BeCAP
Berlin Center of
Advanced Packaging

Forschungsschwerpunkt
Technologien der Mikroperipherik

Fraunhofer
IZM
Institut
Zuverlässigkeit und
Mikrointegration

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LCA for Environmental Management and Eco-Design in the Electronics Industry
- State of the Art and Screening Approaches -

InLCA/LCM 2002 - Life Cycle Assessment and Life Cycle Management
E-Conference (www.lcacenter.org/lca-lcm), May 20-25, 2002

Contents

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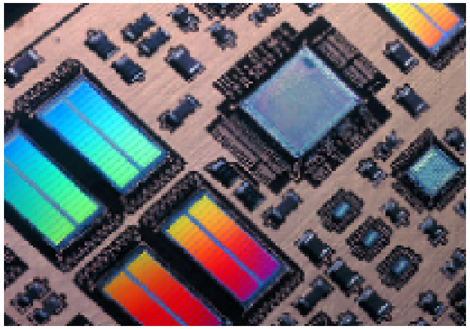
1. Environmental Engineering @ BeCAP

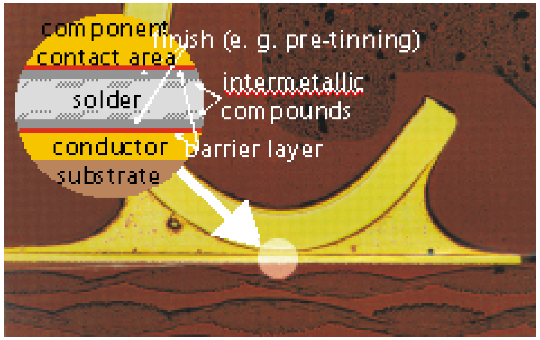
Fraunhofer Institut Zuverlässigkeit und Mikrointegration
Technische Universität Berlin, Forschungsschwerpunkt Technologien der Mikroperipherik
Green Electronics
Head of Department: H. Griese

Research and Development



- **Sustainable electronic products and processes**
- **ReUse strategies**
- **Analytics and environmental assessment**
- **Life Cycle Management**
- **Assessment of remaining lifetime**

Service for the Industry



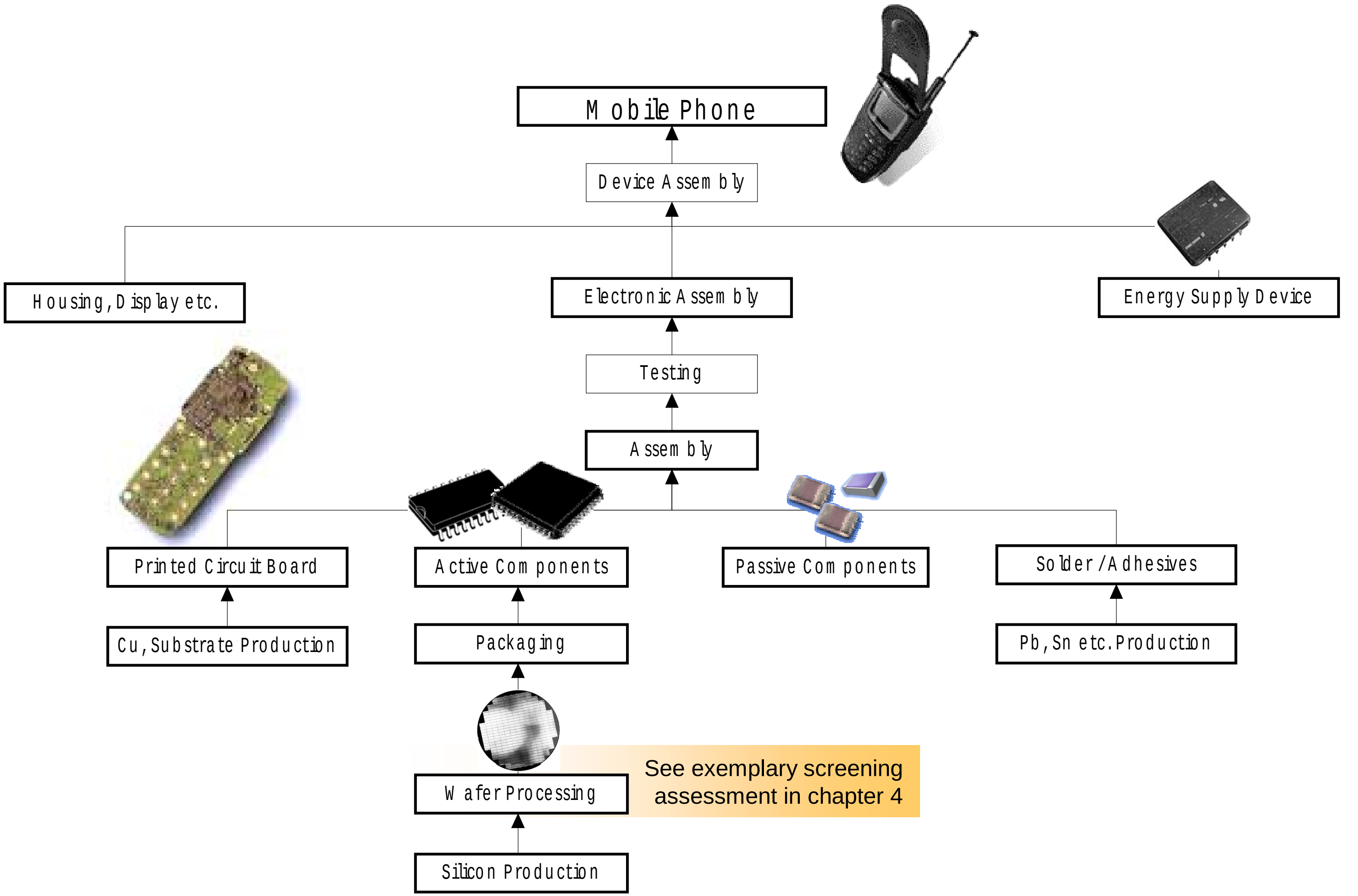
- **Industrial working group "Lead-free Interconnection Technologies in Electronics"**
- **Demonstration Center "Production Cycles"**
- **Demo-lab for environmental management**

International Networking

- **Electronics Goes Green 2000+**
- **IEEE/ CPMT TC Chair for Green Electronics**
- **Cooperation with the Universities of Wisconsin, Tokyo and Delft**

2. Introduction

2.1 Overview - Production and Components of a Mobile Phone



Mobile Phone

Device Assembly

Housing, Display etc.

Electronic Assembly

Energy Supply Device

Testing

Assembly

Printed Circuit Board

Active Components

Passive Components

Solder/Adhesives

Cu, Substrate Production

Packaging

Pb, Sn etc. Production

Wafer Processing

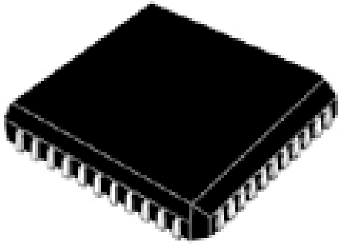
Silicon Production

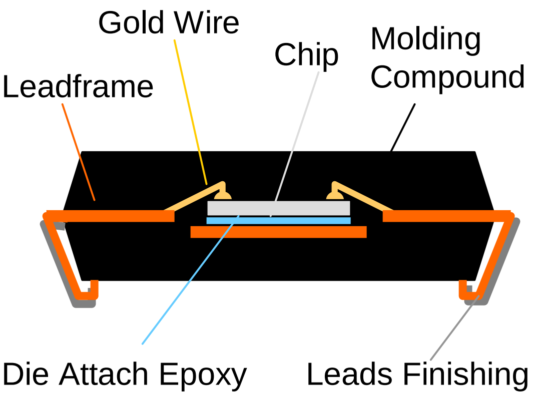
See exemplary screening assessment in chapter 4

2. Introduction

2.2 Example - Composition of an Electronic Component

Exemplary Composition Plastic Leaded Chip Carrier (PLCC)





Cross section of a PLCC

Name of the part	Material weight (mg)	Material name	Material analysis (element)	Material analysis (weight%)
Leadframe	739	Cu-Alloy	Cu Fe P	97.5 2.4 0.1
Molding Compound	1520	epoxy resin	SiO_2 epoxy Sb_2O_3 Br	70.0 27.0 2.0 1.0
Chip	21	Doped silicon	Si Al	99.4 0.6
Die Attach Epoxy	6.4	Glue	Ag epoxy resin	75 25
Wires	1.6	Gold	Au	99.99
Leads finishing	12	Tin\Lead	Sn Pb	85 15

(Source: ST Microelectronics)

EEE Design Directive on the Impact on the Environment of Electrical and Electronic Equipment

Working paper of DG 3, Enterprise (Version 1.0, February 2001)

- EEE Directive represents “New Approach” and has to be seen as a part of the holistic approach of the Integrated Product Policy (IPP)
- The objective of the EEE is to harmonize requirements concerning the design of electrical and electronic equipment to ensure free movement of these products, and to improve the products overall impact on the environment, and thus providing efficient use of resources and high level of environmental protection
- To ensure compliance of the EEE an Internal Design Control through an affixed CE marking and a written declaration of conformity is required
- Ecological profile shall reflect the overall environmental influence of the product, taking into consideration the environmental impact of an individual product and the expected number of products to be manufactured.

2. Introduction

2.3 European Legislation supports Life Cycle Thinking

EEE Design Directive on the Impact on the Environment of Electrical and Electronic Equipment

- Manufacturer shall identify and estimate the magnitude of environmental inputs and outputs associated with the product during these phases of the lifecycle:
  - Raw material acquisition
  - Manufacturing
  - Packaging, transport and distribution
  - Installation and use
  - End of life
- For each phase, following aspects shall be assessed where relevant:
  - predicted consumption of materials, energy and other resources
  - anticipated emissions to air, water or soil
  - anticipated pollution through physical effects such as noise, vibration, radiation, electromagnetic fields, etc.
  - expected generation if waste material
  - possibilities for reuse, recycling and recovery of materials

2. Introduction

2.3 European Legislation supports Life Cycle Thinking

EEE Design Directive on the Impact on the Environment of Electrical and Electronic Equipment

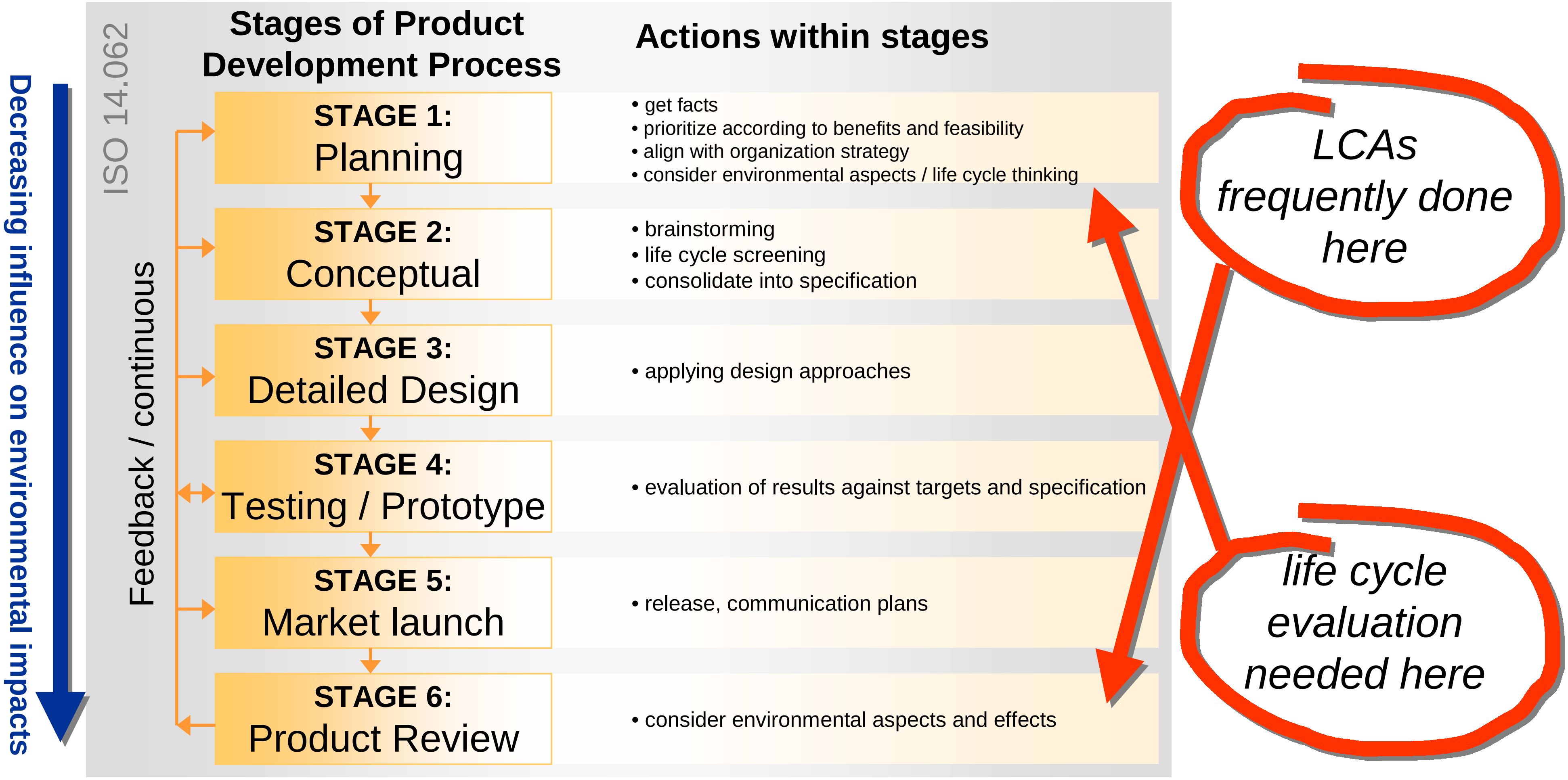
Key points of discussion (on essential requirements)

- EEE Directive can be interpreted, that it requires a full life cycle assessment (LCA)
- Aspects shall only be considered as they can be influenced through product design
- Assessment should be done accordingly (no quantification of essential requirements)
- Clear definition of the scope (in context to other regulations like WEEE / IPP)
- Presumption of conformity should allow the use of international eco-label schemes
- Call for simple and straightforward assessment methodology and tool

