Manufacturability Analysis

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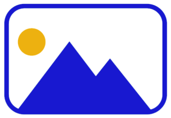
Mountain View Energy

Outline



- Framework
  - Product definition
  - Product value
  - Market/Value chain fit
- Manufacturability Analysis
  - How to define a manufacturing flow
  - When to define it
  - When to implement it
- Examples

Framework

Margin = Price − Cost
Value: Max. Price Limit

Value – Cost > 0

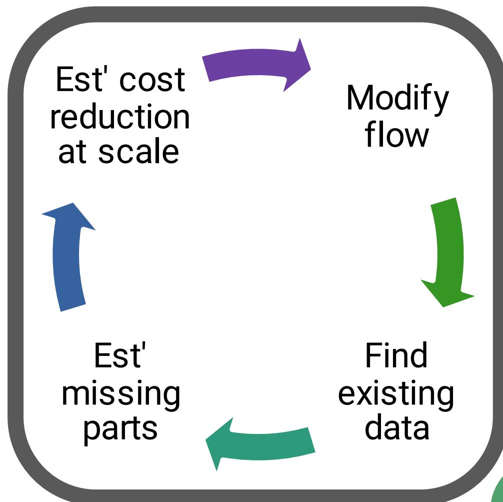
- Product definition
  - Physical
  - Functional
- Product **Value**
  - Need
  - Worth

Manufacturability: How to get **Cost** lower than Value.
Translating physics into finance.

How to Define

Starting Point

- Develop a strawman flow
  - Processes (equipment)
  - Materials
- Find analogous existing mfg flow as a template.

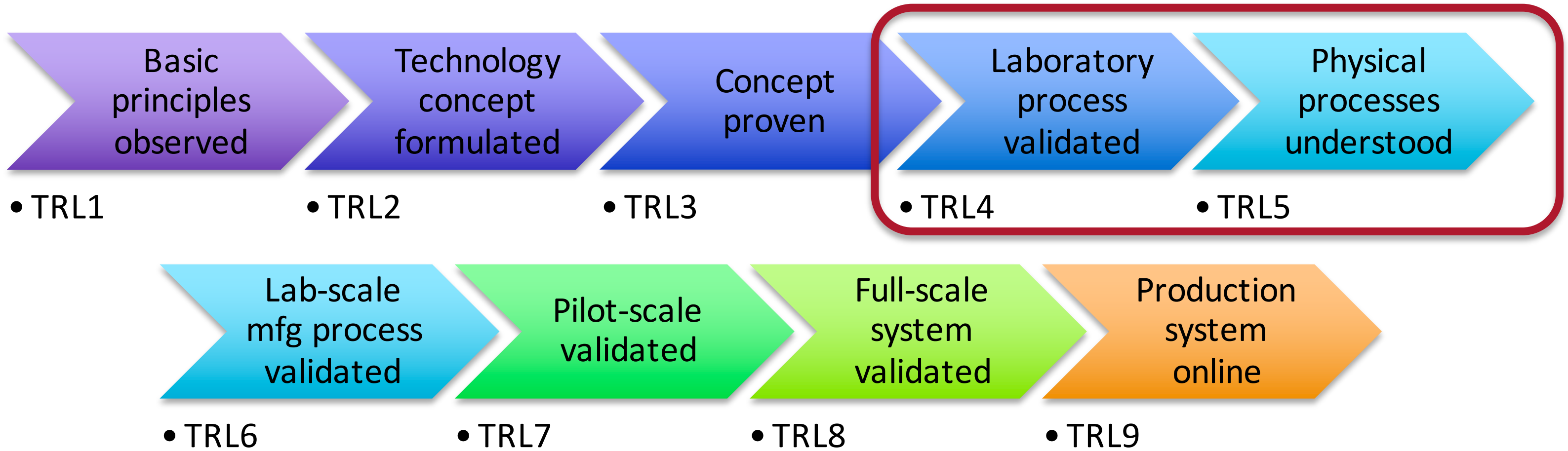


Unknowns drive questions.

