
2008 Solar Annual Review Meeting

Session: Modeling and Analysis
Project Title: Environmental, Health and Safety
Brookhaven National Laboratory



Vasilis Fthenakis

email: vmf@bnl.gov

web: www.pv.bnl.gov

tel: 631-344-2830

Budget and Solar America Initiative Alignment



Brookhaven National Laboratory			
Project Beginning Date	FY07 Budget (\$ millions)	FY08 Budget (\$ millions)	Total Budget (\$ millions)
1980	0.400	0.470	0.9

- This project supports the Solar America Initiative by:
Proactive research, industry outreach, and technical communications on EH&S issues and perceptions
- The overall goal is to preserve the safe and environmentally friendly nature of PV and minimize EH&S risks and associated costs, to ensure the public support and economic viability of PV systems
- Minimization of EH&S risks and costs is paramount for achieving the goal of \$0.06/kWhr by 2020, while having the support of the public is a prerequisite for existence and growth to the scale that would support this low cost.

Project Overview



All aspects of PV technologies are examined to identify, characterize and manage potential EH&S issues

The major areas of investigation are:

- Life-cycle impacts of PV materials and products
- Recycling of manufacturing scrap and spent modules
- EH&S issues in manufacturing facilities

Key Personnel:

V. Fthenakis, H-C. Kim, W. Wang (R. Bhide)

Key Expertise:

Chemical engineering, industrial ecology/lifecycle analysis, mining engineering

Project Update



Past
Future

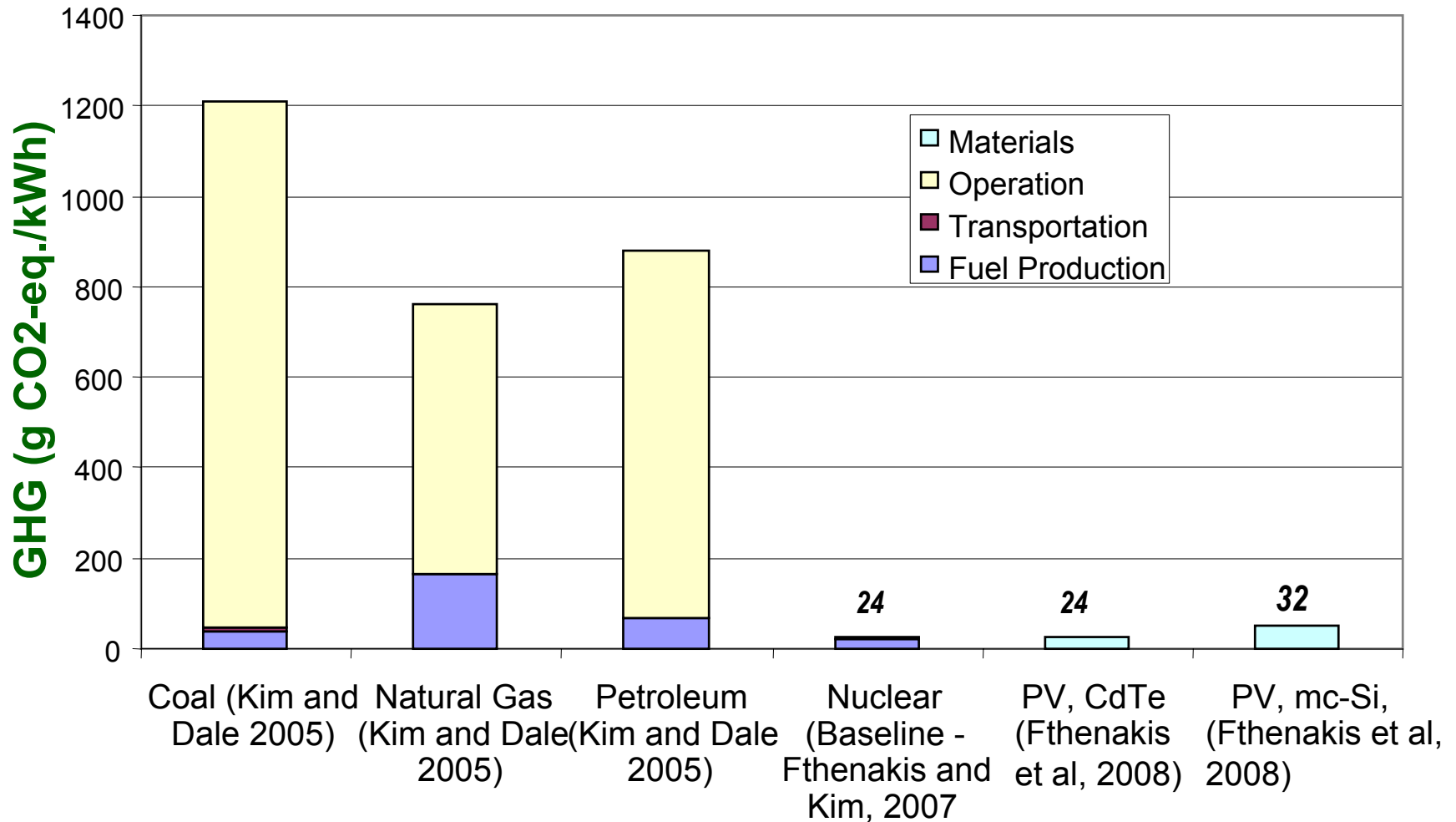
Planned work since April 2007	Status
Life Cycle Analysis/Risk Assessment Buffer options for CIGS PV Greenhouse gas use in c-Si etching operations Energy Payback Times of major PV technologies	July-07 Sept-07 Feb -08
Recycling Pilot scale separations Cd-Te using leaching liquid from actual manufacture - Recovered 99.9% pure Te and Cd	Nov-07
Industry Outreach/Information Dissemination California Energy Commission Expert Workshop Nuclear EU PV Industry Forum-Expert Panel on Sustainability Interviews in Radio, Newspapers, Magazines, Journals	June-07 Sept-07 -Ongoing
International Energy Agency PVPS Task 12 Start & organize Task /represent the U.S. 1 st LCA Expert Meeting	-Ongoing June-07 Nov-07
Life Cycle Analysis/ Risk Assessment/Industry Outreach Workshop on Silane Safety/ Lessons Learnt IEEE PVSC, San Diego LCA of III/V concentrators - EUPV, Valencia	anticipated May-08 anticipated Sept-08
Recycling Improve purity of recovered Cd and Te	Pending



