



# Winning the Global Race for Solar Silicon

David Lynch

Professor of Materials Science &  
Engineering, University of Arizona

[dclynch@email.arizona.edu](mailto:dclynch@email.arizona.edu)

&

Chief Technical Officer, Solar Technology  
Research Corporation, Tucson, AZ

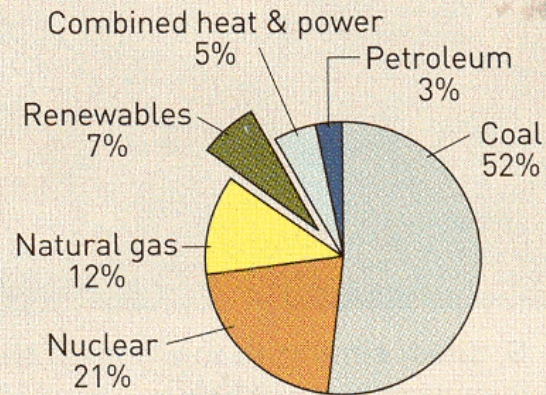
# Topics

- Market Conditions for Photovoltaics
- New Routes for Producing Low Cost Solar Silicon
- The Solar Technology Research Corporation's Approach to Refining Silicon



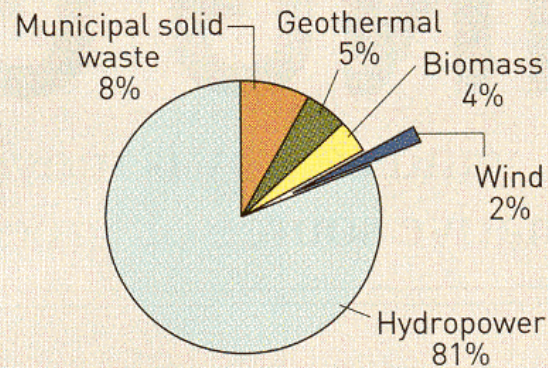
## PLUGGING IN

Renewables remain a small source of electricity ...



2001 electricity generation = 3,532 billion kWh

... and wind energy is a small fraction of renewables

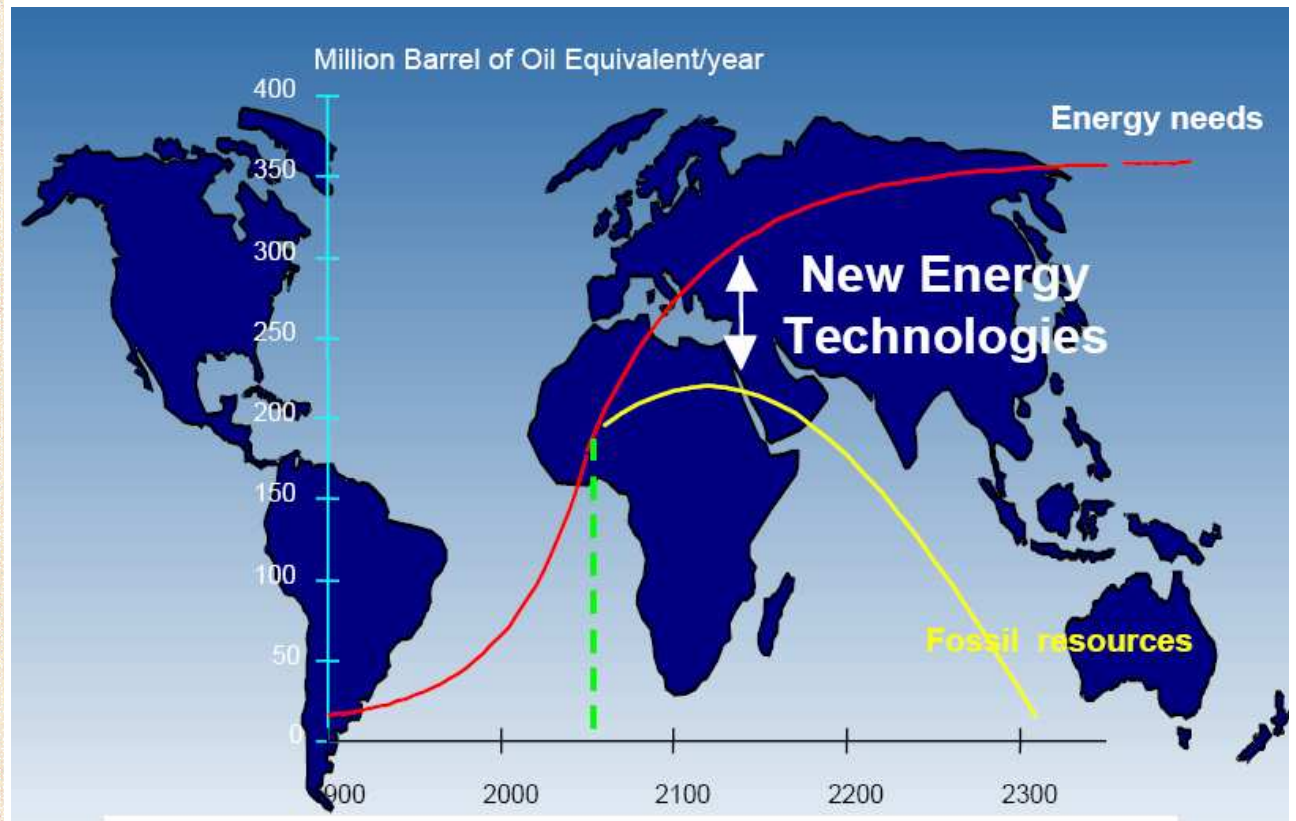


2001 electricity generation from renewables = 263 billion kWh

NOTE: Solar sources generated 0.2% of the electricity from renewables.

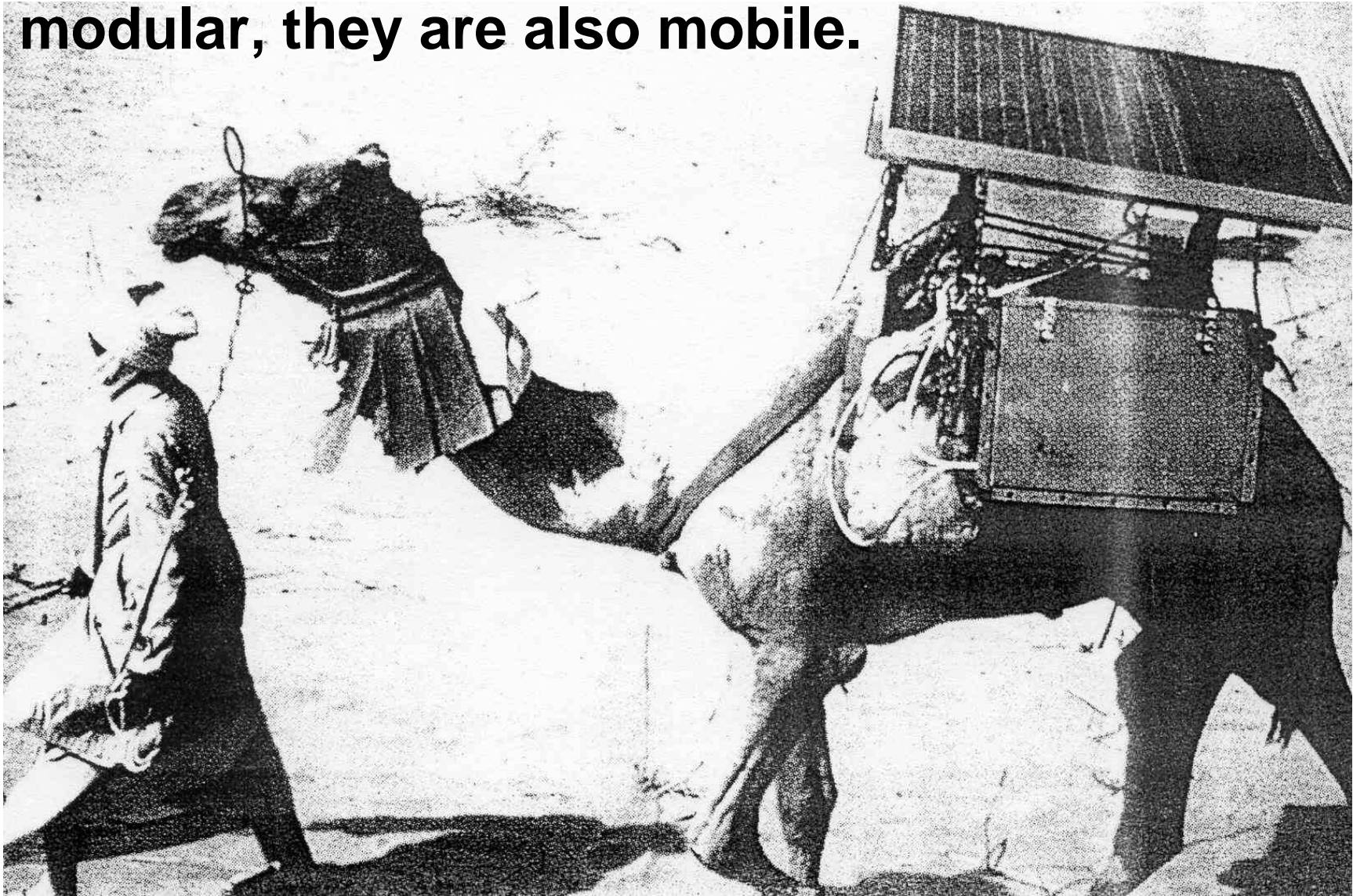
SOURCE: Energy Information Administration

# The Future for Renewable Energy Generation

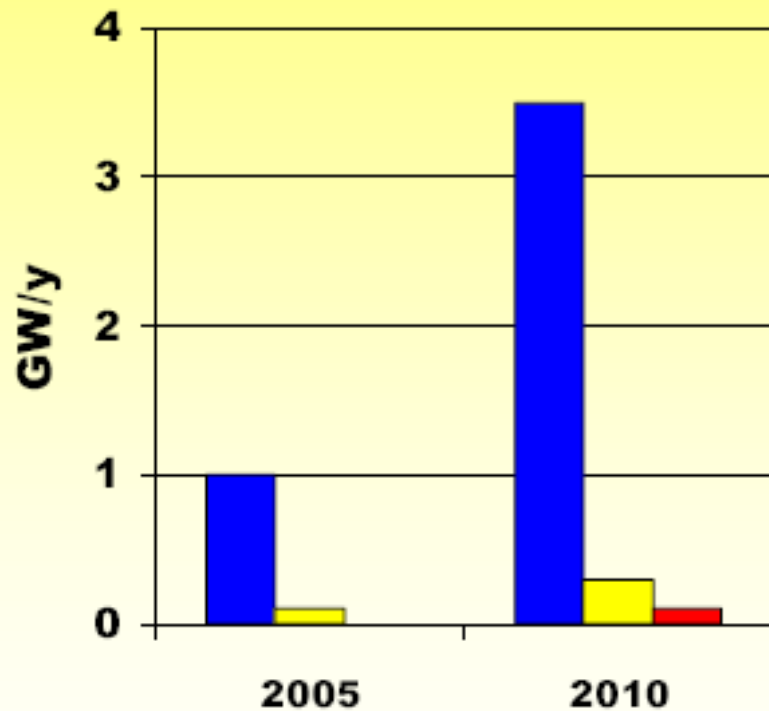


C & E News, Feb. 2003

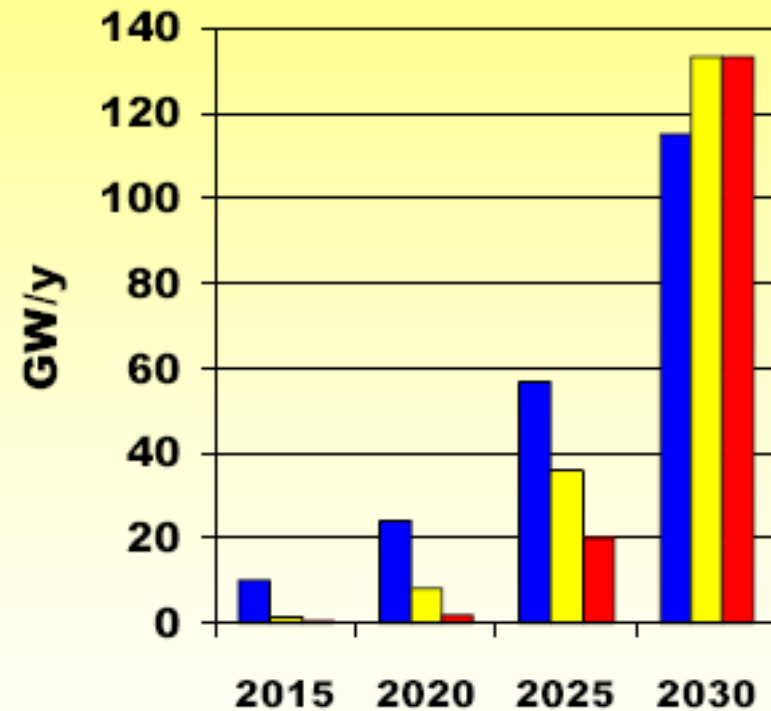
**Photovoltaics are not only modular, they are also mobile.**



Although the role of silicon in photovoltaics is expected to decline, it is still expected to be a growth industry.



