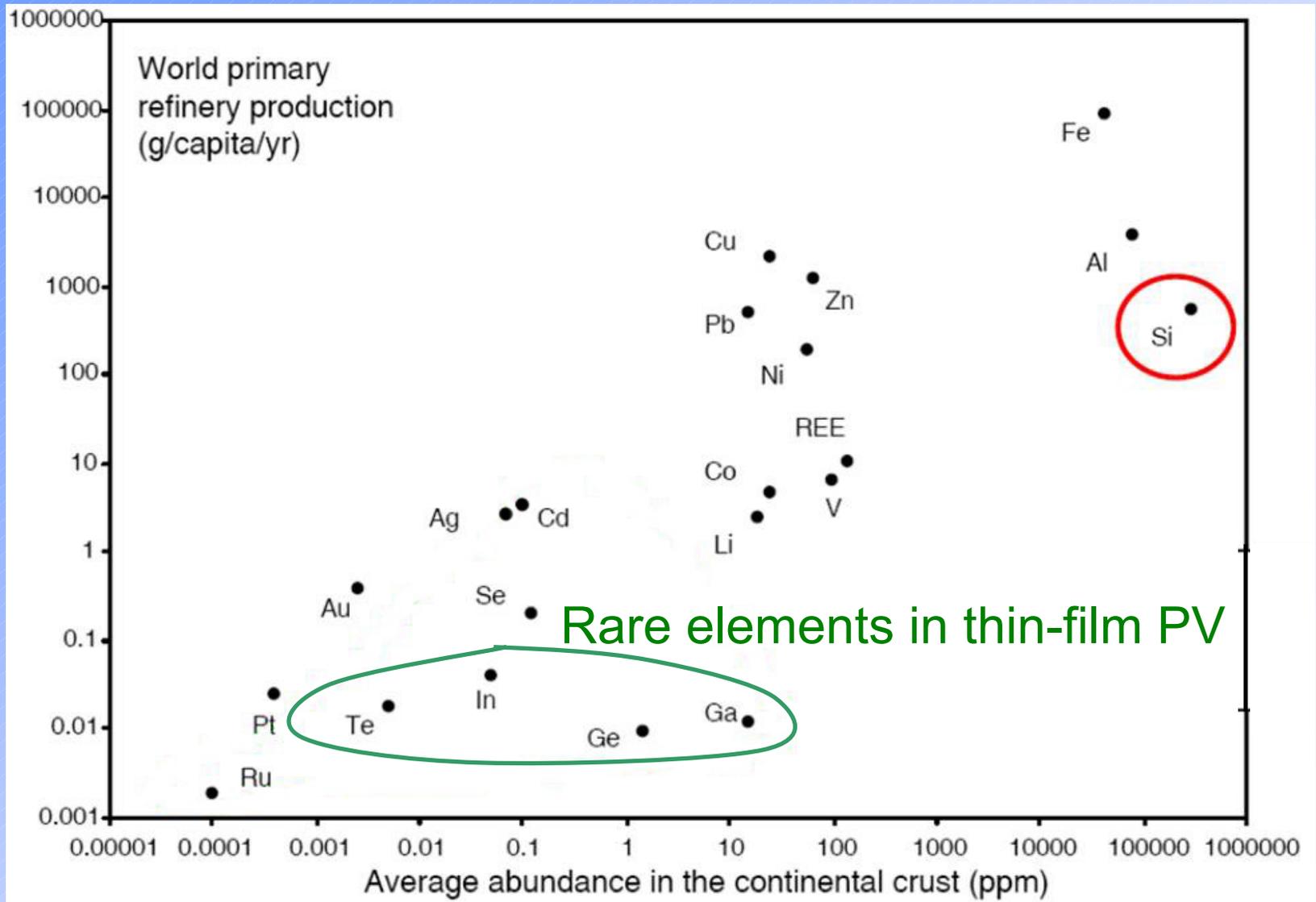
The Triangle of Success



U.S. Grand Solar Plan Projections -Annual Electricity Growth from Renewables -



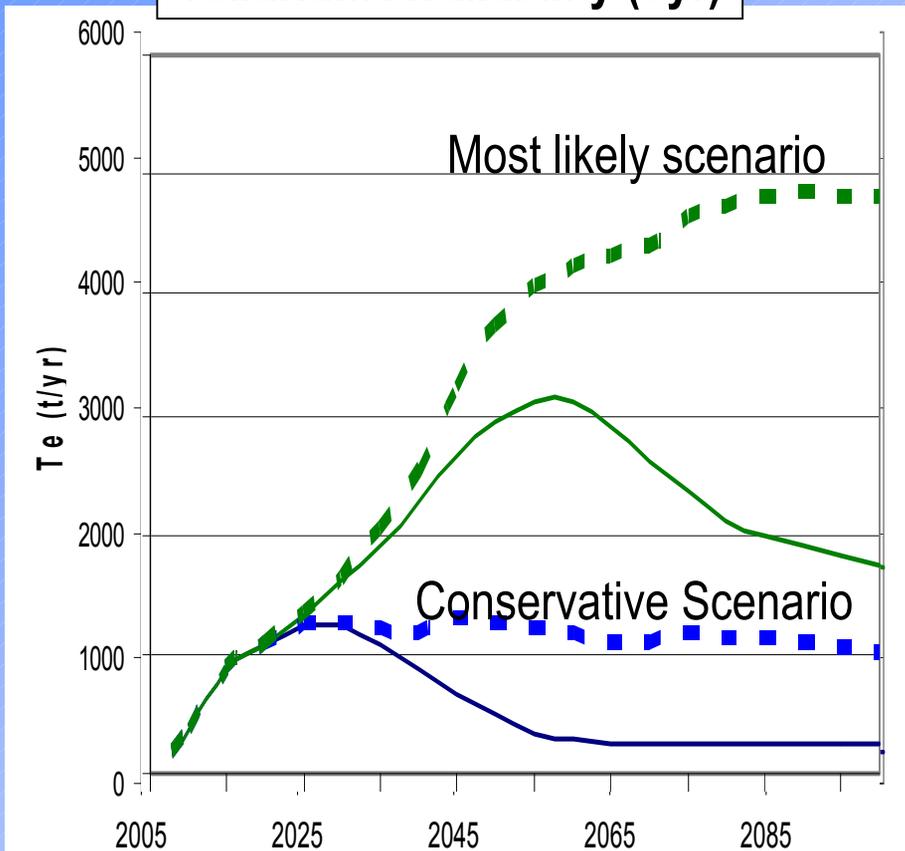
Semiconductor Metal Scarcity



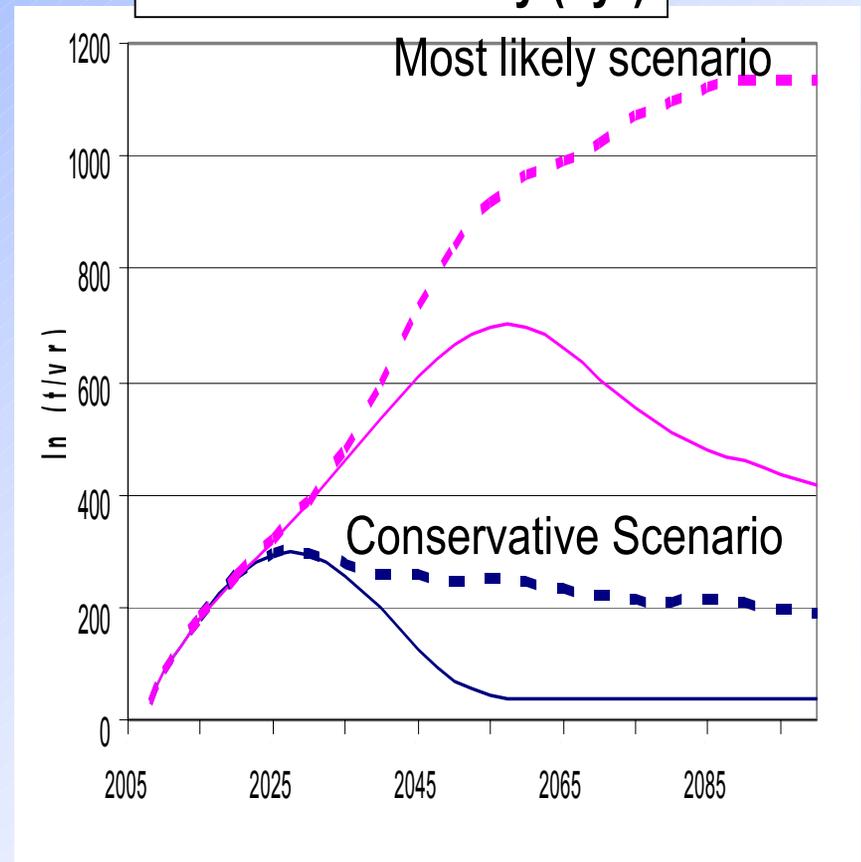
