DELIVERABLE 1
REPORT

Confidential

CONTRACT N° : ENK5-CT-2002-00639

ACRONYM: SENSE

TITLE : Sustainability Evaluation of Solar Energy Systems

PROJECT CO-ORDINATOR : University of Stuttgart

PARTNERS :

IKP University of Stuttgart

Wuerth Solar GmbH & Co.KG.

Free Energy Europe SA

Umicore SA

Zentrum fuer Sonnenenergie- und Wasserstoff-Forschung

Fraunhofer-Gesellschaft zur Foerderung des Angewandten Forschung e.V.

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1 Deliverable 1

According to the contract ENK5-CT-2002-00639, Annex 1, this report is the deliverable number 1 to be submitted after project month 8. It contains the results of the work package 1 “Analysis of requirements” with its task 1.1 to 1.3.

1.1 Investigation of applicability of preliminary studies on PV LCA and recycling (task 1.1)

Task leader: ICT

The goal of task 1.1 was described by “Investigation on applicability of preliminary studies on PV LCA and recycling”.

Each partner has carried out research for his own field of activity and collected information on this theme. It is the aim of the task to bring these information together and to create an “information pool”, so that every partner has access to the knowledge of the others.

For this reason ICT created a form and sent it out to all partners. It was recommended to fill in all the literature (including patents and reports from preliminary studies) available at the partners and send the list back to ICT.

Literature					
No	author	title	source	public or private?	permission to use for SENSE
1	*W. Knaupp, F. Staiß*	*Photovoltaik: ein Leitfaden für Anwender*	*Fachinformationszentrum Karlsruhe, 4. Auflage. Köln: 2000 ISBN 3-8249-0519-1*	*public*	*yes*
2	*B.C.W. van Engelenburg, E.A. Alsema and R.E.I. Schropp*	*Recycling of a-Si Solar Cells*	*Presented at the 13th European Photovoltaic Solar Energy Conferenc, Nice, France, 23-27 October 1995*	*public*	*yes*

Figure 1: Example for the form to fill in the literature data

The complete literature list can be found in Annex 1 of this document.

The ICT collected the files and created one file with the following information: Author, title and source of the articles / reports / patents, the permission to use, a remark which partner has the easiest access to the article. The completed literature list was sent out to all partners.

The documents can be classified into three groups concerning the topics they deal with:

1. Life cycle analysis
2. Recycling
3. Others

The issues the articles deal with are the following:

1. The documents collected in the group “life cycle analysis” comprise the life cycle analysis of the three considered PV Systems (CIS, CdTe and a-Si) and of different types of PV modules (i. e. solar home systems, BIPV, grid, grid connected and stand-alone PV power systems, ground-mounted and building integrated PV system). The themes considered are life cycle analysis, ecological assessment and environmental life cycle assessment of the PV systems mentioned above.
2. “Recycling” documents deal with different mechanical, thermal, chemical recycling methods for the three PV systems.
3. The documents in the third group deal with different issues concerning the environmental risks of the processing, using and recycling of PV systems, the energy requirements for manufacturing the materials needed for PV systems, the energy payback time of the different PV systems, the manufacturing processes, and the future of PV systems.

1.2 Definition of relevant data for LCA/LCE (task 1.2)

Task leader: IKP

The goal of this task was to learn which data will be essential for the LCA that will be conducted in work package 2 and to prepare and pre-structure the to be developed LCA modules. To reach this goal, literature data and – where necessary – estimations on use of energy and materials as well as emissions in the production process were introduced in a model in the LCA/LCE software GaBi4. The results obtained that way are not more than a very rough estimation on the production of the three thin-film solar cell types but give a first hint which data will be relevant to collect or to enquire and where a data collection with reduced effort will be justifiable.

1.2.1 Data requirements and –sources

A considerable part of the required data on materials like glass, aluminium, zinc, cadmium, EVA, desalinated water etc. as well as energy supply and auxiliaries is covered by the data sets contained in IKP's database. Anyway, in WP2 the applicability of the data will be regarded and assessed. Estimations for the materials tellurium, selenium, indium and molybdenum are necessary as no datasets are available in the present databases. "Worst-case" estimations for these materials have been made for this task to evaluate if these data may be relevant or not. Process data have been taken from literature (exception: CdTe were industry data are already available). These data will be collected in WP2 with the industry partners in detail.

The identified relevant – and therefore necessary - material data will be enquired in WP2 in cooperation with the partners and/or literature research.

