Integration of processes for optimizing resource recovery from waste streams

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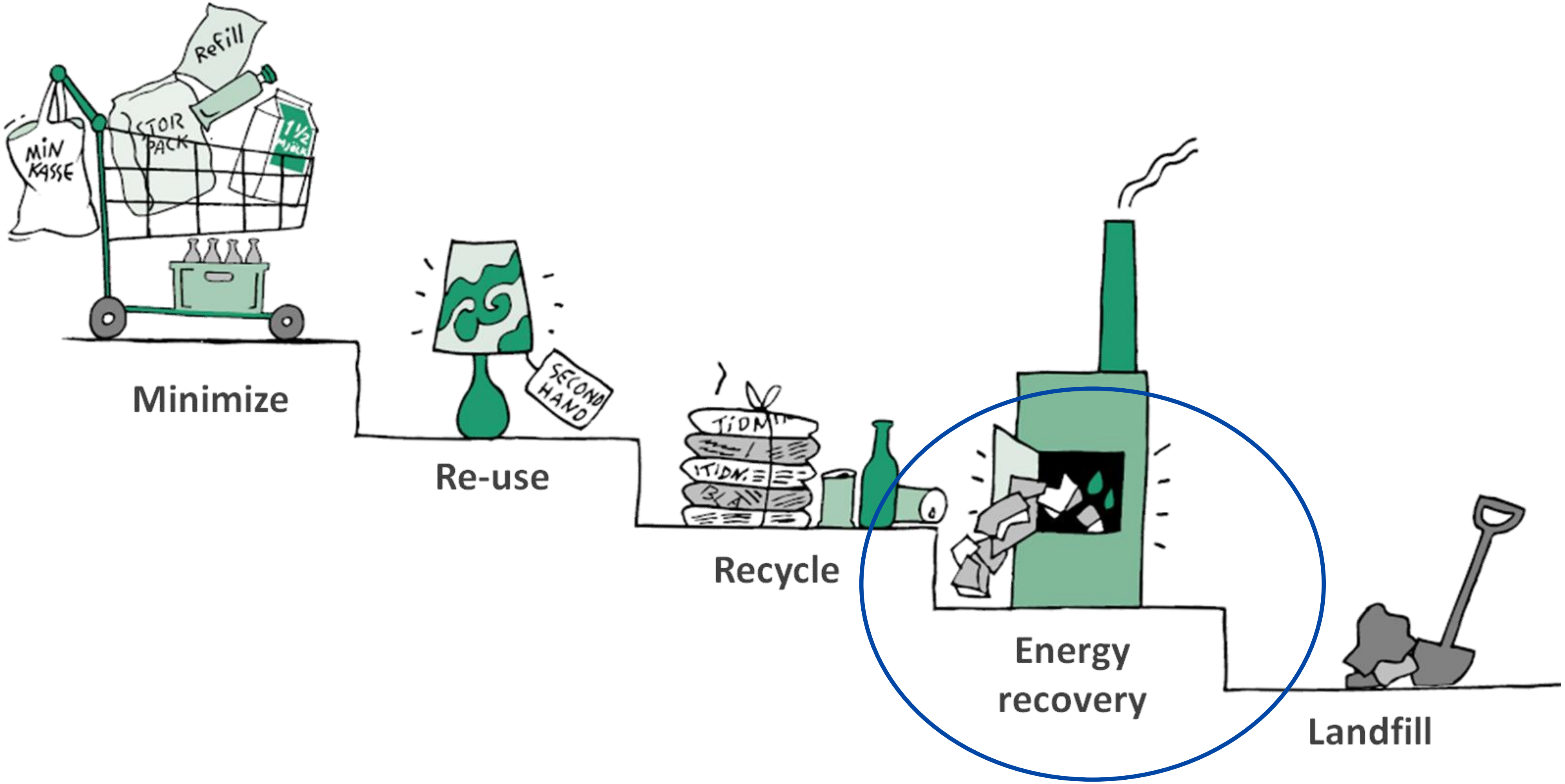
Ingmar Schüßler
SP Technical Research Institute of Sweden

