Photovoltaics – "Green" is a Prerequisite for Sustainable Growth

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Business Evolution: Increasing Stakeholders

Profit

People

Planet

socio-economic

enviro-economic

socio-environ.
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...)

Sustainable Manufacturing

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

- **Low Cost**
- **Resource Availability**
- **Lowest Environmental Impact**

Affordability in a competitive world

Lower than alternatives Life Cycle Impacts & Risks

- Te in CdTe
- In in CIGS
- Ge in a-SiGe & III/V
- Ag in c-Si

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

- Energy Use
- Green House Gases
- EH&S Risks
- End-of-life Disposal
Energy Payback Times (EPBT)

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/m²/yr; the high numbers correspond to insolation of 1700 kWh/m²/yr.

Source: Fthenakis, PV Energy ROI, Solar Today, June 2012
Context:
It Takes Energy to Make Electricity

- PV is in the ballpark with Energy Payback Ratio LCAs

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

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

<table>
<thead>
<tr>
<th></th>
<th>Coal</th>
<th>Gas</th>
<th>Solar PV</th>
<th>Nuclear</th>
<th>Wind</th>
<th>Hydro (a)</th>
</tr>
</thead>
<tbody>
<tr>
<td>U. of Wisconsin</td>
<td>11</td>
<td>4</td>
<td>6 (b)</td>
<td>16</td>
<td>23</td>
<td>-</td>
</tr>
<tr>
<td>World Energy Council</td>
<td>5–11</td>
<td>2–4</td>
<td>6</td>
<td>16</td>
<td>9–20</td>
<td>-</td>
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<tr>
<td>Hydro-Québec</td>
<td>2–7</td>
<td>2–5</td>
<td>3–6</td>
<td>14–16</td>
<td>18–34</td>
<td>170–280</td>
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</tbody>
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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

“The NF3 story”


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

<table>
<thead>
<tr>
<th>Substance</th>
<th>Source</th>
</tr>
</thead>
<tbody>
<tr>
<td>Arsine</td>
<td>GaAs MOCVD</td>
</tr>
<tr>
<td>Boron Trifluoride</td>
<td>Dopant</td>
</tr>
<tr>
<td>Cadmium Compounds</td>
<td>CdTe, CIGS/CdS</td>
</tr>
<tr>
<td>Hydrochloric acid</td>
<td>Cleaning agent – c-Si</td>
</tr>
<tr>
<td>Hydrogen Fluoride</td>
<td>Etchant – c-Si</td>
</tr>
<tr>
<td>Hydrogen Selenide</td>
<td>CIGS selenization</td>
</tr>
<tr>
<td>Phosphine</td>
<td>a-Si dopant</td>
</tr>
<tr>
<td>Hydrogen</td>
<td>a-Si deposition/GaAs</td>
</tr>
<tr>
<td>Silane</td>
<td>a-Si deposition, SiNx deposition, c-Si production</td>
</tr>
<tr>
<td>CF&lt;sub&gt;4&lt;/sub&gt;, C&lt;sub&gt;2&lt;/sub&gt;F&lt;sub&gt;6&lt;/sub&gt;, SF&lt;sub&gt;6&lt;/sub&gt;, NF&lt;sub&gt;3&lt;/sub&gt;</td>
<td>c-Si etching, reactor cleaning</td>
</tr>
</tbody>
</table>
Multi-Layer Protection of PV Manufacturing Facilities

Hazard Development

- Material Utilization
- Accident Initiating Event
  - Contained Release
  - External Release
    - Human Exposure

Layers of Protection

- Safer Materials, Safer Delivery, High Utilization, Reduced Inventories
- Detection, O&M Procedures, Training, Hazard Analysis
- Auto-shut off, Flow Restrictors, Secondary Containment
- Emergency Scrubbing
- Remote Site, Separation Zones, Emergency Planning

EH&S Risks in PV Manufacturing

- It is of the utmost 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

- Low Cost
- Resource Availability
- Lowest Environmental Impact

Recycling
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

- MRSBulletin, April 2012, Vol. 37, No.4
  Materials for sustainable development

- Clean & Green: Best Practices in Photovoltaics

- SEMI: http://www.semi.org/standards

- New Bulgum Brewery
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

- Market
  - Customer Environmental Concerns
- Government
  - Regulations, Incentives
- Business
  - Shareholders Environmental Concerns

Recycling