An Empirical Perspective on the Energy Payback Time for Photovoltaic Modules

Karl E. Knapp, Ph.D.
Energy & Environmental Economics, Inc.

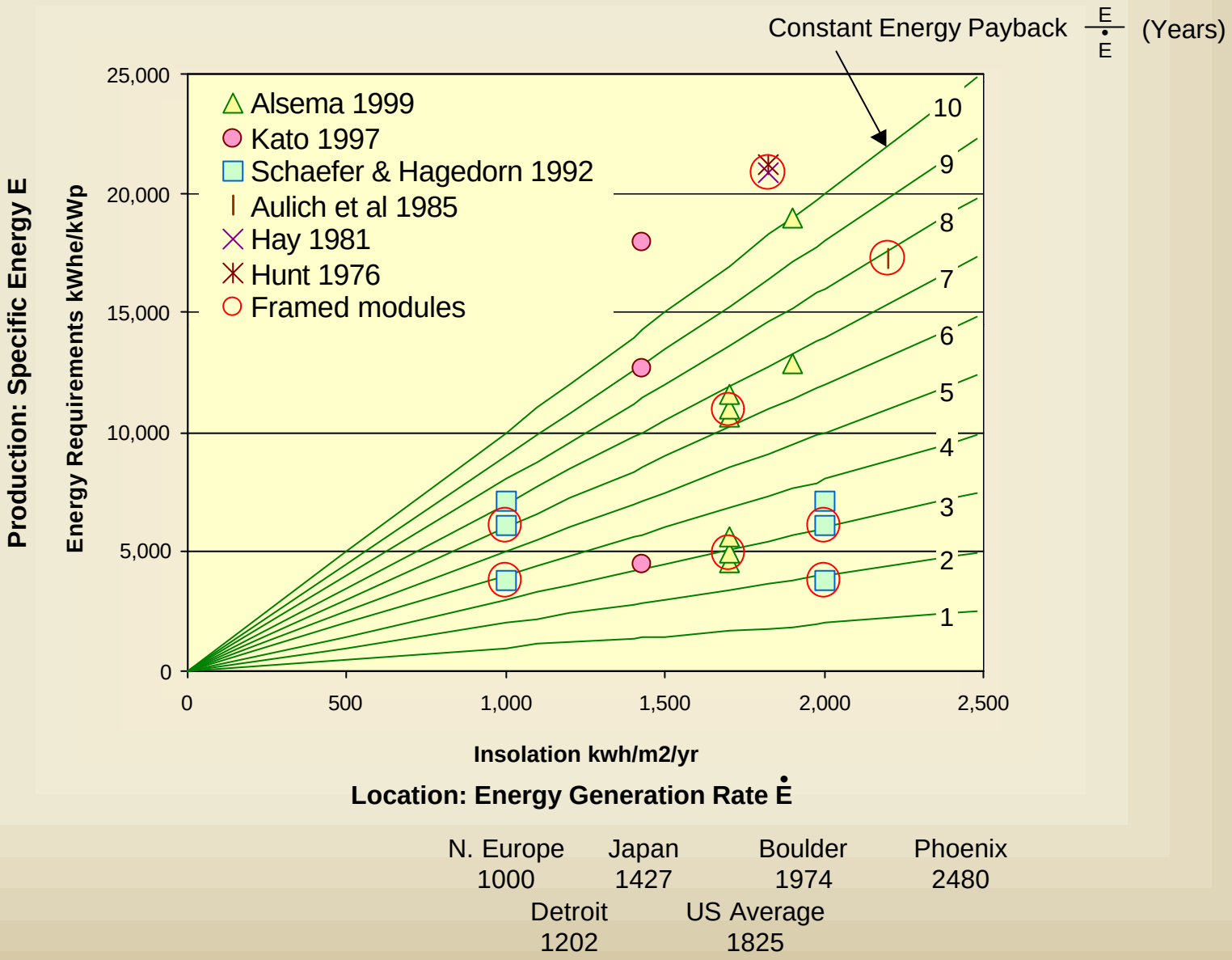
Theresa L. Jester
Siemens Solar Industries

