History of WtE Technologies and Recent Issues in Korea

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WtERT Congress in Hangzhou, China
October 2023

Profile of Prof. Yong-Chil SEO

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Position:

Emeritus Professor, Yonsei University
Director of R&D Center, LSMK
Former President, KSWM, Korea
Chair, WtERT Korea
President, Multi-phase Reactor Tech. Forum

Research Fields: Waste to Energy Techs., Recycling Tech., Waste Treatment Engineering, Air Pollution Control, Mercury (Hg) Management

Profile of Prof. Yong-Chil SEO

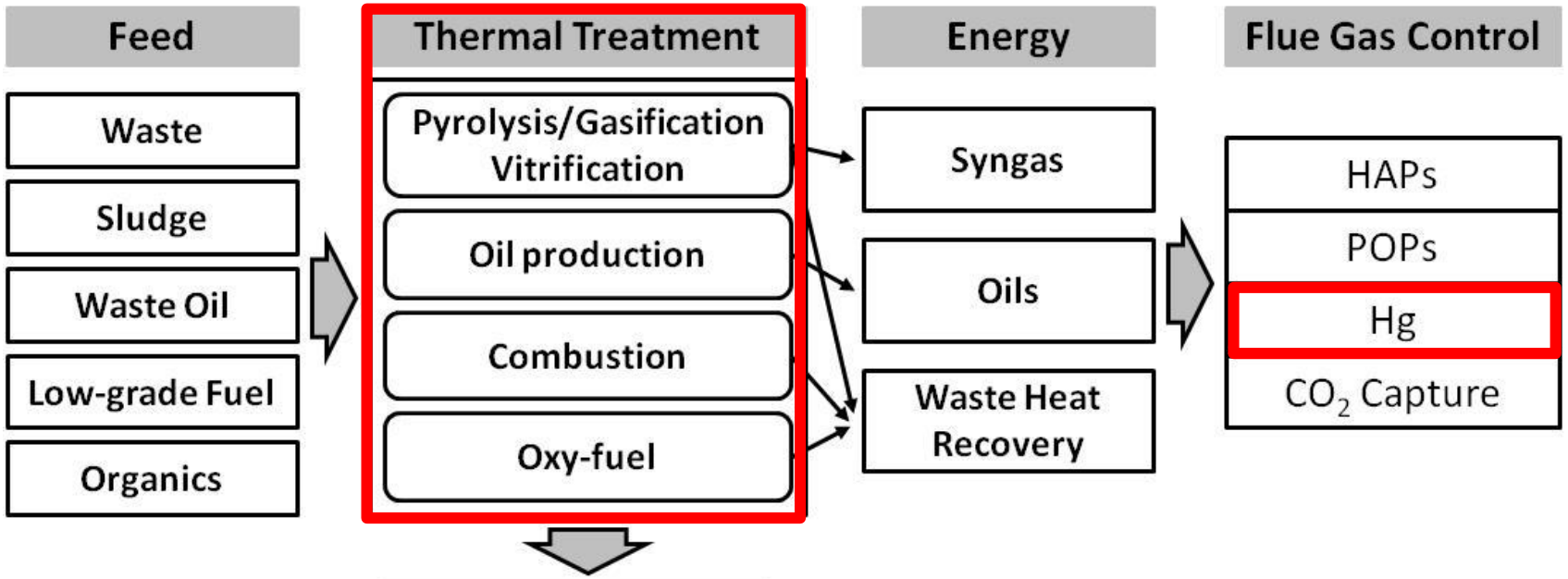
❖ Education

- 77.2 BS, Chem. Eng., Yonsei Univ., Korea
- 77.2-79.6 ROTC (15), Korean Army Officer, Ordinance Div.
- 82.5 MS, Chem. Eng., Illinois Institute of Technology, U.S.
- 85.8 Ph.D., Chem. Eng., Illinois Institute of Technology, U.S.
  (Fluidization of Single and Binary Particles for Gasification of Coals)

❖ Professional Experiences

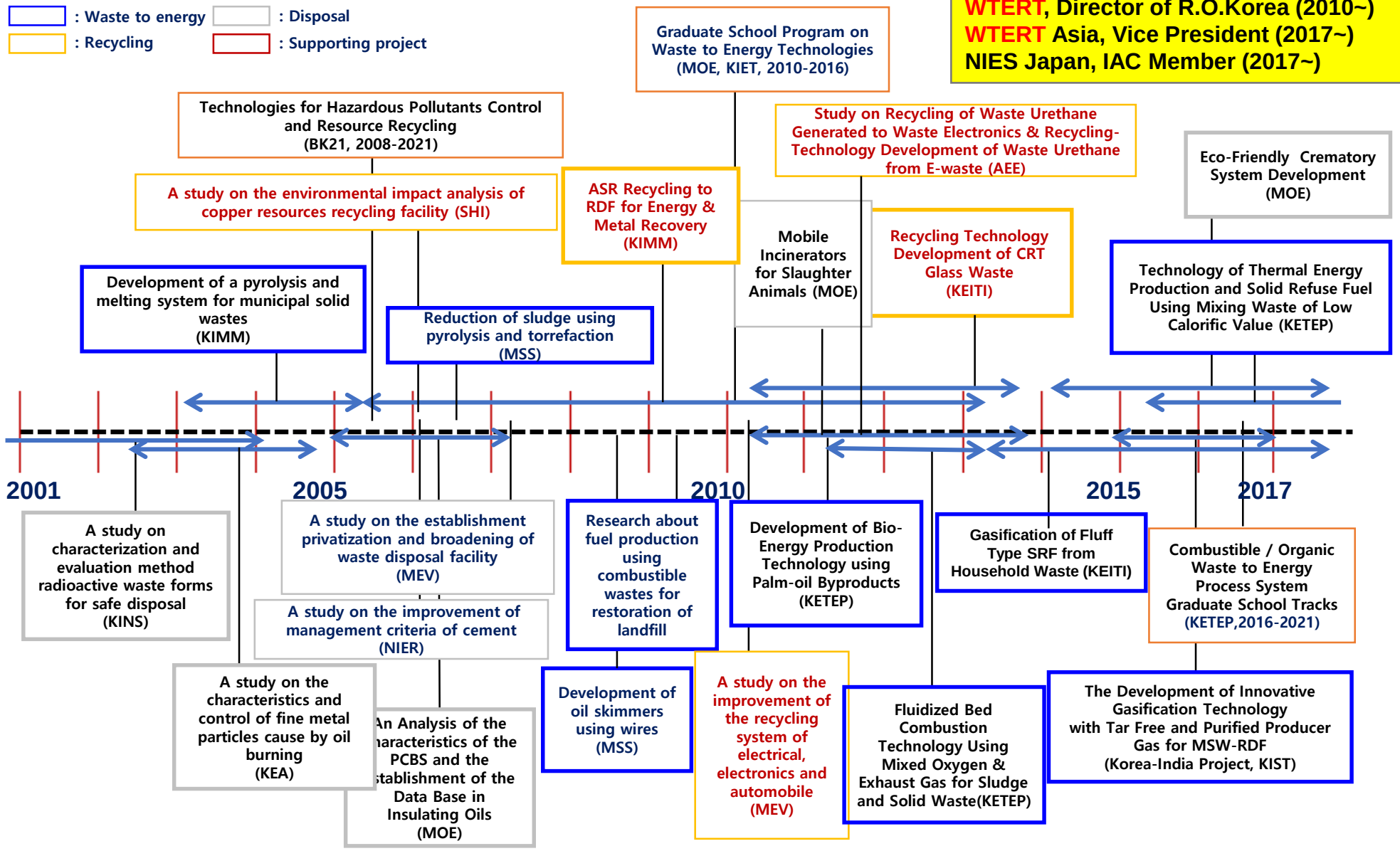
- 85.10-94.3 Principal Researcher and Head, Radioactive Waste Treatment Lab. (Combustion), Korea Atomic Energy Research Institute
- 94.3 - Professor, Dept. of Environmental & Energy Engineering, Yonsei University
- 01.8-03.7 Visiting Scholar, Air Pollution Control Br., ORD, U.S. EPA, RTP, NC
- 06.1-08.1 Dean, The Graduate School for Health and Environment
  Dean, College of Health Science, Wonju Campus, Yonsei University
- 06.3 - 09.8 Leader BK21, Regional Core Scientific Field, Treatment of Multi- Pollutants in Multi-phases
- 08.9 - 09.8 Visiting Scholar, USEPA and NCSU Mechanical Engineering, USA
- 10.3 - 16.2 Director, WtE Center, KMOE
- 12.1 - 13.12 President, Korea Waste Management Society
- 12.3 - 16.2 Chief in Editor, Journal of Material Cycles and Waste Management
- Others: Expert of UNEP on Hg; IAC member of NIES, Japan; Chairs of many conferences

Overview of AWEL (Prof. Seo's LAB)

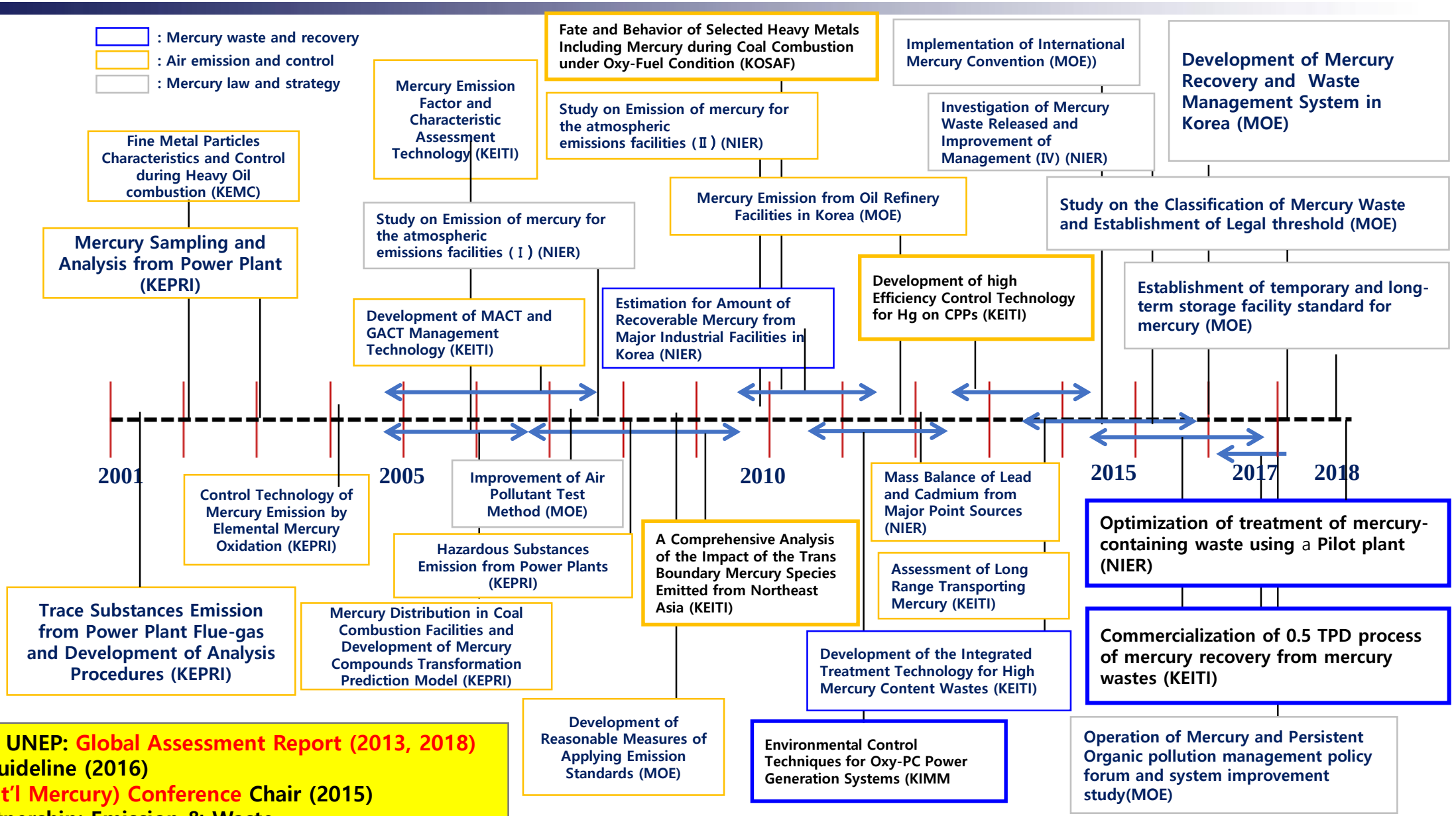


R&Ds on Waste Treatment Technologies

Editor in Chief, JMCWM (2011-14)
Korea Waste Management Society, President (2011-13)
WTERT, Director of R.O.Korea (2010~)
WTERT Asia, Vice President (2017~)
NIES Japan, IAC Member (2017~)