Simon Gandy
AEA Group

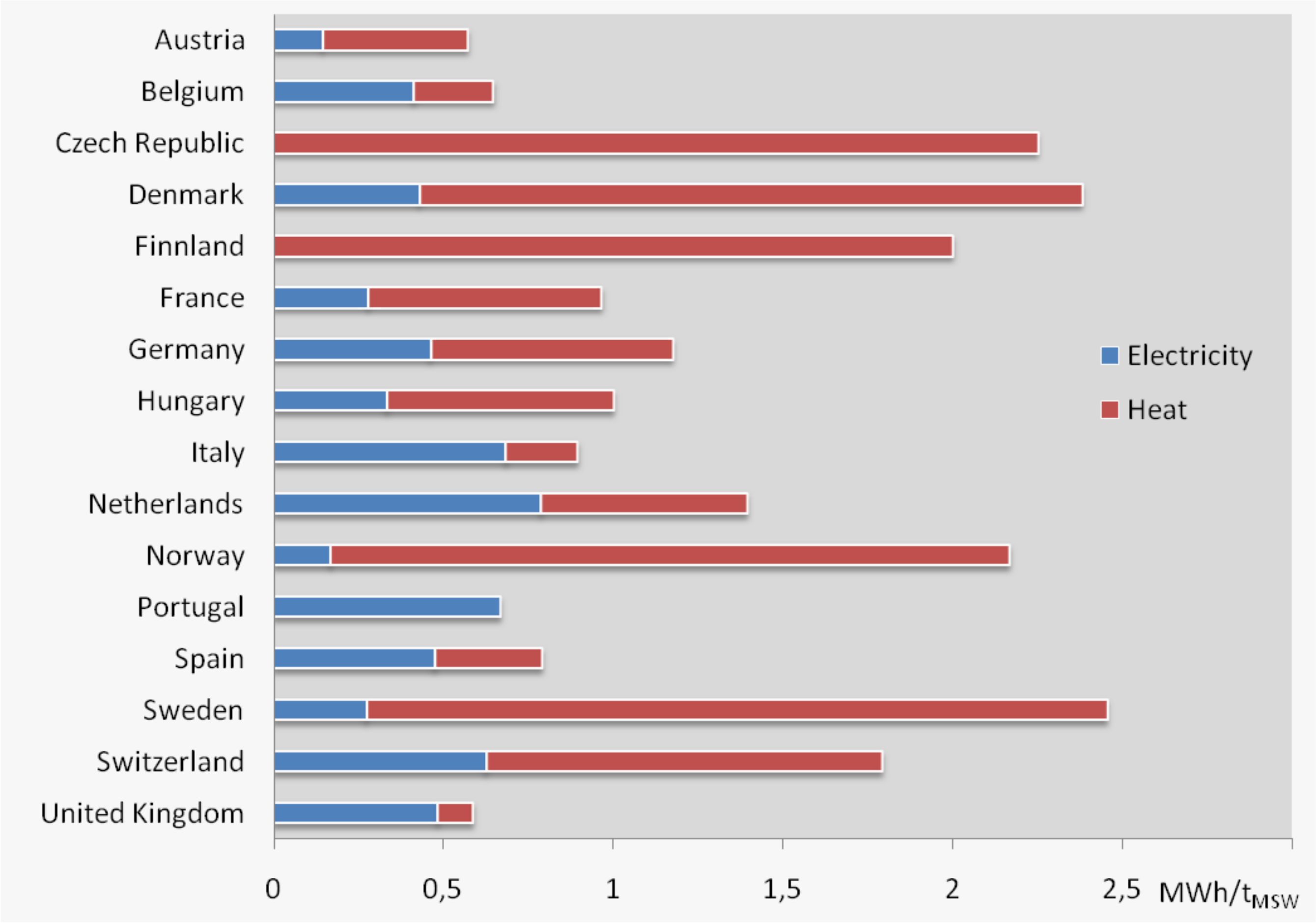
Waste management hierarchy



Resource Recovery from Waste

- Common path: Incineration plants with energy recovery (power and/or heat)
- Energy recovery improvements in incineration plants through
  - Increase electrical efficiencies (Limitations: steam parameters, size)
  - Increase heat utilization (Limitations: climate, size, industrial consumers)

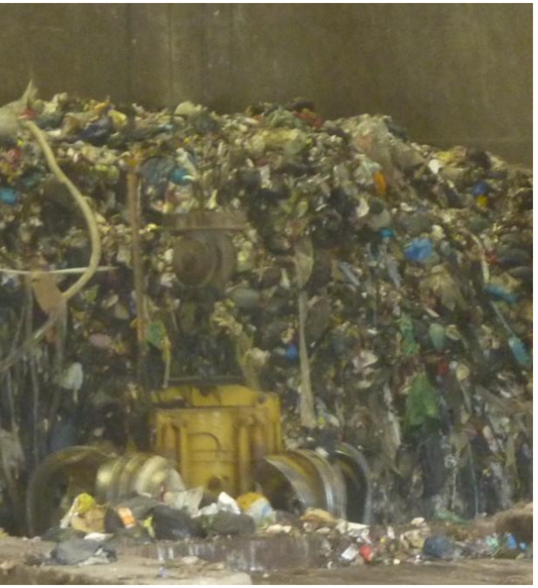
→ Resource recovery improvement by producing high quality products, like Chemicals or Fuels?