Major Accomplishments

- Defined Energy Payback Times (EPBT), GHG and toxic emissions from PV; corrected previous estimates
- Recovered 99.9% pure Te and Cd from CdTe PV manufacturing scrap – scaled-up recycling process
- Assisted the industry on site-specific EH&S issues
- Organized a Symposium on Life-Cycle Analysis in the Fall 2007 Materials Research Society Meeting
- Promoted/established international collaborative LCA studies, enhancing the quality and quantity of PV environmental assessments.
- Led expert workshops by the European PV Industry Association (EPIA), the International Energy Agency (IEA) and the California Energy Commission
- Published in high-impact journals (PIP, EP, ES&T, Scientific American)
 - 12 journal and conference proceedings papers
- Invited presentations in major conferences/seminars (4)
- Answered numerous requests for EH&S information from the public and the industry.

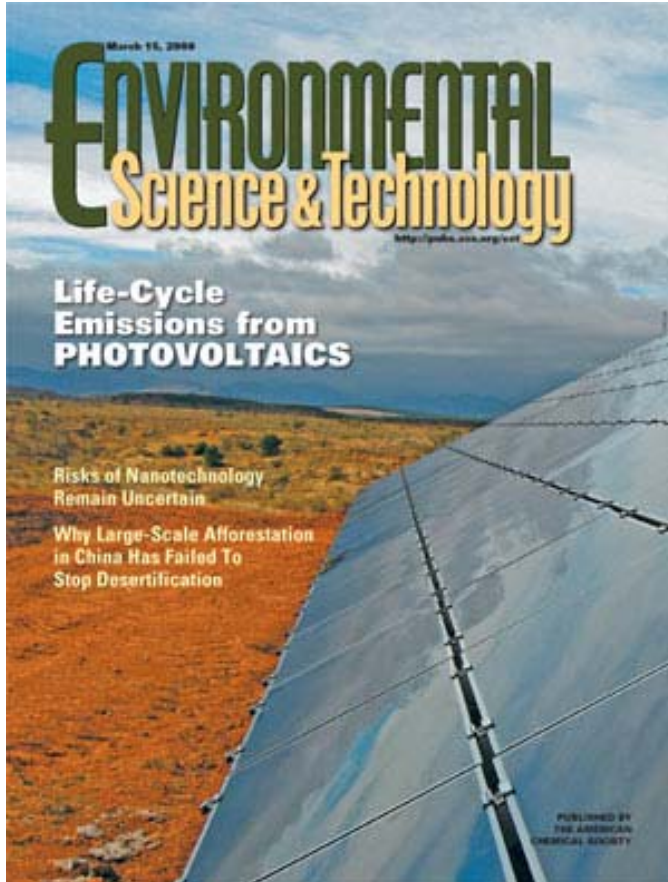
GHG Emissions from Life Cycle Energy of Electricity Production