Te and In Availability for PV: Primary Sources + Materials from Recycling of Spent PV Modules

Accounts for competitive demand

Tellurium Availability (t/yr)



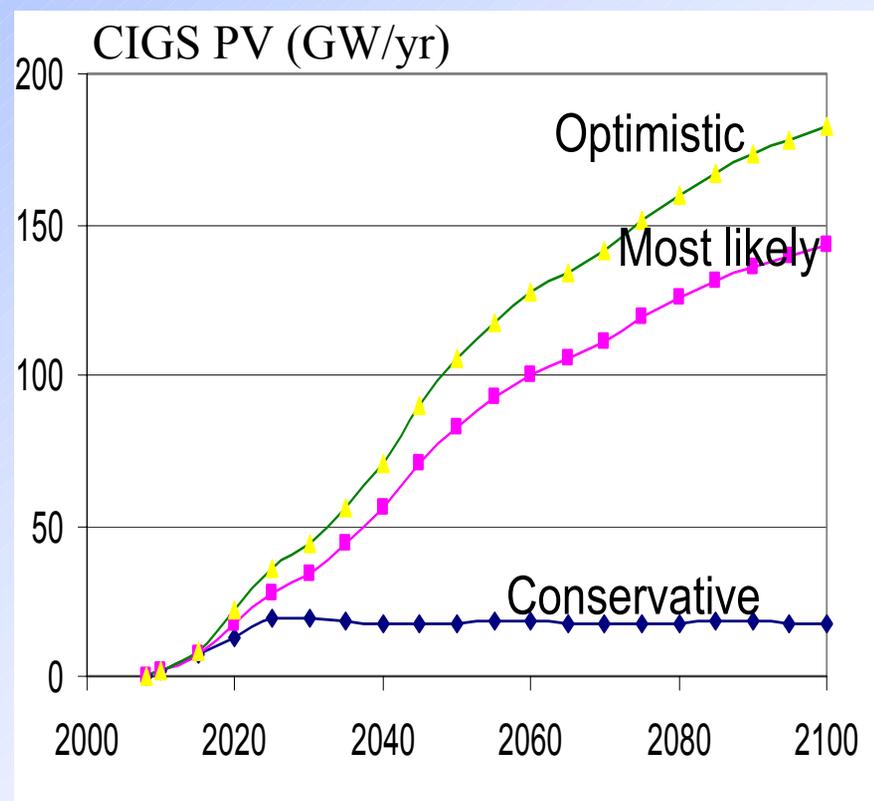
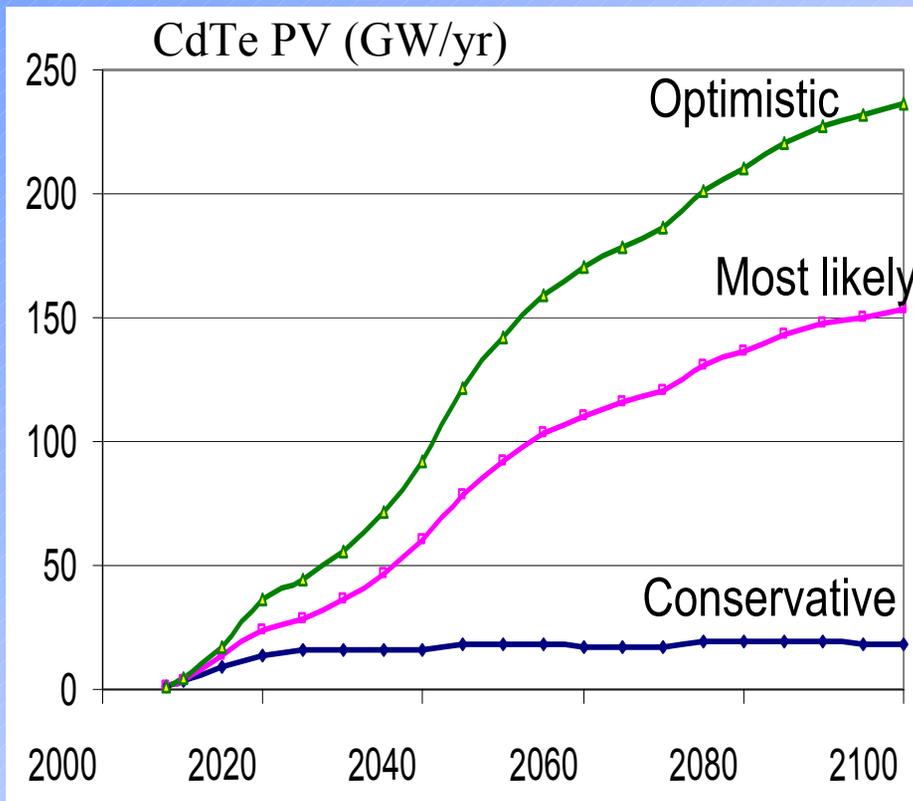
Indium Availability (t/yr)