The environmental impact categories that will be used in the project for the presentation of results will be finally defined in task 2.2, for this first assessment a standard set of LCA indicators have been used which are:

- Energy
- GWP (greenhouse warming potential)
- AP (acidification potential, "acid rain")
- POCP (photochemical oxidant creation potential, "summer smog")
- EP (eutrification potential)
- ODP (ozone depletion potential)
- Toxicity for humans and ecosystems (water, air, ground, HTP, AETP, TETP)

1.2.2 Predefined LCA models in software GaBi4

For the models which have been set up in this task as a preparatory work, data as described above has been used. When it became clear during negotiation phase of the project that ANTEC may become insolvent, the LCA relevant data has been collected at ANTEC in Arnstadt, to be sure to have the necessary data for the project on CdTe. So the CdTe data are already industry data.

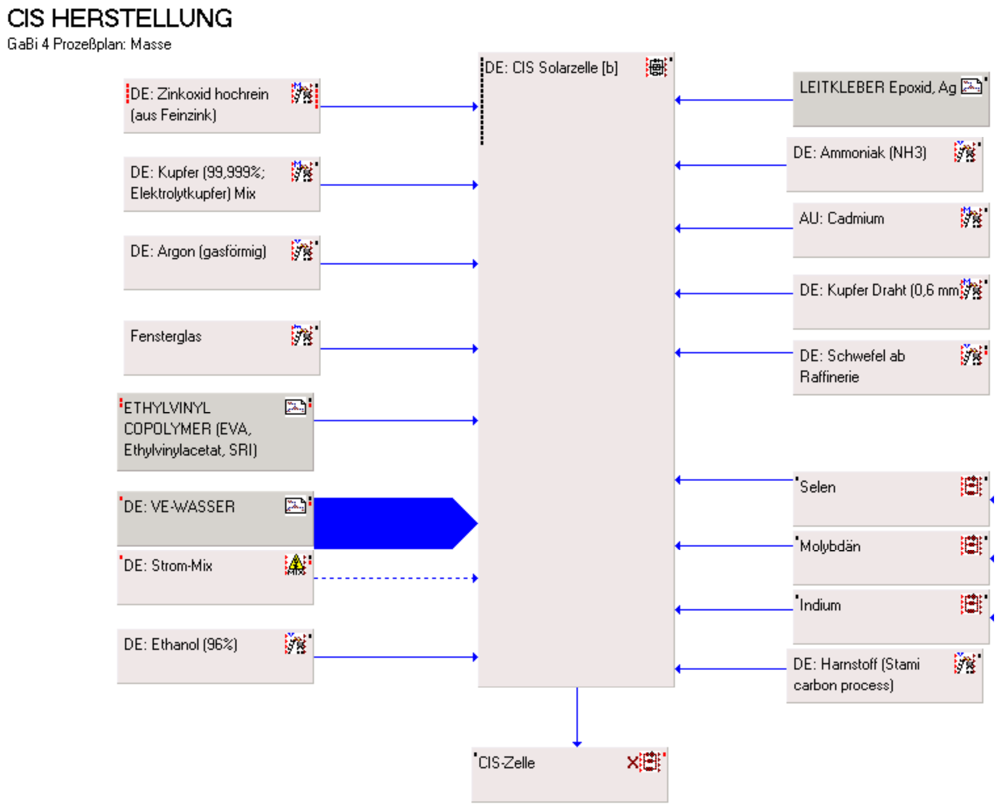

*Figure 2: Screenshot (highest hierarchic level) of **literature based model** of the CIS module production*

Figure 2 shows a screenshot of the highest hierarchical level of the estimated CIS model in the LCA/LCE software GaBi4. The thickness of the arrows represents the mass flow. Each box represents a LCA data set with respective environmental impacts. E.g. the German power mix on the left hand side ("DE: Strom-Mix") contains all environmental information for the electricity needed in the process, including all pre-chains like mining of coal (and of course all other energy carriers) in various countries, transports, power plant emissions etc. This applies respectively to all materials, auxiliaries and energy supplies used in the process.

The production processes for Si-modules (Figure 3, for this first estimation based on literature for crystalline Si) and CdTe (Figure 4, based on industry data) have been modelled respectively.