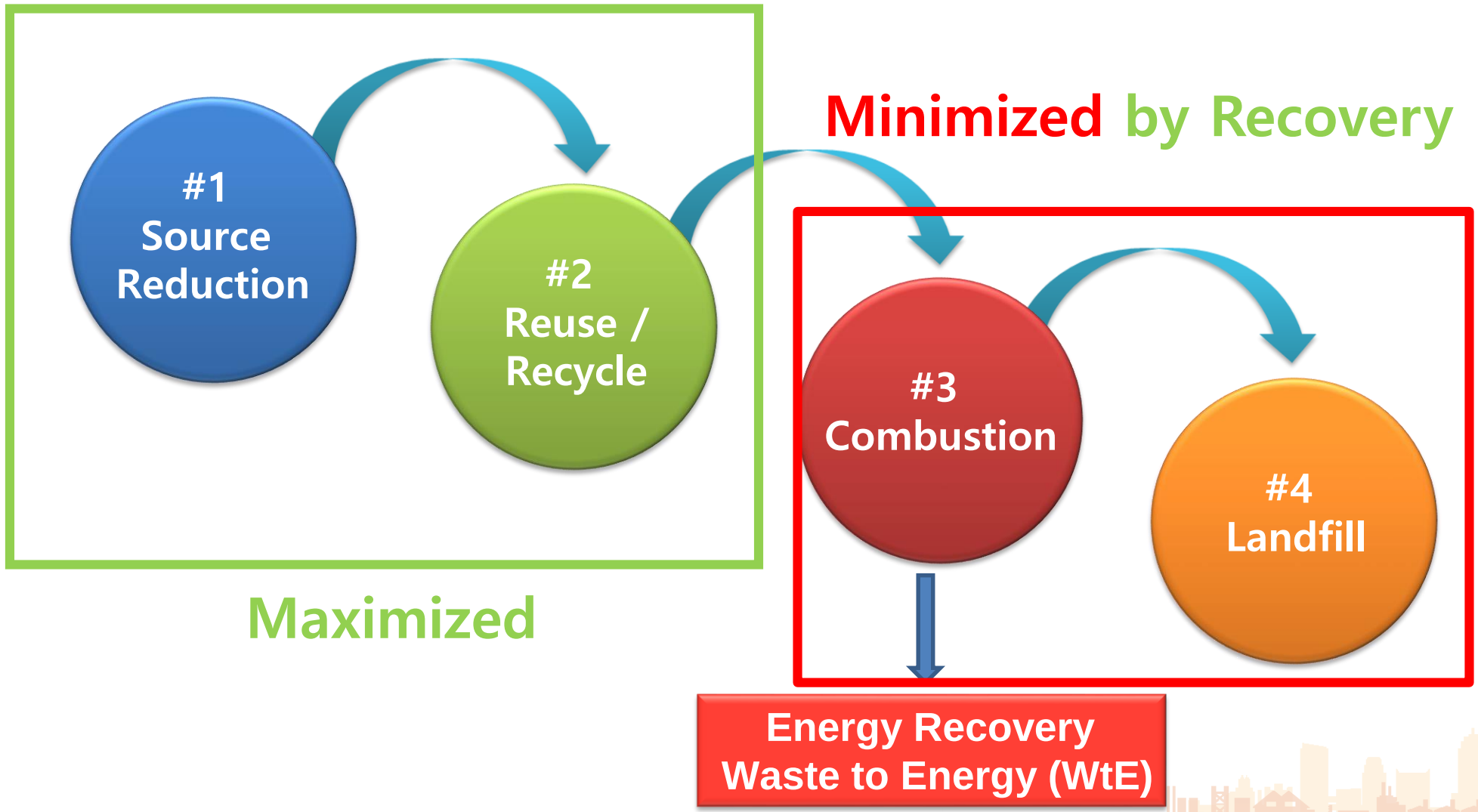
R&Ds on Mercury (Hg) Management



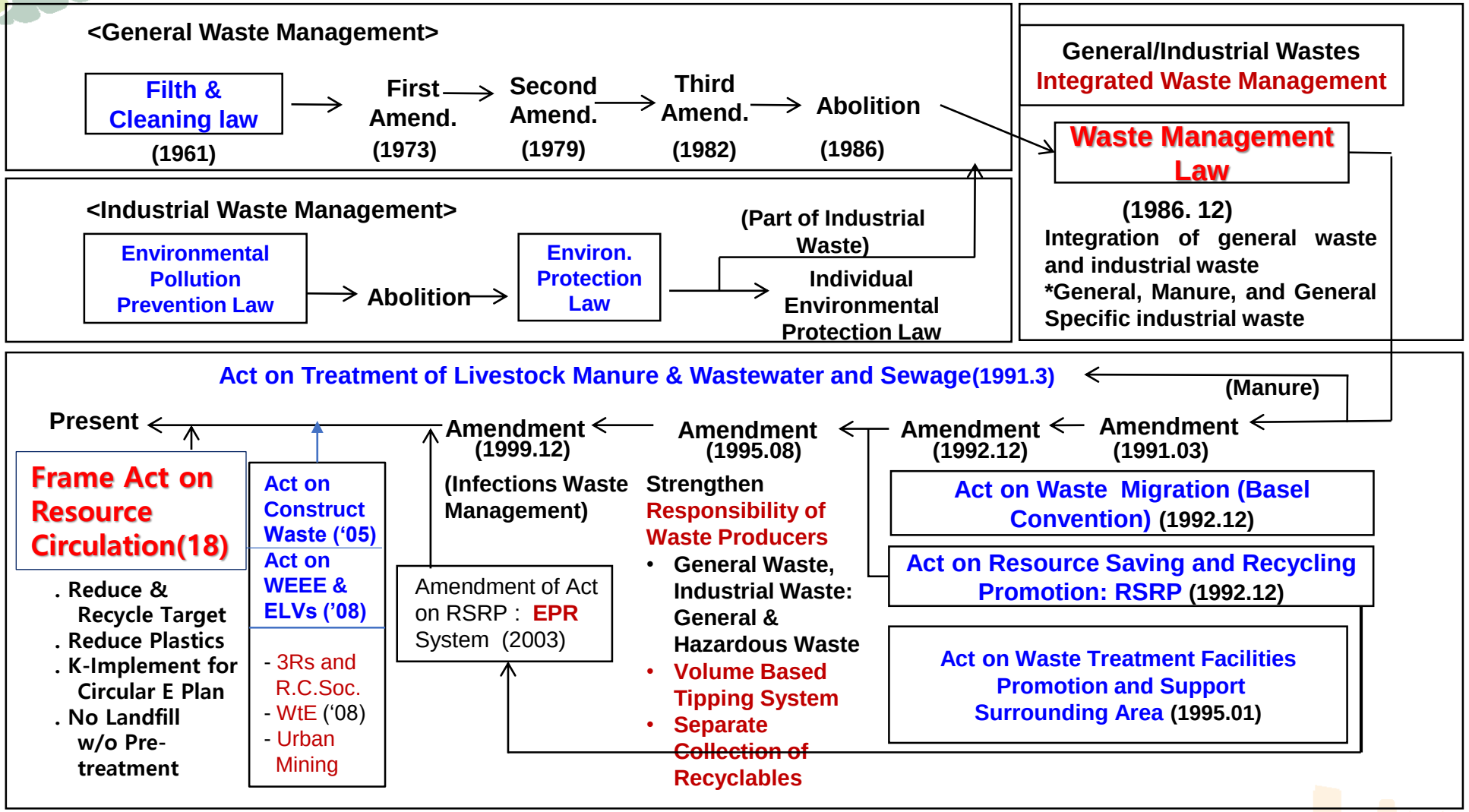
Works for UNEP: Global Assessment Report (2013, 2018)
Hg BAT Guideline (2016)
ICMGP (Int'l Mercury) Conference Chair (2015)
UNEP Partnership: Emission & Waste

Principles of Waste Management

- IWM (Integrated Waste Management) : Adopted with Waste Management Law (1986)
  All are Vital components of waste management with the Priority as follows;



History of Legislation for Waste Management in Korea



Reference: Yang & Seo et al (2015) J Mater Cycles Waste Manag 17:207-217.

Major Waste Management Policies and Systems

Effective Waste Management Policies

Polluter Payment Concept and Waste = Resource

- Volume-rate garbage Charging system (1995.1~) for MSW
- EPR for Industrial Wastes (WEEE, 2003.1) and Other Regulations for RC (ELVs, Construct, etc.)

1994

1.33 kg/day/person

Reduction of Generation

2016

0.93 kg/day/person

❖Volume-rate garbage disposal System with Separate Collection of Recyclables (1995.1)

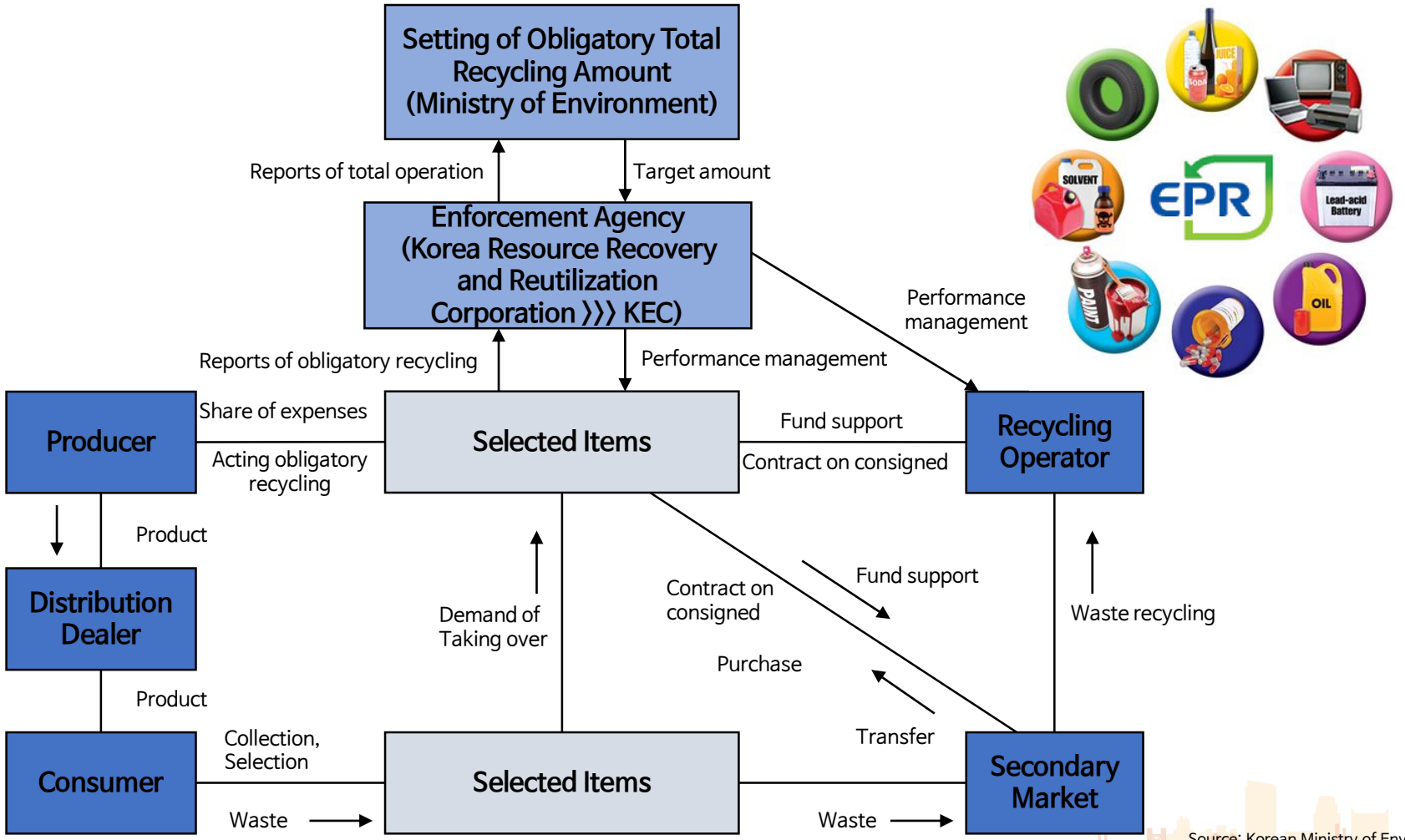
Households must discharge all recyclables into separate bins and buy and use only bags (priced) from markets for others .
Price of a bag by volume will be determined by local governments depending on the cost of waste handling.

