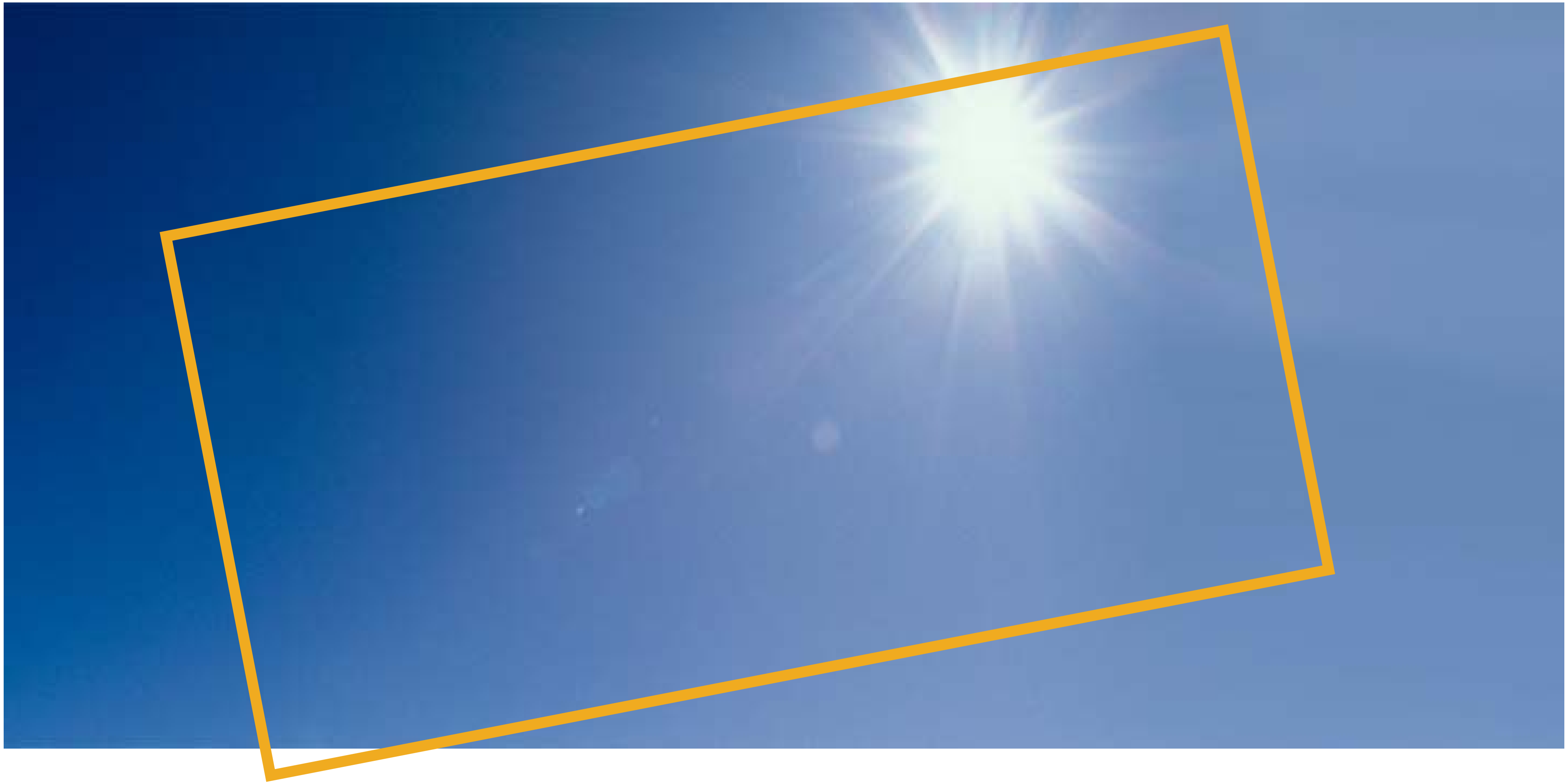


A Voluntary Take Back Scheme and Industrial Recycling of Photovoltaic Modules

K.Wambach, S. Schlenker, A. Müller, B. Konrad
Sunicon AG

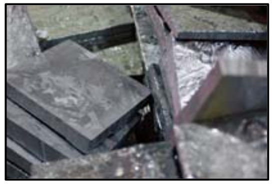
SOLARWORLD
THE SUNPOWERED COMPANY®

www.solarworld.de

Sources of secondary Silicon

mc crystallization

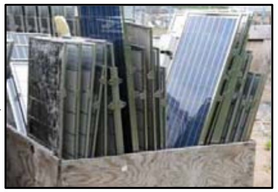
brick sawing



wafering

cell processing

module assembly



cz crystallization

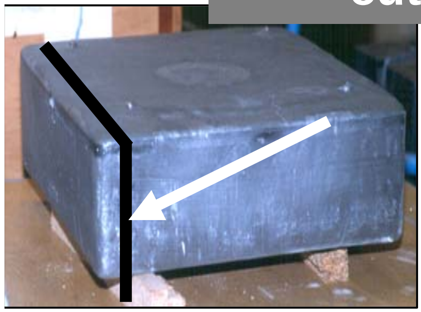
other applications

Semiconductor industry

Si with bulk impurities for remelting

Recycling of ingot parts

cut off sides

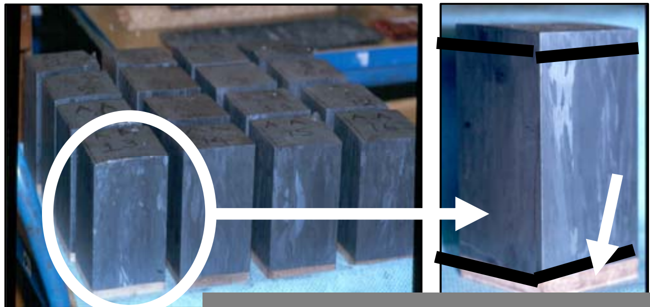


surface cleaning

and etching

as received

after first treatment



cut off bottom and tops

surface cleaning

and etching

multicrystalline ingot-growing: sides

↓

shaping

↓

surface cleaning

↓

etching

↓

crystallization: raw material

Recycling wafer and cell scrap

broken wafer

wafer with emitter and AR-Coating

cell breakage

removal of non-Si-impurities → etching → crushing → etching

Green production policy

Sound environmental strategy

– Resource saving production and technologies

– Recycling of by-products along the value chain if possible

– Continuous adaptation to growing demands

– Careful selection of material for long lifetime, reparable and recyclable products

Added values

- Improvement of reputation of the PV community
- Additional feedstock
- sustainable thinking creates shareholders value
- Cost savings by global standardisation
- Creation of an international environmental data base for PV
- Integration in EMAS /EN14000 certification
- Cost minimisation of waste treatment
- Ensures high quality standards of waste treatment
- Profitable international research cooperations