■ Si ■ Thin Films ■ Polymers



■ Si ■ Thin Films ■ Polymers

Source: EPIA / RWE Schott Solar (2004)

## Predicted Installed PV Capacity

**2008 10.4 GW**

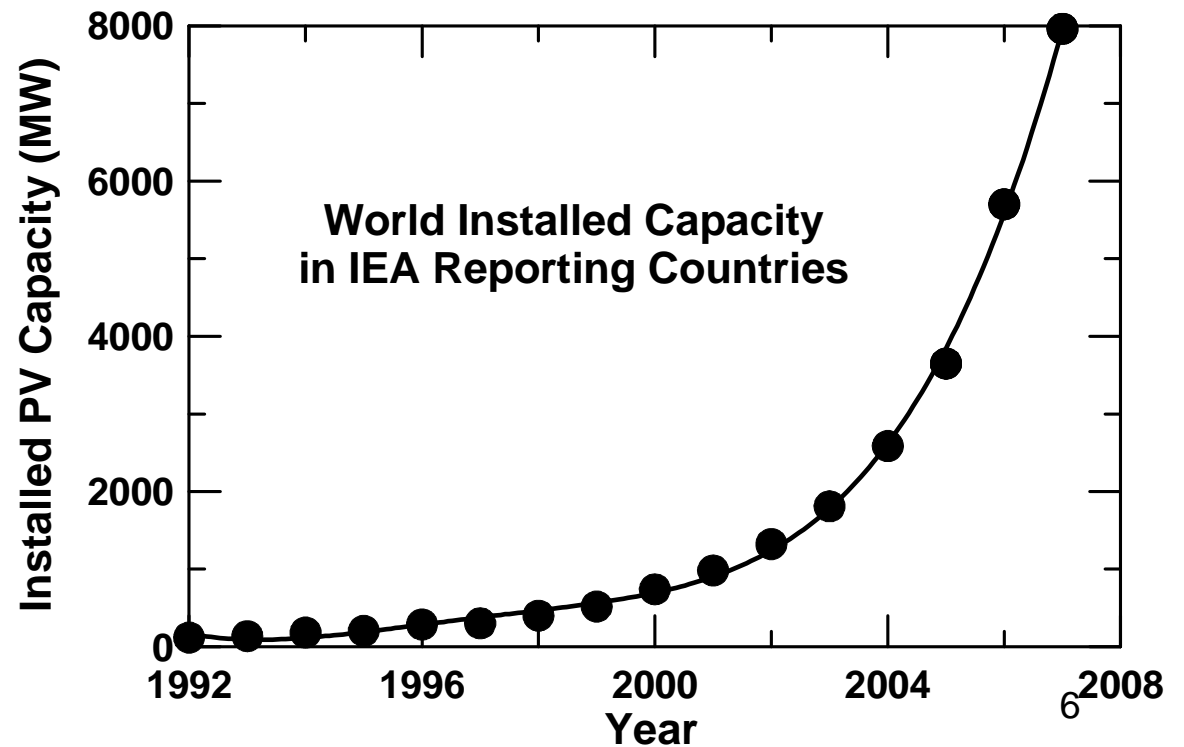
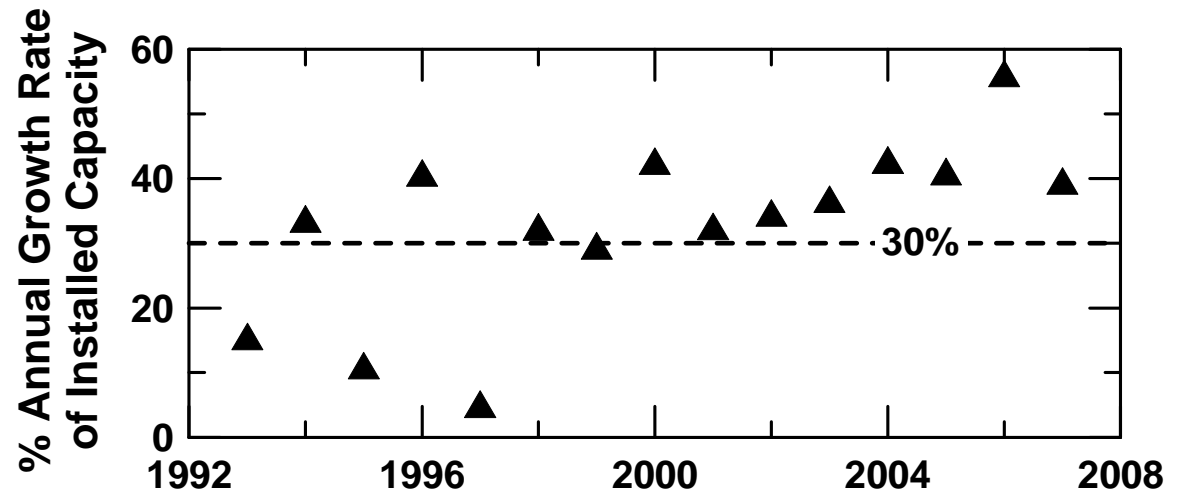
**2009 13.1 GW**

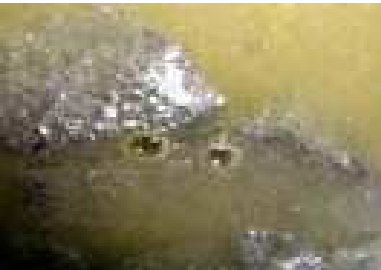
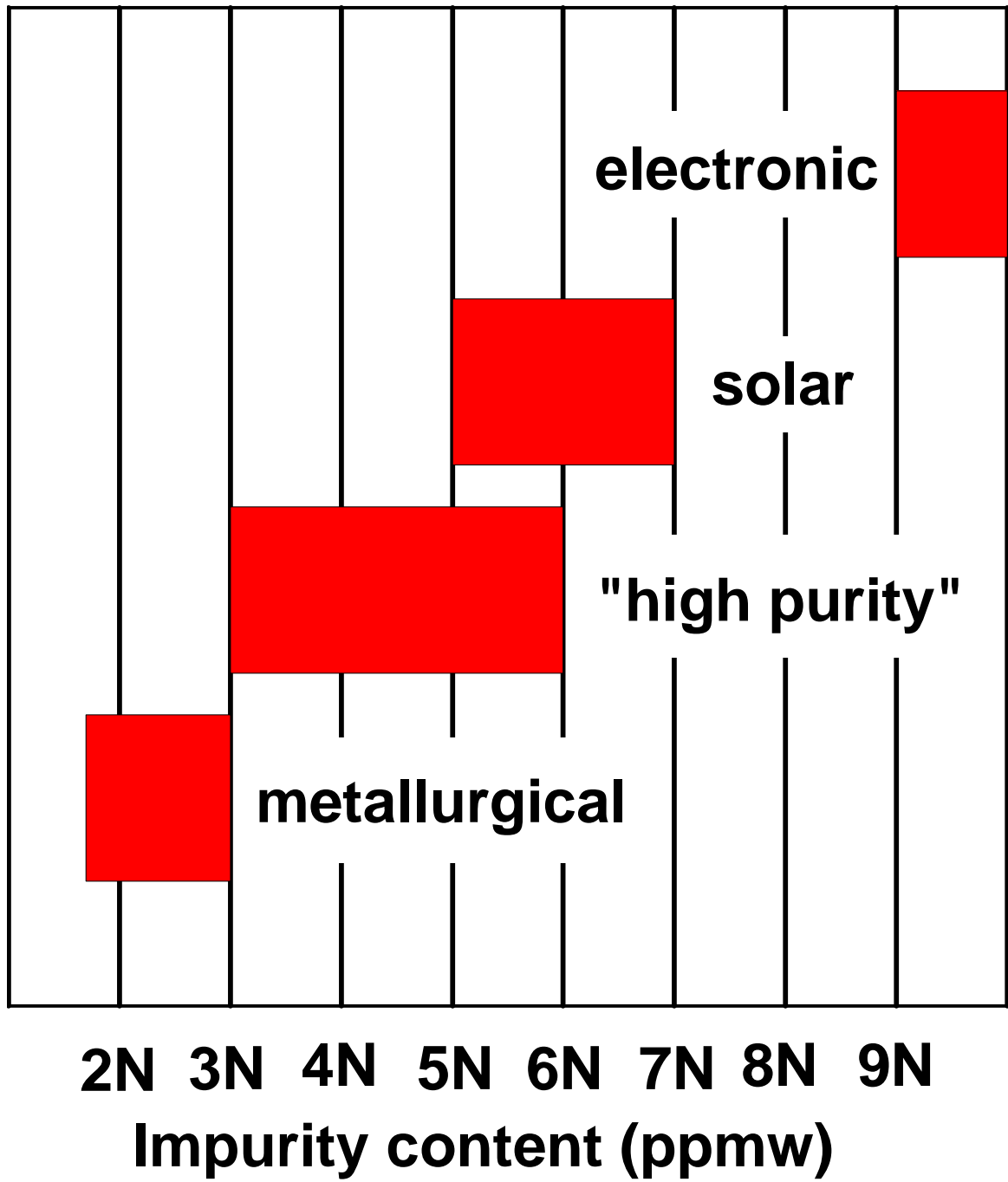
## PV Capacity 2005

