Photovoltaics – "Green" is a Prerequisite for Sustainable Growth

Vasilis Fthenakis[1] and **Brent Nelson**[2]

[1]Brookhaven National Laboratory & Columbia University
[2]National Renewable Energy Laboratory

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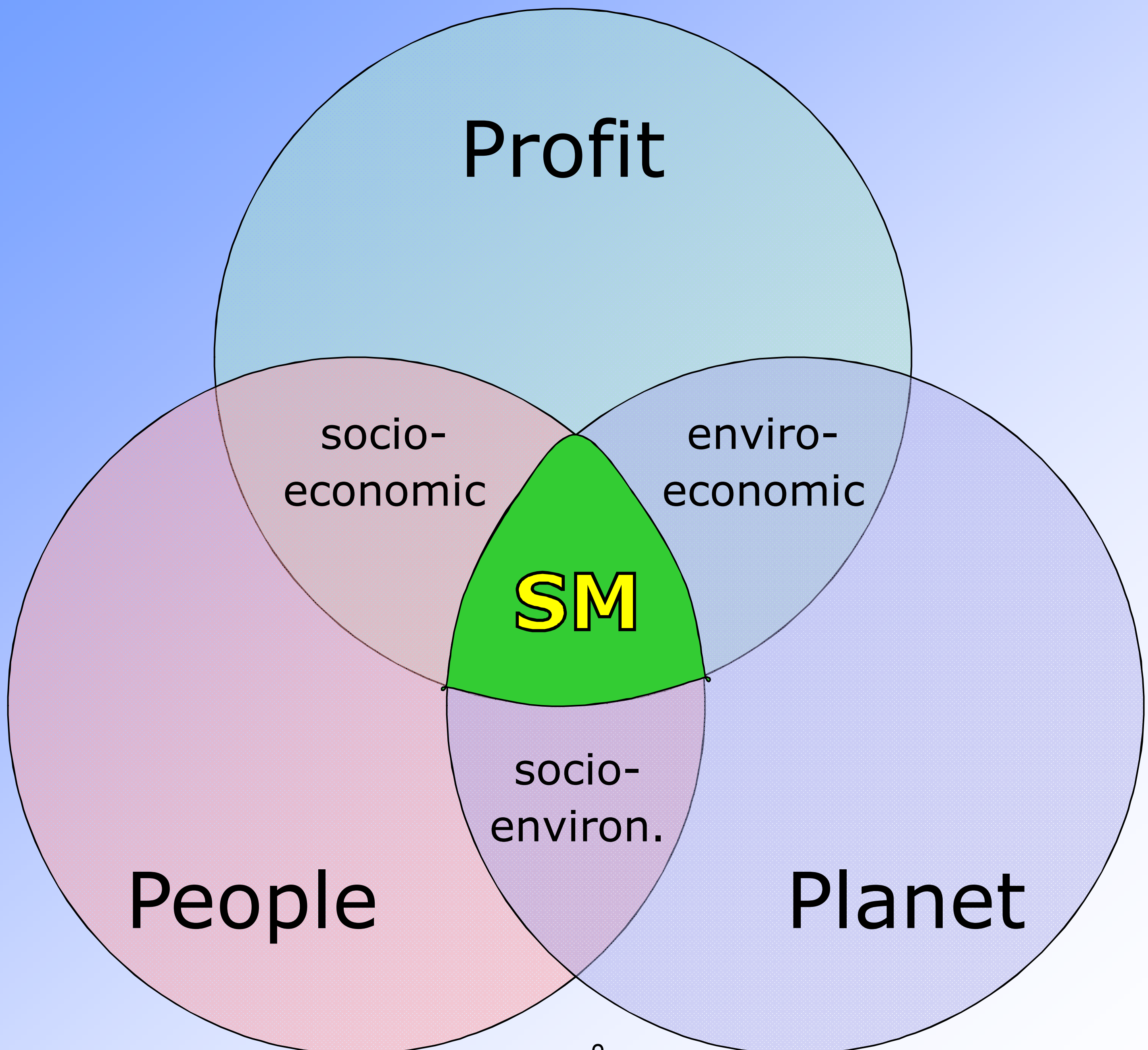
Business Evolution: Increasing Stakeholders



Business Challenge: Engaging Stakeholders

Sustainable Manufacturing

PROFIT

- Owners (e.g., investors, shareholders, analysts, ratings agencies…)
- Customers (e.g., direct, indirect, advocates…)

PEOPLE

- Employees (e.g., current, future, retirees, dependents, representatives …)