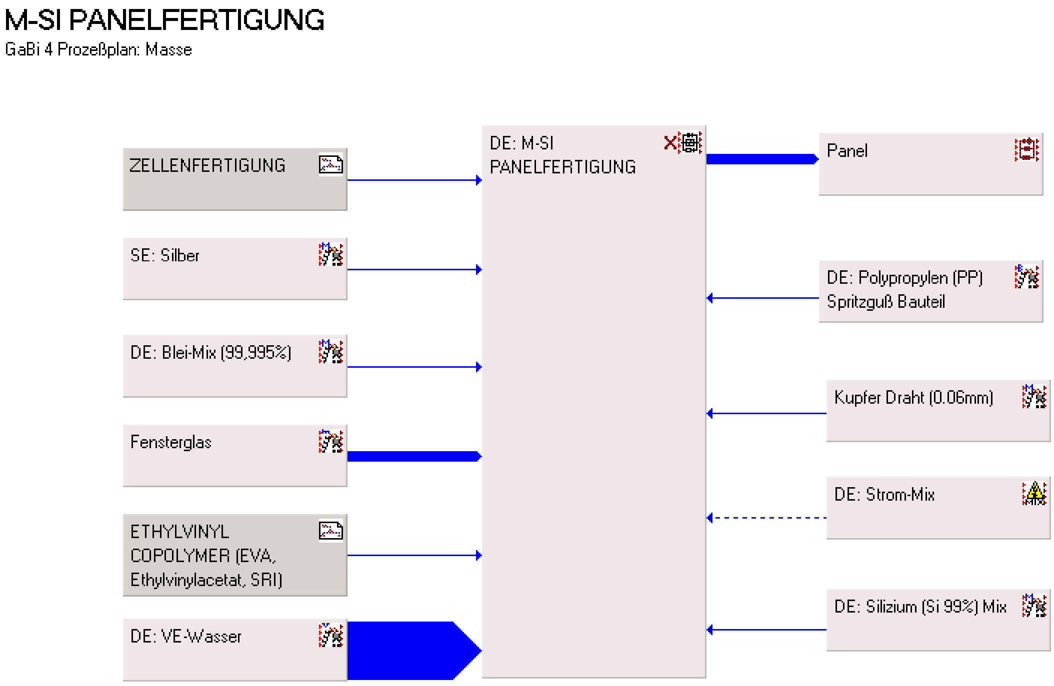

*Figure 3: Screenshot (highest hierarchic level) of **literature based model** of the Si module production*

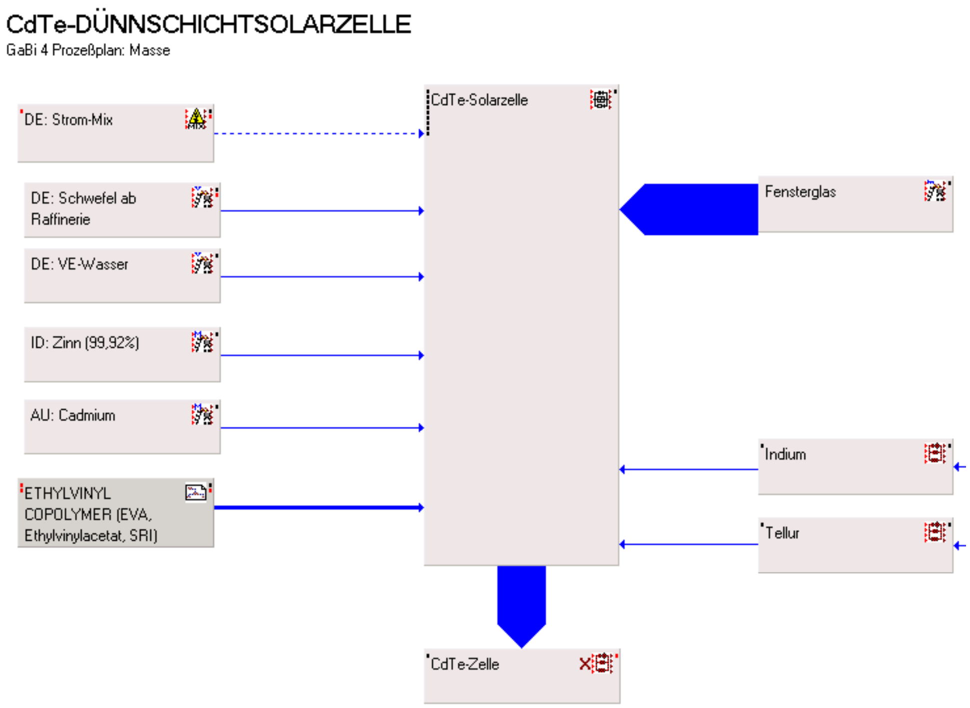

*Figure 4: Screenshot (highest hierarchic level) of **industry data based model** of the CdTe module production*

1.2.3 Results

The analysis of the models leads to the results listed below. As the used data are – as mentioned above – very rough and partly estimated data, it has to be clearly stated that these are preliminary results which may (and will!) change during the project, but give a first hint were “hot spots” may be found.

The results have been normalized and evaluated[1] to be able to assess the relevance of the environmental impacts. According to these results, most relevant environmental issues in the module productions (including pre-chains, excluding use and end of life) are in this order (see chapter 1.2.1 for explanations and abbreviations) : **GWP (and energy consumption), POCP, AP, EP, HTP**.

Main contributor to **GWP and energy consumption** (in this case GWP and energy consumption are related closely, as an important driver for GWP are CO_2 emissions from energy supply) is the electricity supply for the solar cell production (approx. 65 to 85 %). The glass production and the material supply for the photoactive layers contribute with approx. 5 – 20 % each, depending on the solar cell type. As a consequence, the energy consumption during production must be considered as a key topic during data collection in WP2.

