In LCA/LCM Conference

# Development of Risk Assessment Methodology for A Product System

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# 0. Introduction

## Korea Eco-Products Institute

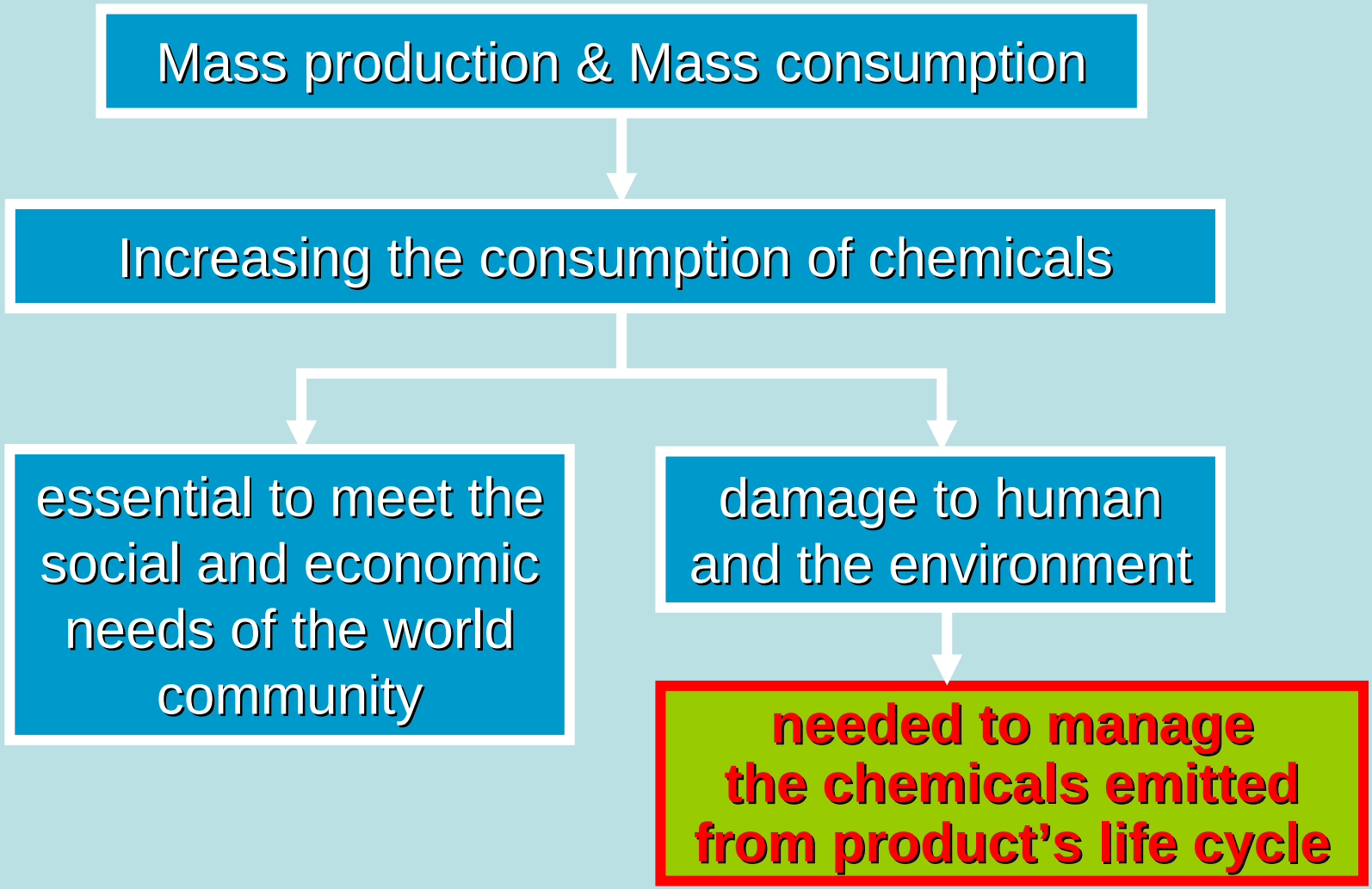

http://www.koeco.or.kr/eng/index.asp

# 0. Introduction

## History of this study

- Title : Standardization of Life Cycle Risk Assessment (LCRA) Methodology using Life Cycle Assessment (LCA) and Construction of its database
- Period : June 2004 ~ March 2007
- Sponsor : Ministry of Environment, Republic of Korea
- Purpose :
  - Constructing the system for effective management of chemical products based on potential risks induced from product's life cycle
  - Applying the results of this project to the Korea Type III environmental declaration program

# 1. Background of this study



# 1. Background of this study

## Conventional Risk Assessment (RA)

the process of establishing information regarding acceptable levels of a risk and/or levels of risk for an individual, group, society, or the environment.