SOLAR 2000 Conference
June 16-21, 2000
Madison, Wisconsin

Overview

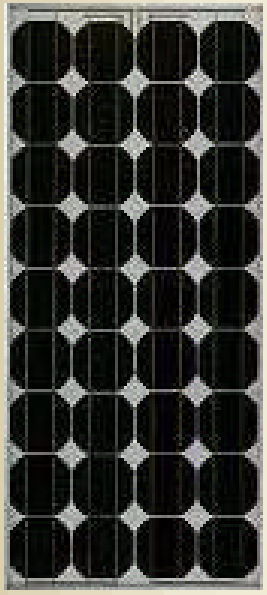
- Energy payback determinants
- Methodology
- Process energy results
- Materials embodied energy results
- Energy payback time results
- Prospects

Energy Payback Depends on PRODUCTION and LOCATION



Two significantly different products were evaluated.

Single-Crystal Silicon



sc-Si

SP75

Ingot

- Polysilicon Preparation
- Crystal Growing
- Ingot Shaping

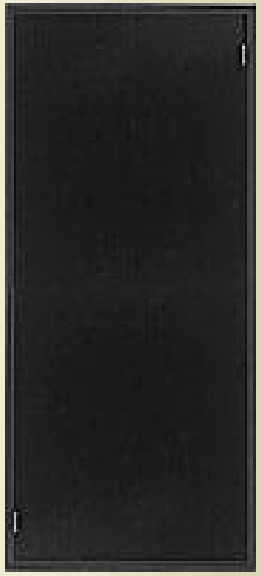
Wafer/ Cell

- Ingot Sizing
- Mounting
- Wire Saw Cutting
- Cleaning
- Chemical Etching
- Phosphorous Diffusion
- Post Diffusion Etch
- Oxidation
- Plasma Etch
- Anti Reflective Coating
- Front Print
- Back Print
- Cell Test
- Packaging

Module

- Stringing
- Circuit Assembly
- Prelamination Lay-up
- Lamination & Cure
- Edge Trim & Inspection
- Framing
- IV Measurement & Labeling
- Packaging

Thin-Film Copper Indium Diselenide



CIS

ST40

Wafer/ Cell

- Cut Glass\
- Wash / Deposit Mo Electrode
- Pattern 1: Isolation
- Wash / Deposit CIG Metals
- Selenize
- Chemical Deposit CdS
- Pattern 2: Via
- Transparent Conductor
- Pattern 3: Isolation
- Test

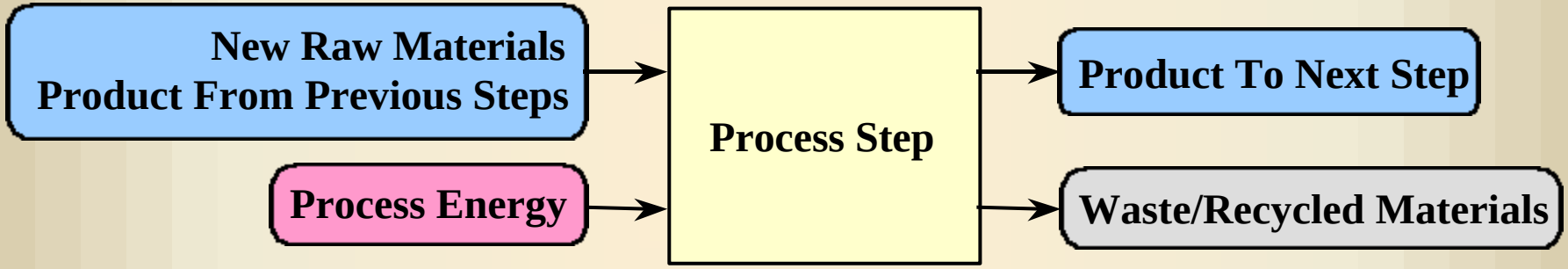
Module

- Attach Leads
- Prelamination Lay-up
- Lamination & Cure
- Framing
- Edge Trim & Inspection
- IV Measurement & Labeling
- Packaging

Analysis uses measured energy use, production bill of materials, and production records.