  ➢ **Life cycle screening** versus **life cycle assessment**

2. Introduction

2.4 Need for Environmental Assessment within Product Development



Stages of Product Development Process	Actions within stages
STAGE 1: Planning	• get facts • prioritize according to benefits and feasibility • align with organization strategy • consider environmental aspects / life cycle thinking
STAGE 2: Conceptual	• brainstorming • life cycle screening • consolidate into specification
STAGE 3: Detailed Design	• applying design approaches
STAGE 4: Testing / Prototype	• evaluation of results against targets and specification
STAGE 5: Market launch	• release, communication plans
STAGE 6: Product Review	• consider environmental aspects and effects

LCAs frequently done here

life cycle evaluation needed here

3. LCAs for Electronics - State of the Art and Obstacles

3.1 Industry Activities

“The electronics industry tends to be proactive
(worldwide) and is a leader in the areas of
– Life-cycle Assessment (LCA)
– Design for Environment (DFE)
– End-of-Life Management (ELM)”

NSF Study on Environmentally Benign Manufacturing (EBM)

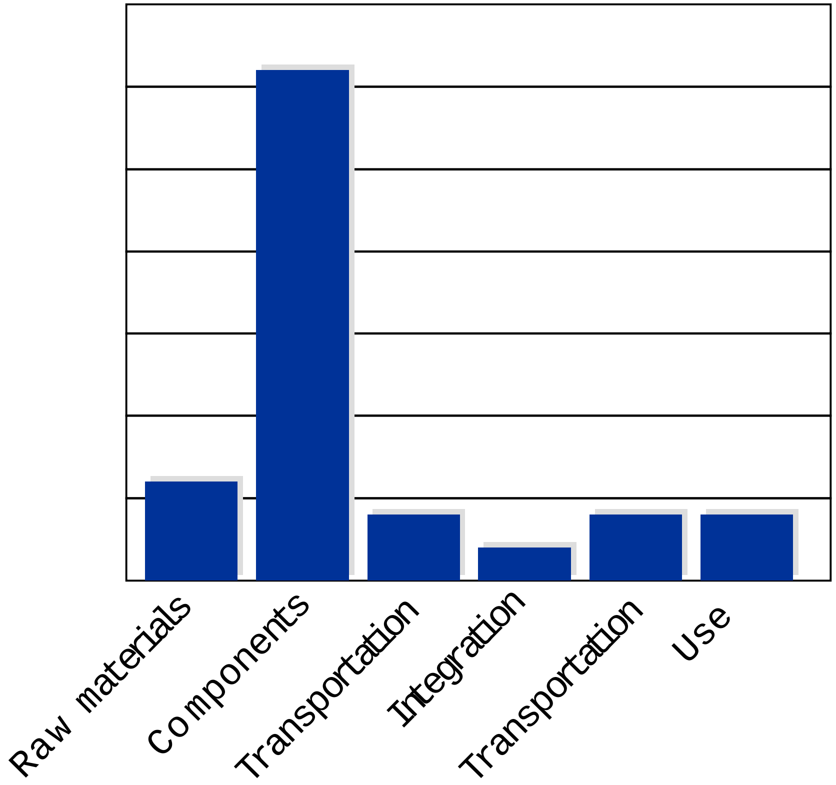
Industry activities (exemplary)

1993	MCC: LCA of a Computer Workstation - Basis for many following studies, but data in the meantime out-of-date
1994/95	IVF: Case study LCAs for capacitors, solders, adhesives
1995/99	Siemens, Fraunhofer IVV et al.: Joint Project LCA in Electronics Manufacturing
1997/98	STMicroelectronics: LCI of electronic components, requested by 6 customers for own LCA studies
1998	Atlantic Consulting / Technical University of Denmark: LCA Report for the EU Ecolabel for Personal Computers
1998	Nokia: Case study LCA / Energy Burden of a mobile phone
2000	Ericsson: (1) Case study LCA of 3rd generation systems (incl. use phase) - , (2) suppliers have to declare constituents of products, but no input/output data is requested
2000	Motorola / Fraunhofer IZM: Case study LCI of wafer processing
2000	Lucent: Inventory and Environmental Performance Tool for Semiconductors

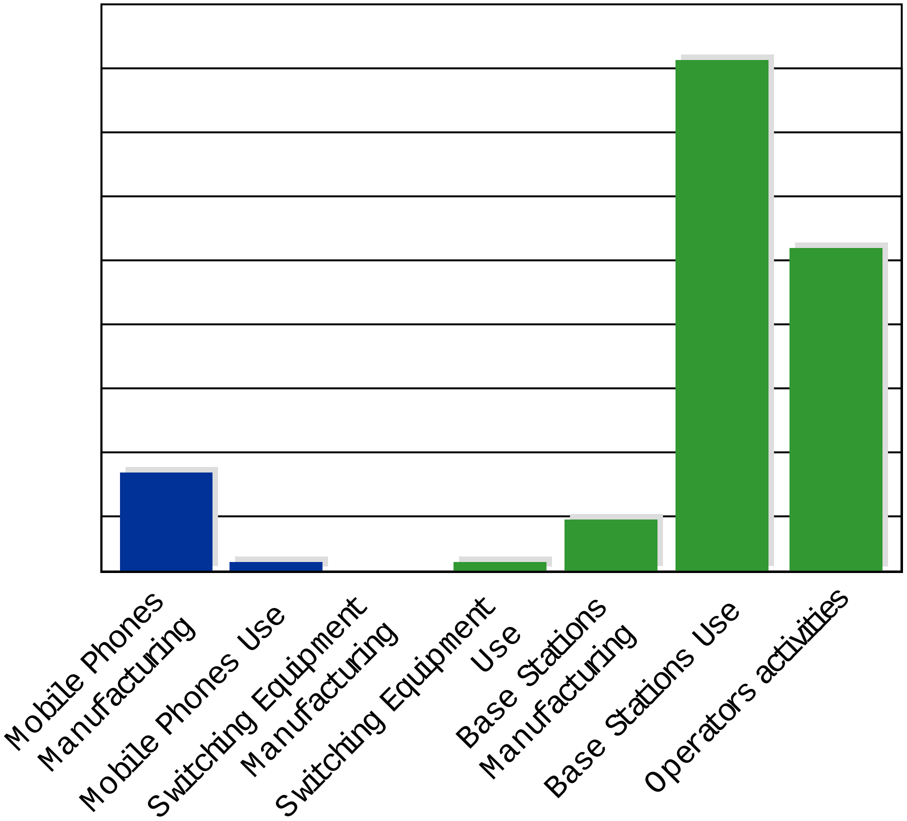
3. LCAs for Electronics - State of the Art and Obstacles

3.2 Examples of published data for telecommunications

Energy burden of a mobile phone (Nokia, 1998)

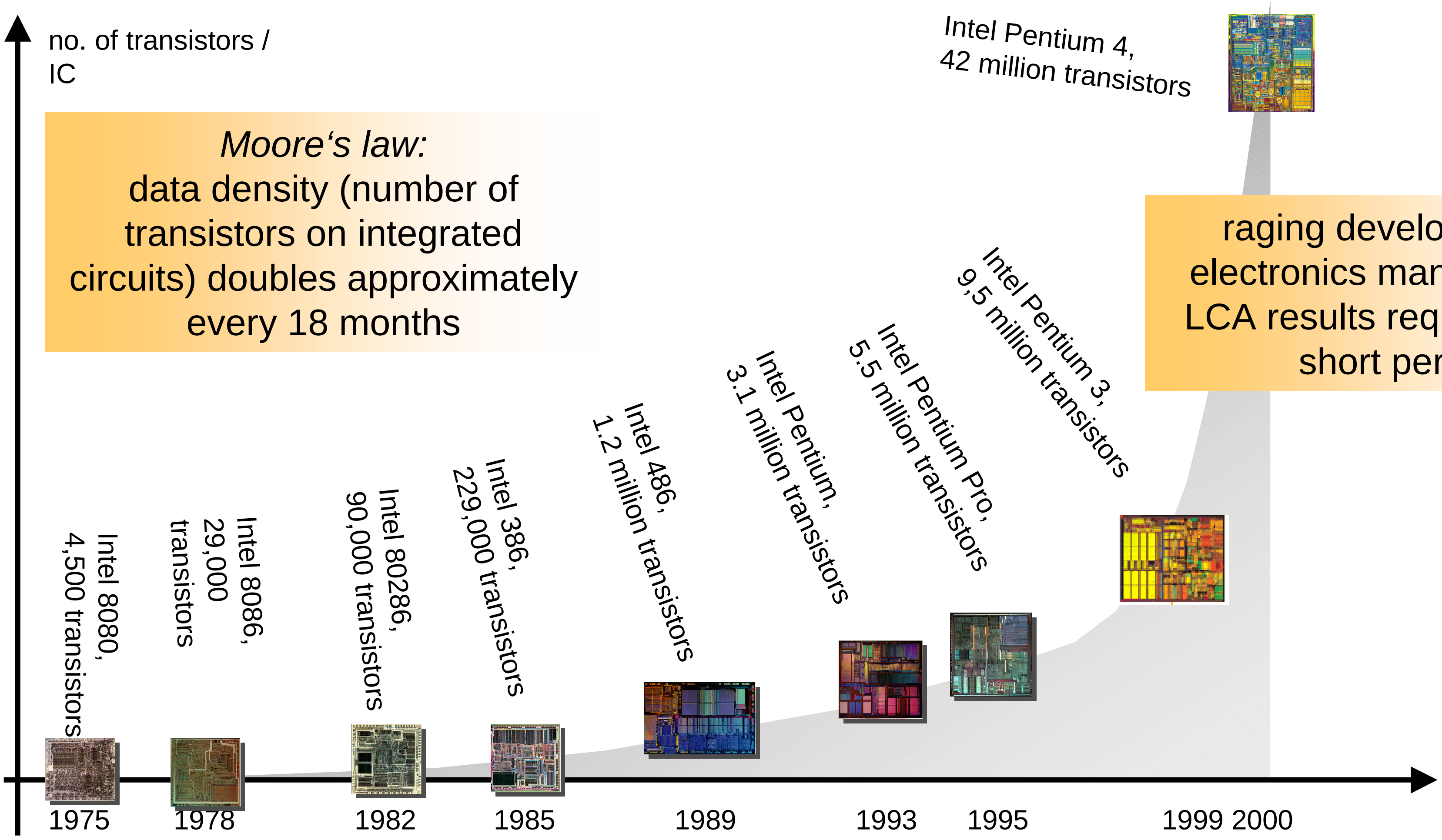


Energy burden of mobile telecommunication (Ericsson, 1999)



3. LCAs for Electronics - State of the Art and Obstacles

3.3 Innovation rates of electronics



Moore‘s law:
data density (number of transistors on integrated circuits) doubles approximately every 18 months

raging development of electronics manufacturing: LCA results required within short periods

(Source: www.intel.com, Processor Hall of Fame)

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3. LCAs for Electronics - State of the Art and Obstacles

3.4 Supply Chains for Electronics are Global

- supply chains for electronics are complex, due to wholesalers origin of components is frequently unknown to the OEM (original equipment manufacturer)
- supply chains for electronics are global - exemplary journey of a single active component (an electronic device usually consists of several hundred components from different suppliers):

Processes	**location**	**following transport [km]**
Si-wafer production	Oregon	1000
wafer-processing	California	11000
IC-packaging	Taiwan	11000
test	California	13000
distribution	Germany	+ X (to customer)

following processes:
electronic assembly, device assembly, packaging, distribution to customer

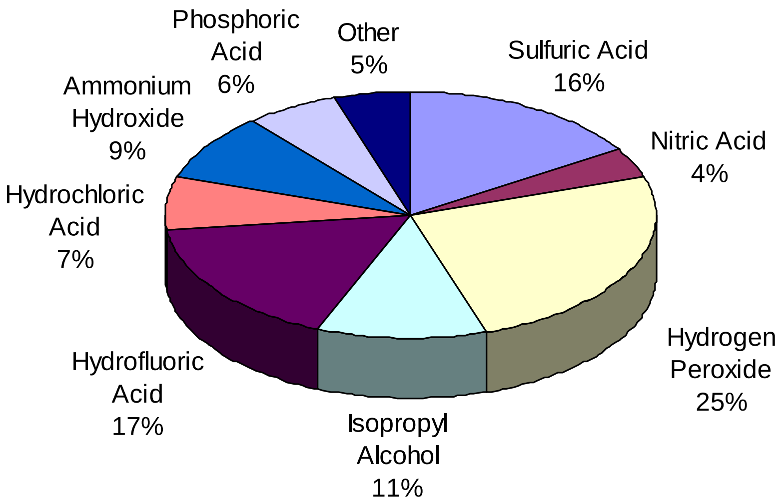
(Source: Nissen)

3. LCAs for Electronics - State of the Art and Obstacles

3.5 Upstream Processes for Chemicals and Emission Impact Assessment

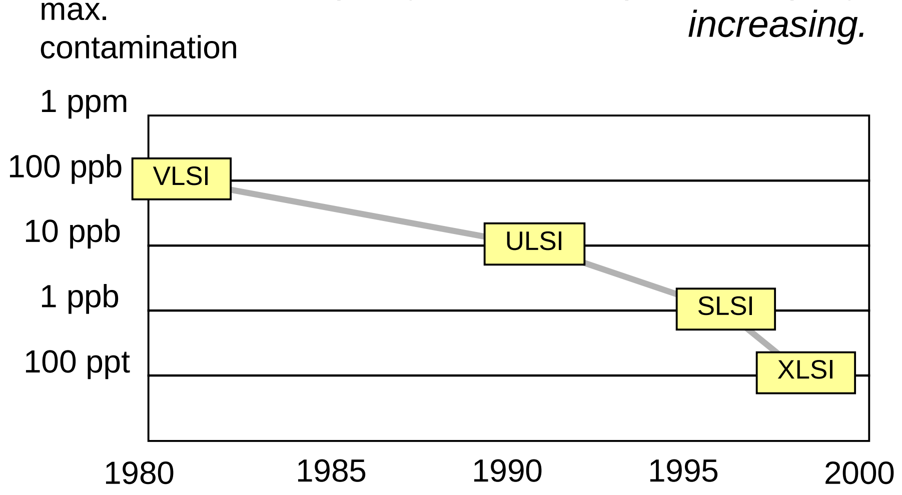
Bulk Chemicals...

...in Electronics are „standard“ chemicals...



Electronics Chemicals Usage
(Source: Sievert, Semiconductor Fabtech)

...but desired purity level is unique and rapidly increasing.