Focus on a hazardous chemical substance from site-specific region.

Cannot consider the chemicals from product's life cycle

**Need to develop a methodology, which can evaluate the potential risks from product's life cycle**

# 2. Analysis of current methodologies

## Current methodology

- Eco-indicator 99 (Goedkoop & Spriensma, 1999; Hofstetter, 1998)
- EDIP (Wenzel et al., 1997; Hauschild & Wenzel, 1998)
- Fh-IUCT (Walz et al., 1998; Keller et al., 1998; Herrchen et al., 1997)
- USES-LCA (Huijbregts, 1999), CalTOX (McKone, 1993) etc.

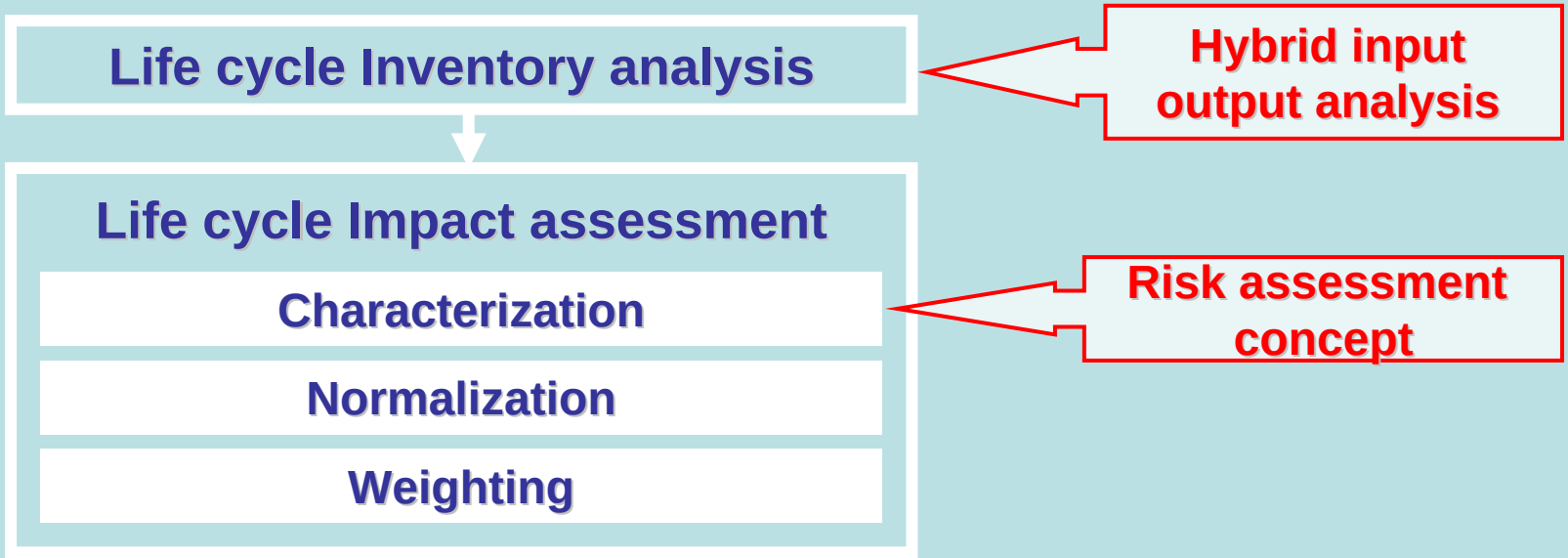
- A series of Life cycle impact assessment (LCIA) method
- On the toxicity impact, chemicals move within the defined boundaries (e.g. European area)

→ They are not reflect the domestic environmental conditions.

**Need to develop a methodology, which reflect the domestic environmental conditions**

# 3. Development of proposed method

## Basic concept




## Two obstacles of conventional LCA

1. The number of chemical substances included in LCI database is not enough to evaluate the overall potential risks.
2. The results of LCIA have not given the apparent understanding since in most cases it evaluates the potential risks at the emission level.