EU waste policy

Sustainable product design

high ranking of durable, reparable products

recycling of components (keeping the value)

Extended producer responsibility,

Polluter pays

therefore

Manufacturer obligation of taking back their products

Si-wafer

Silicon

Silver and other valuable metals

Glass

Metal

Prerequisites of recycling

- Responsibility
  - Finance (polluter pays principle)
  - Legislation
  - Incentives
- Organisation
  - Management system
  - Logistics
  - Best available technology
  - Communication and education
- Resources and Environment,
  - External auditing
  - LCA
  - Transparency

End Of Life Modules

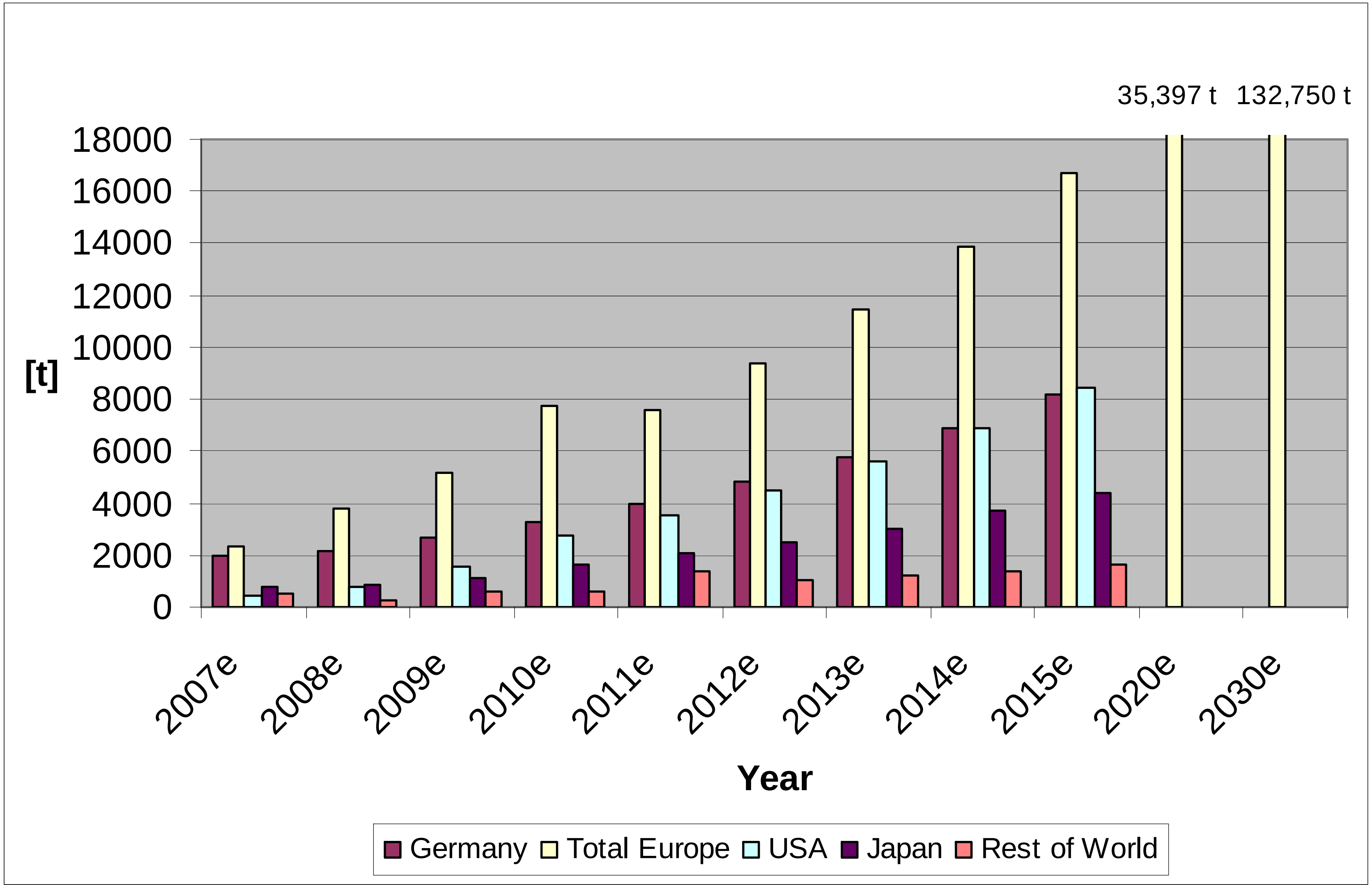
- Sources:
  - Manufacturing waste
  - Transportation
  - System assembly
  - Other defects
  - Spent modules

- Main defects
  - Broken glass
  - Electrical defects
  - Delamination
  - Other

Assumptions

Production losses	0.20%
Transport, and mounting damage, wrong system designs	0.50%
Cumulated losses in first 2 years	0.80%
Total (damages of new modules)	1.50%
Damage of installed systems (blanket estimation)	0.30%

Waste forecast



Objectives

- Promote the protection of the climate and the environment in enhancing increased and sustainable use of PV technology.
- Create a positive environment for the ongoing growth of the PV industry
- Install an overall waste management policy
  - guarantees highest economically feasible collection and recovery rates
  - appropriate treatment of waste PV modules.

Mixed system approach

- Industrial waste
  - Production
  - Transport
  - Installation
  - Replacement
- End-user
  - Free collection of systems > e.g. 2kWp
  - Bring in to installer small quantities
  - Other negotiable

Preconditions: high-value recycling

Avoid any unnecessary damage!

Dismount system carefully

Do not bend or break

Use standard packaging systems for transportation

Inform about materials and hazardous substances

Specify demands for material returned

Thin film modules

SolarWorld

CIS-Module	Producer A	Producer B	CdTe-Module	Producer C	Amorph. Si-Module	Producer D
Recycling Fractions	%		Recycling Fractions	%	Recycling Fractions	%
Glass	75.27	84.6	Glass	83.5	Glass	89.78
Aluminium	15.05	10.15	Aluminium	12.29	Aluminium	0.04
Indium	0.02	0.02	Tellurium	0,13		
Copper (Cable)	1.51	0.85	Copper (Cable)	0.2		
Gallium	0.01	0.01				
Recovery Fraction	%		Recovery Fraction	%	Recovery Fraction	%
Polymers	6.52	5.08	Polymers	3.67	Polymers	9.84
Hazardous	%		Hazardous	%	Hazardous	%
Cadmium	0.0005		Cadmium	0.1336	-	-

