2.626 Fundamentals of Photovoltaics
Fall 2008

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Background in Remaining Topics

Lecture 18 – 2.626
Tonio Buonassisi
Agenda

• 2.626 Status Review
# Remaining Lectures At a Glance

<table>
<thead>
<tr>
<th>Date</th>
<th>Event</th>
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<tbody>
<tr>
<td>11/11</td>
<td>Veteran’s Day Holiday</td>
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<tr>
<td>11/18</td>
<td>Theory: Remaining Topics</td>
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<tr>
<td>11/25</td>
<td>Guest: Brendan Neagle (Modules, Installations)</td>
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<tr>
<td>12/2</td>
<td>Tour: Evergreen Solar (10-11am)</td>
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<tr>
<td>12/9</td>
<td>Presentations Day 2</td>
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<tr>
<td>11/13</td>
<td>Modules</td>
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<tr>
<td>11/20</td>
<td>Guest: Mike Rogol (Prices, Markets, Trends)</td>
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<tr>
<td>11/27</td>
<td>Thanksgiving Holiday</td>
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<tr>
<td>12/4</td>
<td>Presentations Day 1</td>
</tr>
</tbody>
</table>
Agenda

Tour
• Evergreen signup sheet.
• Option: Additional Tours

Class Projects
• Class Budget: $400!
• Resources Check.
• Presentations Lottery.
Remaining Topics

Modules:
- Design criteria, tradeoffs, costs.
- Building integration, BIPV.
- System integration.
- Scaling, and integration into the power grid.
- Appropriate technology selection.
- Failure: failure modes in stationary and tracking systems, accelerated testing, field testing, service and warranty contracts.
Remaining Topics

Cost & Manufacturability:
• Cost: Building a cost model, key drivers of cost, substitution economics.
• Manufacturing: Environments, models, operations, process yield, handling.
• Predicting shortages and bottlenecks.
• Scaling: the multi-GW plant. Production technologies. Factory Tour.

Price and Markets:
• What sets price (and profit)
• Energy future and overview of renewable energy sources
• Economics and market dynamics
• Fluctuations in supply and demand, drivers for oversupply/undersupply conditions, and what this means for profits.
• Subsidies: Why subsidize? How much to subsidize? Role of PV in the global energy market.
Price, Markets & Subsidies
Markets

Customer Needs

Substitution Economics

- What type(s) of grid electricity will PV substitute?
  - What will this mean for traditional gencos?
- What is a fair selling price for PV electricity?
Markets

“Value” of PV Electricity

PV Installations Worldwide

Seasonal and Diurnal Electricity Prices

Image removed due to copyright restrictions.
Incentives!  Tax Breaks!

Support Mechanisms!
# Summary of Support Mechanisms

<table>
<thead>
<tr>
<th>Measure</th>
<th>Advantages</th>
<th>Disadvantages</th>
<th>Examples</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Margin enhancement</strong></td>
<td>Feed-in tariff</td>
<td>Stable revenues. Technology specific</td>
<td>Germany/Spain/USA</td>
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<tr>
<td></td>
<td>Premium to fossil market</td>
<td>Greater transparency</td>
<td>UK</td>
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<td></td>
<td>Tax relief</td>
<td>Simple</td>
<td>USA</td>
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<td></td>
<td>Grants/soft loans</td>
<td>Simple</td>
<td>EU member states, USA</td>
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<tr>
<td><strong>Penalties</strong></td>
<td>Carbon caps</td>
<td>Transparent</td>
<td>European emissions trading</td>
</tr>
<tr>
<td><strong>Mixture</strong></td>
<td>Renewable Obligations</td>
<td>Transparent, market driven. Technology independent</td>
<td>UK</td>
</tr>
</tbody>
</table>

Many forms of support

“best” depends on other policy objectives

Many forms of support

“best” depends on other policy objectives

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Slide courtesy D. Kammen, UC Berkeley
Subsidy schemes of important European PV markets
United States

• Lack of federal leadership led to fractionalized energy policy.
  – Huge state-to-state variation.
  – Website compiling all state-specific information: http://www.dsireusa.org/
Image removed due to copyright restrictions.
Please see: http://www.dsireusa.org/documents/SummaryMaps/RPS_map.ppt.
Image removed due to copyright restrictions. Please see:
Image removed due to copyright restrictions.
Please see: http://www.dsireusa.org/documents/SummaryMaps/Rebate_map.ppt.
Projections
% of Total Production

Evolution of the Energy Mix

Technological Projections
Some “solutions” are radically different!

“Bucky” Fuller’s global electrical grid proposed in the 1970s augmented with computerized load management and high-temperature superconducting (HTS) cables could transmit electricity from day to night locations and foster low-loss distribution from remote, episodic or dangerous power sources. The resistivity of copper oxide HTS wires vanishes below the 77 K boiling point of liquid N$_2$ available from air. Could HTS nanotubes do the job someday?
Image removed due to copyright restrictions. Please see Fig. 3a in Hoffert, Martin I., et al. “Advanced Technology Paths to Global Climate Stability: Energy for a Greenhouse Planet.” Science 298 (November 1, 2002): 981-987.
Investment & Technology Pipeline
U.S. Gov't R&D by Budget Function, 1955-199

Source: DOE, Clean Energy Futures (2000)
Trends in Nondefense R&D by Function, FY 1953-2004
outlays for the conduct of R&D, billions of constant FY 2003 dollars

Source: DOE, Clean Energy Futures (2000)
Funding-Patent Correlation for Energy

Image removed due to copyright restrictions. Please see Fig. 2b in Margolis, Robert M., and Daniel M. Kammen. “Underinvestment: The Energy Technology and R&D Policy Challenge.” Science 285 (July 30, 1999): 690-692.

Funding-Patent Correlation for PV