POCP drivers are found in the use of organic solvents in production processes and from the EVA production (during oil exploitation considerable amount of hydrocarbon emissions are occurring, and oil is an important raw material for EVA production). Therefore, emission of organic solvents should be another focus in the data collection.

AP, EP and the toxicity categories are dominated mainly by the energy supply (like GWP). Another driver for AP and toxicity are the metals Te, Se, In and Mo, estimated in a worst case model (see below) with a share of up to 50%.

The worst case estimated models for some metals (Te, Se, In, Mo, see chapter 1.2.1) did not contribute significantly for GWP, energy consumption, POCP and EP. In contrast to that, they contribute considerably to AP and HTP. So the respective material production should be addressed in WP2 with a high attention to AP and HTP impacts.

[1] Normalisation and evaluation are instruments in LCA to rank the environmental relevance of different environmental impacts among each other

1.3 Definition of boundary condition for calculation of energy payback time (task 1.3)

Task leader: ZSW

Calculation of energy pay back time of PV modules requires exact definition of the products which are to be considered. According to the product portfolios of the three participating module manufacturers a scope of products was defined.

For calculation of required transport energy and primary energy the places of production as well as deployment and recycling of the modules had to be defined.

Furthermore energy payback time is naturally depending on parameters like the solar irradiation and the position and orientation of the modules, therefore definitions of the deployment scenarios are necessary.

1.3.1 The scope of products

Generally 3 types of PV products have to be considered

A) "Power modules"

- standard module sizes, e.g. 120 cm x 60 cm (the largest possible sizes)
- little variation in design
- large production volume
- with or without frames
- optimised long-term stability (>25 years useful life)
- deployment in large PV plants (on buildings or on the ground), optimised power output (orientation, location)
- use with large inverters
- grid-connected (no energy storage)
- market in countries with PV funding

B) "BIPV Modules"

- variable module sizes (mainly large size)
- variable module designs (variation in glass thickness, module format, type of encapsulation),
- with or without frames
- small or medium sized production lots
- mounted to the facade or the roof of buildings (new or retrofit)

- replacement of conventional building materials (facade plates and roofing materials (concrete, natural stone, brick, aluminium, steel, plaster, wood, tiles, shingles, slate, .)...
- not optimised power output (vertical, misorientation given by the building)
- grid-connection
- market: highly developed countries

C) "Mobile Modules" (Consumer products)

- Small and medium formats
- Small to large production lots
- Large variation in product design
- No grid connection
- Energy storage (batteries, charge controllers)
- Integration in systems (PV-home systems, small electronic devices)
- World-wide market
- Low-cost and high-end versions possible

1.3.2 Places of fabrication of PV modules to be considered

- Germany
- France
- Benelux

Energy-mix for calculation of environmental impacts:

Two different option are relevant for the choice of the energy-mix:

- For the LCA model of the production site of the partners in SENSE with the goal of an environmental optimisation respectively weak point analysis, the country-specific energy-mixes should be used according to the country the production plant is located. For the implementation of use phase effects and recycling, the relevance of the different energy-mixes can be addressed by scenario analysis.
- For an overall evaluation of solar technologies among each other, an consistent power mix will be used. We propose the UCPTE mix as a basis. The influence of using various national mixes on the results can be analysed with scenario analysis.

1.3.3 Places of deployment of the PV modules

The places of deployment relates to impact to energy harvesting, transport, take-back etc. and have therefore to be defined clearly. The following regions have been defined to be used in SENSE:

A) Power modules

a) Central Europe (Germany)
b) Mediterranean areas
c) Solar belt region

B) BIPV modules

a) Central Europe
b) Mediterranean
c) Solar belt region

C) Mobile modules

a) Central Europe
b) Mediterranean areas
c) Solar belt region

1.3.4 Places of recycling activities

The places where the recycling activities will take place may have a certain influence on results, as e.g. the electricity-mix may be very different and therefore the eco-profile and primary energy consumption for the use of electricity will be different.

For the calculations in SENSE, Central Europe is assumed to be the location of recycling.

1.3.5 Scope of the LCA

Details of definitions (to be further detailed during LCA calculations – loop-back to manufacturers) :

A) Power Modules (CIS, CdTe)

- Glass-glass modules, glass-Tedlar modules, aluminium frames
- Installation on the ground (concrete-steel mounting) or on top of buildings (with fastening materials)
- Interconnection and cabling to the inverters
- Inverters

B) BIPV Modules (CIS, CdTe)

- Glass-glass modules
- No consideration of fastening materials
- Complete cabling
- Inverters

C) Mobile Modules (a-Si, CIS)

- Glass-glass or glass tedlar modules with (without) plastic frame
- Cabling to charge controller and battery
- Battery

1.3.6 The functional unit

To make different systems or scenarios comparable, results must be related to always the same reference value. This is called the “functional unit”.