Resource related Constraints alleviated with Recycling & Technological Advances

Material-related sustainability will be improved with enhanced recovery during primary production, **reducing the thickness** of the semiconductor layers, and efficient **recycling** of spent modules.

Especially needed is R&D on developing thinner layers.



Fthenakis, *Renewable & Sustainable Energy Reviews*, in press

Environmental Considerations

- Environmental footprints of energy technologies should be quantified in a life cycle framework
 - Land Use
 - Energy Use
 - Green House Gases
 - EH&S Risks
 - End-of-life Disposal
 - Recycling

Zero impact technology does not exist → compare with other energy producing technologies as benchmarks

Land Use



Sinzheim, Germany, with permission from Juwi, 2006

1.4MW

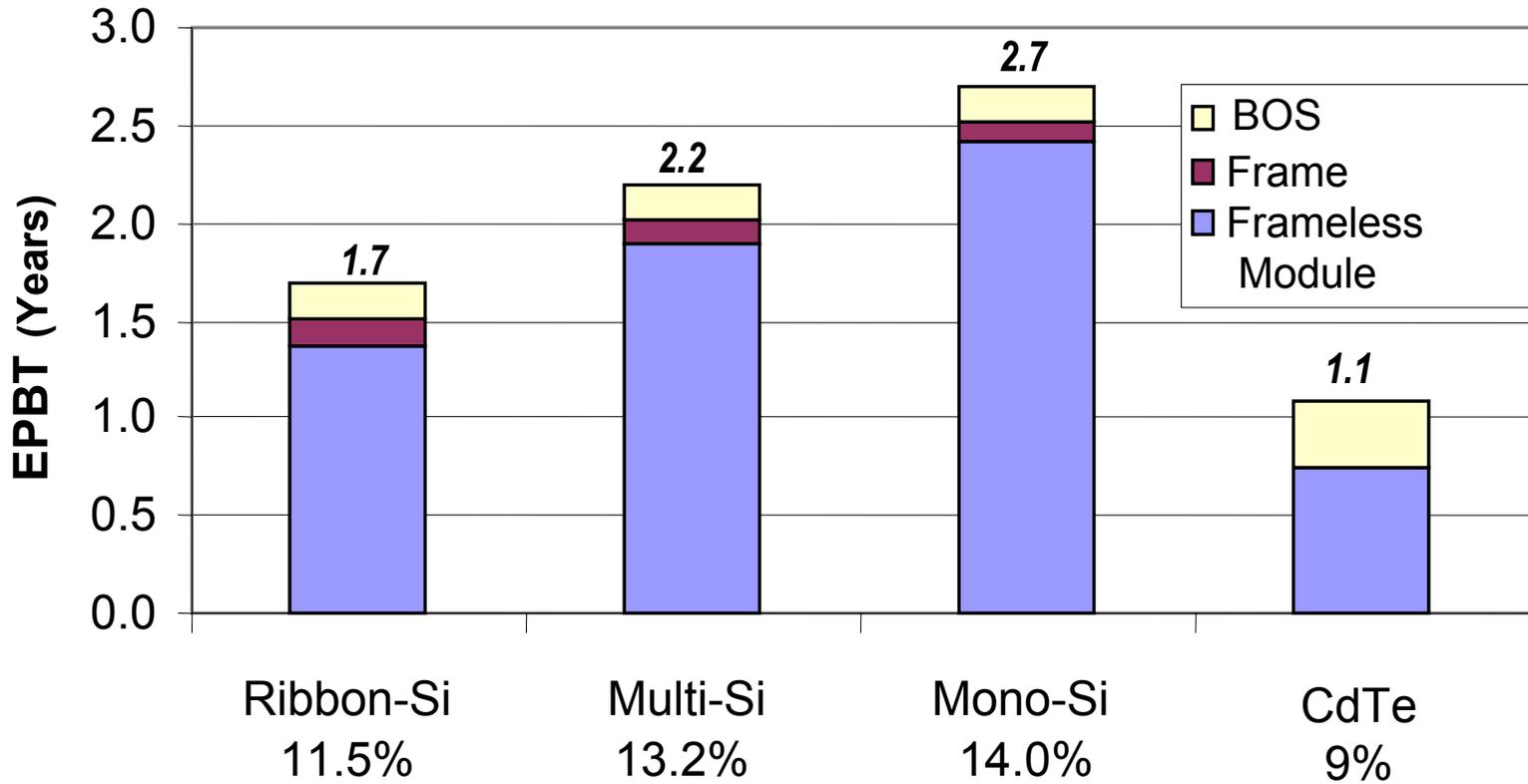
More Land is used by the Coal Life Cycle than PV



Fthenakis V. and Kim H.C., *Sustainable and Renewable Energy Reviews*, 2009

Energy Use Payback Times (EPBT)