Fthenakis and Kim, Energy Policy, 2007

Fthenakis et al., Environmental Science & Technology, 2008.

Recognition by the Scientific Community



Greener Green Energy: Today's solar cells give more



How free is Solar Energy?



New photovoltaics change costs

The New York Times

Photovoltaic Cells Are Still Very Green, Comparative Test Shows *February 26, 2008*



Dark Side of Solar Cells Brightens
A life cycle analysis proves that solar cells are cleaner

2007-08 Publications



- Greenhouse gas Emissions from Solar Electric and Nuclear Power: A Life Cycle Study, Energy Policy, 35, 2549-2557, 2007.
- CdTe Photovoltaics: Life-cycle environmental profile and comparisons, Thin Solid Films, 515, 5961-5963, 2007.
- Emissions from photovoltaic life cycles, Environ. Sci. Technol., 42 (6), 2168–2174, 2008
- A Solar Grand Plan, Scientific American, 298(1), 64-73, 2008.
- Life Cycle Inventory Analysis in the Production of Metals used in Photovoltaics, Renewable and Sustainable Energy Reviews, in press.
- The Technical, Geographical and Economic Feasibility for Solar Energy to Supply the Energy Needs of the United States, Energy Policy, in press.
- Recycling of CdTe Photovoltaic Modules: Recovery of Glass, Cadmium and Tellurium, Proceedings 21st European Photovoltaic Solar Energy Conference, Dresden, Germany, 4-8 September 2006, pp. 2539-2541.
- Fluorinated Greenhouse Gases in Photovoltaic Module Manufacturing: Potential Emissions and Abatement Strategies, 22nd European Photovoltaic Solar Energy Conference, Milan, Italy, 3-7 September 2007.
- Cu(InGa)Se₂ Thin-Film Solar Cells: Comparative Life-Cycle Analysis of Buffer Layers, 22nd European Photovoltaic Solar Energy Conference, Milan, Italy, 3-7 September 2007.
- Life Cycle Assessment of present and Future Photovoltaic Systems, AIST Symposium Renewable Energy 2007, Chiba, Japan, October 11, 2007.
- Comparative Life-cycle Analysis of Photovoltaics Based on Nano-materials: A Proposed Framework. Materials Research Society Symposium Proceeding Vol. 1041, R01-03, 2008.
- The Fuel Cycles of Electricity Generation: A Comparison of Land Use. Materials Research Society Symposium Proceeding Vol. 1041, R05-03, 2008.