The functional unit of the PV systems is the amount of energy gained by the modules within their whole life cycle. **Dimension: kWh/m*2**

The gained energy depends on:

- Peak power or efficiency of the module (to be separately considered for the three technologies CdTe, a-Si and CIS and the three product types)
- Site of installation (latitude, climate), possible scenarios to consider in SENSE:
  a) Central Europe
  b) Mediterranean
  c) Solar belt
- Installation, possible scenarios to consider in SENSE:
  a) facade,
  b) sloped roof
  c) flat roof
  d) ground
- Inclination, possible scenarios to consider in SENSE:
  a) optimum orientation (depending on latitude)
  b) deviation from optimum
  c) with tracking

- Alignment, possible scenarios to consider in SENSE:
  a) optimum alignment (south)
  b) deviation of 30° to the West or East
- Expected lifetime

A multi-dimensional array of EPBT will result from the LCA.

The main dimensions are: Module type (power/PVIB/Mobile), technology (aSi, CIS, CdTe), site of deployment (Central Europe, Mediterranean, solar belt), type of installation (roof, facade, ground).

The influence of balance of systems (BOS) components will be considered separately.

1.3.7 Summary of the scope of products (by technology) to be considered

The above mentioned general scope of products is restricted by the product portfolios of the module manufacturing project partners Würth Solar, Antec Solar and Free Energy Europe. The restriction gives more reliable results of the LCA, because only consolidated data from these manufacturers are necessary.

	CIS	CdTe	a-Si
Power-Modules	**x**	**x**	
BIPV Modules	**x**	**x**	
Mobile Modules	**x**		**x**

Table 1: Scope of Products

Appendix 1

Literature

No	author	title	source	public or private?	permission to use for SENSE	partner	
1	Ackerman Peter	Photovoltaik auf der Basis einer CuInS2- Zelle	Brandenburgisches Umweltforschungszentrum e. V., Neuruppin, 1998			ZSW	
2	Aguado-Monsonet Miquel A.	The enviromental impact of photovoltaic technology (task 6-INTESUDMED Project)	Institute for Prospective Tecnological Studies (IPTS) Report January 1998; www.jrc.es/cfapp/reports/details.cfm?ID=59	Public	yes	Ambit	
3	Alsema E. A.	Environmental Aspects of Solar Cell Modules	Dept. Of Science, Technology and Society, Utrecht University, August 1996, Univ. Of Utrecht report nr. 96074 ISBN 90-73958-17-2 August 1996 www.chem.uu.nl/nws/www/publica/96074.htm			ZSW, Ambit	
4	Alsema E. A.	Energy requirements of thin-film solar cell modules - a review	Renewable and Sustainable Energy Reviews 2 (1998) 387-415, (No. 98079); www.chem.uu.nl/nws/www/publica/98079.htm			Free Energy, Ambit	
5	Alsema E.A.	Environmental life cycle assessment of solar home systems	Utrecht University, Depr. of Science, Technology and Society, Dec. 2000, Report no. NWS-E-2000-15			Free Energy	LCA
6	Alsema E.A.	Energy Pay-back time and CO2 Emissions of PV Systems	Prog. Photovolt. Res. Appl. 8, 17-25 (2000) and Department of Science, Technology and Society Utrecht University, Padualaan 14, NL-3584 CH Utrecht, The Netherlands			Free Energy, IKP	
7	Alsema E.A. and B.C.W. van Engelenburg	Environmental Risks of CdTe and CIS Solar Cell Modules	11th Photovoltaic Solar Energy Conference, 12-16 October 1992, Montreux, Switzerland	public	yes	ICT	
8	Alsema E.A. Nieuwlaar E.	Levenscyclusanalyse van fotovoltaïsche systemen met dakopstelling Een studie gericht op de bijdrage van Balance-of-System componenten in het milieuprofiel van PV-systemen op daken Universiteit Utrecht, Copernicus Instituut Sectie Natuurwetenschap en Samenleving	Rapport NWS-E-2002-04;ISBN 90-393-3186-3; Jul02		yes	IKP	
9	Alsema E.A. , E. Nieuwlaar	Energy viability of photovoltaic systems	Energy Policy 28 (2000) 999 - 1010 und Department of Science, Technology and Society, Utrecht University, Padualaan 14, NL-3584 CH Utrecht, The Netherlands Received 24 May 2000			Free Energy	
10	Alsema et al.	health, safety and environmental issues in thin film manufacturing (CIS, CdTe, a-Si)	Presented at the 14th European Photovoltaic Solar Energy Conference, Barcelona, 1997, 4 pages (No. 97052); www.chem.uu.nl/nws/www/publica/97052.htm	public	yes	Umicore, Ambit	
11	Alsema, E.A,	Energy Requirements and CO2 Mitigation Potential of PV systems	BNL/NREL Workshop "PV and the Environment 1998", Keystone, CO, 1998 (No. 98054); www.chem.uu.nl/nws/www/publica/98054.htm			Ambit	
12	Alsema, E.A., P. Frankl, and K. Kato,	Energy Pay-Back Time of Photovoltaic Energy Systems: Present Status and Future Prospects,	2nd World Conference on Photovoltaic Solar Energy Conversion, Vienna, 6-10 July 1998 (No. 98053)., p. 2125-2130, www.chem.uu.nl/nws/www/publica/98053.htm			Ambit	