Implementation of Quality Levels
(Source: Sievert, Semiconductor Fabtech)

- Specific production & cleaning processes, specific transportation & packaging requirements
- No generic data available, data for „standard“ chemicals not applicable

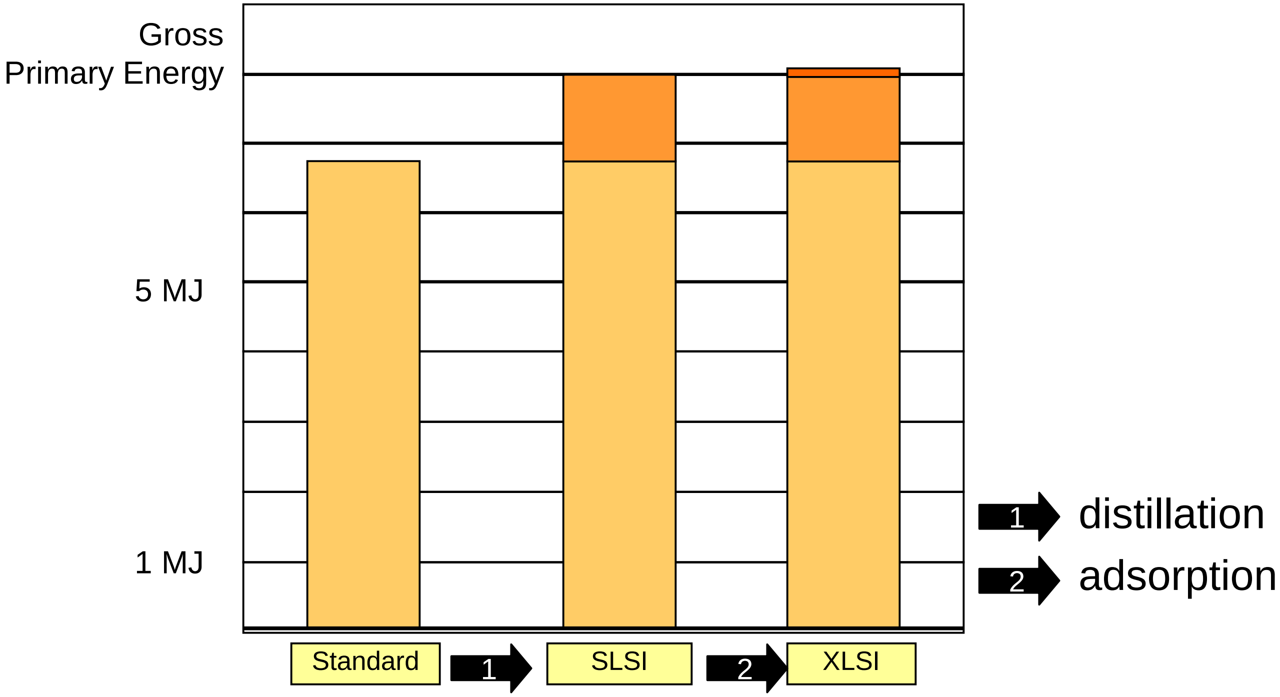
VLSI: very large scale integration
ULSI: ultra large scale integration
SLSI: super large scale integration
XLSI: extra large scale integration

3. LCAs for Electronics - State of the Art and Obstacles

3.5 Upstream Processes for Chemicals and Emission Impact Assessment

Example - Gross Primary Energy for Hydrogenperoxide

- Reference Unit:
  1 kg 30% H_2O_2-solution



(source for purification processes: one chemical supplier, different processes for purification possible; source for standard quality: Boustead)

3. LCAs for Electronics - State of the Art and Obstacles

3.5 Upstream Processes for Chemicals and Emission Impact Assessment

Microelectronics Process Chemicals	**Potential Emissions**
AsH_3	AsH_3
BCl_3	Cl_2, BCl_3, HCl, $SiCl_4$, CCl_4, $CHCl_3$
Br_2	Br_2, HBr, $SiBr_4$
CF_4, C_2F_6, C_3F_8, C_4F_8, C_5F_8, CHF_3	C_2F_6, CF_4, C_5F_8, C_4F_8, C_3F_8, CHF_3, HF, F_2, SiF_4, OF_2, COF_2, C_2F_4, CO
CH_3COCH_3 (Acetone)	CH_3COCH_3
CH_3OH (Methanol)	CH_3OH (Methanol)
C_2H_5OH (Ethanol)	C_2H_5OH (Ethanol)
$(CH_3)_2CHOH$ (Isopropanol)	$(CH_3)_2CHOH$ (Isopropanol)
$CH_3O(CH_2)_3OOCCH_3$ (PGMEA)	$CH_3O(CH_2)_3OOCCH_3$ (PGMEA)
$C_2H_5OOCCC(OH)CH_3$ (Ethyl lactate)	$C_2H_5OOCCC(OH)CH_3$ (Ethyl lactate)
$C_4H_6ON(CH_3)$ (NMP)	$C_4H_6ON(CH_3)$ (NMP)
$C_4H_8SO_2$ (Sulfolane)	$C_4H_8SO_2$ (Sulfolane)
$CH_3(CO)C_5H_{11}$ (2-Heptanone)	$CH_3(CO)C_5H_{11}$ (2-Heptanone)
Cl_2	Cl_2, HCl, $SiCl_4$, CCl_4, $CHCl_3$
HBr	HBr, Br_2, $SiBr_4$
HCl	Cl_2, HCl, $SiCl_4$, CCl_4, $CHCl_3$
HF	HF, F_2, SiF_4, OF_2, COF_2
NF_3	NF_3, HF, F_2, SiF_4, OF_2, COF_2, NO, NO_2, N_2O
NH_3	NH_3

3. LCAs for Electronics - State of the Art and Obstacles

3.5 Upstream Processes for Chemicals and Emission Impact Assessment

Microelectronics Process Chemicals (cont'd)	**Potential Emissions** (cont'd)
$NH(Si(CH_3)_3)_2$ (HMDS)	$NH(Si(CH_3)_3)_2$ (HMDS)
N_2O	N_2O, NO, NO_2
O_3	O_3
PH_3	PH_3
SiF_4	HF, F_2, SiF_4, OF_2, COF_2
SiH_4	SiH_4
SF_6	SF_6, HF, F_2, SiF_4, OF_2, COF_2, SOF_2, SO_2F_2, SO_2
$Si(OC_2H_5)_4$ (TEOS)	$Si(OC_2H_5)_4$, CH_3OH, HCOOH, C_2H_5OH, CO, CO_2
$PO(C_2H_5O)_3$ (TEPO)	$PO(C_2H_5O)_3$ (TEPO)
$TiCl_4$	$TiCl_4$
WF_6	WF_6, HF, F_2, SiF_4, OF_2, COF_2

(source: Sematech)

- high number of microelectronics' specific process chemicals and emissions
- for most chemicals no generic upstream data (neither LCA nor LCI) available
- for most emissions no impact assessment data (such as Eco-Indicator 99) available

3. LCAs for Electronics - State of the Art and Obstacles

3.6 Obstacles for Assessing Waste Disposal

Highly complex waste streams: Leaching from landfills and incineration products are varying by orders of magnitude depending on specific circumstances

- Leaching of heavy metals from German municipal waste landfills:

	Age of Landfills			
	1-5 years	6-10 years	11-20 years	21-30 years
Zn	0,02-24 mg/l	0,016-125 mg/l	0,01-43,5 mg/l	0,05-9 mg/l
As	0,003-0,03 mg/l	0,002-0,097 mg/l	0,001-0,37 mg/l	0,0026-0,182 mg/l
Pb	0,005-0,92 mg/l	0,005-0,317 mg/l	0,005-1,3 mg/l	0,005-0,19 mg/l
Cu	0,003-40 mg/l	0,002-3,3 mg/l	0,0025-1,03 mg/l	0,004-0,27 mg/l
Ni	0,02-1,4 mg/l	0,012-10,6 mg/l	0,007-1,93 mg/l	0,008-0,348 mg/l

(Source: Krümpelbeck)

- Recovery of metals from e-scrap at secondary copper smelters:

- e.g. economics of lead recovery depends on tin content (simultaneously recovered)
- e.g. silver recovery regularly near 100% at secondary copper smelters, but halogenes (flame retardents in e-scrap!) cause volatile silver halogenides (loss of silver)
- simulation of processes for e-scrap very complex, current research activities at smelters

3. LCAs for Electronics - State of the Art and Obstacles

3.6 Obstacles for Assessing Waste Disposal

Today's disposal routes for e-scrap unknown to a large extend:
See findings of the Basel Action Network on e-scrap exports to Asia (www.ban.org)

Dissolving gold from electronics scrap, Guiyu, China (source: Basel Action Network)

E-scrapping dismantling operation, Guiyu, China (source: Basel Action Network)

Pending legislation for e-scrap in Europe:
Uncertainty according to future recycling technologies of today's electronics

- Recycling rates are under discussion currently
- Mandatory take-back will be followed by
    - new recycling plants (e.g. secondary copper smelters adapted to e-scrap),
    - new logistics

4. Environmental Assessment - Screening Approaches for Electronics

4.1 Requirements for a DfE/LCM-Tool

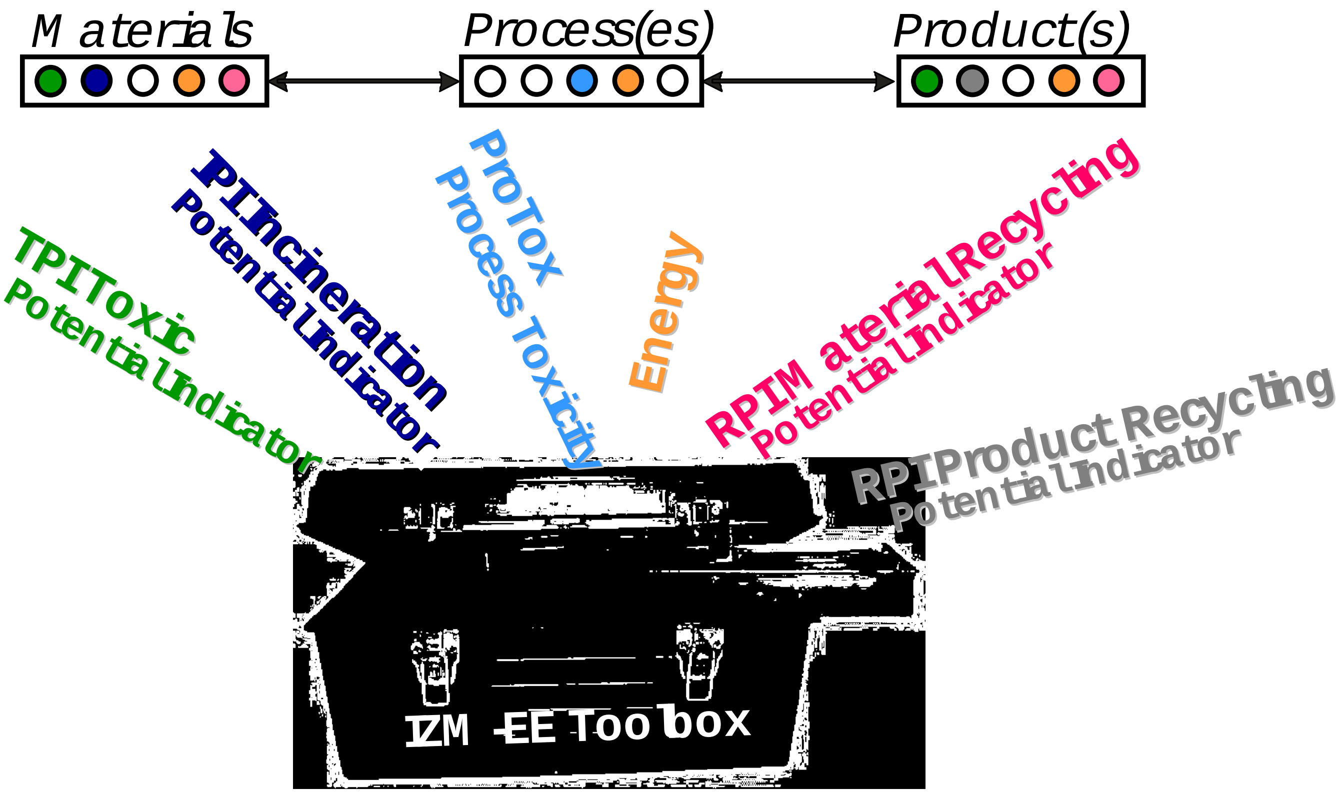
- Faster than LCA (keeping pace with innovation cycles)
- Applicable within the design process - preferred one-indicator-solution
- Minimized data gaps and uncertainties
- Based on published data
- Environmental assessment based on experts' substance assessment
- Addressing electronics specific environmental topics: Toxicity of a variety of chemicals, greenhouse effect / energy, water consumption, disposal / recycling

→ No "one fits all" methodology known

→ Fraunhofer IZM developed a set of tools - known as Fraunhofer IZM/EE Toolbox -, addressing specific topics

4. Environmental Assessment - Screening Approaches for Electronics

4.2 IZM/EE-Toolbox - Modular Environmental Assessment Tools



TPI Toxic Potential Indicator
- Assessment of toxicity potential (material and product composition)

IPI Incineration Potential Indicator
- Assessment of plastics

ProTox Process Toxicity
- TPI-assessment of input/output data of processes
- for details see following slides