Source: Korean Ministry of Environment

Major Waste Management Policies and Systems

Effective Waste Management Policies

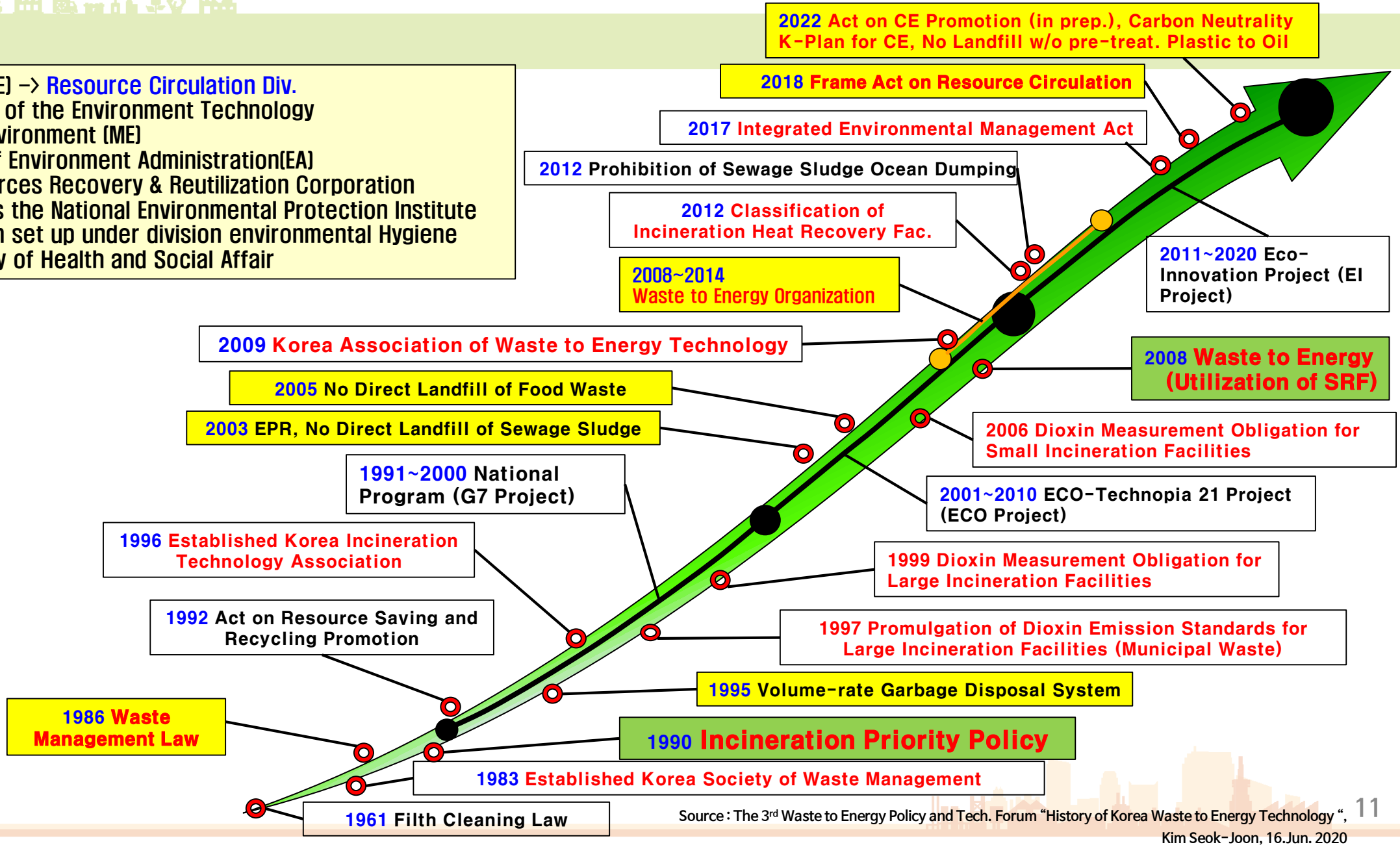
▪ EPR(Extended Producer Responsibility) System (2003.1~)



Source: Korean Ministry of Environment

History of Waste Management (Major Policies & Issues Related to WtE)

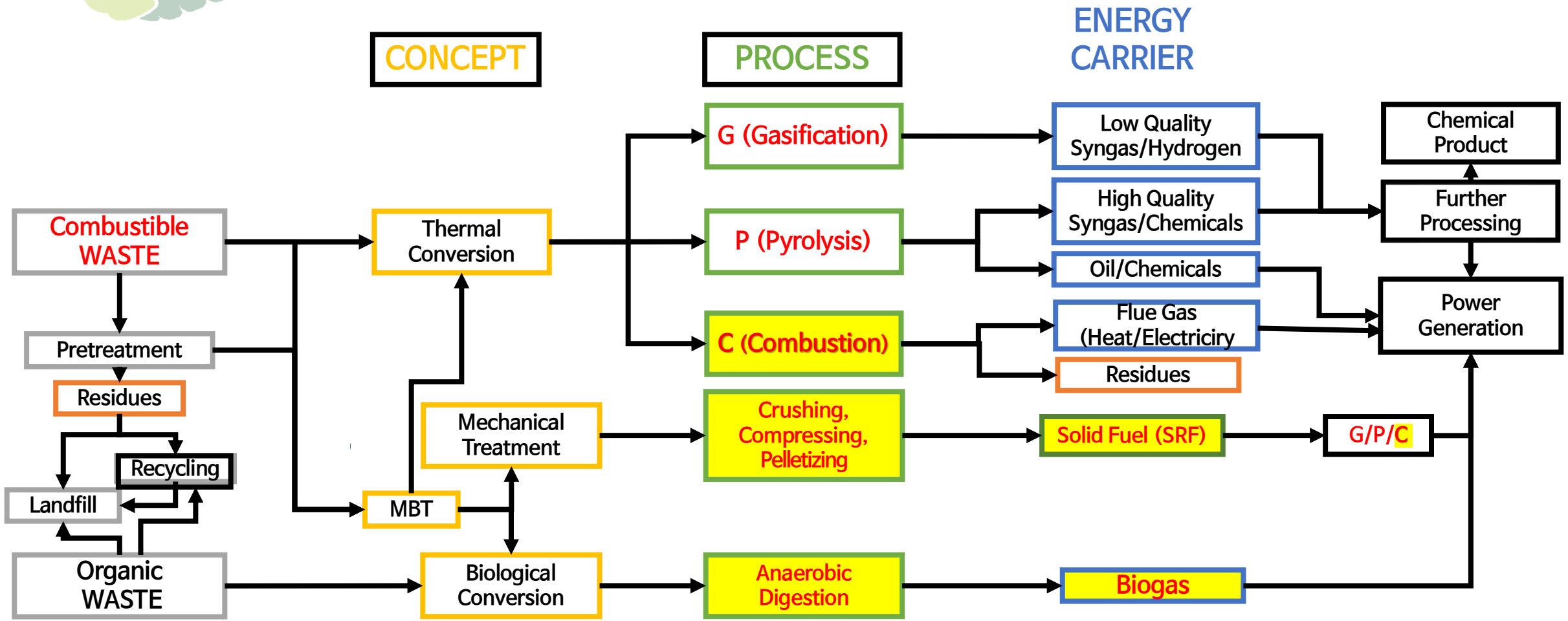
- 2005 Waste Div. (ME) -> Resource Circulation Div.
- 2000 Incorporation of the Environment Technology
- 1994 Ministry of Environment (ME)
- 1980 Established of Environment Administration(EA) /Korea Resources Recovery & Reutilization Corporation
- 1978 Established as the National Environmental Protection Institute
- 1967 Pollution team set up under division environmental Hygiene in the Ministry of Health and Social Affair



Source : The 3rd Waste to Energy Policy and Tech. Forum "History of Korea Waste to Energy Technology ", Kim Seok-Joon, 16.Jun. 2020

WtE Technologies for Combustible Wastes

- Conversion Technology to Produce Energy from Wastes

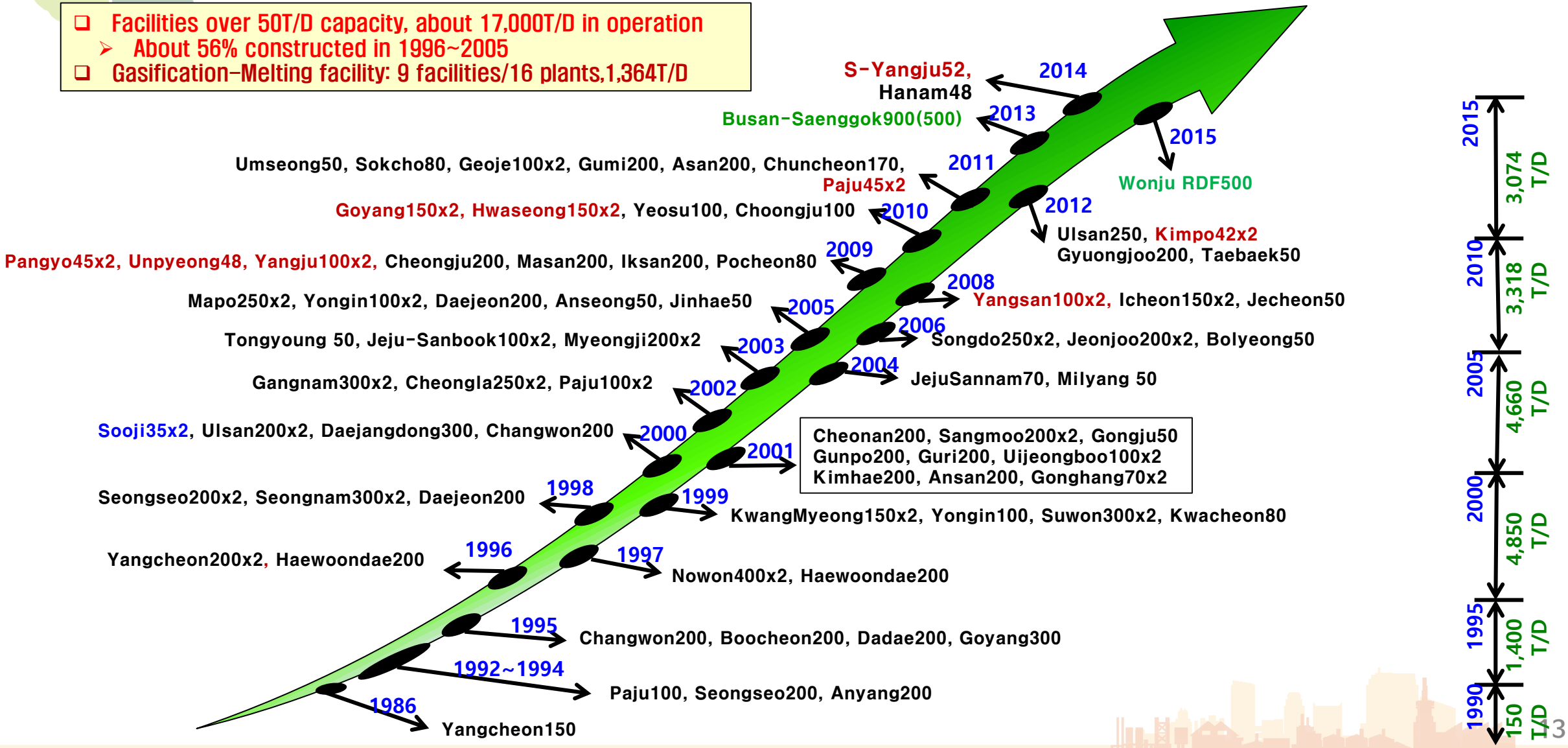


WtE : Combustible/Organic Wastes

History of WtE Technologies (Incineration)

