



จุฬาลงกรณ์มหาวิทยาลัย  
Chulalongkorn University

# Life Cycle Assessment (LCA) and Recycle as the tools for Sustainable PVC

**Pomthong Malakul Na Ayudhaya, Ph.D.**

*Vice President, Chulalongkorn University  
Expert, ASEAN Vinyl Council (AVC)*

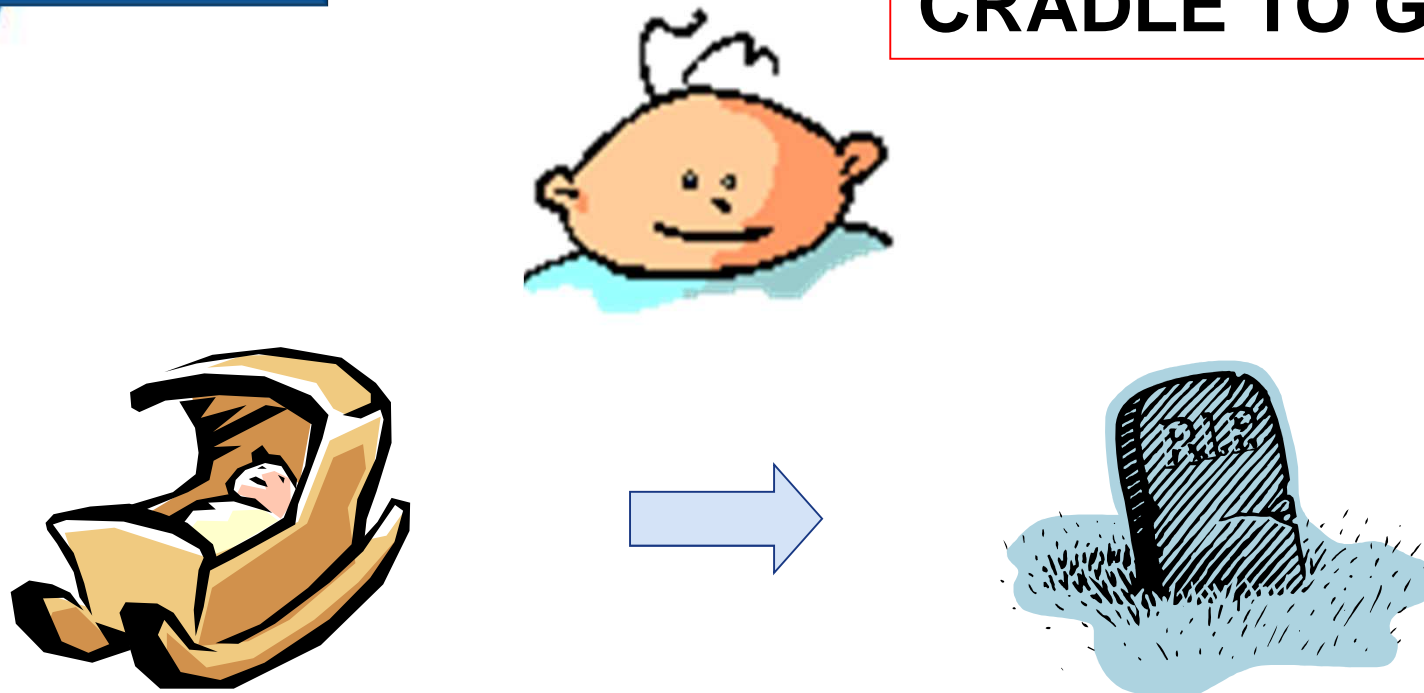
November 23, 2017 : Jakarta, Indonesia

- **Life Cycle Assessment (LCA)**
  - LCA Concept
  - Methodology
  - Utilization of LCA
  - Status of LCA in Thailand and Global Situation
  - Benefits of LCA on Plastic Products
- **Examples of LCA Studies on Plastic Recycling**
- **LCA of Pipe and Fitting**
- **Current Status of PVC Recycling in Thailand**



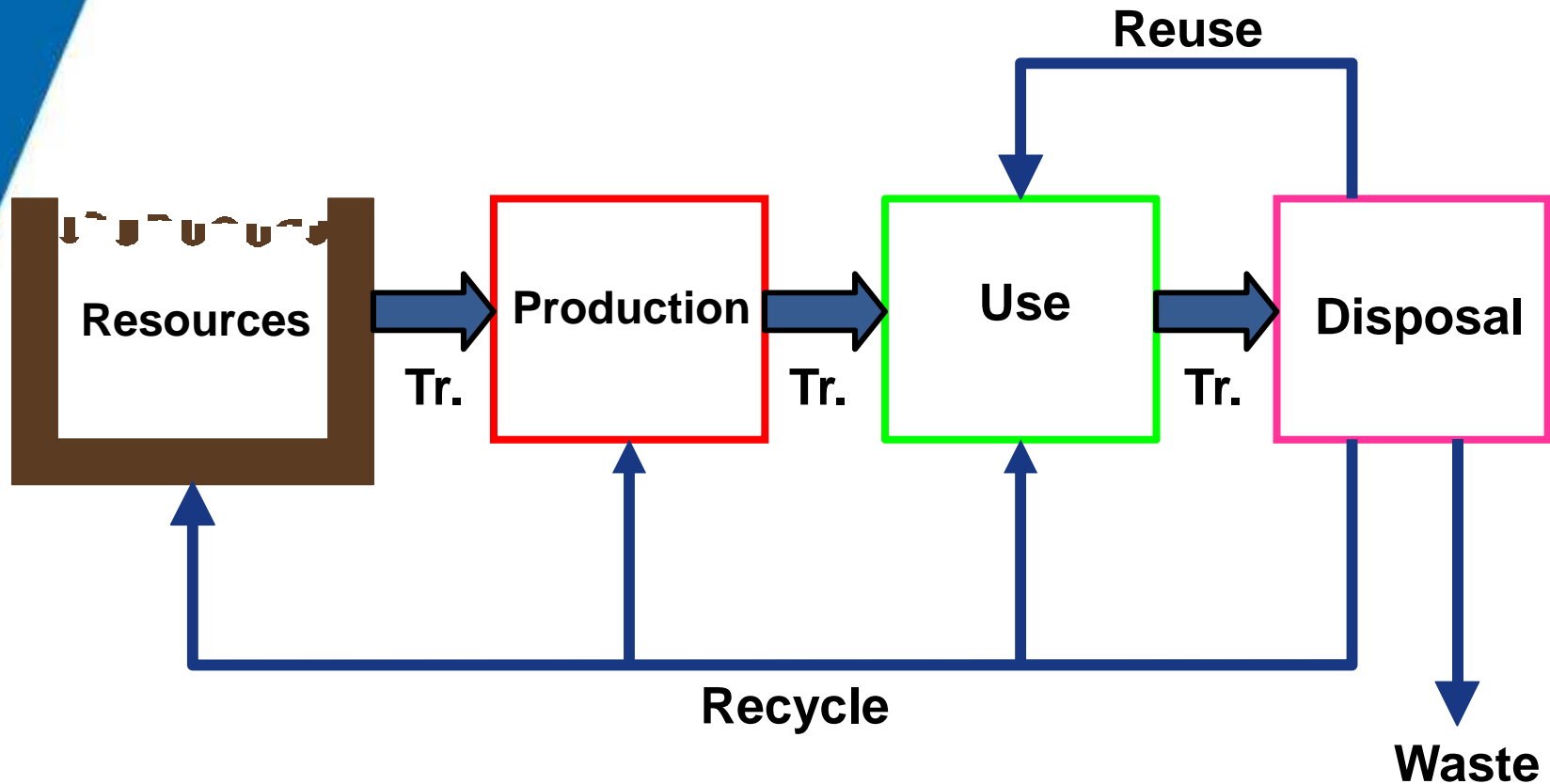
What is LCA ?

CRADLE TO GRAVE



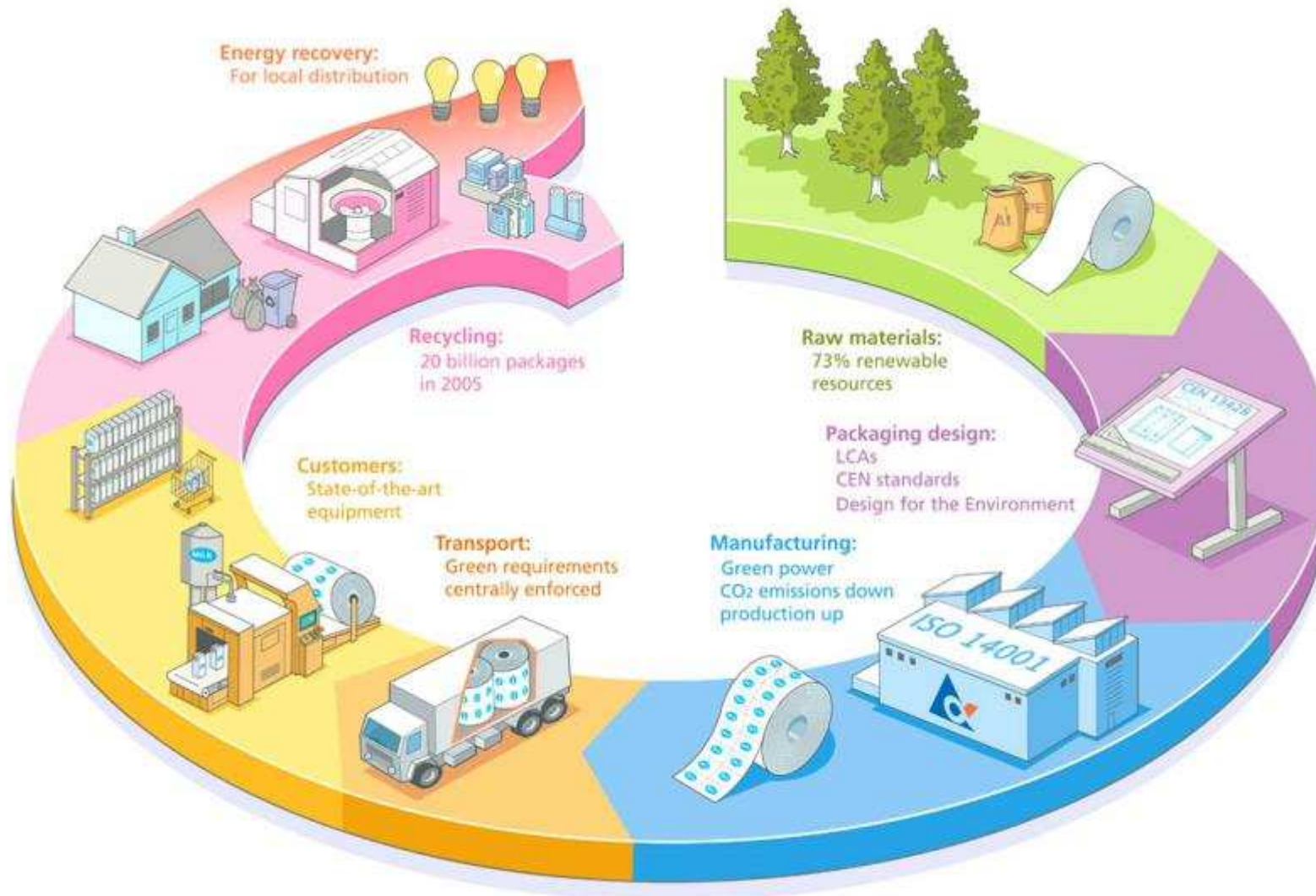
***Quantitative Environmental Impact Assessment***

LCA is a tool to assess the potential environmental impacts of product systems or services at all stages in their life cycle – from extraction of resources, through the production and using the product to reuse, recycling or final disposal.

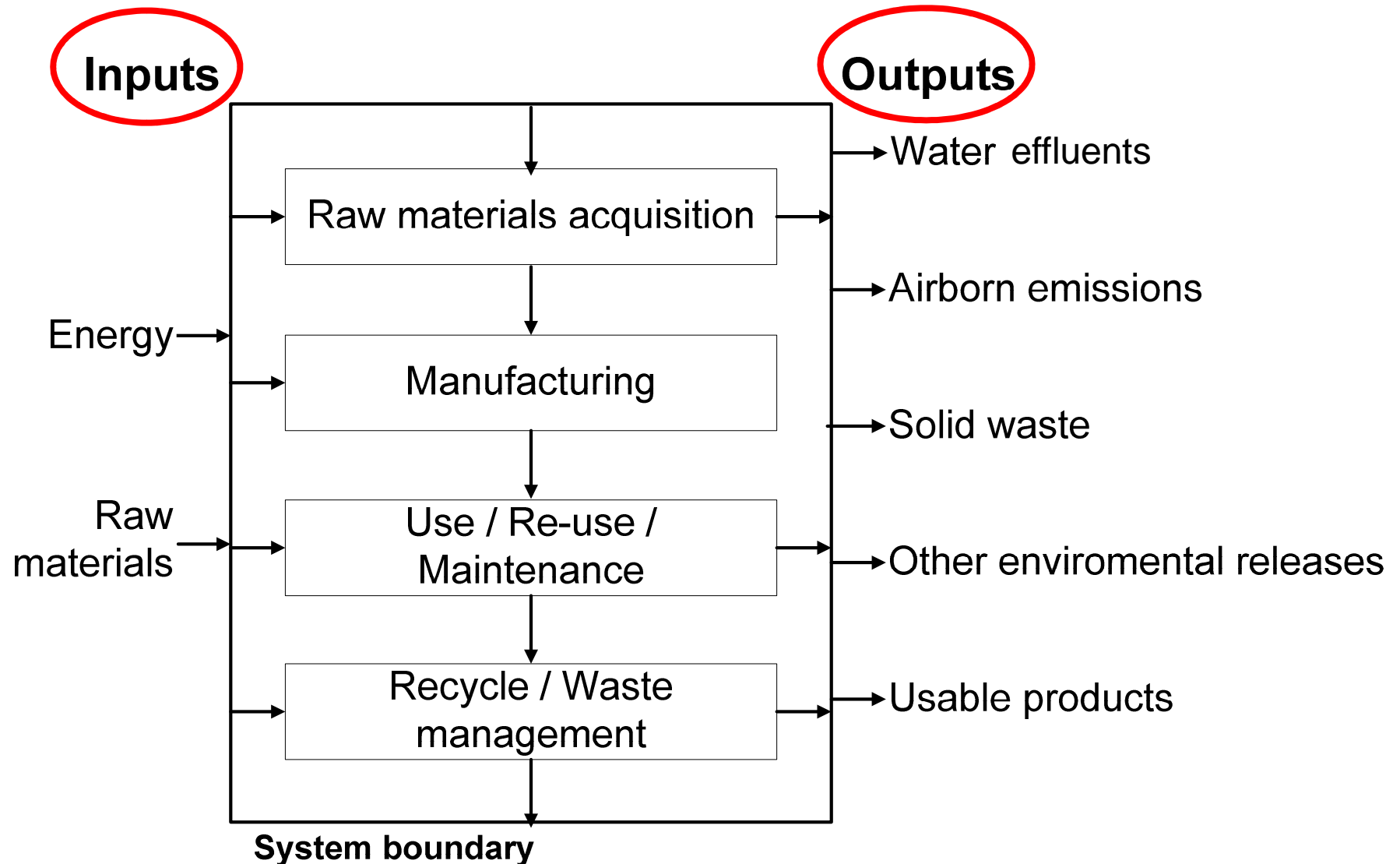


Tr. = Transportation

# Product Life Cycle



Source: TetraPak



## Category

## Items

## Emissions

### Energy

- Electricity (from coal, natural gas, ..)
- Fuel (diesel, LPG, etc.)

### Raw materials

- Iron, aluminium, etc.
- Plastic resins

### Chemicals

- HCl, NaOH, etc.
- Fertilizer, herbicides, etc.

### Air Emissions

- CO<sub>2</sub>, CO, particulates, etc.
- HCs, SO<sub>x</sub>, NO<sub>x</sub>, CFC, etc.

### Wastewater

- COD, BOD
- Toxic substances

### Wastes

- Solid waste
- Heavy metals, etc.

CO<sub>2</sub>

CH<sub>4</sub>

CO

CFC

NO<sub>x</sub>

SO<sub>x</sub>

PAHs

Pb

Cd

PO<sub>4</sub>

N

## Inventory

## Impact category

## Data item

CO<sub>2</sub>

CH<sub>4</sub>

N<sub>2</sub>O

SO<sub>2</sub>

Total N

NMVOC

COD

CFC-11

NO<sub>2</sub>

Global warming

Ozone layer depletion

Acidification

Eutrophication

Photo. Oxidant creation

Human Toxicity

• Heavy metals,  
PAHs, carcinogens



## Global Warming Potential (GWP)

(CO<sub>2</sub> equiv. kg)

<b>CO<sub>2</sub></b>	<b>1</b>
CH <sub>4</sub>	21
N <sub>2</sub> O	310
HFC-23	11700
HFC-41	150
HFC-134a	1300
SF <sub>6</sub>	23900

*Ref: IPCC (Intergovernmental Panel on Climate Changes)*

## Ozone Layer Depletion (ODP)

(CFC equiv. kg)

<b>CFC-11</b>	<b>1</b>
HALON-1201	1.4
HCFC-123	0.02
HCFC-141b	0.11
HCFC-22	0.055

## Acidification Potential (AP)

(SO<sub>2</sub> equiv. kg)

NH <sub>3</sub>	1.88
HCl	0.88
HF	1.6
NO	1.07
NO <sub>2</sub>	0.7
<b>SO<sub>2</sub></b>	<b>1</b>

