Integrated Environmental Assessment of Resource Circulation and Waste Management

Hwong-wen Ma
National Taiwan University
March 15, 2010

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- Conceptual framework of IEA model
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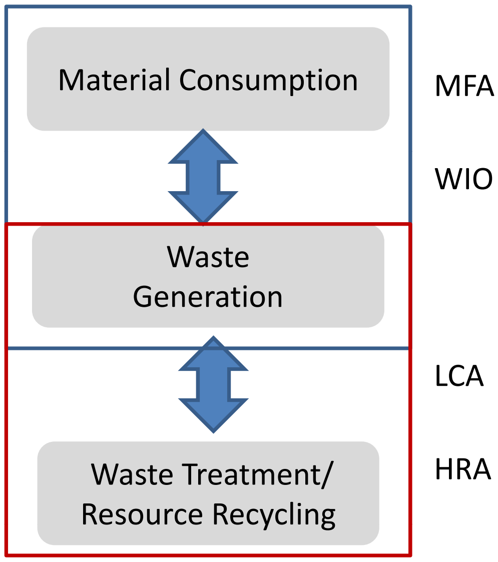
Motivations

- Objectives of Asia Resource Circulation Research Project
  - Highlighting the multiple benefits of the 3Rs Policy
  - Improving governance for 3R implementation in developing Asia
  - Providing policy advices on vision making for sustainable resource circulation in Asia
- Role of NTU's group
  - Developing evaluation methods of impact of national 3R and waste management policies

The Basic Concepts

- **The characteristics of novel WM/3R policy**
  - From " residue treatment" to "resource management"
  - Emphasis on SCP
  - Co-Benefits of GHGs and Energy
- **The evaluation methods should**
  - Link the industrial and household waste together
  - Quantify the relationship between consumption patterns and waste generation
  - Assess the multiple environmental, economic and social impacts

The Assessment Tools



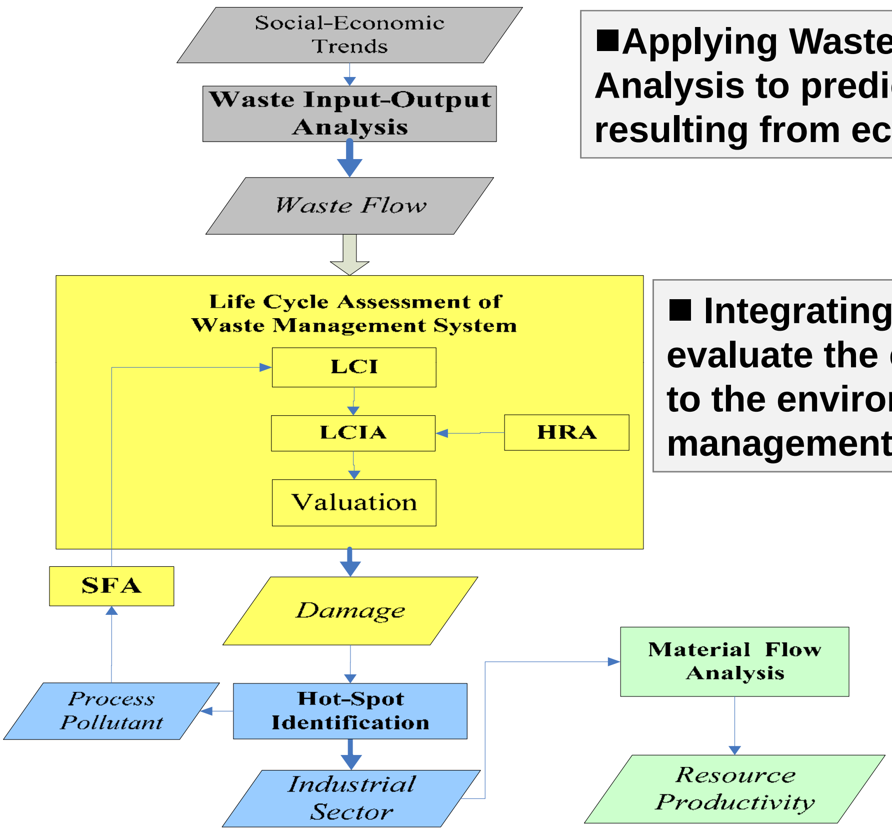
Waste Generation

- MFA : tracing and forecasting the waste flow between sectors
- WIO: reflecting the industrial activities and household demand

Environmental Impact

- LCA : comparing the environmental performance of various waste treatment technologies
- HRA: identifying health impact generated by specific treatment facilities

The Conceptual Framework of IEA Model



■ **Applying Waste Input-Output Analysis to predict waste generation resulting from economic activities**

■ **Integrating SFA, LCA, and HRA to evaluate the externality of releases to the environment from the waste management system**

■ Based on result of the hot-spot identification, using MFA to calculate the resource productivity of specific sectors

Waste Flow Prognosis

Waste Input Output Analysis(1)

	sectors			Waste treatment	Final demand	
Sectors				Data for G Multiplier		
		X_{ij}($)			X	
Wastes				Data for S Allocation matrix	Waste from household	
		W_{kj}(mass)				
Environ. load	Air Emission Water Emission Resource Consumption					
Value added						