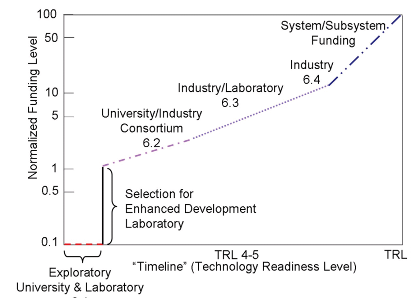
Manufacturability Analysis

- Resources
  eqpt, materials, facilities, time
- Process Flow
- Product Specifications
- Cost
- Unknowns/assumptions

When to Define



- Sooner is better (early in TRL4)
- No later than:
  - Most of the physics is understood
  - **AND**
    - By end of TRL 5 **OR**
    - Next round est'd capital is insufficient to support learning



"Materials Needs and Research and Development Strategy for Future Military Aerospace Propulsion Systems", The National Academies Press: Washington (2011).

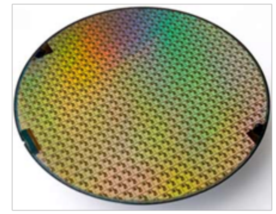
When to Implement

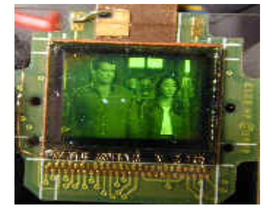
	Employees	Annual R&D Budget	Annual # of Experiments (rate-of-learning)	Next Round Est. Capital	Decision Making Behavior
CMOS	80,000	$2,500,000,000	2,500,000	$100k-$1M	Local planning and execution, several paths.
Storage	75	$30,000,000	20,000	$1M-$10M	Local planning and execution, several paths.
LED Lighting	2,000	$100,000,000	10,000	$1M-$10M	Mid-level planning, several paths.
Solar	50	$10,000,000	2,000	$10M-$100M	Mid-level planning, single path, want mfgt'y.
Solar	7,000	$100,000,000	300	$10M-$100M	Detailed planning, focus on manufacturability.
Solar	200	$30,000,000	400	$10M-$100M	Detailed planning, focus on manufacturability.
Sensors	6	$80,000	32	$10k-$1M	All staff planning, focus on manufacturability.

- The rate-of-learning relative to expenditures governs decision making behavior.
- General rule:
  - When rate of learning to get to the next stage gate is can only support a single overall technology path, then manufacturability must be implemented as a constraint.

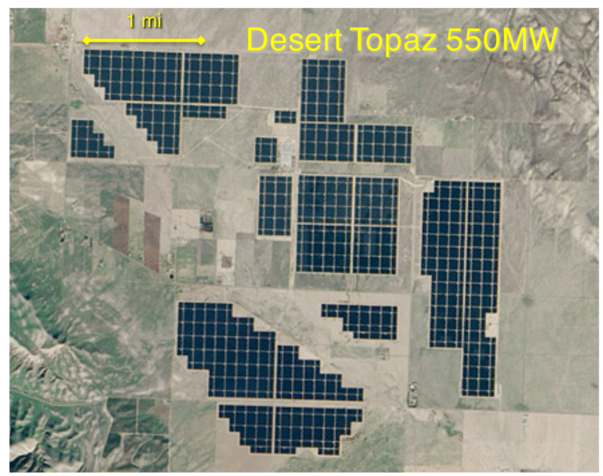
Two Case Studies

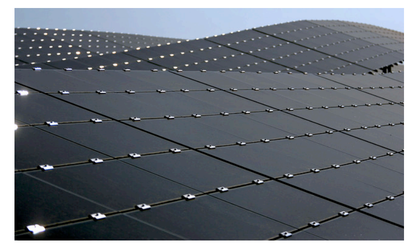
- High learning-rate
  - Implementing a paradigm shift





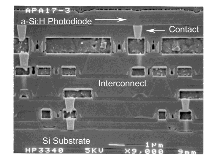
- Low learning-rate
  - Accelerating progress



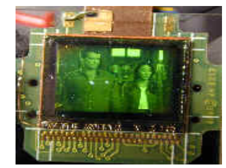


Case 1: High-Rate Learning. Paradigm Shift- Low-cost Instrumentation

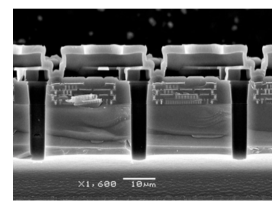
- Landscape
  - Captive manufacturer
  - Core business measurement (electronics, chemistry)
- Find orthogonal markets that technology can intersect
  - Low-cost sensing not otherwise accessible
  - Markets
    - Micro-mover support
    - Photonic crystals for switching
    - Biochemical compound detection
- Results
  - Elevated photodiode array
  - Base technology for AFM
  - OLED microdisplay
  - Seed money for biochemical sensing