# Road Map - ISO 14000

## Evaluation & Auditing Tools

**Environmental Performance Evaluation (EPE)**

ISO 14031 guidelines

**Environmental Auditing (EA)**

14010 general principles

14011-1 audit procedures

14012 qualification criteria for environmental auditors

## Management Systems

**ISO 14004 (EMS)**

general guidelines on principles, systems & supporting techniques

**ISO 14001 (EMS)**

specification with guidance for use

## Product-Oriented Support Tools

**Life Cycle Assessment (LCA)**

14041 general principles & practices

14042 life cycle inventory analysis

14043 life cycle impact assessment

14044 life cycle improvement assessment

**Environmental Labelling (EL)**

14020 basic principles for all environmental labelling

14021 terms & definitions

14022 symbols

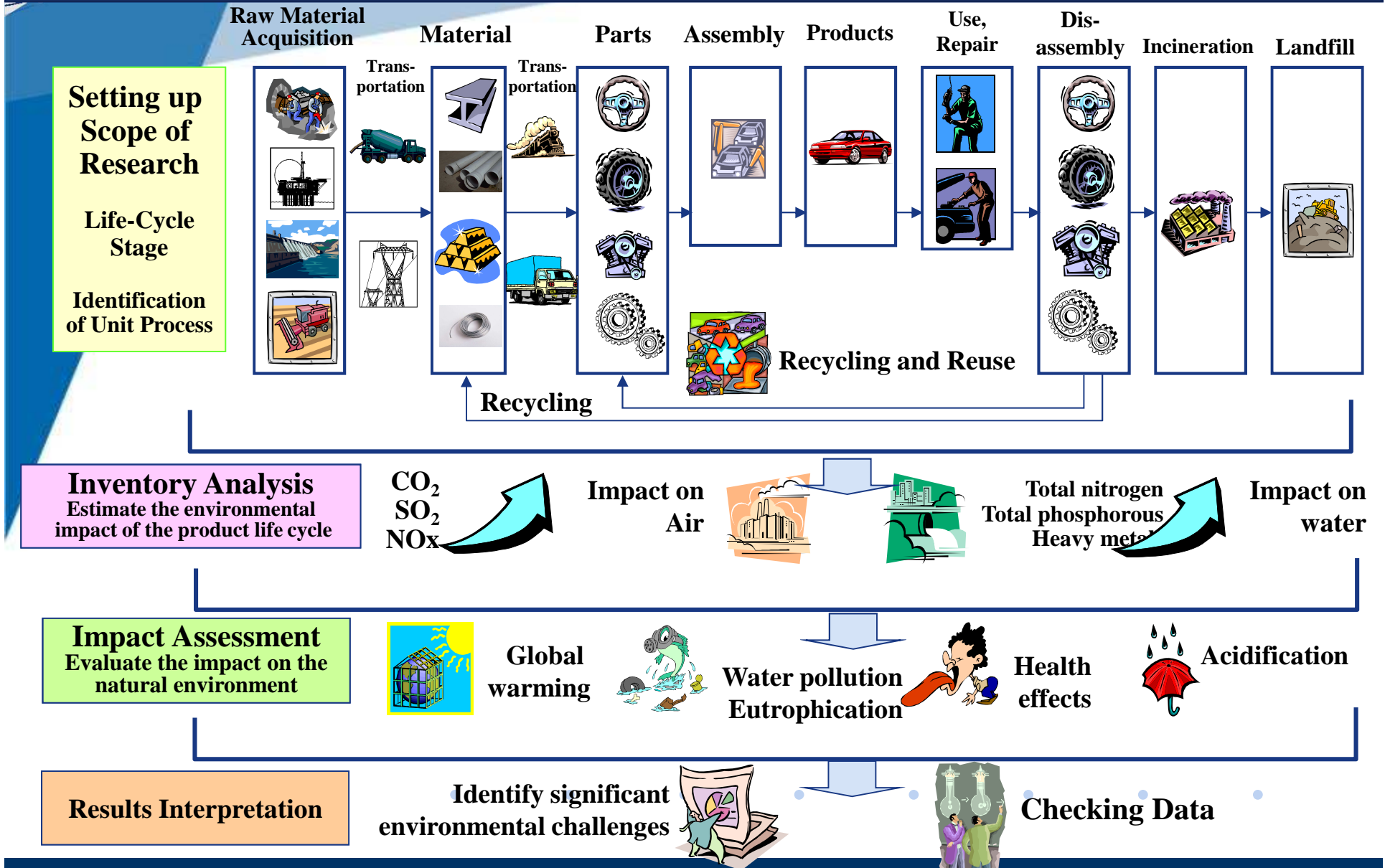
14023 testing & verification

14024 guiding principles, practices & criteria for certification programs

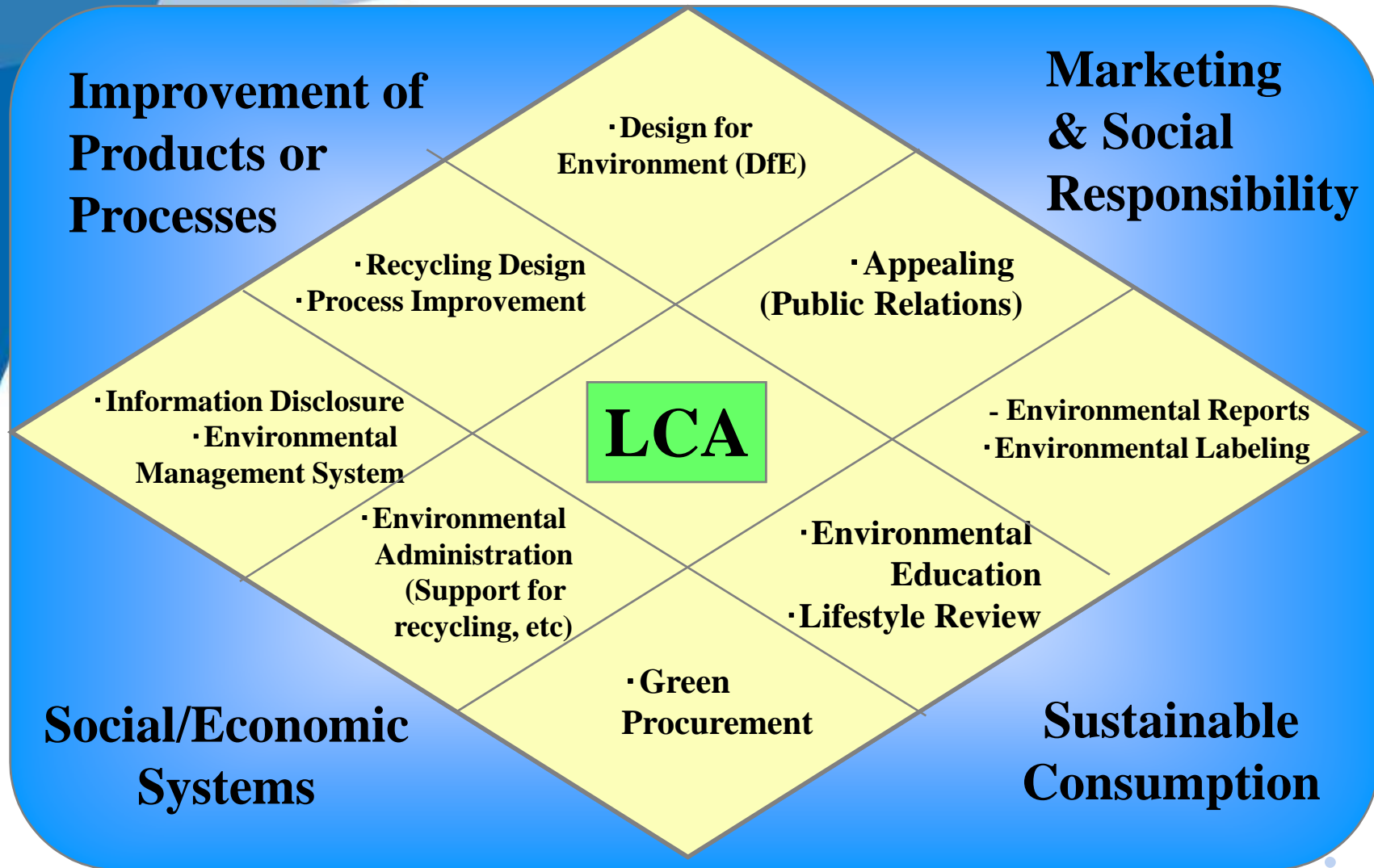
ISO 14067 Carbon Footprint of products

+ CSR (ISO 26000) 2011

# LCA Methodology Based on ISO 14040 Series



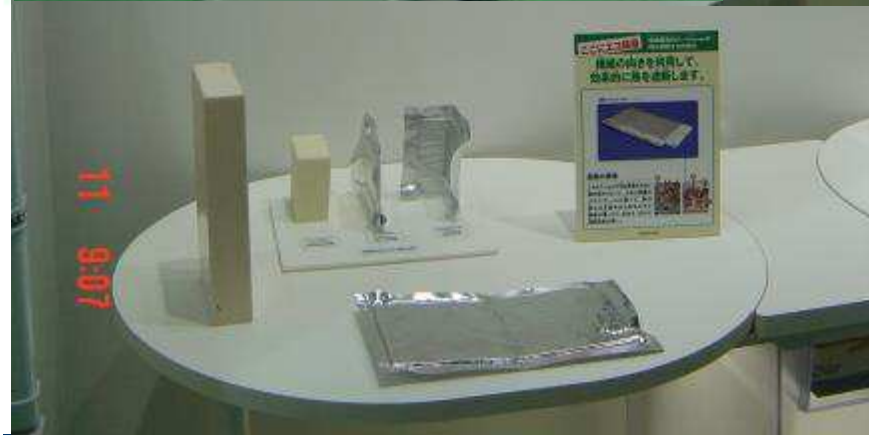
# Utilization of LCA



Adapted from: Ishizaka, Nagano prefecture



## Design for Environment/Improvement



HITACHI

New Vacuum Insulator

For Refrigerator

Eco Products Fair, Tokyo, Japan



### 植物由来高機能軟質ポリブタラムド - リルサン HT

リルサン HTは、ポリブタラムドnewの高柔軟性とポリアミドnewの柔軟性を兼ね備えた新しい高機能軟質PPA樹脂です。植物由来原料 (バイオ) を使用することにより、約45-68%の環境負荷削減を実現し、以下の様な優れた特長を提供します。

45-68%  
環境負荷削減

【主要特性比較】

柔軟性  
耐熱性 (200℃以上)  
耐薬品性 (油類、薬品)  
高剛性 (EPR/PA12より高剛)

高柔軟性 (油類、薬品)  
長期耐熱性  
耐薬品性

耐水性 (PASTESODI)  
成形加工性

UL94 V-0, CECE PBT 15 (同等レベル), CECE Black TLD (同等レベル) の強化グレード、CECE (同等レベル) の強化グレードの強化グレードです。

www.arkema.com

### ここにも! エコリーフ

身近な生活のワンシーンにも、エコリーフによる環境情報は「見える化」されています。

Product Environmental Aspects Data  
**ECO LEAF**

ECOリーフは環境情報表示システムです。QRコードを読み取ると、製品の環境情報（CO2排出量、エネルギー消費量など）がスマートフォンやタブレットで表示されます。

Radexia  
-CO2-

CO2

CO2

環境負荷低減のため、CO2排出量を大幅に削減

従来のプラスチック製品に比べて、CO2排出量を80-90%削減できることがわかりました。

石油資源率99%以上



### LCA (Life Cycle Assessment) ライフサイクルアセスメント

航空機のLCA比較

環境負荷 (CO2排出量)

■ 従来材料を使用した機体  
■ 新素材を使用した機体

CO2削減率

# Eco-Labels/Green Labels



RÓTULO ECOLÓGICO  
ABNT - QUALIDADE AMBIENTAL

Brazil



EU, UK



Australia



USA



Republic of China



Czech Republic



New Zealand



Canada



Croatia



Korea



Singapore



Philippines



Thailand



Spain



Japan



Hong Kong



Sweden (SSNC)



Germany



Eco-Product





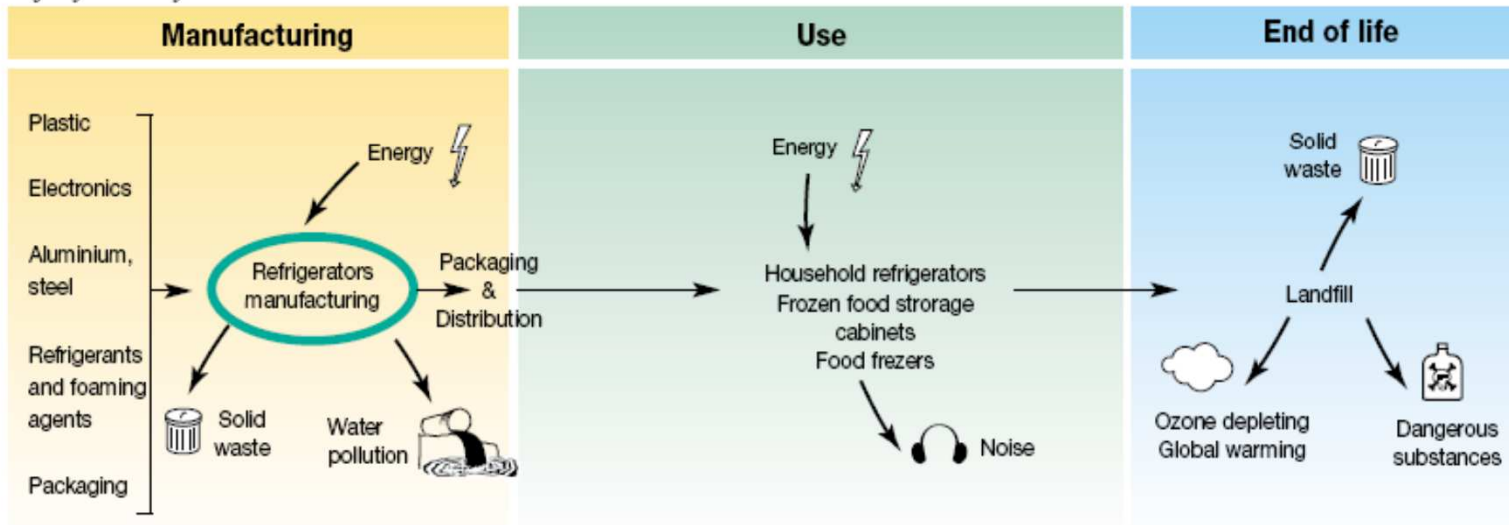
# The European ecological label for refrigerators

Commission Decision 2000/40/EC of 16 December 1999.  
O.J. n° L 13 of 19.1.00



To receive the EU Eco-Label, refrigerators must meet the following ecological and durability criteria

## Life cycle analysis




## ECOLOGICAL CRITERIA

# Eco-labeling Type III

Life cycle stage

## Product Environmental Aspects Declaration




**RICOH**  
Image Communication

Electrophotographic Dry Process Photocopier

### imagio Neo 220

No. AA-02-008



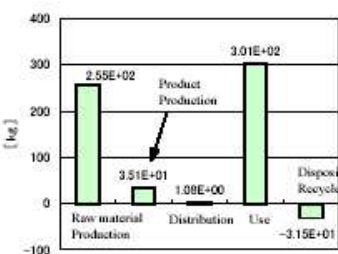
ECO LEAF  
Environmental Label

**Contact:**  
RICOH COMPANY, LTD.  
Corporate Environment Division  
TEL: 03-5742-8773  
FAX: 03-3777-0811  
<http://www.ricoh.co.jp/>  
e-mail : envinfo@ricoh.co.jp

The number of copies when used for 5 years is 298,000. The main environmental burdens are as follows:


- Coping Speed: 22 A4 copies per minute (A4 paper, Horizontal feed, continuous operation)
- Maximum Paper Size : A3
- Global Warming (CO2 equivalent) : 561 kg
- Acidification (SO2 equivalent) : 0.75 kg
- Energy Consumption : 10400 MJ

Emission of Global Warming Gas (CO2 equivalent)



Stage	Emission (kg)
Raw material Production	2.55E+02
Product Production	3.01E+02
Distribution	3.51E+01
Use	1.09E+00
Disposition/Recycle	-3.15E+01

The picture shows a copying machine with an optional document feeder, feed table, branch unit, and inner 1 bin tray.



- Notes:
1. Visit EcoLeaf website under OEMA homepage at <http://www.oema.or.jp/ecoleaf/> for full details including below.
  2. Original LCA data is available on PEIDS: Product Environmental Information Declaration Sheet, and Product Data Sheet.
  3. Unified rules and requirements for EcoLeaf LCA, for intended product category, are available as a PSC: Product Specification Criteria.
  4. All Basic Units based on Japan domestic data. This is due to a lack of base data for full establishment of localized Basic Unit for overseas markets for now.

**[Supplemental environmental information]**

- EcoMark certified
- Acquired ISO14001 certification for domestic sales group companies, as well as all domestic and international production bases.
- Conforms to the International Energy Star Program.
- Received the Energy Conservation Chairman's Prize at the Energy Conservation Award in fiscal 2001.
- Drastically reduced lead and polyvinyl chloride content.
  - In the guidelines set by the Green Purchasing Network, Unloaded solder: Rank A
  - Use of polyvinyl chloride for coated wiring etc.: Rank III
- Uses chromium-free steel sheets: does not use hexavalent chromium during production of steel sheets. Use of chromium-free steel sheets is more than 90%.

**Product Environmental Information Data Sheet (PEIDS)**

Document control no.		Product vendor		Unit Function Code no.				
Product vendor		RICOH COMPANY, LTD.		029601				
EcoLeaf registration no.		AA-02-008		Unit Factor Code no.				
				029601				
PSC name		Product type						
PSC code		PSC-JA		imagio Neo220				
Global Items	Life Cycle Stage	Unit	Raw material	Product	Distribution	Use	Disposition/Recycle	Total
Energy Consumption		MJ	4.59E+03	6.33E+02	1.53E+01	6.16E+03	-7.66E+02	1.04E+04
Energy		kg	1.04E+03	1.53E+02	3.69E+00	1.47E+03	-1.91E+02	2.73E+03
Global Warming Gas (CO2 equivalent)		kg	3.74E+01	5.06E+00	3.33E-01	6.55E+01	-2.07E+00	1.05E+02
Acidification (SO2 equivalent)		kg	7.09E+00	2.49E+00	5.19E-03	1.42E+01	-3.38E-01	2.41E+01
Global Warming Gas (CO2 equivalent)		kg	7.37E-04	2.54E-04	3.42E-09	1.41E-03	-6.07E-05	3.93E-03
Acidification (SO2 equivalent)		kg	1.62E+01	0	0	9.00E+00	-7.69E+00	1.73E+01
Global Warming Gas (CO2 equivalent)		kg	3.60E+01	0	0	2.23E+00	-1.53E+01	2.23E+01
Acidification (SO2 equivalent)		kg	3.33E-01	0	0	1.17E-03	-7.32E-02	4.81E-01
Global Warming Gas (CO2 equivalent)		kg	3.33E-01	0	0	3.19E-01	-1.78E-01	4.78E-01
Acidification (SO2 equivalent)		kg	5.49E-02	0	0	6.19E-02	-3.11E-04	1.17E-01
Global Warming Gas (CO2 equivalent)		kg	8.49E-02	0	0	8.49E-02	-2.00E-03	8.29E-02
Acidification (SO2 equivalent)		kg	1.93E-01	0	0	1.93E-01	9.99E-02	2.94E-01
Global Warming Gas (CO2 equivalent)		kg	2.60E-02	0	0	8.49E-03	-3.24E-01	2.01E-01
Acidification (SO2 equivalent)		kg	0	0	0	9.32E-04	-5.44E-02	1.99E-01
Global Warming Gas (CO2 equivalent)		kg	0	0	0	0	0	0
Acidification (SO2 equivalent)		kg	0	0	0	0	0	0
Global Warming Gas (CO2 equivalent)		kg	1.14E+00	0	0	3.87E-02	-3.89E-01	1.61E+00
Acidification (SO2 equivalent)		kg	4.40E+00	0	0	1.69E+00	-1.15E-01	5.98E+00
Global Warming Gas (CO2 equivalent)		kg	7.83E+00	0	0	3.54E-01	-1.54E+00	6.84E+00
Acidification (SO2 equivalent)		kg	1.54E-01	0	0	0	-3.37E-02	1.21E-01
Global Warming Gas (CO2 equivalent)		kg	1.97E+01	0	0	3.99E-01	-3.74E+00	3.12E+00
Acidification (SO2 equivalent)		kg	1.09E+04	2.29E+03	2.54E-02	7.18E+04	-1.92E+02	1.12E+05
Global Warming Gas (CO2 equivalent)		kg	2.49E+02	3.49E+01	1.09E+00	2.29E+02	-3.09E+01	5.51E+02
Acidification (SO2 equivalent)		kg	1.39E+01	2.54E+02	1.32E-03	1.58E+01	-6.21E-03	3.14E+01
Global Warming Gas (CO2 equivalent)		kg	2.79E-01	2.33E-02	1.67E-02	3.38E-01	-3.20E-02	6.21E-01
Acidification (SO2 equivalent)		kg	1.60E-02	1.68E-03	1.94E-05	1.54E-02	-3.21E-03	3.29E-02
Global Warming Gas (CO2 equivalent)		kg	1.97E-03	7.60E-04	6.46E-09	3.75E-03	1.81E-04	6.86E-03
Acidification (SO2 equivalent)		kg	3.51E-02	5.02E-03	6.58E-03	3.17E-02	-3.71E-03	7.21E-02
Global Warming Gas (CO2 equivalent)		kg	3.54E-03	1.49E-03	1.97E-05	7.33E-03	3.44E-04	1.39E-02
Acidification (SO2 equivalent)		kg	6.92E-03	2.97E-04	3.33E-04	4.70E-03	-1.99E-03	1.29E-02
Global Warming Gas (CO2 equivalent)		kg	3.29E-02	1.08E-03	1.32E-03	1.43E-02	-7.43E-03	4.20E-02
Acidification (SO2 equivalent)		kg	---	1.91E-04	---	---	---	---
Global Warming Gas (CO2 equivalent)		kg	---	7.89E-06	---	3.19E-05	---	---
Acidification (SO2 equivalent)		kg	---	1.13E+00	3.06E-03	0	6.39E-01	3.07E+00
Global Warming Gas (CO2 equivalent)		kg	1.14E+01	0	0	7.22E-01	-4.53E+00	7.58E+00
Acidification (SO2 equivalent)		kg	5.20E-01	0	0	6.81E-01	-3.81E-01	8.20E-01
Global Warming Gas (CO2 equivalent)		kg	5.16E-04	1.99E-04	1.69E-09	9.89E-04	4.67E-05	1.75E-03
Acidification (SO2 equivalent)		kg	2.14E+02	0	0	5.79E+01	-4.20E+01	2.30E+02
Global Warming Gas (CO2 equivalent)		kg	7.83E+01	1.91E+01	3.40E-01	1.09E+02	-9.30E+00	1.91E+02
Acidification (SO2 equivalent)		kg	2.59E+02	3.91E+01	1.08E+00	3.01E+02	-3.16E+01	5.61E+02
Global Warming Gas (CO2 equivalent)		kg	3.30E-01	4.13E-02	1.30E-02	3.93E-01	-2.86E-02	7.49E-01
Acidification (SO2 equivalent)		kg	---	---	---	---	---	---
Global Warming Gas (CO2 equivalent)		kg	---	---	---	---	---	---

I Stage related

A. "Production" stage is intended for two sub-stages listed below.

(1) "Raw material" production: consists of mining, transportation and raw material production.

(2) "Product" production: consists of the parts processing, assembly and installation.

B. "Distribution" stage is intended for transportation of produced product. Transportation of consumables and maintenance goods (e.g. replacement parts) for use of the product are included into "Use" stage.

C. "Use" stage is intended for use of the product (active mode, standby mode, etc.) and production, transportation to disposal/recycle of consumables/maintenance goods (e.g. replacement parts).

D. "Disposition/Recycle" stage is intended for disposal/recycle of the product.

II Stage related

A. Data of the product is available for the following items.

B. Data of the product are in the following items.

III Stage related

A. Impact by resource consumption (e.g. energy, water, etc.)

B. Impact by emission to environment (e.g. CO2, SO2, etc.)

IV Data entry format

A. Exponential notation: after the decimal point, the result of calculation or estimation is considered as "zero" or negligible in comparison to related results.

B. Indicate "0" instead exponential notation, if the result of calculation or estimation is considered as "zero".

C. Indicate "NA" if calculation or estimation can not be done, in order to differentiate to indicate "zero".

D. Row total of the data is automatically calculated, excluding a row includes "NA" item. Row total of such is presented as a blank (no data).