Crystalline Si modules

Component Cryst. Si, standard module	Rel. amount after Oekopol (2003)	Rel. amount (2007)
Weight/kWp	103.6 kg/kWp	102.3 kg/kWp
	%	%
Glass	62.7	74.16
Frame (e.g. AlMgSi0.5)	22.0	10.30
EVA	7.5	6.55
Solar cells	4.0	3.48
Backsheet foil (Tedlar)	2.50	3.60
Junction box	1.2	
Adhesives		1.16

Component Cryst. Si, standard module	Rel. amount after Oekopol	Rel. amount (2007)
Metals and Si	%	%
Cu	0.37	0.57
Ag	0.14	0.06 – 0.1
Sn	0.12	0.12 – 0.16
Pb	0.12	0.0 – 0.07
Si		3

Recycling Technologies

SOLARWORLD
THE SUNPOWERED COMPANY®

Mechanical separation, laminated glass recycling

- High capacities available
- Very universal process, **cost benchmark**
- Impure fractions
- Hardly possible to sell
- Great dependency on module construction and materials used

Chemical and/or mechanical treatment

- Focus to thin film modules
- Costs of waste treatment of chemicals used
- Strong dependency on materials used

Thermal separation

- Very universal process, **cost benchmark**
- Material use, material separation
- Waste gas cleaning, dust removal

Waste incineration, smelters

- High capacities available
- Very universal process, **cost benchmark**
- Waste disposal of residues

Ecological Assessment

Life Cycle Assessment

The recycling of modules was evaluated concerning its environmental effects by an LCA.

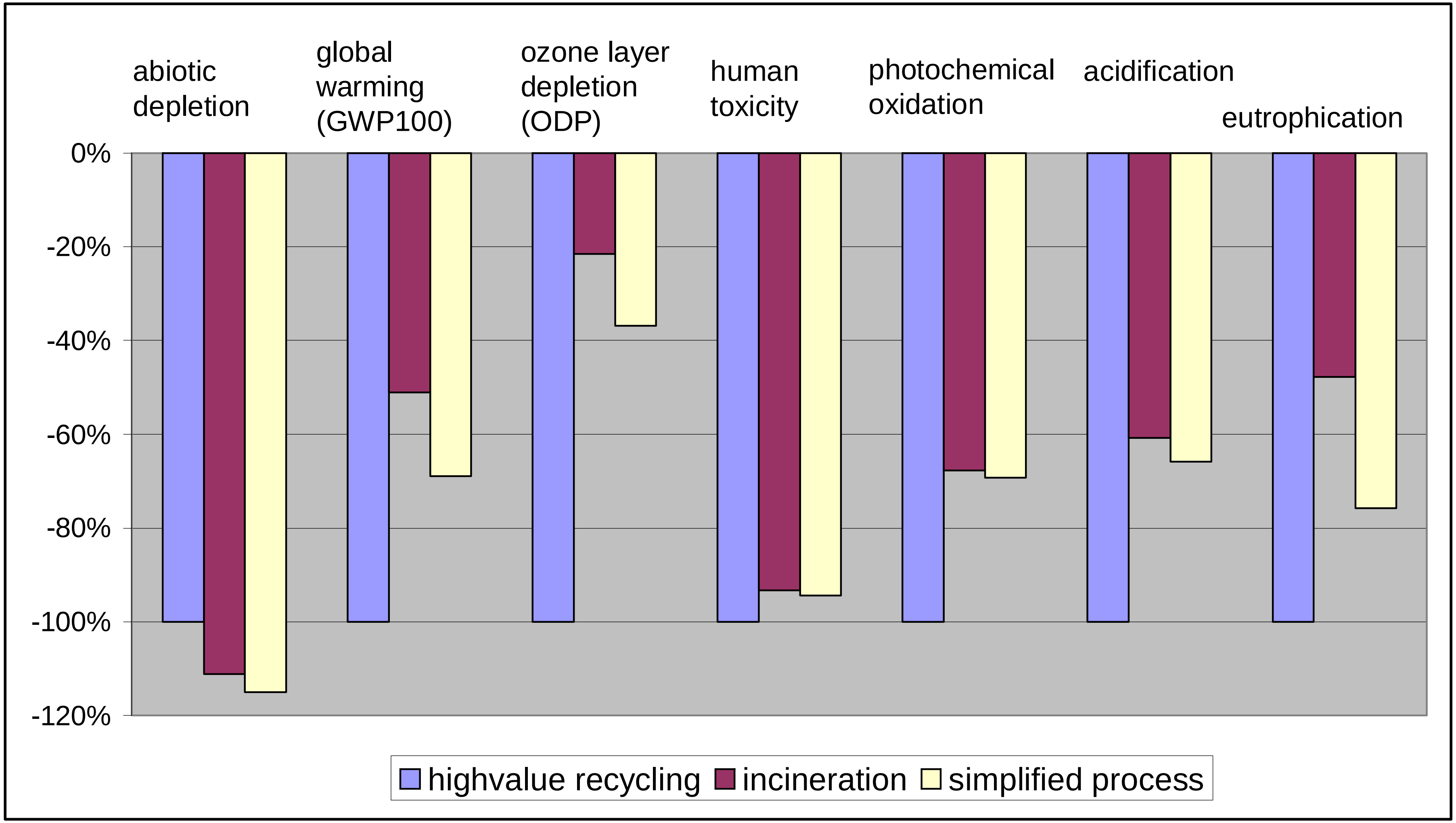
For all impact categories the disburden due to the reuse of silicon, metals and glass is higher than the burden of the environment due to the recycling process itself or a treatment in a waste incinerating plant, respectively a direct landfilling.