2007-08 Publications



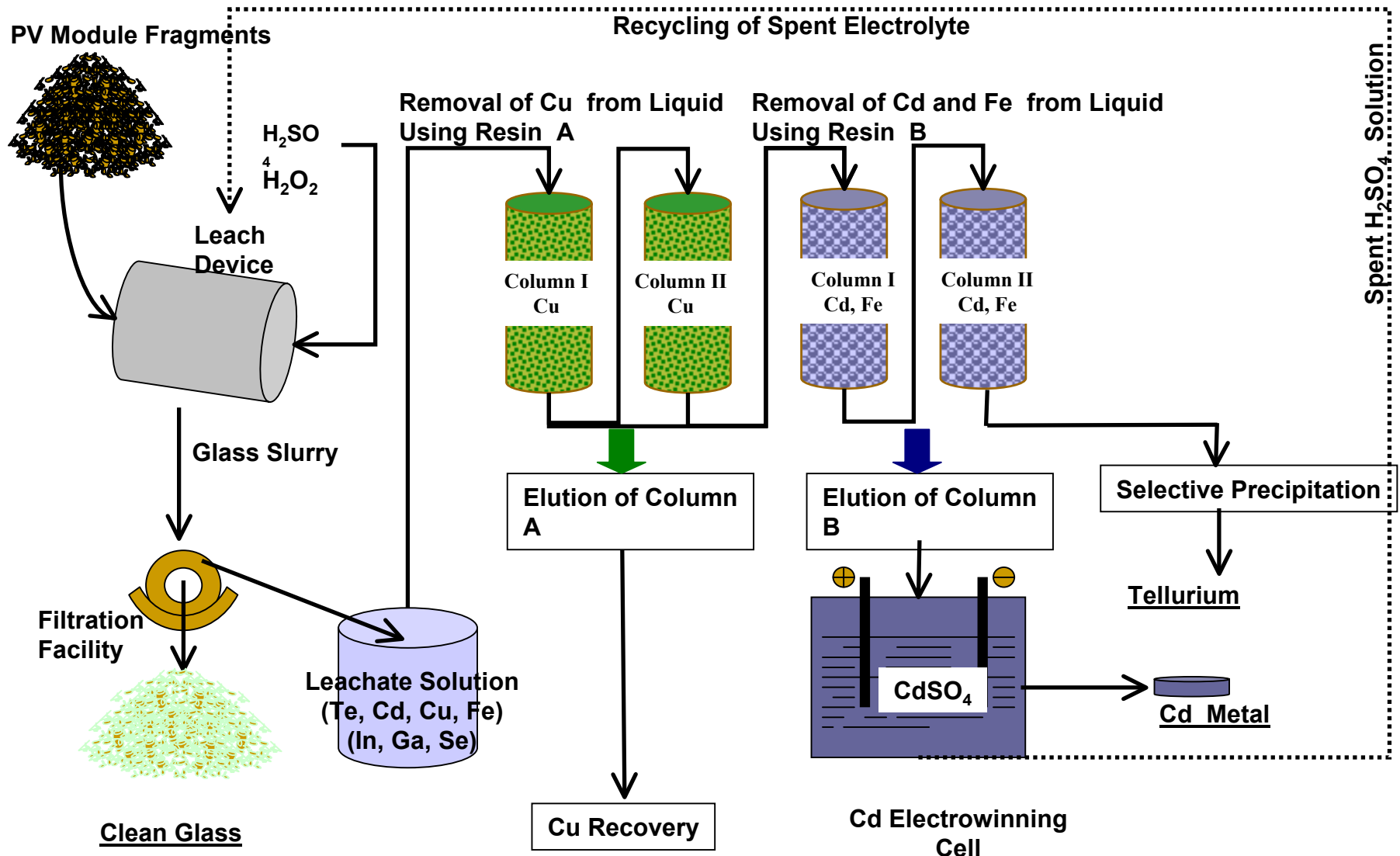
- **Greenhouse gas Emissions from Solar Electric and Nuclear Power:** A Life Cycle Study, Energy Policy, 35, 2549-2557, 2007.
- **Emissions from photovoltaic life cycles**, Environ. Sci. Technol., 42 (6), 2168–2174, 2008
- **A Solar Grand Plan**, Scientific American, 298(1), 64-73, 2008.
- **The Technical, Geographical and Economic Feasibility for Solar Energy** to Supply the Energy Needs of the United States, Energy Policy, in press.
- **Life Cycle Assessment of Present and Future Photovoltaic** Systems, AIST Symposium Renewable Energy 2007, Chiba, Japan, October 11, 2007.
- **Life Cycle Inventory Analysis in the Production of Metals** used in Photovoltaics, Renewable and Sustainable Energy Reviews, in press.
- **CdTe Photovoltaics:** Life-cycle environmental profile and comparisons, Thin Solid Films, 515, 5961- 5963, 2007
- **Fluorinated Greenhouse Gases** in Photovoltaic Module Manufacturing: Potential Emissions and Abatement Strategies, 22nd European Photovoltaic Solar Energy Conference, Milan, Italy, 3-7 September 2007.
- **Cu(InGa)Se₂ Thin-Film Solar Cells:** Comparative Life-Cycle Analysis of Buffer Layers, 22nd European Photovoltaic Solar Energy Conference, Milan, Italy, 3-7 September 2007
- **Recycling** of CdTe Photovoltaic Modules: Recovery of Glass, Cadmium and Tellurium, Proceedings 21st European Photovoltaic Solar Energy Conference, Dresden, Germany, 4-8 September 2006, pp. 2539-2541
- **Comparative Life-cycle Analysis of Photovoltaics Based on Nano-materials:** A Proposed Framework. Materials Research Society Symposium Proceeding Vol. 1041, 2008.
- **The Fuel Cycles of Electricity Generation: A Comparison of Land Use.** Materials Research Society Symposium Proceeding Vol. 1041, 2008