Energy Recovery from MSW in incineration plants for certain European Countries [Figures for 2005, Source: Avfall Sverige (Rapport U2008:13)]

Technologies for Waste to Energy facilities

- Waste Pretreatment
  - Mechanical processes (e.g. sorting, sieving, crushing, …)
  - Thermal processes (e.g. drying, torrefaction, pasteurization, steam explosion)
- Waste Conversion
  - Thermal Treatment (Combustion, Gasification, Pyrolysis)
  - Biological Treatment (Composting, Anaerobic Digestion)
- Energy Conversion
  - Units with external heat supply (e.g. steam or ORC turbines)
  - Units with internal heat supply (e.g. gas turbine, internal combustion engine, Fuel cell)
  - Gas Reforming (e.g. biogas upgrade, FT-Synthesis, methanol synthesis, methanation, Hydrogen extraction)



Thermal Waste Treatment

- Pyrolysis:
  - Fuel conversion without oxygen supply (external heat supply)
  - Product: solid, liquid and gas fraction
- Gasification
  - Fuel conversion with substoichiometric oxygen supply (internal heat generation or external heat supply)
  - Oxygen supply: usually air/enriched air, pure oxygen or steam
  - Product: product gas/syngas (main components CO, CO_2, H_2, C_xH_y, H_2O, N_2)
- Combustion
  - Fuel conversion with excess oxygen supply
  - Oxidizing agent usually air
  - complete fuel oxidization resulting in high temperature Flue gas

Combustion of Waste

- Proven technology; alone in Europe more than 450 Waste-to-Energy (WtE) plants based on incineration
- Typical recovery rates (based on waste LHV)
  - …20-25…(30)% net electrical efficiency for power configuration
  - …10-15…% net electrical, …75-85…% total for CHP configuration (higher with flue gas condensation)
- Challenges
  - Inhomogeneous fuel
  - Low heating values
  - Corrosion risk
- No potential for producing Chemicals/Fuels

Source: Borås Energi och Miljö AB, Sweden

Gasification of Waste

- Some waste gasification plants in operation, mainly air/enriched air gasifiers coupled with steam cycle
- Gasification with air/enriched air
  - Nitrogen diluted product gas
  - Sufficient gas cleaning enables steam generation with improved parameters or gas use in combined cycle applications (already in operation at fossil/biomass gasification plants)
- Gasification with oxygen or steam
  - Nitrogen “free” product gas (syngas)
  - Sufficient gas cleaning enables steam generation with improved parameters, use in combined cycle applications or syngas reforming (already done at fossil/biomass gasification plants)

Company	Gasifier type	Oxygen Supply	No.
AlterNRG (Canada), Westinghouse Plasma Corp., Hitachi Metals (Japan)	Plasma		2 (+1)
Ebara TIFG (Japan)	ICFB	Air	12
Ebara Co. and Ube Industries Ltd (Japan)	ICFB	Oxygen	3
Energos (Norway/UK)	Moving Grate	Air	8 (+6)
Hitachi Zosen (Japan)	BFB	Air	9
JFE (Japan); (Kawasaki Steel and NKK)	Fixed Bed	Enriched air	10
JFE (Japan); Thermoselect (Switzerland)	Fixed bed	Oxygen	7
Kobelco (Japan)	BFB	Air	12 (+1)
Mitsui (Japan)	Rotary Kiln	Air	7 (+2)
Nippon Steel Engineering (Japan)	Fixed Bed	Enriched air	32 (+5)
Plasco Energy Group (Canada)	Plasma		2
Takuma (Japan)	Rotary Kiln	Air	2

WtE gasification-based plants based on data 2001-2011 [Source: Arena, 2012]

Biological Waste Treatment

- Composting
  - Aerobic decomposition of biodegradable material through microorganisms resulting in generation of compost and low temperature heat release
  - Compost can be used as Fertilizer/ Soil conditioner
- Anaerobic Digestion (AD)
  - Anaerobic conversion of digestible material through microorganisms resulting in generation of digestate and biogas (contains mainly CH_4 and CO_2 including fractions of other components like H_2S and H_2O)
  - Digestate (nutrient-rich) can be used as fertilizer
  - Biogas can be used for CHP generation or upgraded to SNG