Notes

The values of inventory analysis and impact evaluation in this sheet are calculated using the LCI basic unit and classification coefficient of the "EcoLeaf" environmental label.

1. The product weight is the standard equipment of the main unit including options, and packaging includes the weight of the packaging materials, accessories, etc.
2. Production Stage
3. Distribution Stage

## Inventory analysis, Impact assessment

# Carbon Footprint/Carbon Label



Japan



UK



Canada



Korea



Thailand



Carbon reduction label



USA



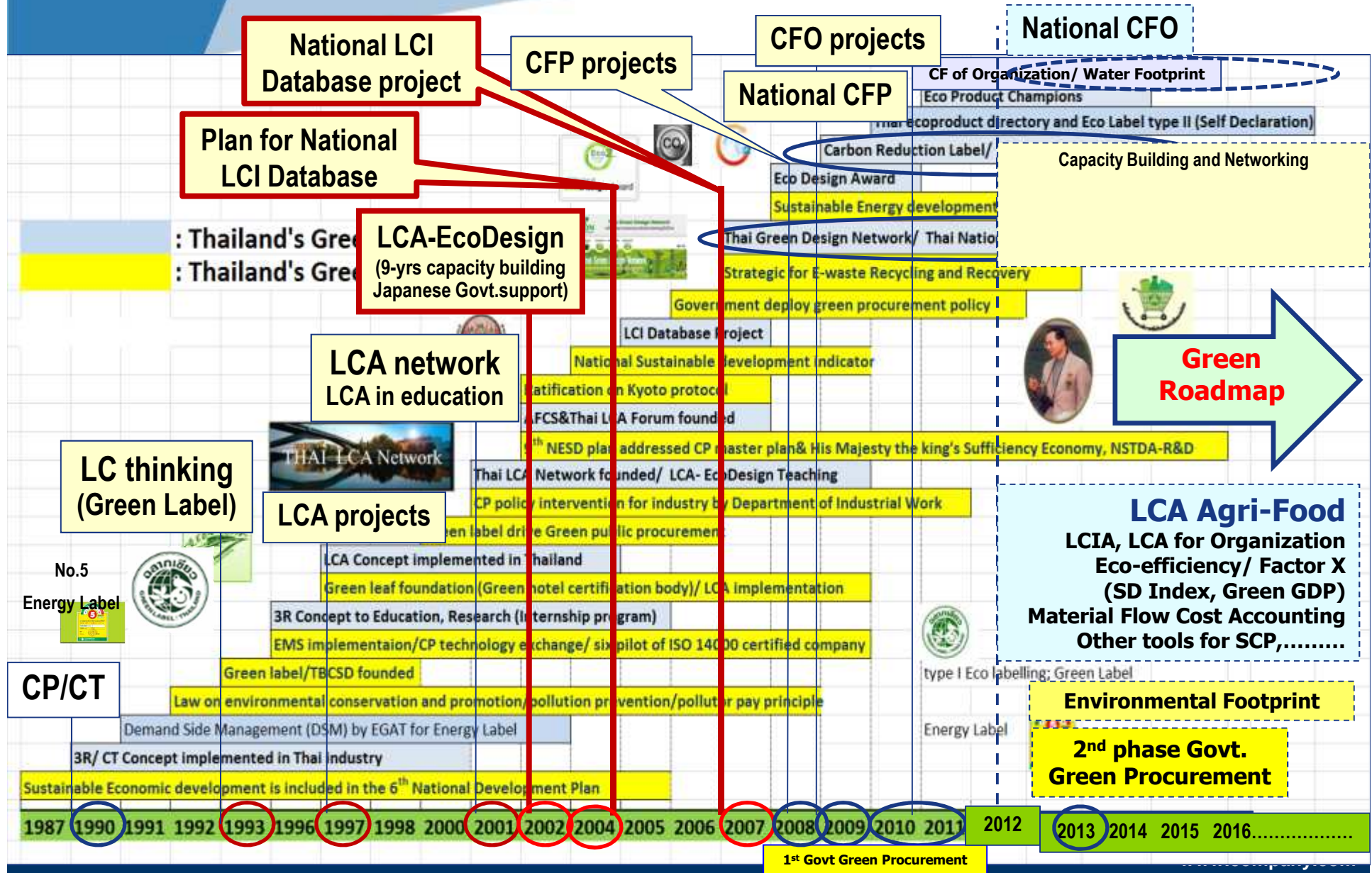
FRANCE



Carbon footprint label



# Thai LCA-related SCP/Green Roadmap



# Thai National LCI Database (Master Plan as of Dec. 2004)

## Infrastructure

### Energy, Utilities and Transportation

Coal, Natural Gas  
Petroleum (gasoline, diesel,  
jet fuel, gas oil)  
Biofuels  
Electricity grid  
Transportation system  
Water supply (surface / ground)

### Recycle and Waste Management

Recycle  
Landfill  
Anaerobic digestion  
Incineration

## Basic Materials

### Industrial Materials

Plastics (PS, PE, PP, etc.)  
Non-ferrous metals  
Ferrous metals  
Aluminum, Copper  
Fibers  
Synthetic rubber (SBR, BR)  
Pulp & Paper  
Petrochemicals (7)

### Agriculture

Cassava  
Rice  
Sugar cane  
Corn  
Cotton  
Natural rubber  
Vegetable oil  
livestock  
Animal feed

### Commodity Chemicals

NaOH  
H<sub>2</sub>SO<sub>4</sub>  
HCl  
Cl<sub>2</sub>  
Lime  
Na<sub>2</sub>CO<sub>3</sub>  
Sulfur  
Fertilizer/ Pesticide

### Building and Construction Materials

Steel  
Gypsum  
Cement  
Glass  
Wood  
Tiles  
etc.

# Thailand National LCI Database

5 Organizations signed MOU to drive the Thai National LCI Database Project



The Federation of Thai Industries



Ministry of Industry by  
Department of Industrial Works



National Metal and Materials Technology Center  
NSTDA, Ministry of Science and Technology



สถาบันสิ่งแวดล้อมไทย  
Thailand Environment Institute

Thailand Environment Institute



Thailand Research Fund

(5 org. signed MOU on 30 Mar. 2007) (MOU with JRC/EU 22 Aug. 2007) (join UNEP/SETAC life cycle initiative)  
( Technical Support by Japanese Government 2003-2010) (Financial Support by Thai Government)

# Thai LCI Database Operation Structure

**Steering Committee**

**Working/Technical Committee**

(5 partners: MTEC/NSTDA, DIW/MOI, TRF, F.T.I, TEI)

ThaiLCD  
(ILCD+ISO std.)  
Web-based  
Software

**Central LCI  
Database  
(MTEC)**

Average data

Average data

Gate-to-gate  
Data collection

Data Verification  
Process (Critical  
review)

**Petroleum Institute of Thailand**

**WG1:  
Natural Gas**

**WG2:  
Refinery  
Products**

**WG3:  
Petrochemical  
Products**

**Industrial Specific Institution**

**WG4:  
Ferrous/n  
on-ferrous**

**WG5:  
Infrastructure  
- Energy/ Utilities  
- Transportation**

**WG6:  
Construction  
materials**

**WG7:  
Agricultural  
materials  
and products**

**WG8:  
Basic  
chemicals**

**WG9:  
Recycle &  
Waste  
management**

**WG10:  
Others**

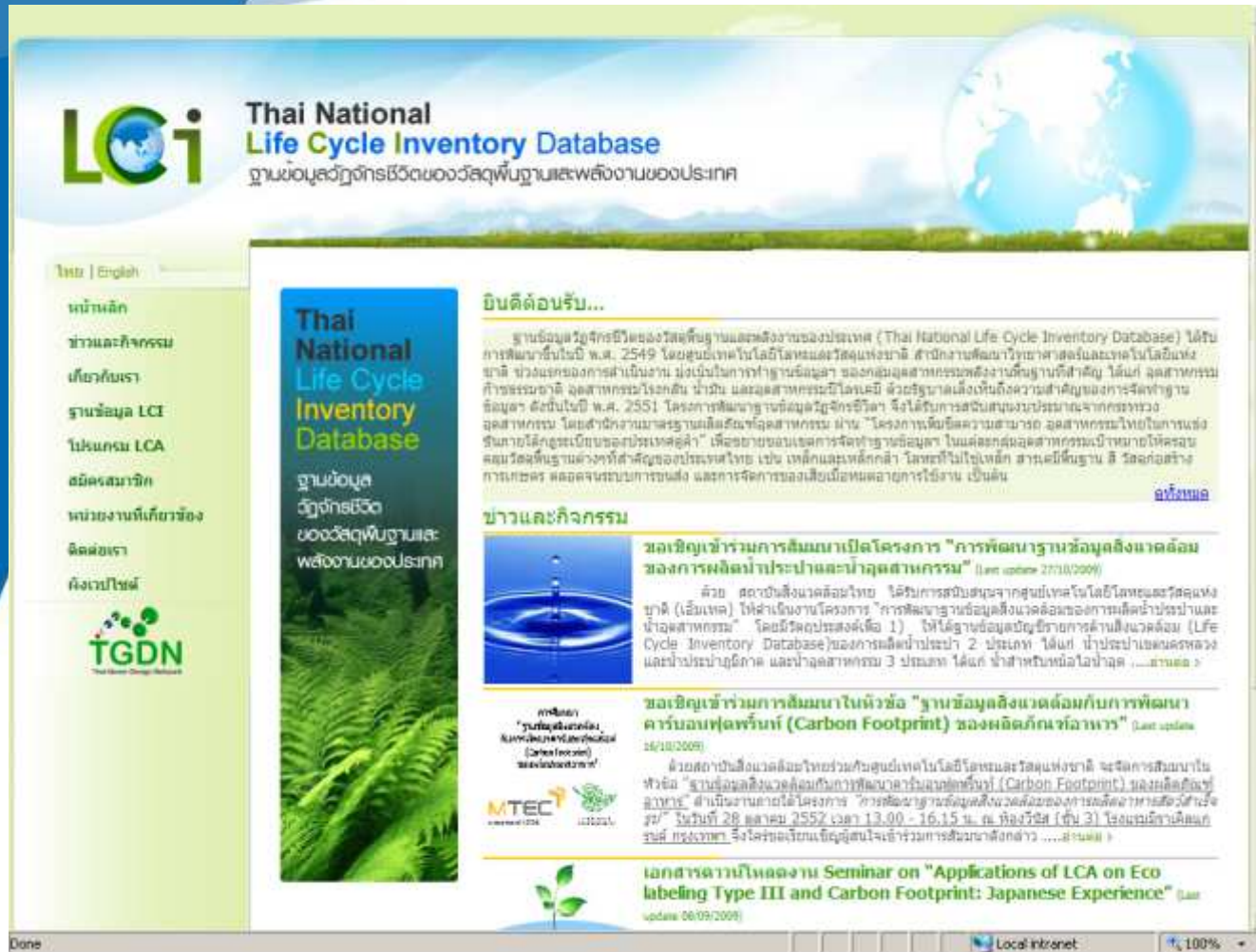


# National LCI Database → for GHG emission factor + others

<b>WG1: Natural Gas</b>	6	<b>WG7: Agriculture/Agro-products (Cont)</b>	
<b>WG2: Refinery</b>	8	Rice	17
<b>WG3: Petrochemicals</b>	19	P...	9
<b>WG4: Ferrous &amp; Non-ferrous</b>			17
Ferrous	9		2+13
Non-ferrous	5		4+43
<b>WG5: Infrastructure/Transportation</b>			1+10
Electric Grid Mix	1		80
Water	6		24
Road Transportation: Truck	188		3
Transportation: Ship & Rail	21+22		
<b>WG6: Construction Materials</b>		<b>WG8: Basic chemicals</b>	
Ceramics	7	Paints + Industrial gases	6+3
Glass & Mirror	7	Basic chemicals + Chemical products	14+2
Alternative Materials for Wood	3	Fertilizers and Herbicides	47
Construction Materials	8	<b>WG9: Recycle/Waste Management</b>	
<b>WG7: Agriculture/Agro-products</b>		Incinerations	8
Feed mill	15	Landfills + Recycle	8+12
Livestock & Products	19	Wastewater Treatment	9
Agriculture Machinery	33	<b>WG10: Others</b> (Textile 30, EE Parts 80, Automotive Parts 3, Vanish oil 3)	116
Rubber	7		
		<b>TOTAL</b>	<b>846</b>

**C1-C4, Benzene, Toluene, p-Xylene, propylene, ethylene, PE, PP, PS, PU, PVC, SAN, VCM, Caprolactam, mixed C4**

# Website of Thai National LCI Database



NATIONAL LCI DATABASE

<http://www.thaiLCIdatabase.net>

# *Global Situation of LCA*

- **Kyoto Protocol**
- **EU, USA, Japan, Asia, Africa**
- **National LCI Databases**
  - Ecoinvent (EU), JEMAI (Japan), USA, Thailand, Malaysia
- **Commercial LCA softwares**
  - SimaPro (Pre'), GaBi, Umberto, etc.
- **LCA Centers/Institutes**
- **Companies**
  - Benz, Coke, Sony, LG, BASF, NatureWorks, PTT, SCG, etc.
- **Governments:**
  - SCP/Green GDP/Green City
- **Product Environmental Footprint (PEF, EU 2014...)**

# Benefits of LCA on Plastic Products

## ➤ Comparison

- Between products (selection/evaluation)
- Between processes/method/management

## ➤ Product Development/Improvement

- Green design/Eco-design
- Green products/more environmental friendly
- Better eco-efficiency (economic & ecology)

## ➤ Communication

- Reports
- Environmental declaration
- Labels

## ➤ Policy

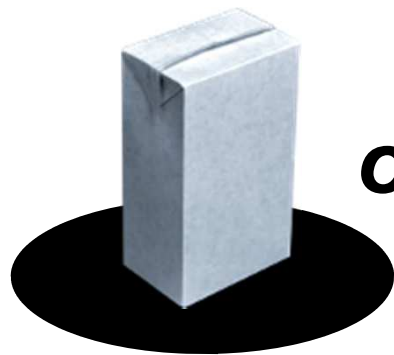
- Decision making
- Management policy
- Environmental tax/subsidization/investment

# Comparison between Products

*Which one would you choose?*



*or*



*or*



*or*



*or*



# Grocery bags

Advertisement

# PlasticORPaper

WHY PLASTIC BAGS ARE BETTER



Splinter- and crack-resistant plastic lumber (shown above) comes from recycled plastic bags, an in-demand commodity.



Recycling of plastic bags and film has increased 24 percent between 2005 and 2006, enough to build 1.5 million medium-sized decks.

Last year, *The ULS Report*, a newsletter devoted to conserving resources and reducing waste, reviewed data on the environmental impact of grocery bags. They found that plastic bags:

- \* USE 70% LESS ENERGY TO PRODUCE THAN PAPER BAGS
- \* GENERATE 80% LESS WASTE
- \* TAKE 91% LESS ENERGY TO RECYCLE PER POUND
- \* GENERATE 79% LESS GREENHOUSE GAS EMISSIONS THAN BIODEGRADABLE BAGS

PLASTICS. TOO VALUABLE TO WASTE. **RECYCLE.**

Many retailers have plastic bag collection programs. To find a plastic bag recycling program in your community, visit [PLASTICBAGRECYCLING.ORG](http://PLASTICBAGRECYCLING.ORG).



## Plastic

- Use 70% less energy to produce than paper bags
- Generate 80% less waste
- **Take 91% less energy to recycle per weight (lb)**
- **Generate 79% less greenhouse gas emissions**

## PAPER OR PLASTIC?

What's the most eco-friendly way to serve your soda?

**BY EMILY HEIN**  
A six-pack of aluminum soda cans contains about as much liquid (72 fluid ounces) as a two-liter soda bottle (69 fluid ounces), but in terms of environmental impact, they're not so similar. If you're trying to make your summer barbecues a little greener, which should you choose?

### Plastic Bottles

**What they are:** 4) polystyrene terephthalate (PET) plastic, derived from petroleum and natural gas  
**Energy used to make:** the same amount used to run a 60-watt lightbulb for about 16 hours

**Health:** PET is one of the safest plastics, but research has found that the heavy metal antimony (which causes diarrhea) can leach from plastic bottles into liquids that have been stored for more than six months.

**Dispose:** Only 29 percent of plastic bottles actually get recycled, according to the Container Recycling Institute (CRI). Furthermore, plastic can be recycled only a few times.

**General environmental impact:** In addition to the nonrenewable resources needed to make them, plastic bottles often wind up in rivers, streams and oceans where they harm fish, birds and other wildlife. Plastic production is a major source of industrial pollution, pumping out sulfur oxides and nitrogen oxides, which contribute to acid rain and global warming.



**BOTTOM LINE:** Plastic bottles are convenient and the best choice for carrying lots of low-alcohol, acidic beverages, such as 7UP. However, when you take into account the fact that only 29 percent of plastic bottles are recycled, aluminum cans are the better choice.

**Winner!!!!**

- **Energy efficient production**
- **High product-to-package ratio**
- **Less Greenhouse gas emissions**

### Aluminum Cans

**What they are:** Roughly 60 percent of soda cans are made from new aluminum (mined bauxite ore), and 40 percent are made with recycled aluminum.

**Energy used to make:** the same amount used to run a 60-watt lightbulb for 42 hours

**Health:** Aluminum cans have an interior coating that may contain the hormone-disrupting chemical bisphenol A, although levels in soda are usually undetectable.

**Dispose:** Aluminum is easily—and infinitely—recyclable, and it's recycled

much more often than plastic. Rates are as high as 32 percent in the U.S., according to the CRI.

**General environmental impact:**

Rarely mining can be very destructive, blighting landscapes and polluting water, and new aluminum production uses more energy than any other type of metal. Over half of that comes from hydroelectric power, which is generated by damming rivers and streams, disrupting aquatic habitats. The next largest source of energy is coal-fired power, a major contributor to global warming.



# LCA Studies Around the World

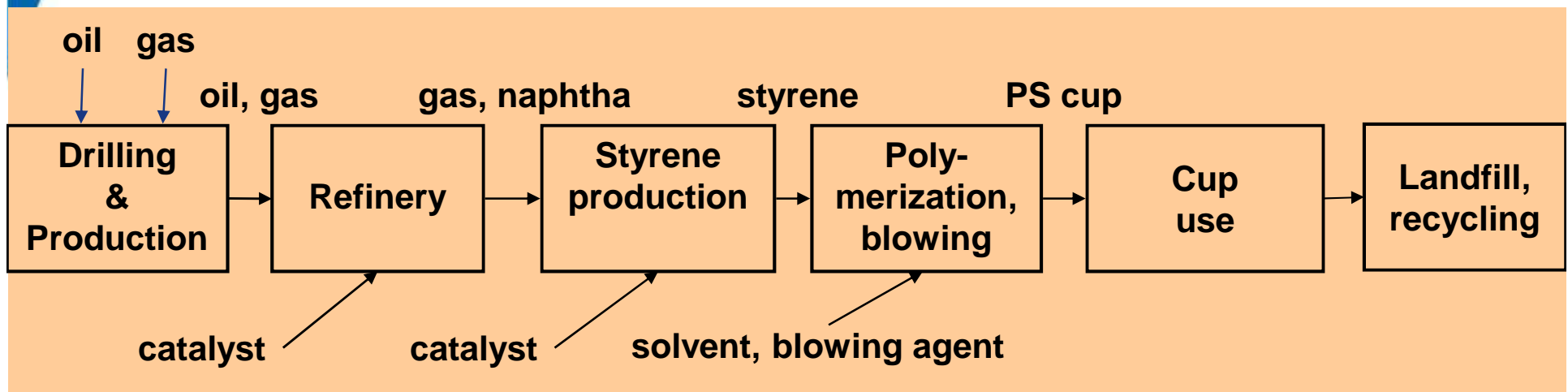
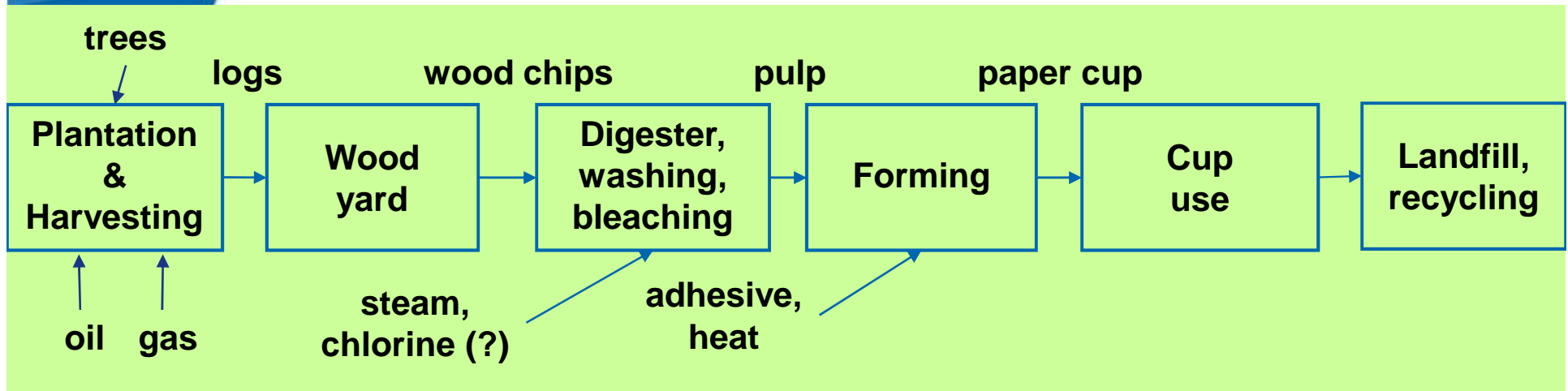
## Comparing Plastic and Other Materials