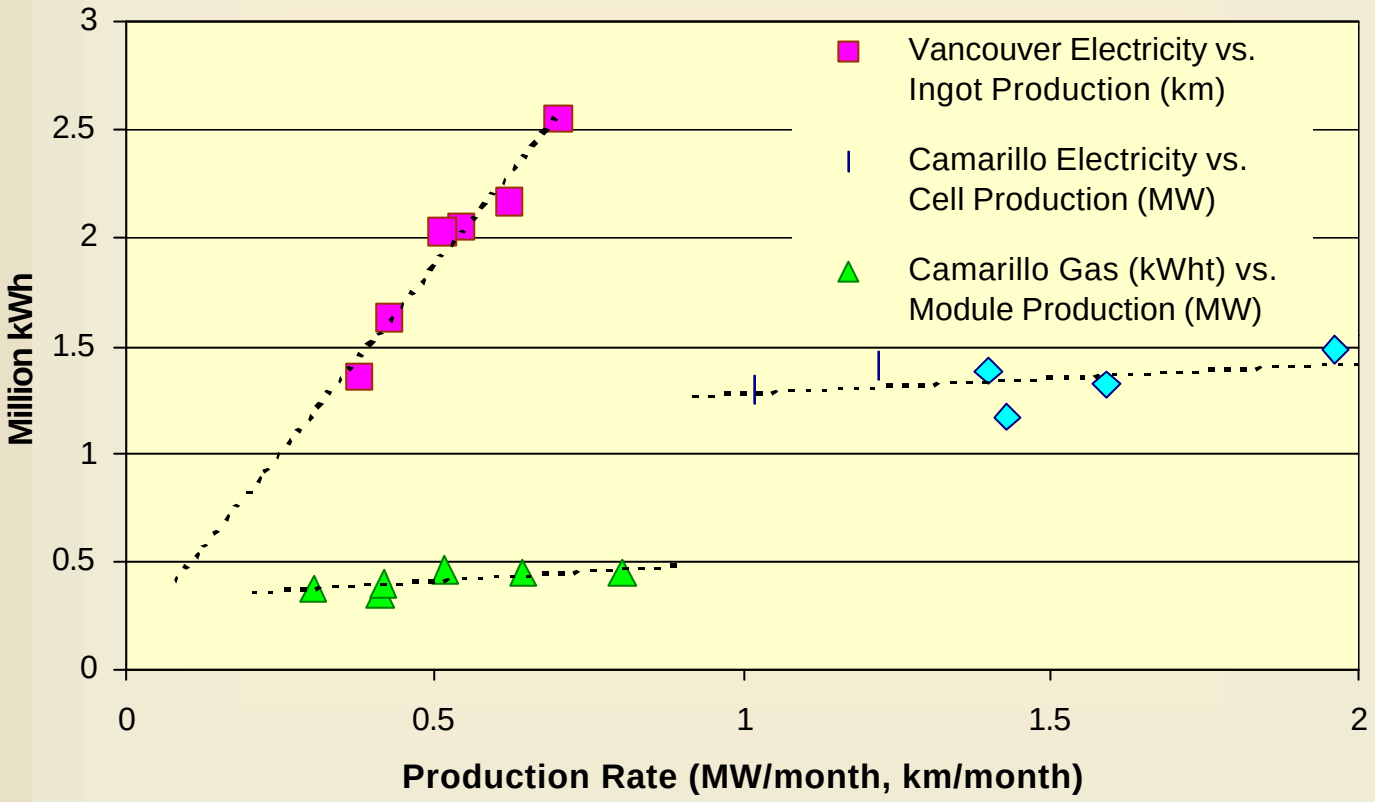
Energy Requirements

Total energy input per unit of product manufactured
Results expressed in kWh_e/kW_p