- WIO evaluates environmental loadings from the waste management system induced by final demand
- In this study, WIO is developed to estimate the direct and indirect waste generated by household demand and industrial activities

$$X = (I - A)^{-1} F$$
$$G = W_t / X_t$$
$$\hat{W} = G \cdot X = G \cdot (I - A)^{-1} F$$
$$Q_{Treat} = SG \cdot (I - A)^{-1} F$$
$$I_{LCIA} = CF_w SG \cdot (I - A)^{-1} F$$

symbol		
F	final demand	(n╳1)
A	input coefficient	(n╳n)
I	identity matrix	(n╳n)
W	waste generated by sectors	(k╳n)
G	waste output per unit monetary total output	(k╳n)
S	allocation matrix of waste treatment	(m╳k)
Q_{treat}	matrix of waste treatment demand for each sector	(m╳n)
CF_w	characterization factor of impacts by unit treatment capacity	(l╳m)
I_{LCIA}	impact matrix of impact by industry	(l╳n)

TaiWan WIO Table

	Taiwan WIO	Japan
Input-output table	**52**, **166** sectors	**102** sectors
Waste classification	**199** General wastes **191** Hazardous wastes	**79** waste types
Recycling	Only waste out	With waste in
Treatment classification	**28** for General wastes **19** for Hazardous wastes	**13** treatment sector
Impact categories	12 midpoints	CO_2 Emission landfill volume
Year of compilation	2007	1990,1995,2000
Export of waste	Under compiling	Yes
Household waste	Under compiling	Yes

Environmental Impact Assessment

Life **C**ycle **A**ssessment Model of **W**aste **M**anagement

Model	Developer/Country	Inventory Data Sources	Uncertainty analysis	Impact Assessment
MSW-DST	RTI&EPA/US	Local Survey	None	None
ORWARE	KTH/ Sweden	Local Survey	None	None
WISARD	Ecobilan/UK	Local Database	None	None
IWM-1/IWM-2	P&G/ U.K.	Existing Database	None	None
ISWM Tools	CSR/Canada	Existing Database	None	None
EASEWASTE	DTU/ Denmark	Local Database	None	TI (EDIP97)
WASTED	Ryerson Unv. /Canada	Existing Database	None	None
LCA-IWM	EU project	Local Survey	None	TI(CML2000)

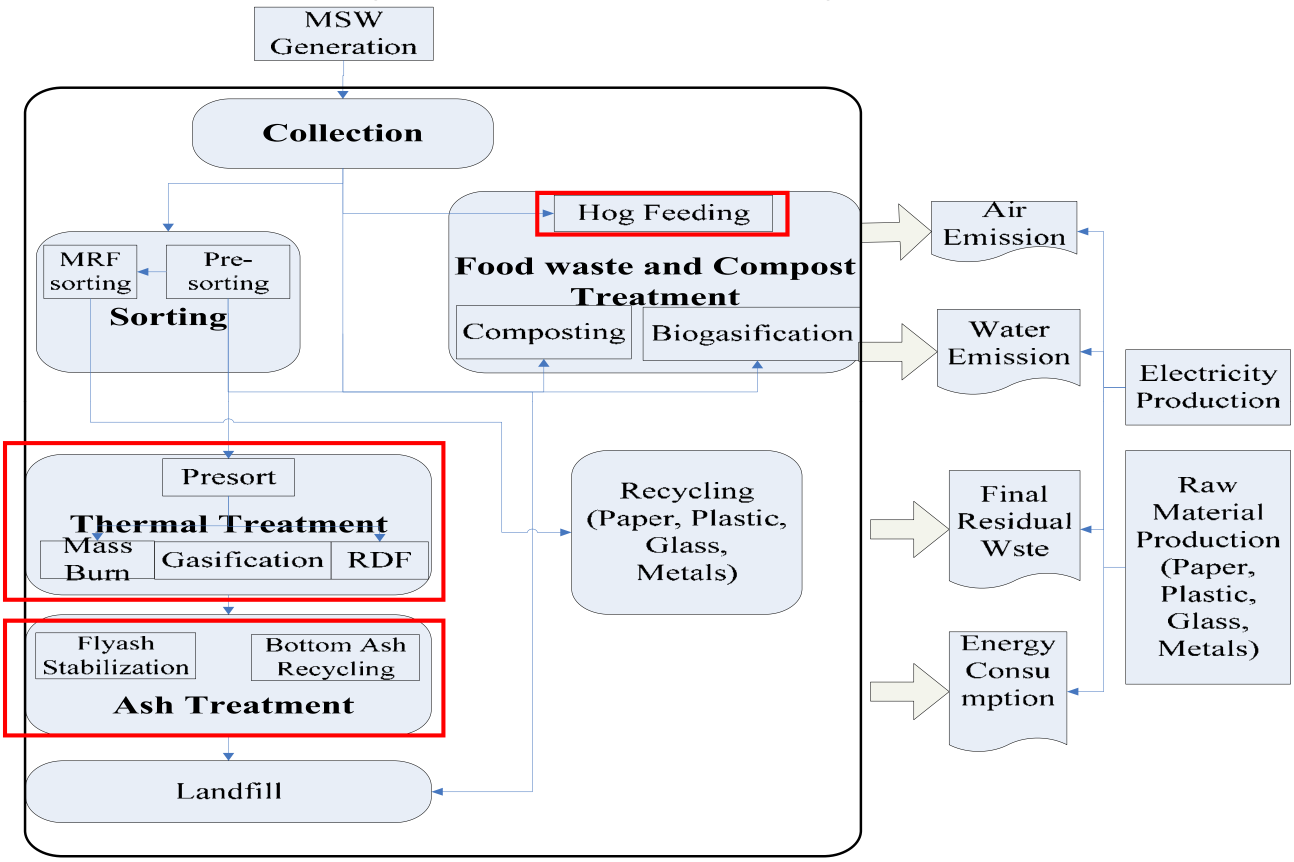
- **Issue of credibility on inventory analysis**
- **The industrial waste treatment technologies are excluded**
- **Limitation of impact assessment : site-dependency and toxicity impact**