PLANET

- Environment (e.g., nature, nonhuman species, future generations, scientists, ecologists, spiritual communities, advocates, non-profits, NGOs…)

Socioeconomic

- Community (e.g., residents fair trad groups, chambers of commerce, resident associations, schools, community organizations, special interest groups…)
- Civil society organizations (e.g., NGOs, faith-based organizations, labor unions…)

Socioenvironmental

- Government (e.g., public authorities, local policymakers, regulators, opinion leaders…)

Enviroeconomic

- Industry (e.g., suppliers, competitors, industry associations, industry opinion leaders,and media)
- Government incentives

Sustainability - Energy & Climate Challenges

- Sustainable development meets the needs of the present generation without compromising the ability of future generations to meet their own needs (Brundtland, 1987)

- Concerns about the sustainability of fossil-fuel energy supply and its impact on the environment, are the key drivers of photovoltaic energy development

- Photovoltaic life-cycles must remain safe and environmentally friendly

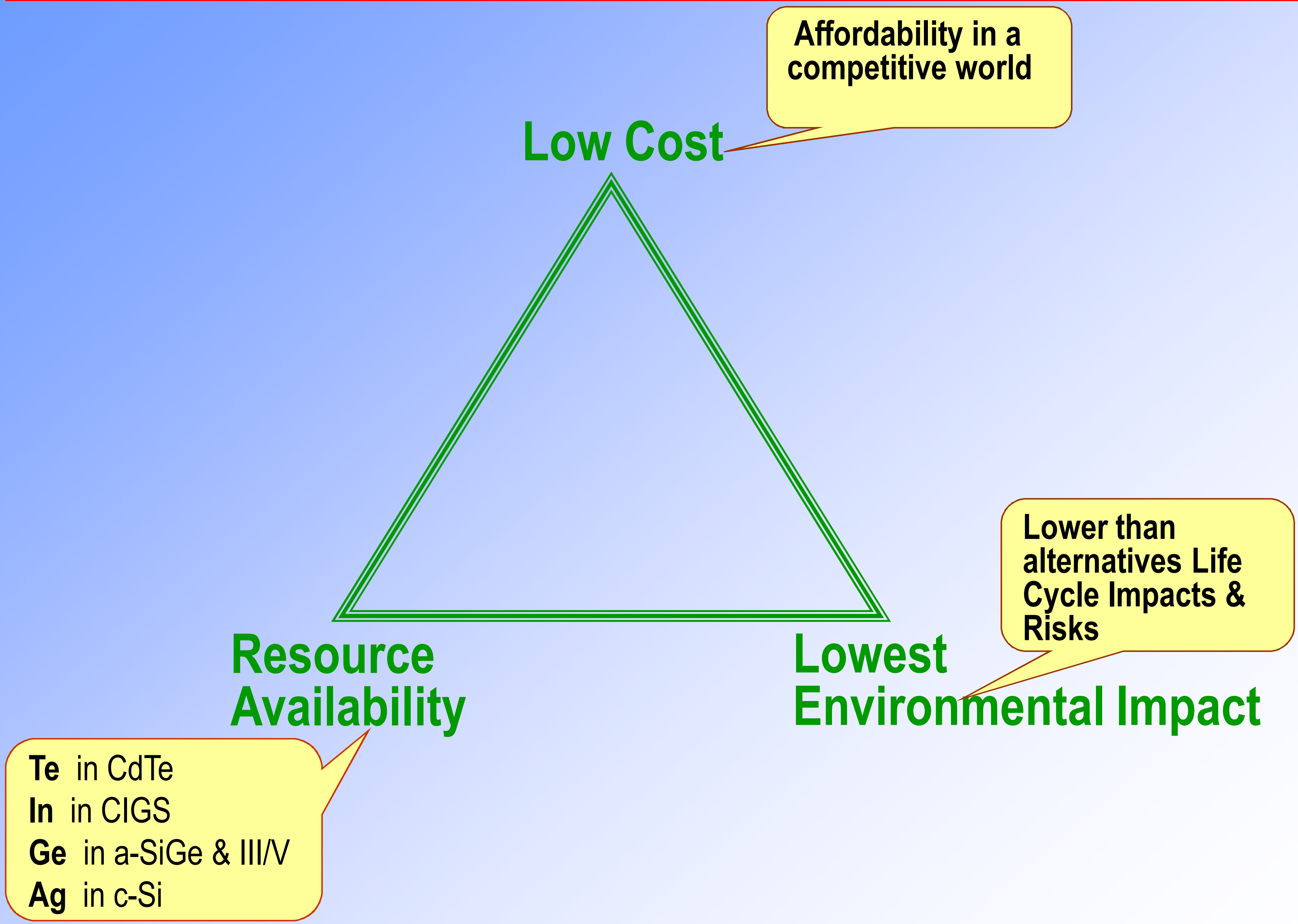
PV Sustainability Criteria

- 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:

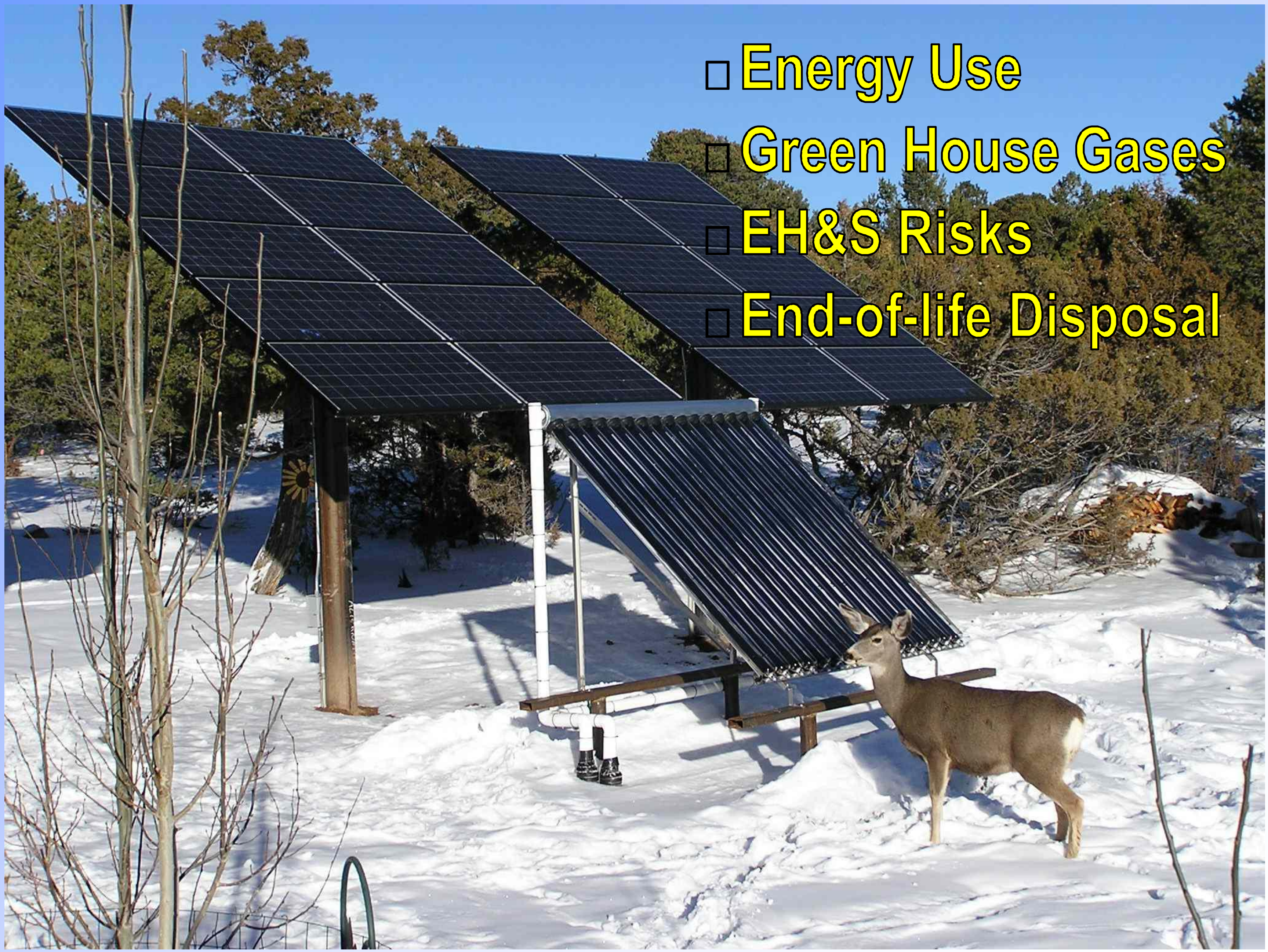
- Cost
- Resource Availability
- Environmental Impact