Household Waste Incinerators ('90~'05 Construction, Mainly Foreign Tech., Replacement Needed, High Efficiency, CCUS)

- Facilities over 50T/D capacity, about 17,000T/D in operation
  - About 56% constructed in 1996~2005
- Gasification-Melting facility: 9 facilities/16 plants,1,364T/D



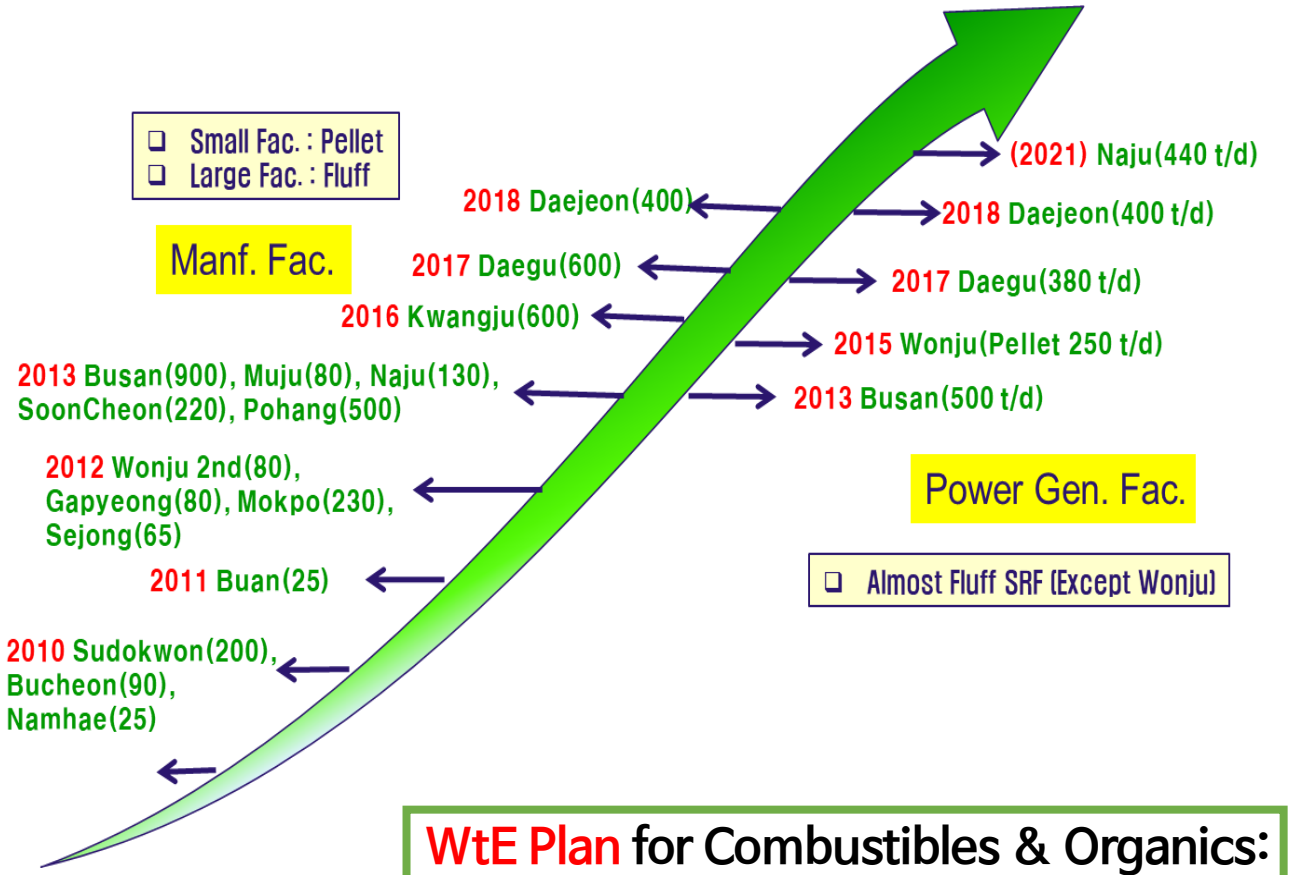
Source : The 3rd Waste to Energy Policy and Tech. Forum "History of Korea Waste to Energy Technology ", Kim Seok-Joon, 16.Jun. 2020

History of WtE Technologies (SRF)

SRF Manufacturing and Power Plants ('08~ WtE Plan, Still negative Perception. No Continuation of policy)

State of Municipal Waste SRF Manufacturing Facilities

Region		Business Period	Capacity (ton/day)	Fuel Type	Business Fund
Sudokwon Landfill		07-10	200	Pellet	Finance
Gyeonggi	Bucheon	07-10	90	Pellet	Finance
	Gapyeong	09-12	80	Pellet	Finance
Jeonbuk	Buan	07-11	25	Pellet	Finance
	Muju	09-13	80	Pellet	Finance
Gangwon	Wonju 1st	08-12	80	Pellet	Finance
	Wonju 2nd	12-14	80	Pellet	Private
Jeonnam	Naju	09-13	130	Pellet	Finance
	Sooncheon	09-13	220	Pellet	Private
	Mokpo	09-12	230	Pellet	Finance
Busan		09-13	900	Fluff	Private
Gyeongbuk	Pohang	09-13	500	Fluff	Private
Gyeongnam	Namhae	07-10	25	Pellet	Finance
Choongnam	Sejong	10-12	65	Pellet	Finance
		13-16	600	Fluff	Private
Daejeon		15-18	400	Fluff	Private
Daegu		14-17	600	Fluff	Private



WtE Plan for Combustibles & Organics: SRF(RDF) and Biogas ('08)

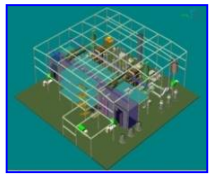
▶ and Medium scale Self Development Tech.)

Source : Waste to Energy Policy and Technology Forum Workshop, "Internal and external SRF Manufacturing and Using Industrial State ", Choi Yeon-Seok, 20.Aug.2020

History of WtE Technologies (Gasification)

Waste to Gasification R&D (High Cost, Contribute to Hydrogen Economy and Carbon reduction, Not Commercialized)

- ✓ No Commercialized, Demo-scale Development up to 8 tons/d, More R/D Support Needed.
- ✓ Present, Limitations of Private-led Commercialization in the Development Stage of Tech.



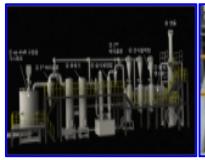
2013~ 2018 (Pilot-Scale Plants)

- ✓ SRF(Waste) with Air Gasifier - Wet Purification - Gas Engine Power Generation System Developed (8T/D)
- ✓ Waste Gasification - Syngas High Temp. Purification – Reforming - Methanol Conversion Tech. Developed (200Nm^3/hr)
- ✓ High Quality Syngas Production System Developed for Industrial Waste (100T/D Capacity)
- ✓ Dyeing Sludge-Rice Husk Mixed, Catalyst Fluidized Bed Gasification Technology (2T/D Scale)
- ✓ Municipal Waste Pretreatment with Air-Gasification-Gas Engine Power Generation Tech. Developed (0.5T/D & 30T/D)



2009~ 2012

- ✓ Biomass(Rice Husk) Gasifier with Air-Wet Purification-Gas Engine Power Generation System (20T/D)
- ✓ Drying Sludge Gasification Syngas Production with Air and Wet Purification System (Pilot Scale)
- ✓ Feasibility Study on Acetic Acid Fuel Network from Fuel(CO) Produced by Oxygen Gasification Syngas Process



2007~ 2009

- ✓ H_2/CO Production Ratio Control Tech. Development for Waste Syngas Utilization with Oxygen (Pilot Scale)
- ✓ Syngas Production from Mixed Industrial Waste/Sludge Cake using a Gasification Process (Pilot Scale)
- ✓ Development of Oxygen Combustion Burner using Syngas from Oxygen-Gasifier of Waste (Pilot Scale)

2000 ~ 2007

- ✓ Development of Oxygen Waste Gasification Melter and Syngas Purification System (Pilot Scale)
- ✓ MSW, ISW, ASR, RDF, RPF etc.

Source : The 4th Waste to Energy Policy and Technology Forum "Sate and Prospect of Waste Gasification Syngas Utilization Technologies ", Koo Jea-Hoi, 27.Oct. 2020

History of WtE Technologies (Pyrolysis)

Pyrolysis (liquefaction) (High Cost, Contribute to Hydrogen Economy and Carbon reduction, Need Scale-up R/Ds)

2020
Low Grade Waste Plastic Bag Pyrolysis Pilot-scale Design · Production · Operation **(10 ton/day)**
; Semi-Batch Kiln type, catalyst de-chlorination
Support Org. : Ministry of Environment

Since 2018
Development of Low Chlorine Eco Oil Manufacturing Tech. for Low Grade Mixed Waste Plastic
Support Org. : Ministry of Environment

2012 ~
Development of a Commercial-scale (20 tons/day) Biomass to Oil by Fast Pyrolysis

2010 ~
Development of a Commercial-scale (6,000 ton/yr) Plant for Mixed Waste Plastics: **Stopped**

2006 ~ 2009
- Government-led Commercial-scale (1,000 ton/yr) R&D for Mixed Waste Plastics

Economically Feasible Scale-up Required

Support Org.	Scale(ton/yr)	Process
Ministry of Industry	1,000	

2000 ~ 2005
- Government-led Demo-scale(600~3,000 ton/yr) R&D for Pretreatment Waste Plastic