**Germany 1.42 GW**

**Japan 1.41 GW**

**USA 0.48 GW**





# Photovoltaics: The Production Path

Metallurgical Si - \$ 3 per kg

Electronic Si - \$ 40-60 per kg



Missing Link

Scrap Si - \$ 25 per kg

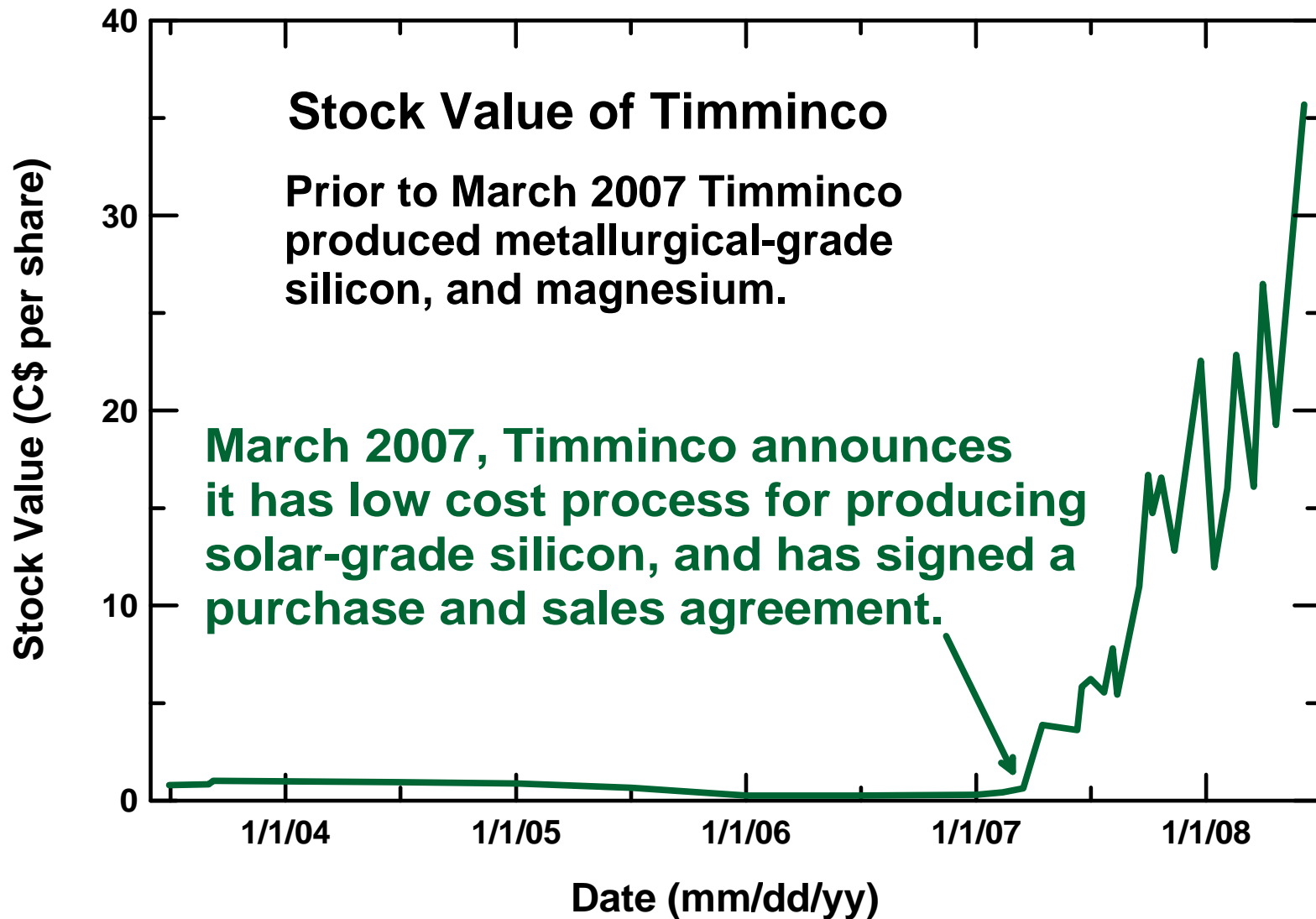
Solar Grade  
Aim \$ 10-14 per kg



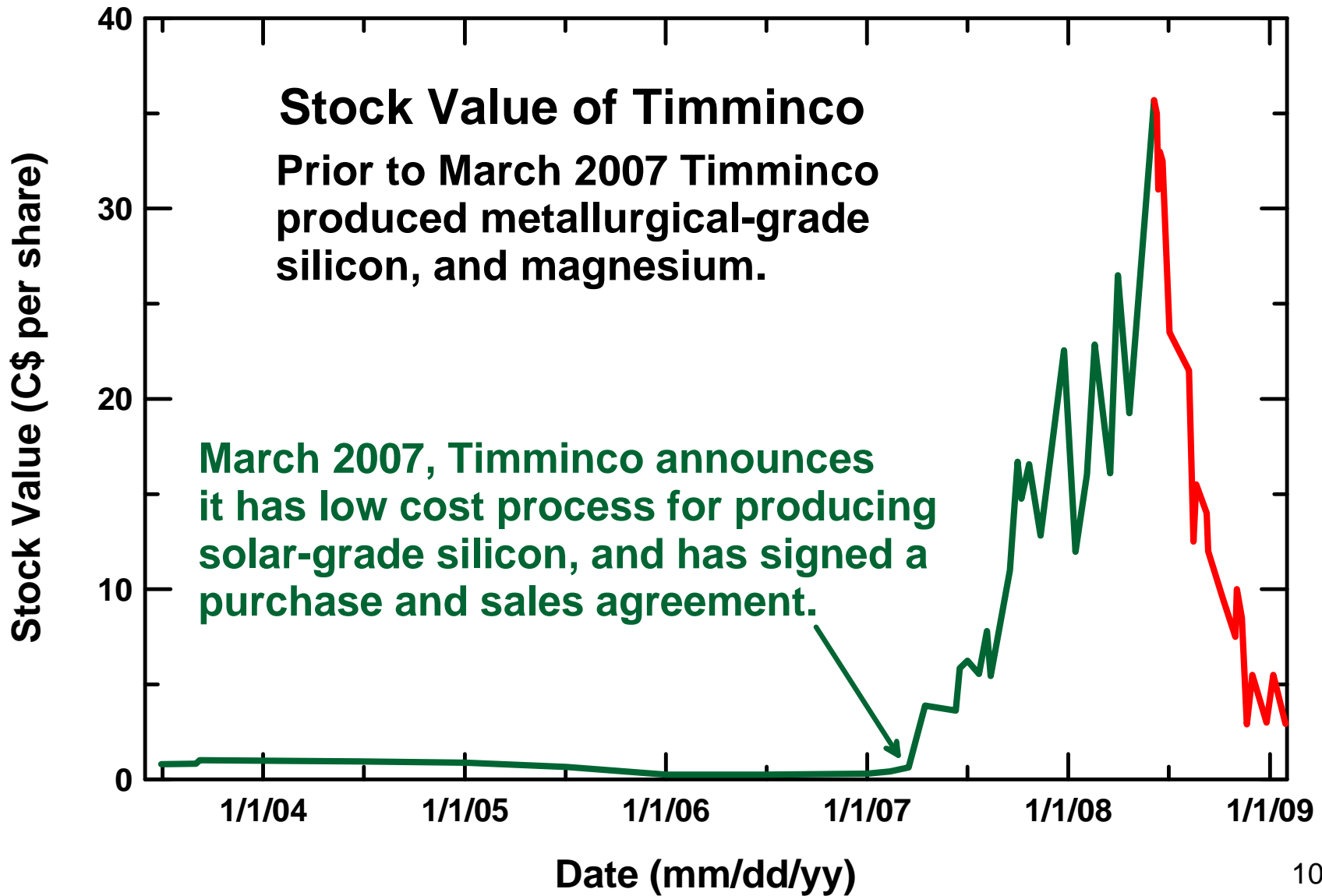
\$ 2	\$ 25	\$ 40	\$ 100
------	-------	-------	--------