Insolation: 1700 kwh/m2-yr

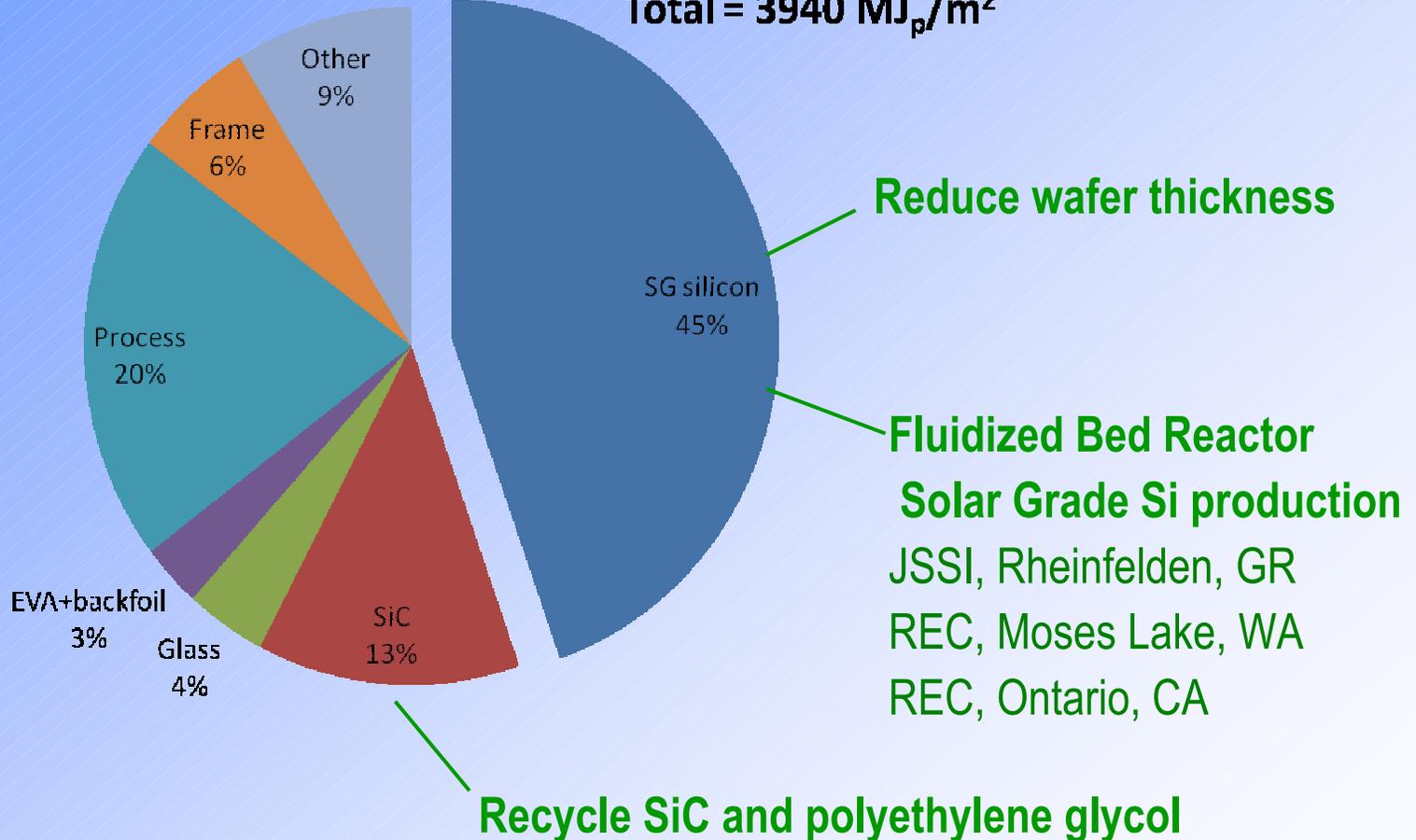


Based on data from 13 US and European PV manufacturers

Breakdown of Primary Energy Demand in Multi-Si PV Module Production

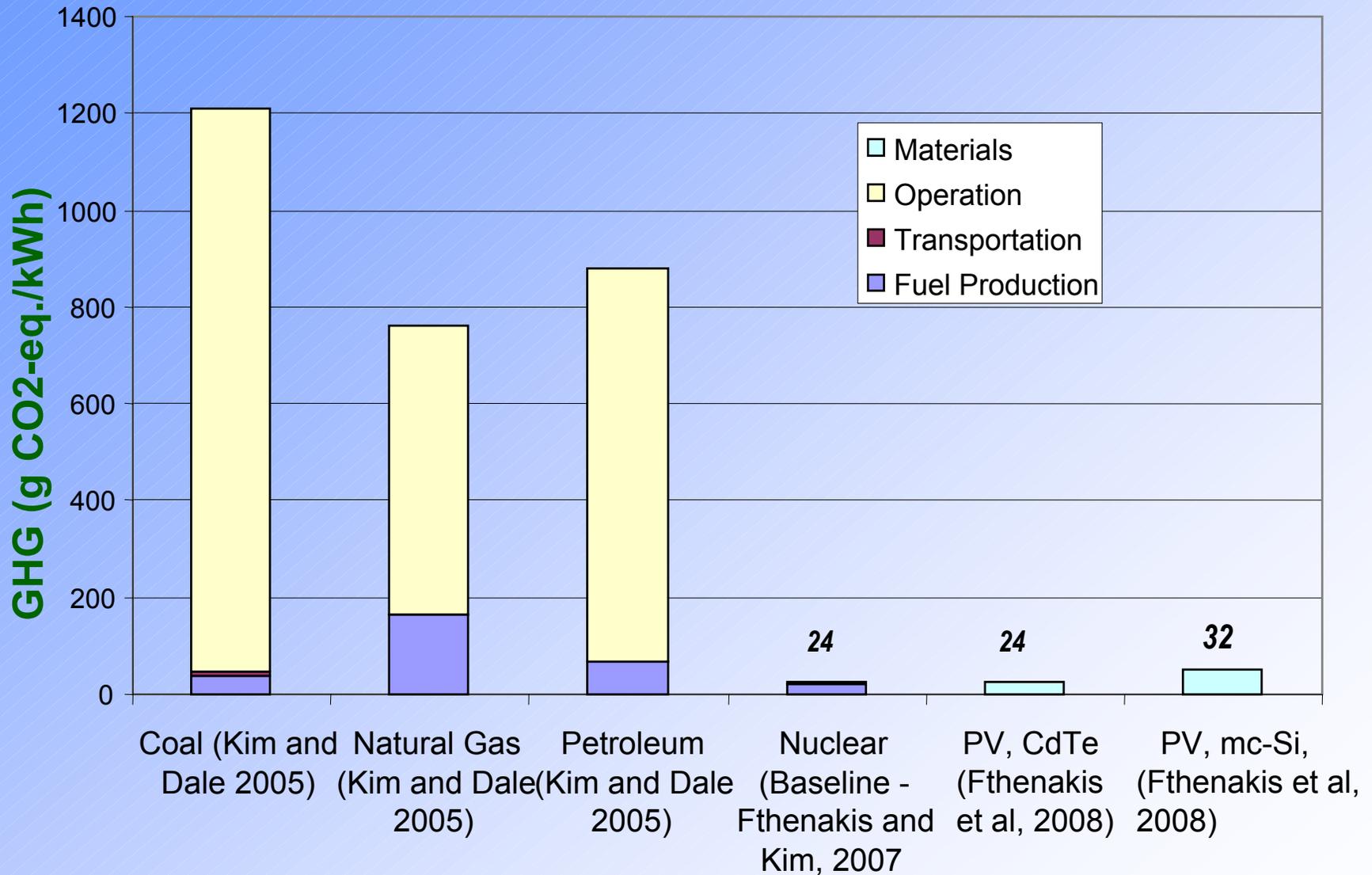
Options to Reduce Energy Demand

Total = 3940 MJ_p/m²



Data source: Alsema, deWild-Scholten, 2006

GHG Emissions from Life Cycle Energy of Electricity Production



California Energy Commission, *Nuclear Issues Workshop*, June 2007
 Fthenakis et al., *Environmental Science & Technology*, 2008



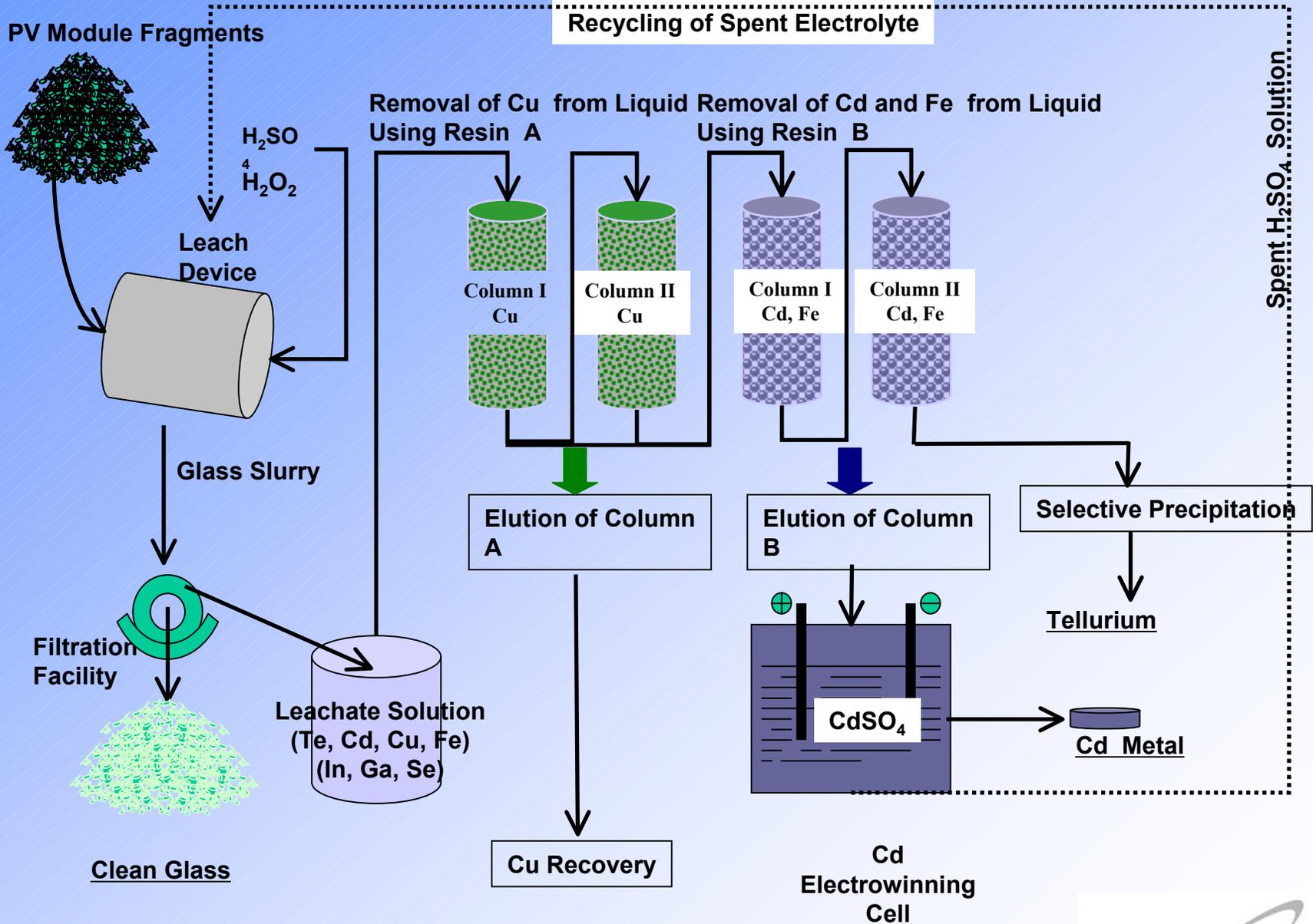