# 3. Development of proposed method

## Life cycle inventory analysis

$$M = P \cdot X^{-1} \cdot Y$$

**M: Life cycle inventory** **$X^{-1}$: Leontief multiplier**

**Y: Final demand matrix** **P: emission factor**

## Emission factors

1. Emission factor consists of 146 toxic release inventory (TRI), presented in the Korea PRTR program, per 128 industrial sectors.
2. The unit of the emission factor is [kg/$]
3. The total amount of each chemical in the domestic country is;
   = amount of *i* chemical ×(GDP_domestic / GDP_other country)

# 3. Development of proposed method

## Characterization / Life cycle impact assessment

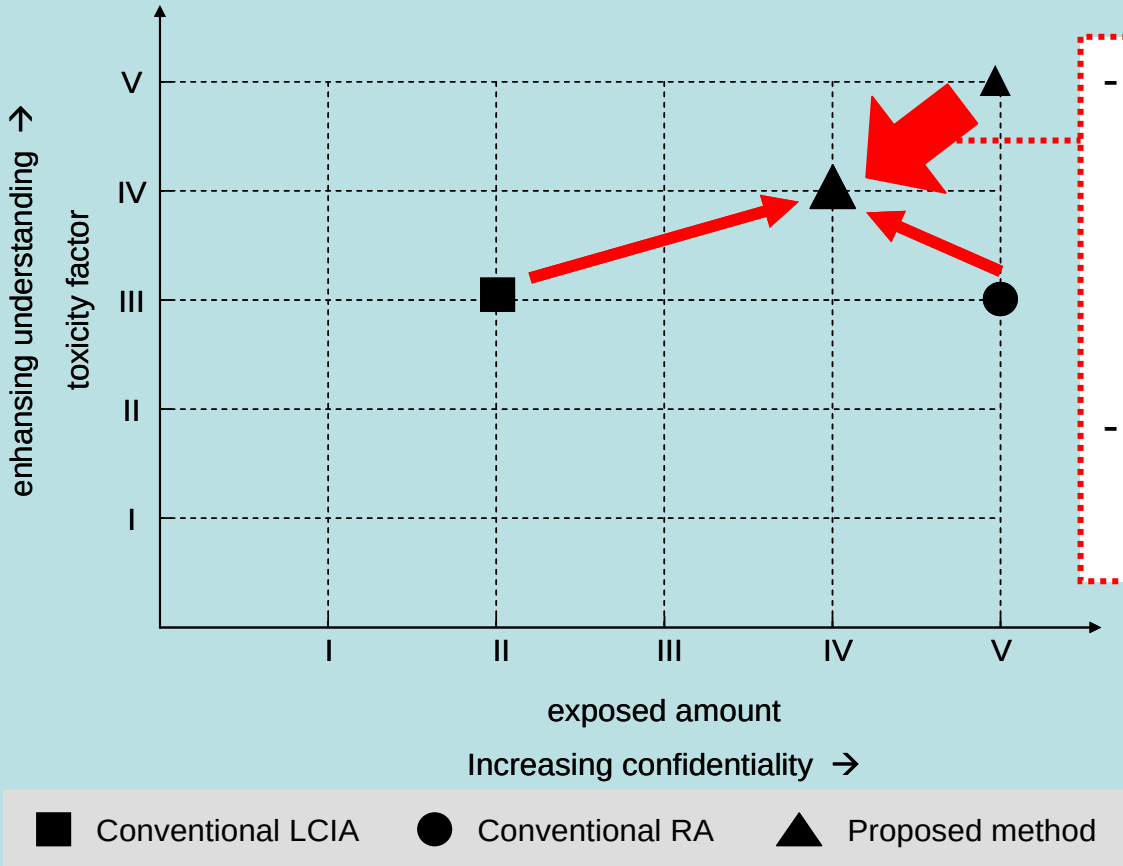
| Type | Exposed concentration | Toxicity factor |
|---|---|---|
| I | only emission, no further exposure analysis, no effect analysis | None |
| II | emission data, no fate data, effect analysis | Partially risk indicator |
| III | emission data, some fate analysis, effect analysis | equivalent indicator (e.g. $LD_{50}$, etc) |
| IV | emission data, generic fate analysis, effect analysis | mid-point indicator (e.g. ADI, LADE, CR, HI etc) |
| V | emission data, site-specific fate analysis, effect analysis | end-point (damage) indicator (e.g. DALY etc) |

Source: "Nordic Guidelines on the Life-Cycle Assessment (1995)"

**Potential risk = Exposed concentration × Toxicity factor**

# 3. Development of proposed method

## Characterization / Life cycle impact assessment




- it is **difficult to collect site-specific data** for the exposed concentration **throughout product's life cycle**
- the toxicity factors **at the end-point level** are **not available**.