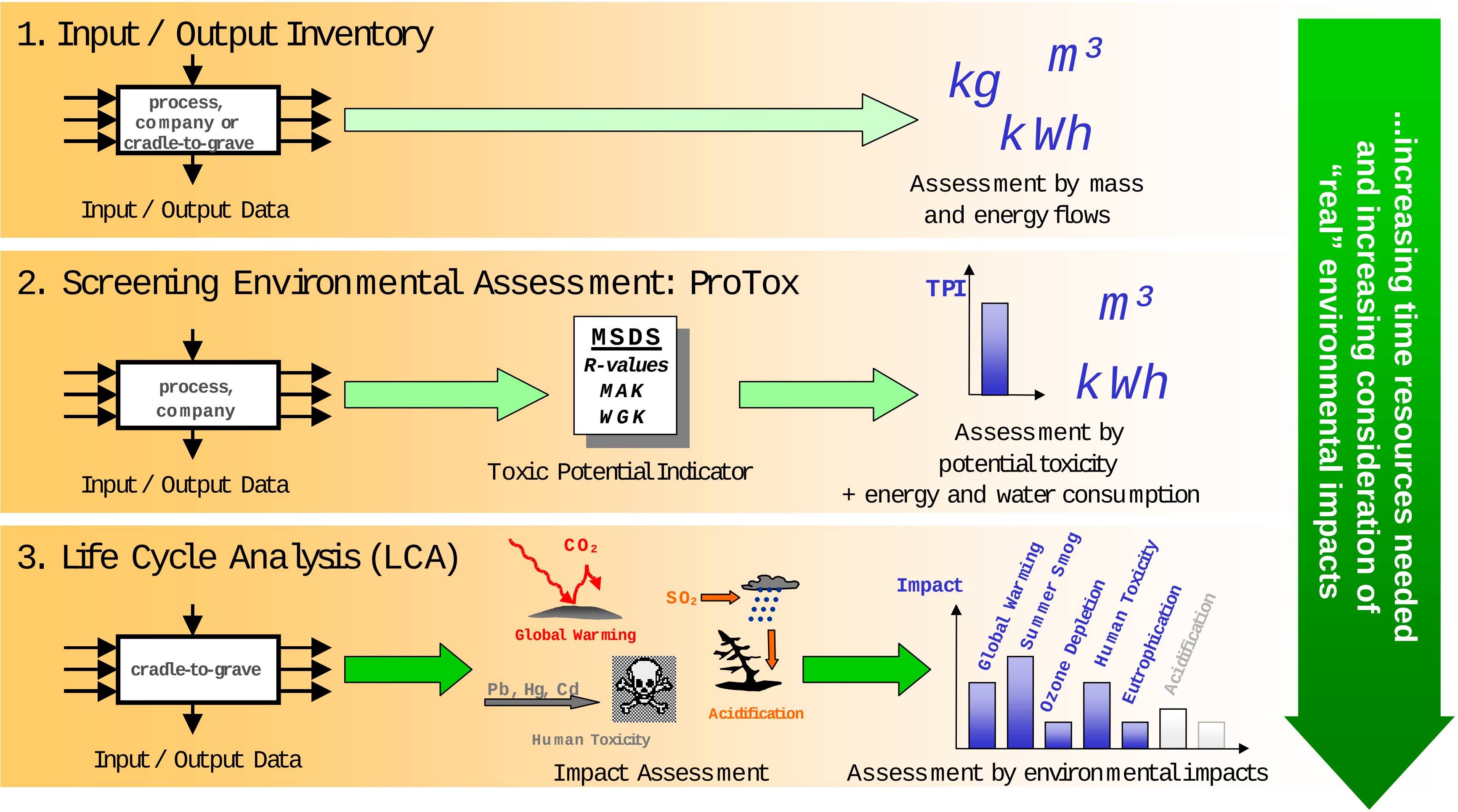
Energy
- Energy consumption for raw materials, for manufacturing processes in electronics industry, and for product usage

RPI Recycling Potential Indicator
- Assessment of product recyclability (economics and technological feasibility)

For more information:
www.pb.izm.fhg.de/ee/070_services/toolbox/index.html

4. Environmental Assessment - Screening Approaches for Electronics

4.3 ProTox: The Step between Inventory and LCA



1. Input / Output Inventory

process, company or cradle-to-grave

Input / Output Data

kg m^3 kWh

Assessment by mass and energy flows

2. Screening Environmental Assessment: ProTox

process, company

Input / Output Data

MSDS
R-values
MAK
WGK

Toxic Potential Indicator

TPI

m^3 kWh

Assessment by potential toxicity + energy and water consumption

3. Life Cycle Analysis (LCA)

cradle-to-grave

Input / Output Data

CO_2

Global Warming

SO_2

Acidification

Pb, Hg, Cd

Human Toxicity

Impact Assessment

Impact

Global Warming

Summer Smog

Ozone Depletion

Human Toxicity

Eutrophication

Acidification

Assessment by environmental impacts

…increasing time resources needed and increasing consideration of "real" environmental impacts

4. Environmental Assessment - Screening Approaches for Electronics

4.4 ProTox: Methodology

(1) Goal and Scope Definition
- Function and functional unit
- System Boundaries: gate-to-gate for a process, technology, or manufacturing site

(2) Inventory Analysis
- raw materials, auxiliaries input
- additional water and energy input
- emissions, waste water, waste output

See ISO 14040ff

(3) ProTox Assessment
- one-indicator-assessment of mass flows: Toxic Potential Indicator (TPI)
- additional consideration of water and energy consumption

See following slides

(4) Interpretation
- benchmarking of processes, technologies, or manufacturing sites; changing of product design; identification and ranking of optimization options etc. etc.

4. Environmental Assessment - Screening Approaches for Electronics

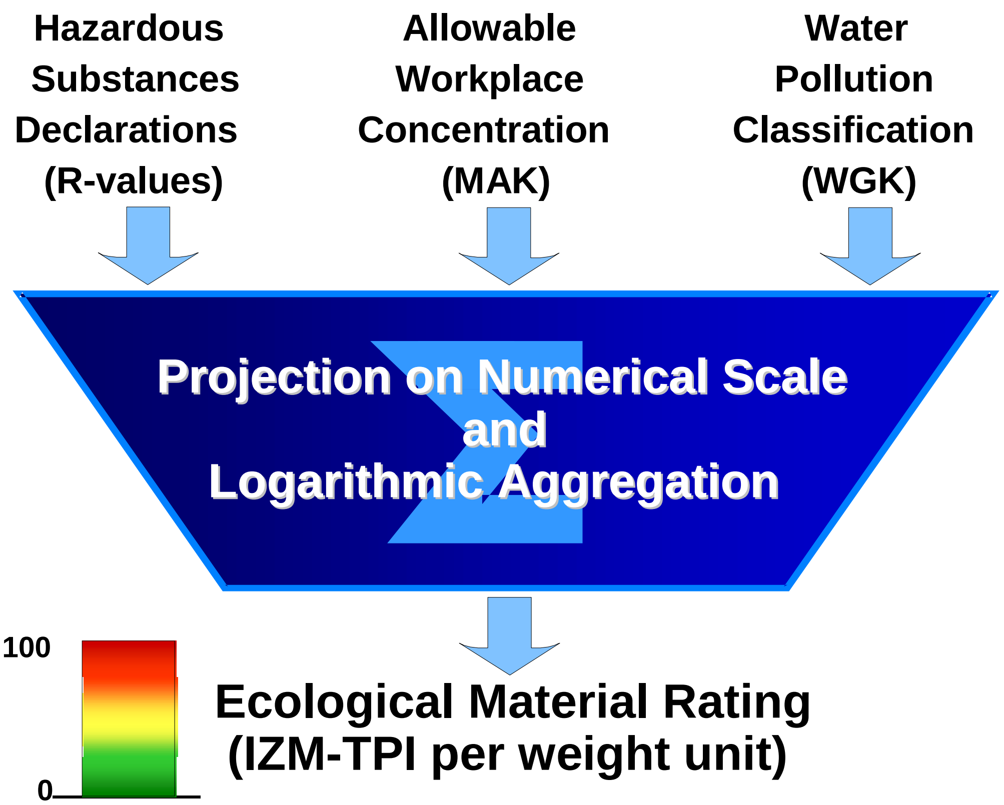
4.4 ProTox: Methodology

Precondition for TPI calculation:
- **chemical substance name,**
- **Material Safety Data Sheet,**
- **mass flows**

Mathematical aggregation with equal weights for
- **human toxicity,**
- **damage to aquatic systems,**
- **declared hazardous properties**

All impacts are *potential* impacts

Applicable only for hazardous chemicals



Hazardous Substances Declarations (R-values)

Allowable Workplace Concentration (MAK)

Water Pollution Classification (WGK)

Projection on Numerical Scale and Logarithmic Aggregation

Ecological Material Rating (IZM-TPI per weight unit)

4. Environmental Assessment - Screening Approaches for Electronics

4.4 ProTox: Methodology

Hazardous Substance Declaration (R-values)

- European legislation: Directive 67/548/EEC on the approximation of laws, regulations and administrative provisions relating to the classification, packaging and labelling of dangerous substances

Allowable Workplace Concentration (MAK)

- German legislation, but threshold limits are similar worldwide; for the US the Threshold Limit Values (TLV) of the American Conference of Governmental Industrial Hygienists (ACGIH) are recommended
- Carcinogenity is considered separately as classified by the European Union (for the US: ACGIH classification)

Water Pollution Classification (WGK)

- German legislation: Classification of substances as “not water-hazardous”, or WGK 1, 2 or 3
- for substances which are not legally classified the WGK can be calculated by considering the R-values

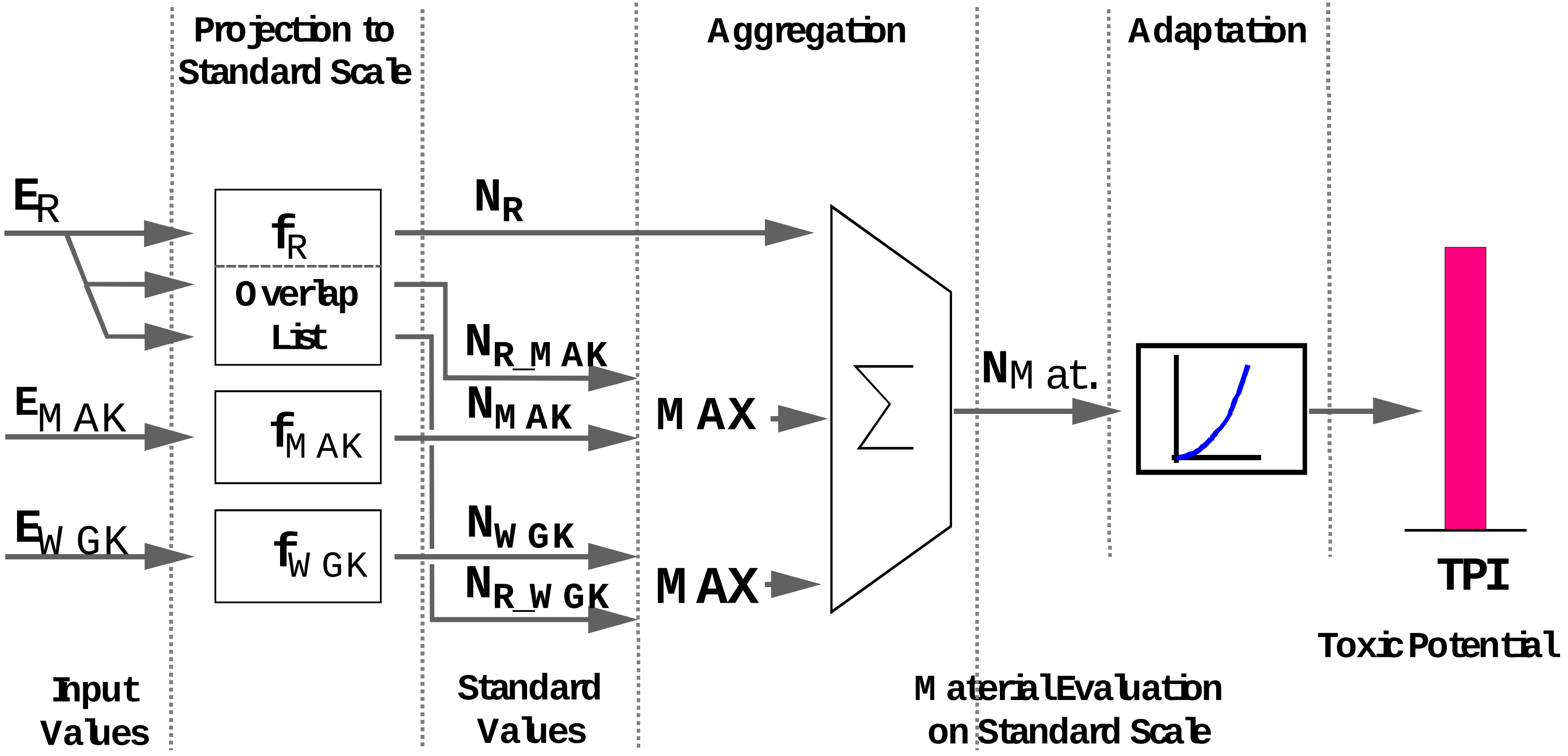
→ all classifications agreed by experts commitees

→ all classifications mandatory for substances distributed within Germany (and frequently done worldwide), see Material Safety Data Sheets!

4. Environmental Assessment - Screening Approaches for Electronics

4.4 ProTox: Methodology

TPI - What happens in the „Black Box“



Projection to Standard Scale

Aggregation

Adaptation

E_R

f_R

Overlap List

N_R

N_{R_MAK}

E_{MAK}

f_{MAK}

N_{MAK}

MAX

E_{WGK}

f_{WGK}

N_{WGK}

N_{R_WGK}

MAX

$\sum$

$N_{Mat.}$

TPI

Toxic Potential

Input Values

Standard Values

Material Evaluation on Standard Scale

4. Environmental Assessment - Screening Approaches for Electronics

4.4 ProTox: Methodology

Example: Calculation of TPI for Mercury

Input Values

MAK 0,08 mg/m^3

WGK 3

R23 "(Hazardous if inhaled), R33 "(Danger of cumulative effects)

Step 1: Evaluation on Standard Scale from 0 (harmless) to 7 (extremely hazardous)

$$N_{MAK} = \log\left(\frac{10^4}{MAK}\right) = 5{,}1$$

WGK3 ⇔ $N_{WGK}=7$

R23 (in Overlap List) with $N_{R\_MAK} = 5$, R33 becomes $N_R = 4$

4. Environmental Assessment - Screening Approaches for Electronics

4.4 ProTox: Methodology

Example: Calculation of TPI for Mercury

Step 2: Aggregation with Elimination of Overlaps

$$N_{Stoff} = Aggr\left(N_R, \max\left(N_{MAK}, N_{R\_MAK}\right), \max\left(N_{WGK}, N_{R\_WGK}\right)\right)$$

$$Aggr\quad\left(N_1 \ldots N_n\right) = \ln\left(\sum_{i=1}^{n} e^{N_i} - n + 1\right)$$