Life Cycle Assessment Model for Taiwan Waste Management (TWM-LCA)

- TWM-LCA V.1
  - Developed in 2007, under the support from UNEP/SETAC LC Initiative and NSC
  - Focused on household waste treatment system
  - Developing probabilistic inventory database
  - LCIA methods: Impact-Oriented
  - Applications:
    - Mid-Term WM policy in Taoyuan
    - Environmental Benefit of PAYTs
    - Regional cooperative waste policy in central Taiwan

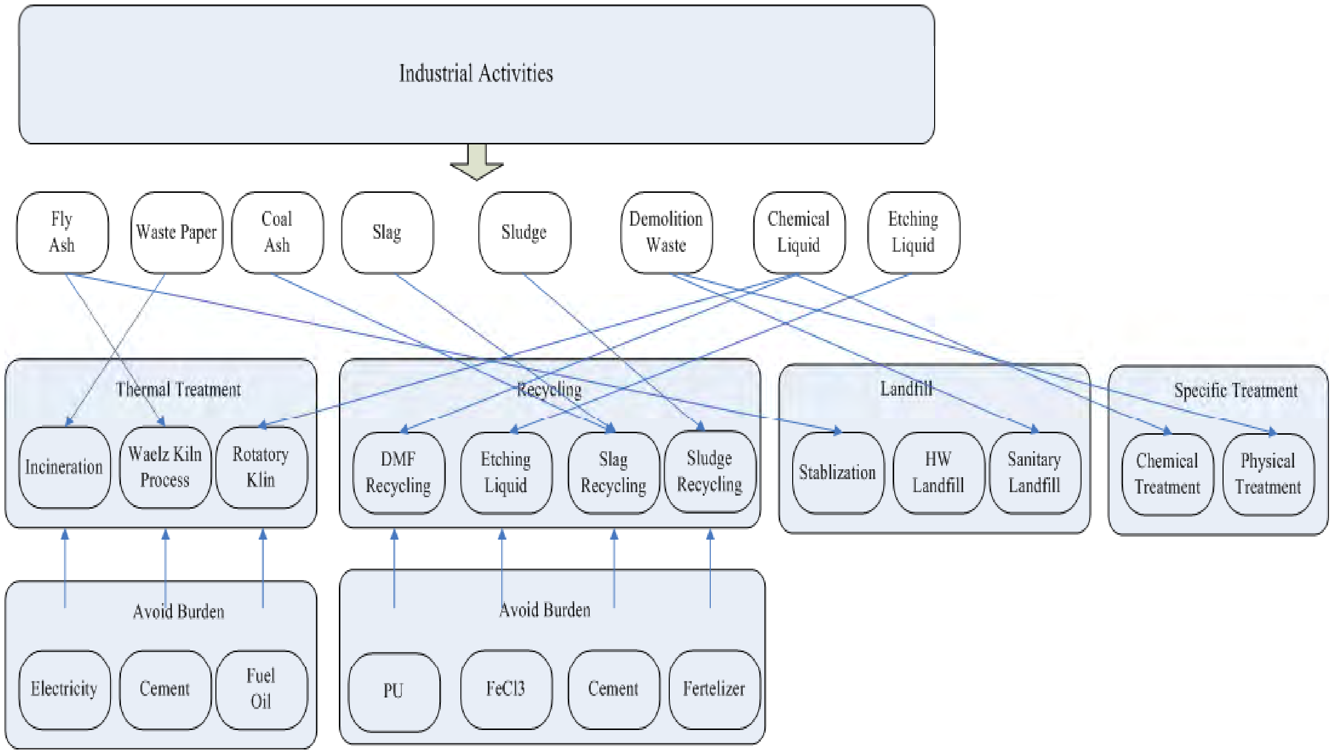
- TWM-LCA V.2
  - Extended the coverage to Industrial Waste.
  - Following the Best-Practice LCIA recommend by ILCD
  - External Cost Valuation
  - Fully-Integrated with TW-WIO

System Boundary(1)



System Boundary(2)

- Presently covering 65% of total non-hazardous industrial waste and 75% of hazardous industrial waste



Impact Assessment

Damage	Indicators	Impact Categories	Category Indicator	Characterization Model
Human Health	DALYs	Human toxicity	kg-eq Bezene$_{air}$ (carcinogenic) kg-eq Toluene$_{air}$ (non-carcinogenic)	CalTOX with local parameters
		Respiratory	kg-eq PM2.5$_{air}$	TRACi
		Smog	kg-eq NOx$_{(air)}$	TRACi
Ecosystem Diversity	Species	Global warming	Kg-eq CO2	IPCC(2007)
		Aquatic ecotoxicity	kg-eq 2,4-D$_{(water)}$	CalTOX + IMPACT2002+
		Terrestrial ecotoxicity	kg-eq 2,4-D $_{(soil)}$	CalTOX + IMPACT2002+
		eutrophication	kg-eq PO_4—limited	IMPACT2002+
		Aquatic acidification	kg-eq SO_2	IMPACT2002+
Resource Availability	Increased cost	Fossil depletion	Kg-eq Crude Oil	ReCiPe
		Metal depletion	Kg-eq Fe	ReCiPe
-	-	Water consumption	m^3/ m^3	Distant-to-target