- Carrefour Group
  - LCA study by Price-Waterhouse-Coopers (Feb, 2004) : Compare environmental impact of four types of bags: HDPE, paper, biodegradable plastic (50% corn starch and 50% polycaprolactone compostable plastic), and reusable plastic (flexible PE)
- Swiss Agency for the Environment
  - Life Cycle Inventories for packagings: paper, plastics, glass, aluminium and steel (1998)
- Eco-Profiles of the European Plastic Industry (2005)
- Boustead Consulting Associate Ltd.
  - LCA for three types of grocery bags – Recyclable plastic; Compostable, biodegradable plastic; and Recycled, Recyclable paper (2007)
- Chulalongkorn University, Kasetsart University





# Life Cycle of Paper Cup & PS Cup



# Data Acquisition

## Cups

Paper vs. Plastic Cups

		Hocking 1991	Lave et al. (EIO-LCA) 1995
Plastic (100,000 cups)	Electricity (kWh)	20-30	2630
	Air emissions (kg)	7-8	10
Paper (100,000 cups)	Electricity (kWh)	980	5150
	Air emissions (kg)	18-28	19

 **Plastic**

# Data Acquisition

## Bags/Sacks

Paper vs. Plastic Grocery Sacks

		Allen & Bakshani	Graedel & Allenby	Ciambrone
PE (60,790 sacks)	Energy (M BTU)	40	40	34
	Air pollution (lb)	73	76	59
Paper (30,395 sacks)	Energy (M BTU)	50	49	39
	Air pollution (lb)	195	198	49

**Plastic** 

# Comparison of Environmental Impacts of 3 Types of Bags (Paper/PE/Compostable)

(Equivalent to 1,000 Paper Bags)



	Paper Bag (30% Recycled Fiber)	Traditional Polyethylene Bag	Compostable Plastic Bag
Total Energy Usage (MJ)	2622	763	2070
Fossil Fuel Use (kg)	23.2	14.9	41.5
Municipal solid Waste (kg)	33.9	7.0	19.2
GHG (CO2 Equiv. Tons)	0.08	0.04	0.18
SOx (kg)	0.579	0.0758	0.413
NOx (kg)	0.264	0.0681	0.456
Fresh Water Usage (Gal)	1004	58	1017

Boustead Consulting & Associates Ltd. (2007)

# 9 Packaging Materials for Drink Containers were compared using LCA

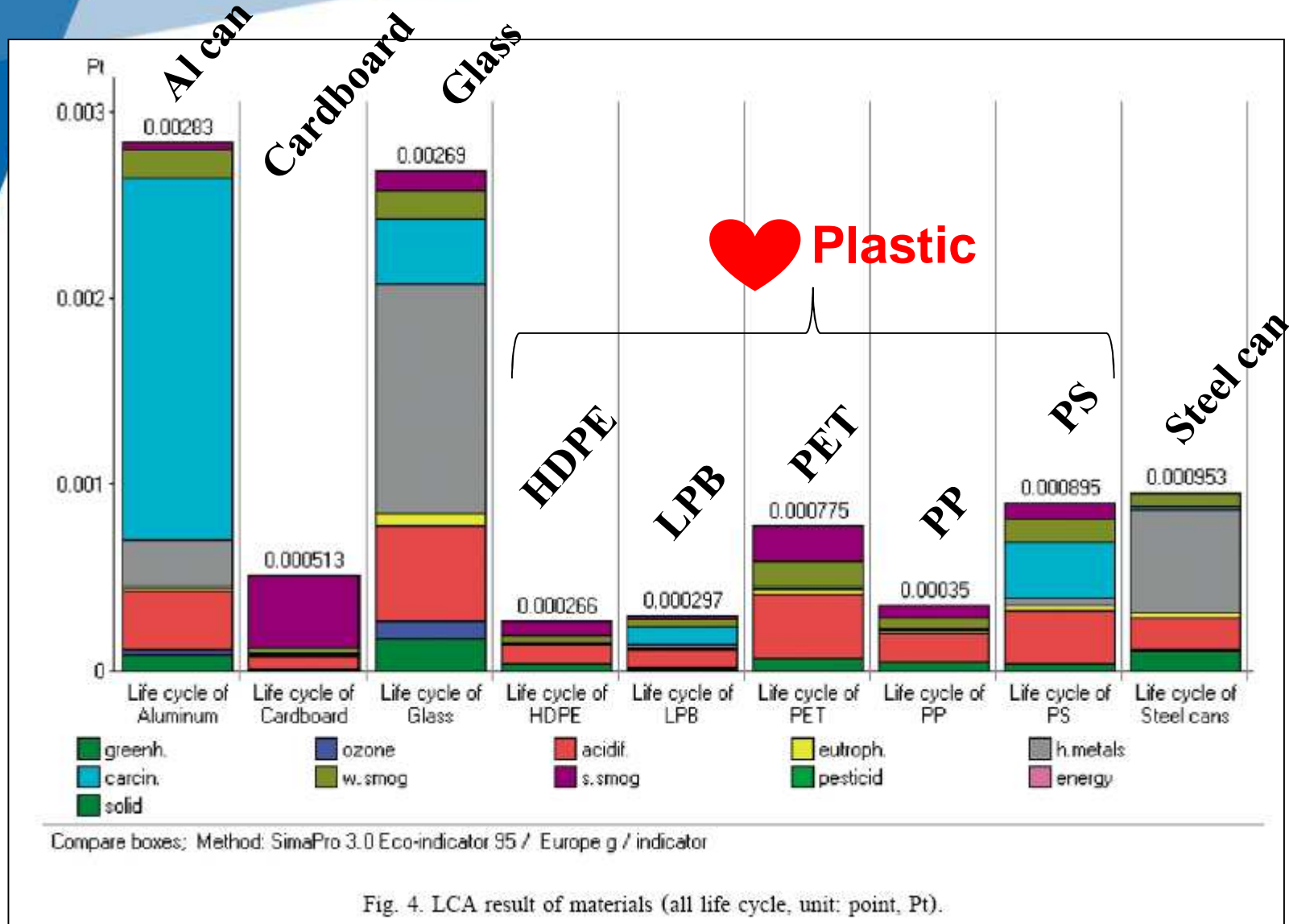
*Huang & Ma (2004) Journal of Science of the Total Environment*

**Basis of Comparison : 1 liter**

Table 1  
Average function units of nine packaging materials

Packaging materials/containers	Average function units of bottles (g/l)	Average function units of bottle tops (g/l)
PET containers	PET 89.02	PP 5.12
HDPE containers	HDPE 59.57	PP 12.77
PP containers	PP 82.33	PP 7.17
PS containers	PS 57.00	Aluminum foil 2.00
Steel cans	Tin plate 156.27	None
Aluminum cans	Aluminum ingots 46.20	None
Glass containers	Glass (brown) 1015.63	Aluminum ingots 8.13
Cardboard boxes	Cardboard liquid 37.76	PP 1.12
	PE 6.66	
Liquid paperboards	Cardboard liquid 29.46	None
	PE 8.42	
	Aluminum foil 2.21	

# LCA Results – Total Environmental Impact Points






# Plastic Pouch & Glass Bottle for Milk Packaging (per 1 million liters)




Source: Carnegie Mellon University, USA

	Glass		Plastic pouch 	
<b>Material required (MTon)</b>	45.4		0.4	
	Energy (GJ)	Water (m3)	Energy (GJ)	Water (m3)
<b>Phase I: Production of raw materials</b>	671.92	1,608.0	32.22	25.6
<b>Phase II: Production of bottles/pouches</b>	530.27		4.56	
<b>Total</b>	1,202.19	1,608.0	36.78	25.6
<b>Phase III: Filling &amp; distribution</b>	Fuel (liter)	Energy (GJ) Single [Return]	Fuel (liter)	Energy (GJ) Single [Return]
	2,049	114.75 [213.43]	1,120	62.73 [106.64]

# Emissions During Phase I & Phase II

per 1,000,000 liters of milk



		Glass	Plastic Pouch
<b>Air emissions</b>			
CO	kg	54.3	0.6
CO <sub>2</sub> (GHG)	kg	6,610.2	760.0
SO <sub>x</sub>	kg	134.8	5.2
NO <sub>x</sub>	kg	68.1	4.8
CH <sub>4</sub> (GHG)	kg	39.5	3.2
HCl	kg	5.3	0.0
Dust	kg	67.6	1.4
<b>Water emission</b>			
Suspended solids	kg	352.3	0.2
Chloride	kg	4,535.5	0.1

# Comparison of Environmental Performance between Retort Pouch and Steel Can for Tuna Meat

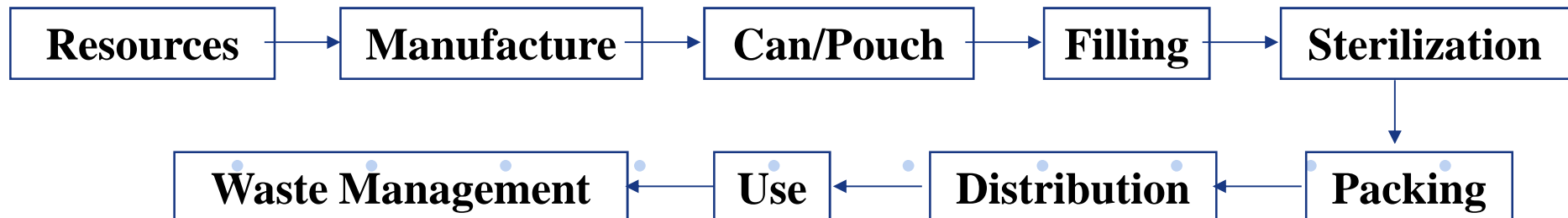
Source: Ratanawan Mungkung et al. (2007) – Kasetsart University



Steel can	Retort Pouch
<ul style="list-style-type: none"> <li>• Tin-free steel</li> <li>• 2 pieces/coated</li> <li>• 85 gm filling</li> <li>• 11,765 cans per ton tuna meat</li> <li>• ~70% Recycled</li> </ul>	<ul style="list-style-type: none"> <li>• PET/Al foil/Nylon/PP</li> <li>• Laminated</li> <li>• 100 gm filling</li> <li>• 10,000 pouches per ton tuna meat</li> <li>• ~10/20/70% Re/Inc/LF</li> </ul>




## Product Life Cycle

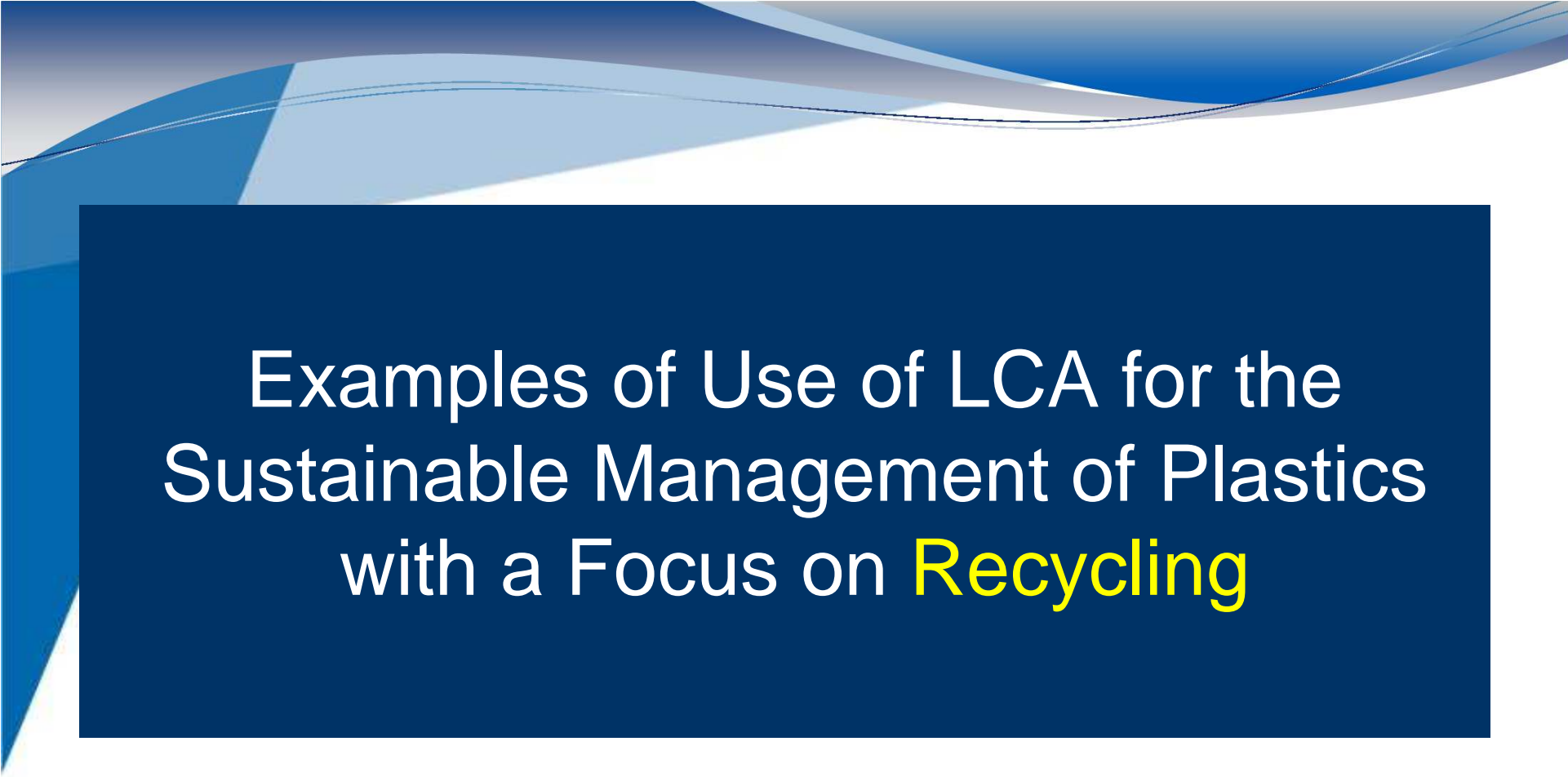




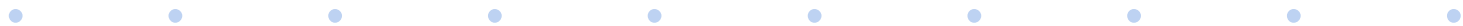
# Life Cycle Comparison between Steel Can and Retort Pouch for 1 Ton of Tuna Meat

		Steel Can	Retort Pouch 
<b>Resources Used</b>			
Coal	kg	550.80	36.03
Natural Gas	m3	58.0	29.13
Petroleum	kg	69.59	50.6
<b>Environment/Emission</b>			
Global Warming	CO <sub>2</sub> kg	3,100	1,150
Acidification	SOx kg	25.8	8.66
<b>Energy Utilization</b>			
Filling & Packing	kWh	317.29	259.19
<b>Total</b>	<b>Points</b>	<b>82,200</b>	<b>42,800</b>

- *Transportation load for 1 ton steel can tuna ~1.5 times retort pouch.*
- *Cardboard weight for 1 ton steel can tuna ~1.7 times retort pouch.*
- *It needs to recycle steel can 5 times to get the same environmental load as the retort pouch.*



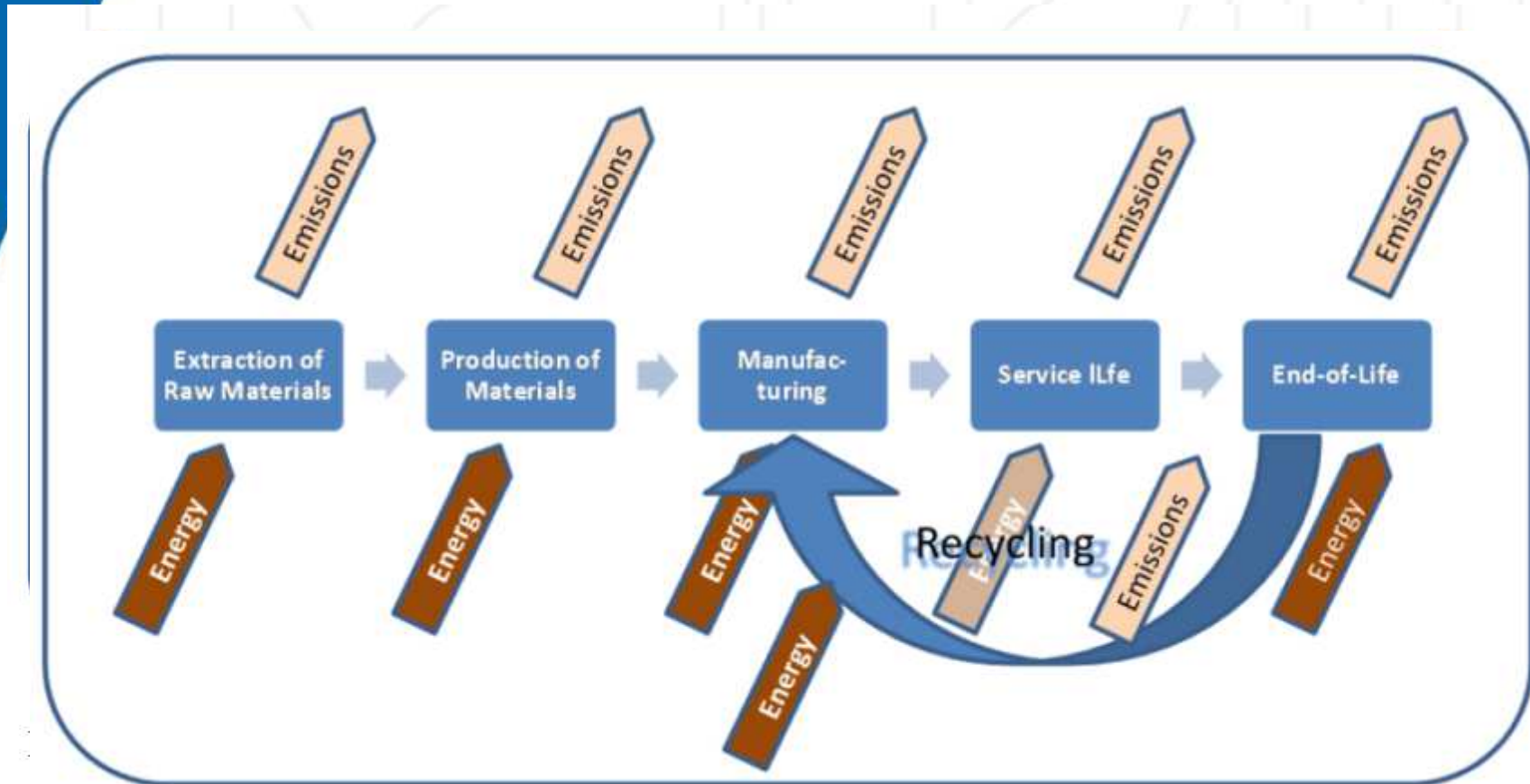
# Examples of Use of LCA for the Sustainable Management of Plastics with a Focus on **Recycling**