# Is there a pot of gold at the end of the race for solar silicon?



# Only if you get it right!

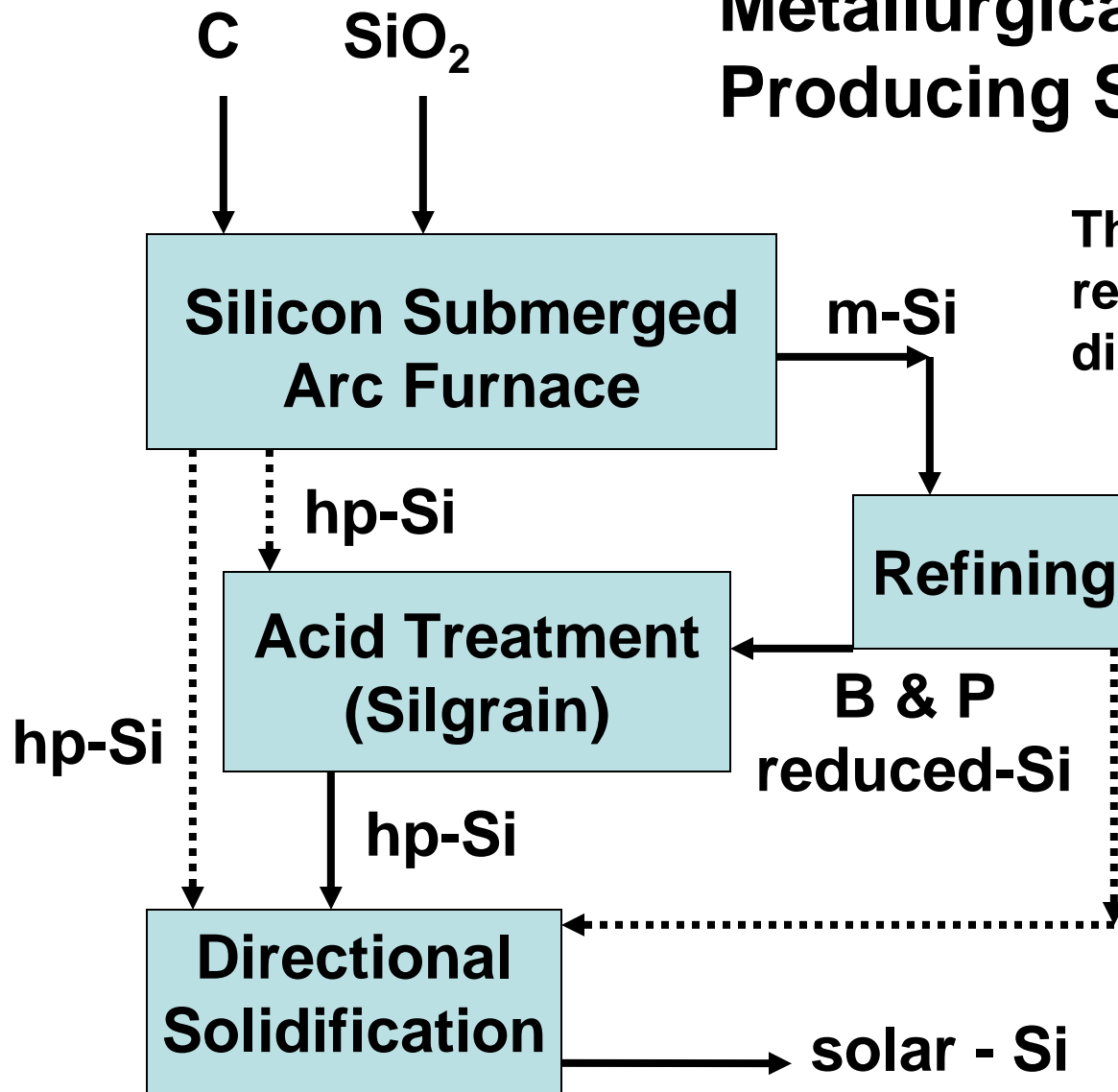


# Some of the Players in the Race

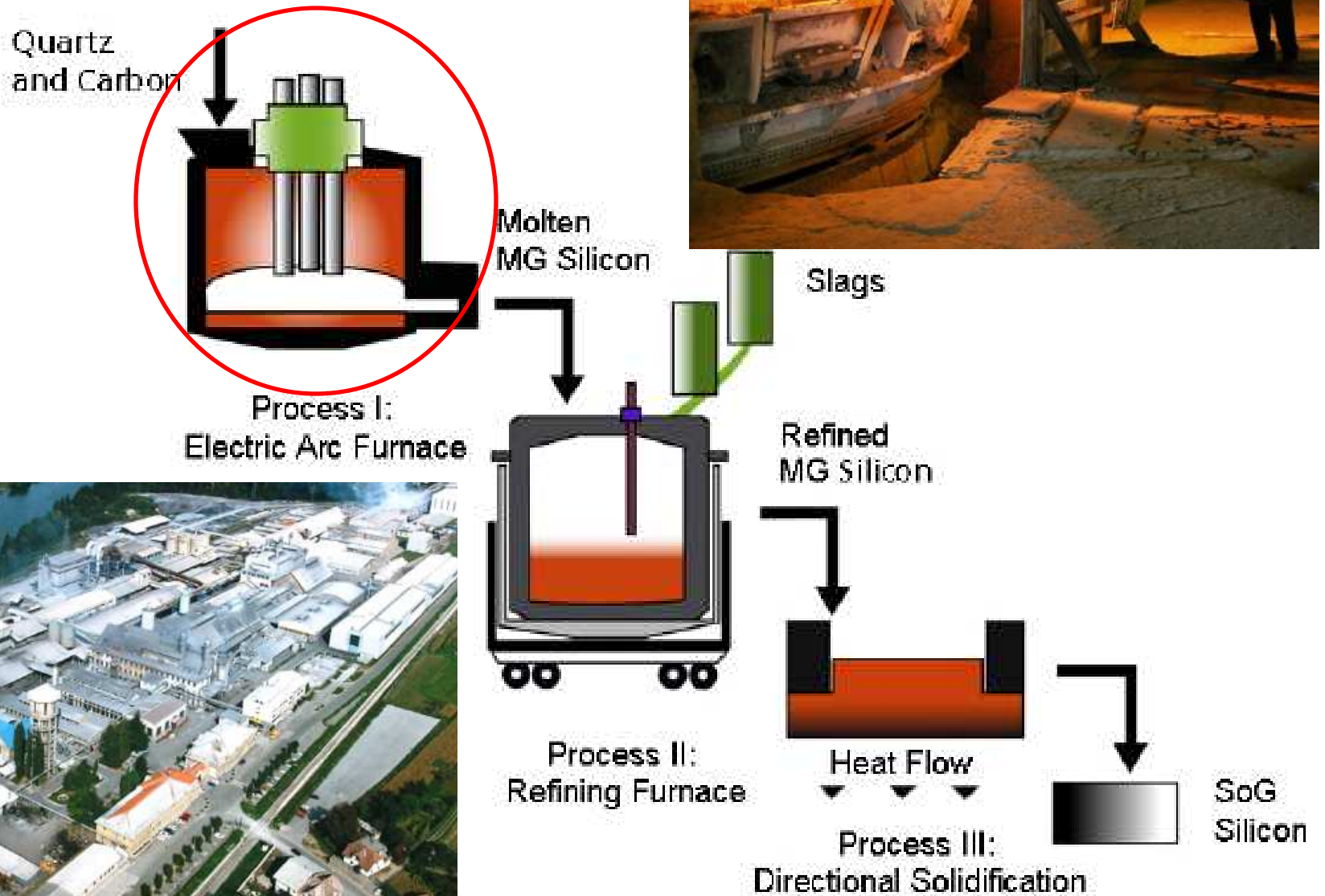
Tech.	Company	Tech.	Company
Integrated Reduction of Silica to s-Si	Solsilk/FESIL Solarvalue ??? Elkem Solar	Siemens TCS  Silane	Hemlock, Wacker, Tokuyama, MEMC, & numerous new entrants REC Silicon
Up-grade m-Si	Elkem Solar, Dow Corning, Solarvalue, JFE, Nippon Steel. Timminco, STRC & others	Fluid Bed TCS Silane	Hemlock & Wacker REC Silicon

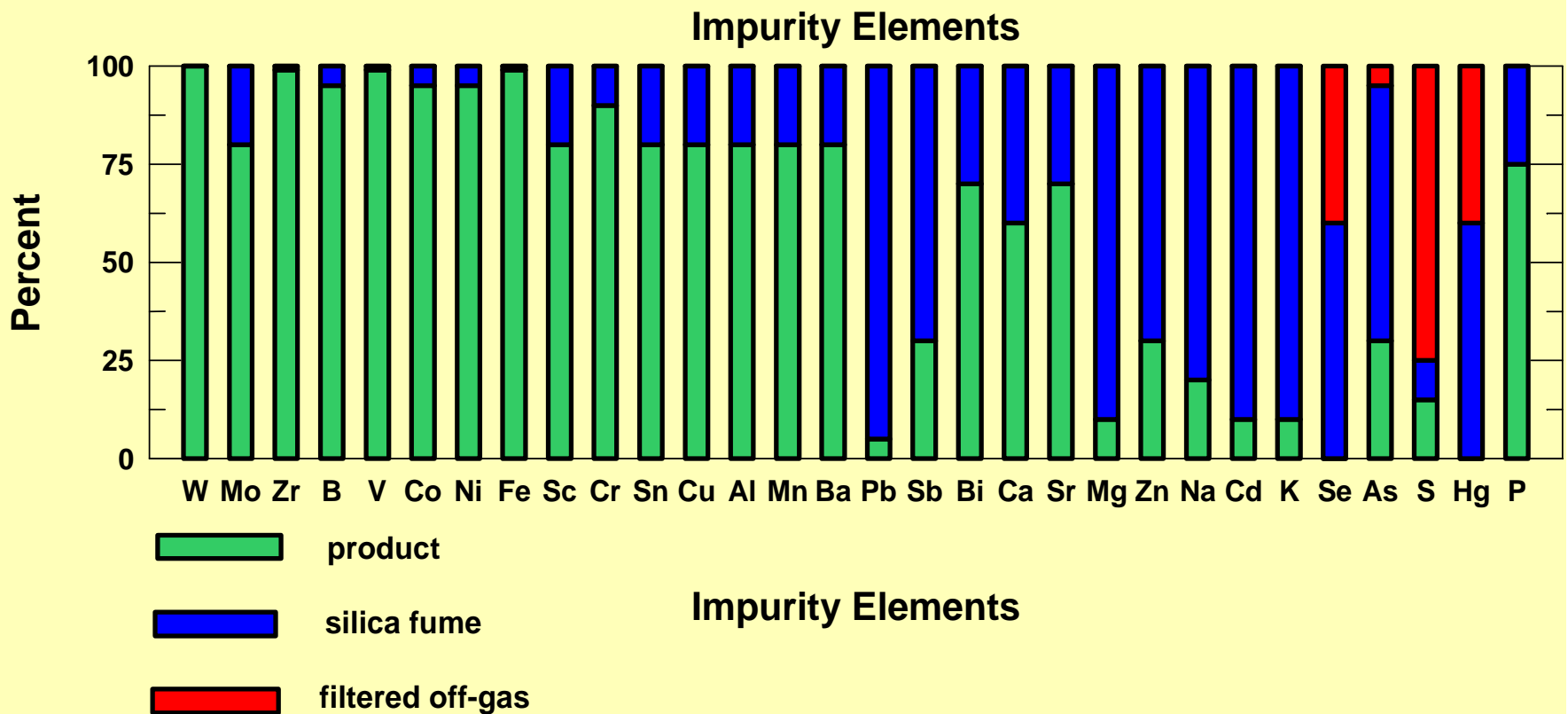
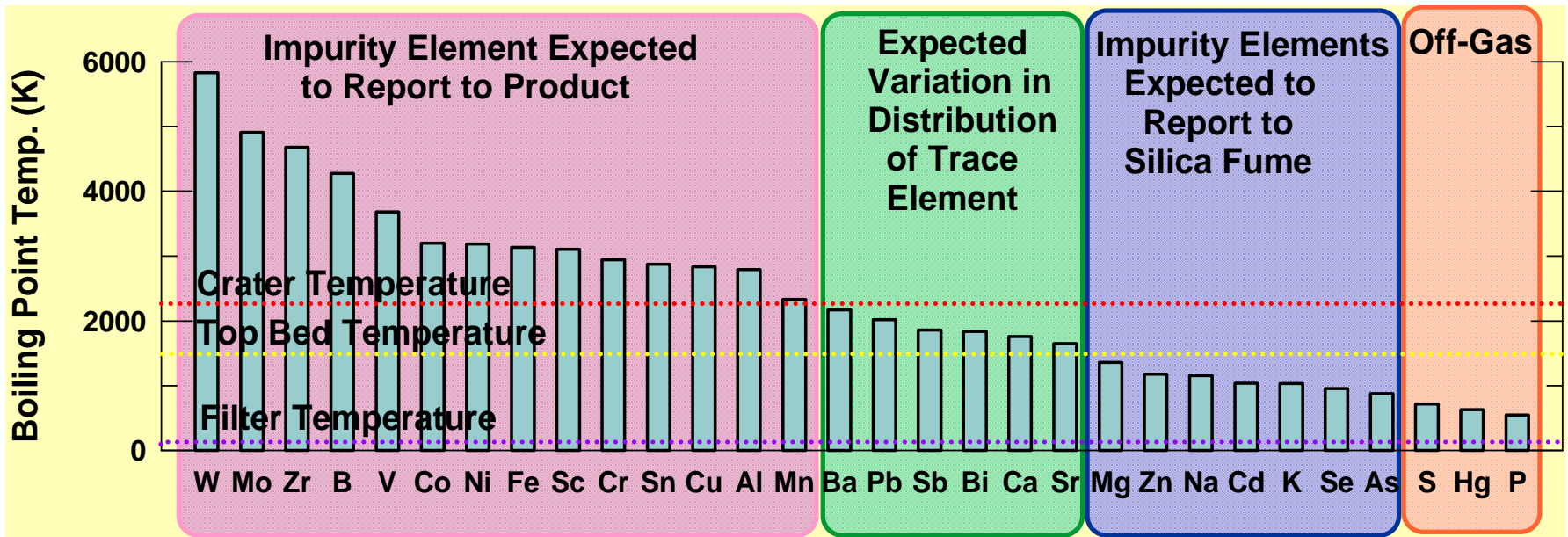
# General Approach of Metallurgical Processes for Producing Solar Silicon