EH&S Risks

- It is of the outmost importance for the PV industry to minimize EH&S risks, preserving safe and environmentally friendly facilities and operations.
- Addressing EH&S concerns is the focus of numerous studies at BNL (>200 publications, tutorials, workshops, presentations, site visits).
- The US PV industry exercises continues vigilance to minimize the risks of hazardous substances.

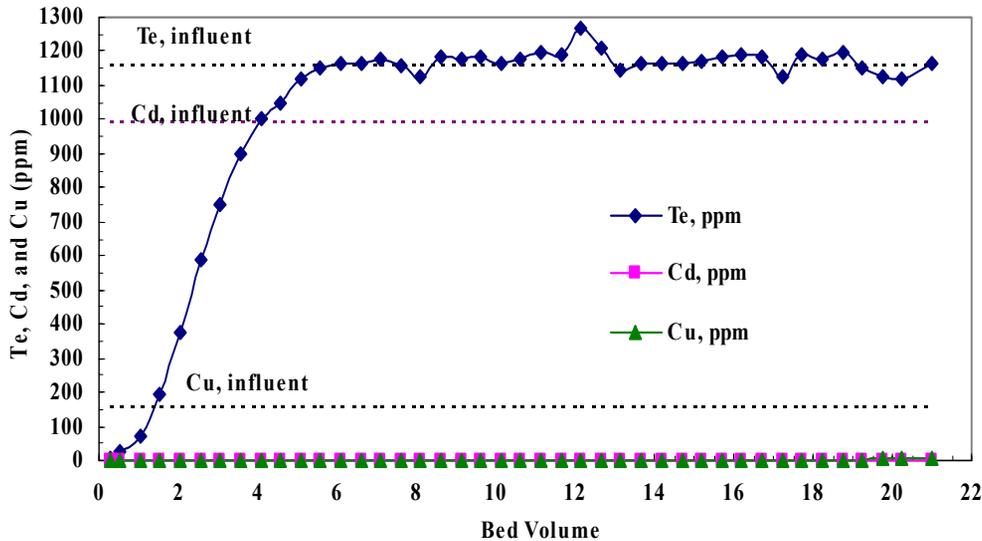
Recycling of Spent Modules

- Provides a source of materials
- Resolves environmental issues related to end-of-life