**The Netherlands**  
***PET bottle recycling***

# Modelling of Recycling in LCA

Tom N. Ligthart and Toon (A.)M.M. Ansems  
*TNO, Utrecht,  
Netherlands*



## Reduction in Non-Renewable Energy Use (NREU) Resulted from Recycling PET Bottle

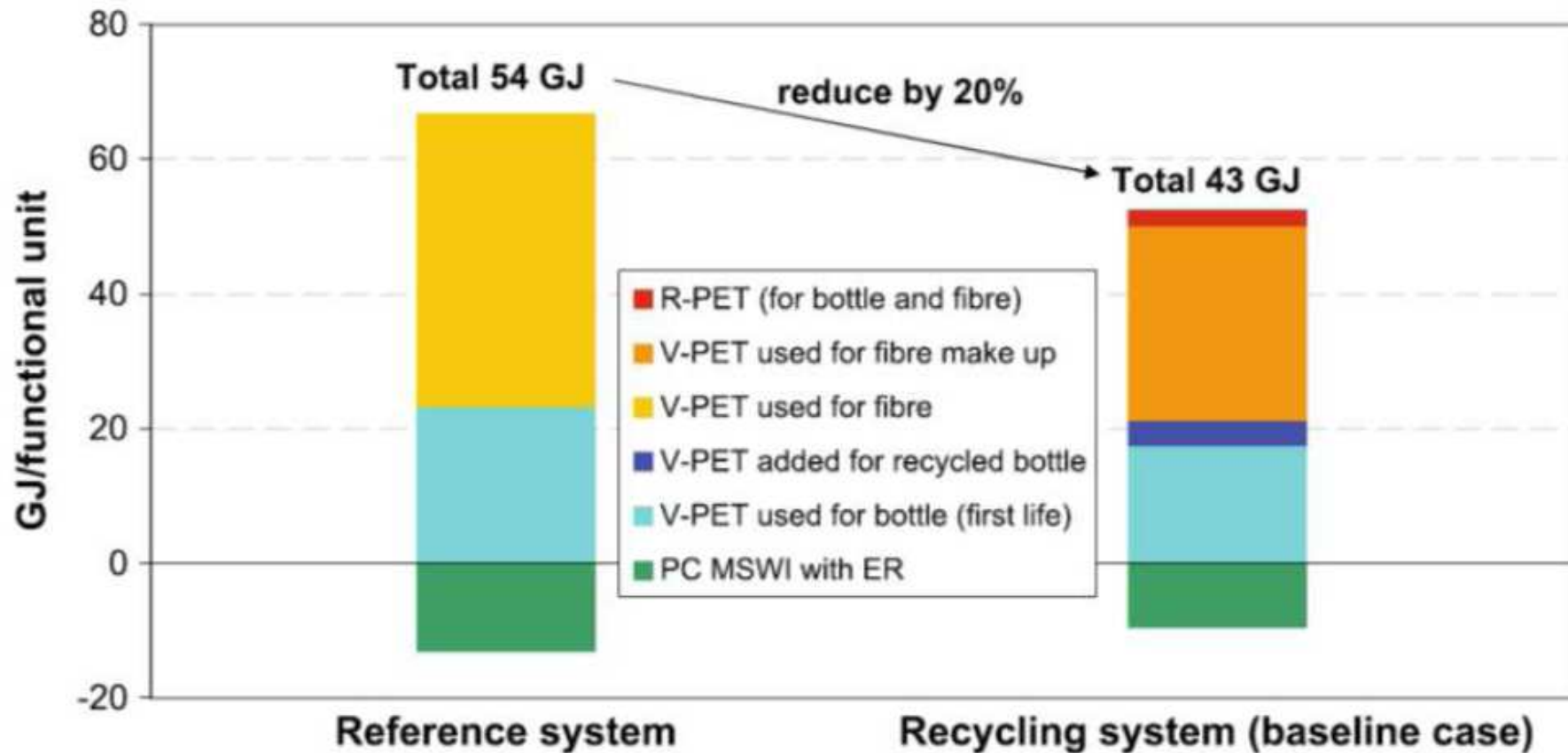
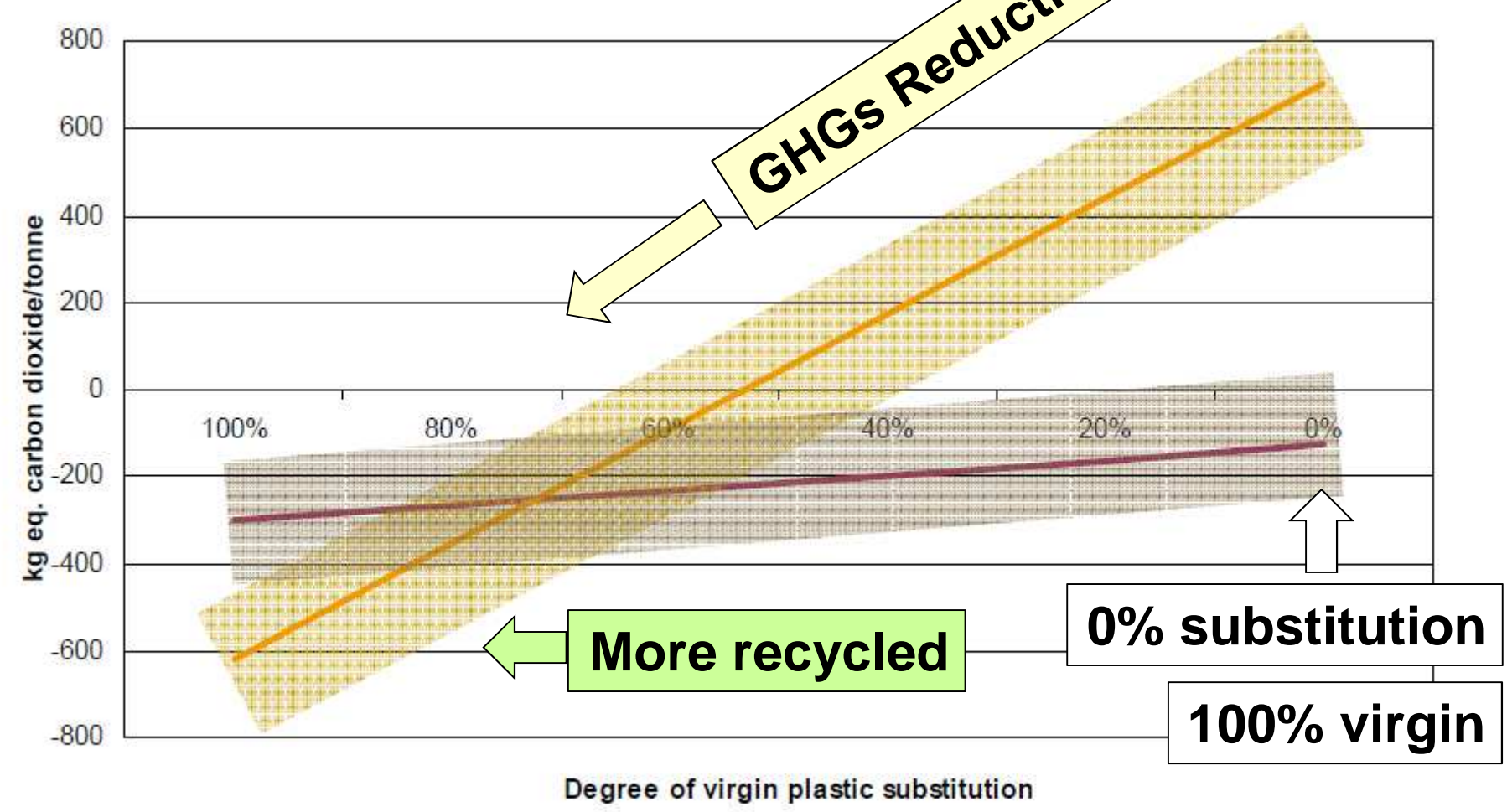


Fig. 20. Cradle-to-grave non-renewable energy use (NREU) recycling system and the reference system in which no recycling takes place (Schen et al., 2011).

# LCA of Management Options for Mixed Waste Plastics



0% substitution

100% virgin

# LCA and recycling policy — a case study in plastic

Brandon Kuczenski and Roland Geyer

*Life Cycle Assessment IX*  
Boston, MA

October 1, 2009



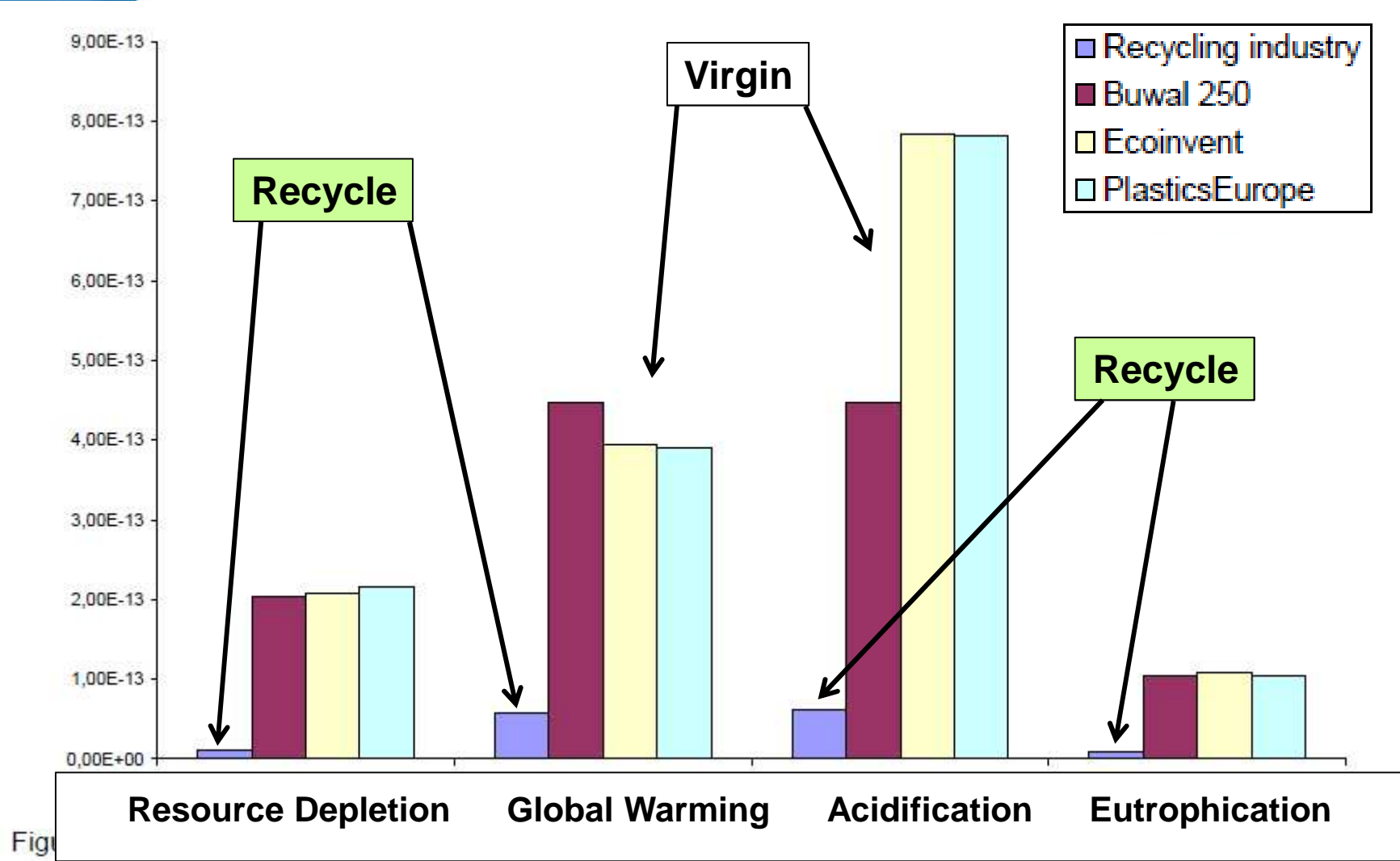
DONALD BREN SCHOOL OF  
ENVIRONMENTAL SCIENCE & MANAGEMENT  
UNIVERSITY OF CALIFORNIA, SANTA BARBARA

- Each kg of PET recycled help us avoid 1 kg disposal and 0.78 primary production
- PET bottle recycling saves 54% of the primary energy demand associated with consumption (mostly feedstock), but avoids only 23% of GHG production.

Spain

# Technological Institute of Plastics, Valencia

## Environmental Comparison between Recycled vs. Virgin HDPE



Fig



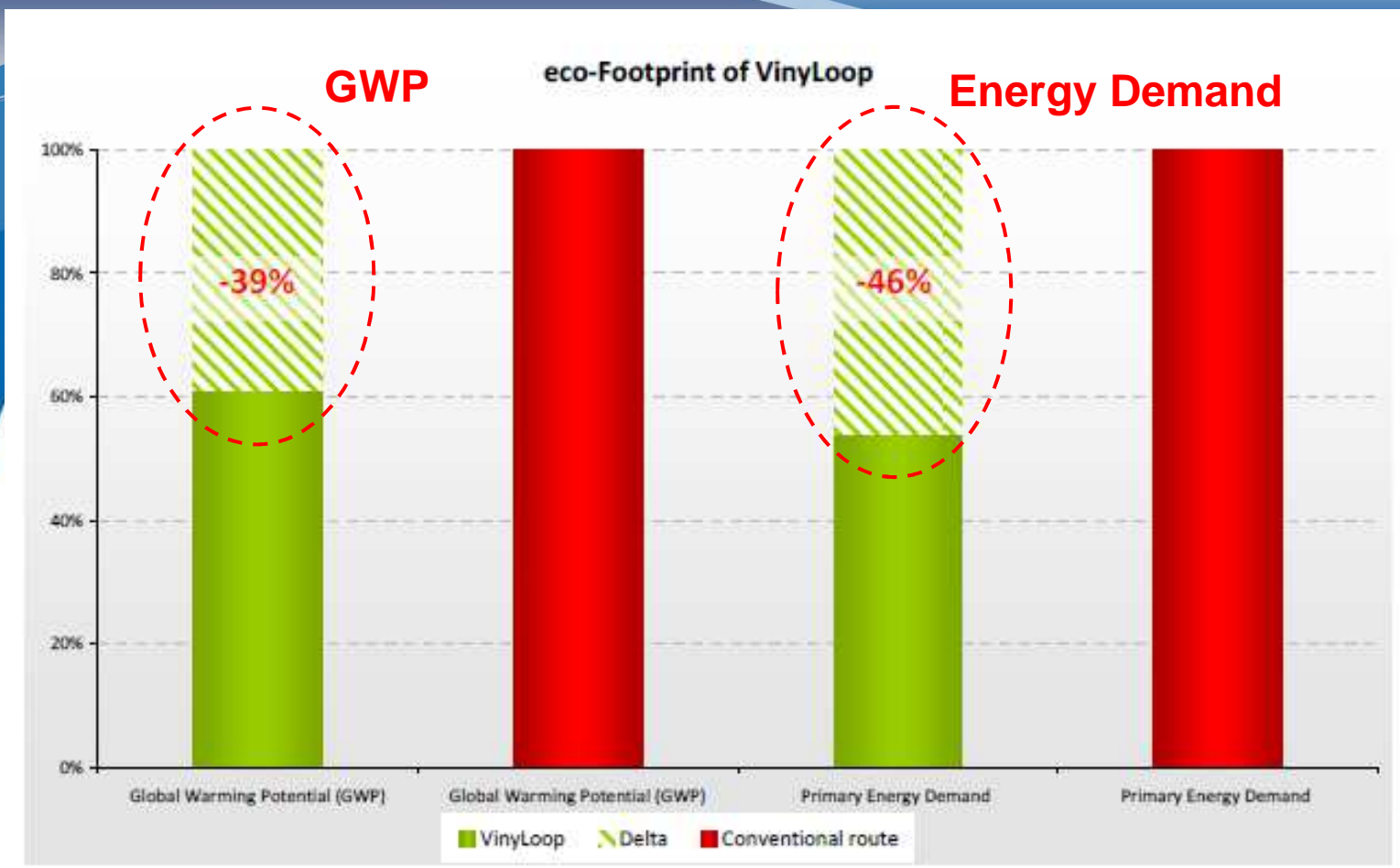
## **The VinyLoop<sup>®</sup> Eco-Footprint**

**Benchmarking of the environmental impact of PVC compound recycled in the VinyLoop<sup>®</sup> process with PVC compound produced in conventional route (virgin PVC compound and incineration)**

**February 2012**

**The VinyLoop Recycled PVC from cable waste reduces the environmental footprint. For each kilogram of PVC compound (functional unit) recovered through the VinyLoop process, the production of 1kg of PVC compound and the incineration of the corresponding amount of PVC waste are avoided.**





Impact Category	Unit	VinyLoop®	PVC conventional route	Delta
Global Warming (GWP 100a – IPCC 2007)	kg CO2-Eq	61%	100%	-39%
Primary Energy Demand	MJ	54%	100%	-46%



# Life Cycle Assessment Study of PVC Pipe and Fitting in Thailand

**Dr.Pomthong Malakul Na Ayudhaya**

**The Petroleum and Petrochemical College  
Chulalongkorn University**

**Dr.Manit Nithithanakul  
Mr.Sompit Petchprayoon  
Mr.Seksan Papong**



Pipe

- Diameter: 18 mm. and 55 mm.
- Length: 4 m.
- Class: 8.5
- Grade: Standard
- Service period  $\geq$  50 years\*

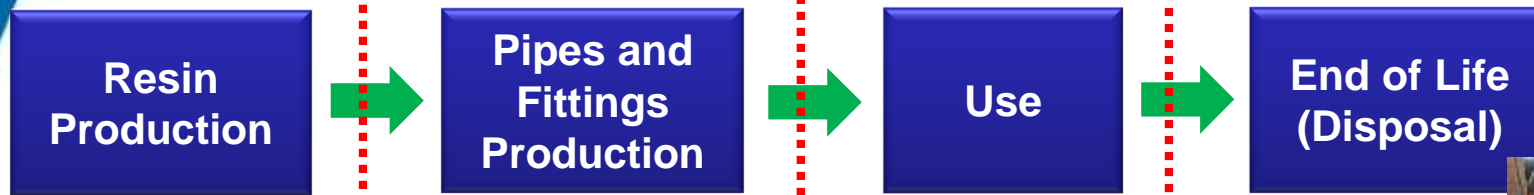


Fitting

- Elbow 90 °
- Class 13.5
- Grade: Standard
- Service period  $\geq$  50 years\*

Functional units: 1 piece or set (pipe & fitting)  
and 1 kg of product (pipe & fitting)

\*Same as the service life used in other LCA studies of PVC pipes, including TEPPFA.



- TPC
- VNT



- ❖ Advanced Pipe
- ❖ Nawaplastic
- ❖ Thai Pipe



Literatures

### Scenarios

- Landfill
- Incineration
- Recycle
- Combination

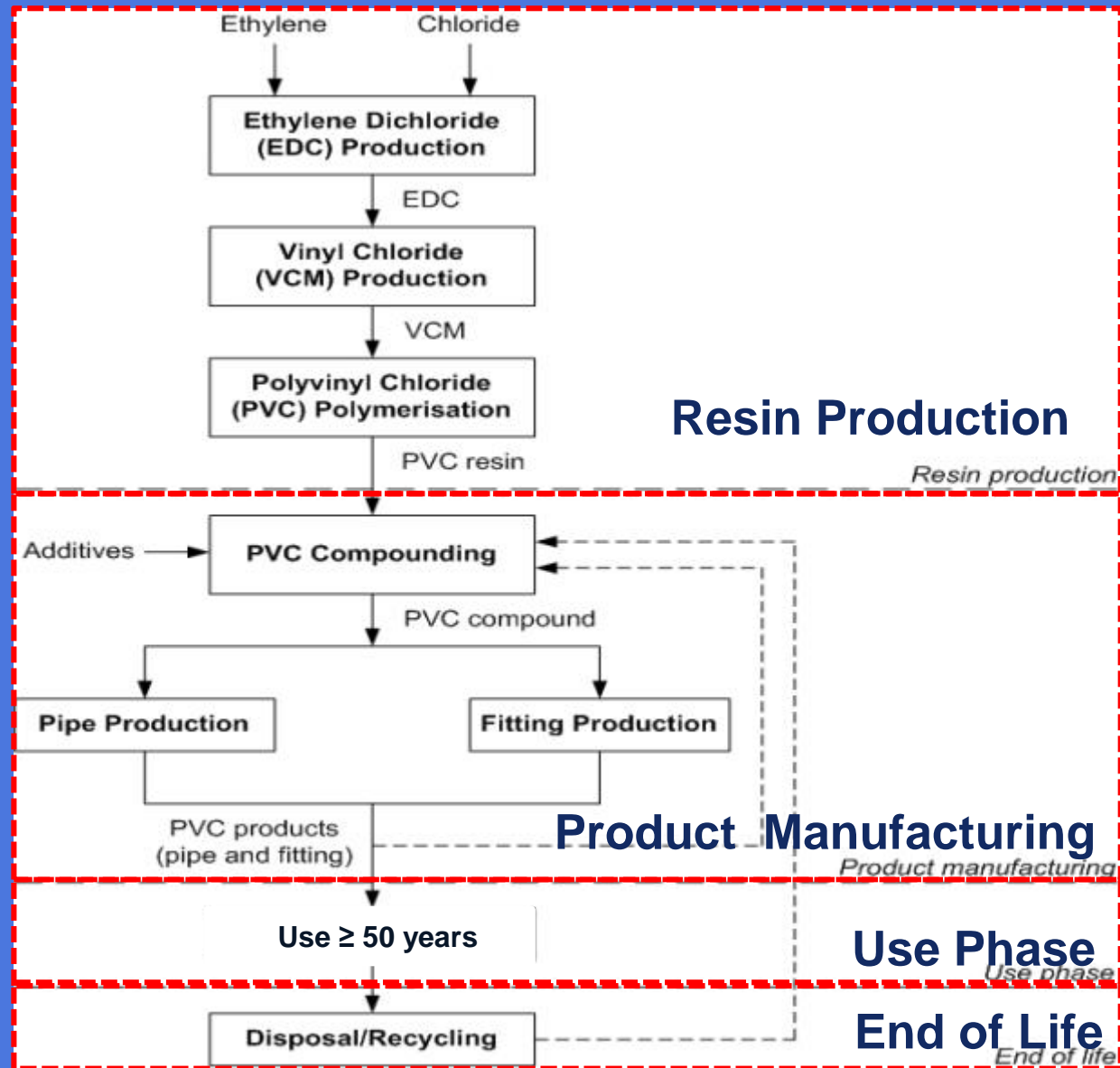
### Including:

- Recycle 0%
- Recycle 30%
- Recycle 50%
- Recycle 75%
- Recycle 90%



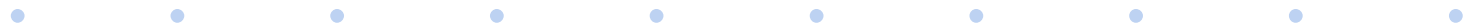
Secrecy agreements were signed with companies providing data