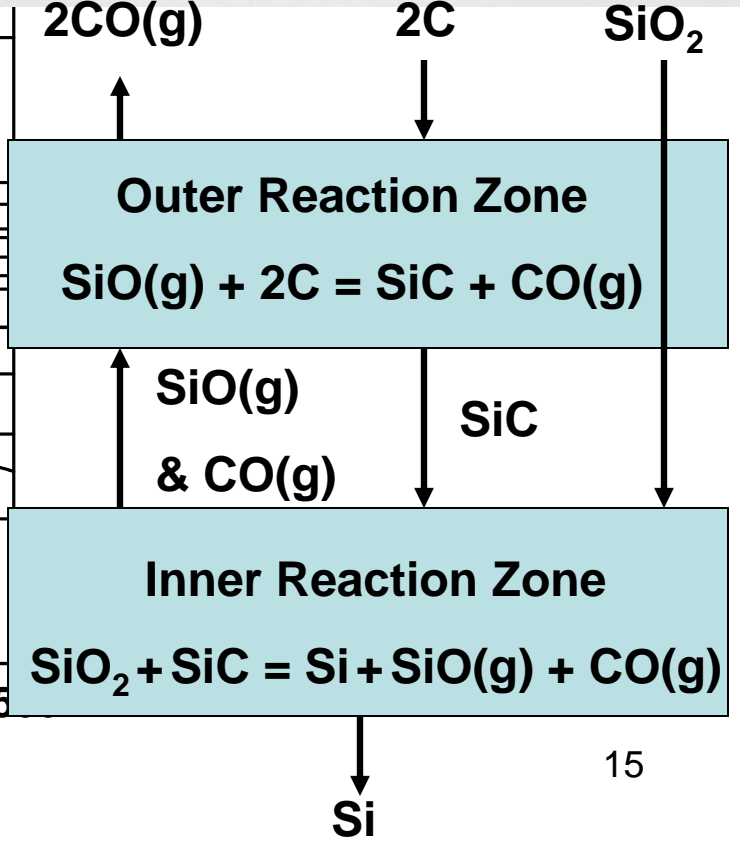
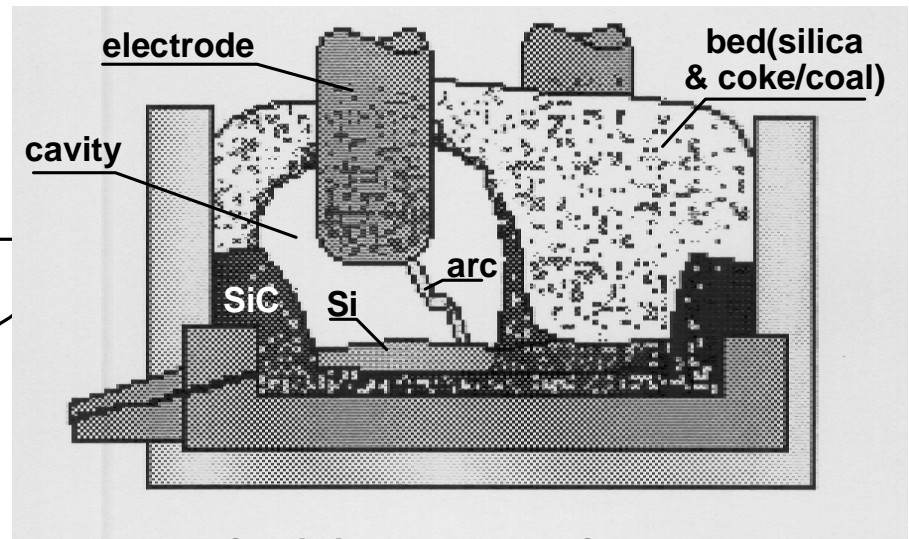
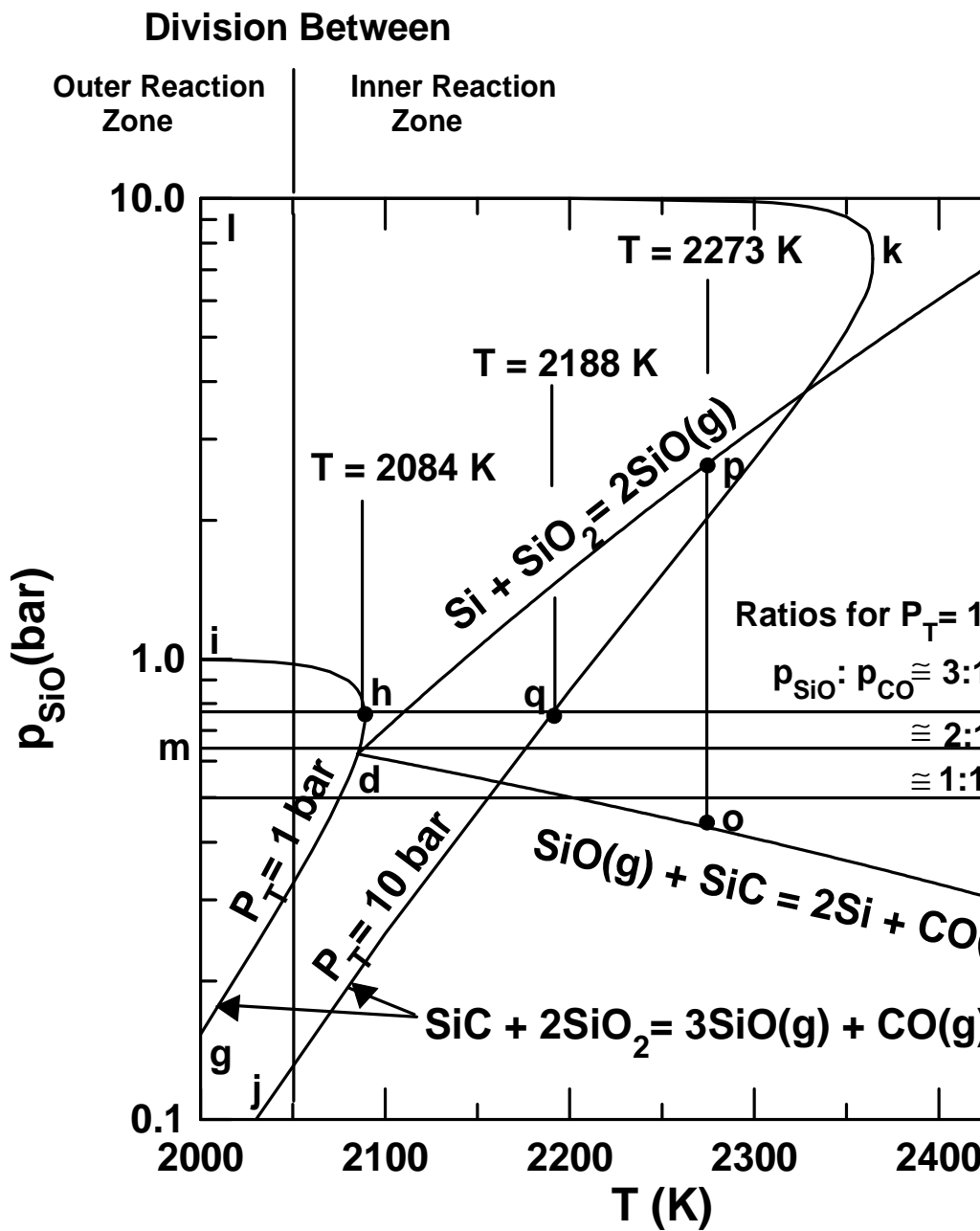
The primary issues is removal of B and P before directional solidification.



Solsilk/FESIL  
SolarValue  
Elkem Solar  
Dow Corning  
Nippon Steel  
JFE  
Timminco  
STRC

