3 Case study on Plastics : PET Bottle
Life Cycle of Plastics

Crude Oil → Polymer → Product → Use → Waste

Recovery → Polymer → Product → Use
Overview of PET bottle recycling

Containers and Packaging Recycling Law

Specified business entities

Local governments

Consumers

Obligation to recycle

Selective collection and storage

Selective discarding

Fiber Industry
(wash, crash, melt, spin)

Bottle Industry
(deporimerization)

Containers and Packaging Recycling Law
Players

- Producers
  - Plant designers
  - Product designers
  - Energy suppliers
  - Related industrial sectors
- Consumers
- Municipal and governmental authorities
- Waste treatment agencies
Role of KIH ‘configuration engine’

1. To inform players of their role in life cycle as a stakeholder
2. To accumulate knowledge/information of life cycle from information suppliers
3. To interpret massive life cycle data with transparency for rational decision making
Overview of PET bottle recycling

Containers and Packaging Recycling Law

Specified business entities

- **Fiber Industry** (wash, crash, melt, spin)
- **Bottle Industry** (deporimerization)

Obligation to recycle

Local governments

Selective collection and storage

Consumers

Selective discarding
Objective of this case study

- To develop a ‘configuration engine’, which takes LCA as an environmental metric concurrently with an economic metric, for chemical process designer,

- To clarify steps, tools and information in a form of business-model.

- To show actual design procedure of PET bottle recycling processes using configuration engine.
IDEF0: Integration Definition for Function Modeling type 0

A method to model activities of an organization or a system.

**Input:**
Objects that are transformed into output

**Control:**
Conditions required to produce correct output

**Activity:**
A0

**Output:**
Objects that are produced by a function

**Mechanism:**
Means to perform a function
Top activity A0: **Design Chemical Process**

**Constraints**
- External constraints (law, etc)
- Enterprise’s constraints (Resource, etc)
- Technical constraints

**Desired function of the process**

**Input**
- Knowledge, database
- Process simulator
- Economic evaluation tools
- LCA tools
- Monte Carlo simulator

**Output**
- Optimal design

**Evaluation tools, databases**

**Mechanism**

**Control**
One layer-down from A0

Input

Constraints

Control

Output

Process diagrams

Needs to change design configurations

Needs to regenerate alternatives

Needs to check parameters

Desired function of the process

Database, Knowledge

Economic evaluation tools

LCA tools

Monte Carlo simulator

Process to be optimized

Optimal design

Scope, Objectives, Constraints

Configure design problem

Generate alternatives

Analyze process

Evaluate process

Optimize process

A1

A2

A3

A4

A5

Process input/output

Idea for options

Mechanism

A1

A2

A3

A4

A5
Changes of CO₂ emissions by installation of the process

Oil Drilling & Monomer Production

Esterification

Trans Esterification

s-phase Polycondensation

PET resin

Bottle Manufacturing

Consumption

Incineration

10,000 t/yr

Process Input/Output

EG

PTA

BHET

Polymerization

EG

PTA

Hydrolysis

DMT

Metathesis

EG

DMT

Polymerization

EG

DMT

Elec.

Flaking + Washing

Used Bottles
Multi-objective evaluation result

The Net Present Value [Billion Yen]

Better design

Reduction of CO$_2$ emissions [kt]

The Net Present Value [Billion Yen]

DMT route
PTA route
BHET route
Whole picture of the design procedure

Configure design problem (A1)

Desired function of the process

Generate alternatives (A2)

10,000 t/yr as used-PET inlet

BHET, DMT, PTA route

Analyze process (A3)

Process input

Evaluate process (A4)

Economic evaluation tools

BHET route with LNG or Heavy oil

Optimize process (A5)

Optimal design

LCA tools
Conclusion of this case study

- IDEF0 model defines each step of the activities
  - systematic and transparent integration of tools that are conventionally available but separately existing in each field.
- Integration of these engines construct KIH
  - KIH for process designer may play significant role in becoming the sustainable chemical industry with stakeholders of its products.
LCA showed that material recycling (MR) system decrease environmental impact.