Material Productivity Evaluation

Resource Productivity Evaluation

- Material Flow Analysis is the most fundamental tool to evaluate RP
- The key industrial sectors with greater influence are examined by hot-spot identification
- Using material flow indicators to monitor the trend of RP of key industrial sectors

$$MUE = 1 - TWO / TMI$$

MUE: Material Use Efficiency
TWO: Total Direct and Indirect Waste Generated by Sector
TMI: Total Direct and Indirect Material Input of Sector

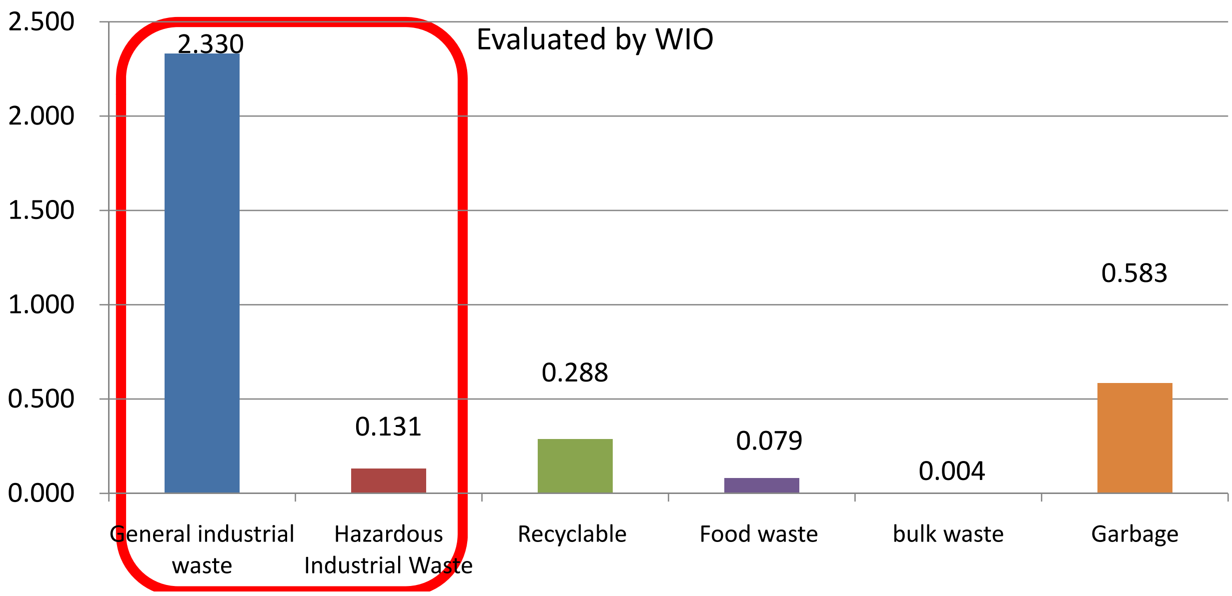
$$WOPS = TWO / PV$$

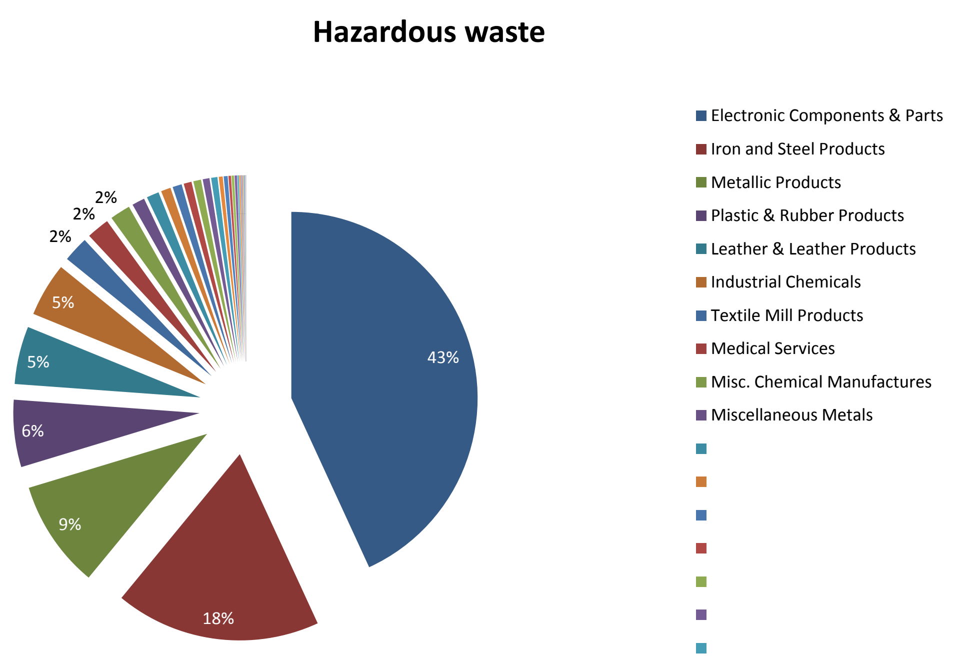
WOPS: Waste Output per Service
TWO: Total Direct and Indirect Waste Generated by Sector
PV : Production Value of Sector