Future Plans

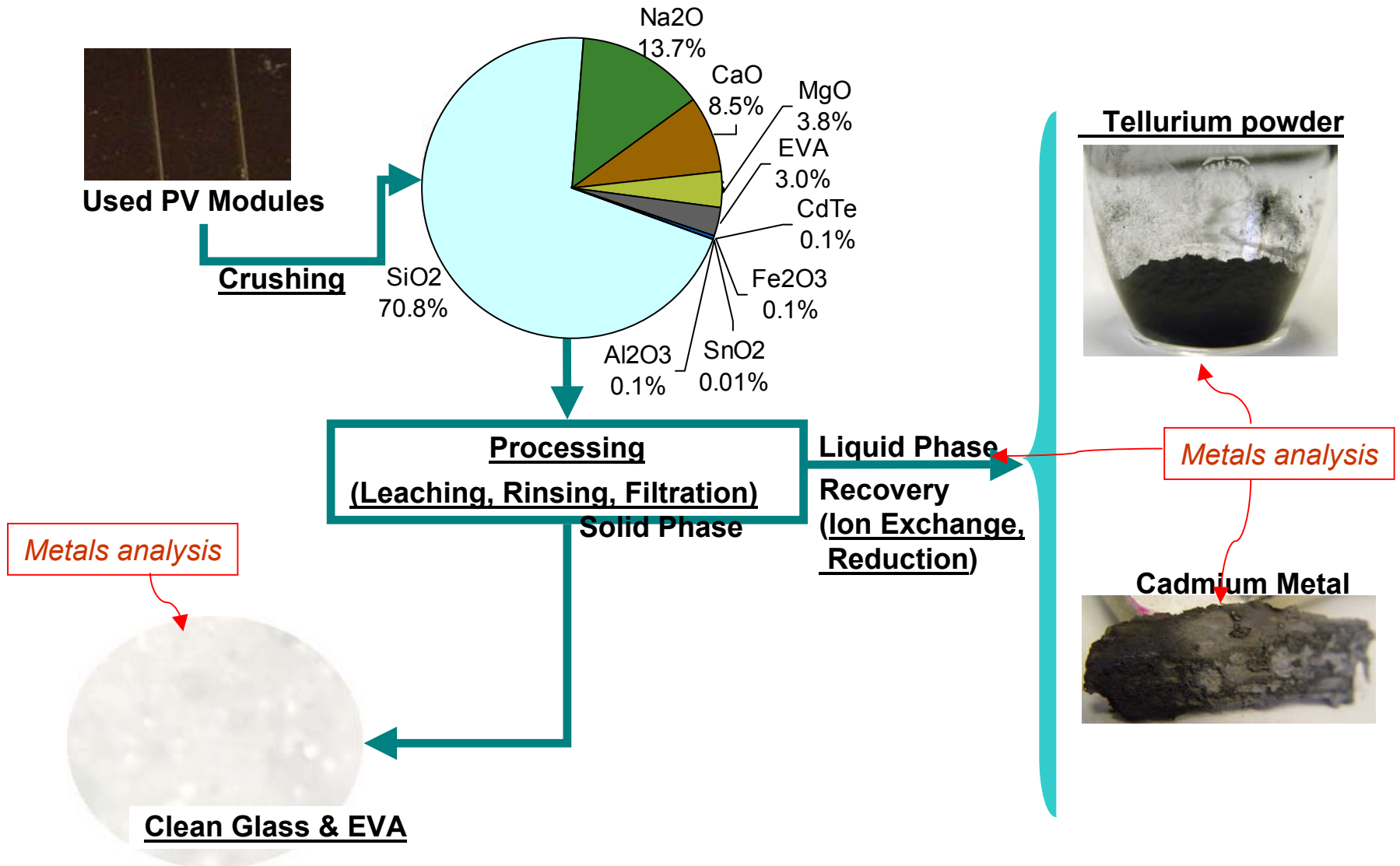


Recycling	
Improve purity of recovered materials	FY09
Cost analysis of module collection and CdTe PV recycling	FY09
Collection Infrastructure/Collaboration with PVCYCLE	FY09
Life Cycle Analysis/ Risk Assessment	
Investigate the effect of Chinese PV production	FY09
Solar grade Si production	FY09
CIGS PV	FY10
Nanostructured-PV	FY10
Nanomaterials Toxicity	FY11
Organic Cells	FY11
CSP Systems	FY12+

Recycling of Spent CdTe or CIGS PV Modules



Recovery of Valuable Materials /Cleaning Waste

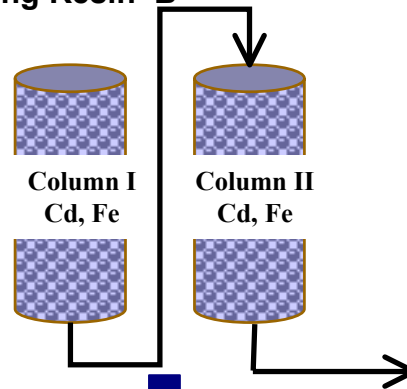