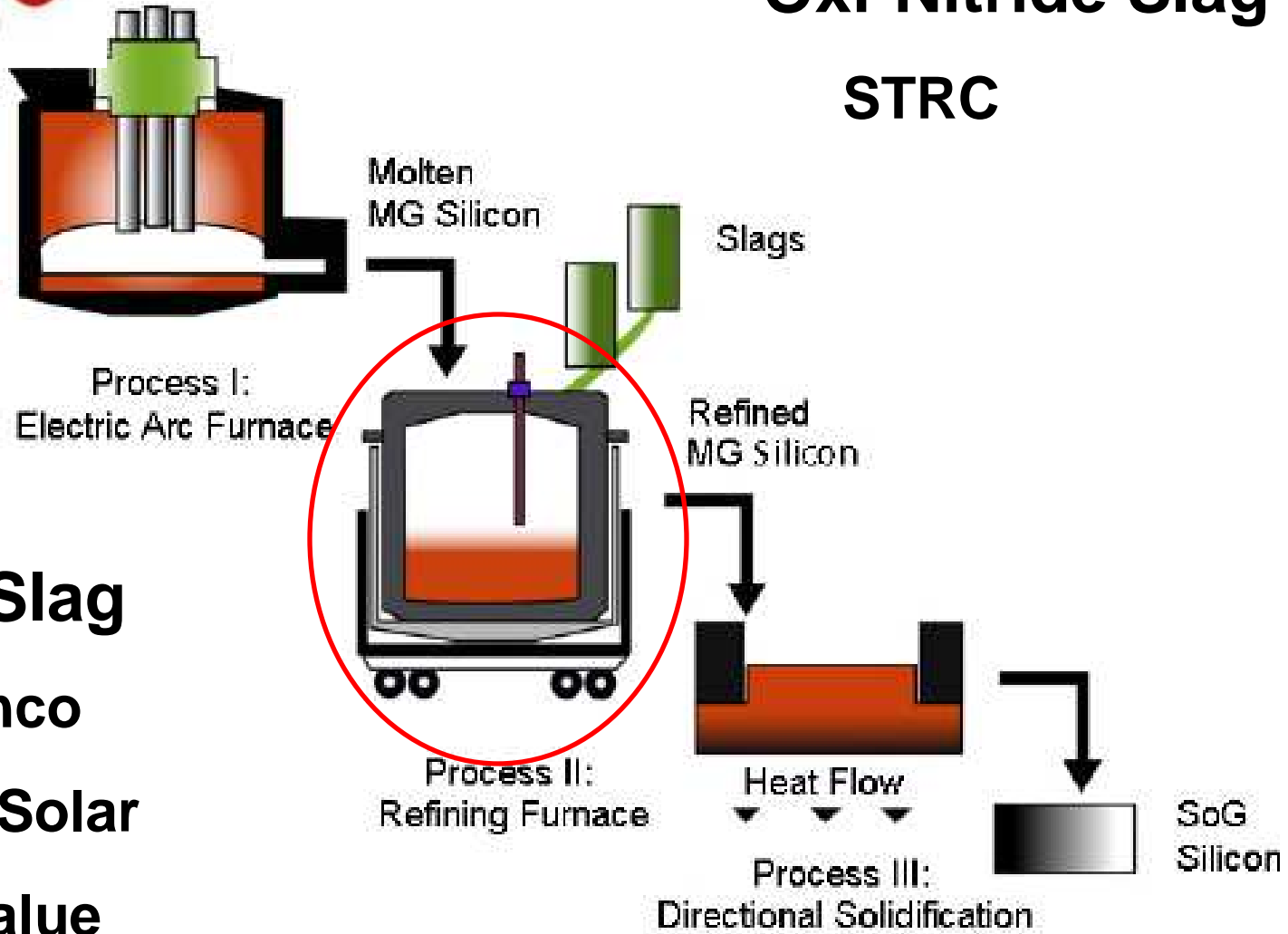






# Oxi-Nitride Slag

## STRC



**Oxide Slag**

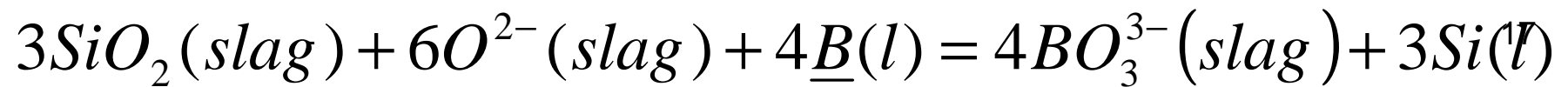
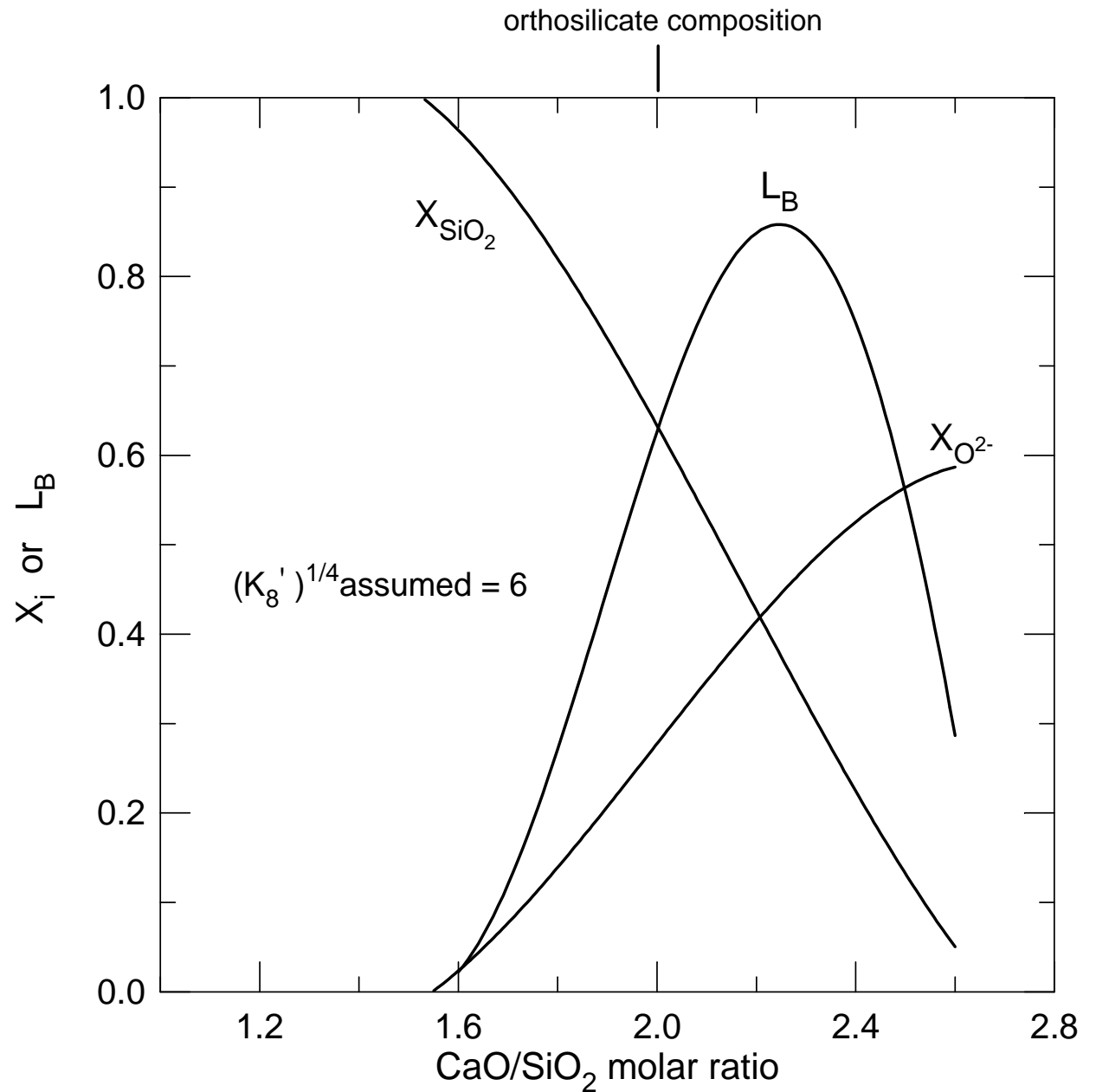
**Timminco**

**Elkem Solar**

**Solarvalue**

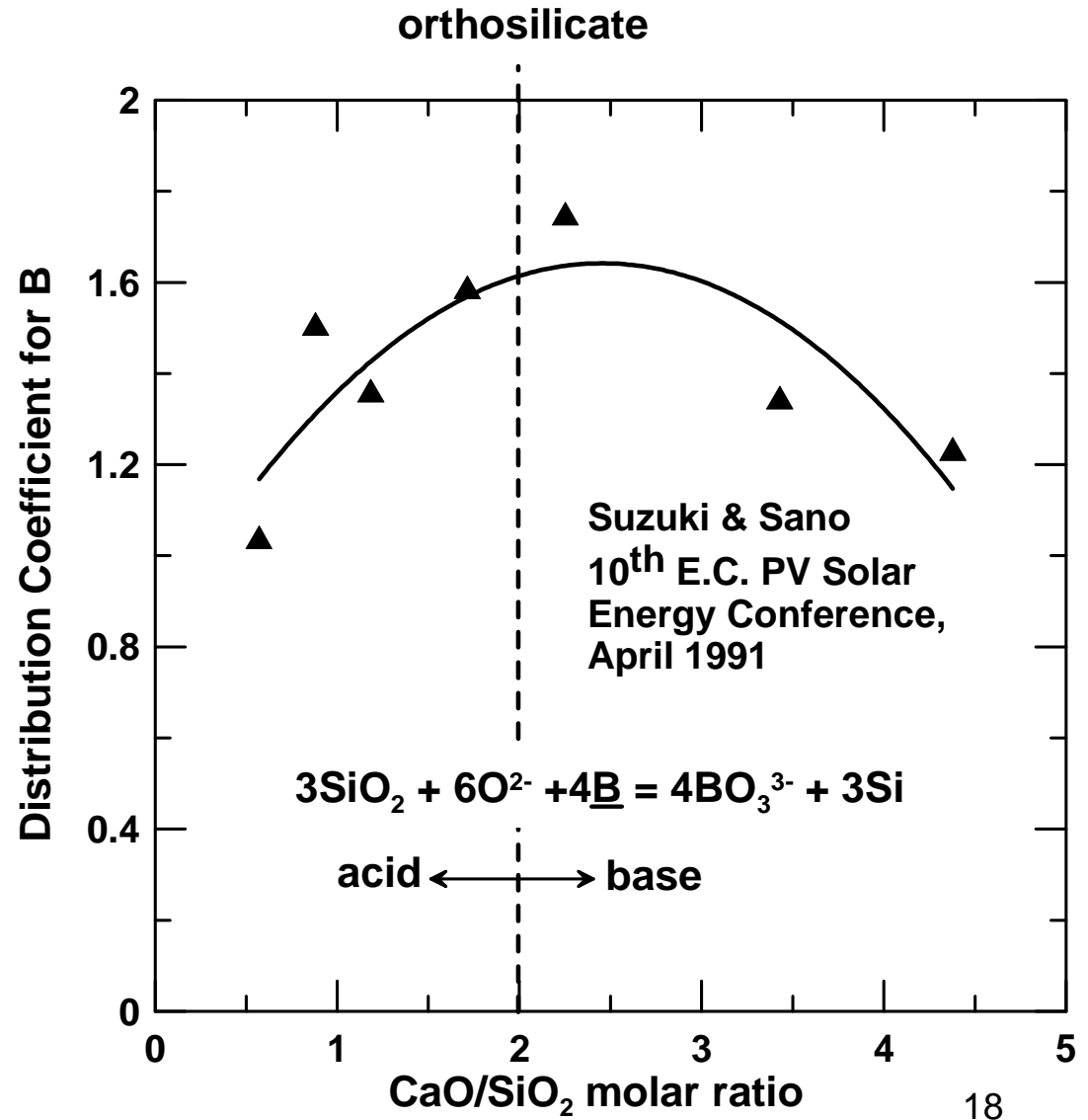
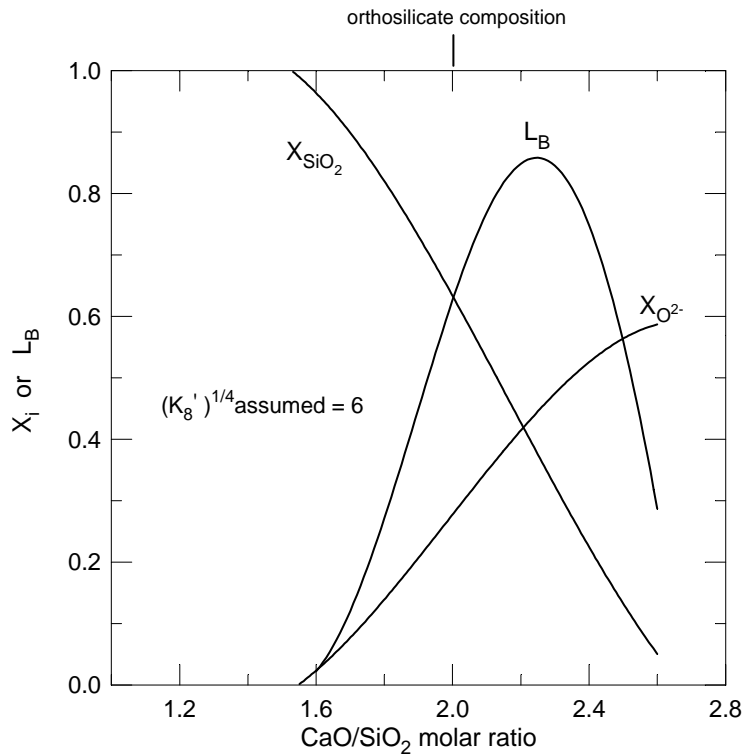


# Refining with an Oxide Slag, B Removal



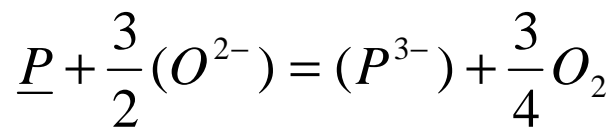
# Refining with an Oxide Slag, B Removal

Process	Slag: Si Mass Ratio
Batch	17
Counter Current	1.4

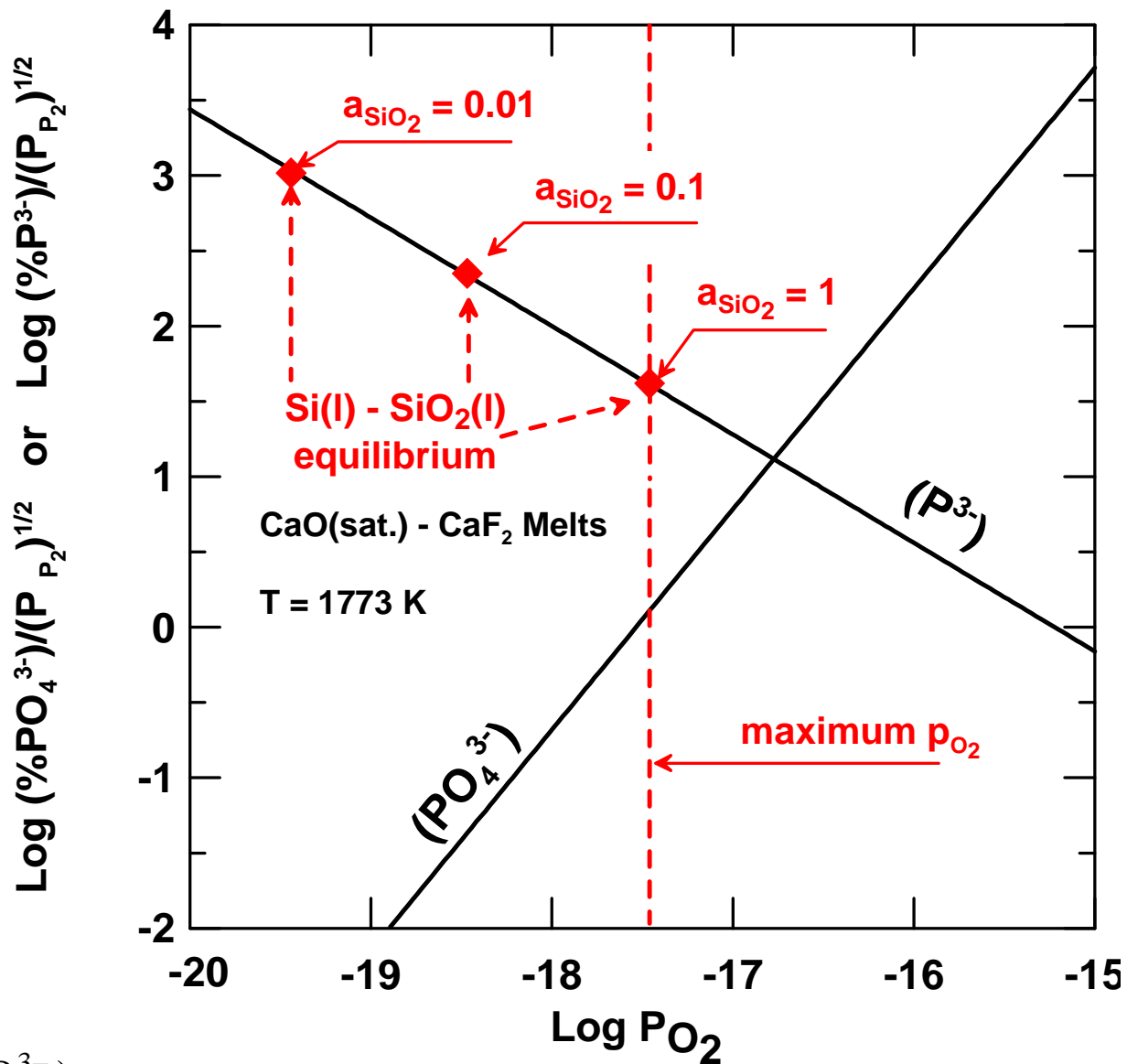
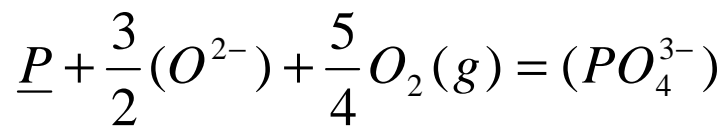