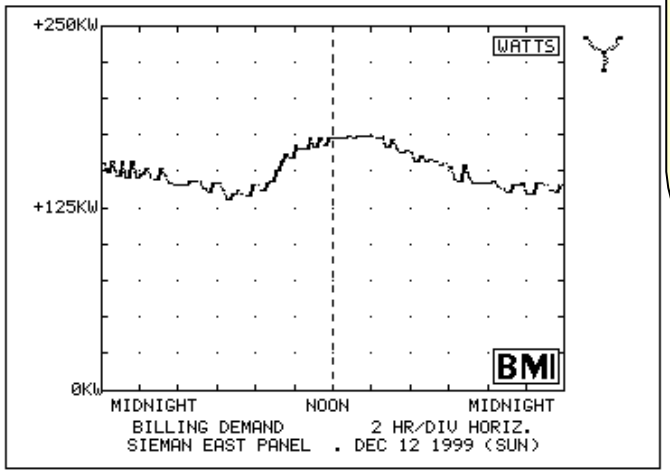
- Includes
  - All added process energy
  - All direct AND indirect materials
  - Required upstream processes
- Does not include
  - Energy embodied in facility
  - Labor equivalent
  - Transportation
  - End-of-life
  - Unnecessary upstream energy

sc-Si process energy requirements derived from production records and utility bills.

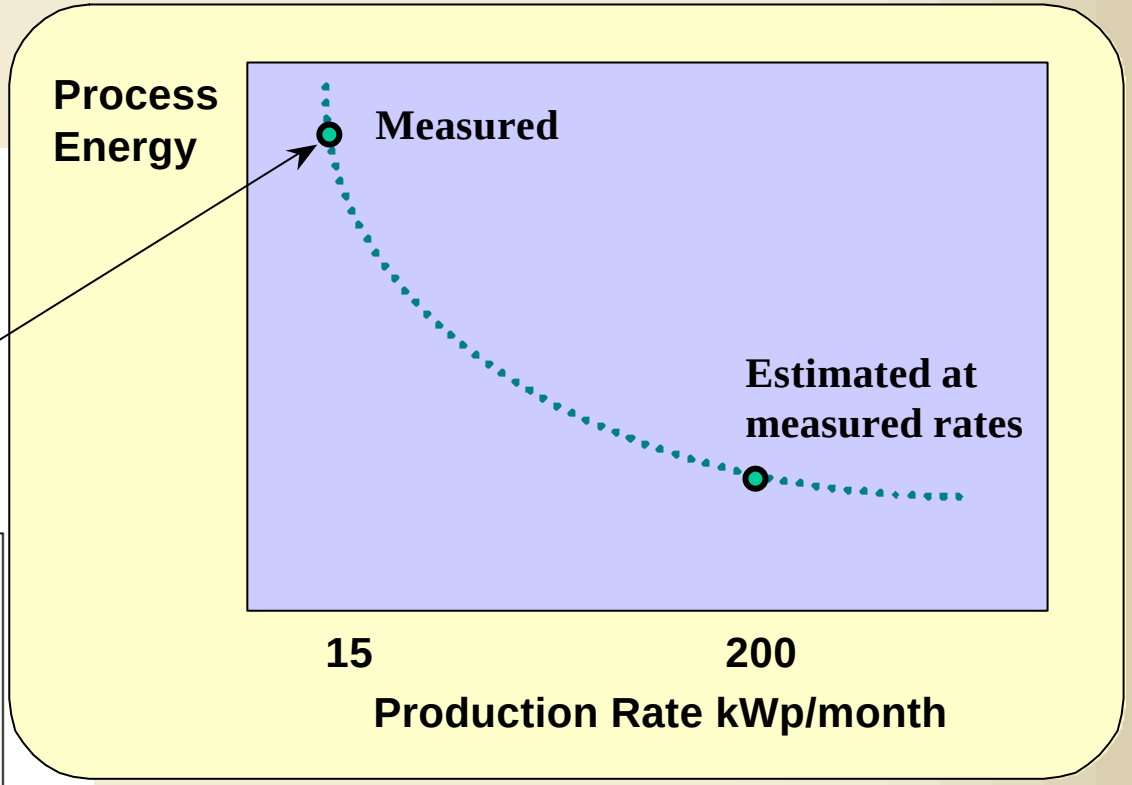


CIS process energy requirements derived from direct measurements, equipment ratings, and production records.