Elimination of N_{R_MAK} from R23, adoption of higher MAK-Evaluation with $N_{MAK} = 5{,}1$

$$N_{Hg} = \ln\left(e^{4} + e^{5,1} + e^{7} - 2\right) = 7{,}18$$

Step 3: Projection on Exponential Scale from 0 to 100

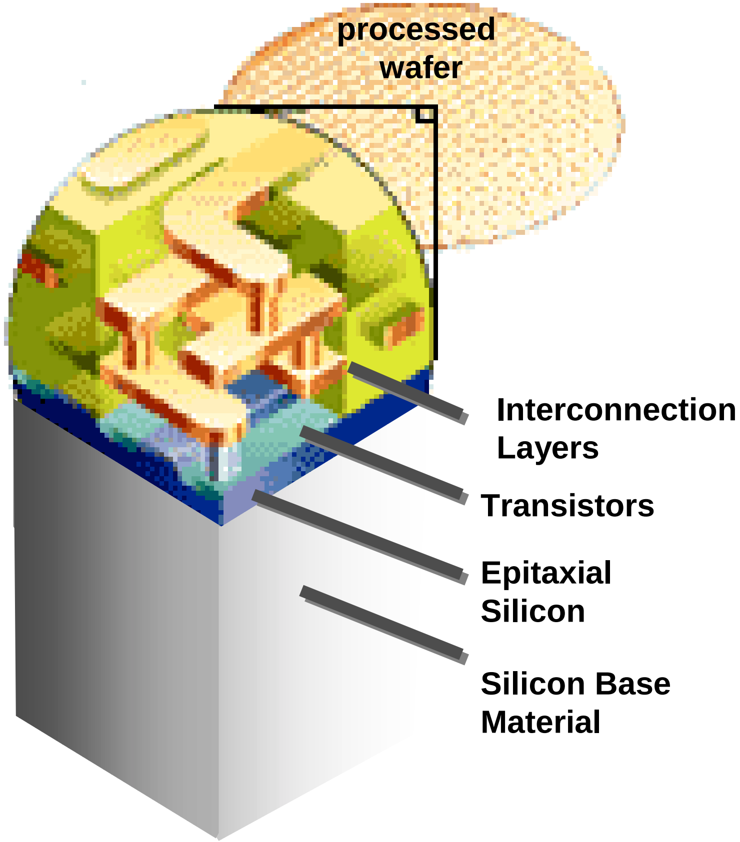
$$TPI_{Hg} = \left(e^{N_{Hg}} \text{-}1\right) : Scaling\ Factor = \left(e^{7,18} \text{-}1\right) : 32{,}869 = 39{,}91$$

4. Environmental Assessment - Screening Approaches for Electronics

4.5 ProTox Case Study I - Identification of Environmentally Significant Aspects of a Wafer Fab

Goal and Scope

- Identification of environmentally significant aspects within wafer processing (semiconductor manufacturing) - which processes are the most environmentally significant ones?
- For reasons of simplification: only assessment of input mass flows

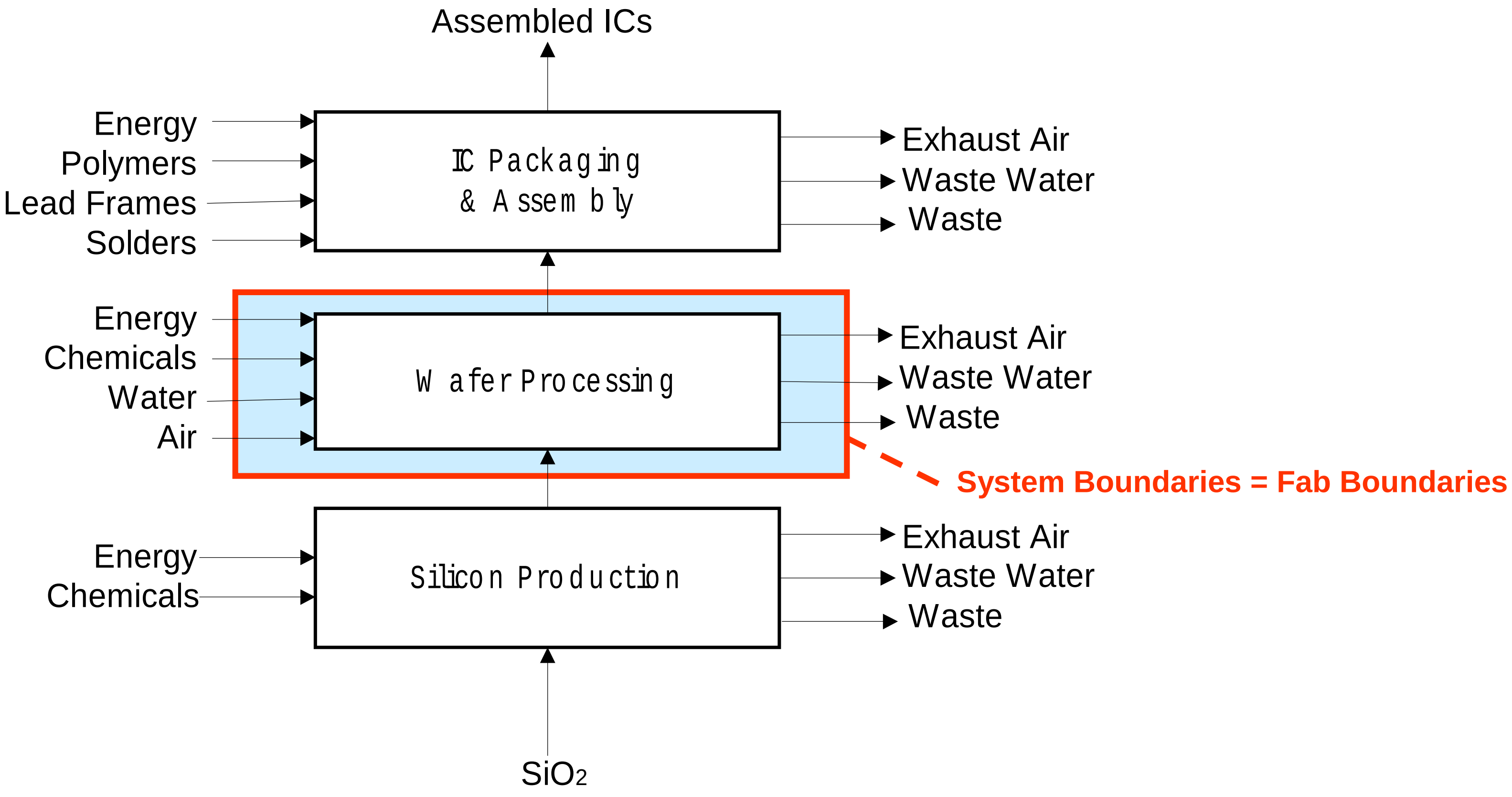


Wafer processing:
from bare silicon wafers to integrated circuits

4. Environmental Assessment - Screening Approaches for Electronics

4.5 ProTox Case Study I - Identification of Environmentally Significant Aspects of a Wafer Fab

System Boundaries: Wafer Fab



Selection of a Functional Unit

Number of mask-steps within processing is a measure for performance:

- functional unit: 1 cm² wafer area processed error-free with a single mask-step
- reference unit for inventory calculations is the number of production units

$$\mathrm{ProductionUnits(PU)} = A_{Wafer}\, n_{Masksteps}\, Yield\left[cm^2\right]$$

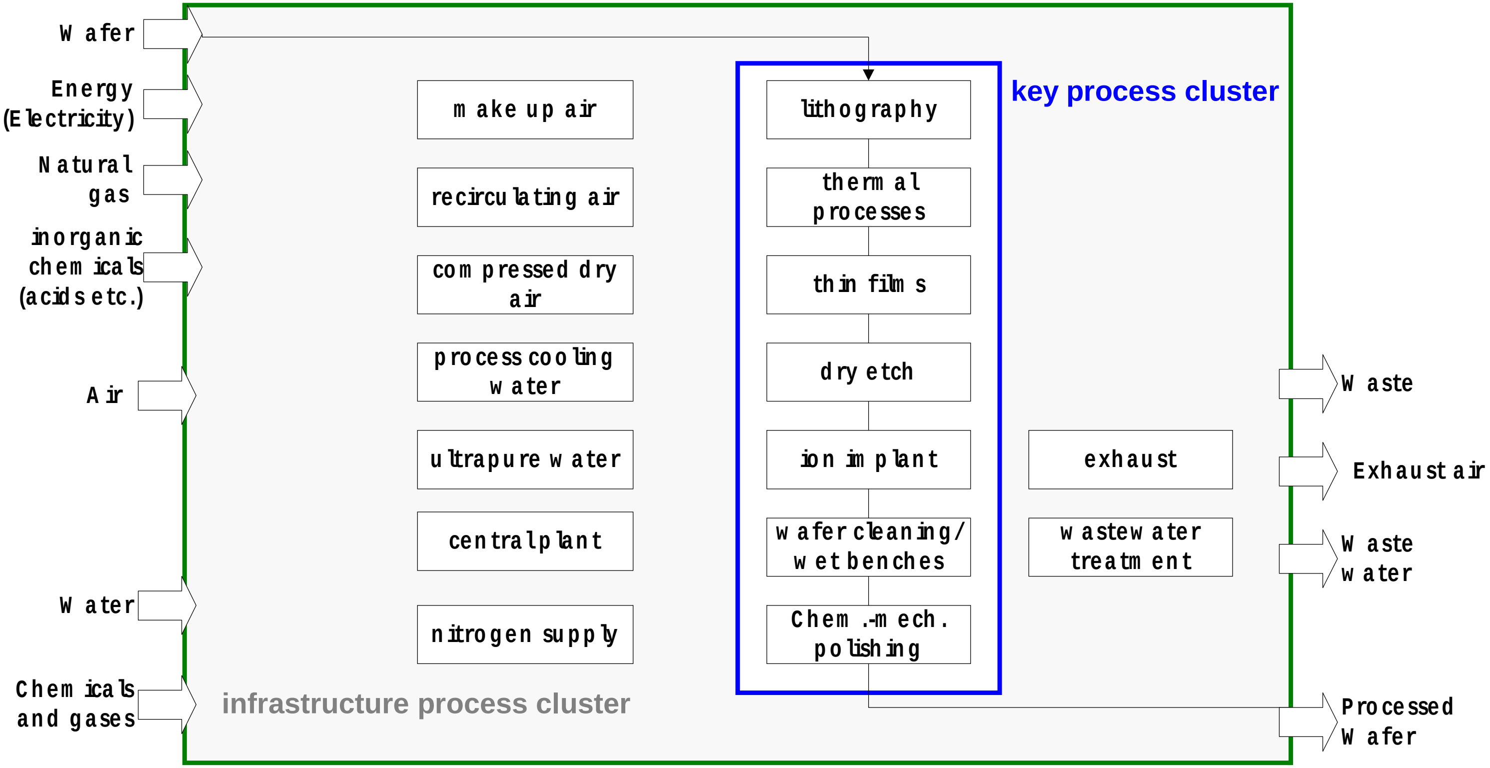
with	A_{Wafer}	as output wafer area in a defined period of time
	$n_{Masksteps}$	as average number of mask-steps in wafer processing
	Yield	average yield for defined period / product range

4. Environmental Assessment - Screening Approaches for Electronics

4.5 ProTox Case Study I - Identification of Environmentally Significant Aspects of a Wafer Fab

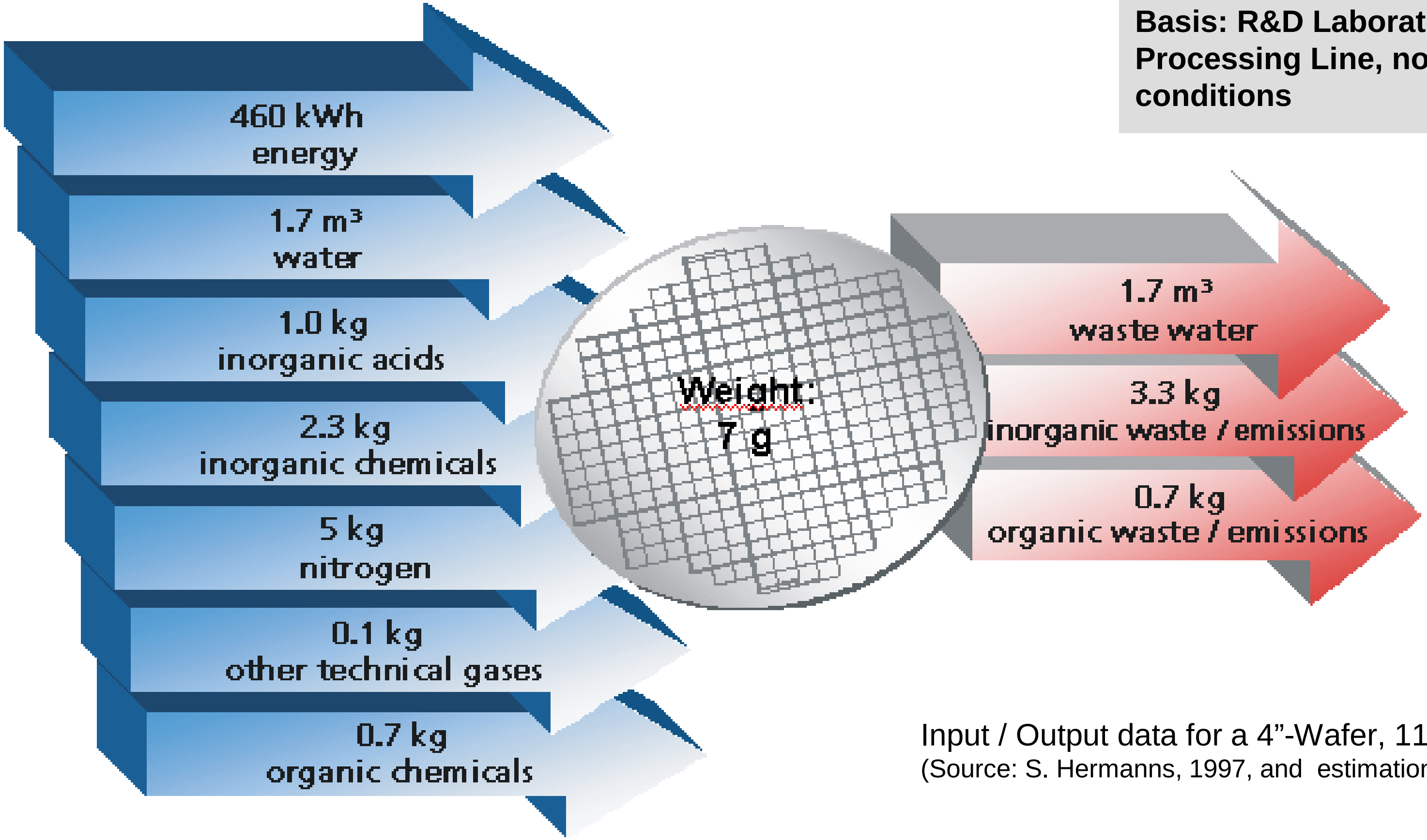
Definition of Process Clusters in Wafer Processing

- reduction of number of processes to a sensible number of clusters is essential for effective data gathering and evaluation



Exemplary aggregated input / output data for wafer processing

Basis: R&D Laboratory Processing Line, no real fab conditions



460 kWh energy

1.7 m³ water

1.0 kg inorganic acids

2.3 kg inorganic chemicals

5 kg nitrogen

0.1 kg other technical gases

0.7 kg organic chemicals

Weight: 7 g

1.7 m³ waste water

3.3 kg inorganic waste / emissions

0.7 kg organic waste / emissions

Input / Output data for a 4”-Wafer, 11 mask-steps

(Source: S. Hermanns, 1997, and estimations K. Schischke)