The Triangle of Success



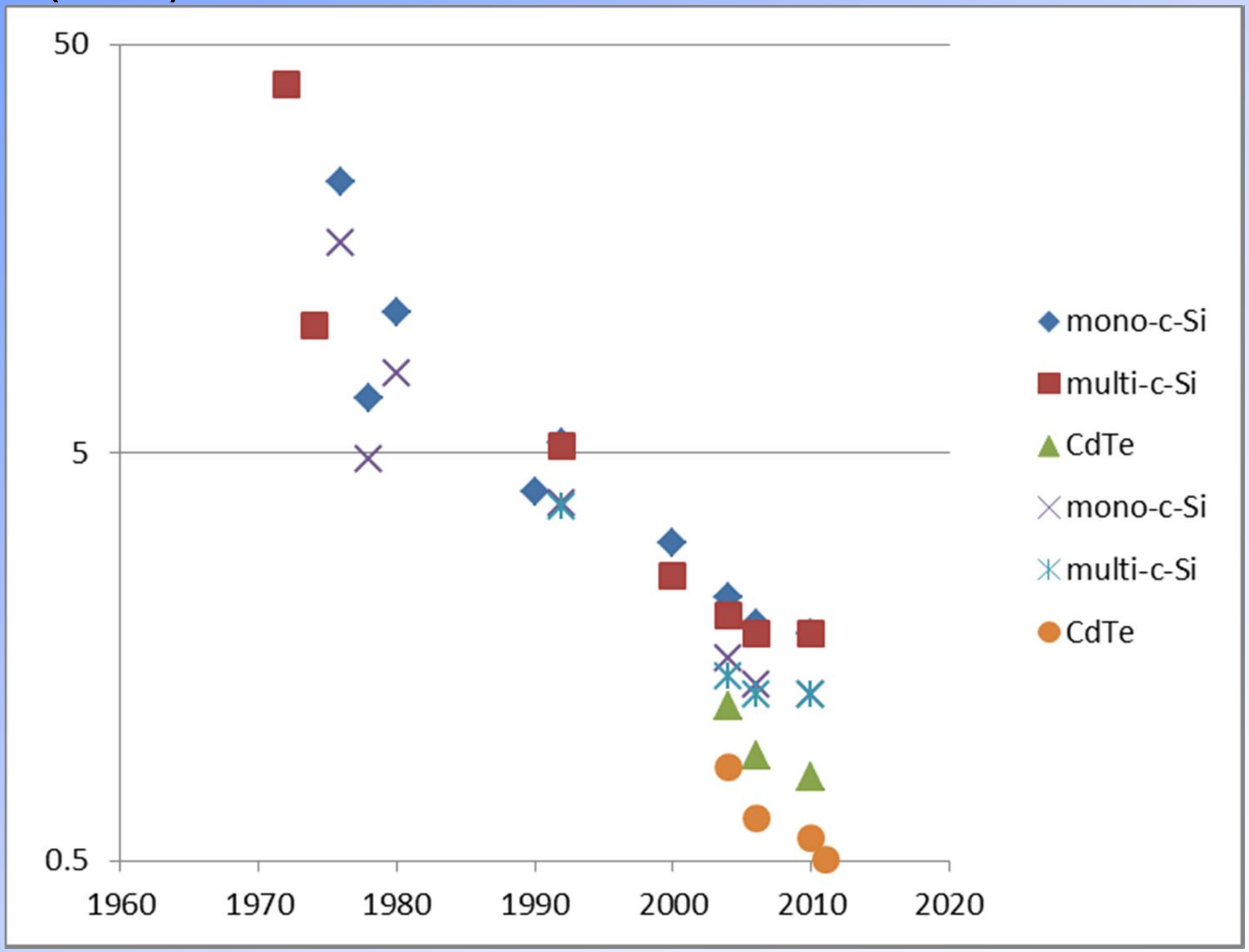
Fthenakis: Renewable & Sustainable Energy Reviews; MRS Bulletin, April 2012

Environmental Considerations



Energy Payback Times (EPBT)

EPBT (Years)



EPBTs of various PV systems were reduced from about 40 yrs to 0.5 yrs from 1970 to 2010.