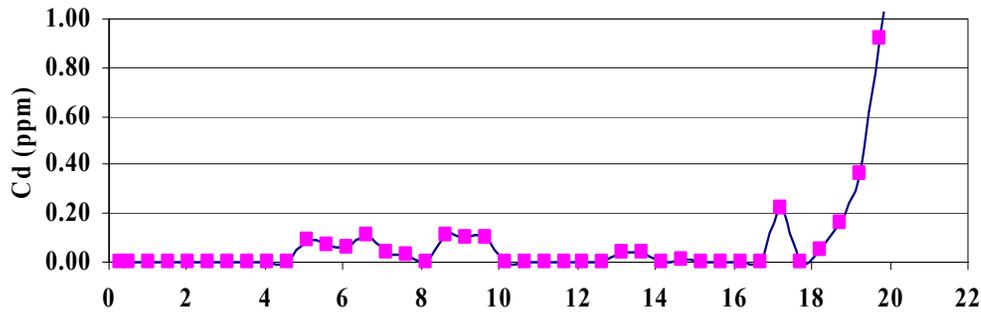
Recycling R&D at BNL: CdTe and CIGS PV Modules



CdTe PV Module Recycling: Cd-Te Separations



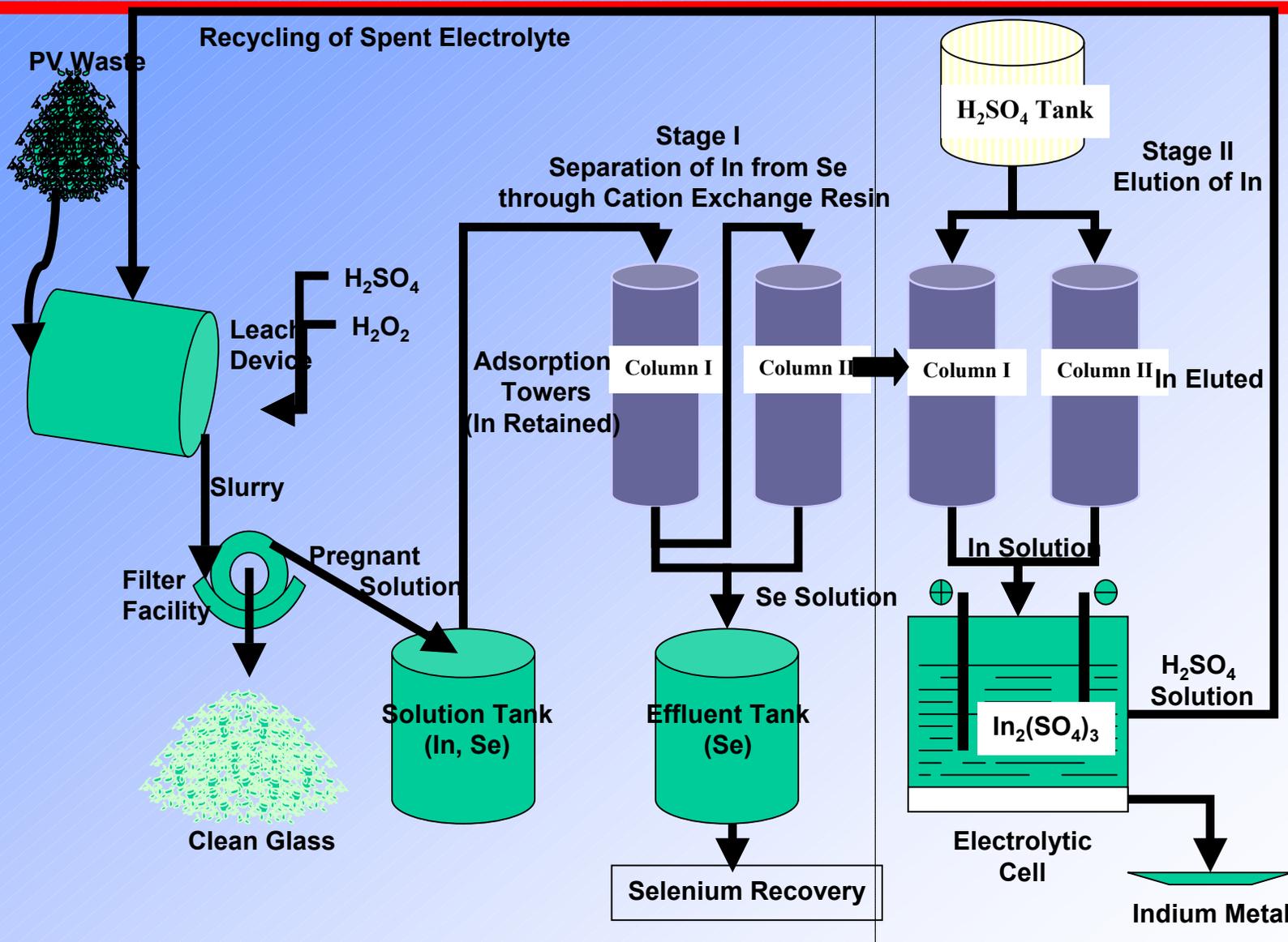
Cd separation 99.99%



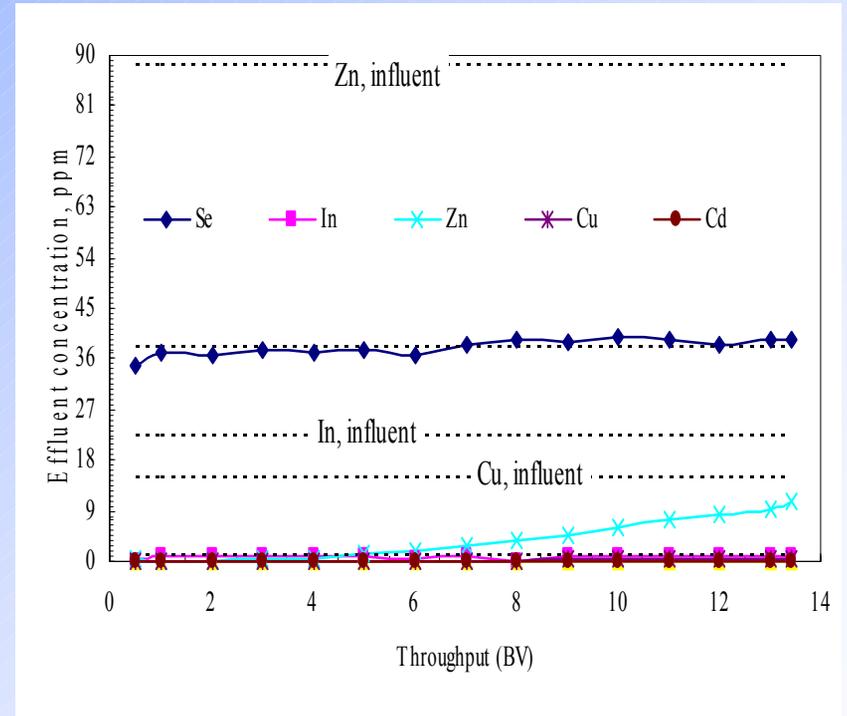
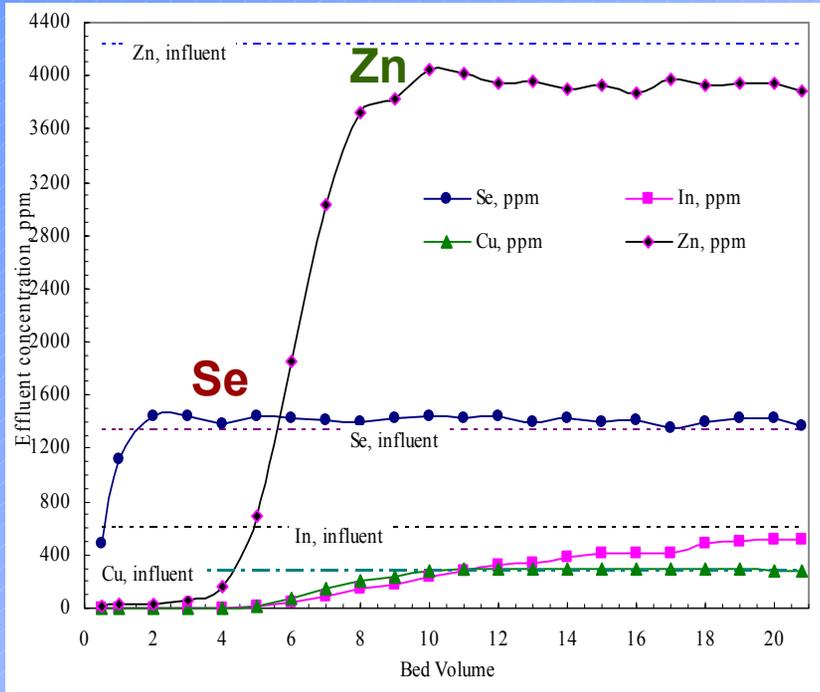
Cd effluent concentration <0.3 ppm

- Cd, Te extraction & separation was completed at a projected cost of 1 ϕ/W_p
- On going work on purity of recovered metals

Recycling Se and In from End-of-Life CIGS PV Modules



CIGS Recycling: Separation of Se, In, Cu, Cd & Zn



Seeking CIGS Industrial Partner for Collaborative Research on recovering high-purity Indium

The PV CYCLE Voluntary Initiative



Current Members:

- Aleo
- Ava Solar
- Avancis
- Arendi
- BP Solar
- Conergy
- Ersol
- First Solar
- GE Solar
- Isofoton
- Johanna Solar
- Kyocera
- Q-Cells
- Photowatt
- REC
- Sanyo
- Schott Solar
- Schueco
- Scheuten Solar
- Sharp
- Siliken
- Solarfabrik
- Solarworld
- Solon
- Solpower
- Solyndra
- Sulfurcell
- Sunpower
- Sunways
- Würth Solar
- EPIA

Associated (partial list):

- BSW
- ECN
- 5N PV

Suntech joins PV module recycling group (May 7, 2009)
Yingli, China, to join PV CYCLE (May 11, 2009)

