iNEMI®
International Electronics Manufacturing Initiative

Photovoltaics: The iNEMI Road Map

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Advancing manufacturing technology

Topics

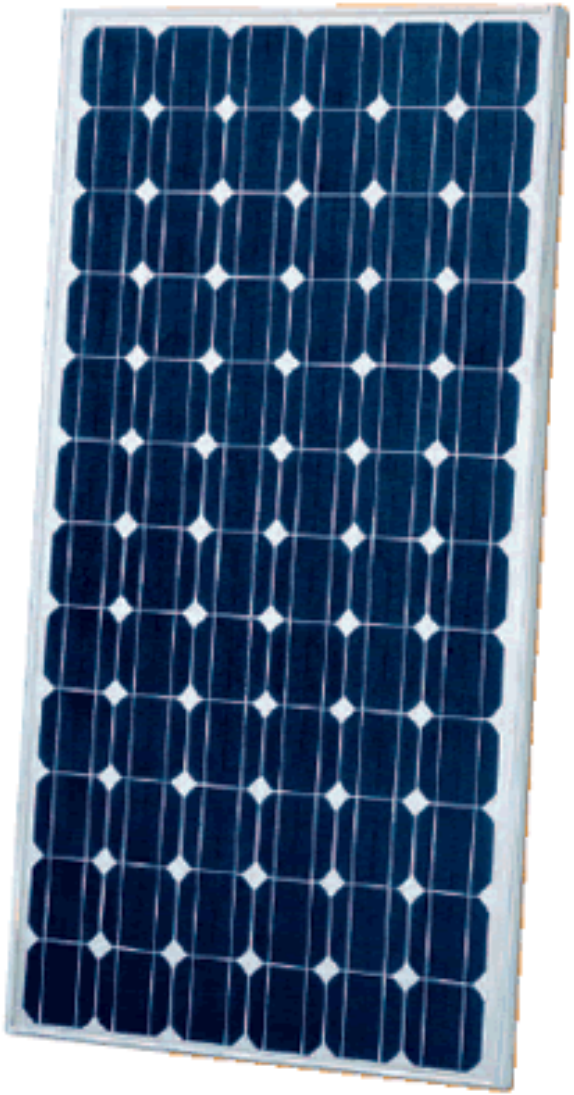
- The 2011 iNEMI Solar PV roadmap
- Involvement of the electronics supply chain
- Example of an electronics opportunity – micro-inverters

The iNEMI Photovoltaics Roadmap

- Nine Chapters
  - Technologies
    - Crystalline Silicon
    - Concentrating PV
    - Thin Film Amorphous Silicon
    - Thin Film Cadmium Telluride (CdTe)
    - Thin Film CIGS
    - Thin Film Organics
  - Balance of System/Inverters
  - Materials

Crystalline Silicon

- 20,000 MW installed worldwide
- Most established technology
- Efficiency is good
  - –Monocrystalline: 16-23%
  - –Polycrystalline: 15-18%
- Good technology for cloudy climates
- Well-suited to modest installations
  - –Highly scalable
  - –Favorite for rooftops