# Processes Involved in the System



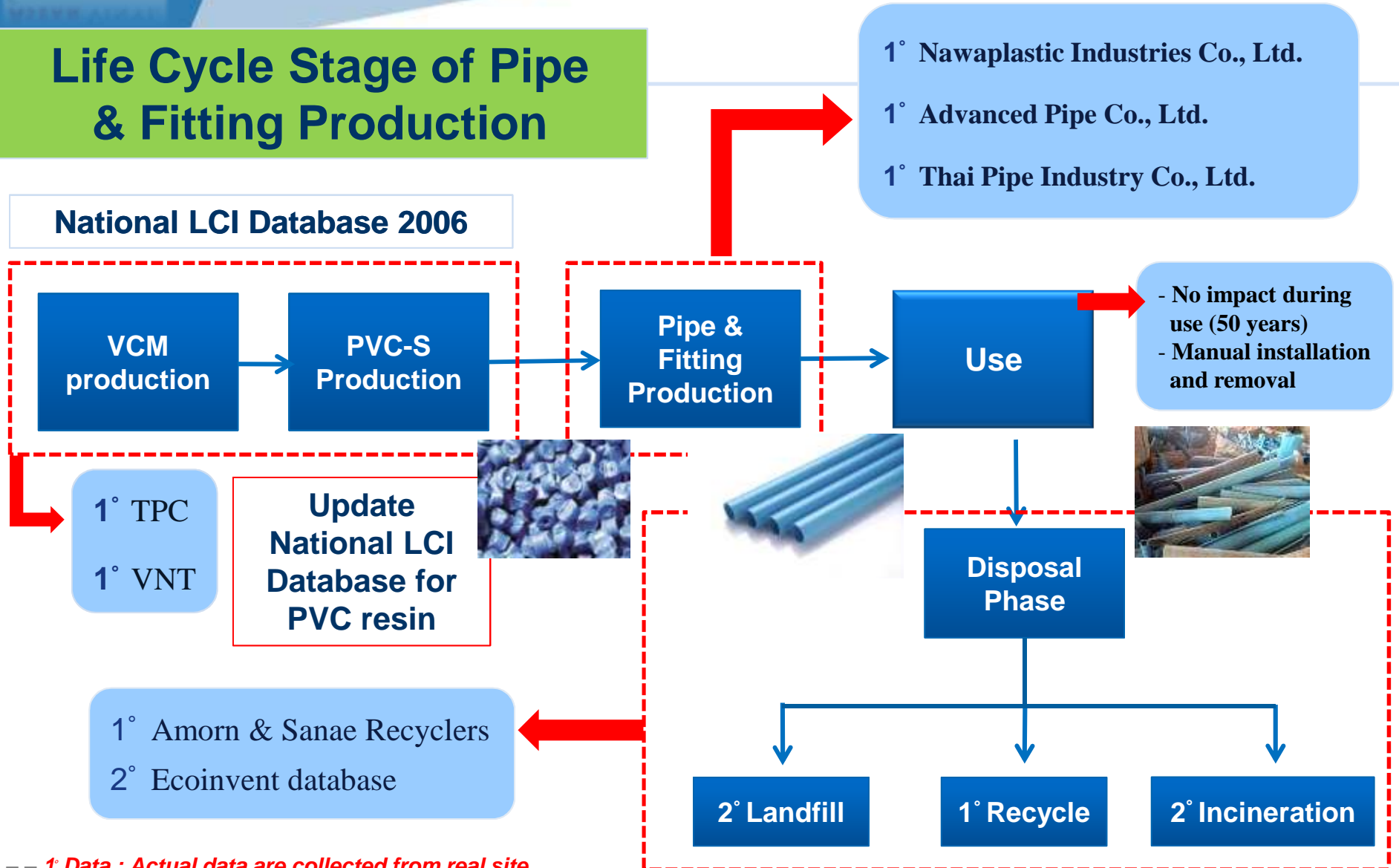


# Research Methodology



## Life Cycle Stage of Pipe & Fitting Production

National LCI Database 2006



# End of Life Scenarios

Scenarios	End-of-life treatment (%)		
	Mechanical recycle	Landfill	Incineration
<b>Base case*</b>	<b>30</b>	<b>67</b>	<b>3</b>
1	100	0	0
2	0	100	0
3	0	0	100
4	50	50	0
5	70	30	0
6	75	25	0
7	80	20	0
8	90	10	0

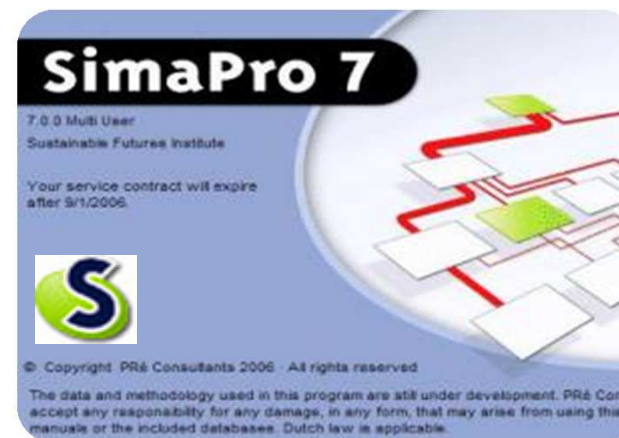
\* Base Case recycle is based on previous study by MTEC

The total amount of general PVC post consumer products (wastes) was found to be about 30% of the total amount of PVC product production. The rest was assumed to be treated by current waste treatment system in Thailand based on PCD statistics (landfill and incineration).



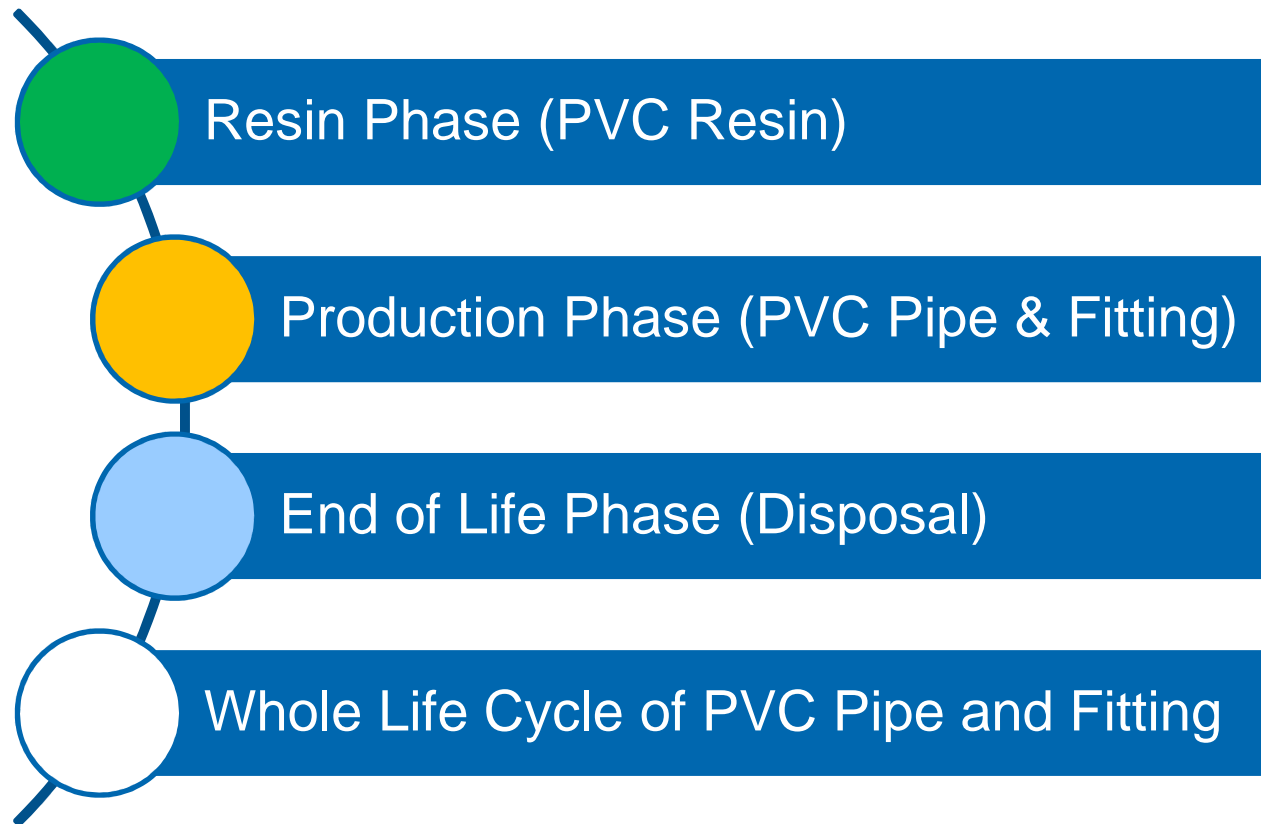
**LCA Technique based on ISO14040 series framework**

**LCA Software: SimaPro 7.1**  
Licensed

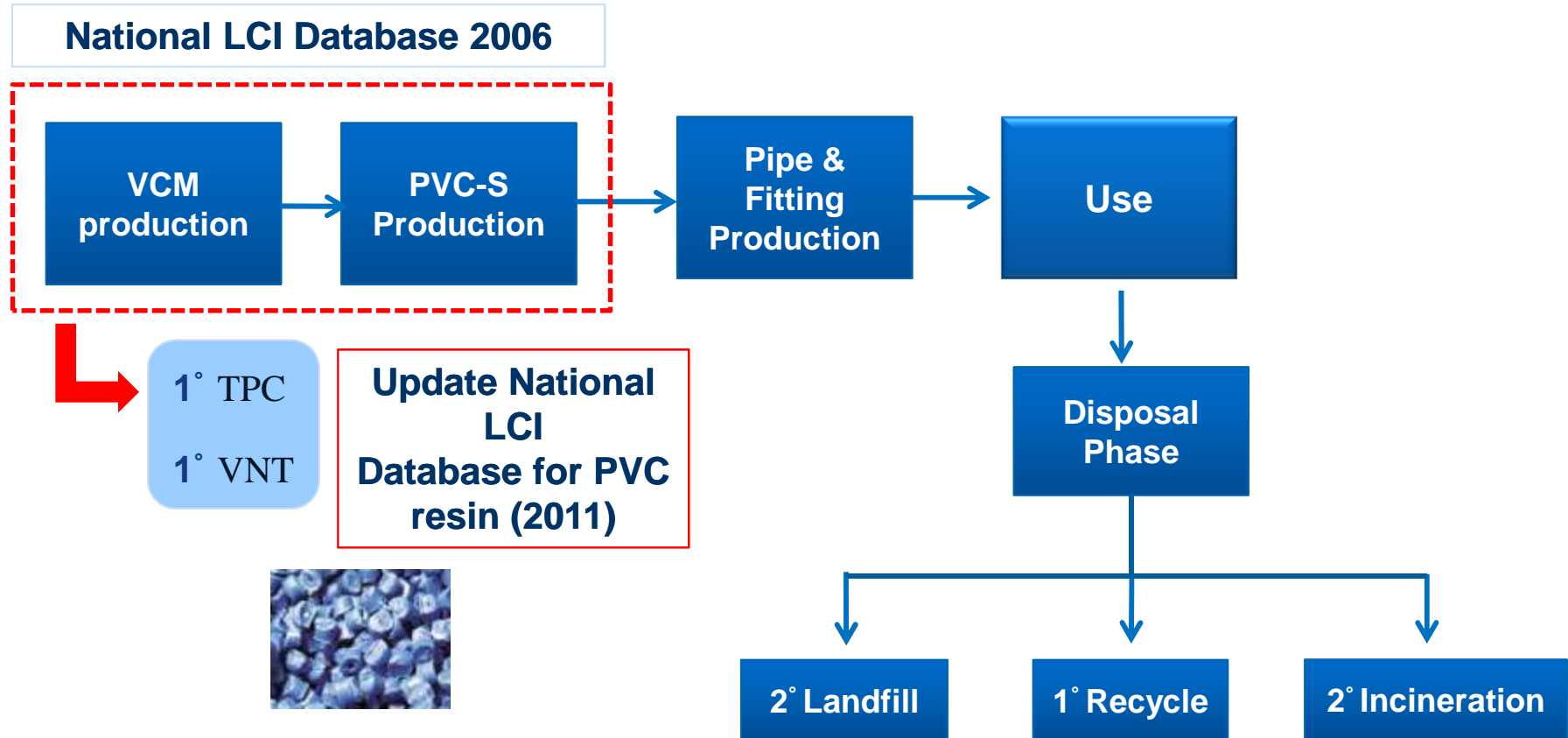


LCIA Method	Environmental Impact categories
CML 2 baseline 2000 V2.03	<ul style="list-style-type: none"> <li>• Global warming potential (CO<sub>2</sub>eq)</li> <li>• Acidification (SO<sub>2</sub>eq)</li> <li>• Eutrophication (PO<sub>4</sub>eq)</li> <li>• Human toxicity (kg 1,4-DB eq)</li> </ul>
Eco-indicator 95	<ul style="list-style-type: none"> <li>• Energy resource (MJ)</li> </ul>

Impact Category	Impact on	Scale	Reference substance	Description
Global warming potential (GWP)	Ecosystem	Global	Carbon dioxide (CO <sub>2</sub> eq)	Gaseous compounds adsorb infrared light and trap heat radiation.
Acidification potential (AP)	Ecosystem	Regional/ Local	Sulfur dioxide (SO <sub>2</sub> eq)	Emission of acid can degrade some material.
Eutrophication potential (EP)	Ecosystem	Local	Phosphate (PO <sub>4</sub> eq)	Chemical nutrients (nitrogen (N) and phosphorus (P)) in water bodies increase the rate of plant production and accumulation of organic matter that can degrade water and habitat quality.
Human toxicity potential (HTP)	Human health	Global/ regional / local	1,4 -dichloro- benzene (1,4-DB) eq	The degree to which a chemical substance elicits a deleterious or adverse effect upon the biological system of human exposed to the substance over a designated time period.
Energy Resource	Resource	Global/ regional / local	Energy (MJ)	Energy consumption in particular phase or throughout the life cycle of the product.

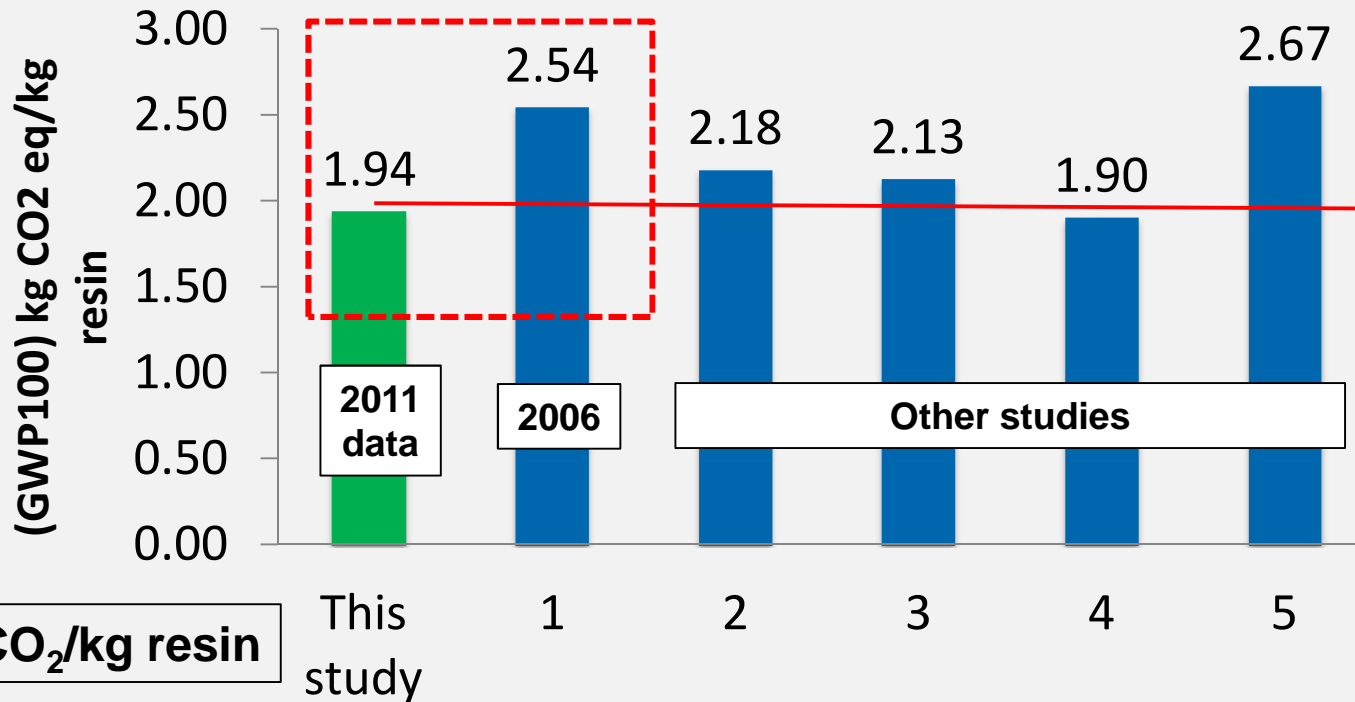


# 1. Resin Production Phase



# Global Warming Potential (GWP) of PVC Resin (kg CO<sub>2</sub> per kg resin)

**24% reduction from 2006 figure**

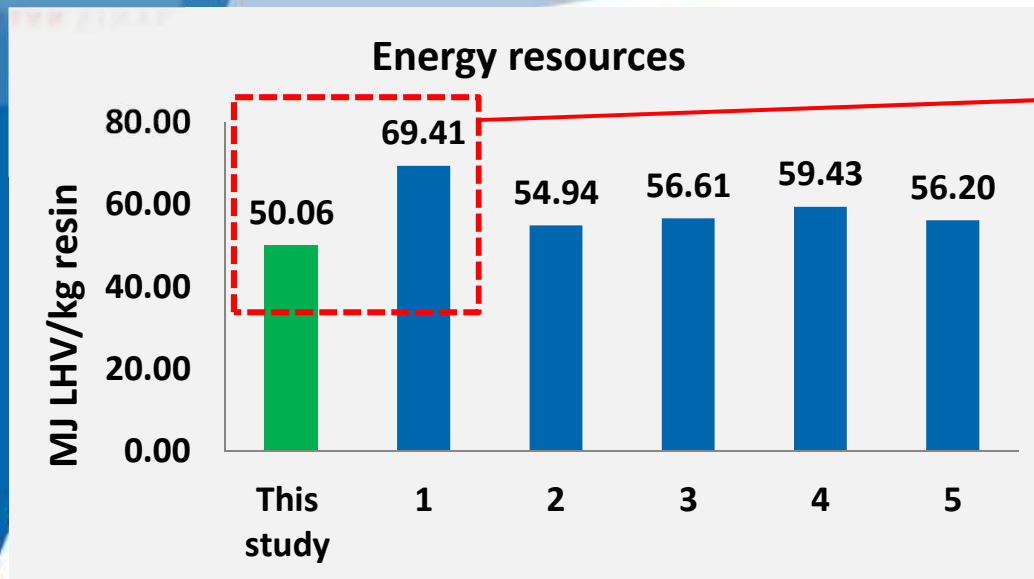


**10-27% lower than other studies**

**1.94 kg CO<sub>2</sub>/kg resin**

1	PVC-S National LCI Database Thailand (2006)
2	PVC (S) I (of project IDEMAT 2001) – Delft U. of Technology
3	PVC suspension A (of project Industry data)
4	Polyvinylchloride, suspension polymerised, at plant/RER U (of project Ecoinvent unit processes) – International Database
5	Polyvinylchloride resin (S-PVC), suspension polymerization, production mix, at plant RER (of project ELCD) – European Life Cycle Database