Recovery rates

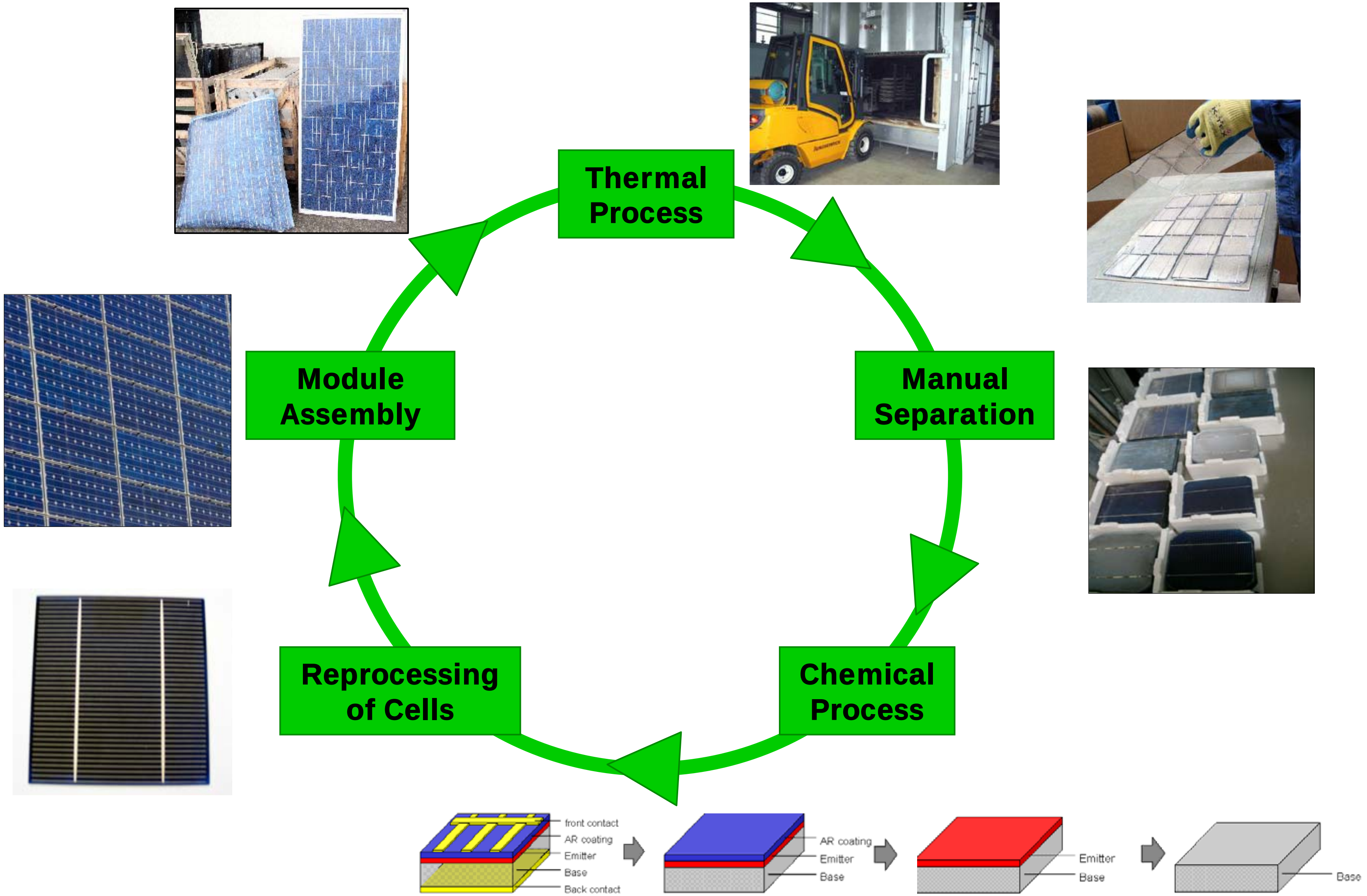
waste incineration: 10 - 20%

Recycling: > 75%

Comparison of 3 waste treatment technologies

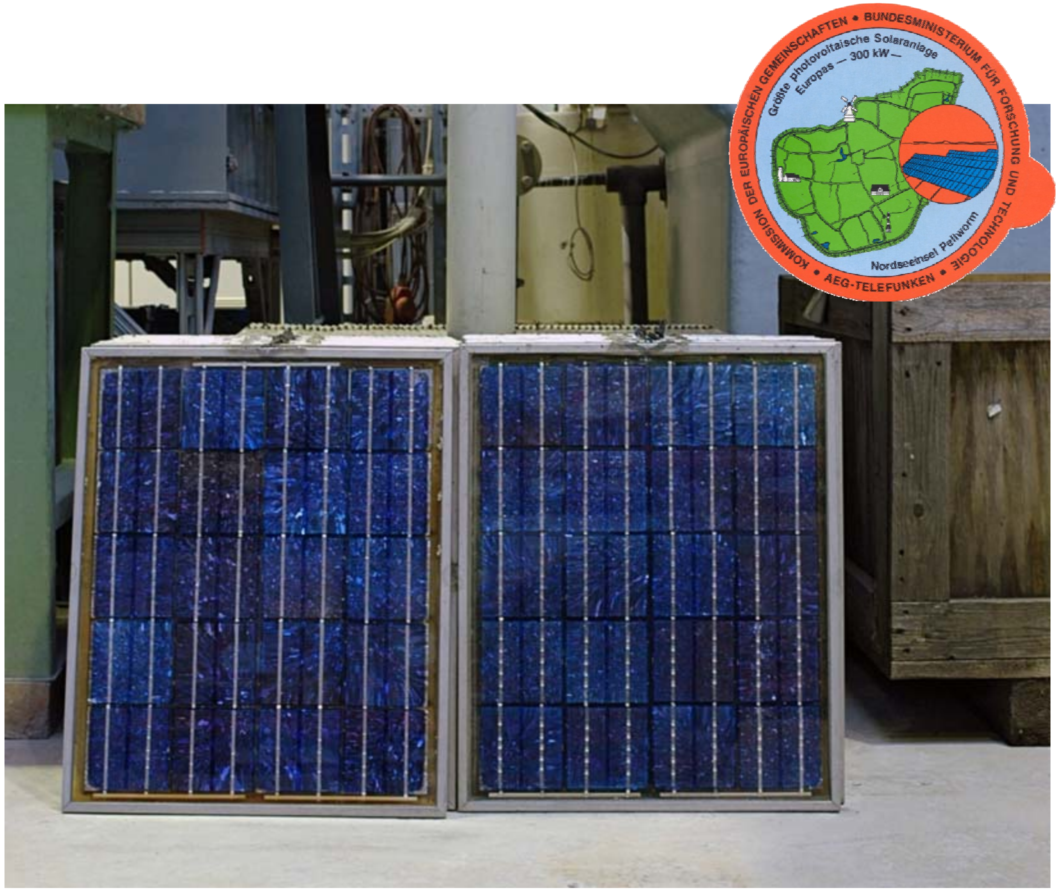


Ongoing recycling process



Results of ongoing process

Recycling of Germany´s oldest PV system, “Pellworm”



- Double-glass modules with stainless-steel frames
- Cell type: Multicrystalline
  100 x 100 x 0.4 mm
- Backsheet metallisation:
  Al (< 1 % Ag)
- PVB polymer lamination
- Ultrasonic welding of interconnectors
- Dimension: 460 x 560 mm
- Number of cells in module: 20

Second-generation systems

- 252,720 Wp have been recycled – 15,795 modules containing 315,900 cells (cell efficiency: 8 %) and

  88 % of the original efficiency
- Total efficiency of six new systems: 237,788 Wp
- New cell efficiency: 12-14 %
- 3.3 tons of steel recycled
- 487 kg broken cells recrystallized into new silicon ingots
- 18 tons of glass returned into glass-recycling loop