The low numbers correspond to insolation of 2,400 kWh/m^2/yr ;

the high numbers correspond to insolation of 1700 kWh/m^2/yr

Source: Fthenakis, PV Energy ROI, Solar Today, June 2012)

Context:
It Takes Energy to Make Electricity

Å PV is ñin the ballparkòwith Energy Payback Ratio LCAs

Å Energy Payback is decreasing for convention fuels as resources take more energy to extract

Å Energy Payback is decreasing for renewables with increasing manufacturing and product efficiencies

	Coal	Gas	Solar PV	Nuclear	Wind	Hydro (a)
U. of Wisconsin [1] [2]	11	4	6 (b)	16	23	-
World Energy Council [3]	5–11	2–4	6	16	9–20	-
Hydro-Québec [4] [5]	2–7	2–5	3–6	14–16	18–34	170–280

The figures from the World Energy Council and Hydro-Québec are compilations of life-cycle assessments.

Notes:

(a) The hydropower figures combine run-of-river and reservoir systems.

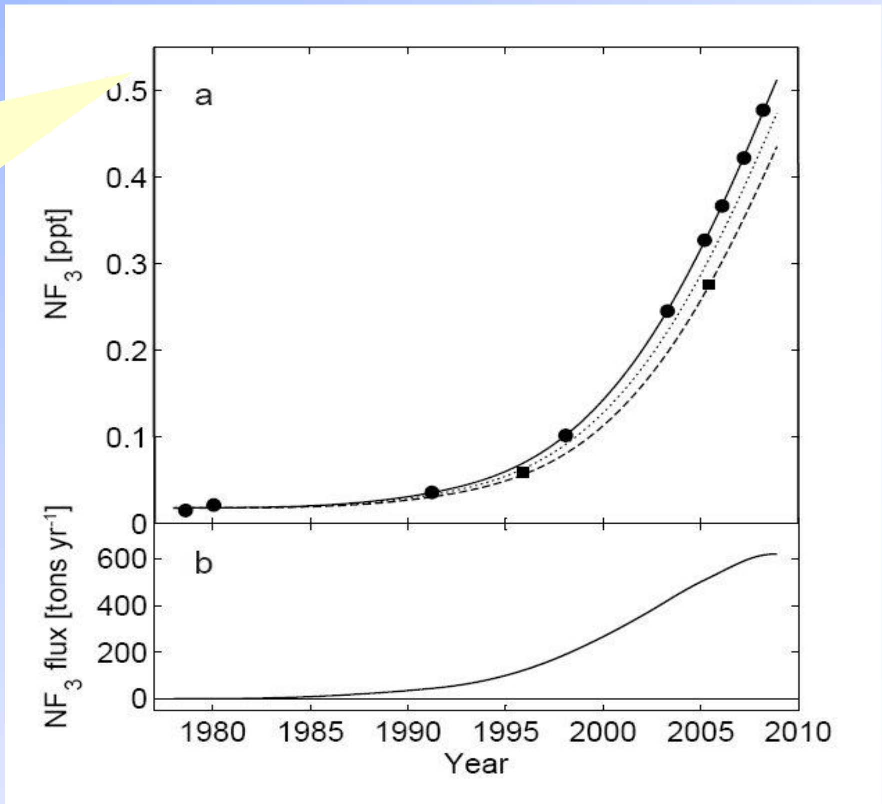
(b) This PV figure assumes a mean insolation of 208 Wm^{-2}, the value for Denver, Colorado.

http://lightbucket.wordpress.com/2008/04/30/energy-payback-ratios-for-electricity-generation/

GHGs in PV Module Manufacturing

"PV: Climate killer? The NF3 story"

Photon Magazine, Dec. 2008



Weiss et al (2008), Nitrogen trifluoride in the global atmosphere, *Geophysical Research Letters*, 2008

The environmental risks related to the use of GHGs in PV manufacturing are relatively low,