# Energy Demand and Acidification Impact of PVC-S Resin (per kg resin)

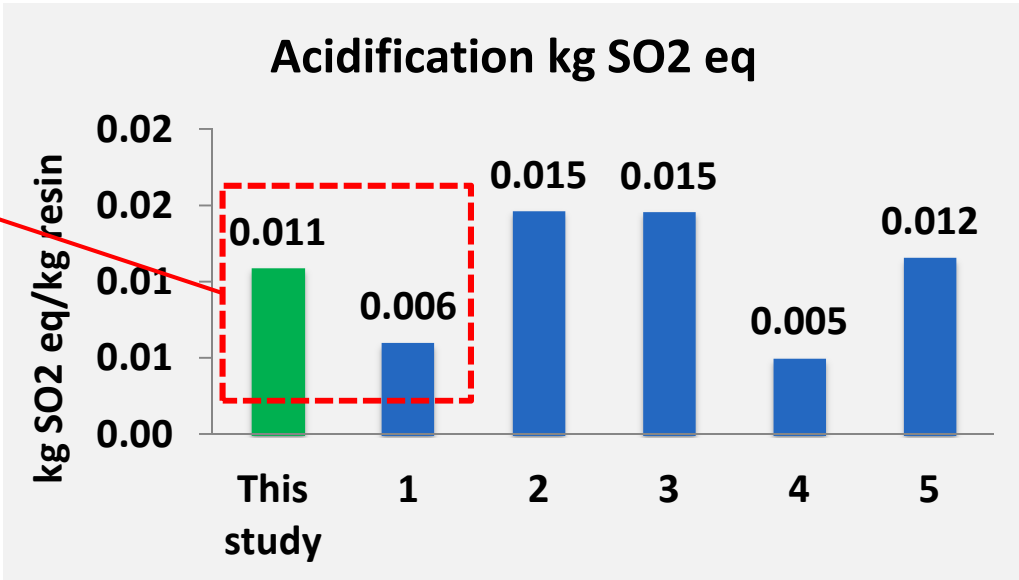


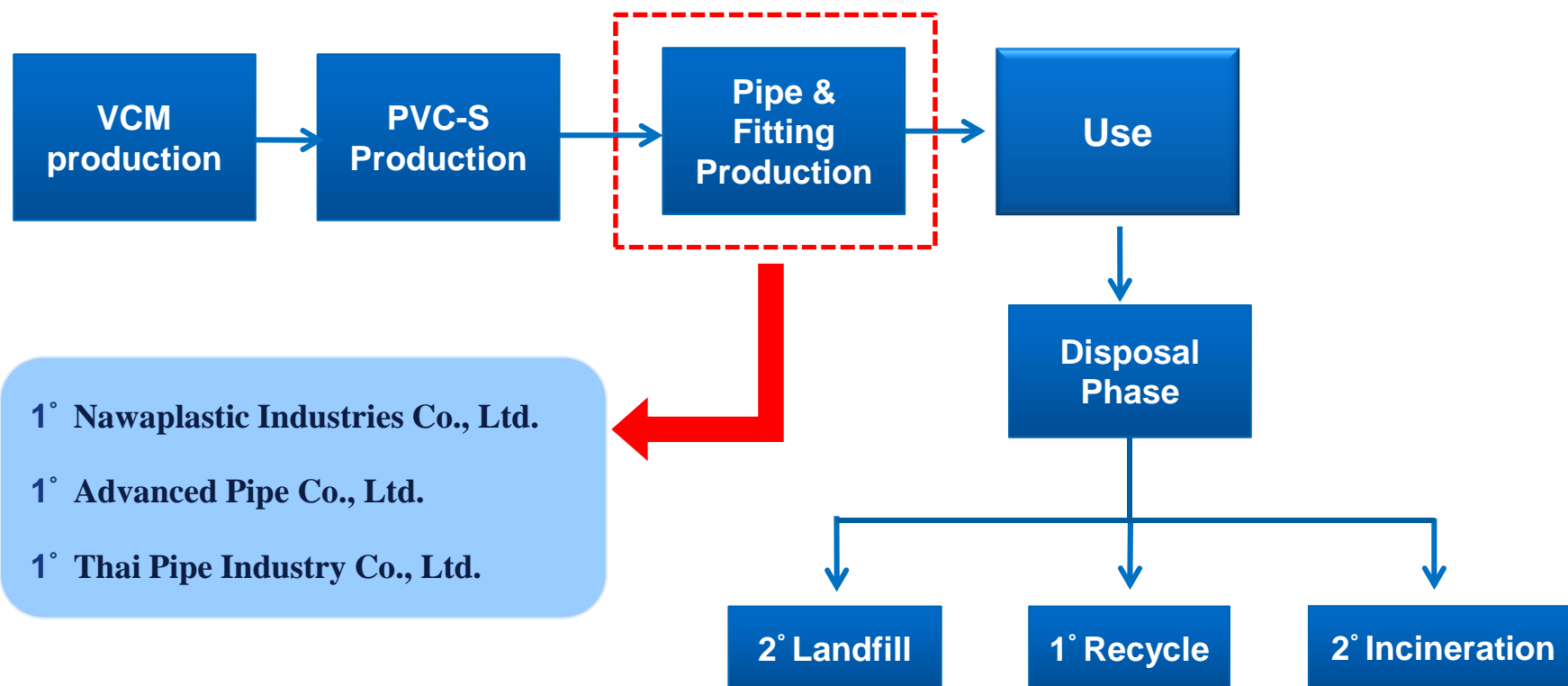
**28% reduction from 2006 figure**

**~50 MJ/kg resin**

**From ethylene, chlorine and EDC (2011 data are more detailed)**

**~0.01 kg SO<sub>2</sub>/kg resin**





## Advanced Pipe Co., Ltd.



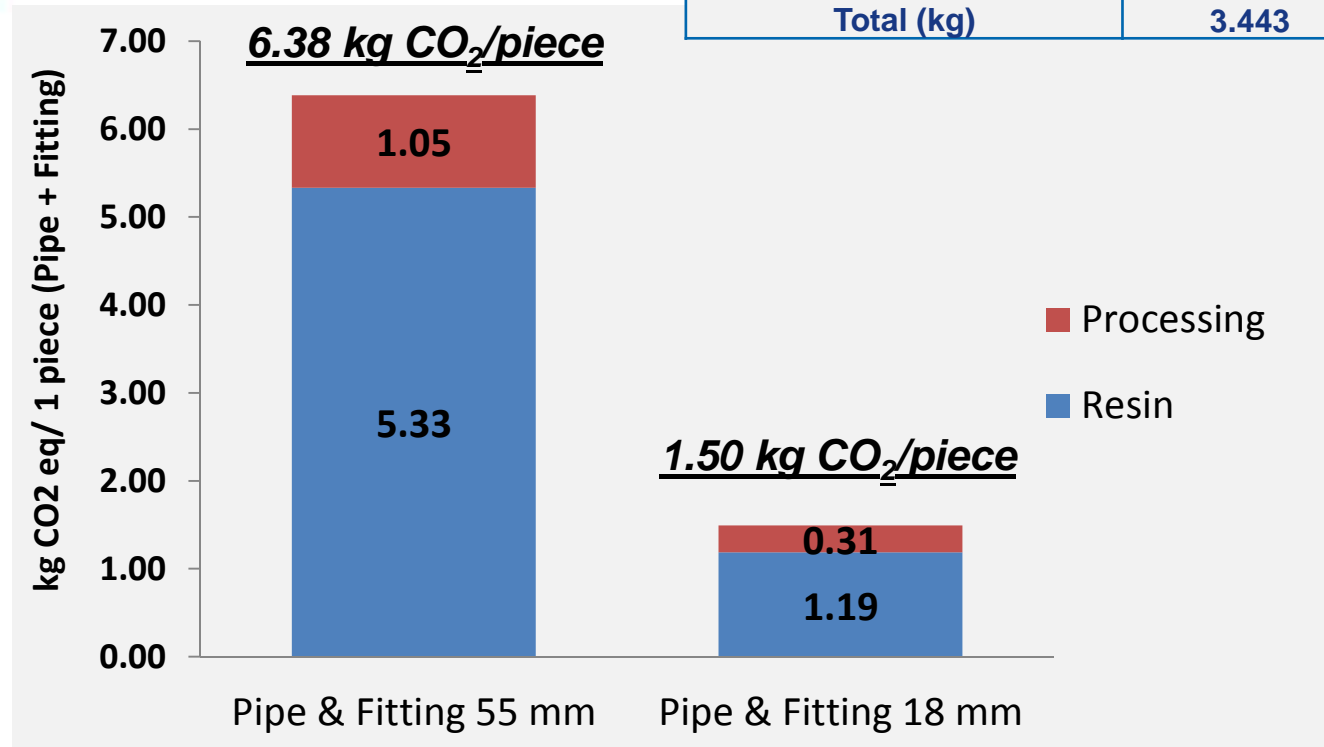


## Nawaplastic Industries Co., Ltd.



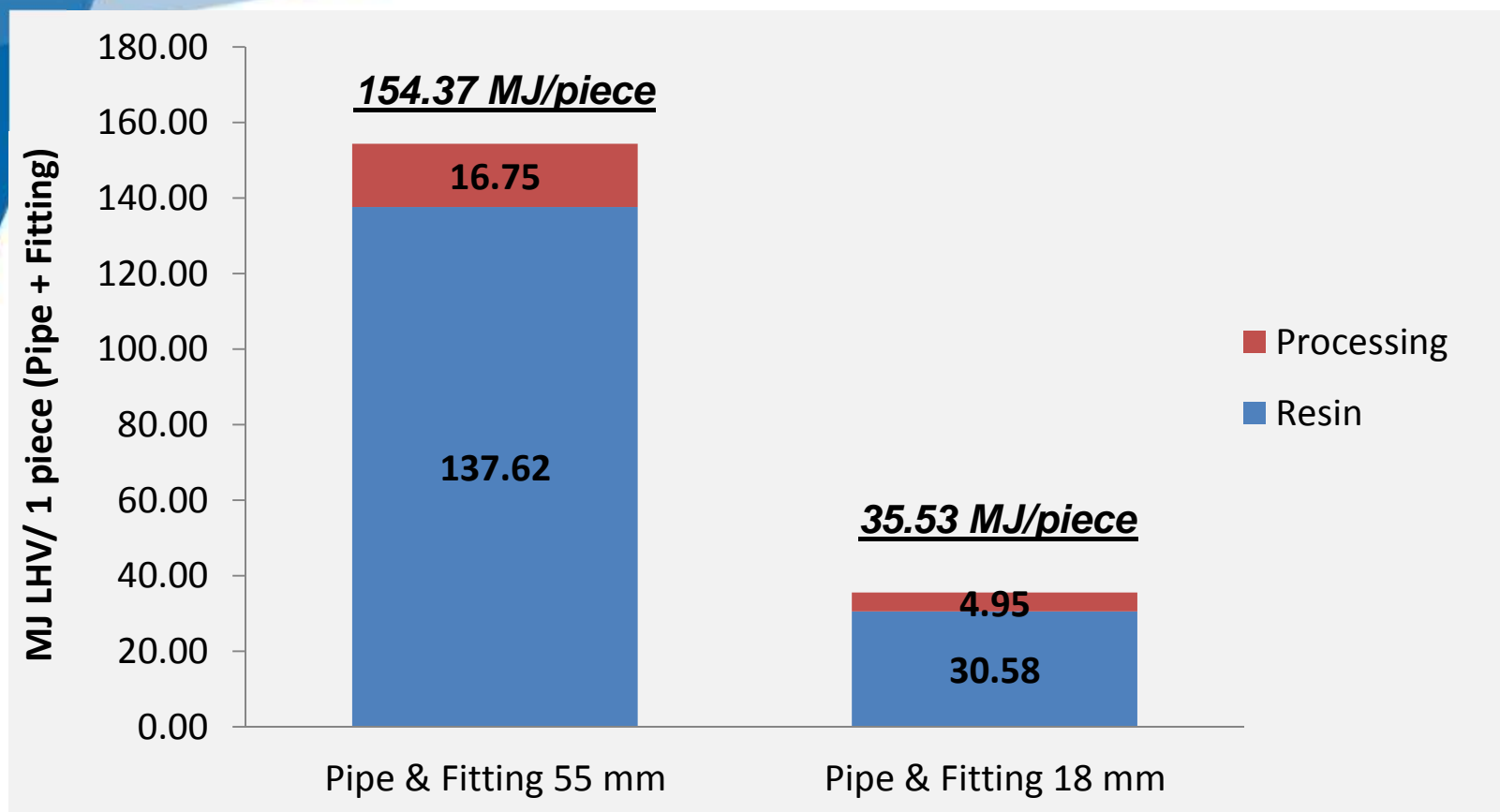
# Global Warming Potential (GWP) of PVC Pipe and Fitting (Cradle-to-Gate)

Weight per piece	55 mm	18 mm
Pipe	3.152	0.750
Fitting	0.291	0.033
<b>Total (kg)</b>	<b>3.443</b>	<b>0.784</b>



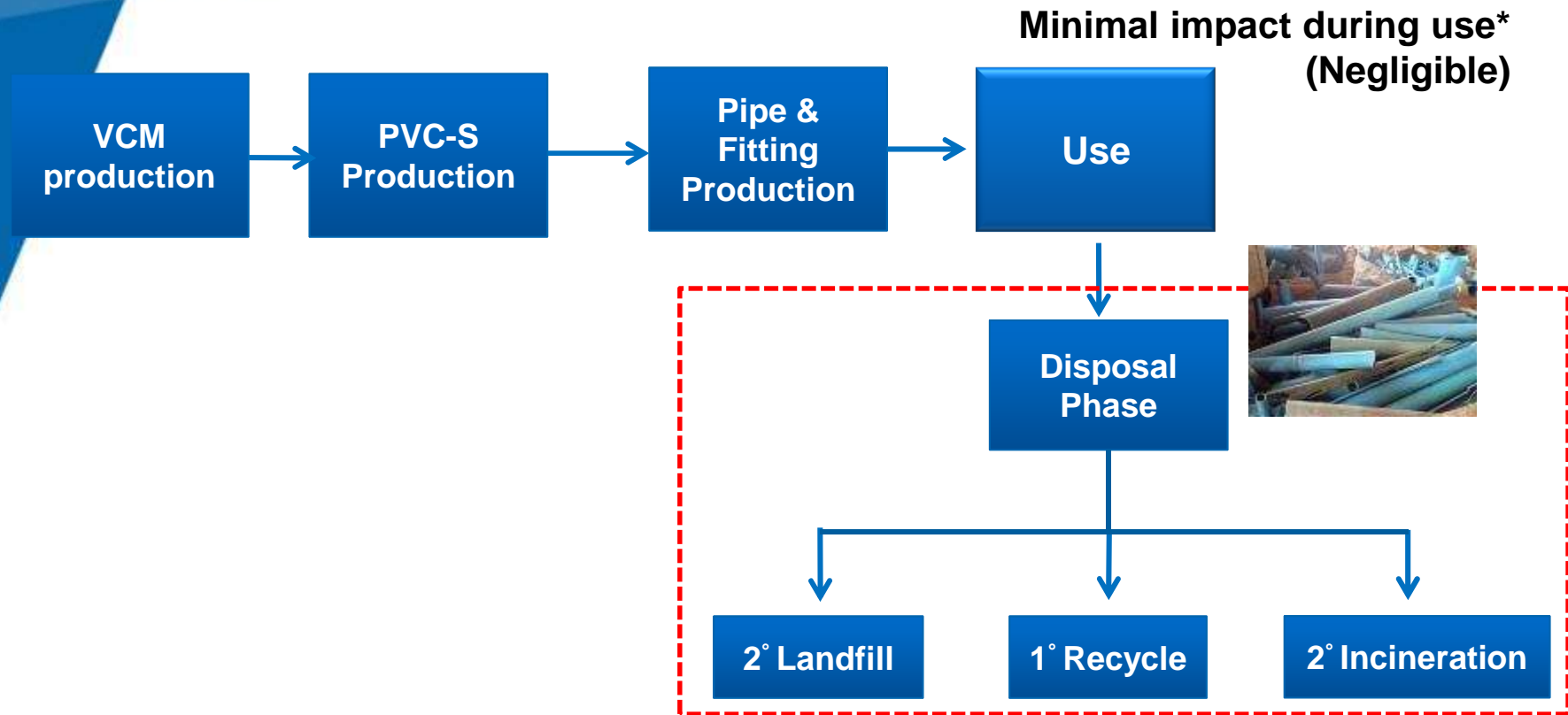
- Total GWP of pipe & fitting for both 55 mm and 18 mm is 1.85-1.91 kg CO<sub>2</sub> eq per kg of pipe & fitting.
- Resin itself contributes ~80% while processing contributes about 20%.

# Energy Use of PVC Pipe and Fitting (Cradle-to-Gate)



- Energy resources for producing 1 piece (pipe + fitting) of 55 and 18 mm are 44-45 MJ per kg (of pipe & fitting together).
- Approx. 85% of energy use is from resin phase.

# 3. End of Life Phase (Disposal)

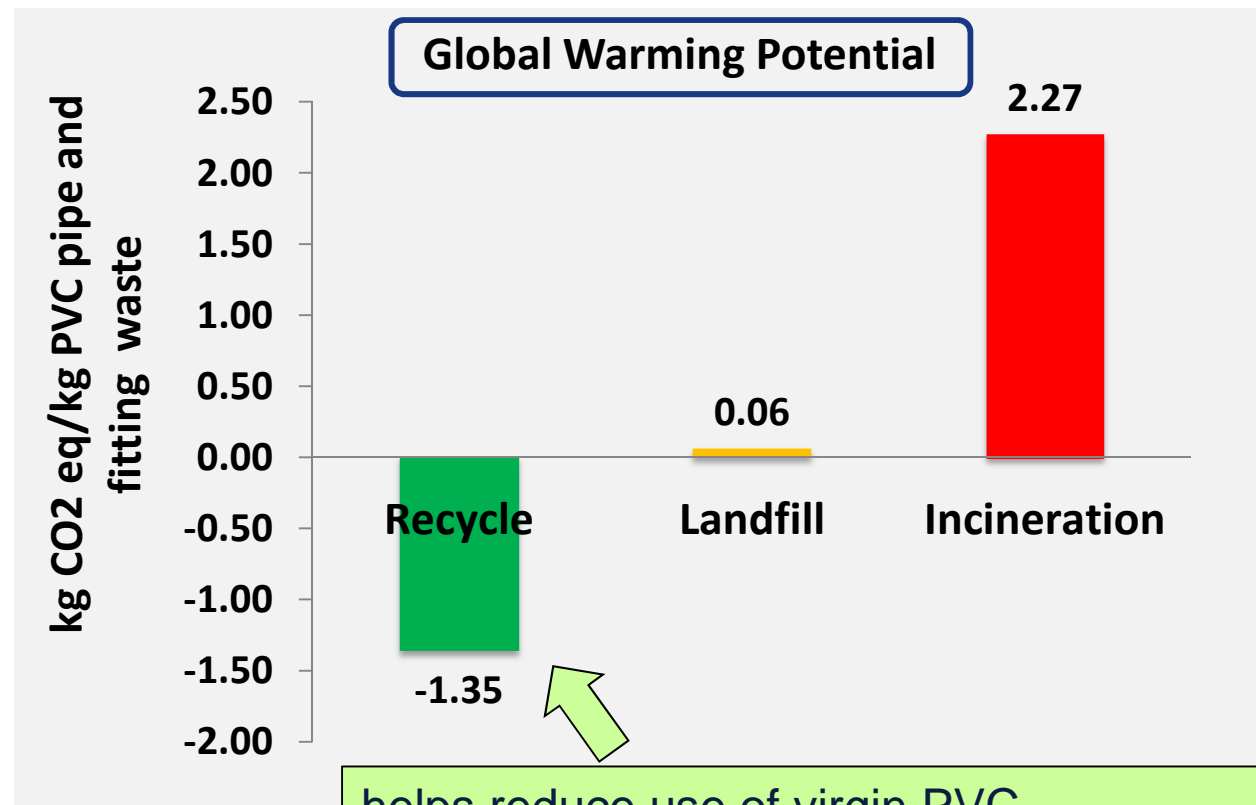


**Comparison between three disposal technologies  
100% Recycle / 100% Landfill / 100% Incineration**

**Basis: treatment of 1 kg PVC waste**

# 3. End of Life Phase (Disposal)

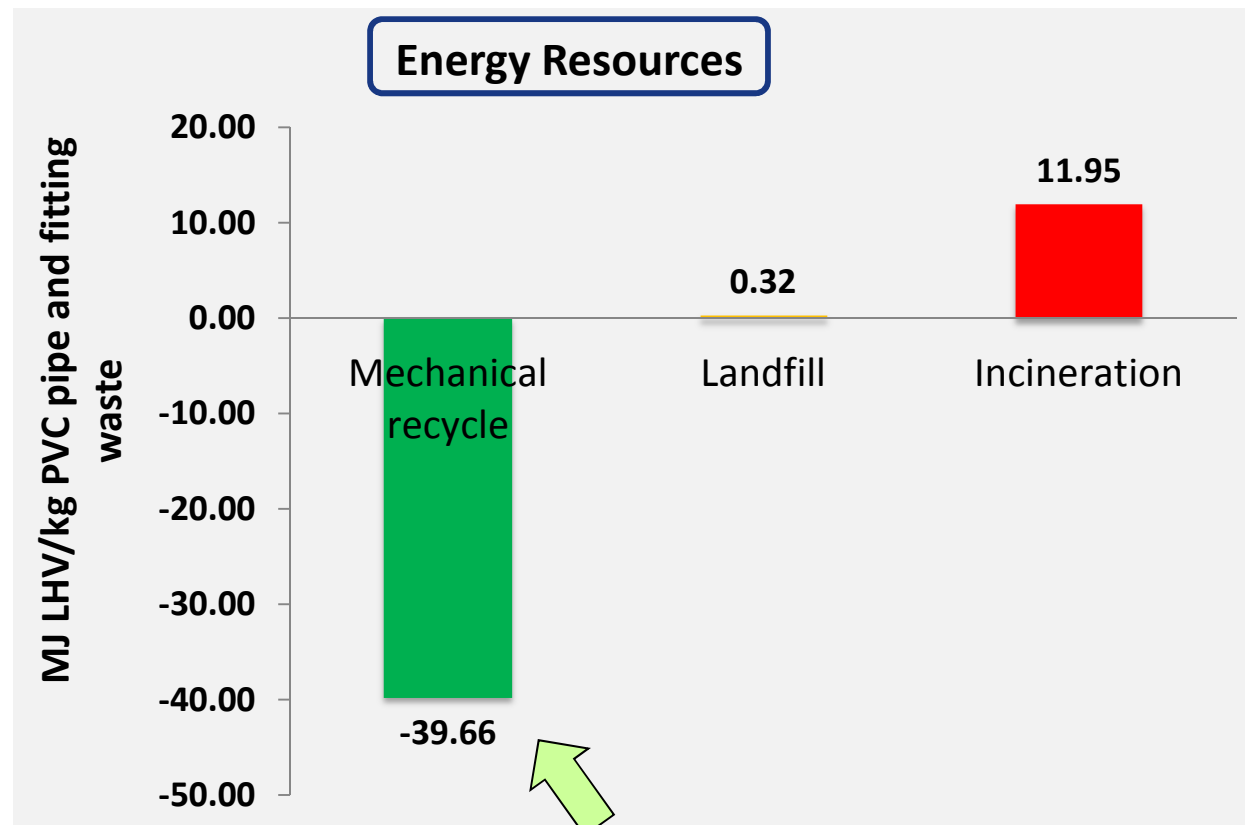
Comparison between three disposal technologies 100% Mechanical Recycle / 100% Landfill / 100% Incineration (per 1 kg of PVC waste)