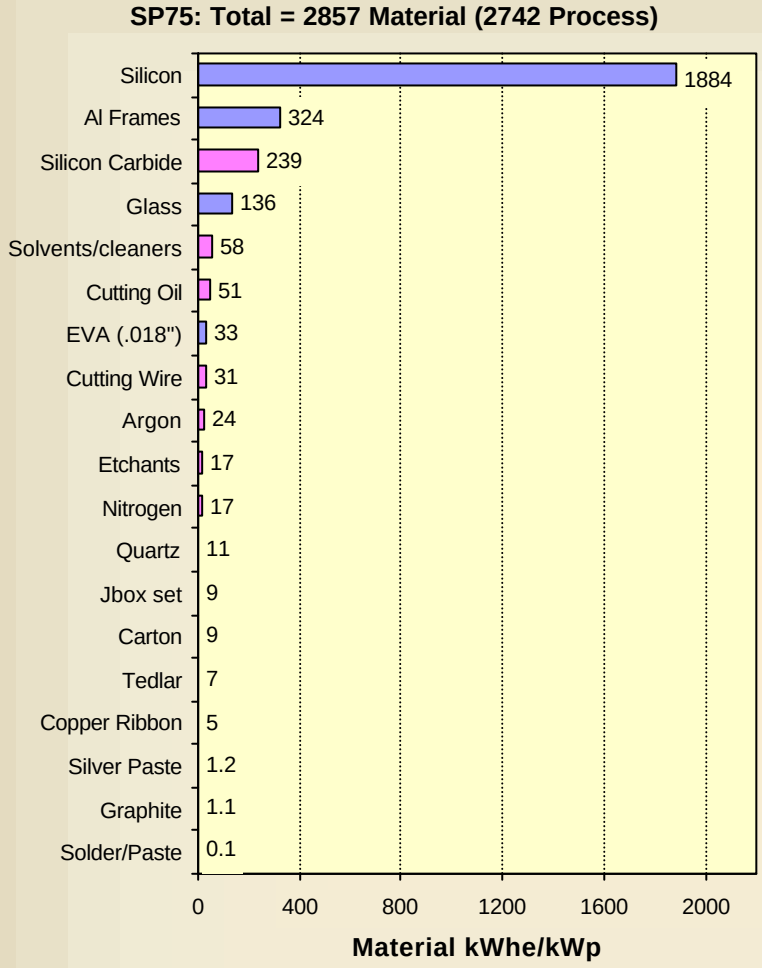
```
SIEMAN EAST PANEL  . Dec 13 1999 (Mon)
BILLING DEMAND              12:00:11 AM

   FROM: MIDNIGHT Dec 11 1999 (Sat)
   To:   MIDNIGHT Dec 12 1999 (Sun)

   DEMAND INTERVAL:    15 min
   SLIDING INTERVAL:   No

Total:
          MAX:     175.1 kW, 12:57 PM
          MIN:     131.6 kW,  6:42 AM

Phase A-N:
          MAX:      59.1 kW,  2:12 PM
          MIN:      45.3 kW,  6:42 AM
Phase B-N:
          MAX:      55.6 kW, 12:57 PM
          MIN:      40.5 kW,  6:42 AM
Phase C-N:
          MAX:      60.5 kW, 12:57 PM
          MIN:      45.9 kW,  6:42 AM
```