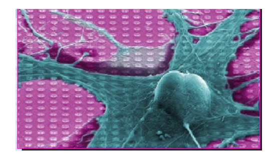
a-Si:H PD Array (HP/Agilent Technologies)



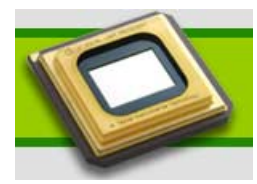
OLED Microdisplay. (HP/Agilent Technologies)



Inkjet Head (Memjet Inc.)



Neuron Communications (Infineon)



Digital Light Projector (Texas Instruments)

Wafer Fab as Manufacturing Platform

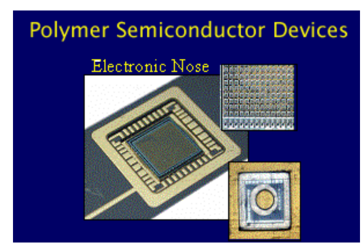
	Semiconductor Mfg.	Machining	Mach./Semi.
Minimum Feature Size	0.25 µm	100 µm	400:1
Alignment Tolerance	< 25 nm	~ 10 µm	40,000:1
Manufacturing Cost	$\$4 \times 10^{-7}$/FET	~$\$2 \times 10^{-1}$ /switch	200,000:1

For the number of devices made, a <u>semiconductor fab</u> is the most precise and <u>least expensive</u> manufacturing platform.

$50,000

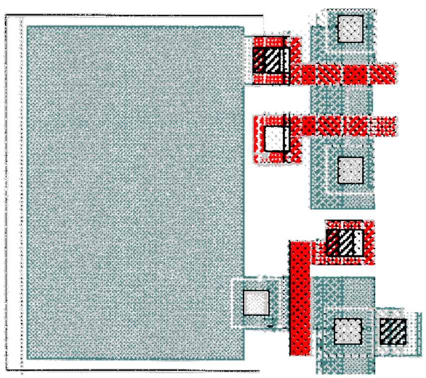
Gas Chromatograph

$50

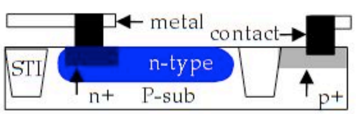


Electronic Nose

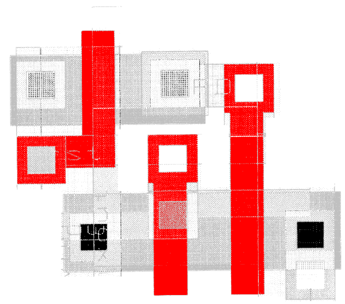
Rapid-Prototyping: Rapid Success



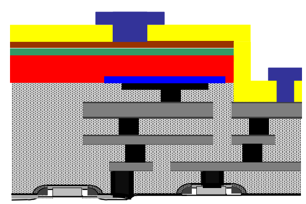
c-Si 3T Pixel

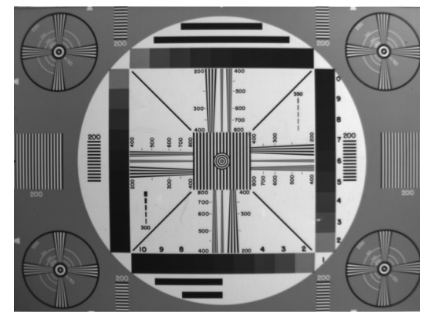


From: S.-G., et al., Ch. 5, Lee, in "Photodiodes – World Activities in 2011", Park, J. W. ed.,, ISBN 978-953-307-530-3 (2011).