Installed in 1983 in Chevetogne: Belgium's first PV system

- Double-glass modules with stainless-steel frames
- Cell type: 4-inch monocrystalline
- Backsheet metallisation: Ag
- EVA polymer lamination
- Soldered interconnectors
- Dimension: 460 x 800 mm
- Number of cells in module: 36

Recycling of Chevetogne system

Recycling of 1,900 modules in Freiberg, 2009

	Input [kg]	Relative amount [%]	Output [kg]	Yield [%]
Glass	5.93	65.82	5.75	96.96
Plastics	0.94	10.43	*	*
Cells, broken cells	0.26	2.89	0.22	84.62
Cu	0.09	1.00	0.07	77.78
Al	1.58	17.54	1.58	100.00
Junction box	0.21	2.33	*	*
Total	9.01	100.00	7.62	84.57 **

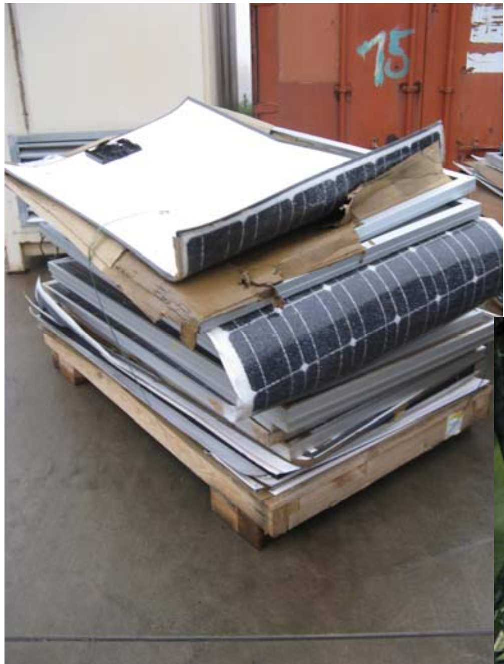
* Energy recovery

** Mixed components: 0.24 kg (2.66 %)

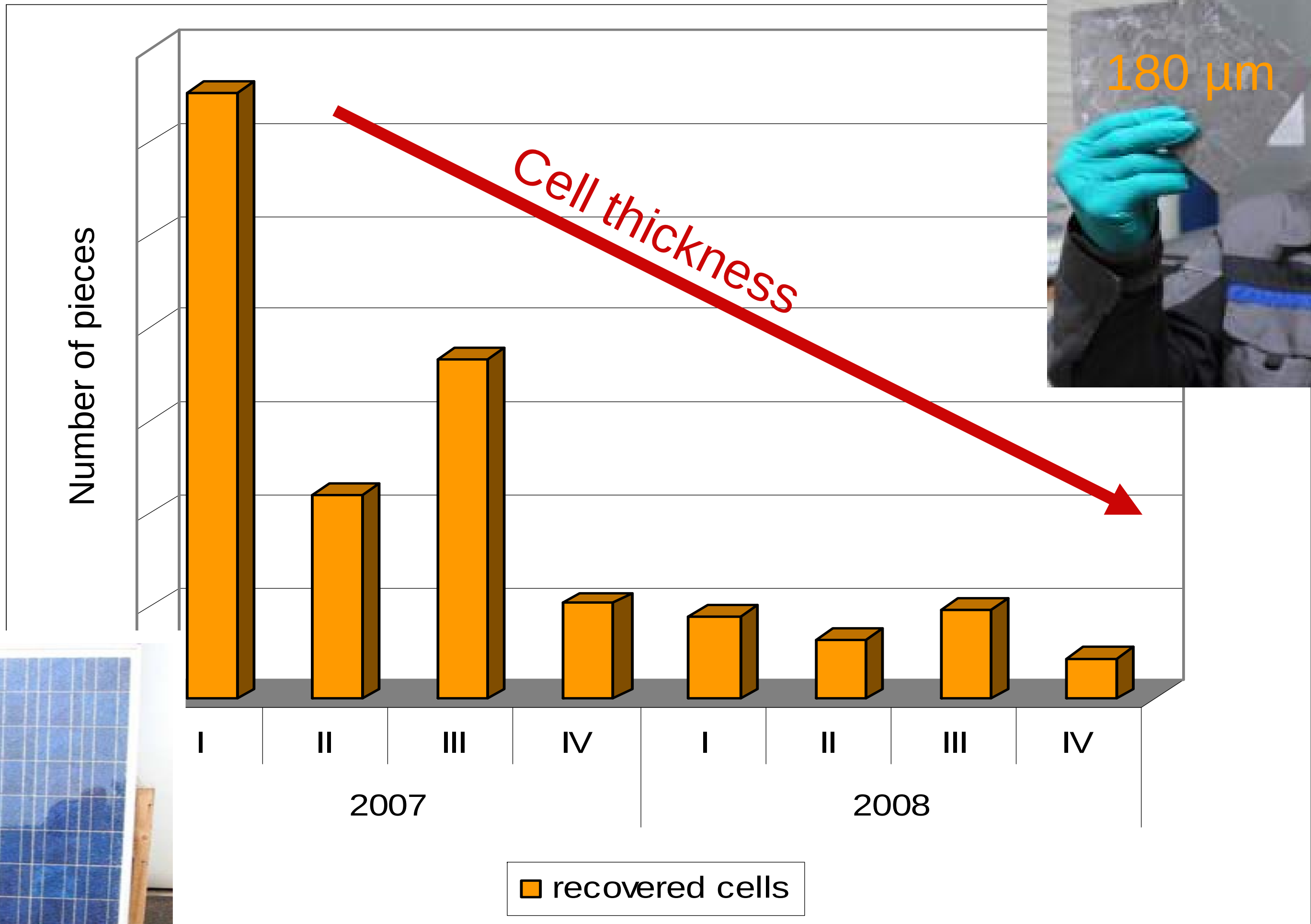
Current situation

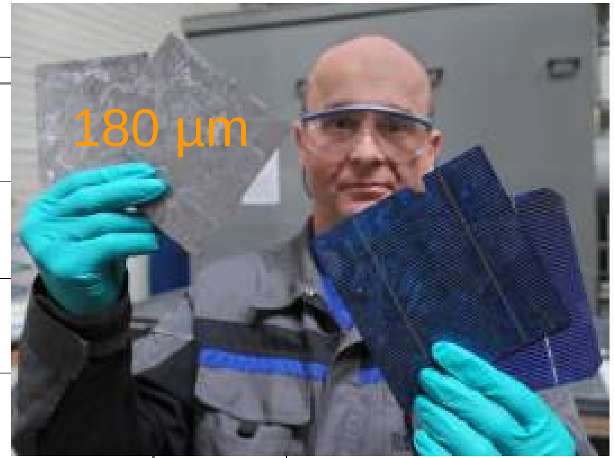
Returned modules:

- Predominantly damaged products
- Dismantled frames
- Reduced valuable metal
- Wide variety of module types
- Reduced cell thickness



Rate of whole cells





Requirements for new treatment

Reasons for need of new procedure

- **Increasing volume of defective solar modules**
- **Declining recovery of whole cells**
- **Inefficiency of manual glass-cell-connector separation**
- **Wide product variety**

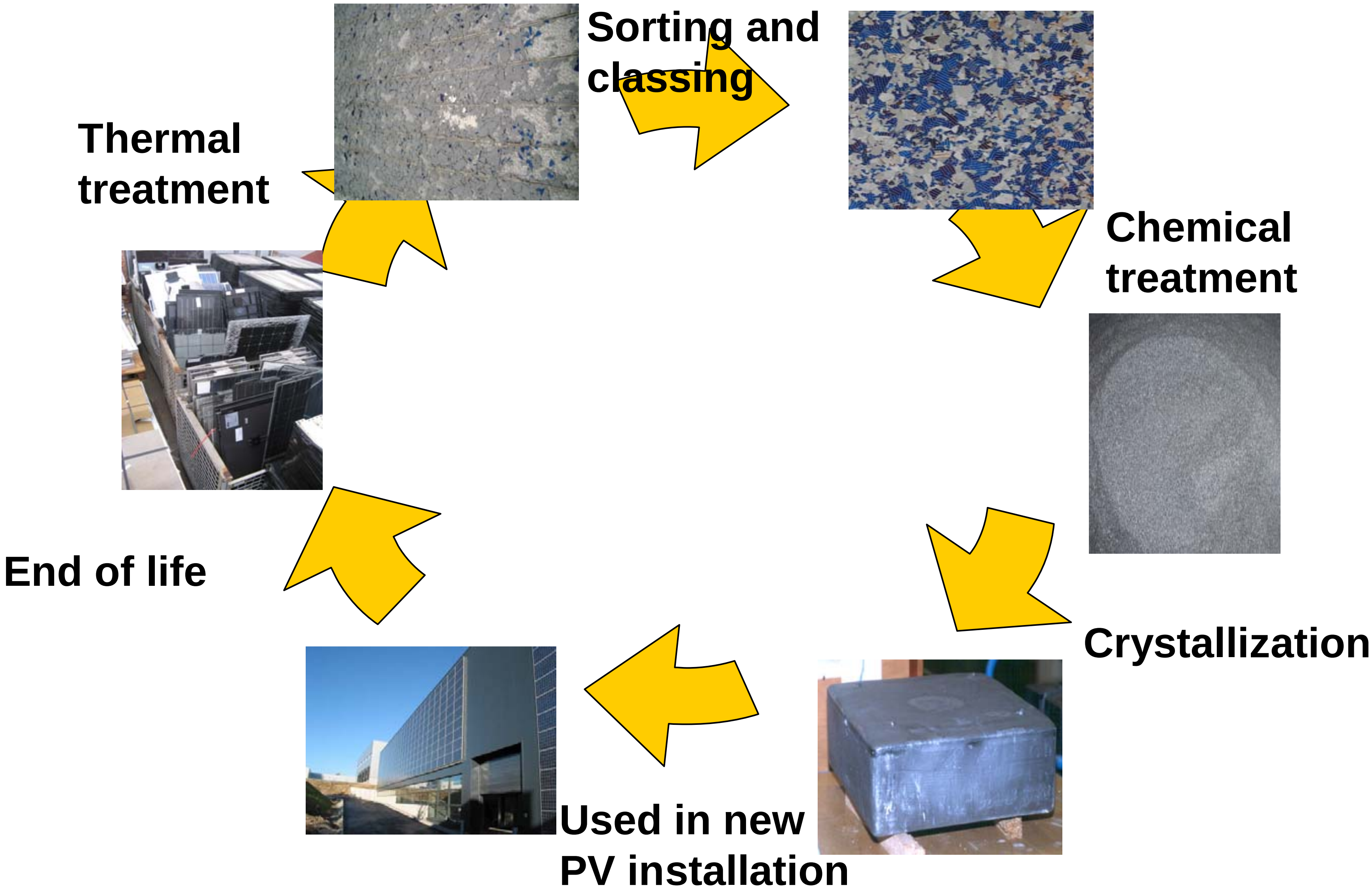
Objectives of new process

- **High recycling rates**
- **Valuable end product**
- **Cost efficiency**

Key points of new procedure

- **Removal of organic components in thermal process step**
- **Automated separation of components**
- **Advanced chemical process**

Recycling of PV modules: New automated process



Thermal treatment

Thermal treatment of modules at 600°C

Sorting and classing

After thermal treatment, separation of components

Frames

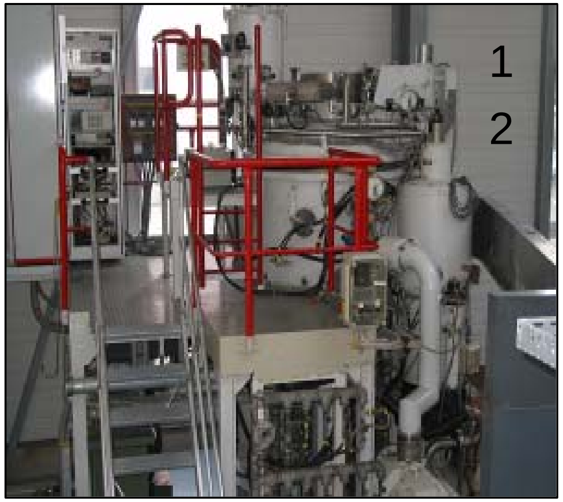
Ribbons

Glass

Chemical treatment

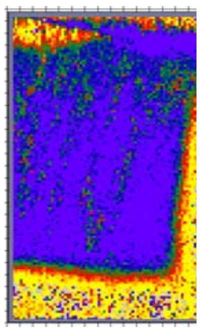
Chemical treatment of cell fractions to remove coatings