# 3. Development of proposed method

## Exposure analysis / Characterization / Life cycle impact assessment

**to human body**
(Lifetime Average Daily Exposure, **LADE**)

**Source: "Example Exposure Scenarios (US-EPA, 2004)"**

**Inhalation (mg/L)**

$$LADE_{i\_inhalation} = \frac{(C \times ET \times EF \times ED)}{AT}$$

**Ingestion (mg/kg/day)**

$$LADE_{i\_ingestion} = \frac{(C \times (IR/BW) \times EF \times ED)}{AT}$$

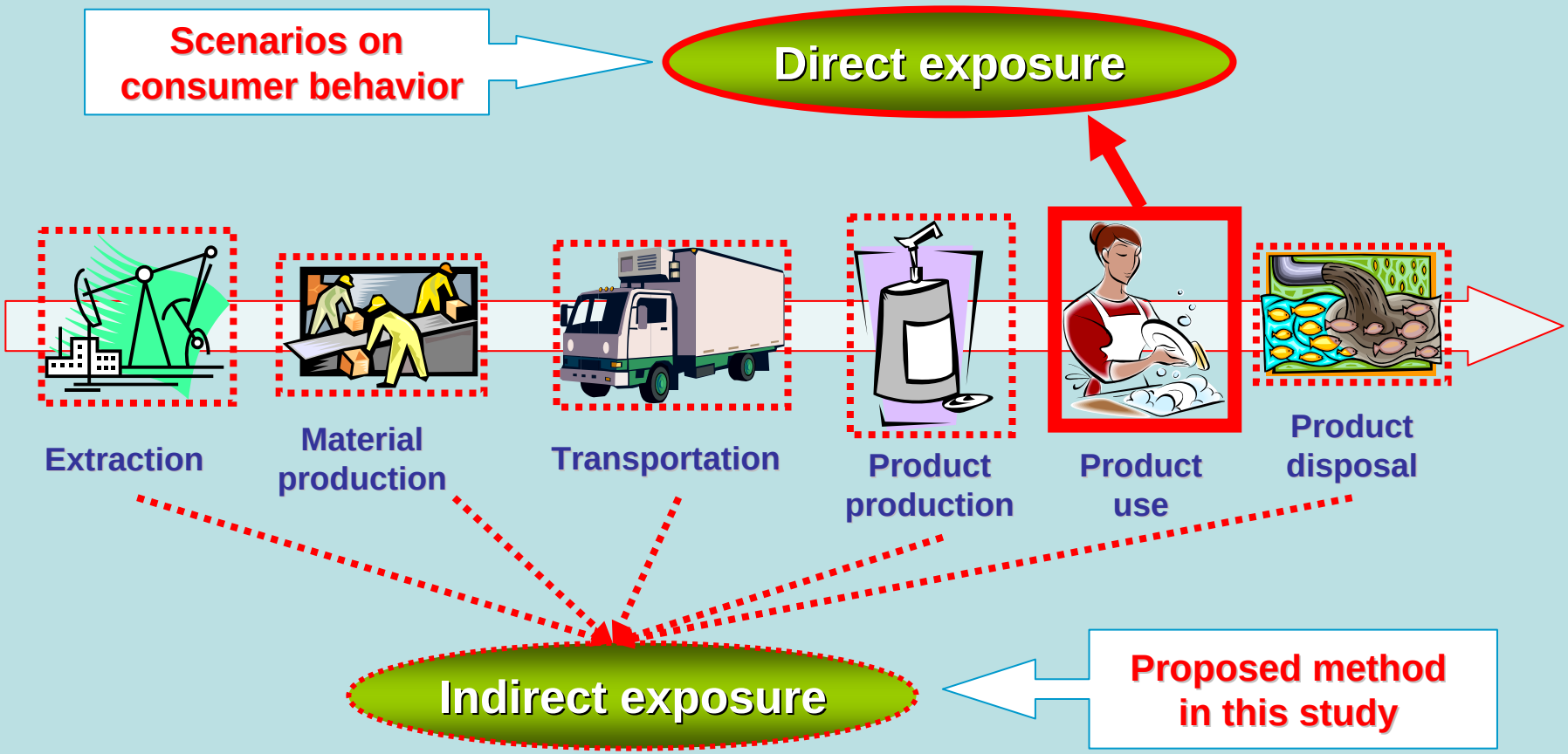
**Dermal contact (mg/kg/day)**

$$LADE_{i\_dermal} = \frac{(C \times CF \times (SA/BW) \times AF \times EF \times ED)}{AT}$$