Concentrating PV

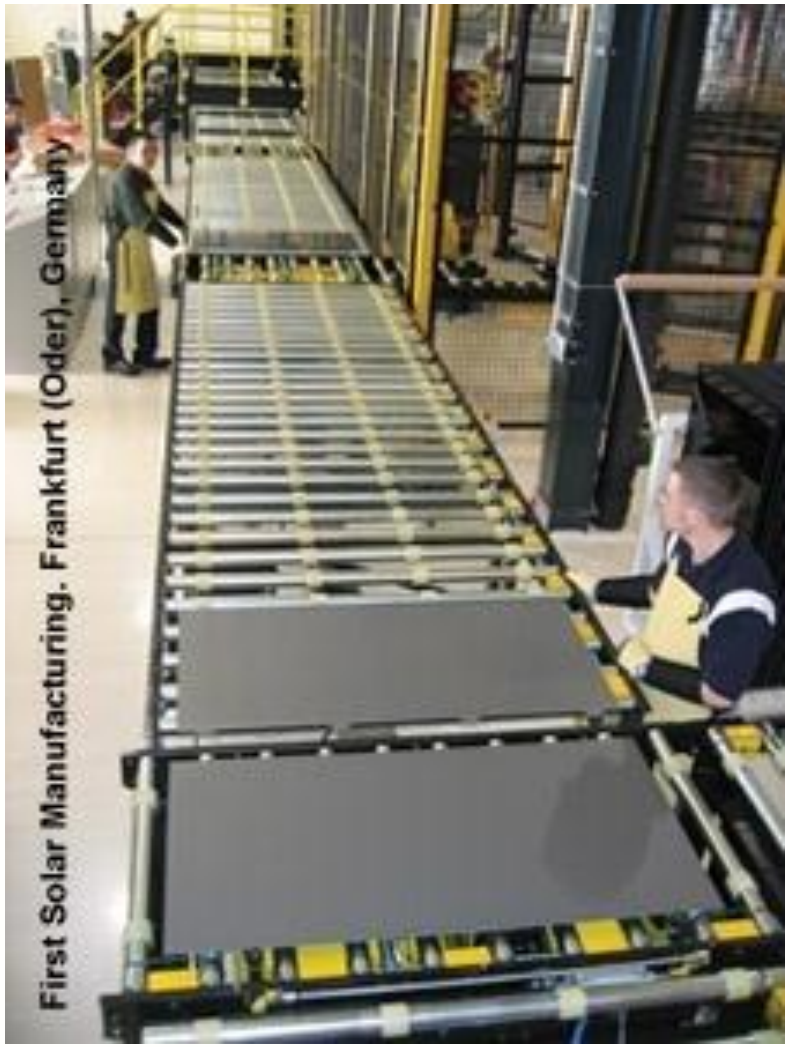
- ~25 MW installed worldwide
- Light focused onto small semiconductor targets
- Materials inexpensive
  - –Very low volume of semiconductors
  - –Other materials readily available/inexpensive (glass, acrylic, steel, aluminum)
  - –Packaging can be complex (high UV flux / temperature)
- Requires direct sun
  - –Must be mounted on trackers
  - –Holds promise for locations with clear skies
- Good fit for large installations

Tracking

Technology	Cost Adder	Efficiency Improvement	Best Application
Flat Plate	0%	0%	Standard flat panel
Fixed Tilt	5%	15%	Standard flat panel
Single-Axis	10%	22%	Standard flat Panel
Dual-Axis	20%	32%	CPV

Thin Film

- 2,000 MW installed worldwide
- Lowest cost/Watt today
- Semiconducting material applied directly to panel
- Very low cost
  - –Offset by low efficiency 5-14%
  - –Competes with crystalline panels
- Productive in cloudy climates
- Strong contender for BIPV
  - –Works on curved surfaces
  - –Can use flexible substrates
- Economies of scale important
- Several varieties



Thin-Film Technologies

- Cadmium Telluride (CdTe)
  - Most established to date – First Solar
- Amorphous Silicon
  - Manufactured like LCD TV screens
- CIGS (Copper Indium Gallium Selenide)
  - Could become highest-efficiency thin-film technology
  - Technical problems still being worked out
- Organic
  - Currently the least well researched
  - No high-temperature processes – it's like paint
  - Opens myriad possibilities – PV on product packaging

Most work on curved and flexible substrates

Balance of System

- Inverters
  - Inverter warranties are shorter than those of modules
  - Inverter efficiency highly impacts real cost – 92-95%
  - Much research is being done to address these two issues
  - New technologies appearing
    - Micro Inverters
    - Shading control
- Energy storage
  - What to do when the sun goes down?
- Tracking

