Motivation

- Promote international collaboration on EH&S and sustainability
- Facilitate a common understanding of technical and perceived EH&S issues
- Disseminate knowledge to stakeholders and energy-policy decision makers
Justification

- The growth of PV is based on the promise of environmentally friendly energy generation and is sustained by the support of the environmentally conscious public.
- Competitive interests try to undermine PV environmental benefits and prospects.
- We need to be proactive, ahead of environmental regulations.
- International collaboration is needed as “we are all partners in safety.”
Task 12 Objectives

- Quantify the EH&S profiles of PV in comparison to other energy technologies
- Define and address EH&S and sustainability issues that are important for market growth
### Task 12 Technical Experts/Contributors

*(committed during kick-off meeting, March 16/07, Brussels)*

<table>
<thead>
<tr>
<th>Name</th>
<th>First Name</th>
<th>Country</th>
<th>Company/ Organization</th>
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<tbody>
<tr>
<td>Alsema</td>
<td>Erik</td>
<td>The Netherlands</td>
<td>Utrecht University</td>
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<tr>
<td>Despotou</td>
<td>Eleni</td>
<td>Belgium</td>
<td>EPIA</td>
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<tr>
<td>Fthenakis</td>
<td>Vasilis</td>
<td>USA</td>
<td>Brookhaven National Laboratory</td>
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<tr>
<td>Held</td>
<td>Michael</td>
<td>Germany</td>
<td>LBR Stuttgart University</td>
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<tr>
<td>Jungbluth</td>
<td>Niels</td>
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<td>Austria</td>
<td>Umweltbundesamt GmbH</td>
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<td>Shibasaki</td>
<td>Maiya</td>
<td>Germany</td>
<td>LBP Stuttgart University</td>
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<td>Salomon</td>
<td>Oliver</td>
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<td>Glockner</td>
<td>Ronny</td>
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<td>ELKEM Solar</td>
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<td>Wambach</td>
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<tr>
<td>de Wild-Scholten</td>
<td>Mariska</td>
<td>The Netherlands</td>
<td>ECN</td>
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Task 12 Organisation

- Sub-task 1: Recycling of manufacturing waste and spent modules
- Sub task 2: Life cycle assessment
- Sub-task 3: EH&S in Manufacturing Facilities
- Sub-task 4: Information Dissemination
Activities /Expertise in Europe (partial list)

1. Utrecht/ECN: Energy analyses, risk assessments and LCA’s for PV technology, since 1990;

2. Crystal Clear project – Sustainability and recycling (2004-2008);
   • crystalline silicon technology – existing and future
   • up-to-date LCI data collected, published and analysed

3. RESOLVED project – recycling of thin film modules: LCA study
4. PV CYCLE

■ Aims in:

• Supporting recycling research projects,
• Defining a voluntary take back and recovery system for PV modules,
• Supporting education and information programs for owners of PV modules,
• Promoting industry-leading sustainable product life cycle management.
Planned and Proposed Activities in Europe

1. Further work within CrystalClear (c-Si):
   • Evaluation of new processes
   • Update of LCI industrial production (-> status 2008)
   • Use & abatement of fluorinated gases

2. Proposed FP6/FP7 projects
   • Concentrators
   • Dye sensitized cells
   • CdTe
   • All major cell technologies - Updates
Activities /Expertise in the United States

- Life Cycle Analysis
  - Greenhouse Gas Emissions
  - Energy Payback Times (EPBT)
  - Toxic Emissions
- Recycling (Collection Infrastructure, Recovery of Cd, Te, Se, In)
- Silane Safety
- Risk Analysis
- Comparisons of PV with other energy technologies
- Solar energy potential to satisfy all the US energy needs
## SubTask 1 - Recycling

<table>
<thead>
<tr>
<th>Task 12 PV EH&amp;S</th>
<th>Leader</th>
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<tbody>
<tr>
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<td>Country</td>
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<tr>
<td>Activity 1a</td>
<td>DEU</td>
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<td>Activity 1b</td>
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<td>Activity 1c</td>
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<table>
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<th>Activity 1c</th>
<th>Collection Infrastructure</th>
<th>Leader</th>
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</table>
Module Recycling - Deutsche Solar AG

- End of life module
- Recovered cells
- Reprocessed cells
- New module
- Reprocessing
- Recovered wafers
- Module assembling
- Second lifetime
- Thermal treatment
Recycling Activities of SolarMaterial