**to the environment**
(Predicted Environmental Concentration, **PEC**)

# 3. Development of proposed method

**Exposure analysis** / Characterization / Life cycle impact assessment



# 3. Development of proposed method

## Exposure analysis / Characterization / Life cycle impact assessment

### Setting general exposure factors to reflect the domestic conditions

| Exposure factor | Value | Reference |
|---|---|---|
| body weight | 65 kg | KRISS, 1997 |
| average lifetime | 70 year | KNSO, 2003 |
| exposure duration | 70 year | Yonsei Univ., 1995 |
| daily water intake | 2L/day | Yonsei Univ., 1995 |
| daily air ingestion | $20m^3$/day | Yonsei Univ., 1995 |
| exposure surface area | 17,000 $cm^2$ | US EPA, 1996 |
| Absorption fraction | Organic 1.0%<br>Inorganic: 0.1% | US EPA, 1995 |

# 3. Development of proposed method

## Risk characterization / Characterization / Life cycle impact assessment

### Human Cancer – Cancer Risk (CR)

$$TCR = \sum_i \sum_j CR_{ij}$$

$$= \sum_i \left[ (LADE_{i\_ingestion} \times CPF_{i\_ingestion}) + (LADE_{i\_dermal} \times CPF_{i\_dermal}) \right] + \sum_i \left[ (LADE_{i\_inhalation} \times UR_{i\_inhalation}) \right]$$

### Human non-cancer – Hazardous Index (HI)

$$THI = \sum_i \sum_j HI_{ij} = \sum_i \frac{LADE_{i\_inhalation}}{RfC_{i\_inhalation}} + \frac{LADE_{i\_ingestion}}{RfD_{i\_ingestion}} + \frac{LADE_{i\_dermal}}{RfD_{i\_dermal}}$$

### Ecotoxicity – Ecotoxicity Index (EI)

$$TEI = \sum_i \sum_k \frac{PEC_{ik}}{PNEC_{ik}}$$

# 3. Development of proposed method

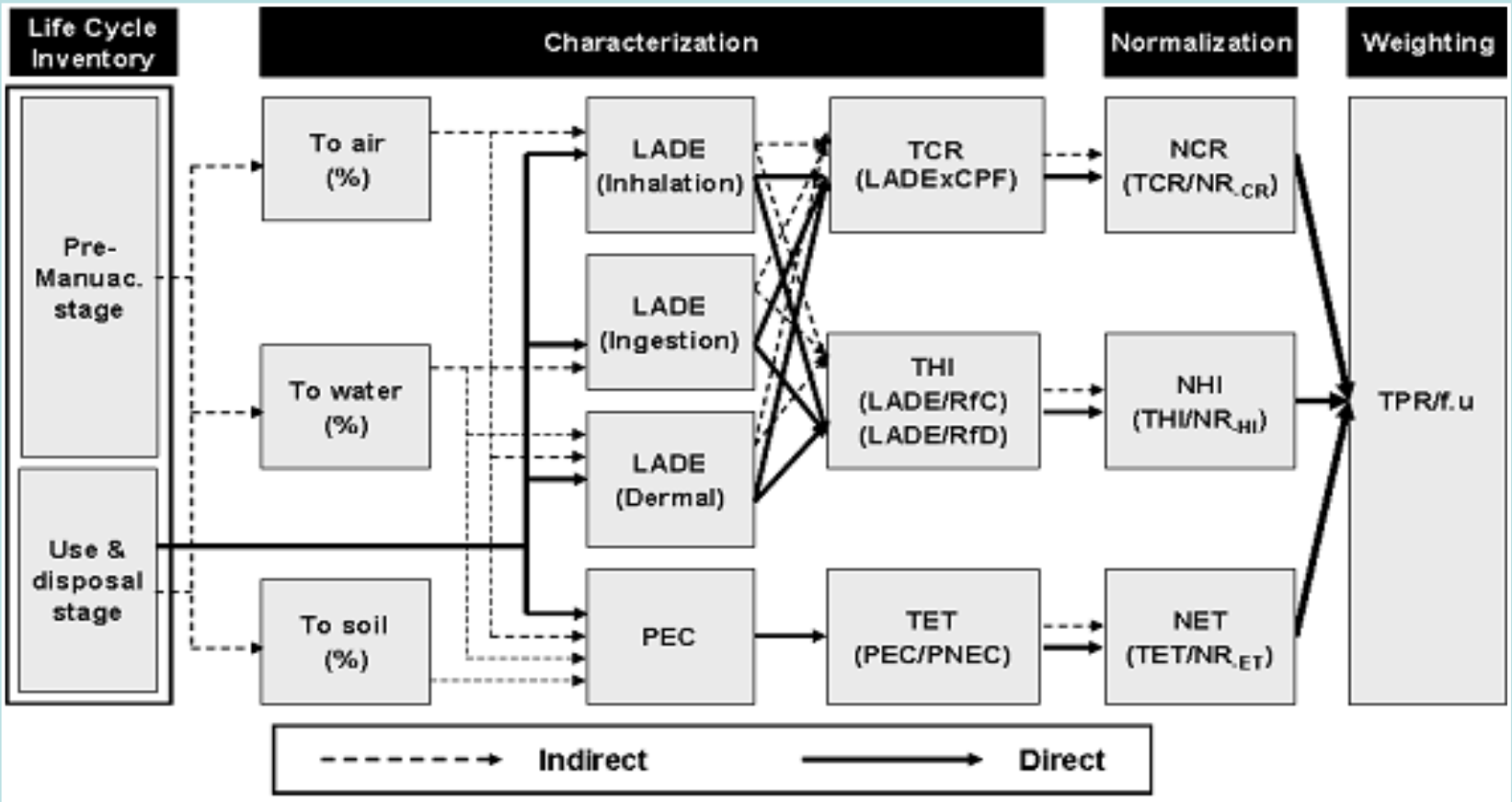
**Risk characterization / Characterization / Life cycle impact assessment**