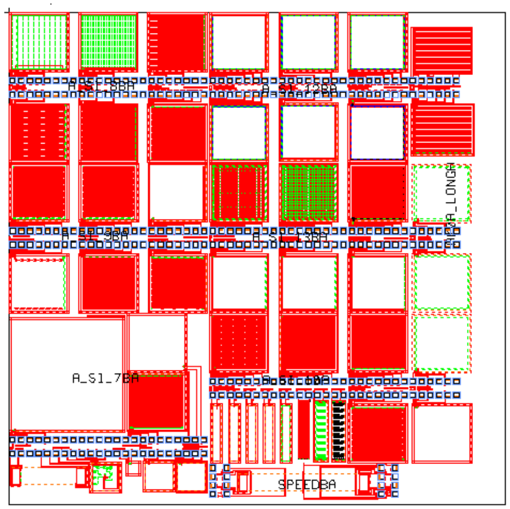
α-Si:H 3T Pixel

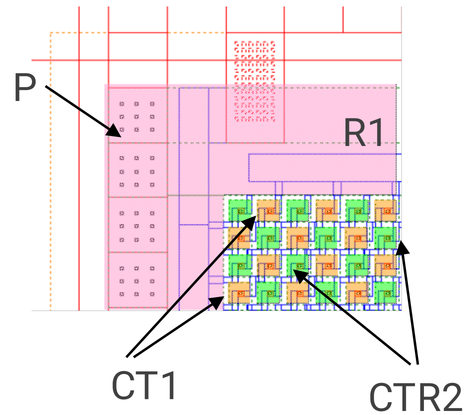




Month 3

Rapid-Prototyping: High-precision R&D

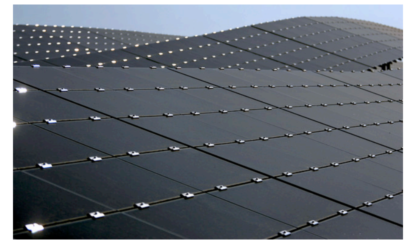




Pixel Simulator

- Low-cost access to wide experimental space. (Combinatorial Experimentation)
  - Miniaturization
  - Large process precision
- 400 experiments per run.
  - Materials (8 splits per lot, with statistics)
  - Device physics (55 experiments, n=450)

Case 2: Low-Rate Learning. 60MW Solar Module Pilot Line



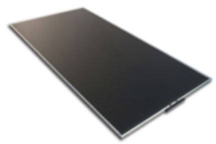
- Goal: Prevent being blindsided; have a backup plan
- Strategy: Demonstrate at scale
  - 55 full-sized modules per hour
  - Yield > 80% 24 hour period
- Success Criteria
  - Product relevant module efficiency and distribution.
  - Repeat on two consecutive runs.
- Constraints
  - High cost ($250,000 per run, 2 weeks 24x7 operation)
  - Only 8 experiments (3-12 data points per expt.)
- Operational Strategy
  - Detailed planning and program discussions

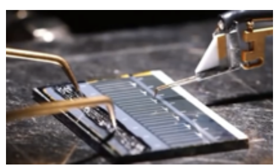
Typical Experiment Schedule

Day	1	1	2	3	4	4	5	6	7	8	9
	Ramp	1 Process Testing			2 Testing	3 Operational	4 Module Expt 1		5 Expt 2	6 Expt 3	7 Cooldown
		Stage 1: Process Development				Stage 2: Module Development					

Flying Tiger Team Strategy

- Rapid Learning Strategy
  - Move up the hierarchy as quickly as possible.
  - Gain speed, sacrifice stability.





Month 4: Establish Line Performance
- Repeatability

Month 2: Establish Module Performance
- Hero Module

Month 1: Dial in Unit Processes
- Hero Cell

High-risk, predicated on knowing 1st and 2nd order physics.

Other Thoughts

- Know what the **end-customer** values
- Thoroughly define possible failure mechanisms
  - **Mundane** mechanisms are most often the source
- Use binary search algorithms to isolate problems
  - More effective than “shot-gunning”
- Shortcuts buy time at the expense of risk.
  - Speed vs thoroughness (no right answer, only balance)
- Always question assumptions
  - short-cuts require assumptions
- Select the right metrics and quantify

Summary

- Manufacturability: How to get Cost lower than Value
- Framework
  - What does the end-customer value?
  - Product definition | value | value chain position.
- Analysis
  - Method for defining strawman manufacturing flow (Cost-based).
  - Define the flow sooner rather than later for risk analysis.
    - ~TRL5 | update as needed | effort commensurate with knowledge
  - Implement manufacturability constraint when only a single path can be supported.