Recycling of:

- by-products like sides of ingots
- defective semi-finished products like ingots, wafer, cells
- end-of-life modules and modules with transport damage or other defects
Recycling of thin-film solar cells
first tests

Recycling Steps

- Dismantling
- Crushing & Grinding
- Thermal Treatment
- Hot wire cutting
- Ablation, Sanblasting
- Water jet cutting
- Chemical treatment
- Glass melting
Recycling of Cd and Te from CdTe (Se and In from CIGS) PV Modules

1. PV Module Fragments
2. Leach Device
3. Glass Slurry
4. Filtration Facility
5. Clean Glass
6. Recycling of Spent Electrolyte
7. Removal of Cu from Liquid Using Resin A
8. Column I Cu
9. Column II Cu
10. Elution of Column A
11. Elution Solution (Cu)
12. Cu Recovery
13. Removal of Cd and Fe from Liquid Using Resin B
14. Column I Cd, Fe
15. Column II Cd, Fe
16. Elution of Column B
17. Spent H₂SO₄ Solution
18. H₂SO₄, H₂O₂
19. CdSO₄
20. Cd Metal
21. Cd Electrowinning Cell
22. Tellurium
23. Selective Precipitation
24. Effluent Solution (Te)
25. EPIA
26. Brookhaven National Laboratory
Separation of Cd from Te in CdTe Recycling

CD separation 99.99%

Cd effluent concentration <0.3 ppm

RESULT: Cd, Te extraction & separation completed at a projected cost of 1 ¢/Wp
Separation of Se, In, Cd and Zn in CIGS Recycling

Research in progress
First Solar Module and Manufacturing Scrap Recycling

Recycling Steps

• Module/scrap size reduction
• Film removal
• Solid-Liquid separations
• Glass-EVA separation
• Glass rinsing
• Precipitation
• Dewatering
First Solar Process Results

Module (and manufacturing scrap)

Clean Glass

Metals rich filter cake
## Subtask 2 – Life Cycle Cycle Analysis

<table>
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<th>Task 12 PV EH&amp;S</th>
<th>Leader Country</th>
<th>Leader Name</th>
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<tbody>
<tr>
<td><strong>Activity 2a</strong> Guidelines for common approach</td>
<td>All</td>
<td>Erik Alsema / Niels Jungbluth / Vasilis Fthenakis</td>
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<td><strong>Activity 2b</strong> Mono and multi-c-Si US</td>
<td>NL</td>
<td>Erik Alsema / Mariska deWild</td>
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<td><strong>Activity 2c</strong> Ribbon c-Si</td>
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<td>Mariska deWild / Erik Alsema</td>
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<td><strong>Activity 2d</strong> a-Si</td>
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<td><strong>Activity 2e</strong> CIGS</td>
<td>DEU/IT</td>
<td>Maiya Shibasaki / Marco Raugei</td>
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<td><strong>Activity 2f</strong> CdTe</td>
<td>US/IT</td>
<td>Vasilis Fthenakis / Marco Raugei</td>
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<td><strong>Activity 2g</strong> Concentrator PV</td>
<td>SPAIN/US/NL</td>
<td>TBD / Vasilis Fthenakis / Mariska deWild</td>
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<td><strong>Activity 2h</strong> Production of Si feedstock</td>
<td>NORWAY</td>
<td>Ronny Glockner</td>
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<tr>
<td><strong>Activity 2i</strong> Incorporate data in Ecoinvent</td>
<td>SWISS</td>
<td>Niels Jungbluth</td>
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</table>
Competitive interests try to undermine PV environmental benefits
-GHG Emissions -ExternE & Australian Coal Association Research Programs-

Comparison of Energy Technologies: Major Studies

<table>
<thead>
<tr>
<th>Technology</th>
<th>ExternE, Germany 2003</th>
<th>ACARP, Australia 2001</th>
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<tbody>
<tr>
<td>Coal</td>
<td>900</td>
<td>900</td>
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<tr>
<td>Gas CC</td>
<td>400</td>
<td>440</td>
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<tr>
<td>PV, mc-Si</td>
<td>180</td>
<td>100</td>
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<tr>
<td>Nuclear</td>
<td>20</td>
<td>40</td>
</tr>
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</table>
Life Cycle GHG Emissions: BNL/Utrecht/ECN Updates