Economical Weakness

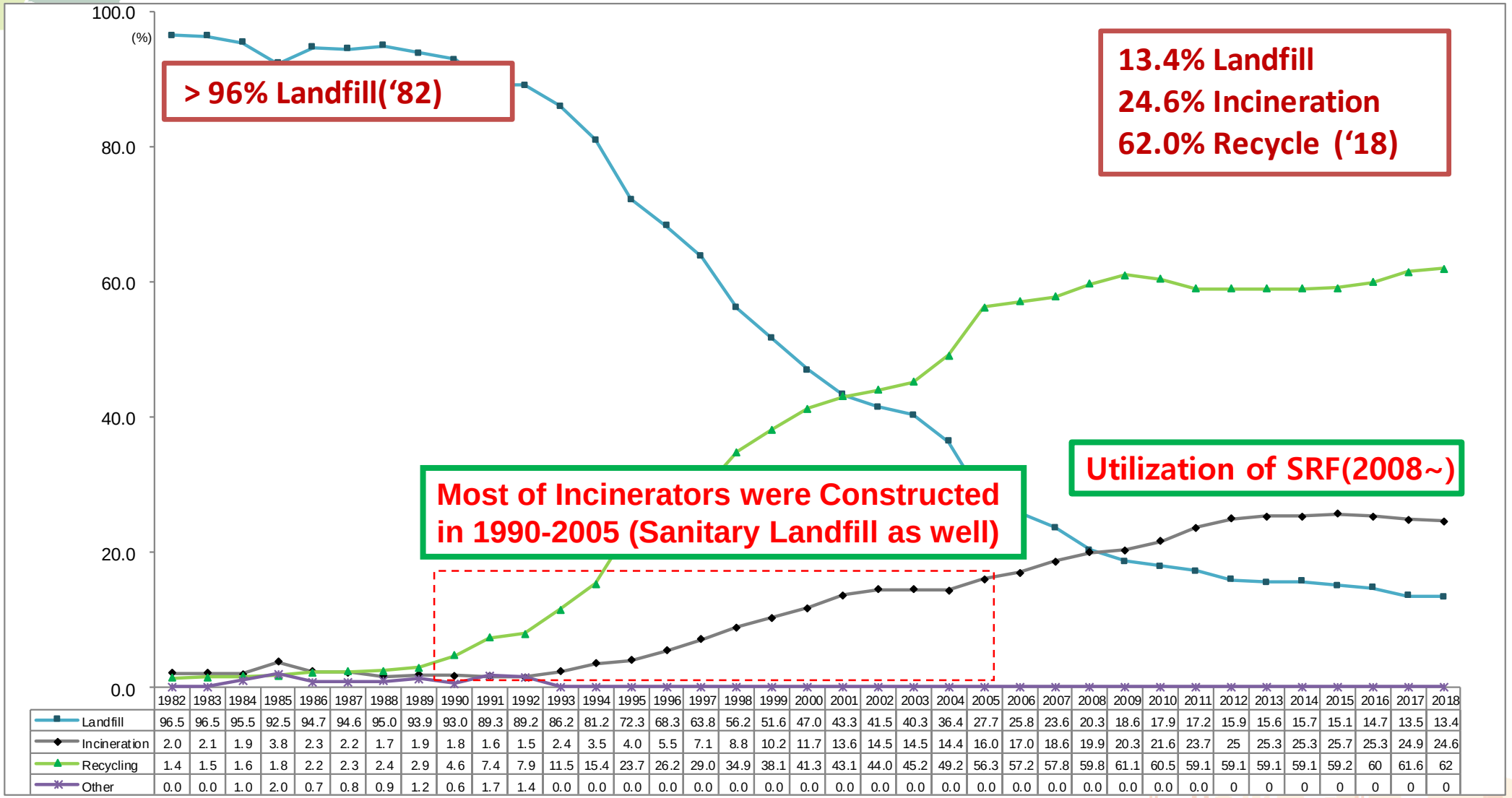
Support Org.	Scale(ton/yr)	Process
Ministry of Industry	600	
Ministry of Science and Technology	3,000	

1990s
- Basic Research and Small-scale Process Development
- Decrease in trust due to Introduction of Non-qualified Foreign Tech.
- Lack of Systematic Tech. Development

Source : The 4th Waste to Energy Policy and Technology Forum "State and Prospect of Waste Plastic Pyrolysis Liquefaction Technology ", Oh Se-Cheon, 27. Oct. 2020

Historical Review and Status on Waste Management

- Treatment of Household Waste in Korea (‘82 ~ ‘18)

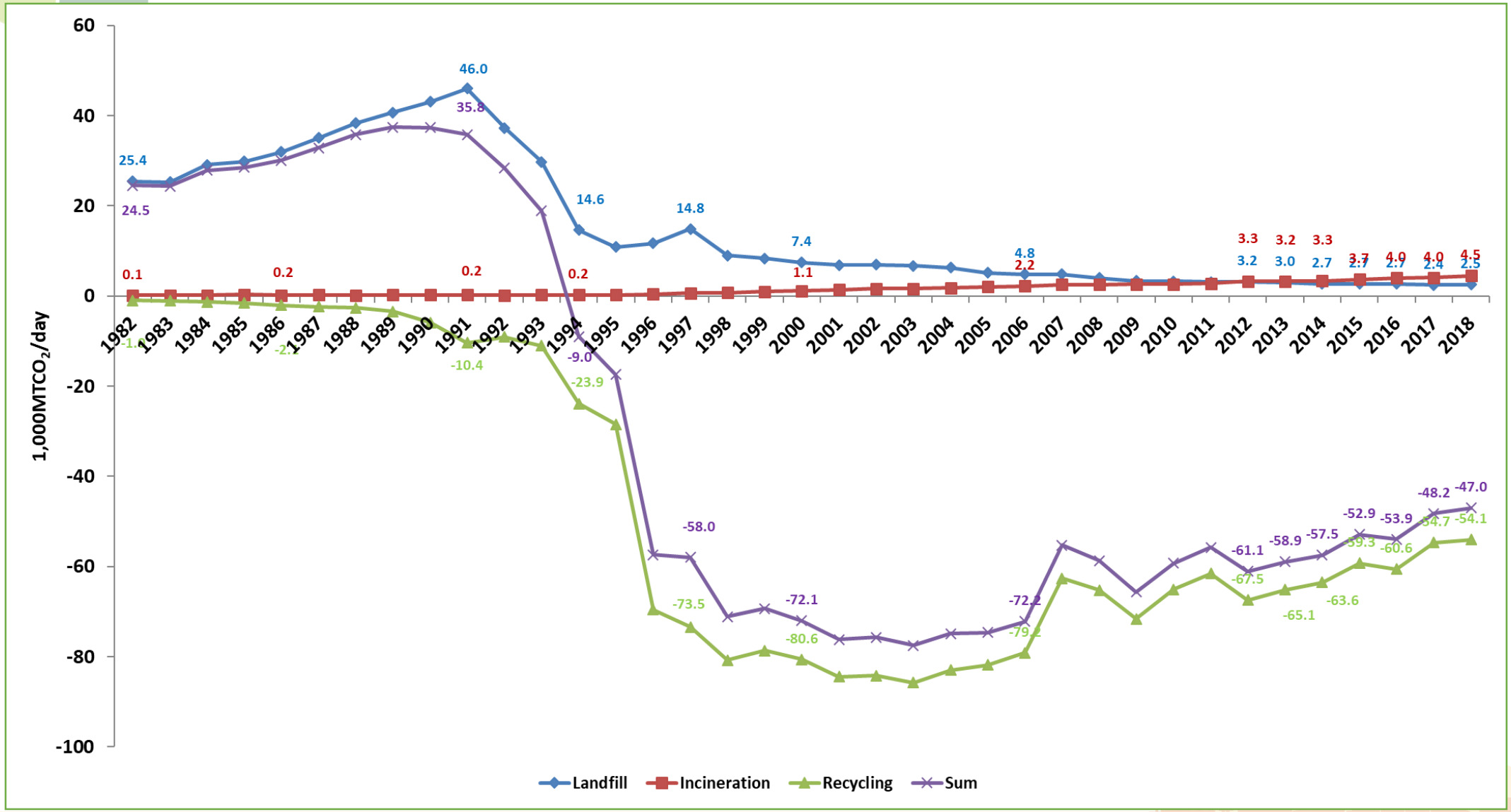


	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
Landfill	96.5	96.5	95.5	92.5	94.7	94.6	95.0	93.9	93.0	89.3	89.2	86.2	81.2	72.3	68.3	63.8	56.2	51.6	47.0	43.3	41.5	40.3	36.4	27.7	25.8	23.6	20.3	18.6	17.9	17.2	15.9	15.6	15.7	15.1	14.7	13.5	13.4
Incineration	2.0	2.1	1.9	3.8	2.3	2.2	1.7	1.9	1.8	1.6	1.5	2.4	3.5	4.0	5.5	7.1	8.8	10.2	11.7	13.6	14.5	14.5	14.4	16.0	17.0	18.6	19.9	20.3	21.6	23.7	25	25.3	25.3	25.7	25.3	24.9	24.6
Recycling	1.4	1.5	1.6	1.8	2.2	2.3	2.4	2.9	4.6	7.4	7.9	11.5	15.4	23.7	26.2	29.0	34.9	38.1	41.3	43.1	44.0	45.2	49.2	56.3	57.2	57.8	59.8	61.1	60.5	59.1	59.1	59.1	59.1	59.2	60	61.6	62
Other	0.0	0.0	1.0	2.0	0.7	0.8	0.9	1.2	0.6	1.7	1.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0	0	0	0	0	0	0

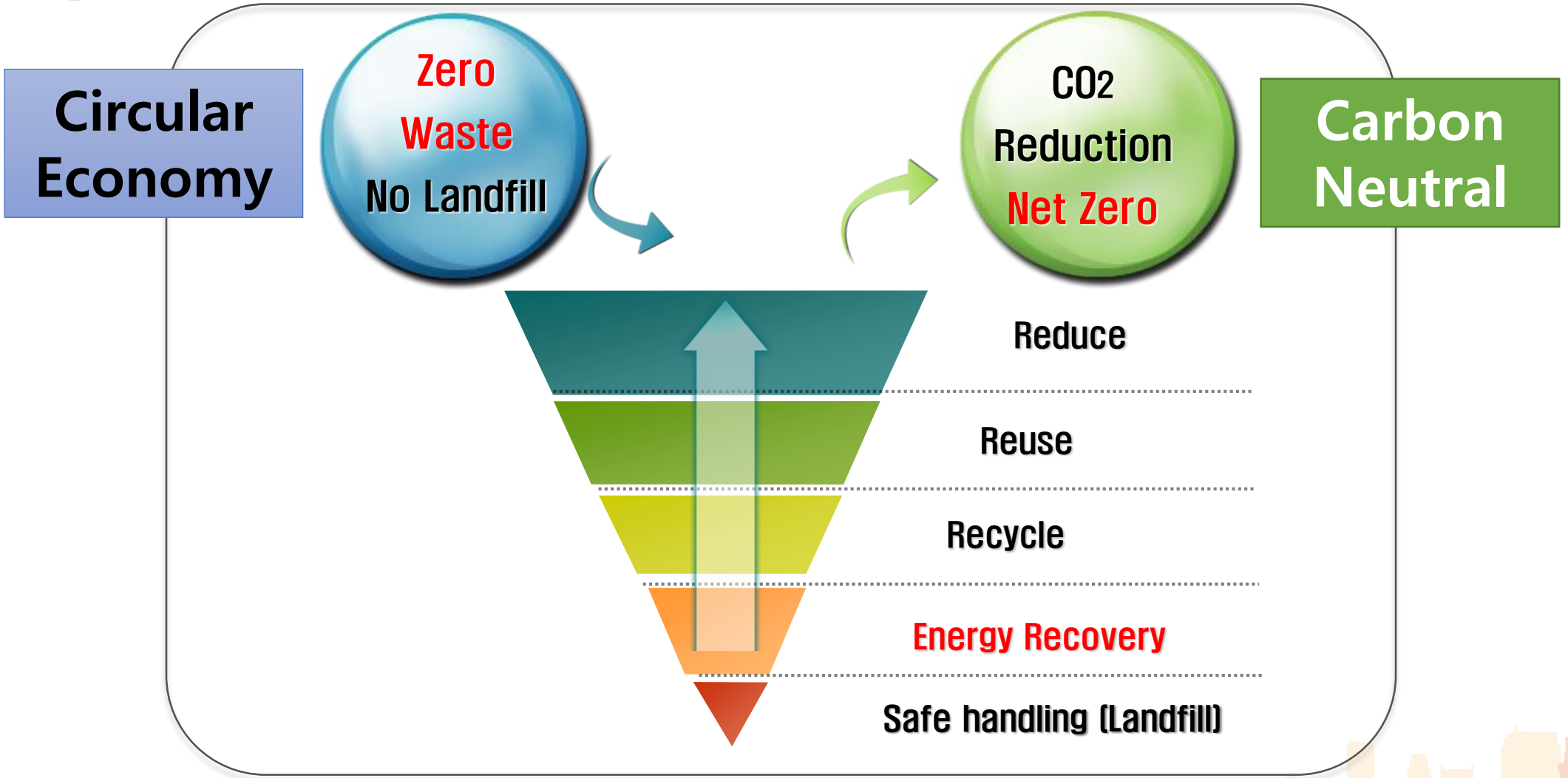
Source: Environment statistics yearbook, Korean Ministry of Environment