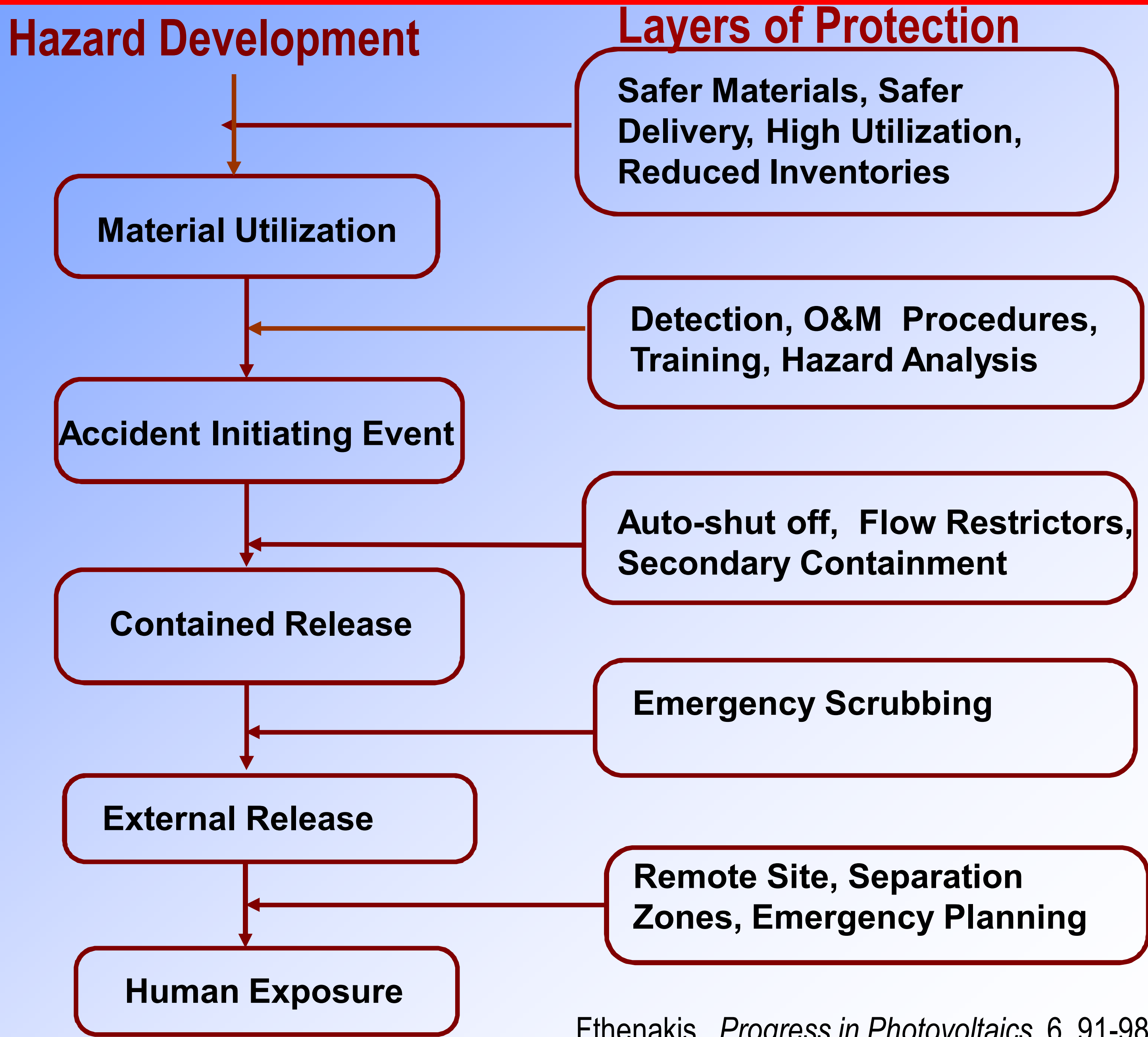
if Best Practices on production, use and abatement are implemented,

Fthenakis et al., *Environ. Sci. Technol*, 2010; EUPVSC, Hamburg, 2011.

Hazardous Substances in PV Manufacturing

Substance	Source
Arsine	GaAs MOCVD
Boron Trifluoride	Dopant
Cadmium Compounds	CdTe, CIGS/CdS
Hydrochloric acid	Cleaning agent – c-Si
Hydrogen Fluoride	Etchant – c-Si
Hydrogen Selenide	CIGS selenization
Phosphine	a-Si dopant
Hydrogen	a-Si deposition/GaAs
Silane	a-Si deposition, SiNx deposition, c-Si production
CF_4, C_2F_6, SF_6, NF_3	c-Si etching, reactor cleaning

Multi-Layer Protection of PV Manufacturing Facilities



Fthenakis, *Progress in Photovoltaics*, 6, 91-98, 1998

EH&S Risks in PV Manufacturing

- 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)

- The US PV industry exercises vigilance to minimize the risks of hazardous substances