- **Coal (Kim & Dale 2005)**
- **Natural Gas (Kim & Dale 2005)**
- **Petroleum (Kim & Dale 2005)**
- **Nuclear (Baseline - Fthenakis and Kim, 2007)**
- **PV, CdTe (Fthenakis and Kim, 2006)**
- **PV, mc-Si, (Fthenakis and Alsema, 2006)**

GHG (g CO2-eq./kWh):

- Materials
- Operation
- Transportation
- Fuel Production

GHG emissions for each energy source are as follows:

- Coal: 24 g CO2-eq./kWh
- Natural Gas: 600 g CO2-eq./kWh
- Petroleum: 800 g CO2-eq./kWh
- Nuclear: 24 g CO2-eq./kWh
- PV, CdTe: 37 g CO2-eq./kWh
Energy Payback Times (EPBT): Studies by Others

Sustainability –
what are the major challenges and tasks for national and international energy economics?

Prof. Dr.-Ing. Alfred Voß

Institute of Energy Economics and the Rational Use of Energy (IER)
University of Stuttgart
www.ier.uni-stuttgart.de

EnerKey Experience Exchange Workshop
Stuttgart, 13 July 2006
## Energy Payback Times (EPBT): Studies by Others

### Sustainability –

Sustainability – what are the energy payback times for renewable energy at national and international levels?

### Specific Cumulated Energy Demand (CED) and Energy Pay-Back Time (EPBT)

<table>
<thead>
<tr>
<th>Source</th>
<th>Cumulative Energy Demand (CED) (without fuel) ([\text{kWh}<em>{\text{prim}} / \text{kWh}</em>{\text{el}}])</th>
<th>Energy Pay-Back Time (EPBT) [months]</th>
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<tbody>
<tr>
<td>Hard Coal</td>
<td>0.27</td>
<td>3.1</td>
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<tr>
<td>Lignite</td>
<td>0.16</td>
<td>3.2</td>
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<td>Gas CC</td>
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<td>0.8</td>
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<td>Nuclear (PWR)</td>
<td>0.07</td>
<td>2.8</td>
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<tr>
<td>Wood CHP</td>
<td>0.08</td>
<td>13.2</td>
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<td><strong>PV-Modul poly 5 kW</strong></td>
<td><strong>0.61</strong></td>
<td><strong>66.3</strong></td>
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<td>WEA 1500 kW (5,5)</td>
<td>0.06</td>
<td>4.9</td>
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<tr>
<td>WEA 1500 kW (4,5)</td>
<td>0.08</td>
<td>7.2</td>
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<tr>
<td>Hydro 3,1 MW</td>
<td>0.04</td>
<td>11.0</td>
</tr>
</tbody>
</table>
Updated Energy Payback Times

- Fthenakis & Alsema, *Progress in Photovoltaics, 14, 275, 2006*
PV Risks: Studies by Others

“Solar energy systems have greater material requirements ..., so public risks from emissions will be greater” (Inhaber, Science, 1979)

“Commercial nuclear power is 10-15 times less risky than PV” (Bezdek, Energy, 1993)

Paul Scherrer Institute (PSI), Hirschberg et al., 2004
PV Risks – BNL Update
Maximum Consequences per Accident: BNL Update


The diagram shows the fatalities associated with different types of accidents, categorized as follows:

- **Coal**: 434 fatalities
- **Oil**: 3000 fatalities
- **NG**: 100 fatalities
- **LPG**: 600 fatalities
- **Nuclear (Chernobyl)**: 9000-33000 fatalities
- **Nuclear (except Chernobyl)**: 125 fatalities
- **PV, PSI**: 100 fatalities
- **PV, BNL**: 2 fatalities
Subtask 3- Facility Safety

Analysis of a silane explosion in a photovoltaic fabrication plant,

*AIChE Process Safety Progress*, 2006

Guidelines for semi-bulk silane safety,
21nd EUPVSEC, Dresden, GR, 2006
Task 12 PV –EH&S Forthcoming Workshops

- Workshop on recycling infrastructure in collaboration with PV Cycle
- Expert Workshop on Life Cycle Assessment of PV technology

Additional participations are welcome!

“We are all partners in safety”

Email: VMF@BNL.GOV
Working together means winning together!