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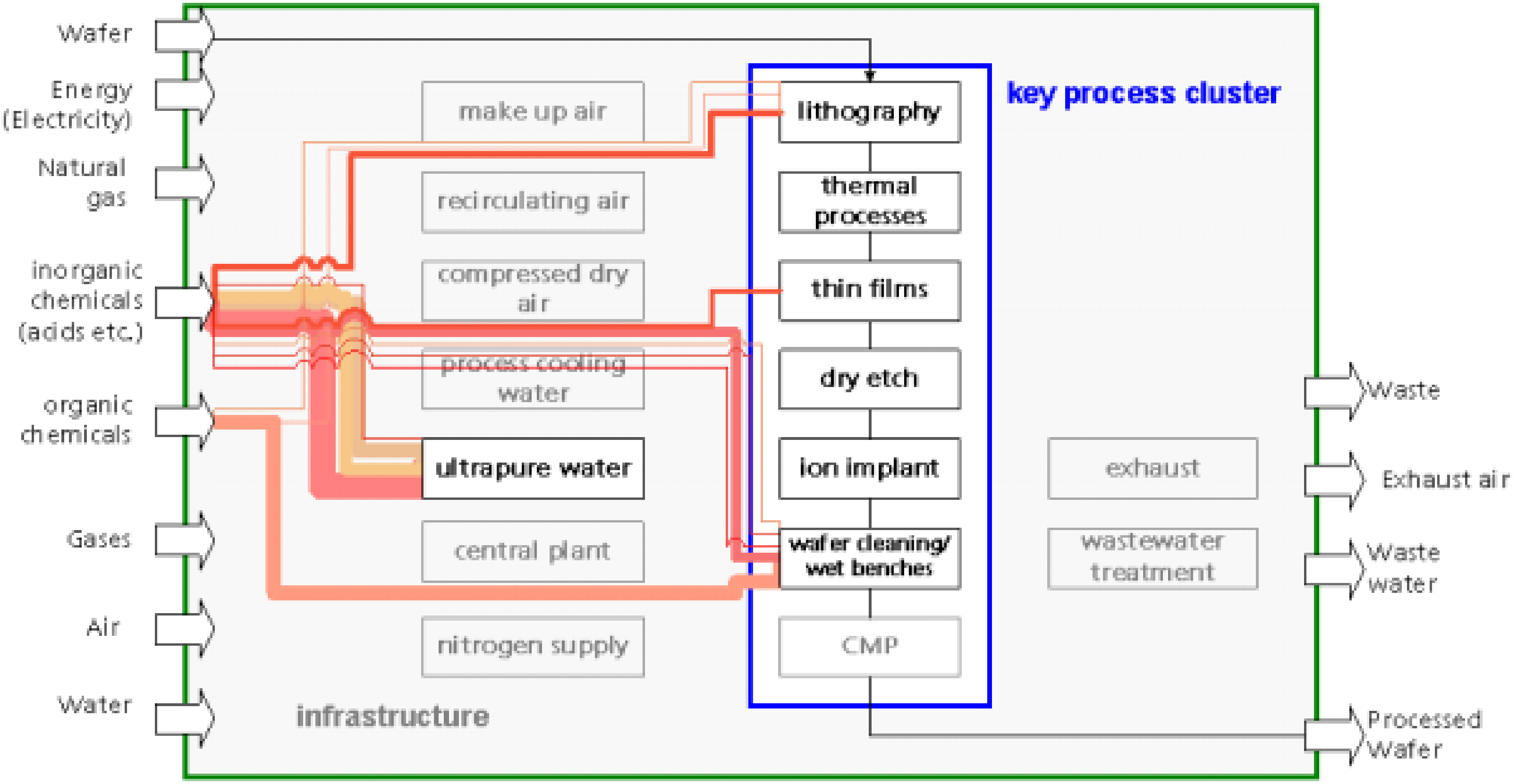
4.5 ProTox Case Study I - Identification of Environmentally Significant Aspects of a Wafer Fab

Mass Flow Analysis - Input of Chemicals



(Source for mass flow data: Hermanns)

Basis: R&D Laboratory Processing Line, no real fab conditions

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4.5 ProTox Case Study I - Identification of Environmentally Significant Aspects of a Wafer Fab

Exemplary calculation of $TPI_{Process}$

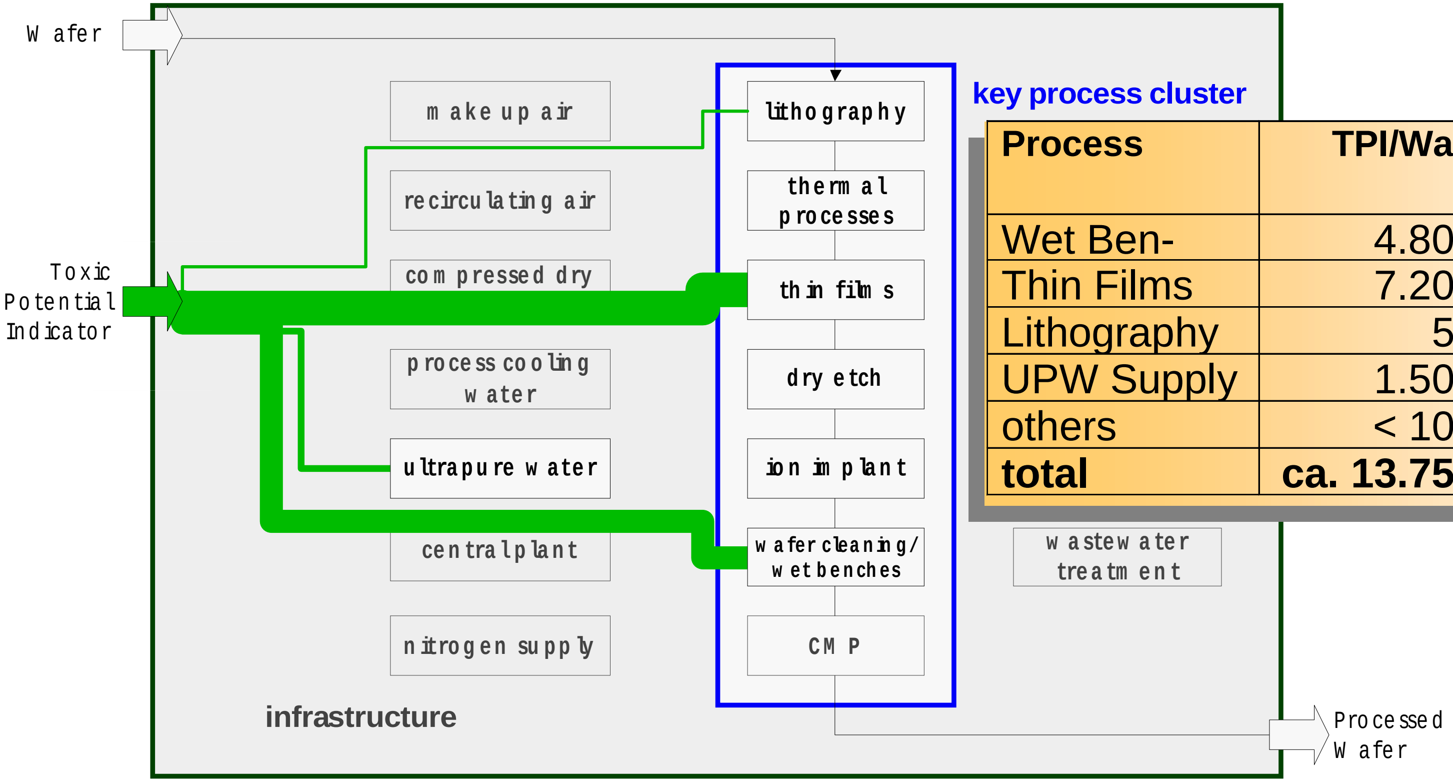
Input Process „Wet Benches / Cleaning“		Hazardous Substance Classifications	substance specific TPI/mg	mass flow specific TPI
Chemical	Input g per Wafer			
H_2SO_4	212,5	R 35; MAK 0,1 mg/m^3; WGK 1	9,55	2.030.000
H_2O_2	72,5	R 34; MAK 1,4 mg/m^3; WGK 1	2,57	190.000
$(NH_4)_2S_2O_8$	0,8	R 8, 22, 36/37/38, 42/43; WGK 1	1,41	1.130
Acetone	600	R 11, 36, 66, 67; MAK 1200 mg/m^3; WGK 1	1,02	610.000
NH_4F	50	R 26/27/28, 35; MAK 2,5 mg/m^3; WGK 1	35,00	1.750.000
HF	1,75	R 26/27/28, 35; MAK 2,5 mg/m^3; WGK 1	35,00	60.000
NH_4OH	10	R 34, 50; WGK 2	12,82	130.000
Total $TPI_{Process\ „Wet\ Benches\ /\ Cleaning“}$ / Wafer			ca.	4.800.000

(Source for mass flow data: Hermanns)

4. Environmental Assessment - Screening Approaches for Electronics

4.5 ProTox Case Study I - Identification of Environmentally Significant Aspects of a Wafer Fab

Identification of Environmentally Significant Aspects



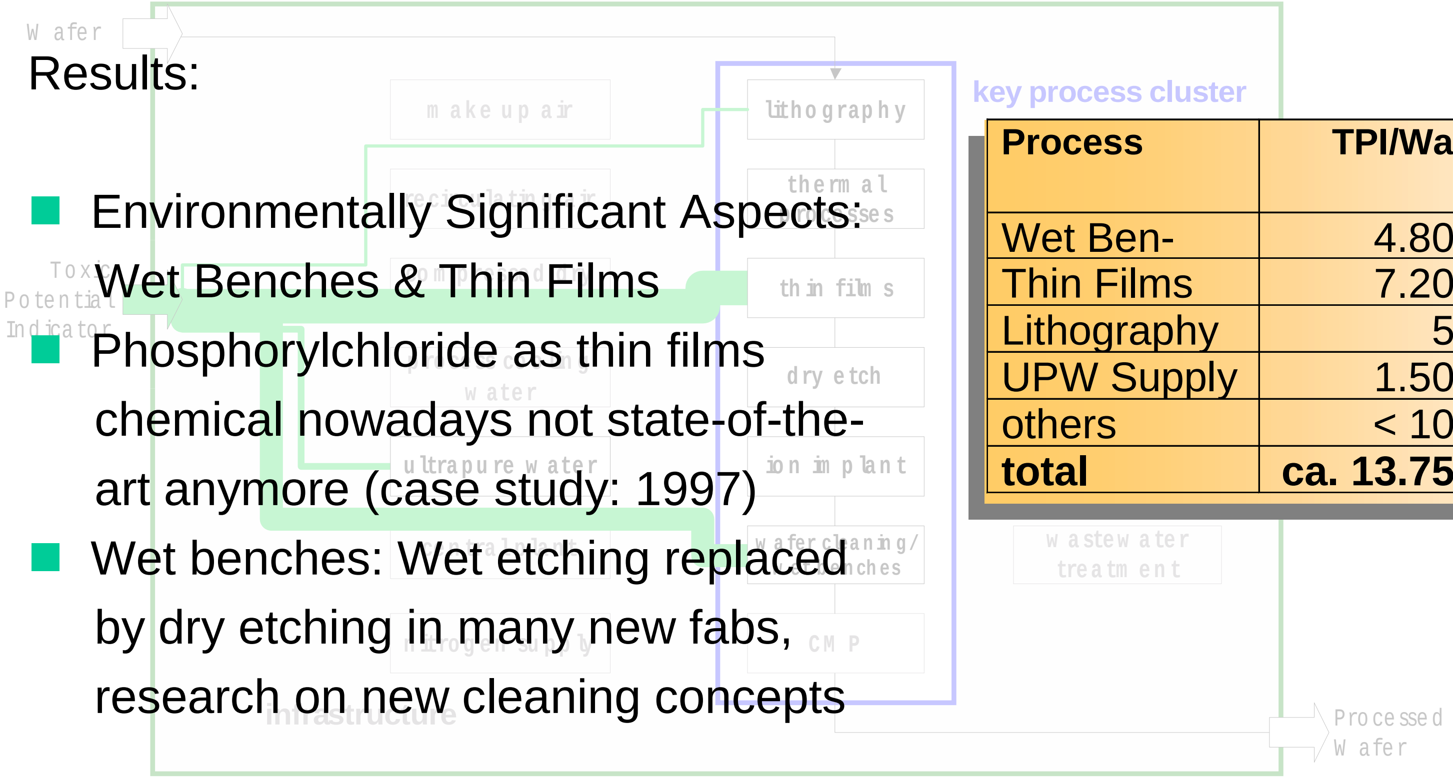
Process	TPI/Wafer	TPI/ cm², mask layer
Wet Ben-	4.800.000	5.700
Thin Films	7.200.000	8.300
Lithography	50.000	60
UPW Supply	1.500.000	1.700
others	< 100.000	< 120
total	**ca. 13.750.000**	**ca. 16.000**

(Source for mass flow data: Hermanns)

4. Environmental Assessment - Screening Approaches for Electronics

4.5 ProTox Case Study I - Identification of Environmentally Significant Aspects of a Wafer Fab

Identification of Environmentally Significant Aspects



Results:

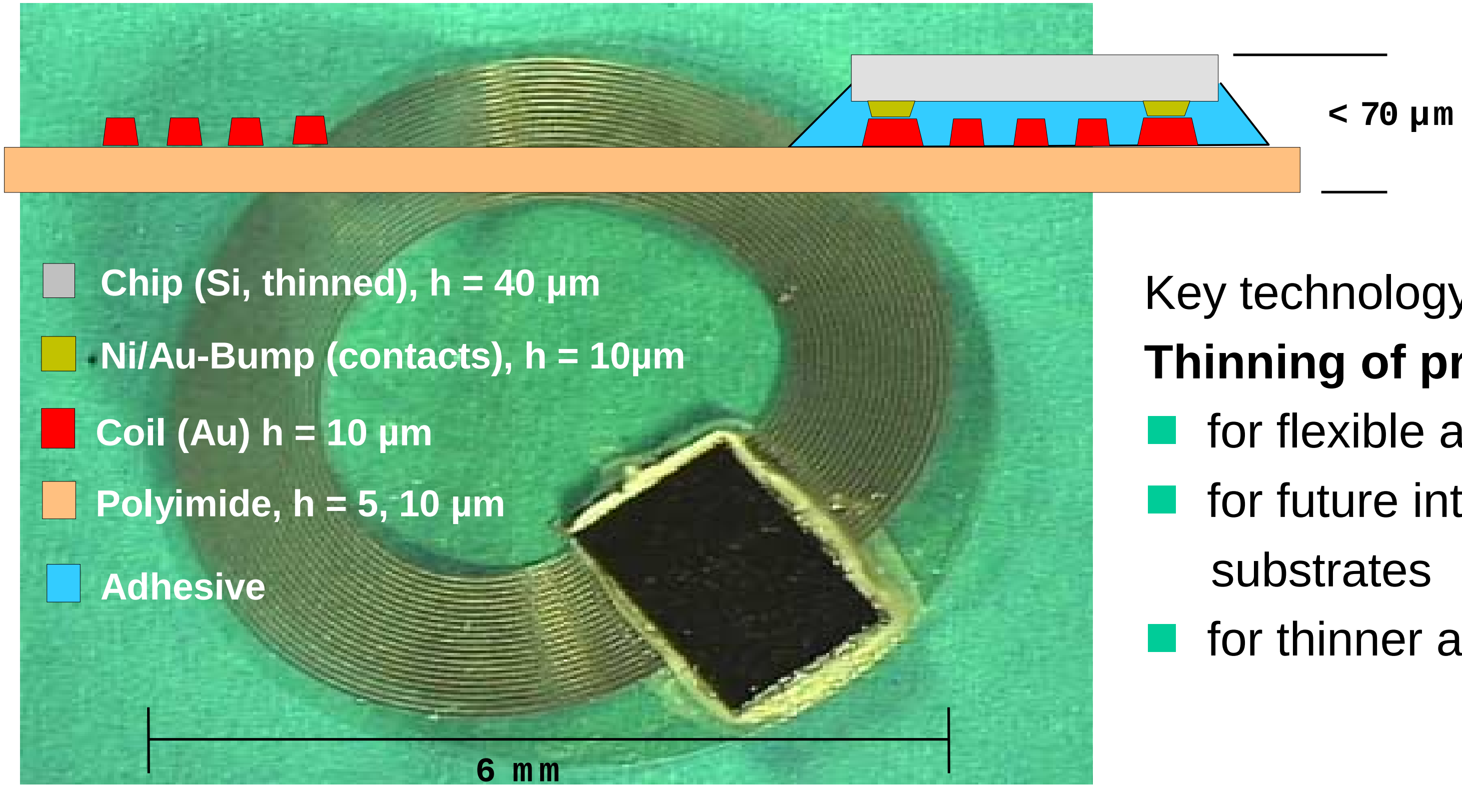
- Environmentally Significant Aspects: Wet Benches & Thin Films
- Phosphorylchloride as thin films chemical nowadays not state-of-the-art anymore (case study: 1997)
- Wet benches: Wet etching replaced by dry etching in many new fabs, research on new cleaning concepts

Process	**TPI/Wafer**	**TPI/ cm², mask layer**
Wet Ben-	4.800.000	5.700
Thin Films	7.200.000	8.300
Lithography	50.000	60
UPW Supply	1.500.000	1.700
others	< 100.000	< 120
total	**ca. 13.750.000**	**ca. 16.000**

4. Environmental Assessment - Screening Approaches for Electronics

4.6 ProTox Case Study II - Eco-Controlling for R&D of new Technologies: Smart Tags

Development of Passive Transponders for Electronic Tags



Key technology for miniaturisation:

Thinning of processed Si-wafers

- for flexible applications
- for future integration into substrates
- for thinner assemblies

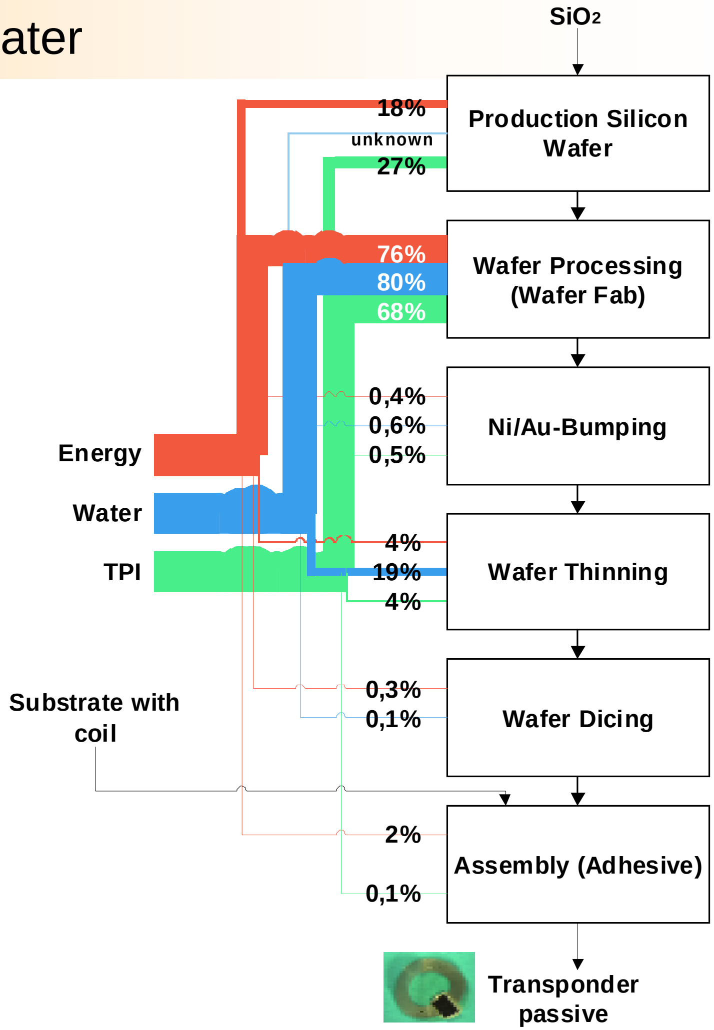
4. Environmental Assessment - Screening Approaches for Electronics

4.6 ProTox Case Study II - Eco-Controlling for R&D of new Technologies: Smart Tags

Sankey Chart for ProTox (Input-TPI), Energy, and Water

Conclusions:

- thinning of Si-wafers is a small but relevant environmental aspect, much more relevant than the interconnection technologies bumping and assembly
- environmental aspects of wafer processing are of high significance
- therefore, the yield of thinning (as of the other following process steps) affects the overall environmental impacts of the tag significantly



4. Environmental Assessment - Screening Approaches for Electronics

4.6 Conclusions: ProTox as a DfE/LCM-Tool for Electronics

Requirements for a DfE/LCM-Tool for Electronics	Characteristics of ProTox
■ Faster than LCA (keeping pace with innovation cycles)	➔ much less time for inventory (see system boundaries), less time for environmental assessment
■ Applicable within the design process - preferred one-indicator-solution	➔ depending on process-know-how, TPI is one-indicator-solution, additional energy, water recommended
■ Minimized data gaps and uncertainties	➔ data gaps minimized, uncertainties about correspondence between potential and real impacts
■ Based on published data	➔ inventory data survey for a process required, for assessment data see MSDS (or published databases)
■ Environmental assessment based on experts' substance assessment	➔ Hazardous substance classification based on experts' committees
■ Addressing electronics specific environmental topics: Toxicity of a variety of chemicals, greenhouse effect / energy, water consumption, disposal / recycling	➔ Toxicity considered, energy and water has to be considered separately, for disposal / recycling and material content of products see other tools of the Fraunhofer IZM/EE Toolbox

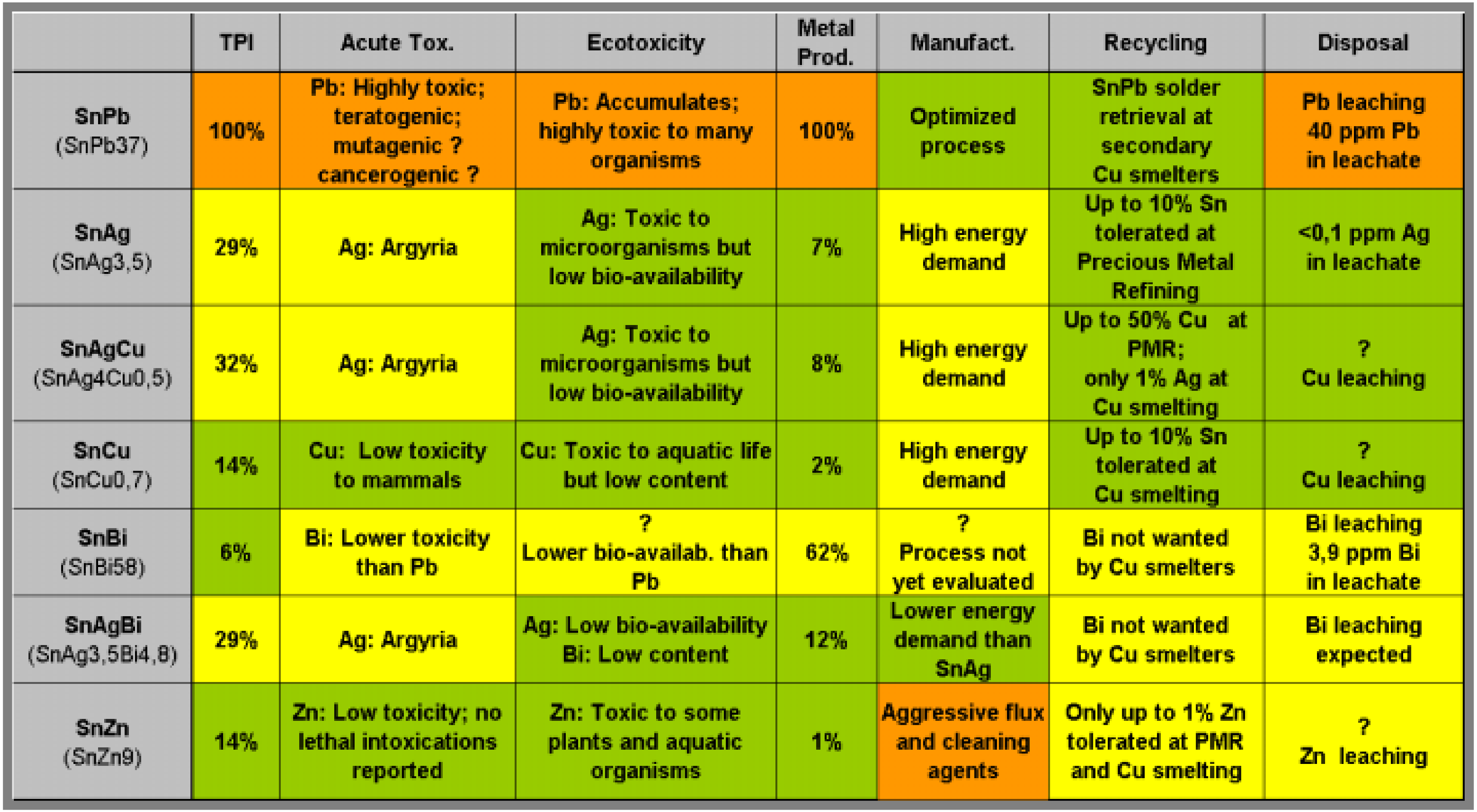
5. Life Cycle Aspects of Lead free Electronics

5.1 Introduction

- world wide trend in electronics towards lead free interconnection systems
- driven by marketing (“green sells better”), legislation (e.g. European draft for a lead ban for electronics), and the demand for higher melting solder systems for automotive
- several replacement alternatives for SnPb-solder are under development, such as Cu, Ag, Bi containing Sn based solders
- green marketing & leadfree legislation based on assumption, that leadfree is environmentally preferable - but there’s no Life Cycle Assessment of a lead ban for electronics by now
- research is currently done by Fraunhofer IZM and others towards an analysis of life cycle aspects of leadfree interconnection systems...

5. Life Cycle Aspects of Lead free Electronics

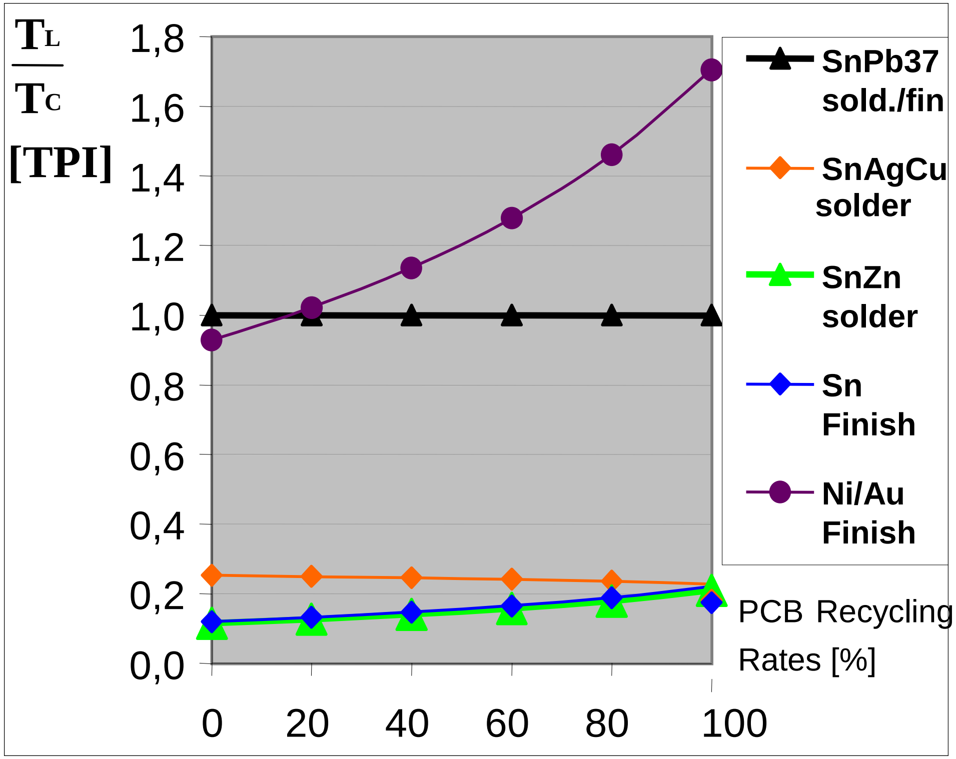
5.2 Environmental Aspects of SnPb and Lead free Solder