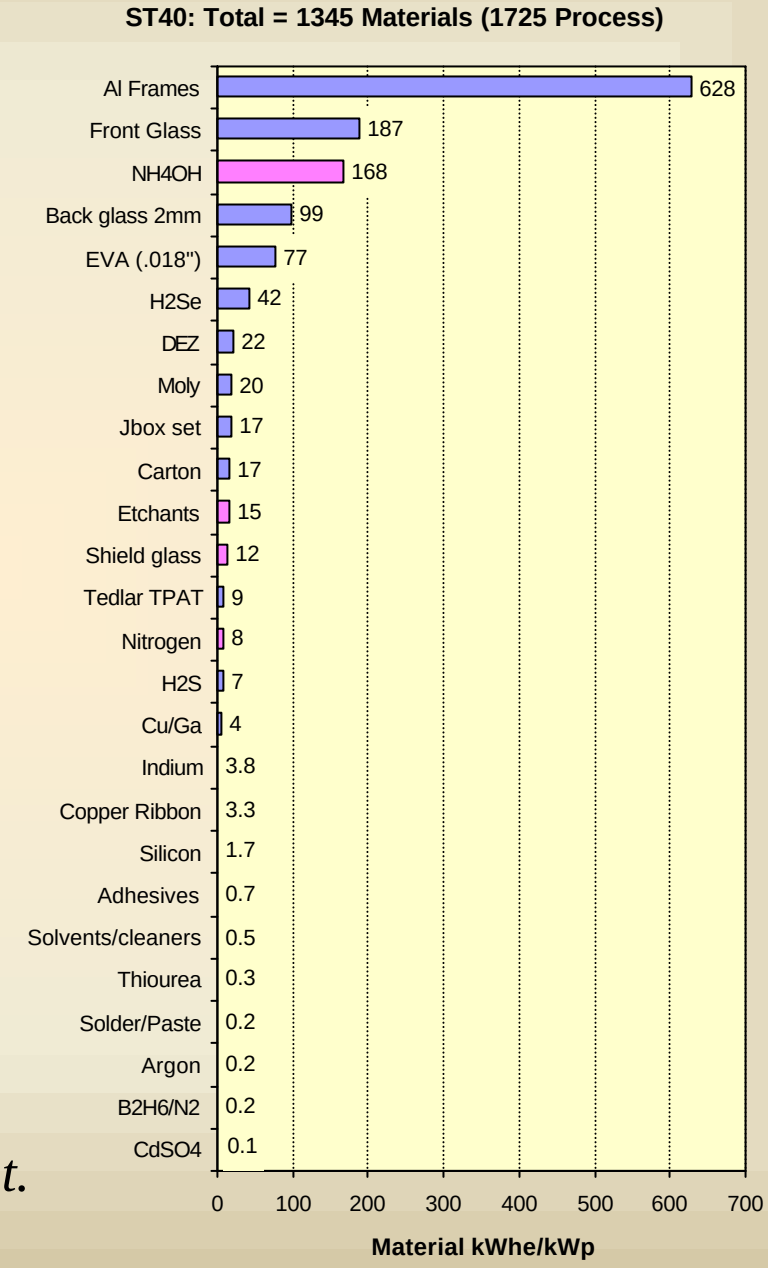



```
BILLING DEMAND (ACCUMULATED):
   MAX:    296.8 kW
           3:14 PM Dec 09 1999 (Thu)
   MIN:    131.6 kW
           6:42 AM Dec 12 1999 (Sun)
```