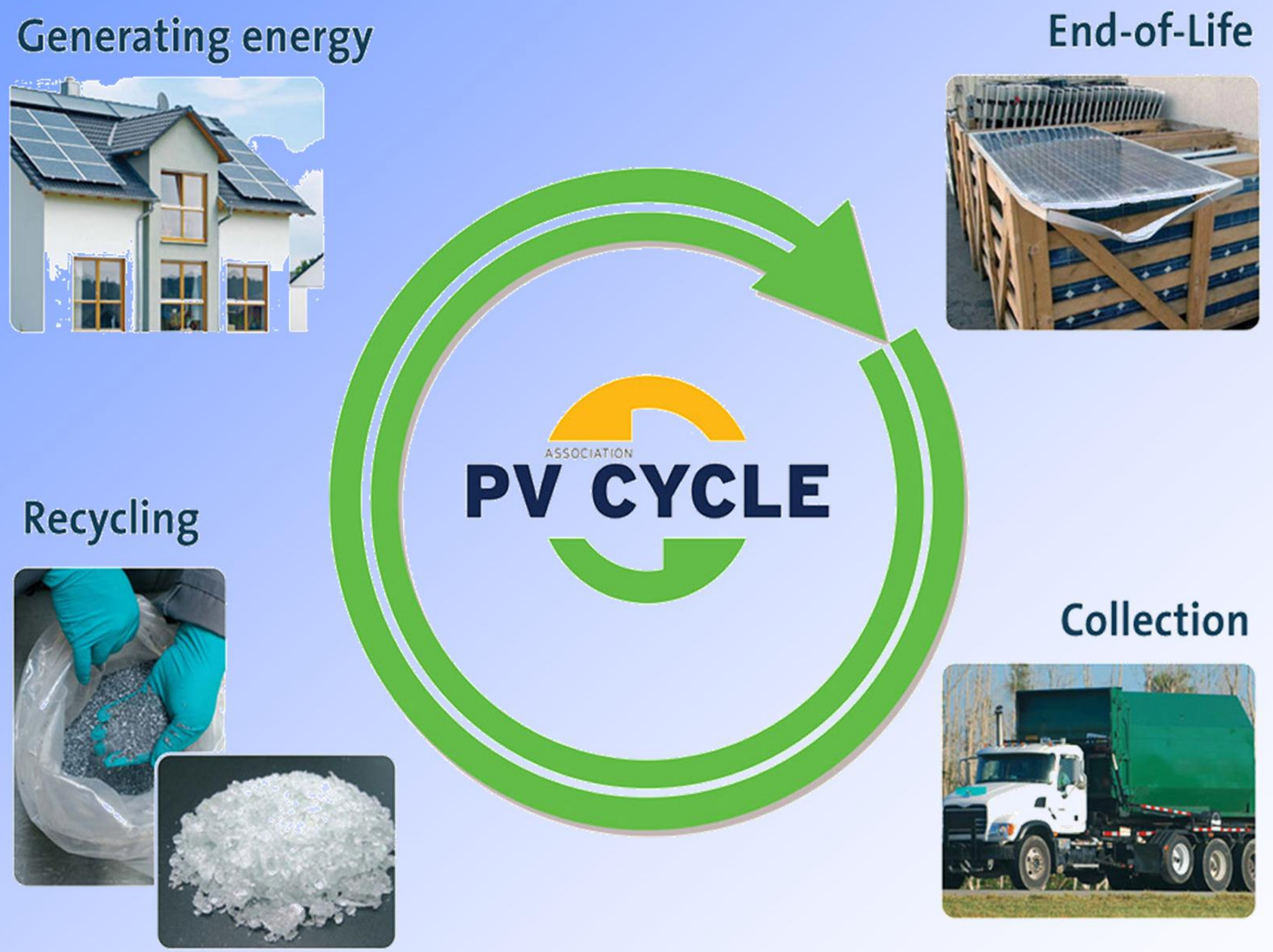
- Continuing vigilance world-wide is especially important in view of fast growth of production and R&D facilities

- We advocate a multiple-layer, defense-in-depth approach for all facilities that handle large quantities of hazardous materials