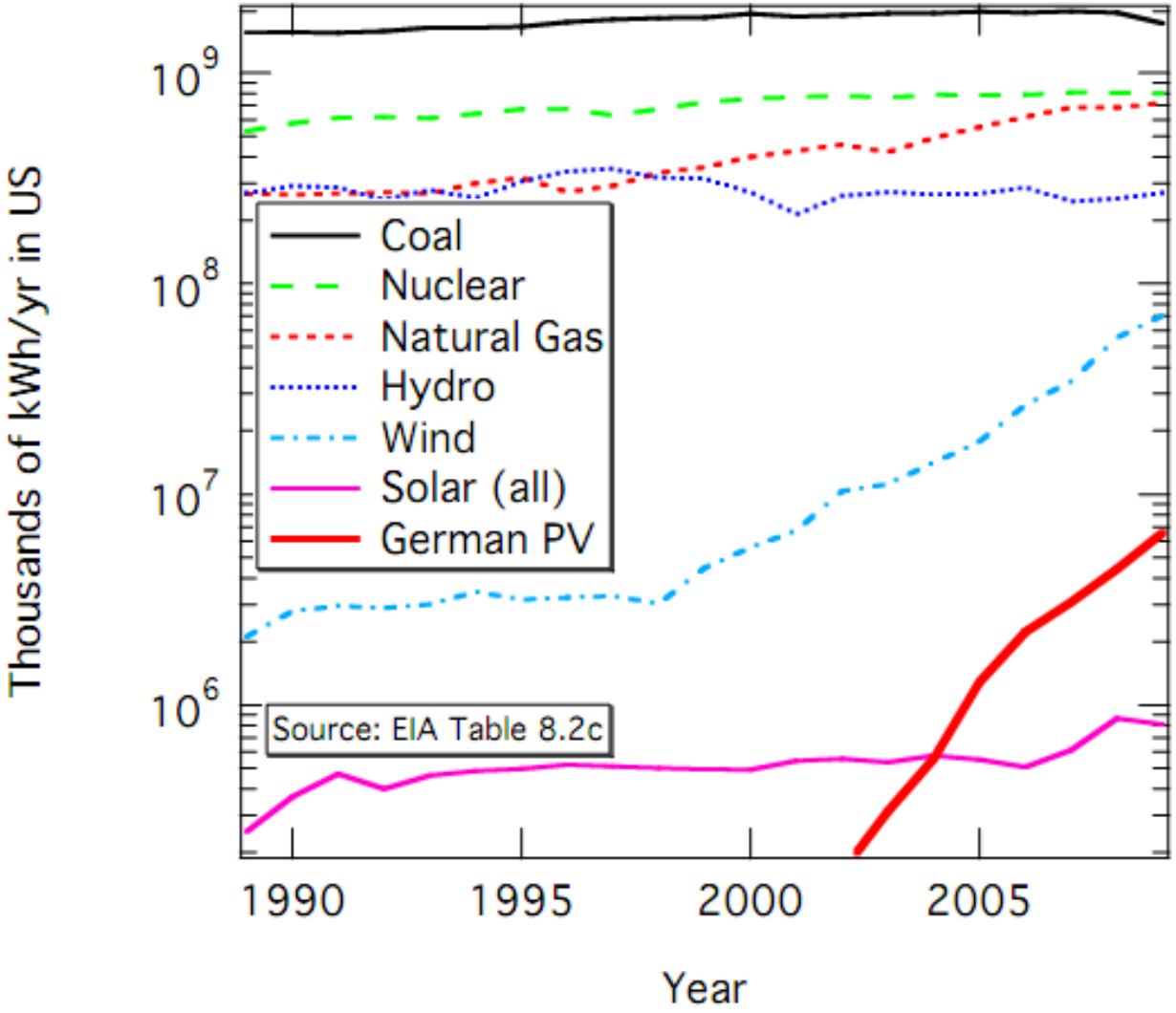
Materials

- Materials shortages can slow PV adoption
  - Polysilicon shortage of 2005-2008 is an example
    - PV became an important demand driver
    - Existing refining capacity couldn't keep up
    - Silicon prices skyrocketed
  - Other materials could experience the same dynamic
    - Indium
    - Tellurium
    - Gallium
    - Silver and Aluminum pastes
    - Plastic encapsulants: PET, EVA, etc