Quality of plastics deteriorates by use, processing for recycling.

Life cycle wide quality management is needed as configuration engine.
Emergence of quality problem

PET bottle life cycle
- Polymerization
- Molding
- Filling
- Consumption
- Disposal

PET fiber life cycle
- Polymerization
- Manufacturing
- Consumption
- Disposal

Bottle collection
recycling
Emergence of quality problem

PET bottle life cycle
- Polymerization
- Molding
- Filling
- Consumption
- Disposal

PET fiber life cycle
- Polymerization
- Manufacturing
- Consumption
- Disposal

Bottle collection
- recycling

Quality information doesn’t flow across life cycle
Dialog between players is needed!
Matrix Model

- Transferring of quality information throughout the life-cycle
- Translating information into comprehensible quality terms
Model Structure

Resin
- IV
- Moisture rate
- DEG
- Acid value
- Color
- PVC contam
- Metal, sand contam
- Other contam

Fiber
- Denier
- DE
- DT
- Shrinking Rate
- Dyeing capacity
- Color

Quality demand
- Low broken thread
- Low unevenness
- High strength
- High measure stability
- Fine color
- Less variation of properties

Fiber manufacturing
- Dehydration
- Heating & pushing-out
- Pre-filtering
- Metal-filtering
- Fiber-spinning
- Wind roll...

Correlation Matrix
# Matrix Structure

<table>
<thead>
<tr>
<th>Fiber</th>
<th>Quality demand</th>
<th></th>
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<tbody>
<tr>
<td></td>
<td>Low broken thread</td>
<td>Low unevenness</td>
<td>High strength</td>
<td>...</td>
<td>...</td>
</tr>
<tr>
<td>Denier</td>
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</tbody>
</table>

Numbers are obtained by...

- Investigation Data from manufactures / organizations
- Information from expertise
- Chemical / physical relationship
Model Calculation

<table>
<thead>
<tr>
<th>Separation</th>
<th>Low broken thread</th>
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<tr>
<td>Label separation</td>
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<tr>
<td><strong>Cap separation</strong></td>
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<tr>
<td>Can separation</td>
<td>0.512</td>
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<tr>
<td>Plastic mixing</td>
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<tr>
<td>Tape adhesion</td>
<td>0.448</td>
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<tr>
<td><strong>Squashing</strong></td>
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<tr>
<td>Washing</td>
<td>0.192</td>
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</table>

Cap separation affects the most on low broken thread.

Squashing does not affect at all.
Life Cycle Wide Quality Management

Conventional quality controls in individual sectors

Lifecycle wide quality control between sectors, consumers
Consumers and Supply Chain

Consumer’s attitude should be involved in the management of supply chain
Pareto Analysis

Consumer’s Attitude → Quality → Supply

Environmental Indicator

Economic Indicator

- Base Case
- Scenario 1

Quality

Supply
Conclusion of this case study

- ‘Configuration engine’ for quality conscious life cycle system design
- Q-model for every stakeholders in plastics life cycle as a ‘configuration engine’, to eliminate the communication barrier regarding lifecycle-wide quality improvements.
  - Propagation function
  - Interpretation function
  - Accumulation and integration of knowledge/information about life cycle quality issues
Example of grouping of knowledge and information
Concluding remarks

• Prototypes of ‘configuration engine’
  – Multi-agent-simulator (MAS) for stakeholders involved in supply/demand chain of biomass wastes
  – Activity model for recycling process designer to incorporate life cycle view
  – Q-model with LCA for stakeholders in plastics recycling system

• Possible framework of KIH and its potential to contribute to realize less-unsustainable resource-productive society
Possible policy implications

• Collaborative partnership among stakeholders is the first step to take effective and productive action against environmental problems.
• Application of KIH enables to constrain adversarial relationship and enhance more productive dialogue among various stakeholders.
• The research demonstrates the new function of governmental agencies as the facilitator to promote the exchange knowledge and information.