**Why is needed to integrate the toxicity of each chemical substance associated with a risk category**

- This method evaluate the potential risk of not a chemical substance but all chemical substances from product's life cycle.
- This method is intended to evaluate the potential risk, not evaluate the actual risk.

# 3. Development of proposed method

## Technical framework / Life cycle impact assessment



# 4. Case study on laundry detergent

## Scope definition

- Target product: household laundry detergent
- Functional unit: 1kg production of detergent
- System boundary: cradle to grave
- Risk categories : Human cancer (CR),
  Human non-cancer (HI), Eco-toxicity (EI)

# 4. Case study on laundry detergent

## LCI results / pre-manufacturing stage

| Chemical substances | CAS No. | unit | The amounts released to | | |
|---|---|---|---|---|---|
| | | | air | water | land |
| aniline | 000062-53-3 | kg | 5.68E-04 | 8.76E-09 | 1.55E-09 |
| acetic Acid | 000064-19-7 | kg | 2.98E-04 | 2.46E-09 | 0.00E+00 |
| butyl benzyl phthalate | 000085-68-7 | kg | 4.85E-04 | 0.00E+00 | 0.00E+00 |
| bis(2-ethylhexyl) adipate | 000103-23-1 | kg | 2.22E-03 | 1.32E-08 | 1.09E-09 |
| epichlorohydrin | 000106-89-8 | kg | 2.64E-03 | 4.54E-08 | 0.00E+00 |
| toluene | 000108-88-3 | kg | 9.12E-06 | 3.89E-07 | 4.19E-11 |
| cyclohexylamine | 000108-91-8 | kg | 2.19E-03 | 1.28E-06 | 0.00E+00 |
| diazinon | 000333-41-5 | kg | 2.14E-03 | 1.32E-06 | 0.00E+00 |
| dimethyldisulfide | 000624-92-0 | kg | 4.89E-03 | 2.60E-06 | 0.00E+00 |
| copper & copper compound | 007440-50-8 | kg | 1.14E-05 | 1.72E-05 | 1.98E-16 |
| iprobenfos | 026087-47-8 | kg | 8.85E-03 | 5.66E-08 | 0.00E+00 |
| : | : | : | : | : | : |

# 4. Case study on laundry detergent

## LCI results / use and disposal stages

| Chemical substances | CAS No. | unit | Amount (water) |
|---|---|---|---|
| sodium alkylbenzenesulfonate | 068411-30-3 | kg | 9.78E-02 |
| primary alkyl ethoxylate | - | kg | 3.60E-03 |
| secondary alkyl ethoxylate | - | kg | 3.66E-02 |
| sodium carbonate | 000497-19-8 | kg | 3.43E-01 |
| sodium sulphate | 007757-82-6 | kg | 2.45E-01 |
| aluminosilicates | 001318-02-1 | kg | 1.63E-01 |
| tallow fatty acid | 067701-01-3 | kg | 4.60E-03 |
| lipase, fungal | 009001-62-1 | kg | 2.00E-03 |
| sodium C14-16 olefin sulfonate | 068439-57-6 | kg | 4.06E-02 |
| fluoresence whitening agent | 016090-02-1 | kg | 1.00E-03 |