13	Antec Solar GmbH	recycling-verfahren fur CdTe/CdS dunnschicht solarzellenmodule	EP 1187224 A1	public	yes	Umicore	rec
14	Baumann A. R.,Hynes K. M. , . E. ,Hill R. ,	An assessment of environmental impacts of thin film cadmium telluride modules based on life cycle analysis,	1st World Conf. on PV Energy Conversion, Hawaii, 1994.		yes	IKP	
15	Bijlsma J. , Blok K., Turkenburg W. C,	Kernenergie en het Kooldioxideprobleem	Dept. of Science, Technology and Society, Utrecht University, 1989.		yes	IKP	
16	Bohland et al.	Economic Recycling of CdTe Photovoltaic Modules	26th PVSC,Sept. 30- Oct 3 1997,Anaheim, CA (USA)	public	yes	Gaiker, ICT	rec
17	Bohland et al.	Recycling silicon photovoltaic modules	United States Patent N° 6063995 (16/05/2000)	public	yes	Gaiker	rec
18	Bohland John,Todd Dapkus, Kristin Kamm and Ken Smigielski	Photovoltaics as hazardous mterials; the recycling solution	2nd world conference and exhibition on photovoltaic solar energy conversion 6- 10 Juli 1998 Vienna, Austria	public	yes	ZSW, Gaiker, ICT	rec
19	Bowerman Biays and Vasilis Fthinakis	EH & S ANALYSIS OF DYE- SENSITIZED PHOTOVOLTAIC SOLAR CELL PRODUCTION	BNL- 52640 Formal Report October 2001			ZSW	
20	Bowerman Biays S. and Vasilis M. Fthinakis	3- V Photovoltaics- An Update of EH & S Issues	BNL- 52640 Formal Report October 2002			ZSW	
21	Ciszek T.F. , T.H.Wang, M.R. Page, P. Menna, R.E. Bauer, E.A. Good, and M.D. Landry	Alterrnative Solar-Grade Silicon Feedstock Approaches	Presented at the NCPV Program Review Meeting Lakewood, Colorado 14-17 October 2001 NREL/CP-520-31007	public	yes	Ambit	
22	Corkish Richard	Can Solar Cells Ever Recapture the Energy Invested in their Manufacture?	Photovoltaics Special Research Centre University of New South Wales, Sydney 2052 Australia		yes	IKP	
23	Craighill AL. Powell JC.	LIFECYCLE ASSESSMENT AND ECONOMIC EVALUATION OF RECYCLING - A CASE STUDY	Resources Conservation & Recycling. 17(2):75-96, 1996 Aug.			ZSW	LCA
24	Deb SK.	THIN-FILM SOLAR CELLS - AN OVERVIEW	Renewable Energy. 8(1-4):375-379, 1996 May-Aug.			ZSW	
25	drinkard metalox inc.	recycling of CIS photovoltaic waste	US patent 5.779.877	public	yes	Umicore	rec
26	Dunkl M.	RECYCLING OF REFRACTORIES FROM THE GLASS MANUFACTURING INDUSTRY	Glastechnische Berichte-Glass Science & Technology. 68(8):266-272, 1995 Aug.			ZSW	rec
27	Eberspacher C. Charles FG. Moskowitz PD.	STRATEGIES FOR ENHANCING THE COMMERCIAL VIABILITY OF CDTE-BASED PHOTOVOLTAICS	Solar Energy Materials & Solar Cells. 41-2:637-653, 1996 Jun.			ZSW	
28	Eberspacher C. Charles FG. Moskowitz PD.	STRATEGIES FOR ENHANCING THE COMMERCIAL VIABILITY OF CDTE-BASED PHOTOVOLTAICS	Solar Energy Materials & Solar Cells. 41-2:637-653, 1996 Jun.			ZSW, ICT	
29	Eberspacher C. , C.F. Gay, P.D. Moskowitz	Strategies for Recycling CdTe Photovoltaic Modules	First WCPEC, Dec. 5-9, 1994, Hawaii	public	yes	ICT	rec
30	eberspracher c. , v.m. fhtenakis, p.d. moskowitz	environmental issues related to commercialization of CuInSe2-based photovoltaics	25th PVSC; May 13-17, 1996, 1417-1420	public	yes	Umicore, ICT	
31	fhtenakis v.m. , c. eberspracher, p.d. moskowitz	recycling strategies to enhance the commercial viability of CIS photovoltaics.	progress in photovoltaics: research and applications, vol. 4, 447-456 (1996)	public	yes	Umicore, ICT	rec
32	Finke A.	Untersuchungen zur Transformation und Mobilität toxischer Stoffe aus Dünnschichtsolarzellen auf der Basis von intermetallisschen Verbindungen (CuIn/GaSe2 und CdTe)	Diss: Fakultät für Landwirtschaft und Gartenbau, TU München, 1997			ICT	
33	Frischknecht R., Hofstetter P., Knoepfel I. (Eidgenössische Hochschule, Zürich); Dones R., Zollinger E. (Paul Scherrer Institut, Villigen/ Würenligen)	Ökoinventare für Energiesysteme	Bundesamt für Energiewirtschaft, 1. Auflage, Marz 1994			ZSW	
34	Fthenakis V. M. and P.	Photovoltaics: environmental, Health and Safety Issues and Perspectives	Progress in Photovoltaics, Millenium Issue, 8, 27-38, 2000			ZSW	