# Refining with an Oxi - Fluoride Slag, B Removal

## Phosphide



## Phosphate



After Tabuchi and Sano 1984<sup>19</sup>

# STRC Approach

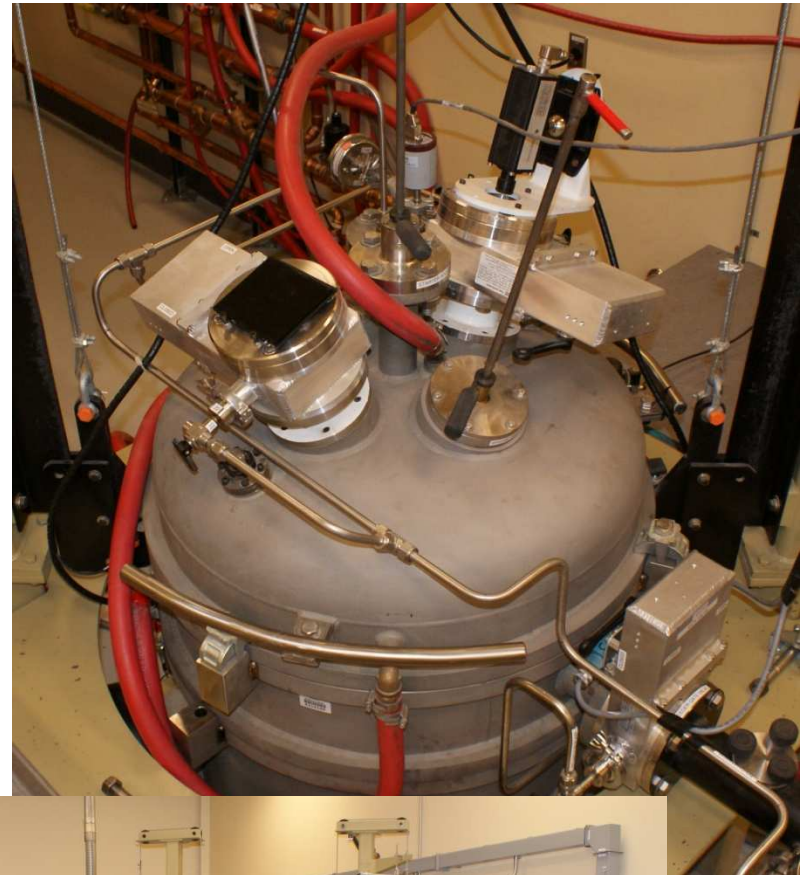
## Technical Approach

- Remove B and P by replacing those elements with other impurities that can be easily removed down stream.
- Oxidative refining
- Silgrain
- Directional Solidification
- Patent Application, US 2007/0245854 A1

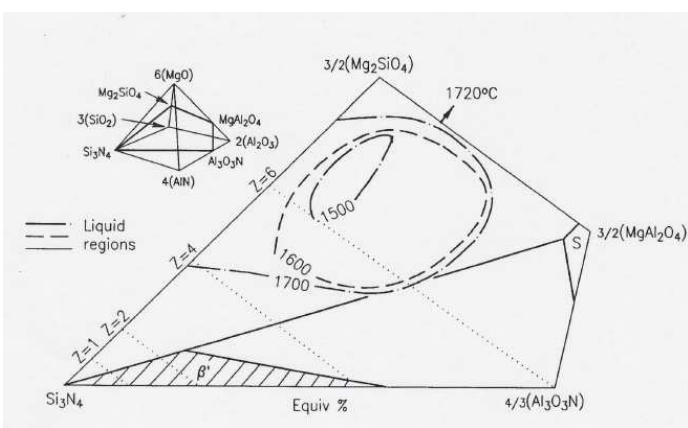
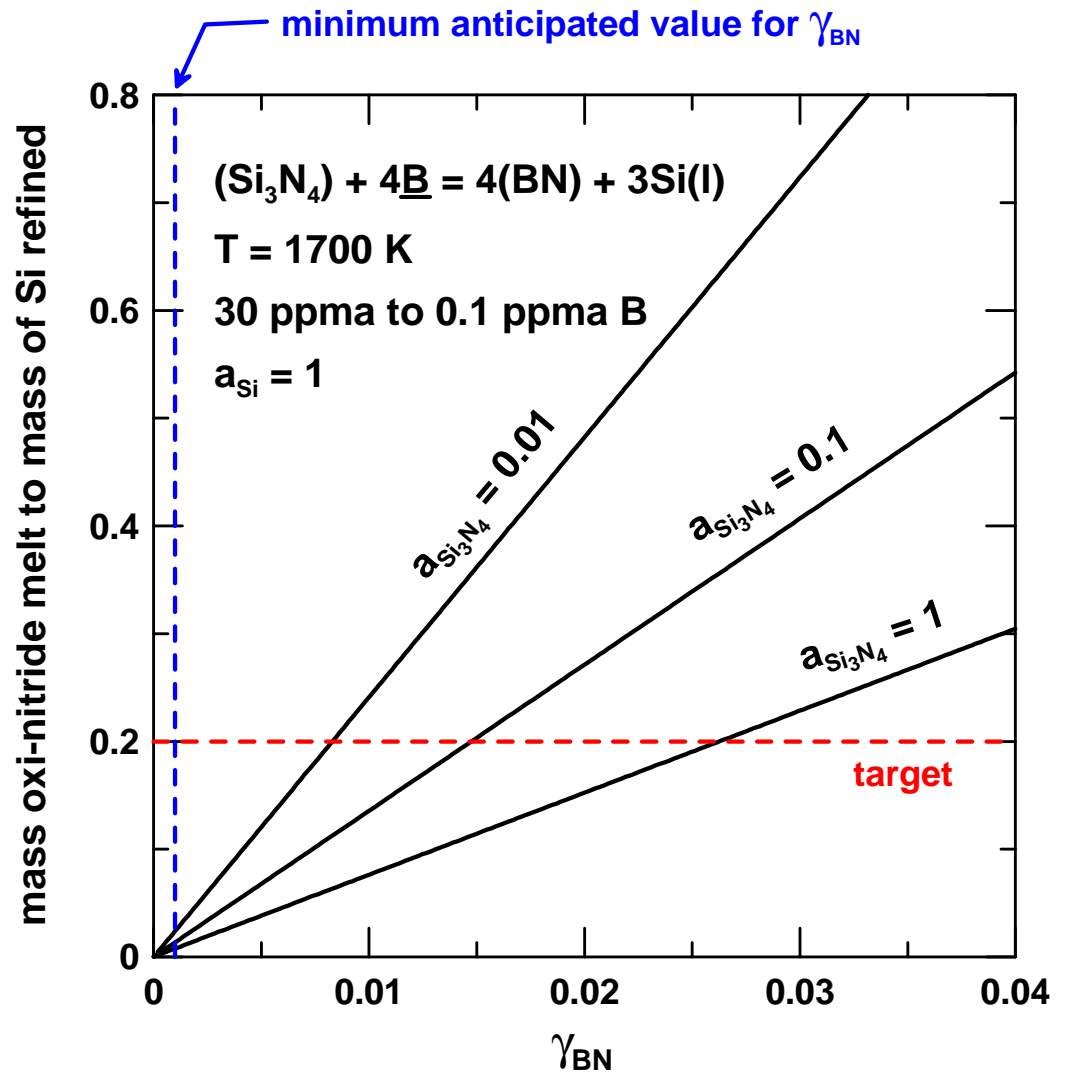
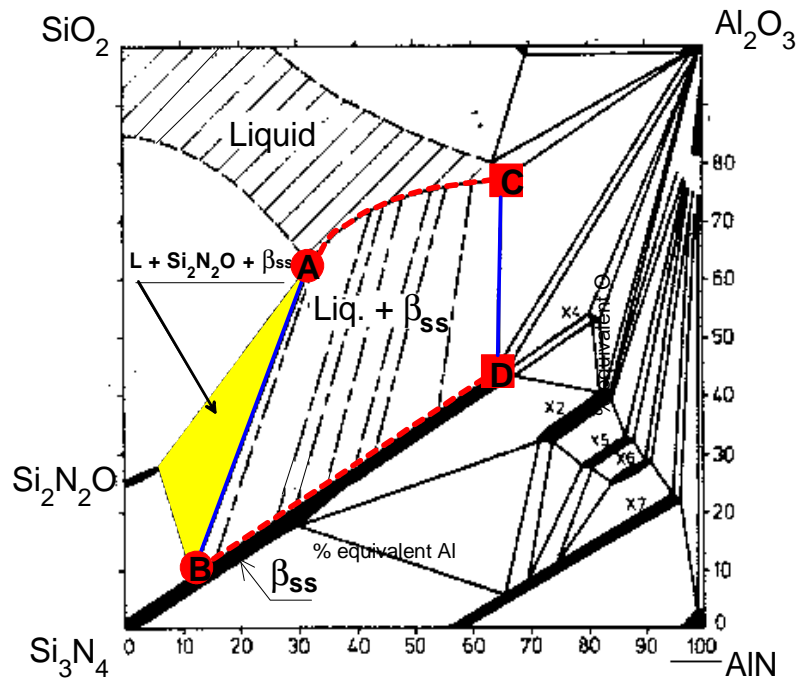
## Business Approach

- Modular Units at 600 metric tons per year
- PV producer financed for guaranteed price
- Estimated production cost: \$12-\$14 per kg (pre directional solidification)
- With projected process improvement, cost estimated at \$8 to \$10 per kg.