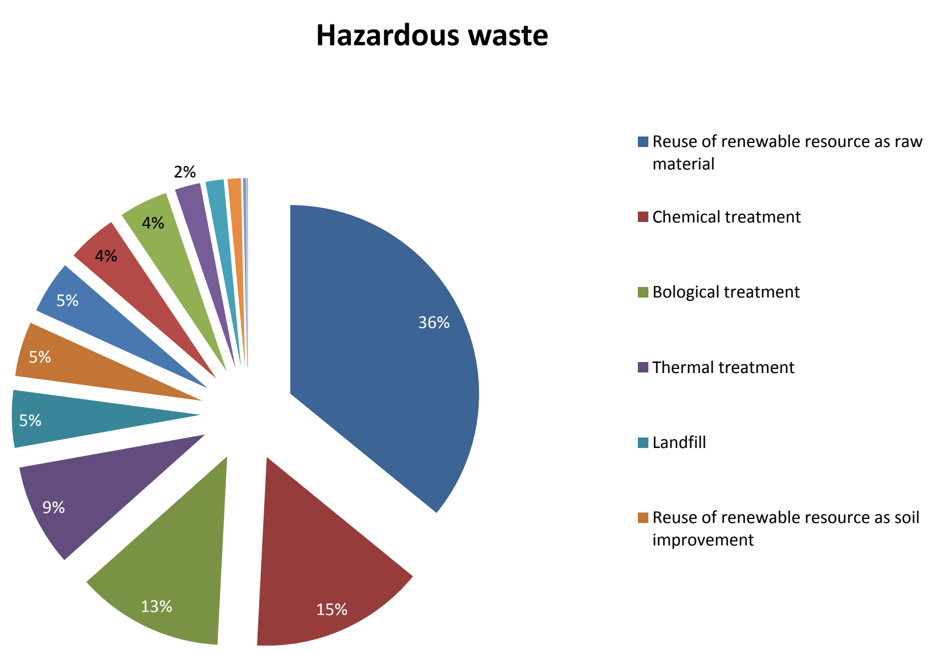
Case Study : Evaluating the environmental burden of the existing WM/3R system in Taiwan

Waste Flow Prognosis (1)

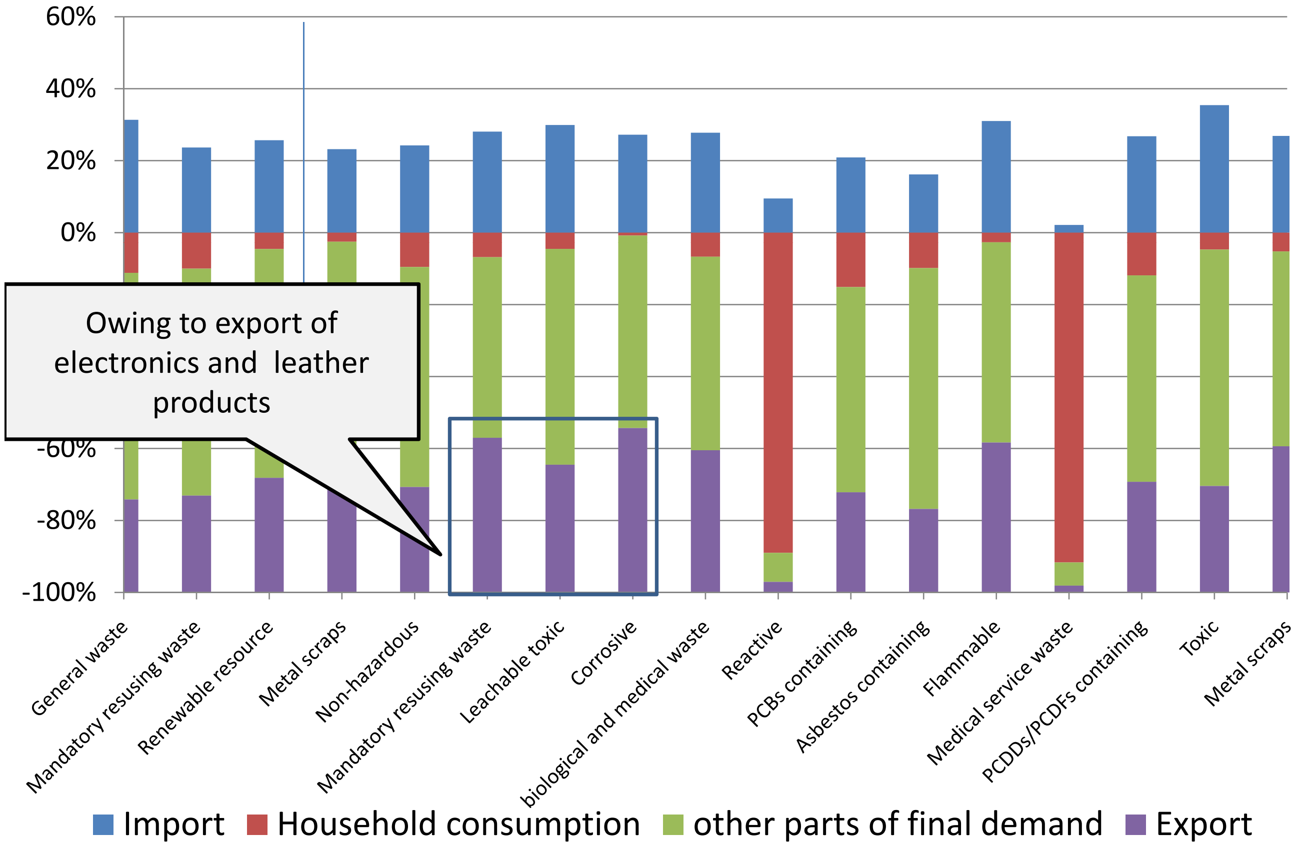
- Based on Material Flow viewpoints, the overall waste generated by household expenditure is up to 3.415 kg/cap-day in 2007.
- **"Waste Debts"** : GIW – 1.752 kg/cap-day, 75% of overall GIW
  HIW - 0.110 kg/cap-day, 85% of overall HIW