	D. Moskokowitz						
35	fthenakis v.m. , p.d. moskowitz	emerging photovoltaic technologies: environmental and health issues update	photovoltaics program review, 903-914, 1997	public	yes	Umicore, ICT	
36	fthenakis v.m. , p.d. moskowitz	the value and feasibility of proactive recycling	photovoltaics program review, 332-337, 1997	public	yes	Umicore	rec
37	fthenakis v.m. , p.d. moskowitz	thin-film photovoltaic cells: health and environmental issues in their manufacture, use and disposal	progress in photovoltaics: research and applications, vol. 3, 295-306 (1995)	public	yes	Umicore, ICT	
38	Fthenakis VM. Moskowitz PD.	THIN-FILM PHOTOVOLTAIC CELLS - HEALTH AND ENVIRONMENTAL ISSUES IN THEIR MANUFACTURE, USE AND DISPOSAL	Progress in Photovoltaics: Research & Applications. 3(5):295-306, 1995, Sep-Oct.			ZSW	
39	Giese Lutz B. , Karin Weimann, Kristina Loge	Die edle Dame India und der böse Bube Cadmius- Möglichkeiten der nassmechanischen Aufbereitung in der Abfallbehandlung zur Wiederverwertung von PV- Dünnschichtmodulen				ZSW	rec
40	Goetz M. , S. Vaucher, R. Tcharner, A. Shar	Ecological Aspects of Amorphous Silicon Technolgy: New Study and Comparison with Crystalline Solar Cell Fabrication	12th European Photovoltaic Solar Energy Conference 11-15 April 1994 Amsterdam, the Netherlands			ZSW	
41	Goozner et al.	Recycing of CdTe photovoltaic waste	United States Patent Nº 5897685 (27/04/1999)	public	yes	Gaiker	rec
42	goozner r.e. , w.f. drinkard, m.o. long, c.m. byrd	a process to recycle thin film PV materials	proceedings 26th IEEE PV specialists conference, 1997	public	yes	Umicore, ICT	rec
43	Green Martin A.	Crystalline Silicon Photovoltaic Cells	Advanced Materials **2001,** 13, No. 12-13, July 4	public	yes	Ambit	
44	Green Martin A.	Thyrd generation photovoltaics: solar cells for 2020 and beyond	Physica E 14 (2002) 65-70	public	yes	Ambit	
45	Greijer Helena , Lennart Karlsoon, Sten-Eric Lindquist, Andrers Hagfeldt	Enviromental aspects of electricity generation from nanocristalline dye sensitized solar cell system	Renewable energy 23 (2001) 27-39	public	yes	Ambit	
46	Griffiths PW. Eames PC. Lo SNG. Norton B.	ENERGY AND ENVIRONMENTAL LIFE-CYCLE ANALYSIS OF ADVANCED WINDOWS	Renewable Energy. 8(1-4):219-222, 1996 May-Aug.			ZSW	LCA
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48	Hagedorn G. , S. Lichtenberger, H. Kuhn	Kumulierter Energieverbrauch für die Herstellung von Solarzellen und photovoltaischen Kraftwerken	Forschungssttelle für Energiewirtschaft München, Juli 1989 051.18			ZSW	
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50	Harvey LDD.	SOLAR-HYDROGEN ELECTRICITY GENERATION AND GLOBAL CO2 EMISSION REDUCTION	International Journal of Hydrogen Energy. 21(7):583-595, 1996 Jul.			ZSW	
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52	Hynes K. M. , A. E Baumann and R. Hill	Life Cycle Analysis of PV Modules Based on Cadmiu Telluride	12th European Photovoltaic Solar Energy Conference 11-15 April 1994 Amsterdam, the Netherlands	public	yes	ZSW, Ambit	LCA
53	Jester T, Knapp K. , Mihalik G.,	Energy Balances for Photovoltaic Modules: Status and Prospects	28th IEEE Photovoltaics Specialists Conference, September 17–22, 2000, Anchorage, Alaska www.solarpv.com/paybackstudy.pdf		yes	IKP	
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57	Johnson, A.J., H.R. Outhred, M. Watt	An Energy Analysis for Grid-Connected Photovoltaic Systems	Environmental Aspects of PV Power Systems , App B-13, UNSW, Dec 1997		yes	IKP	