Policy

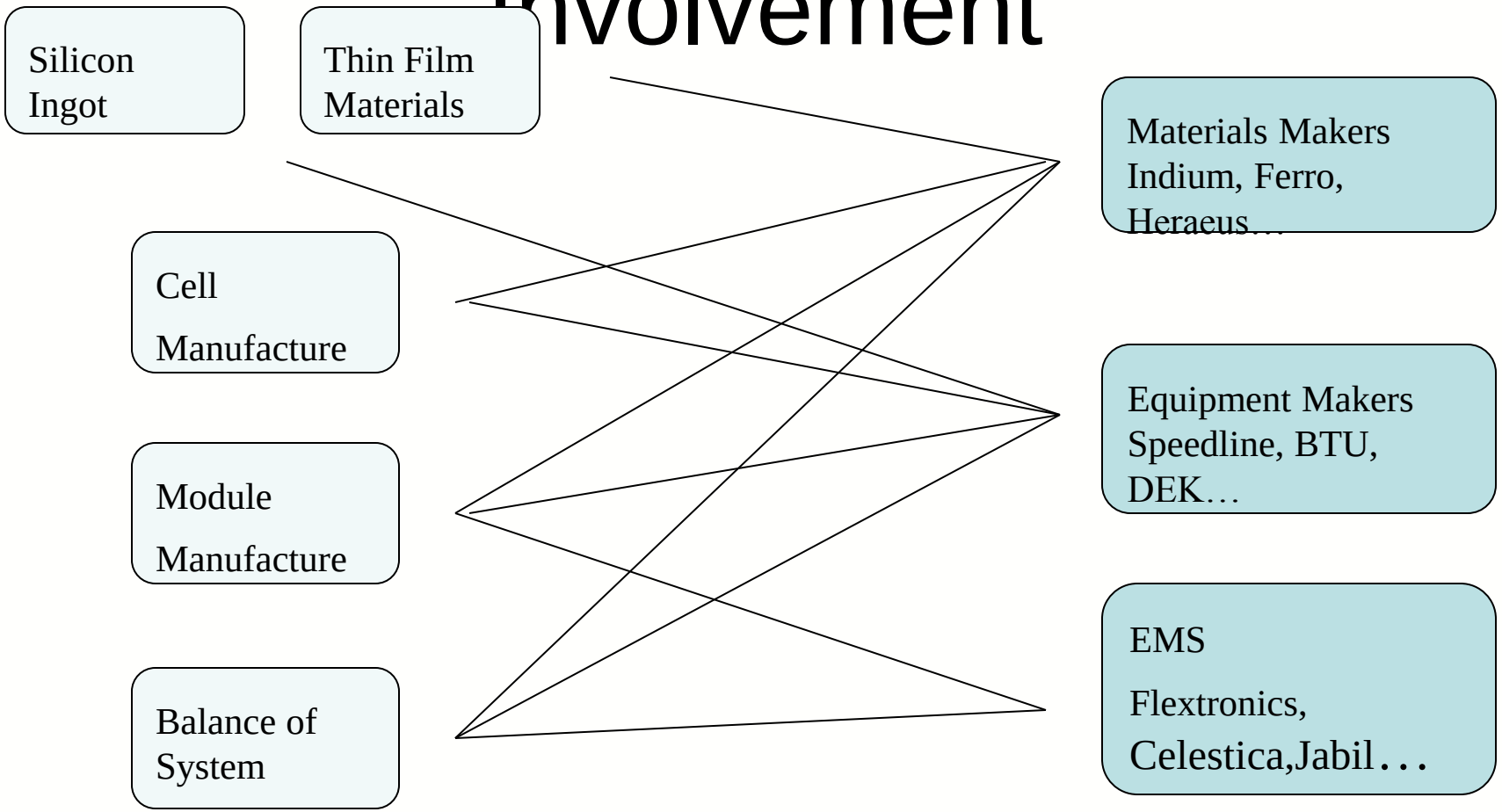
- Addressing the cost of PV
  - PV's Cost is several times that of conventional generation
  - Its success still depends upon subsidies
    - Past success stories:
      - Japan
      - Germany
      - Spain
      - (Italy/Greece)
    - More in the future?
      - US, UK
- Not all materials come from multiple countries

PV's High Cost Delays Adoption in the Absence of FIT Incentives



Courtesy Sarah Kurtz, NREL

Electronics Supply Chain Involvement



Balance of System

- Elements
  - Racking
  - Tracking
  - Connectors and cables
  - Inverters
  - Grid connect hardware and software
- Issues
  - Applicability
  - Reliability

(SGS)

Inverters

- Lifetime 5-7 years vs. 25 years for panels
- Issues include
  - Wearout of electrolytic capacitors in centralized inverters
    - Cheap and available
    - Substitutes are much larger and more expensive!
    - Wearout mechanism is electrolyte evaporation
    - Accelerated by temperature

Micro Inverters

- Convert to AC at the panel
  - No high voltage DC installers needed
  - Can install safety shutoffs at each panel for fire protection
  - Individual panel monitoring (3-5% ar failure rate)
  - Simplified grid connection
  - Add, exchange, substitute panels at will (no string balancing)
- Lower capacity, more units

(Enecsys)

Micro Inverter Industry Characteristics

- Many start-up micro inverter companies
- Increasing involvement of EMS companies
  - Positively impacts cost and learning curve
  - 4-5,000 panels per MW means the EMS model works well
  - Local manufacture where needed

- Challenges

PV Young, but Growing

- A young industry with issues:
  - Which technologies will win?
  - How to grow without subsidies?
  - Reconciling cross-cutting issues?
- Plenty of room to grow
  - Scale will make costs competitive
    - Subsidies will no longer be needed
  - Orders of magnitude growth is possible
    - 20,000 MW today
    - 2,000,000 MW to come?
    - Only solar and nuclear can supply all our

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