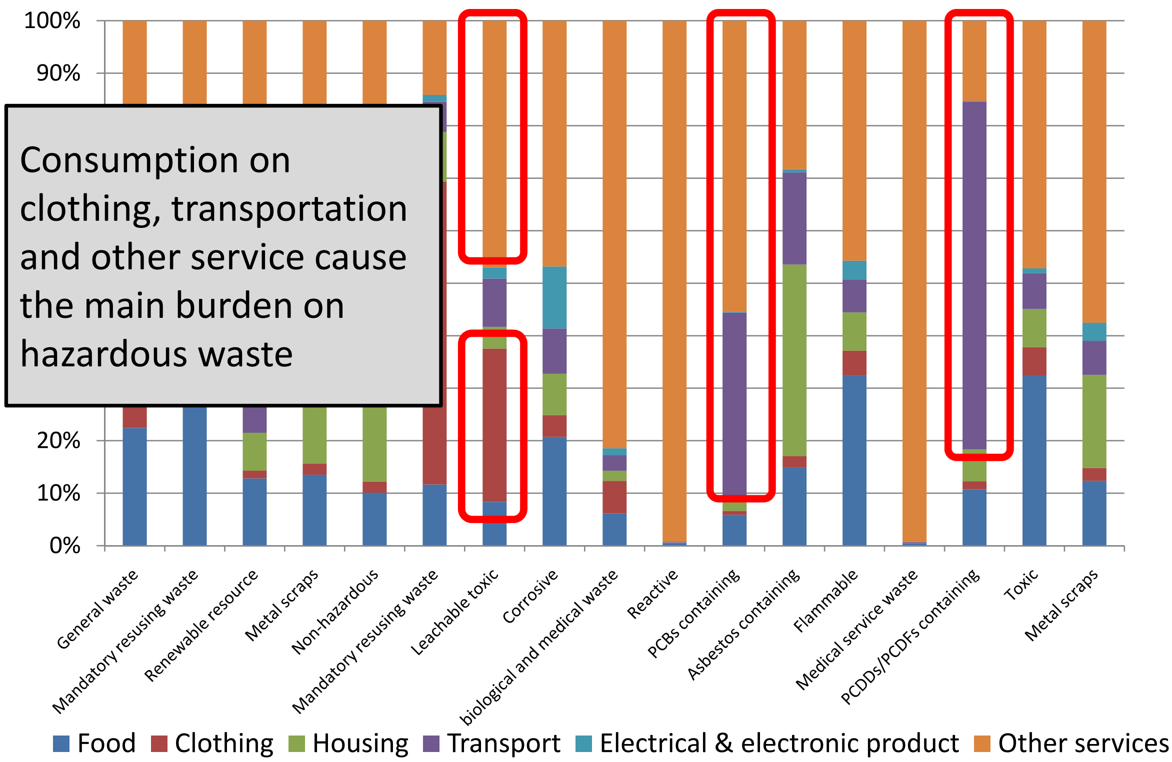

Hazardous waste
Electronic Components & Parts
Iron and Steel Products
Metallic Products
Plastic & Rubber Products
Leather & Leather Products
Industrial Chemicals
Textile Mill Products
Medical Services
Misc. Chemical Manufactures
Miscellaneous Metals
43%
18%
9%
6%
5%
5%
2%
2%
2%


Hazardous waste
Reuse of renewable resource as raw material
Chemical treatment
Bological treatment
Thermal treatment
Landfill
Reuse of renewable resource as soil improvement
36%
15%
13%
9%
5%
5%
5%
4%
4%
2%

Waste Flow Prognosis (2)



Waste Flow Prognosis (3)



Environmental Impact Assessment (1)