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59	Kato K. , A. Murata, K. Yamada, A. Inaba, K. Kurokawa, H. Komiyama	Contribution of photovoltaic energy systems to energy saving, environment and economy - an approach based on life-cycle-analysis	13th european photovoltaic solar energy conferenc, 23-27 October 1995, Nice	public	yes	ICT	LCA
60	Keoleian G.A. , G.McD. Lewis	Modeling the life cycle energy and environmental performance of amorphous silicon BIPV roofing in the US	Renewable Energy 28 (2003) 271-293			Free Energy	LCA
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63	Lecner P. and H.Schade	Photovoltaic Thin-Film Technology Based on Hydrogenated Amorphous Silicon	Progress in Photovoltaics: Res. Appl. 2002; **10**: 85-97	public		Ambit	
64	Lewis Geoffrey M. and Gregory A. Keoleian	Life Cycle Design of Amorphous Silicon Photovoltaic Modules	EPA/600/SR-97/081 October 1997	public summary,full report to be bought at EPA	yes	Ambit	LCA
65	Menezes S.	Investigation of Electrochemical Prozesses for Synthesis and Removal of CuInSe2 Thin Films	Mat. Res. Symp. Proc. Vol 426, 1996, S. 189	public	yes	ICT	rec
66	Mirasgedis S. Diakoulaki D. Assimacopoulos D.	SOLAR ENERGY AND THE ABATEMENT OF ATMOSPHERIC EMISSIONS	Renewable Energy. 7(4):329-338, 1996 Apr.			ZSW	
67	Molenbroek Dr. E.C. , Deege ing. P.	Inventarisatie materiaalverbruik BOScomponenten	Report nr. E21085, Ecofys, Utrecht. (2000),		yes	IKP	
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69	Moskowitz P: D. and V. M. Fthenakis	A checklist of suggested safe practices for the storage, distribution, use and disposal of toxic and hazardous gases in photovoltaic cell production	1991- Elsevier Sequoia, Lausanne			ZSW	
70	Nieuwlaar E., E. Alsema	Environmental Aspects of PV Power Systems	Utrecht University, Depr. of Science, Technology and Society, Dec. 1997, Report no. 97072 and IEA PVPS Task 1 Workshop, Utrecht, The Netherlands, June 1997, UNSW, Dec 1997			ZSW, Free Energy, IKP	
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72	Rey Ingo	Prozeßkettenanalyse zum CdTe- Solarmodul - Unter besonderer Berücksichtiung der Cadmium- Gewinnung-	Fachhochschule Aachen, Februar 1995, Diplomarbeit		yes	ZSW, IKP	
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	Kato		Japan, 1996				
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81	van Engelenburg B. C. W. and E. A. Alsema	Environmental Aspects and Risks of Amorphous Silicon Solar Cells	Revised Edition Jan. 1994 Department of Science, Technology and Society of the University of Utrecht, Report nummber 93008	public	yes	ZSW, Ambit	
82	van Engelenburg B.C.W. and E.A. Alsema	Environmental Risks of Amorphous Silicon Solar Cell Modules	12th European Photovoltaic Solar Energy Conference 11-15 April 1994 Amsterdam, the Netherlands, p. 305-308	public	yes	ICT, Ambit	
83	van Engelenburg B.C.W. , E.A. Alsema and R.E.I. Schropp	Recycling of a-Si Solar Cells	Presented at the 13th European Photovoltaic Solar Energy Conferenc, Nice, France, 23-27 October 1995	public	yes	ICT	rec
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85	Wilson R. Young A.	THE EMBODIED ENERGY PAYBACK PERIOD OF PHOTOVOLTAIC INSTALLATIONS APPLIED TO BUILDINGS IN THE UK	Building & Environment. 31(4):299-305, 1996 Jul.			ZSW	
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89	Alcorn, J., G. Baird	Use of Hybrid Energy Analysis Method for Evaluating the Embodied Energy of Building Materials	Renewable Energy, v8n1-4, 319-322, May 1996		yes		
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99	Boustead, I., G.F. Hancock,	Handbook of Industrial Energy Analysis	John Wiley & Sons, New York, 1979, Noyes Publications, New Jersey, 1990		yes		
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