-43 members so far-

Global Responsibility

The Washington Post

Solar Energy Firms Leave Waste Behind in China - March 9, 2008

SiCl₄ dumping in the fields,
Henan Province, China

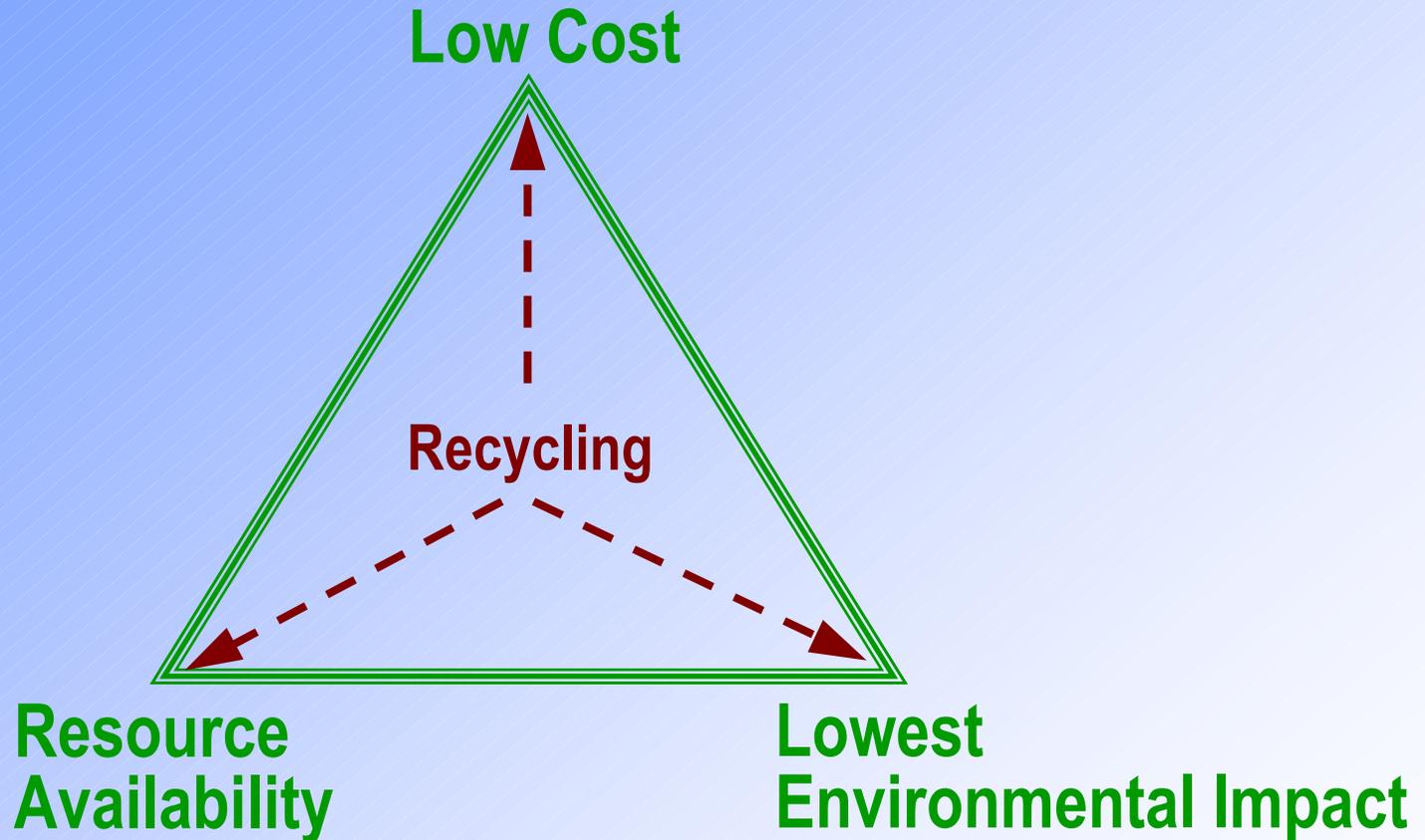
"It's poison air. Sometimes it gets so bad you can't sit outside. You have to close all the doors and windows,"

Qiao Shi Peng, Age 28

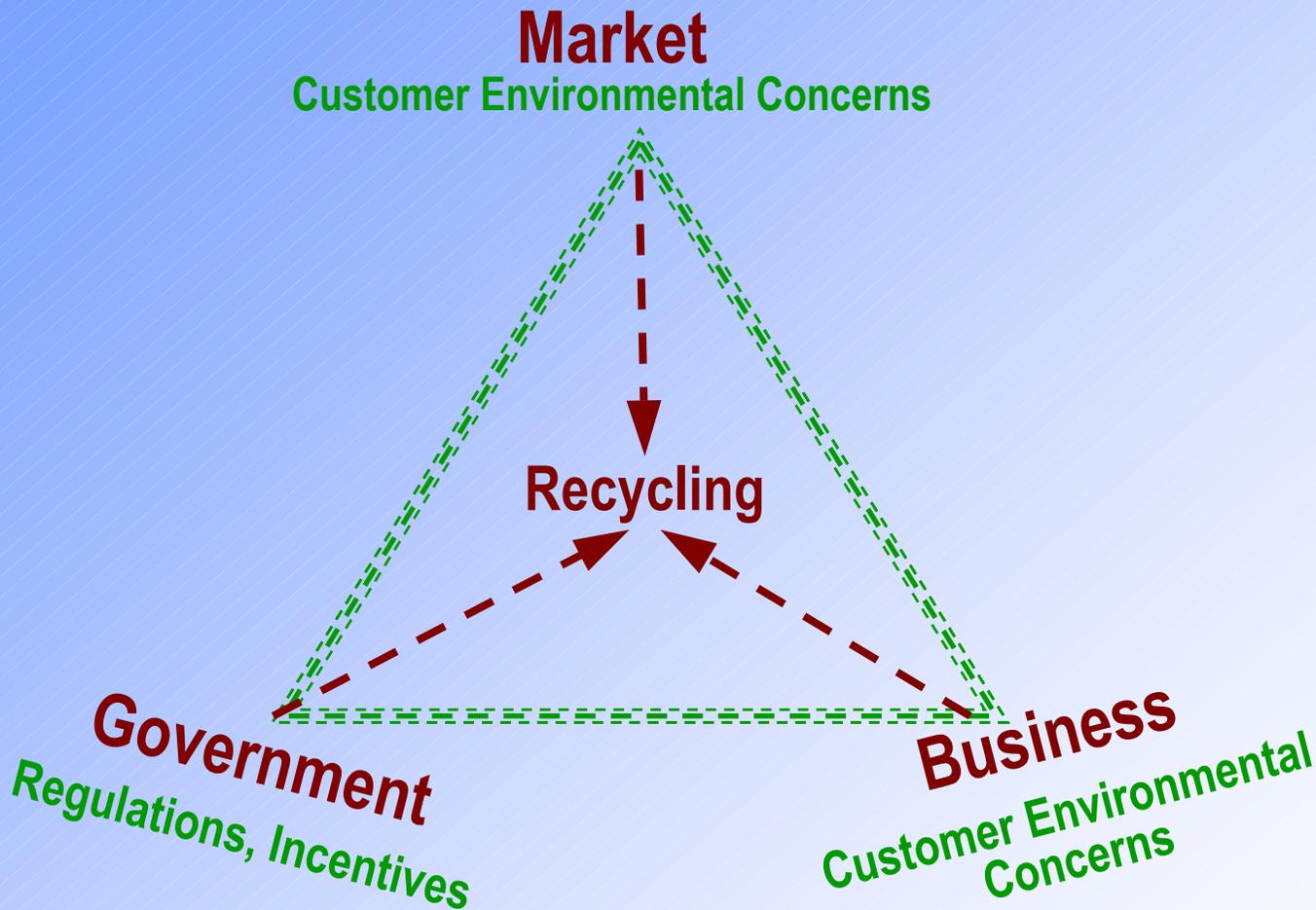


- Photo By Zhang Quanfeng

The Triangle of Success



Synergy Effect



Conclusions

- Major Sustainability metrics include cost, resource availability, and environmental impacts
- These three aspects are closely related; recycling spent modules will become increasingly important in resolving cost, resource, and environmental constraints to large scales of sustainable growth



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National Photovoltaics Environmental Research Center

email: vmf@bnl.gov
www.pv.bnl.gov
www.clca.columbia.edu

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