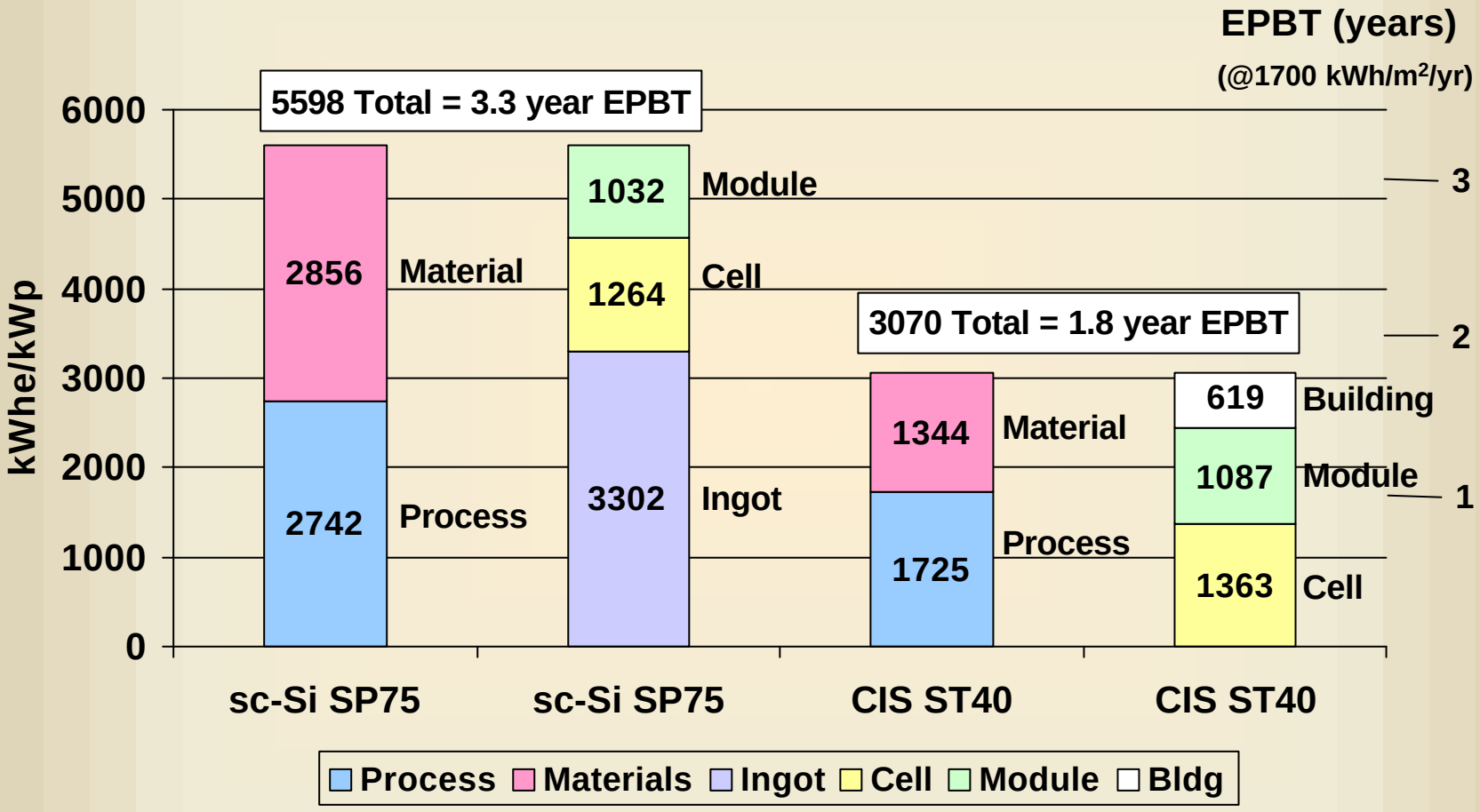
Materials embodied energy is about half of total.