	TPI	Acute Tox.	Ecotoxicity	Metal Prod.	Manufact.	Recycling	Disposal
SnPb (SnPb37)	100%	Pb: Highly toxic; teratogenic; mutagenic ? cancerogenic ?	Pb: Accumulates; highly toxic to many organisms	100%	Optimized process	SnPb solder retrieval at secondary Cu smelters	Pb leaching 40 ppm Pb in leachate
SnAg (SnAg3,5)	29%	Ag: Argyria	Ag: Toxic to microorganisms but low bio-availability	7%	High energy demand	Up to 10% Sn tolerated at Precious Metal Refining	<0,1 ppm Ag in leachate
SnAgCu (SnAg4Cu0,5)	32%	Ag: Argyria	Ag: Toxic to microorganisms but low bio-availability	8%	High energy demand	Up to 50% Cu at PMR; only 1% Ag at Cu smelting	? Cu leaching
SnCu (SnCu0,7)	14%	Cu: Low toxicity to mammals	Cu: Toxic to aquatic life but low content	2%	High energy demand	Up to 10% Sn tolerated at Cu smelting	? Cu leaching
SnBi (SnBi58)	6%	Bi: Lower toxicity than Pb	? Lower bio-availab. than Pb	62%	? Process not yet evaluated	Bi not wanted by Cu smelters	Bi leaching 3,9 ppm Bi in leachate
SnAgBi (SnAg3,5Bi4,8)	29%	Ag: Argyria	Ag: Low bio-availability Bi: Low content	12%	Lower energy demand than SnAg	Bi not wanted by Cu smelters	Bi leaching expected
SnZn (SnZn9)	14%	Zn: Low toxicity; no lethal intoxications reported	Zn: Toxic to some plants and aquatic organisms	1%	Aggressive flux and cleaning agents	Only up to 1% Zn tolerated at PMR and Cu smelting	? Zn leaching

5. Life Cycle Aspects of Lead free Electronics

5.3 Toxic releases from printed wiring boards (PWB) into the environment



T_L	Toxic releases from lead-free PWB
T_C	Toxic releases from conventional PWB

Basic assumptions and conditions:

Measurement of toxicity linked to materials that are not recycled depending on the recycling rate of PWBs, and are thus released into the environment

Evaluation of toxic releases with Toxic Potential Indicator (TPI)

Equal recycling rates for lead-free and conventional PWBs

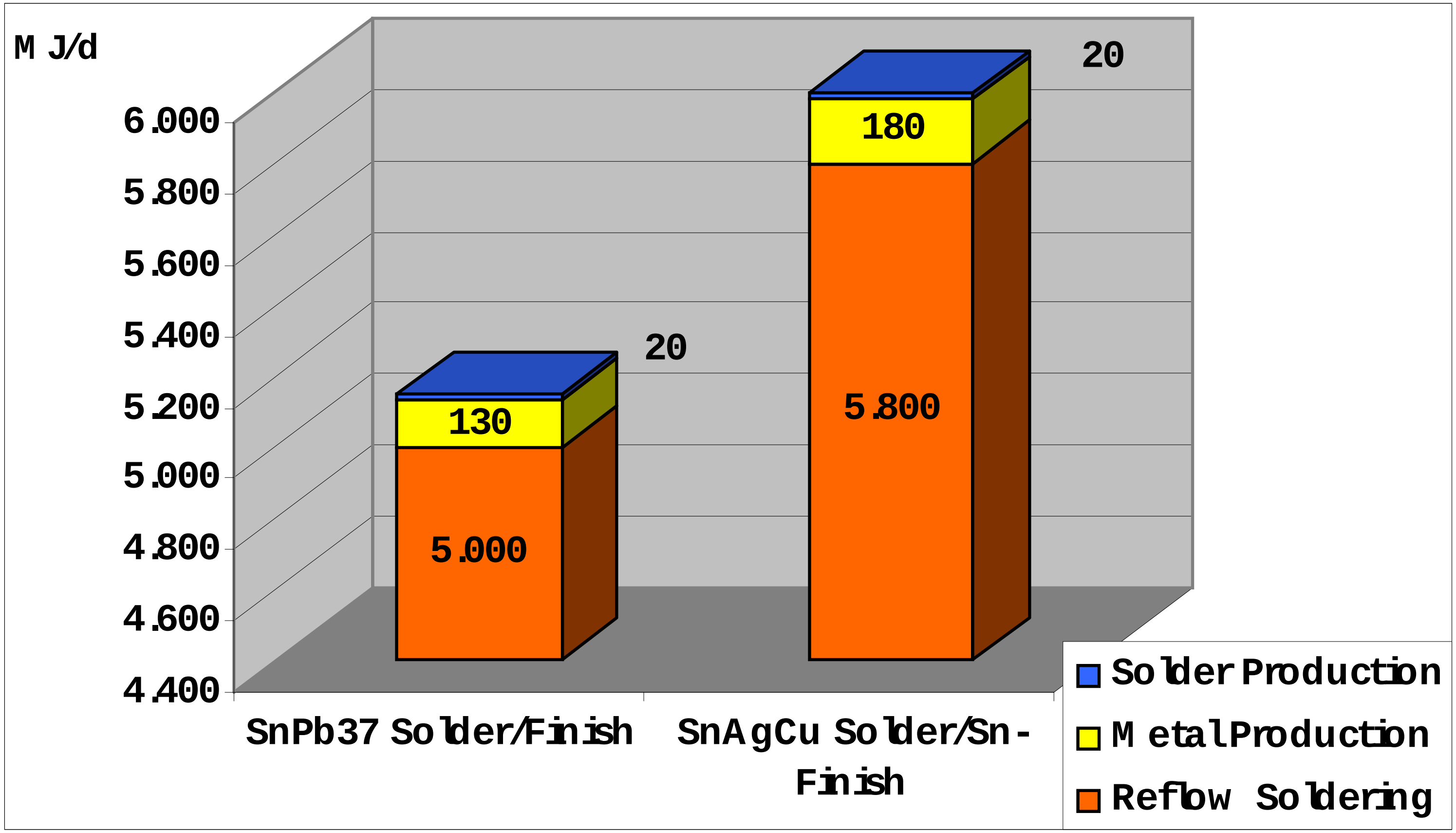
Recovery rates in recycling process (DOWA in Japan): 98 % for silver and copper, 10 % for zinc, 50 % for lead (best case study for conventional materials)

Results:

Despite of best-case conditions for conventional materials, lead-free materials reduce toxic material releases from PWB into environment

5. Life Cycle Aspects of Lead free Electronics

5.4 Daily primary energy consumption in industrial nitrogen reflow soldering process



Assumed Increase in Energy Consumption for Lead-free Reflow Soldering Process:

+ 15 %

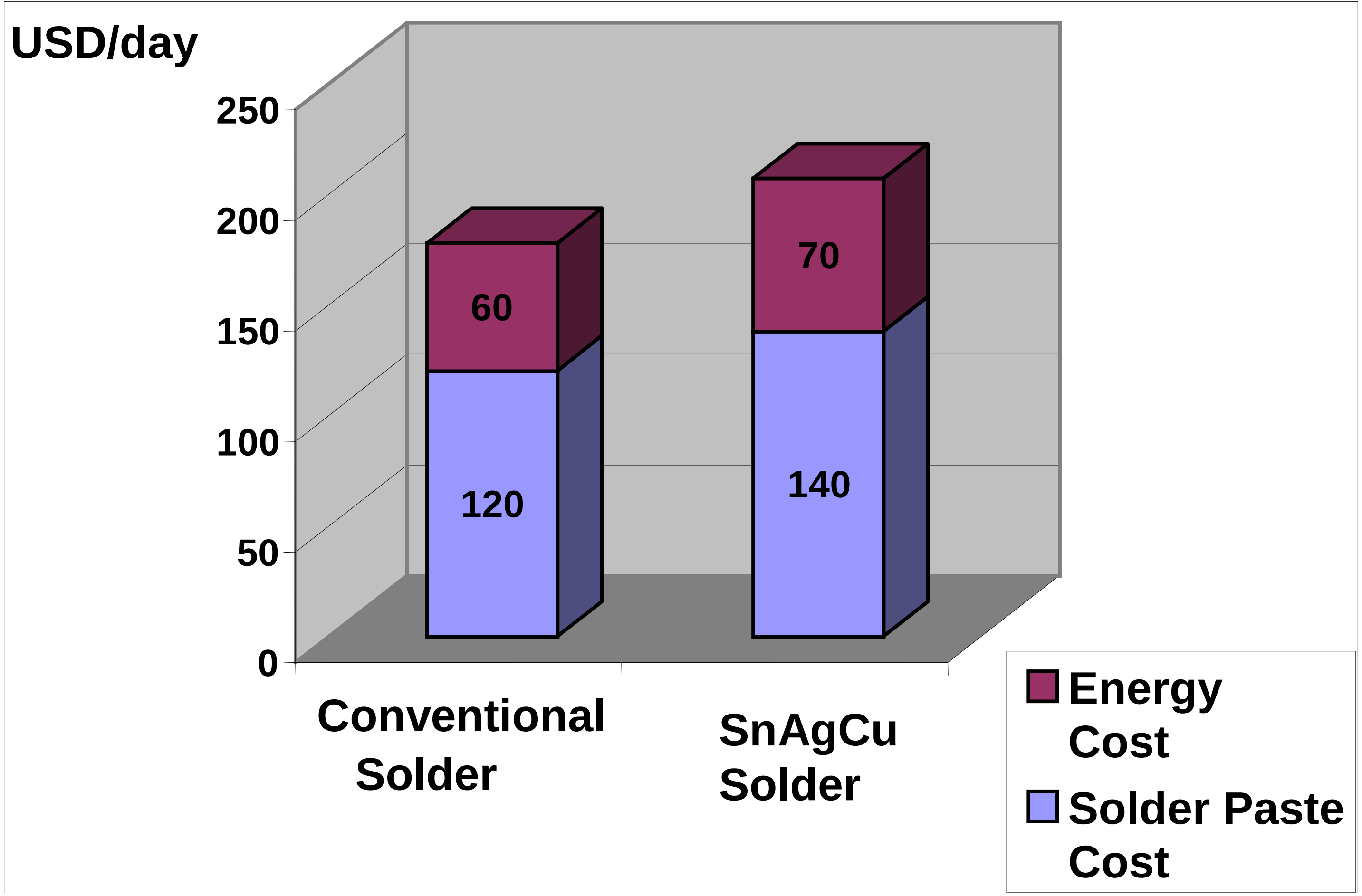
Metal production: production of metals from ore

Solder production: production of solder paste from metals

Production of finish from metals not yet included, but no basic changes expected

5. Life Cycle Aspects of Lead free Electronics

5.5 Additional cost in industrial nitrogen reflow soldering process (without finish manufacturing)



* **Japanese/European Price Levels, Currency Conversion 12/2000**

Assumptions:

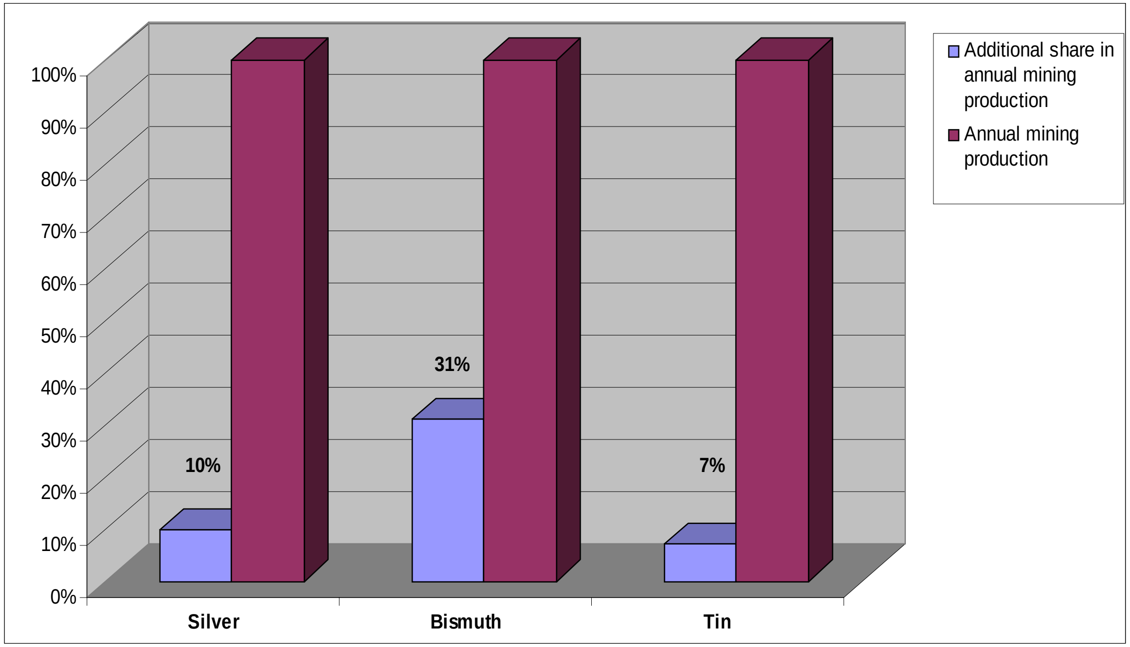
- No additional cost for pre-baking of PCBs and components
- no higher component cost because of higher heat-resistance

Recycling cost reduction for SnAgCu-PCB in copper smelter:

0.10 to 0.20 $/kg (20-40 % at assumed average recycling cost of 0.5 $/kg printed wiring board)

5. Life Cycle Aspects of Lead free Electronics

5.6 WORST CASE for additional metal consumption by lead free soldering



Assumptions and Conditions:

No recycling of used printed wiring boards, minimum recycling of silver from manufacturing solder waste, no recycling of tin and bismuth

Basic data for bismuth insecure, maximum consumption and share in mining production probably much lower

Results:

Besides potentially for Bismuth, lead-free soldering will not considerably increase immediate pressure on resources. Long-term effects on resources and metal markets not yet clear

6. Conclusions and Summary

- Too many data gaps and uncertainties hinder reliable & fast LCAs for complex electronic products
- Life Cycle Assessments are not applicable as DfE-tool for electronics by now:
  - need for screening tools
  - need for research activities and a generic database for:
    - (1) inventory of upstream processes,
    - (2) inventory data for microelectronics specific processes & update of process database has to keep pace with innovation rates,
    - (3) impact assessment of microelectronics specific emissions,
    - (4) waste management and scenarios for e-scrap
- Process related screening supports a combination of ecologic and economic target settings
- Screening Assessment Tool ProTox supports DfE, technology development, and environmental management in the field of electronics manufacturing
- Environmental policy has to be supported by sound LCA studies for scientifically based legislation - especially in the field of electronics (highly complex life cycle aspects)
- Hot topic “lead free electronics”: ban affects world wide supply chains, alternatives have to be environmentally compatible compared to lead

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