Challenge in Treating Industrial Leaching Solution



**Iron from equipment interferes with the Cd Separation
as Fe and Cd were co-exchanged to the resin**

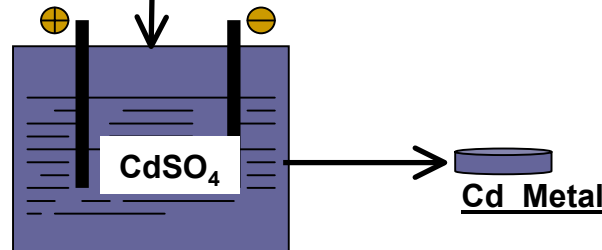
Removal of Cd and Fe from Liquid
Using Resin B



**Purification steps
to remove iron**



Elution of Column
B



Cd Electrowinning

Cd(OH)₂ Cake Contaminated with Fe



After Fe Removal



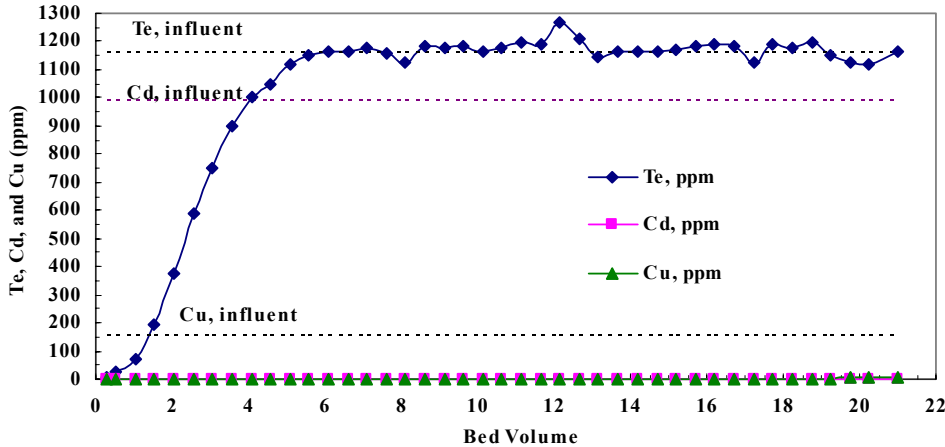


- Barriers encountered or anticipated that may inhibit success of programs
 - Old, failing ICP spectrometer inhibits research on recycling
 - Replacement is needed