■MSW in 2007

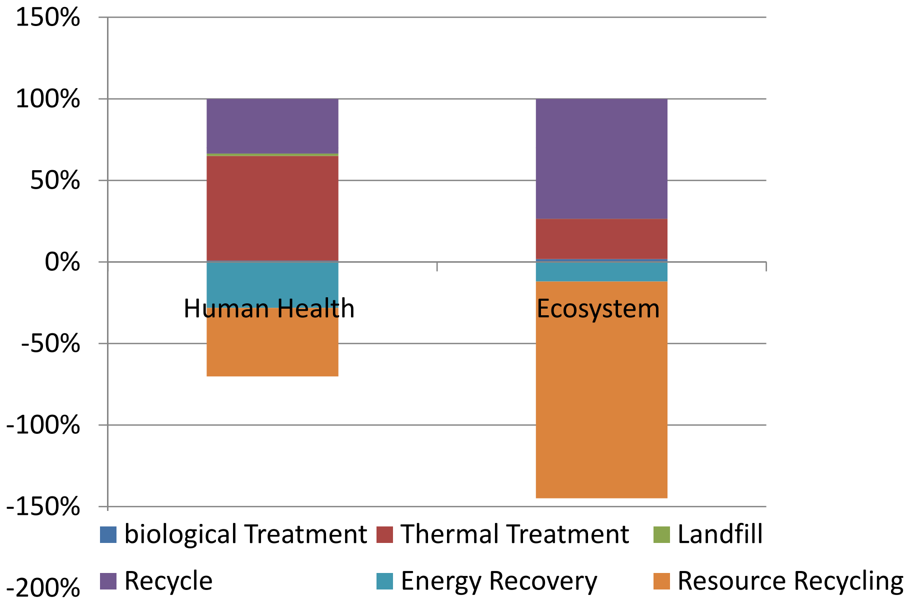
Incinerator : CO2 and Lead
Paper recycling: Lead (water)

Damage Assessment		Impact Assessment	
Categories	Result	Categories	Result
Human Health	2.59E+03 DALYs	Carcinogenic effect	…E+06 kg-eq $Bezene_{air}$
		Non- carcinogenic	…62E+09 kg-eq $Toluene_{air}$
		Respiratory	-3.65E+05kg-eq $PM2.5_{air}$
		Smog	2.06E+06 kg-eq $NOx_{(air)}$
Ecosystem Diversity	-4.36E+01 Species	Global warming	8.41E+08 kg-eq CO2
		Aquatic ecotoxicity	-1.98E+07 kg-eq 2,4-$D_{(water)}$
		Terrestrial ecotoxicity	-5.76E+08 kg-eq 2,4-$D_{(soil)}$
		eutrophication	2.07E+06 kg-eq PO_4^{-}limited
		Aquatic acidification	-3.26E+05 kg-eq SO_2
Resource Availability	-5.72E+09 Increased cost	Fossil depletion	-3.56E+08 kg-eq Crude Oil
		Metal depletion	-1.54E+08 kg-eq Fe
-	-	Water consumption	-4.19E+08 m^3 water

Coal avoided by energy recovery

Environmental Impact Assessment (2)

- The net impact on human health → The improvement of incinerators
- The paper recycling contributes most for GHGs emission reduction
- The Al and Tin recycling offers the largest offset on ecosystem diversity reduction



Environmental Impact Assessment (3)

■ Industrial Waste in 2007

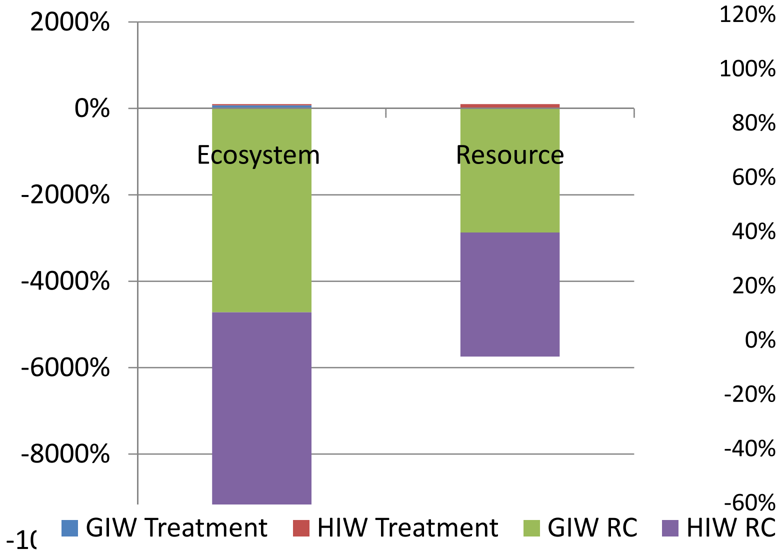
Etching liquid recycling : Lead(air)

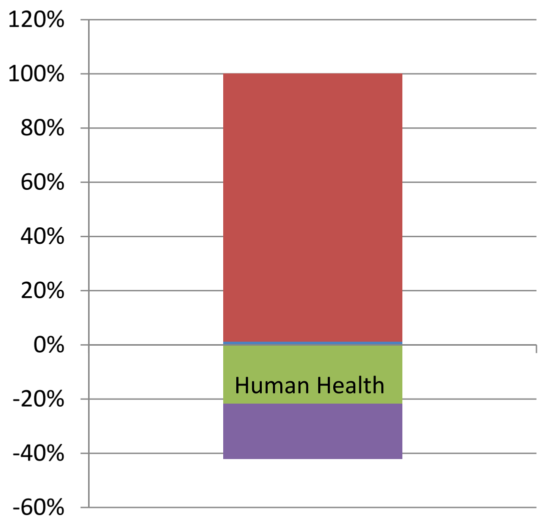
Damage Assessment Categories	Result	Impact Assessment Categories	Result
Human Health	4.34E+04 DALYs	Carcinogenic effect	3.87E+06 kg-eq $Bezene_{air}$
		Non- carcinogenic	8.63E+10 kg-eq $Toluene_{air}$
		Respiratory	-1.22E+06 kg-eq $PM2.5_{air}$
		Smog	-5.96 E+06 kg-eq $NOx_{(air)}$
Ecosystem Diversity	-1.46E+02 Species	Global warming	-4.10 E+09 kg-eq CO2
		Aquatic ecotoxicity	-2.02E+07 kg-eq 2,4-$D_{(water)}$
		Terrestrial ecotoxicity	-1.31E+09 kg-eq 2,4-D $_{(soil)}$
		eutrophication	4.35 E+04 kg-eq PO_4^{-}limited
		Aquatic acidification	-5.85E+06 kg-eq SO_2
Resource Availability	-7.47E+09 Increased cost	Fossil depletion	-4.68E+08 kg-eq Crude Oil
		Metal depletion	-1.14E+08 kg-eq Fe
-	-	Water consumption	-6.29E+09 m^3 water