End-of-life Issues of PV modules

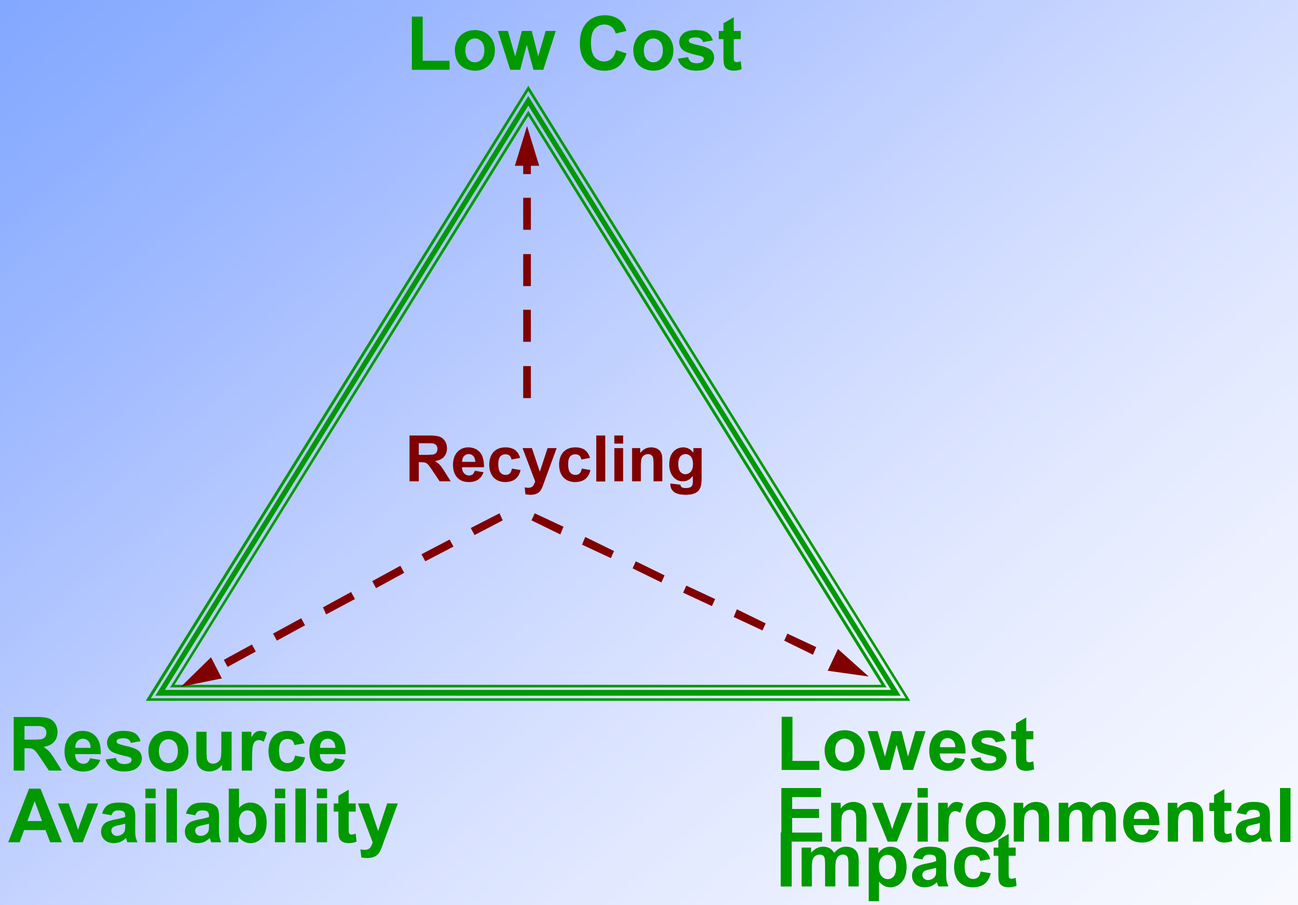
- Rapid growth of PV market will result in an eventual waste disposal issue 25+ years after module installation
- Potential of environmental impacts from disposal of PV as municipal waste
- PV recycling will resolve environmental concerns and will create secondary sources of materials that benefit the environment

PVCYCLE European Industry Cooperative Voluntary Recycling Program



PVCYCLE has 145 company members representing ~90% of the EU market

Recycling-The Triangle of Success



Conclusion

- The PV industry needs to remain proactive in EH&S and adopt a long-term environmental strategy to prevent potential environmental damage by processes and products.
- Current economic times can lead to “survival mode” operation reducing sustainability activities.
- Sustainability of large-scale deployment requires attention to life-cycle issues such as the use of GHGs in manufacturing and end-of-life recycling.

References

- Vasilis Fthenakis' Bibliography
  http://www.bnl.gov/pv/biblio.asp
- MRSBulletin, April 2012, Vol. 37, No.4
  Materials for sustainable development
- Clean & Green: Best Practices in Photovoltaics
  http://asyousow.org/health_safety/solar_report.shtml
- SEMI: http://www.semi.org/standards
  http://www.semi.org/en/Standards/ctr_026630
- New Bulgum Brewery
  http://www.newbelgium.com/culture/alternatively_empowered/sustainable-business-story.aspx

Engaging Stakeholders…

- *can solve problems*
- *helps management see the future*
- *facilitates trust*
- *identifies potentially influential partners*
- *can improve the company's public image*

Recycling -Synergy Effect