Extraction of Metals/Separation and Recovery of Cadmium

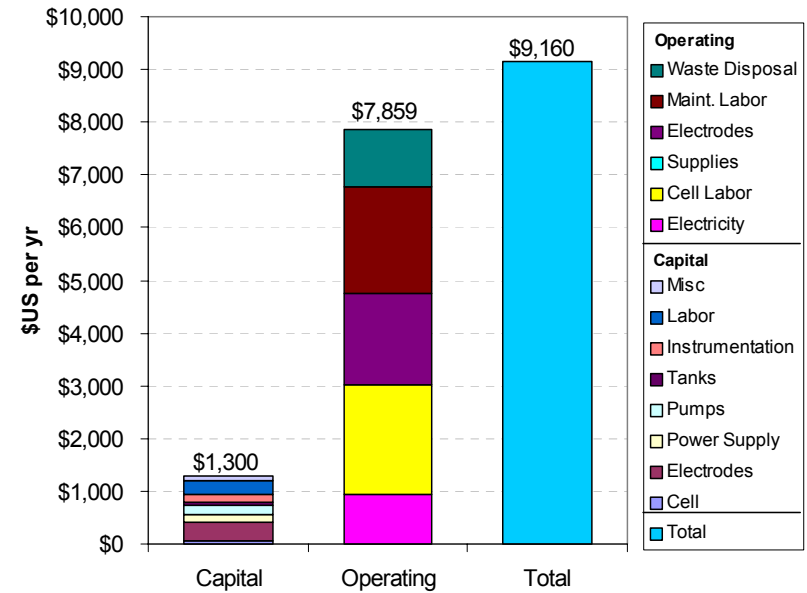


Cd-Te separation 99.99%



Cost of Recovery

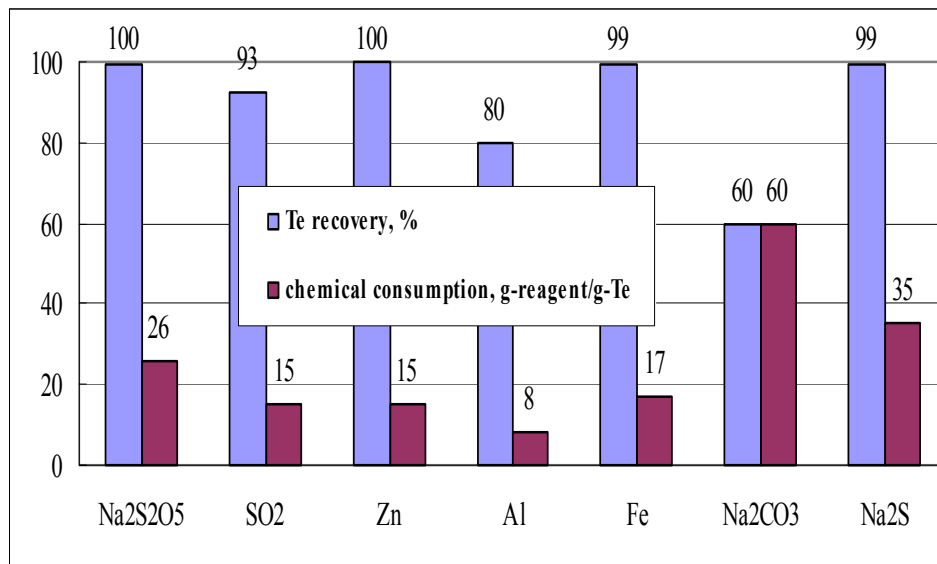
Electrowinning Cost Estimates - 10 MW/yr Scrap (5.4 tonne/day)