Historical Review and Status on Waste Management

- **GHG Emission from Household Waste in Korea('82 ~ '18)**

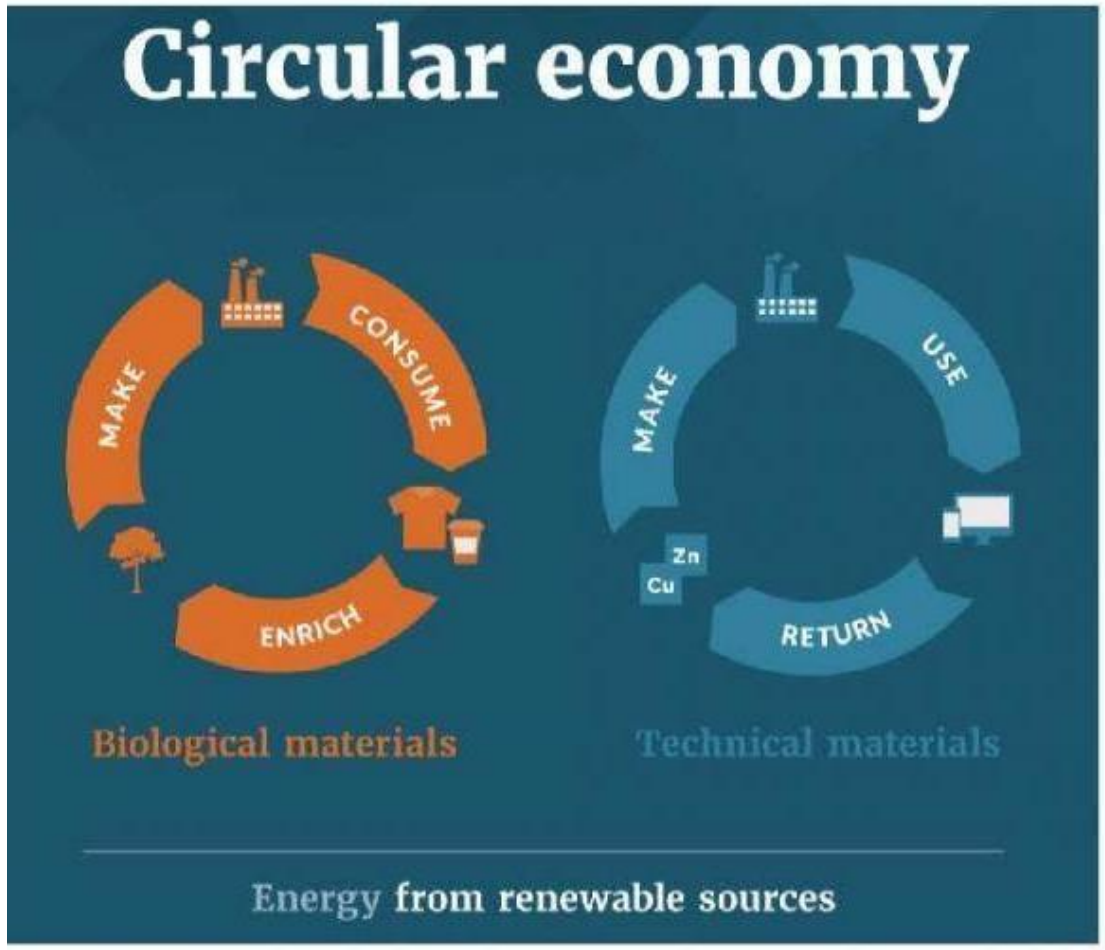


Waste Management Principles (Integrated WM)



Linear Economy & Circular Economy

A circular economy is based on the principles of designing out waste and pollution, keeping products and materials in use, and regenerating natural systems.



(https://www.ellenmacarthurfoundation.org/circular-economy/what-is-the-circular-economy)

Frame Act on Resource Circulation (2018.1)

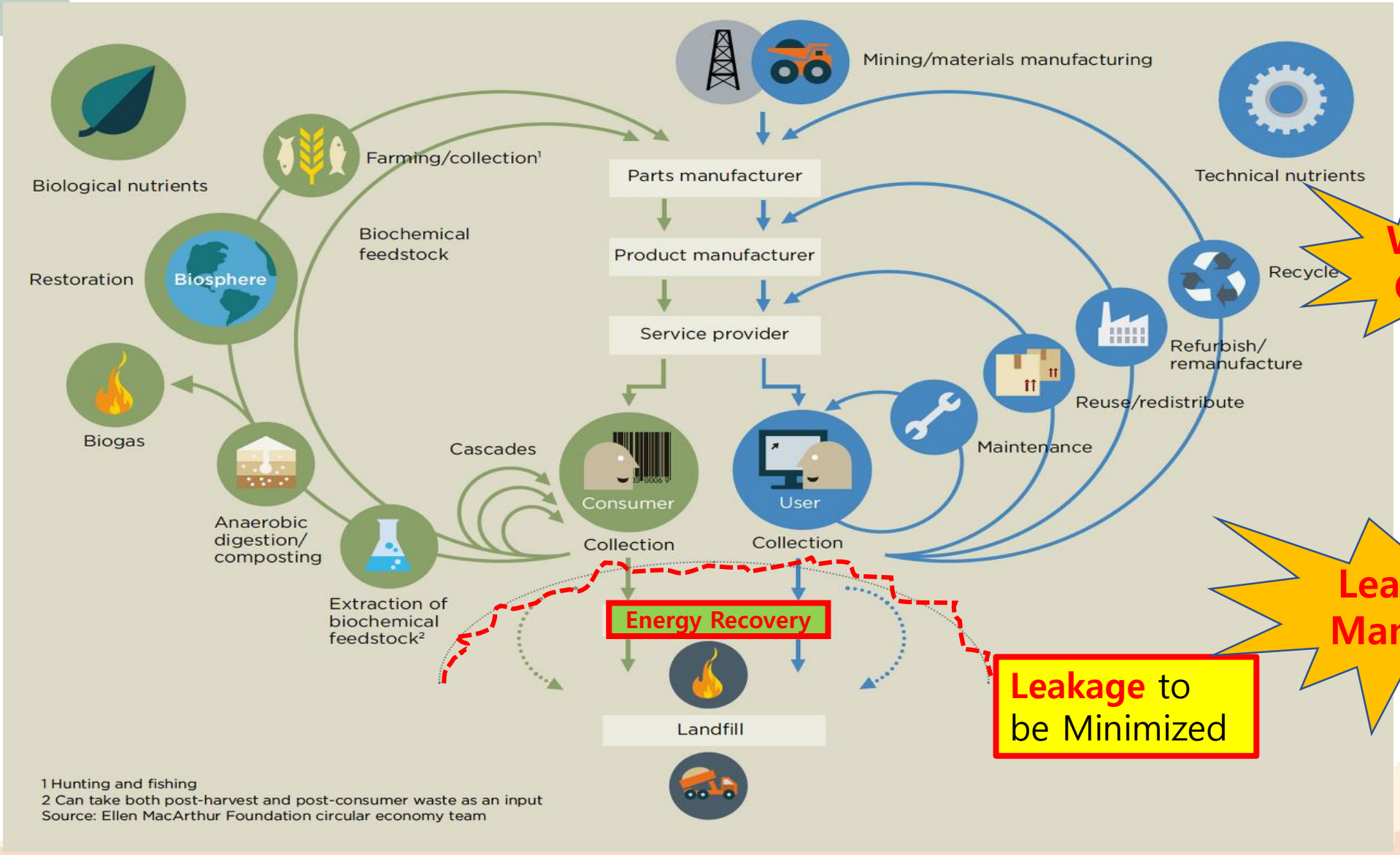
1. Establishment of RC Infrastructure
2. Enhancement Measures for RC
3. Support RC Industries

Zero Landfill,
Maximize Recycling

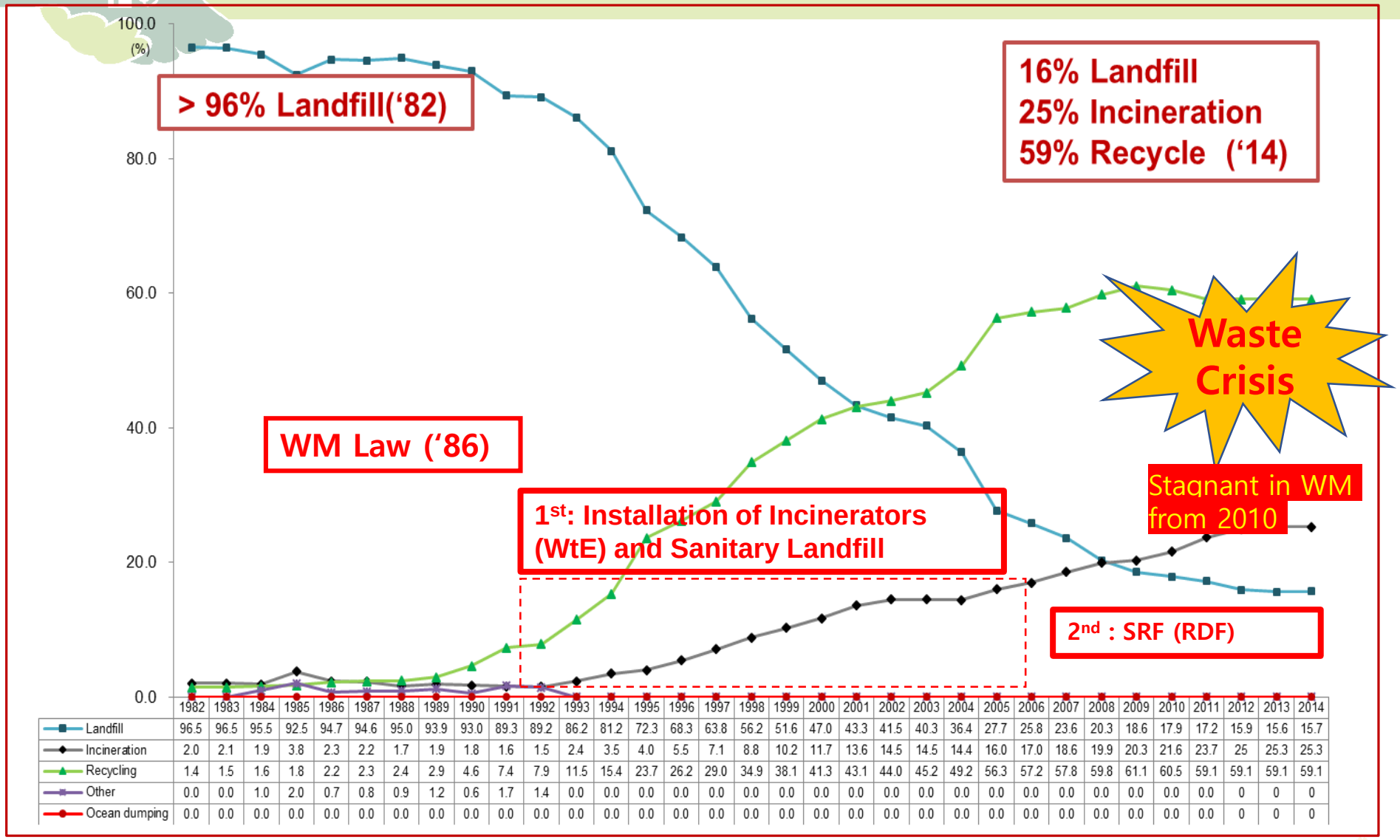
Not Clear in Recognizing the Role of Waste to Energy
(Considered Only as One of Recycle or Disposal Measures)

Circular Economy and Waste Management

- Circular Economy Butterfly Diagram (Ellen MacArthur Foundation)



History of Korean SWM and Recent Situation w.r.t. WtE



	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014
Landfill	96.5	96.5	95.5	92.5	94.7	94.6	95.0	93.9	93.0	89.3	89.2	86.2	81.2	72.3	68.3	63.8	56.2	51.6	47.0	43.3	41.5	40.3	36.4	27.7	25.8	23.6	20.3	18.6	17.9	17.2	15.9	15.6	15.7
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Other	0.0	0.0	1.0	2.0	0.7	0.8	0.9	1.2	0.6	1.7	1.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0	0	0
Ocean dumping	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0	0	0

Recent (4-5 yrs.):
Frame Act on RC, Circular Economy, SDGs, ESG, Net Zero

Regress in WtE:
-Discontinuance of WtE policy
-Public Objection
-Not counted WtE as Carbon Neutral Benefits
-Unbalance in WM: No Strategy on Leakage Manage !
-Zero Landfill

Need to understand WtE Role for WM for CE and Net Zero

Source: Environment statistics yearbook, Korean Ministry of Environment

Establishment of the WtE Forum (’20~)

Changes in Waste Management and Policy regarding WtE are needed

Even Though the ‘Frame Act on Resource Circulation (2018)’ with the goal to establish Circular Economy and SDGs, the adversity with waste crisis has become more serious, since the amount of waste has increased and the lack of policy and strategy on WtE utilization due to public objection and nonrecognition of WtE for suitable WM during 2018~2020.
Academic societies with business enterprises and nongovernmental organizations realized the policy reformation to promote WtE and the enhancement of public awareness with recognition of WtE role for Circular Economy

Policy Improvement

Waste to Energy Policy & Tech. Forum

Enhancement of Public Awareness

Delay in installation of waste disposal facilities

Increased waste disposal costs due to delayed facility installation by NIMBY. Waste mountain incidents. Plastic disposal.
Problems of waste disposal and illegal dumping.
Return of non-recyclable waste after export to overseas.