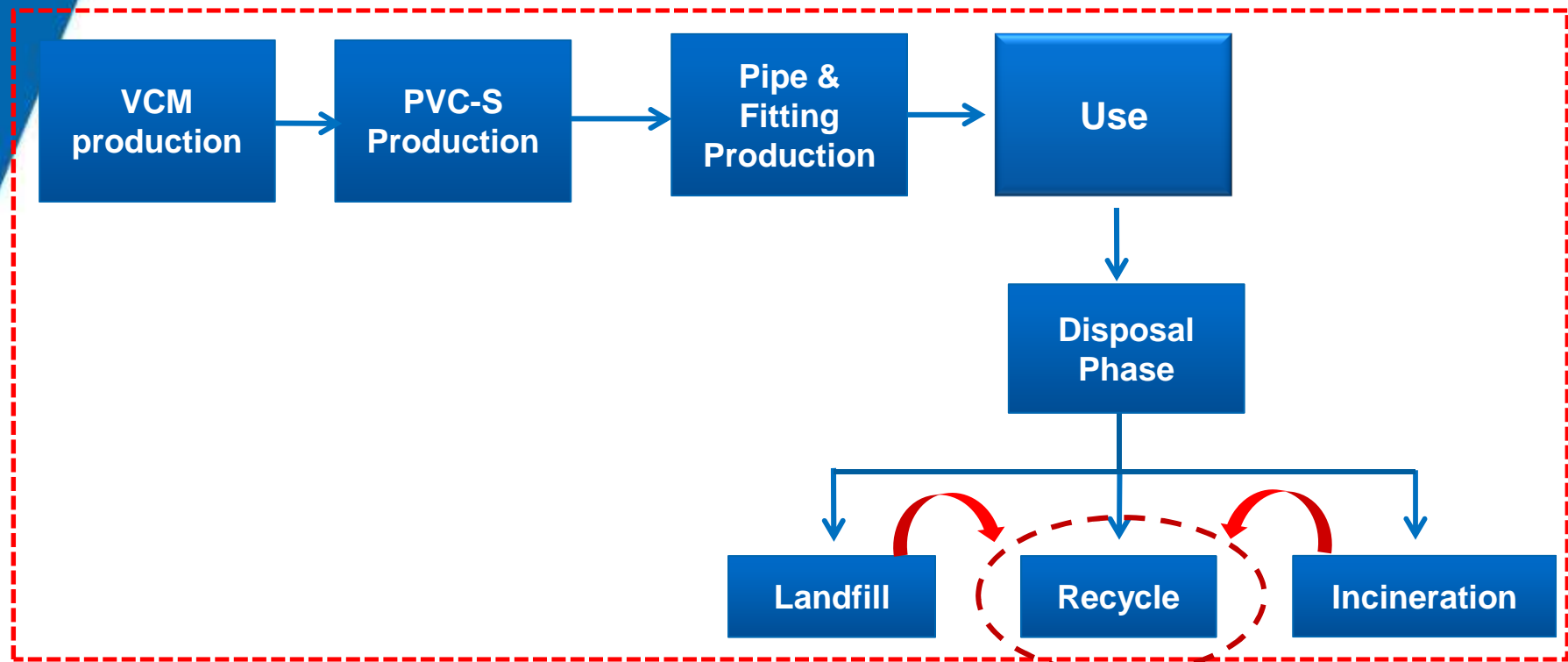
helps reduce use of virgin PVC  
 = credits → benefits → negative environmental impact

# 3. End of Life Phase (Disposal)

**Comparison between three disposal technologies 100% Mechanical Recycle / 100% Landfill / 100% Incineration (per 1 kg of PVC waste)**



## Effect of Recycle on the Life Cycle Environmental Performance of PVC Pipe & Fitting



Using scenario analysis



**Collection**



**Recycle shop  
Company A**

- **Collection**
- **Sorting**
- **Separating**
- **Cutting**
- **Cleaning**
- **Drying (air)**



**Sorting**



**Separating / Cutting**







**Recycle shop  
Company A**



## Recycle shop Company B

- From A
- Grinding (course)
- Grinding (fine)



Grinding



Course Grinding



Course Grinding



Fine Grinding



Packing

Shown already

Scenarios	End-of-life treatment (%)		
	Mechanical recycle	Landfill	Incineration
<b>Base case*</b>	<b>30</b>	<b>67</b>	<b>3</b>
1	100	0	0
2	0	100	0
3	0	0	100
4	50	50	0
5	70	30	0
6	75	25	0
7	80	20	0
8	90	10	0

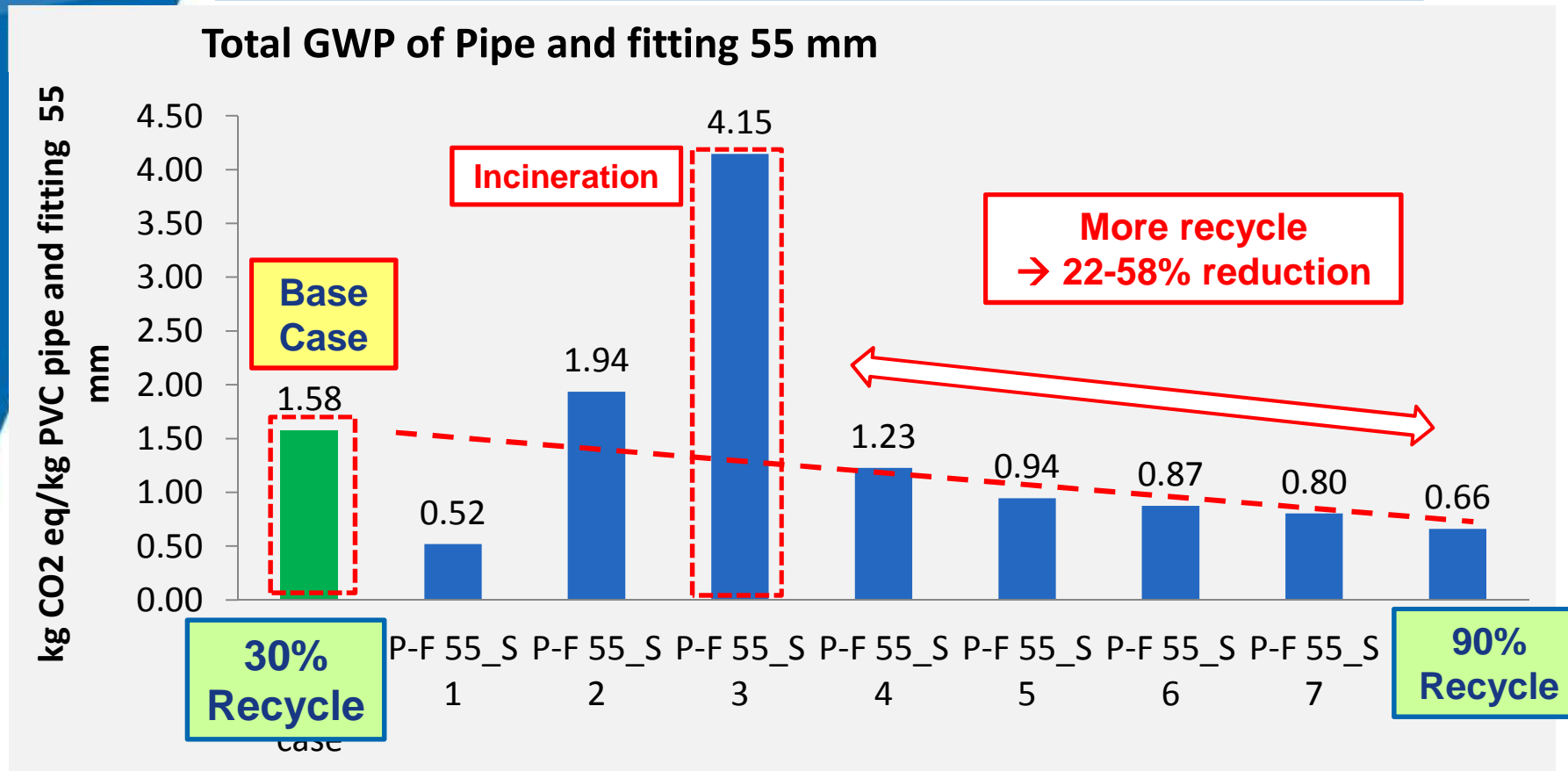
**Increasing Recycle**

**Minimizing Landfill**

**Zero incineration**

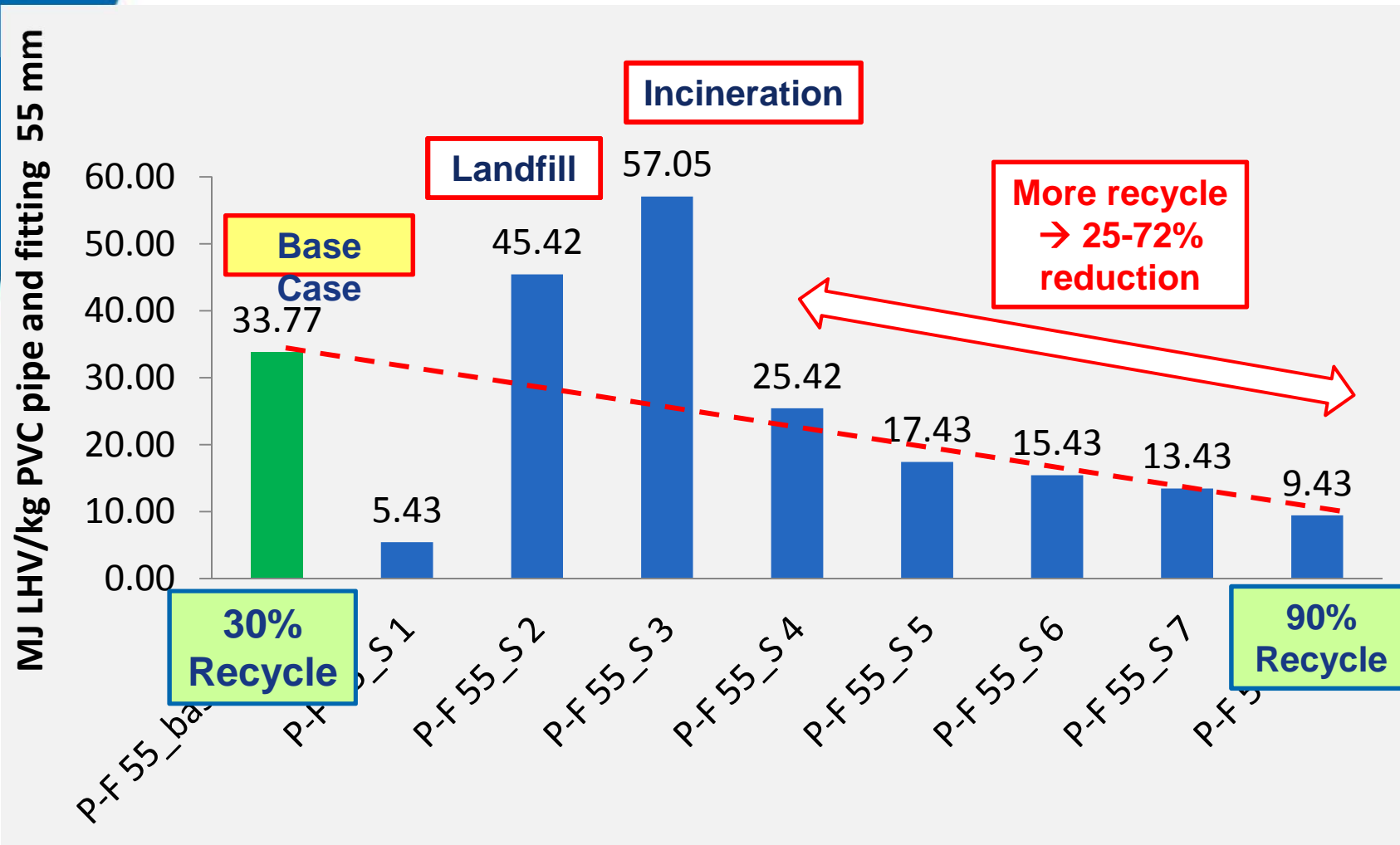
\* Base Case is considered as current situation (based on MTEC study)

## NET GWP (kg CO<sub>2</sub> eq/kg pipe and fitting set)



The more recycle, the better to the environment

## NET Energy Used (MJ/kg pipe and fitting set)



# Study of PVC Recycling in Thailand Using Material Flow Analysis (MFA)



*Pomthong Malakul Na Ayudhaya,  
Ph.D.*

*The Petroleum and Petrochemical College  
Chulalongkorn University*

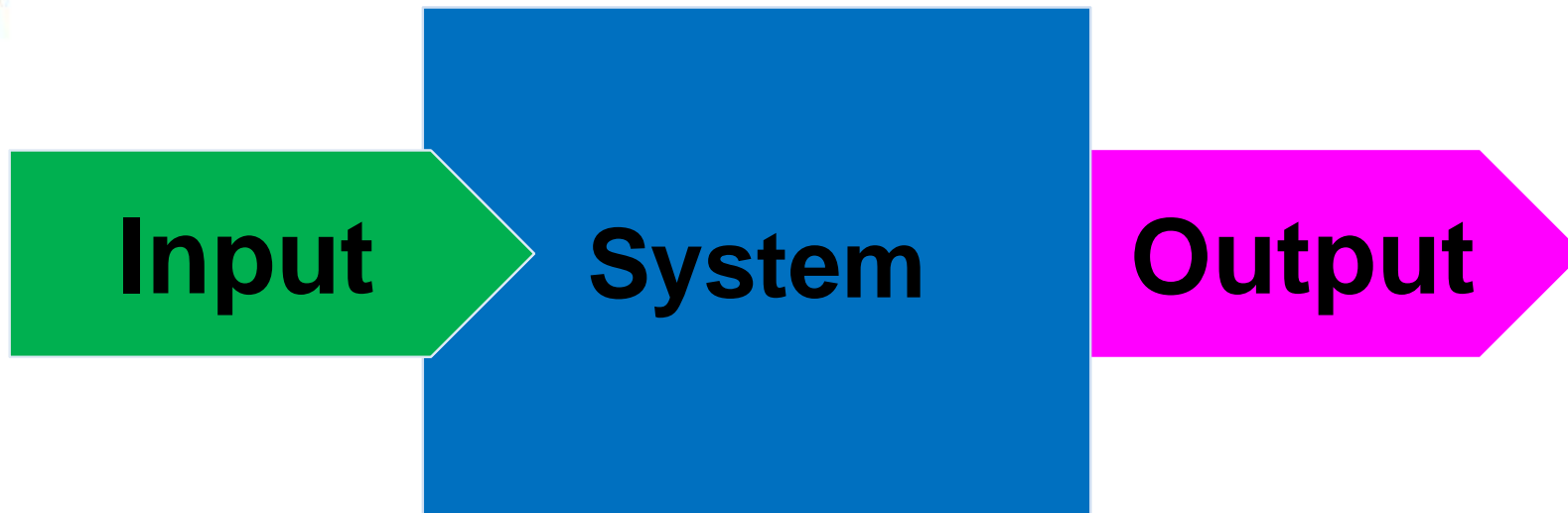


**Research Team :**  
Asst. Prof. Dr. Pomthong Malakul Na Ayudhaya (PPC-CU)      Mr.Namsak Choonhajutha (AVC)  
Asst. Prof. Dr. Manit Nithitanakul (PPC-CU)      Ms.Jirawadee Pipattanatornkul (AVC)  
Dr.Ampira Charoensaeng (PPC-CU)  
Mr. Seksan Papong (MTEC)

78

# Concept of Material Flow Analysis (MFA)

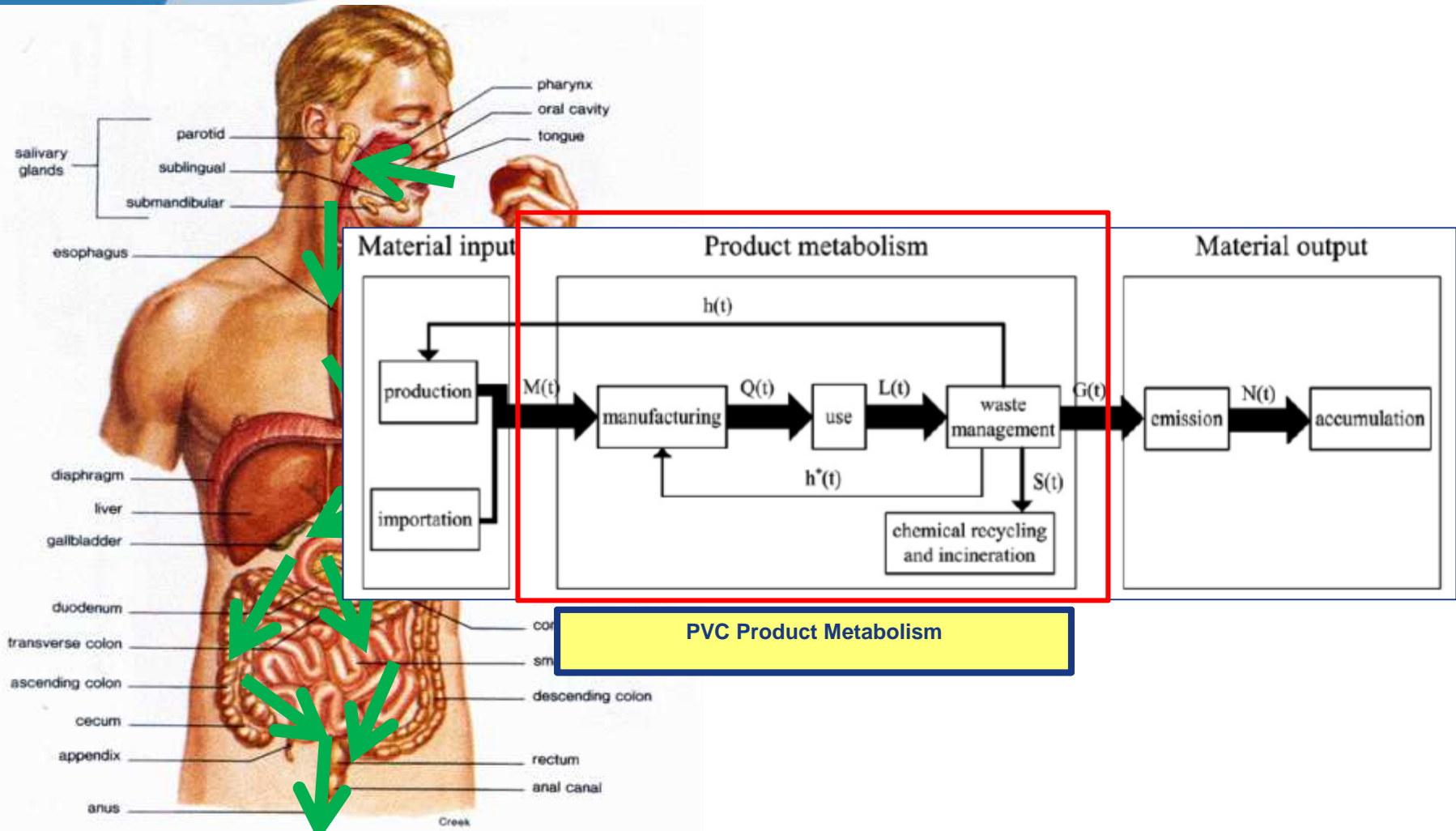
Material Flow Analysis (MFA) is a systematic assessment of flow and stock of materials within a specific system. This tool can be used to identify and analyze the flow of materials added in and removed out from the system.



*MFA sometimes referred to as “Product Metabolism”*

• • • • • • • • • •

## Concept of Product Metabolism



PVC Product Metabolism

Metabolism in our body





Thank you for  
your kind  
attention

**Dr.Pomthong Malakul Na Ayudhaya**

**Pomthong.m@chula.ac.th**

• • • • • • • • • •