*** This study assumed that all chemical substances of detergent are released to the environment**

# 4. Case study on laundry detergent

## Indirect exposed concentration / to human / LCIA results

| Chemical substances | CAS NO. | Inhalation ($mg/m^3$) | Ingestion (mg/kg-day) |
|---|---|---|---|
| aniline | 000062-53-3 | 3.81E-12 | 3.30E-18 |
| acetic acid | 000064-19-7 | 2.08E-12 | 2.51E-19 |
| butyl benzyl phthalate | 000085-68-7 | 3.38E-12 | 0.00E+00 |
| bis(2-ethylhexyl) adipate | 000103-23-1 | 1.55E-11 | 3.58E-18 |
| epichlorohydrin | 000106-89-8 | 1.84E-11 | 1.16E-17 |
| toluene | 000108-88-3 | 6.33E-14 | 5.35E-17 |
| cyclohexyl amine | 000108-91-8 | 1.53E-11 | 3.64E-16 |
| diazinon | 000333-41-5 | 1.48E-11 | 3.80E-16 |
| dimethyldisulfide | 000624-92-0 | 3.41E-11 | 7.46E-16 |
| copper and copper compound | 007440-50-8 | 7.97E-14 | 4.94E-15 |
| iprobenfos | 026087-47-8 | 6.17E-11 | 1.62E-17 |
| : | : | : | : |

# 4. Case study on laundry detergent

## Direct exposed concentration / to human / LCIA results

| Chemical substances | First laundering | | Washing machine | |
|---|---|---|---|---|
| | inhalation | dermal contact | inhalation | dermal contact |
| linear alkyl benzene sulphonate | 1.87E-07 | 1.10E-03 | 5.61E-07 | 1.81E+00 |
| primary alkyl ethoxylate | 6.90E-09 | 4.07E-05 | 2.07E-08 | 6.67E-02 |
| secondary alkyl ethoxylate | 6.99E-08 | 4.12E-04 | 2.10E-07 | 6.75E-01 |
| polymer | 1.44E-08 | 8.48E-05 | 4.31E-08 | 1.39E-01 |
| sodium carbonate (light) | 6.54E-07 | 3.86E-03 | 1.96E-06 | 6.32E+00 |
| sodium sulphate | 4.69E-07 | 2.76E-03 | 1.41E-06 | 4.53E+00 |
| zeolite 4Na | 3.11E-07 | 1.84E-03 | 9.33E-07 | 3.01E+00 |
| tallow fatty acid | 8.77E-09 | 5.18E-05 | 2.63E-08 | 8.48E-02 |
| sodium carbonate (dense) | 1.03E-07 | 6.06E-04 | 3.08E-07 | 9.92E-01 |
| enzyme | 3.83E-09 | 2.26E-05 | 1.15E-08 | 3.70E-02 |
| alpha olefin sulphonate | 7.75E-08 | 4.57E-04 | 2.33E-07 | 7.49E-01 |
| fluoresence whitening agent (1) | 1.92E-09 | 1.13E-05 | 5.76E-09 | 1.85E-02 |
| perfume | 2.16E-09 | 1.27E-05 | 6.47E-09 | 2.08E-02 |
| fluoresence whitening agent (5) | 1.11E-09 | 6.57E-06 | 3.34E-09 | 1.08E-02 |

# 4. Case study on laundry detergent

## Exposed concentration / to environment / pre-manufacturing

| Chemical substances | CAS No. | PEC | Chemical substances | CAS No. | PEC |
|---|---|---|---|---|---|
| aniline | 000062-53-3 | 5.02E-17 | cyclohexyl amine | 000108-91-8 | 1.04E-14 |
| acetic Acid | 000064-19-7 | 7.16E-18 | diazinon | 000333-41-5 | 1.08E-14 |
| butyl benzyl phthalate | 000085-68-7 | 0.00E+00 | dimethyl disulfide | 000624-92-0 | 2.13E-14 |
| bis(2-ethylhexyl) adipate | 000103-23-1 | 1.02E-16 | copper and copper compound | 007440-50-8 | 1.41E-13 |
| epichlorohydrin | 000106-89-8 | 3.31E-16 | iprobenfos | 026087-47-8 | 4.62E-16 |
| toluene | 000108-88-3 | 1.53E-15 | : | : | : |