Direction of Waste Management in Korea

Future Waste (Household) Management for Zero Waste & Net Zero

Prevent of GHG Emission

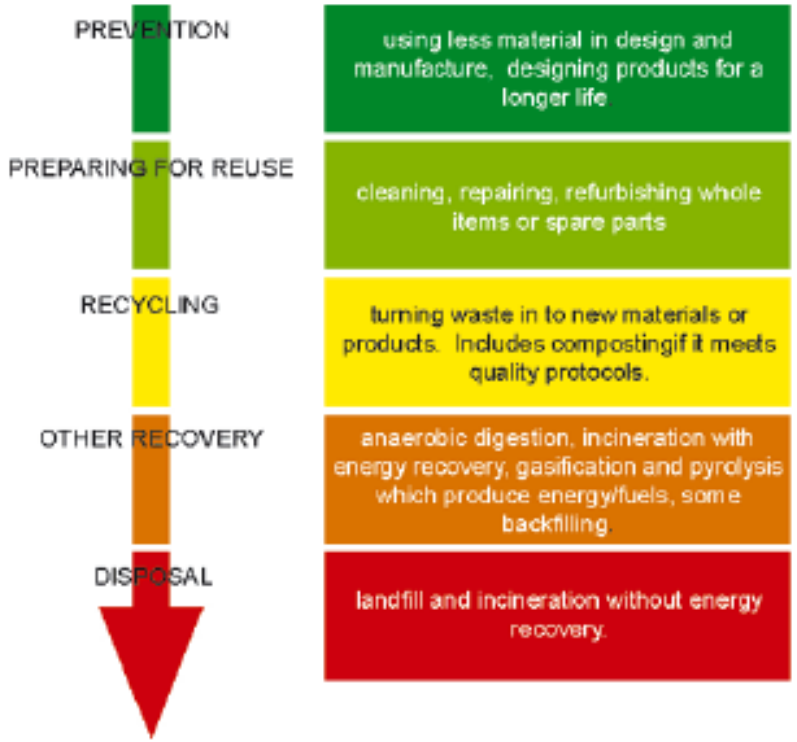
Reduction of Air Pollutants

Energy Save

Resource Preserve

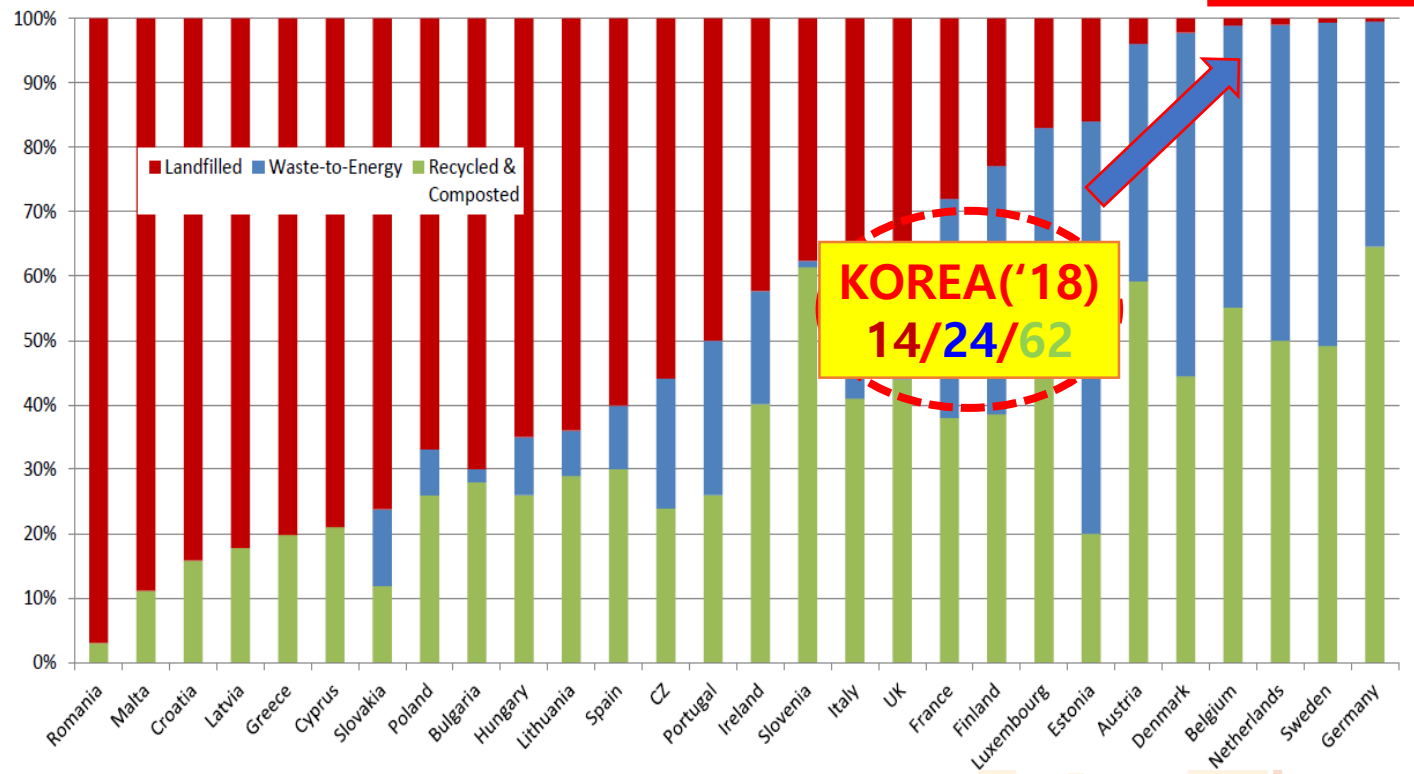
Job Growth

ZERO WASTE
NET ZERO
CIR. ECON.



Hierarchy of WM

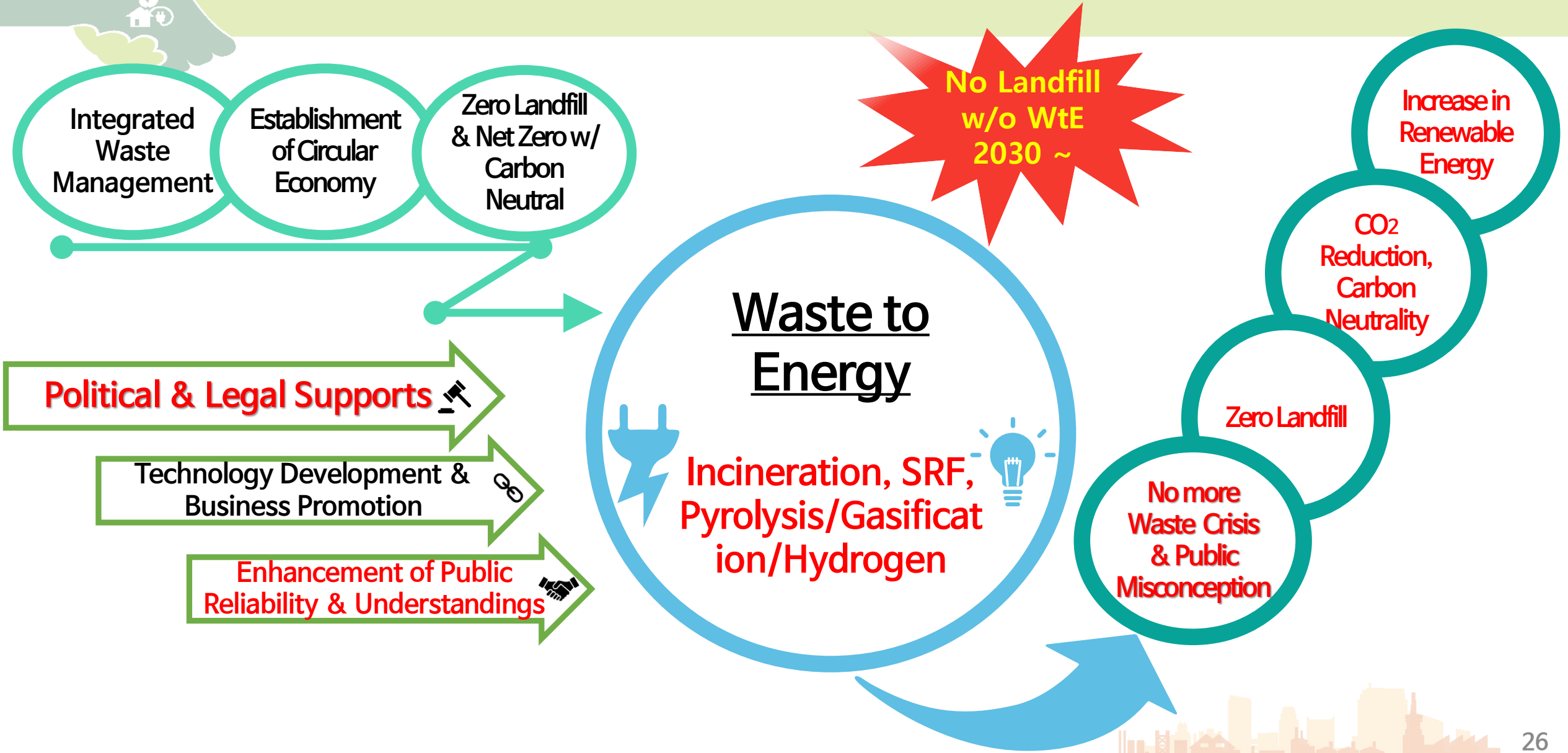
Source : Advanced Collection, Processing, Energy Recovery and Disposal Technologies for the Municipal Solid Waste Value Chain : Global Market Analysis and Forecasts, Navigant Consulting Inc., 2014



Status of Waste Management in EU

Source : Developments and trends shaping the future for Waste to Energy technology suppliers, ESWET, 2015

Role of WtE for Circular Economy and Carbon Neutral Goal



Issues and Future Directions of WtE in WM for CE and Carbon Reduce

- Recognition of Role of WtE with Optimal after Maximum Recycling is essential to achieve Zero Landfill, CE, and Carbon Reduce, and to Avoid Waste Adversity
- No Landfill without Pre-Treatment (WtE) after 2030 in Korea
- Provision for the Replacement of Aged Incineration Plants over 30yrs operation
- More WtE Facilities across the country should be Installed by 2025~2030
- Policy to Support WtE Facilities and Public Understanding must be formulated
- Higher Efficiency in Energy Conversion and CCUS at existing WtE plants
- Technology Development for Renewables (Hydrogen, Chemicals etc.) by Pyrolysis & Gasification, and Domestic Conventional Tech. (Incineration)

A Project to construct a bio-oil production facility from biomass by-products in Quang Nam Province, Vietnam Feasibility Study (May ~ Dec. 2023)