Anaerobic Digestion of Waste

- Proven technology, several AD plants with food (and similar) waste as feedstock in operation
  - used digester types: mesophilic and thermophilic reactors
- Proper feedstock mixing avoids operation problems (e.g. foaming) and reduces unnecessary resource consumption
- Pre-treatment technologies enable higher gas yields and use of new feedstock materials
- Biogas upgrade units in operation at several AD plants; as well proven technology
  - main technologies in use: water scrubbing, PSA, chemical absorption

Substrate	TS [%]	VS [% of TS]	Methane yield $m^3_{CH_4}/t_{VS}$
Source separated food waste – household	33	85	461
Source separated food waste – canteen	13	92	650
Source separated food waste – restaurants	27	87	506
Fruit and vegetable waste	15	95	666
Slaughterhouse waste –stomach/intestinal	16	83	434
Slaughterhouse waste – residual blood	10	95	547
Returned product (dairy)	20	95	520
Grease interceptor sludge	4	95	682

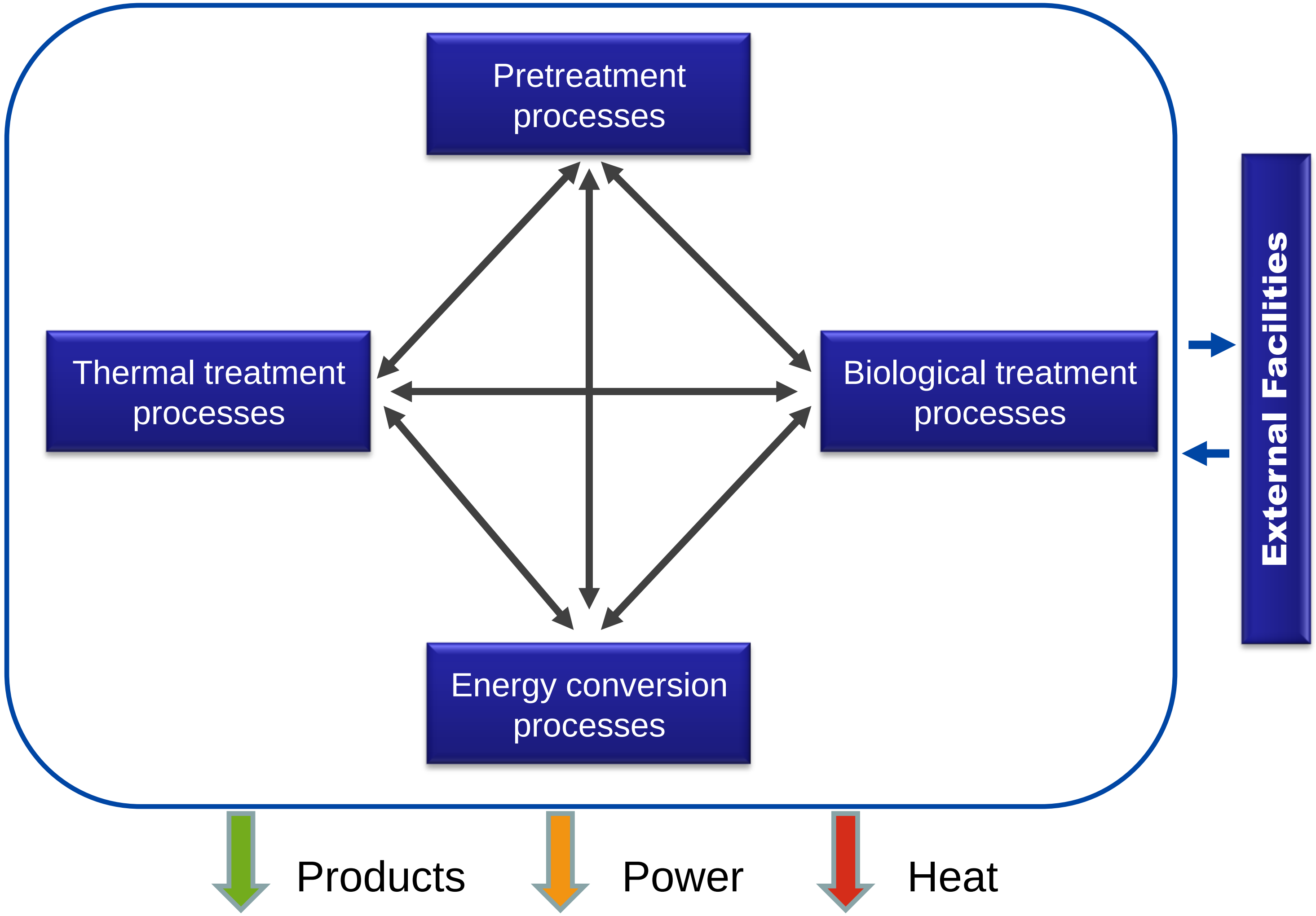
Examples for measured methane yield in batch digestion experiments [Source: SGC, 2009 (Rapport SGC 200)]