BOF slag and coal ash recycling

Environmental Impact Assessment (4)

- Reusing and recycling industrial waste to substitute cement and concrete offers net benefit on ecosystem diversity and resource availability
- The side effect of etching liquid recycling should be further investigated to ensure the public health





Environmental Impact Assessment (5)

- The contribution of WM/RC system on GHGs emission mitigation are higher than 3.3 million tons (1.2% of total GHGs emissions)

→ The energy recovery rate of MSW incinerators needs to be improved

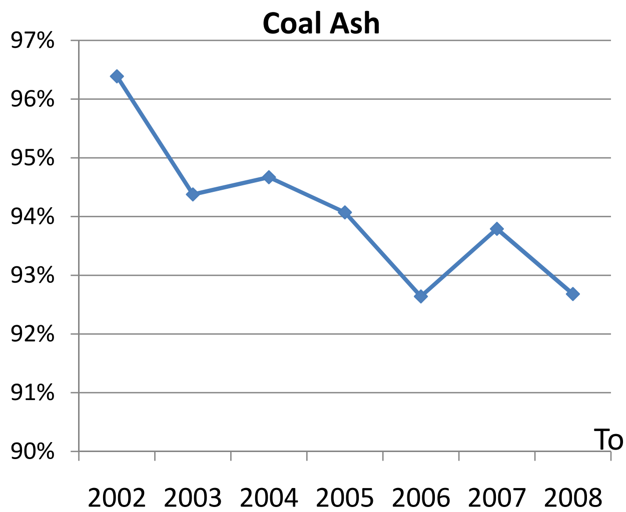
- The WM/RC generates net impact on human health; the hot-spot being the lead emissions

→ Substance flow analysis of lead is necessary

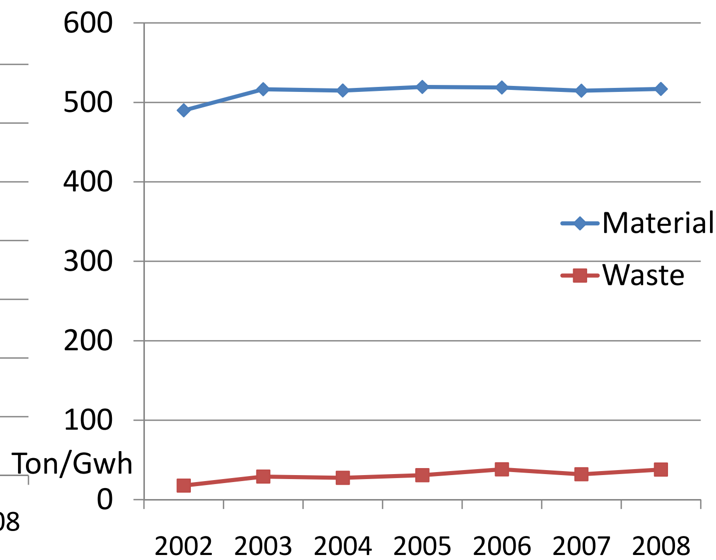
Resource Productivity Evaluation

- The coal ash and mixture of fly ash and bottom ash generated from electricity supply contributes to 15% of general industrial waste
- No significant improvement of RP has been found in this industry
- 96% are recycled and reused to replace cement in 2007
- The capacity and suitability of coal ash recycling will be a key issue

MUE



MIPS and WOPS



Merits attempted

- Footprint concept
- Inter-industrial linkage
- Comprehensive coverage of waste categories and treatment technologies
- Advanced impact assessment
- Decision support for resources circulation policies

Transition of Taiwan WM/3R Policy

- Waste Resource Cycling Promotion Act is the main regulation of future WM/3R policy

➢ Adapting the WEEE, EuP, RoHS-like mechanism

➢ Imposing "Industrial Waste Fee" on industrial sectors

Scenario Setting
- Estimating "learning curve" based on empirical experience of EU
- Identifying the price elasticity of industrial waste generation
- Incinerator as district energy supply → assessing the benchmark of energy recovery efficiency
- Assessing effectiveness of individual policies or measures

Future Development and Applications in ARCR project

Collaboration with IGES

- The integration of IEA and CGE model
  - Geographical coverage
  - Sector coverage
  - The relationship between social and economic situation and consumption patterns
- Harmonizing the scope of environmental impact assessment and economic cost calculation
  - Treatment technologies coverage

Extended Applications in Other Regions

- Introducing the conceptual framework to apply IEA model to WM/3R issues
- From the national WIO to multi-regional WIO
- Establishing a common inventory database
  - Gathering the possible policy transition pathways to identify the soundness of treatment technologies
  - Designing common inventory framework for supporting participant countries to establish their own databases

Thanks for your intention!