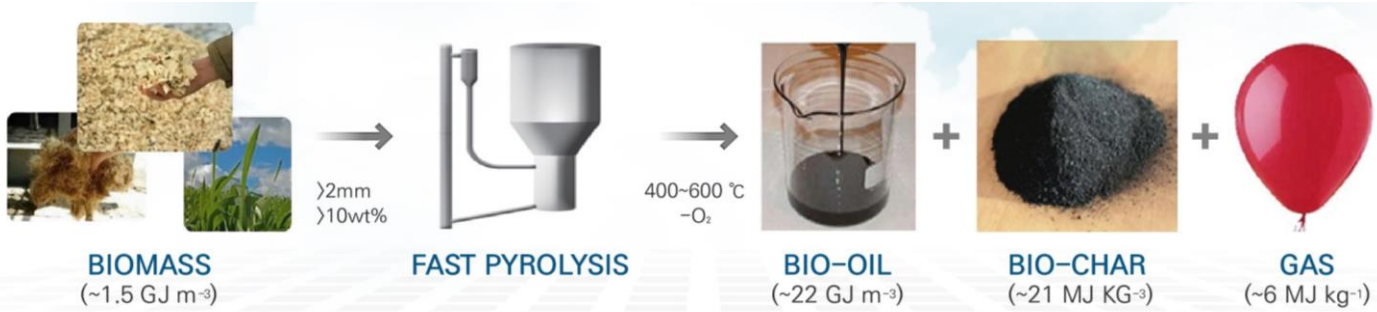
Technical Report Meeting
Golden Lotus Luxury, Danang
2023. October 27

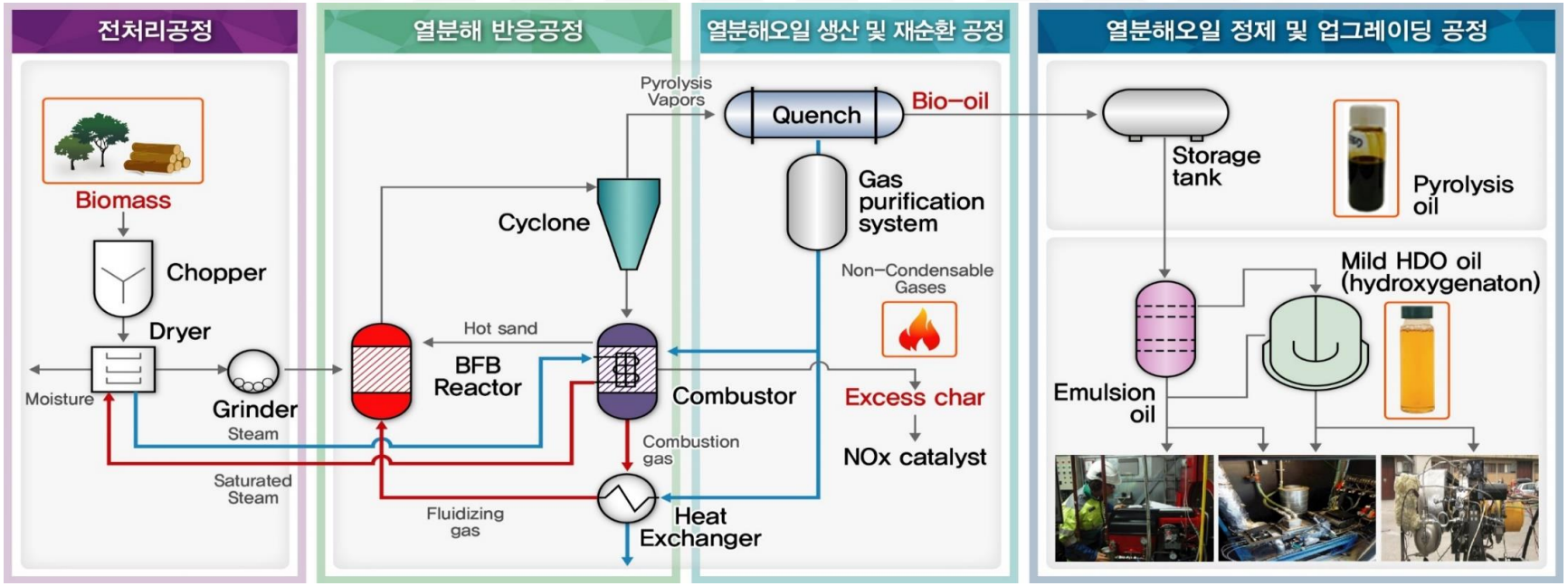
Recent Work in Progress
by YC Seo

Technical Feasibility Study
- Construction & Operation of 20 tons/d Unit

Utilization of the plant of 20 tons/d Fast Pyrolysis Unit for Biomass Byproducts in Vietnam.

"Bio-oil Production Plant for 20 tons/day of Biomass using Fast Pyrolysis"

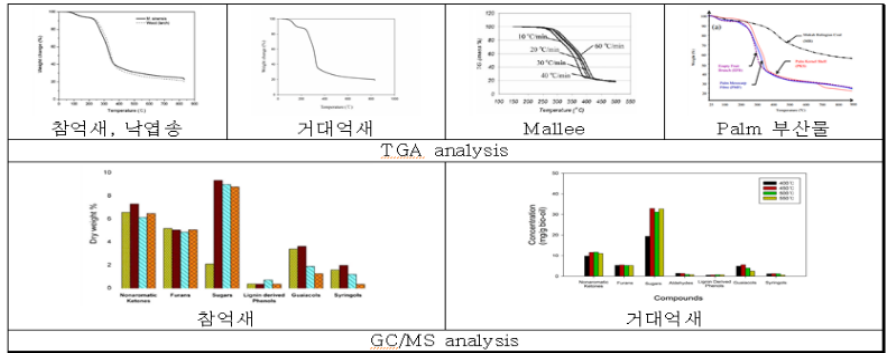




- Analysis Results of Feedstock & Oil Product

바이오매스 물리화학적 특성 분석 D/B화
Analysis of Physical & Chemical Properties of BM

구분	Cellulose	Hemi-cellulose	Lignin	Extra
목재가공부산물(%)	39.4	20.4	19.9	20.3



Physical properties		Geodae-Uksae 1	M. sinensis	EFB	Wood (larch)	목재가공부산물
Water Content (wt. %)		11.20	10.24	9.00	12.40	2.66
Volatile (wt. %)		67.50	71.20	65.00	73.30	79.52
Fixed carbon (wt. %)		19.80	15.19	19.50	13.50	18.40
Ash (wt. %)		1.50	3.37	6.00	0.80	2.09
Element (wt. %)	C	51.30	42.65	41.80	43.70	45.40
	H	6.20	5.46	5.70	5.50	6.20
	O	42.20	51.64	37.40	50.80	45.20
	N	0.40	0.25	0.80	0.03	3.10
	S	0	0	0	0	0
HHV (MJ/kg)		19.20	16.80	16.40	17.60	21.70

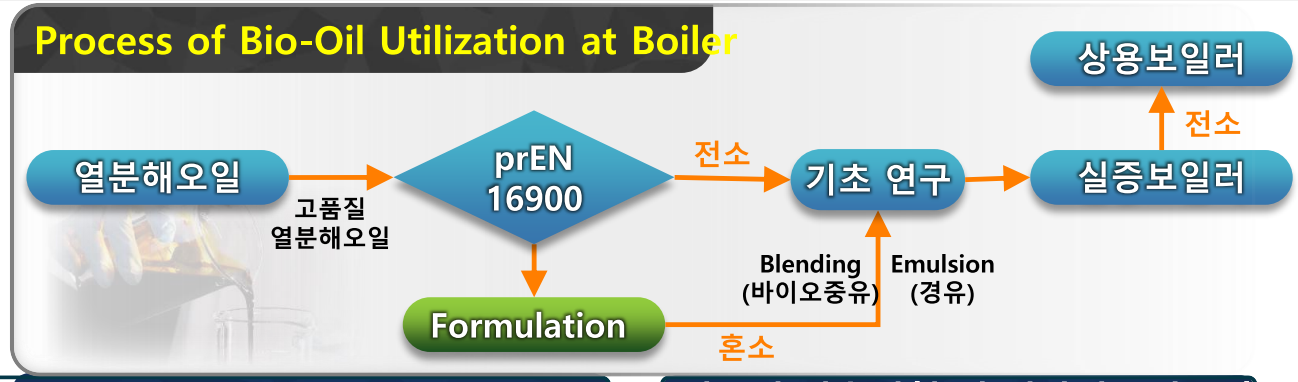
실증화 공정 생산 열분해오일 분석
Analysis of Bio-oil Product Quality

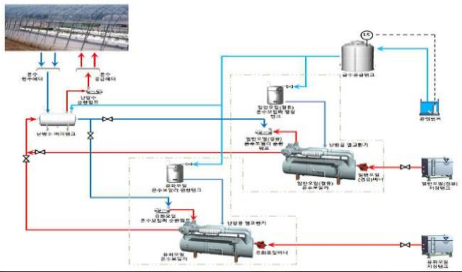
시험항목	단위	품질 기준(prEN16900)	실증화공정(열분해오일)
총발열량	MJ/kg	14이상	19.72
수분	wt%	30이하	16.78
동점도(40 ℃)	mm^2/s	125이하	14.01
밀도(15 ℃)	kg/dm^3	1.3이하	1.13
황 함량	wt%	0.1이하	0.03
회분	wt%	0.25이하	0.019
유동점	℃	-9이하	-43
고형분	wt%	2.5이하	0.84
pH	-	-	2.04
질소 함량	wt%	Report	-

- ☑ 바이오매스 분석 (TGA, 공업, 원소 분석 외)을 통한 활용가능한 목질계 바이오매스의 특성 분석 D/B화
- ☑ 20T/D급 실증화 공정을 통한 열분해오일 생산 실험 및 품질 분석
- ☑ 국제 품질기준(prEN16900)에 적합한 오일 생산 (Oil Quality was Good enough to meet prEN16900)

- Utilization of Oil Product

Process of Bio-Oil Utilization at Boiler

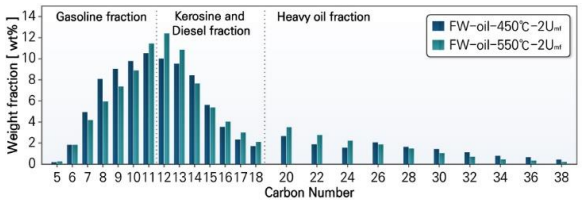




실증화/상용화 보일러 적용 실험

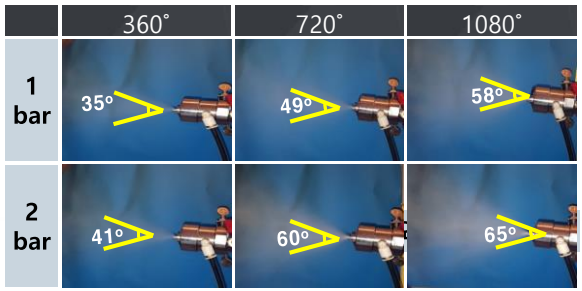
분해오일 특성 분석 / 노즐개발
Oil Property Analysis/Nozzle Dev.

열분해오일 특성 연구



열분해오일 특성 분석을 통한 휘발유/경유 Fraction 분석

열분해오일 분사 노즐 개발



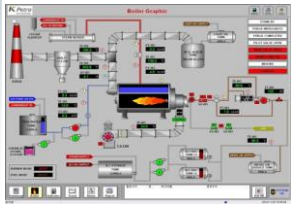
분해오일 기초실험 및 평가시스템 구축
Basic Test & Assessment of Oil Product

열분해오일 연소 기초 특성 연구

혼/전소 기초실험 장치

연소특성 분석

보일러 적용 평가시스템 구축



열분해 오일 특성 분석

열분해 오일 특성 분석

보일러 적용 실험 및 사업화 방안 제
Test in Boiler for Commercialization

실증화/상용화 보일러 적용 실험

실증화공정 적용

상용화공정 적용

열분해오일 공급 사업화 방안

상용화급 보일러 적용에 따른 열분해오일 공급 확약