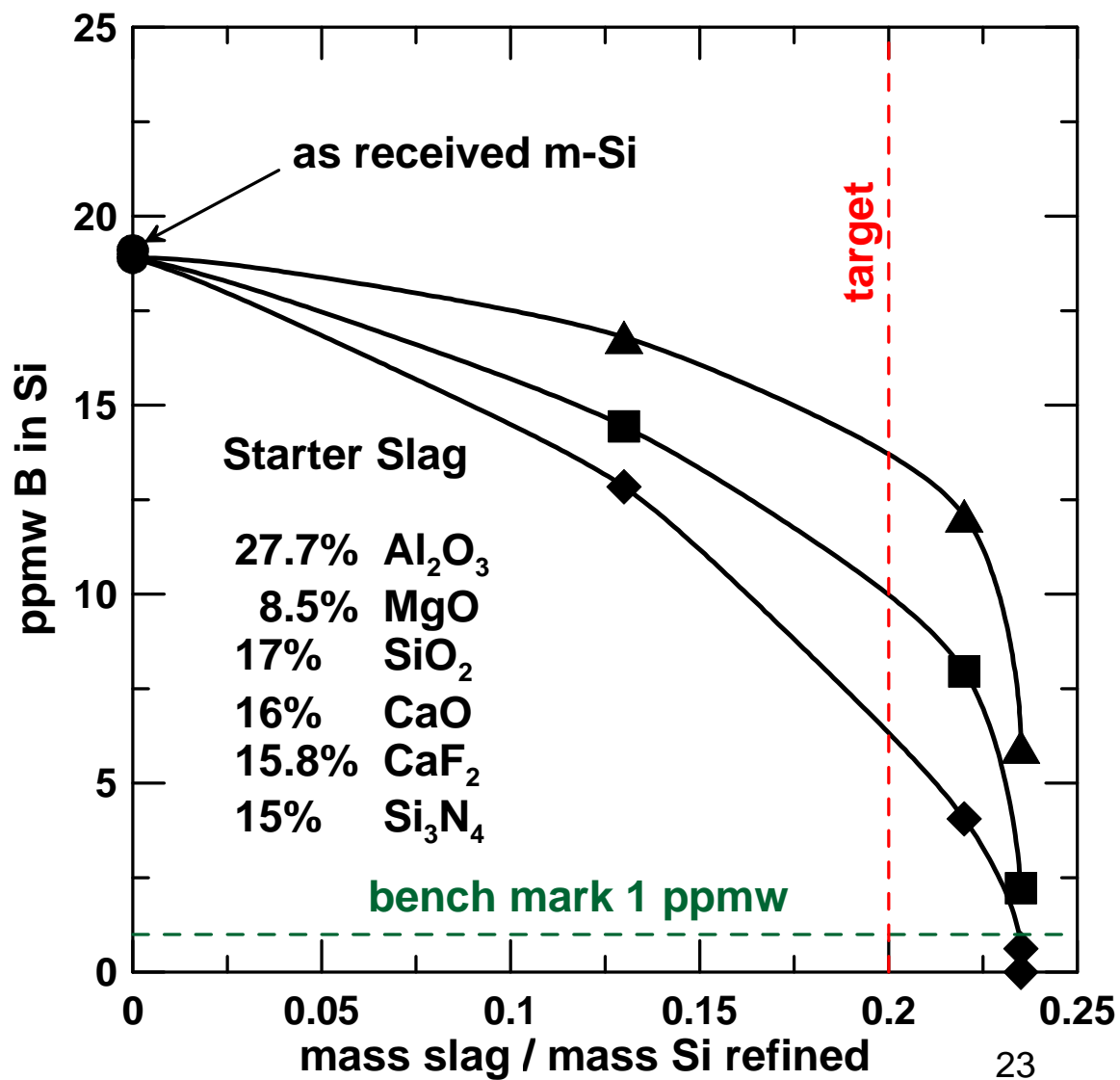
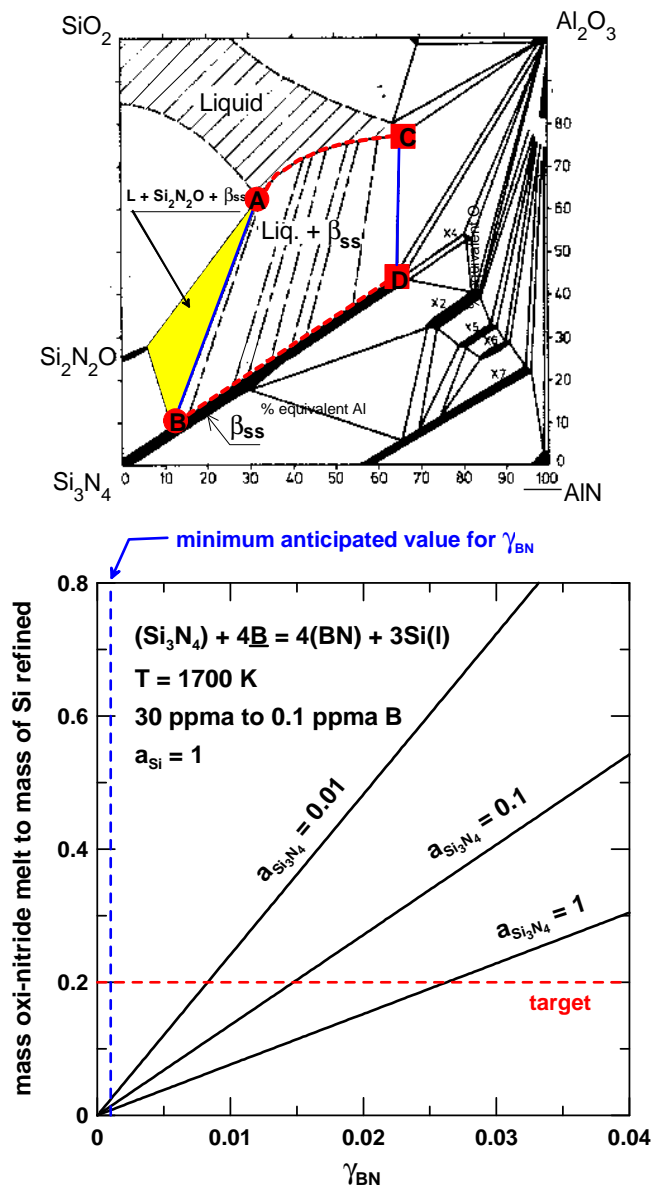
# STRC / UA Research Laboratory



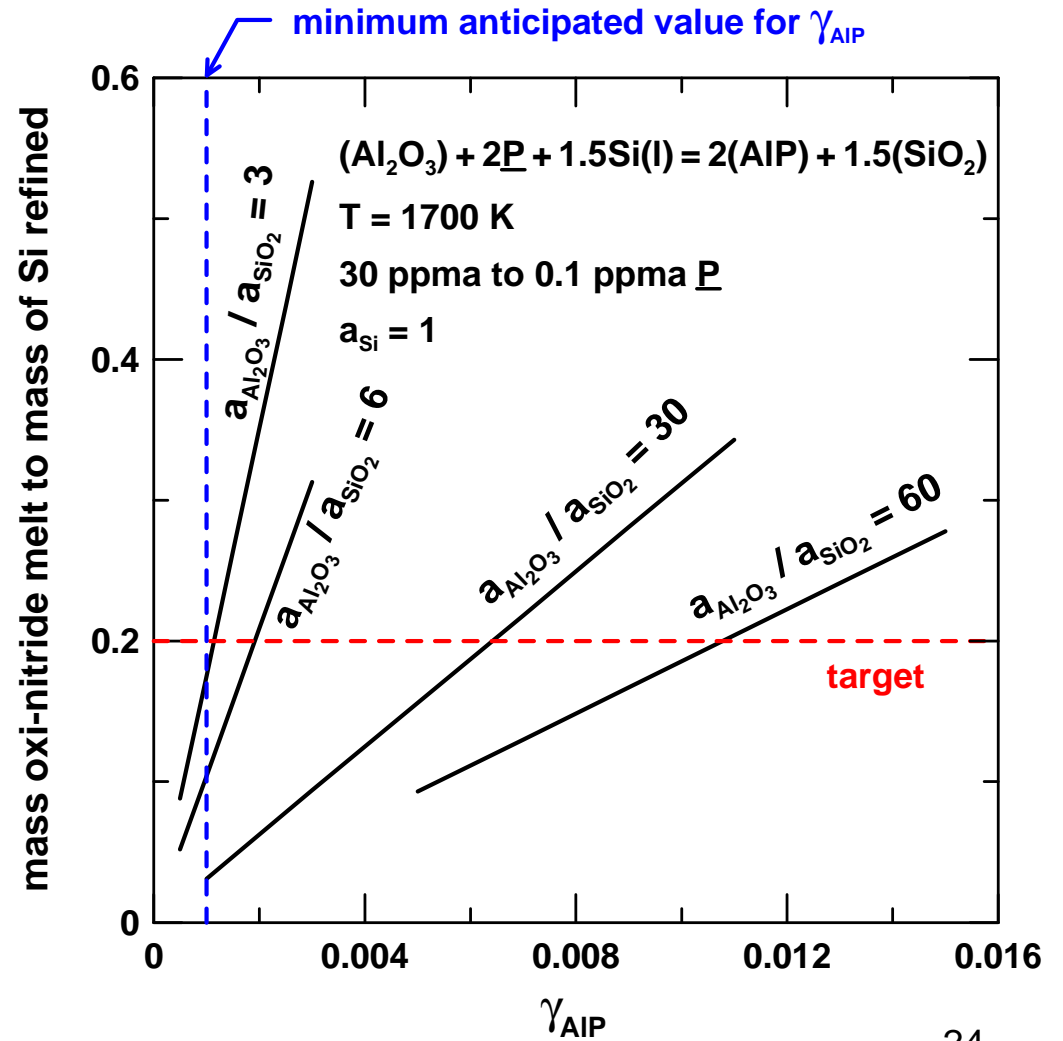
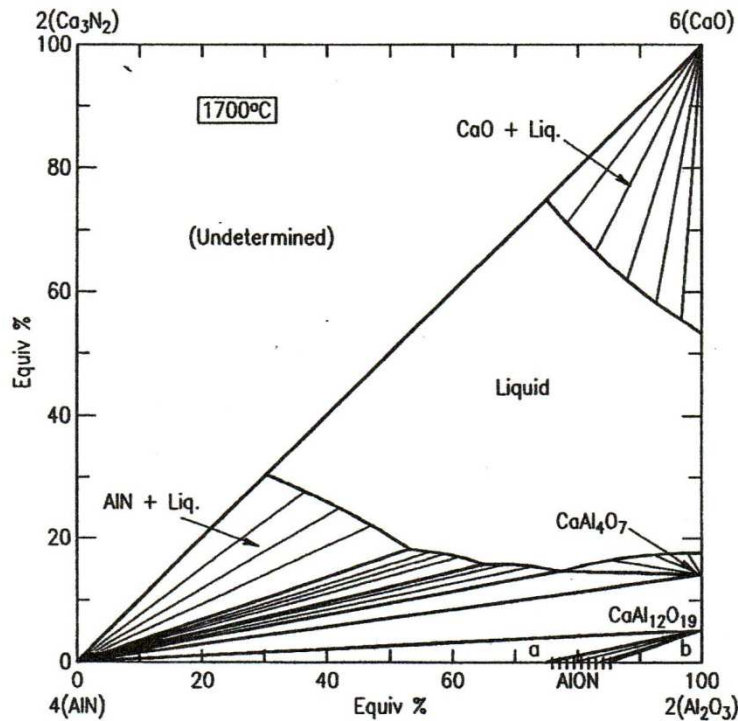
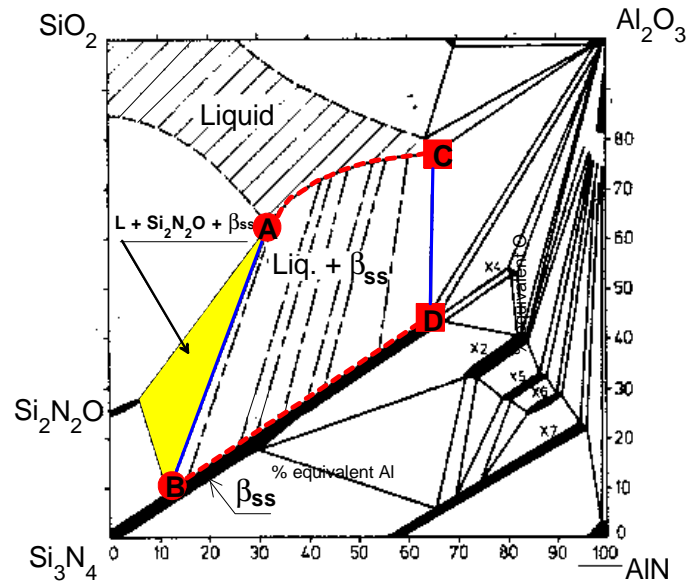
# STRC Technical Approach to Refining for B



# STRC Technical Approach to Refining for B



# STRC Technical Approach to Refining for P





# Conclusions

- **For Si photovoltaics to compete in the market there must be cost compression all along the cost chain.**
- **Opportunity exists to significantly reduce the cost of silicon for photovoltaics through metallurgical refining practice.**
- **Si Photovoltaics are expected to remain a growth area, even though market share will decline.**