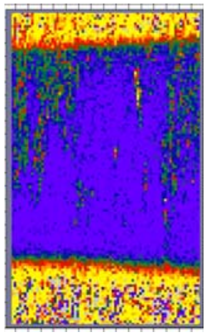
Crystallization



Ingot

Use of purified cell fractions to make new ingots





R [Ωcm]	**1.08**	**1.21**
LTLD [µs]	**4.29**	**4.77**

Past and future recycling process of PV modules

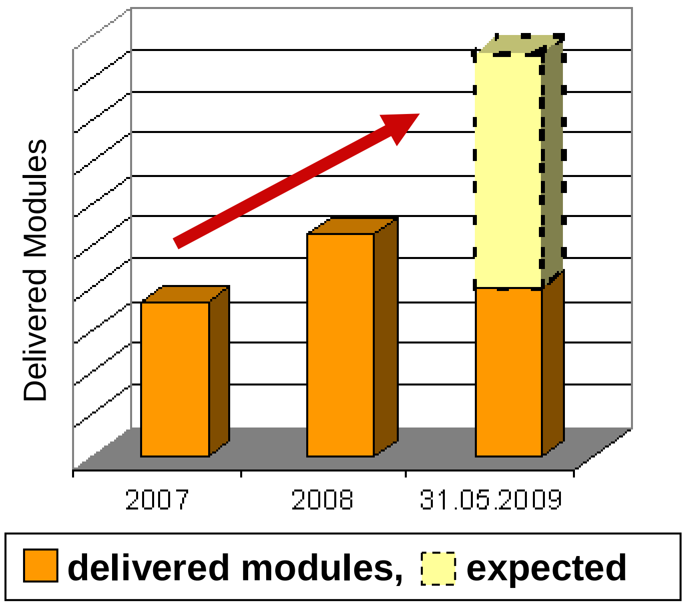
SOLARWORLD
THE SUNPOWERED COMPANY

Current Process

Manual Feeding

Thermal Treatment

Manual Sorting



Automatic Process

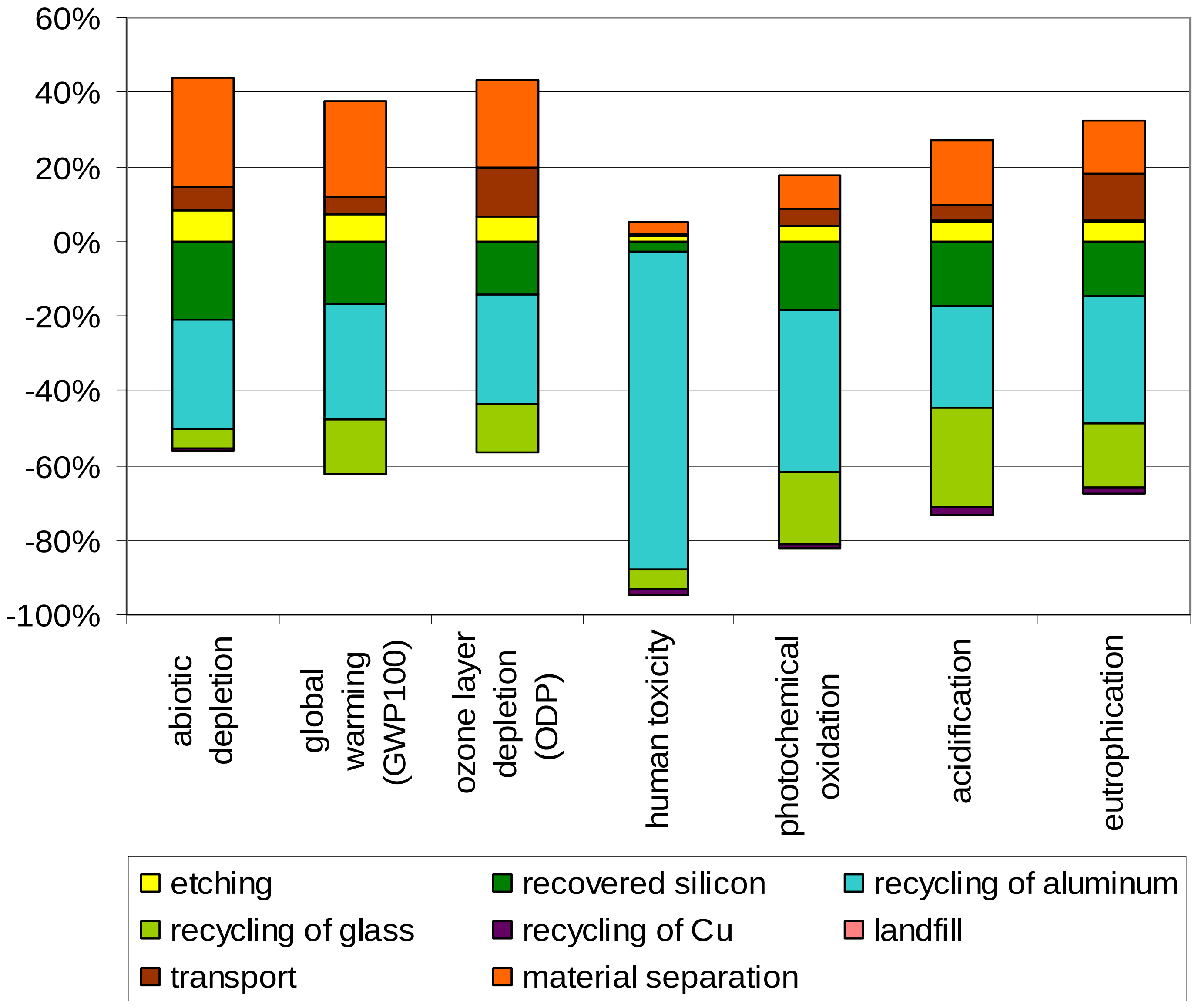
Higher Throughput

Automatic Feeding

Thermal Treatment

Automatic Classing and Sorting

Environmental evaluation module recycling

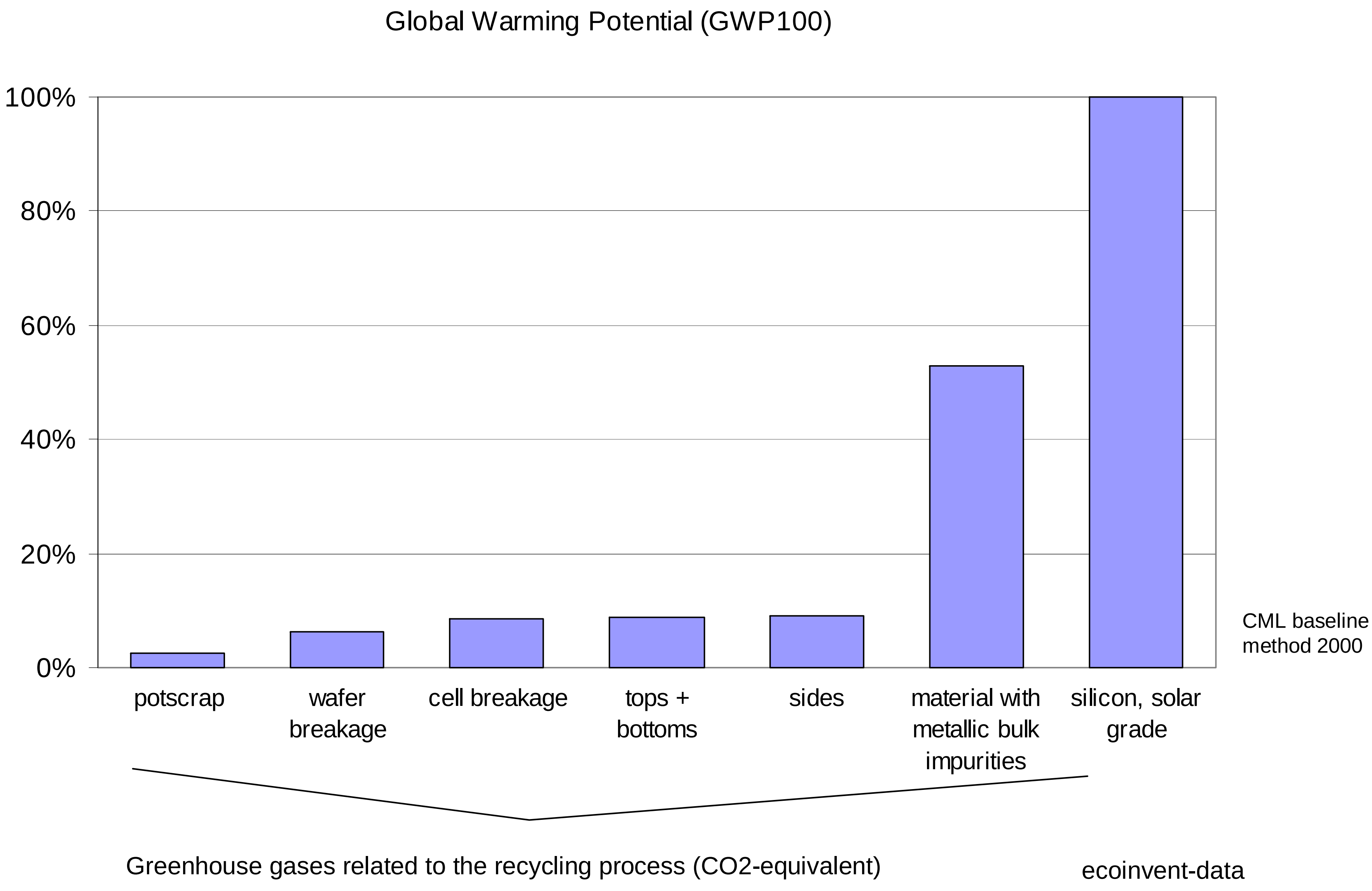


Source of data:
Ecoinvent-data base

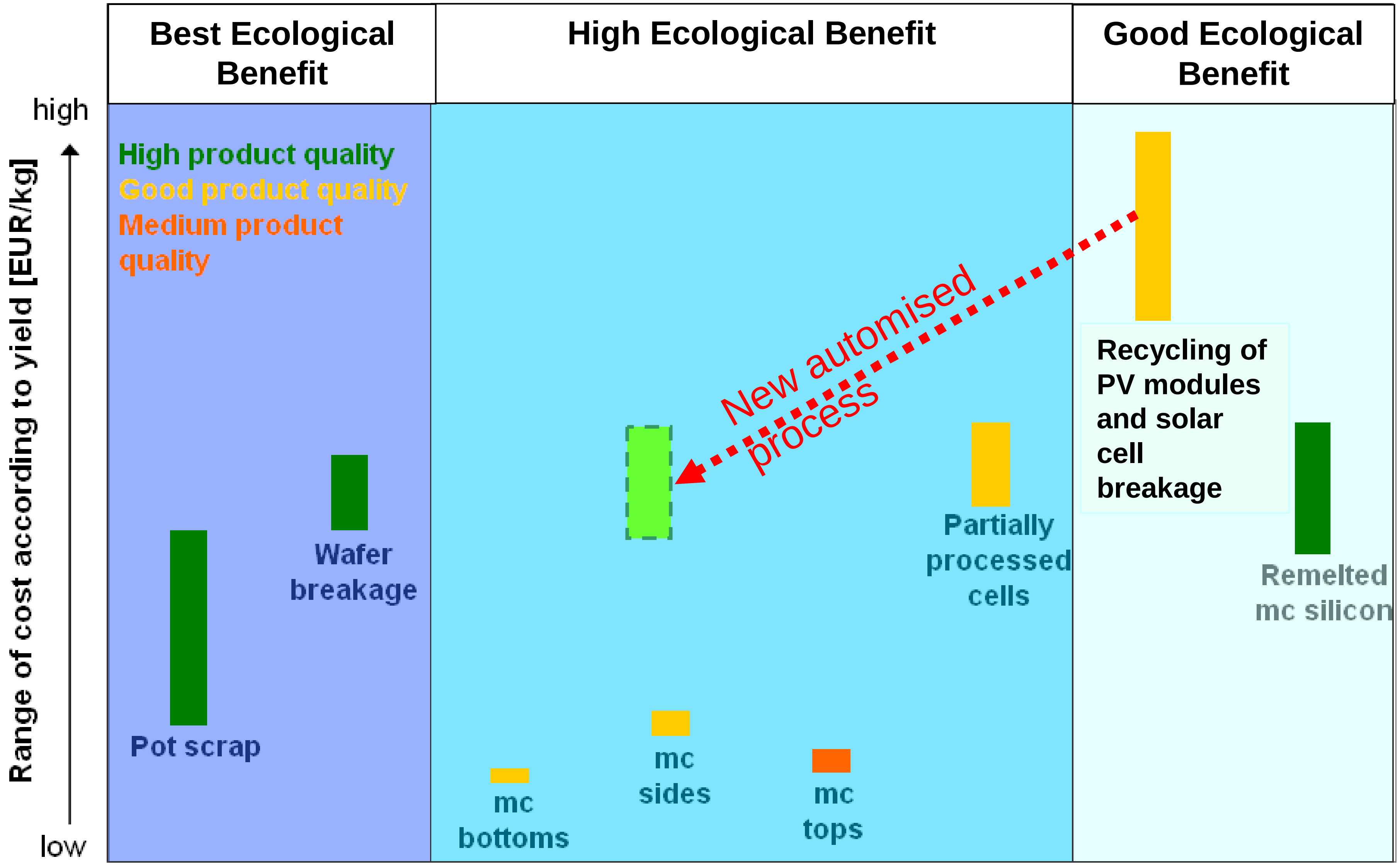
Software:
Sima pro

Method:
CML baseline method 2000

Global warming potential



Economy versus ecology



Summary and outlook

- Modules can be recycled in industrial processes with a recycling quota up to 90% and more even today
- The take back and treatment systems must be economically and environmentally feasible utilizing best available practices and external auditing
- All module producers should commit to their extended responsibilities and become members of PVCYCLE Association or similar systems to be installed globally.
- Standardisation and best practice approaches can help saving money and obtain best results
- International cooperation is essential

Back in to the Sun!
Thank you for your attention!