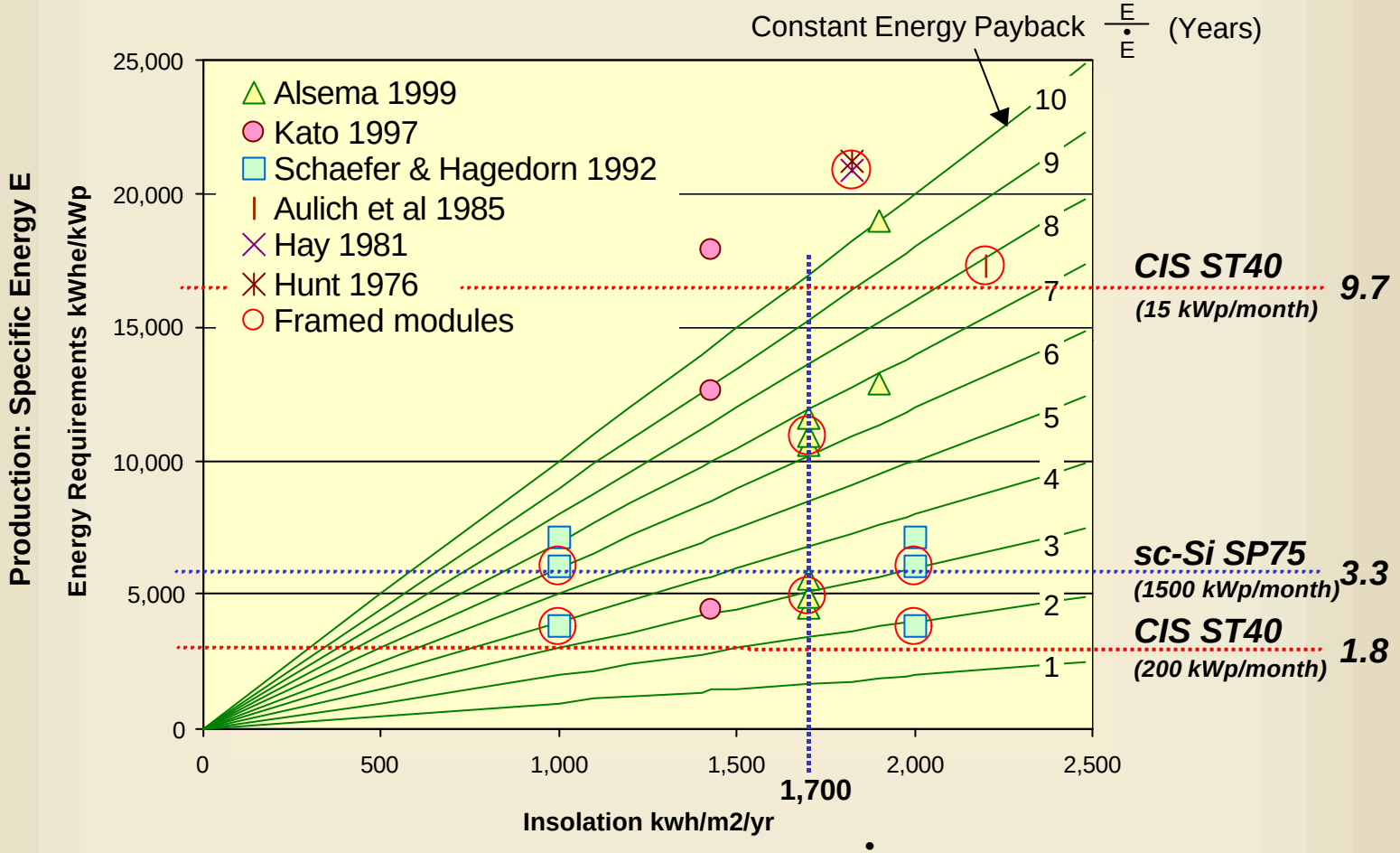


- *Materials energy dominated by a few big-ticket items.*
- *Indirect materials can be significant.*

Production photovoltaic module payback is much less than its expected lifetime.



Results provide empirical support for other analytical methods.



N. Europe	Japan	Boulder	Phoenix
1000	1427	1974	2480

Detroit	US Average
1202	1825

Conclusions, Notes & Prospects

- Production photovoltaic module payback is significantly less than its expected lifetime.
  - Payback time is 2-3 years.
  - Energy output is nine to seventeen times the input.
  - Indirect materials are important
  - Results lend empirical support for related research.
- Most other energy requirements are relatively small.
  - Equipment, building, labor equivalent
  - Balance of systems requirements can be significant.
- Energy intensity improvements driven by cost issues.
  - Yield, lower materials use and cost
  - Innovative processing and product design
- Prospects for reduced energy requirements are likely.

END