# 4. Case study on laundry detergent

## Exposed concentration / to environment / disposal

| Chemical substances | PEC | Chemical substances | PEC |
|---|---|---|---|
| linear alkyl benzene sulphonate | 8.24E-09 | tallow fatty acid | 3.87E-10 |
| primary Alkyl Ethoxylate | 3.04E-10 | sodium carbonate (Dense) | 4.53E-09 |
| secondary Alkyl Ethoxylate | 3.08E-09 | enzyme | 1.69E-10 |
| polymer | 6.34E-10 | alpha olefin sulphonate | 3.42E-09 |
| sodium Carbonate (light) | 2.89E-08 | fluorescence whitening agent(1) | 8.46E-11 |
| sodium sulphate | 2.07E-08 | perfume | 9.51E-11 |
| zeolite 4Na | 1.37E-08 | fluorescence whitening agent(5) | 4.91E-11 |

# 4. Case study on laundry detergent

## Risk characterization / cancer risk

| Chemical substances | Cancer risk (indirect) | |
|---|---|---|
| | inhalation | Ingestion |
| formaldehyde | 7.68E-17 | 0.00E+00 |
| chloroform | 1.91E-13 | 0.00E+00 |
| vinyl chloride | 6.29E-14 | 6.42E-15 |
| acetaldehyde | 1.08E-17 | 0.00E+00 |
| dichloromethane | 1.35E-18 | 5.74E-20 |
| ethylene oxide | 1.19E-15 | 1.60E-17 |
| epichlorohydrin | 1.90E-14 | 1.15E-19 |
| 1,3-butadiene | 7.87E-15 | 0.00E+00 |
| acrylonitrile | 2.21E-15 | 1.35E-18 |
| chlorothalonil | 0.00E+00 | 1.81E-19 |
| arsenic and arsenic compound | 2.63E-13 | 1.72E-17 |
| : | : | : |
| Total | 1.66E-12 | |

There is no effect to human body since CR value of detergent is 1.66E-12.
In general, US EPA announced that there is no effect if TCR value is below $10^{-6}$

In addition,
there are no substance, which can generate potential cancer risk among all substances included in detergent

# 4. Case study on laundry detergent

## Risk characterization / Hazardous index

| Chemical substances | Hazard index (indirect) | |
|---|---|---|
| | inhalation | ingestion |
| formaldehyde | 0.00E+00 | 7.33E-16 |
| dichlorvos | 2.17E-10 | 6.21E-15 |
| vinyl chloride | 8.74E-12 | 1.13E-12 |
| acetaldehyde | 6.35E-13 | 0.00E+00 |
| dichloromethane | 5.59E-14 | 1.28E-16 |
| 1,3-butadiene | 1.64E-11 | 0.00E+00 |
| acrylonitrile | 1.90E-11 | 2.50E-16 |
| chlorothalonil | 0.00E+00 | 1.10E-15 |
| **Chromium & chromium compound** | **1.19E-05** | 1.68E-11 |
| : | : | : |
| Total | **1.19E-05** | |

| Chemical substances (direct) | Hazard index |
|---|---|
| | dermal contact |
| **linear alkyl benzene sulphonate** | **2.18E-02** |
| zeolite 4Na | 3.82E-03 |
| tallow fatty acid | 9.80E-06 |
| fluoresence whitening agent(5) | 4.92E-06 |
| Total | **2.56E-02** |

There is no effect to human body since direct and indirect HI value of detergent are 1.19E-05 and 2.56E-02, respectively. In general, it is regarded that there is no effect if THI value is below 1

# 4. Case study on laundry detergent

## Risk characterization / Eco-toxicity index

| Chemical substances | Eco-toxicity index |
|---|---|
| | Aquatic |
| formaldehyde | 4.18E-12 |
| dichlorvos | 6.81E-11 |
| acetaldehyde | 1.85E-15 |
| **diazinon** | **4.16E-08** |
| carbon disulfide | 6.86E-14 |
| ethylene oxide | 5.34E-16 |
| nitro-benzene | 1.23E-14 |
| **thiram** | **1.19E-09** |
| : | : |
| Total | **4.37E-08** |

There is no effect to the environment since EI value of detergent are 4.37E-08.
In general, it is regarded that there is no effect if TEI value is below 1

# 5. Summary

- This study aims to develop a methodology which evaluates the potential risks associated with a chemical product system.
- The hybrid IOA method is utilized to compile the life cycle inventories of hazardous chemical substances throughout the entire life cycle of the chemical product.
- In the process of the RA, the exposed concentrations to human and the environment which reflect the domestic conditions are calculated by using the national statistics for the general exposure parameters.
- The total risks such as TCR, THI and TEI of a chemical product system are obtained by summing up CR, HI and EI of each chemical substance associated with the product system.
- A case study on household laundry detergent was conducted. From the results, it is known that household laundry detergent has no effect to human and the environment.