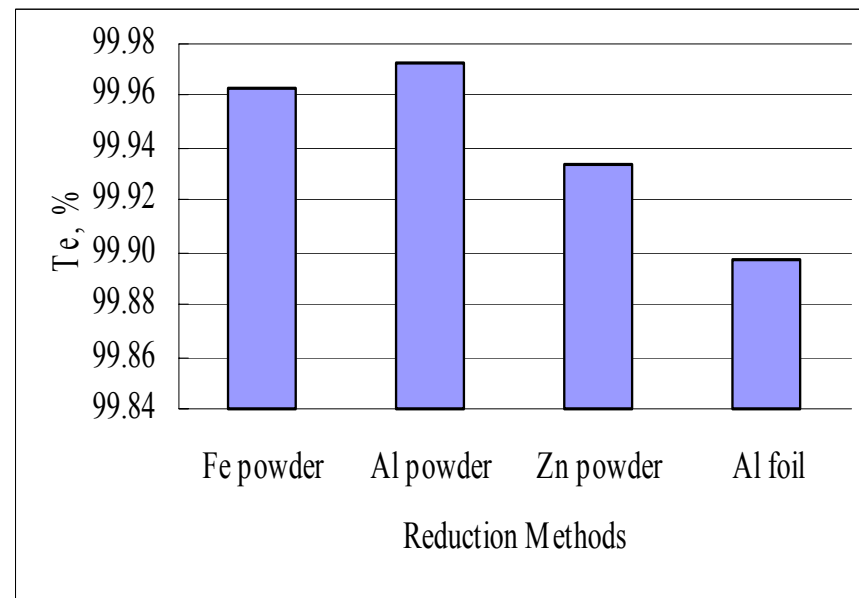
Recovery of Tellurium



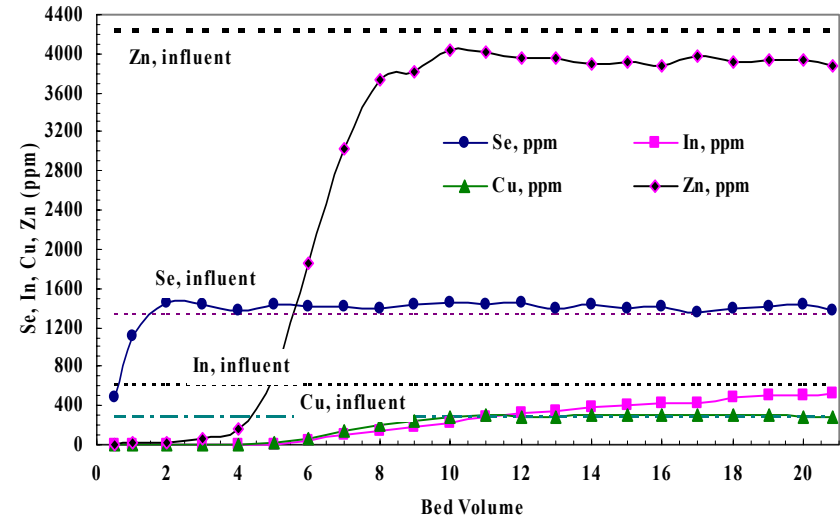
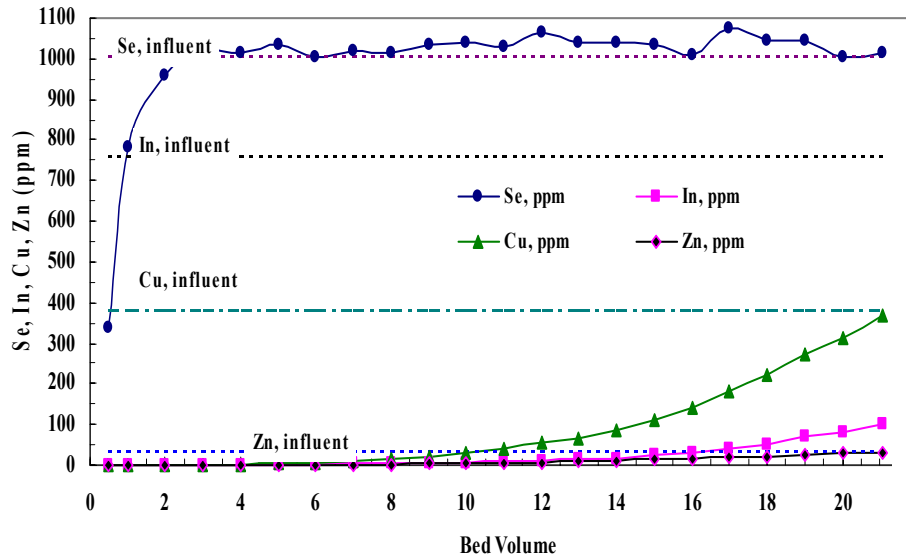
Recovery Methods/ Efficiencies



Purity of Recovered Tellurium



Separation of Se, In, Cd and Zn in CIGS Recycling



Work in progress