IAWARE Concept

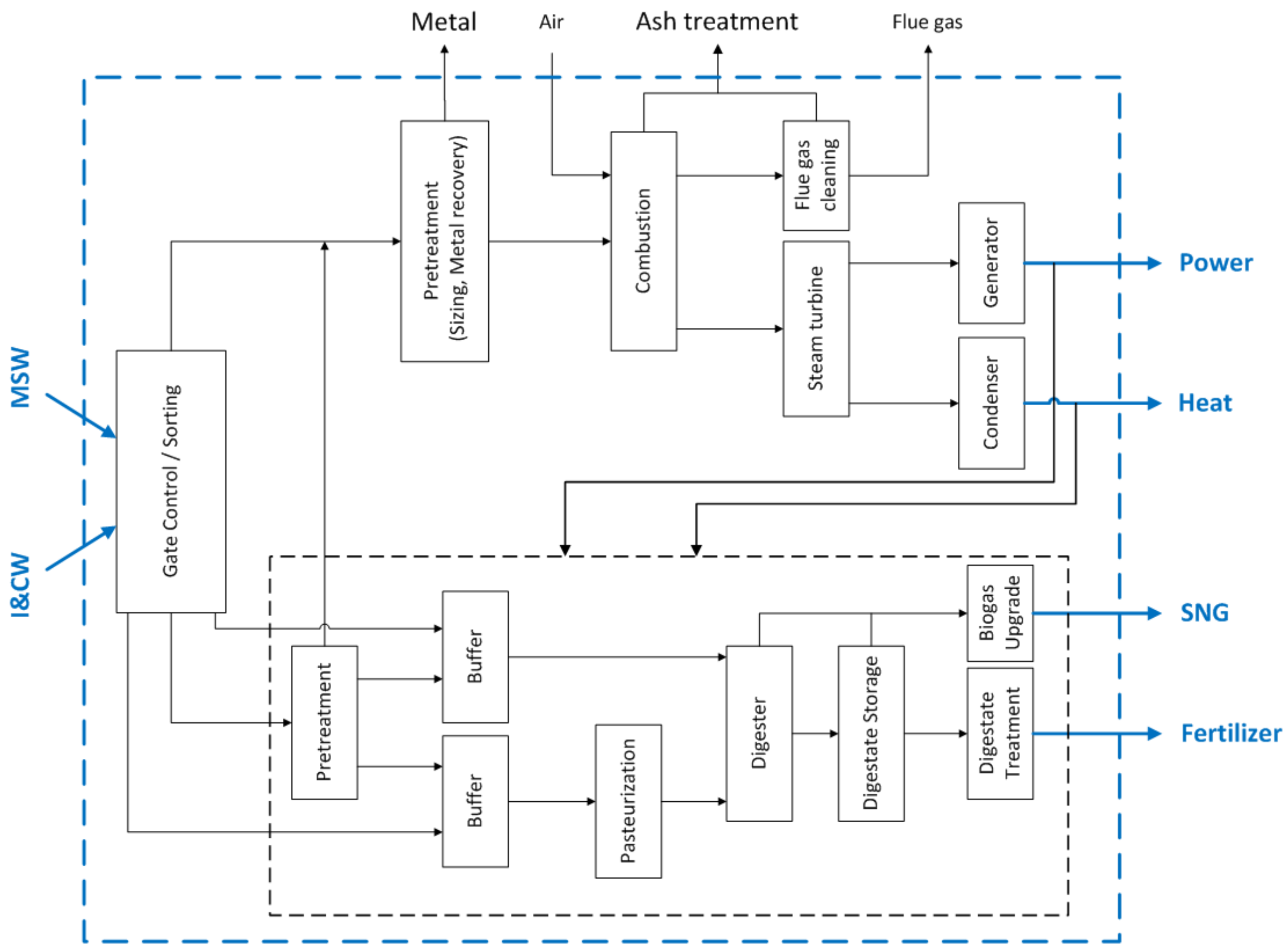
Integrated Advanced Waste Refinery

- Combination of thermal and biological treatment processes for source specific treatment
- Exchange of materials, heat and electricity in between processes to maximize production of high quality products
- Material exchange with external facilities (e.g. biogas from waste water treatment plants for upgrade)

→Survey of various IAWARE configurations based on energy balance as well as LCA simulation

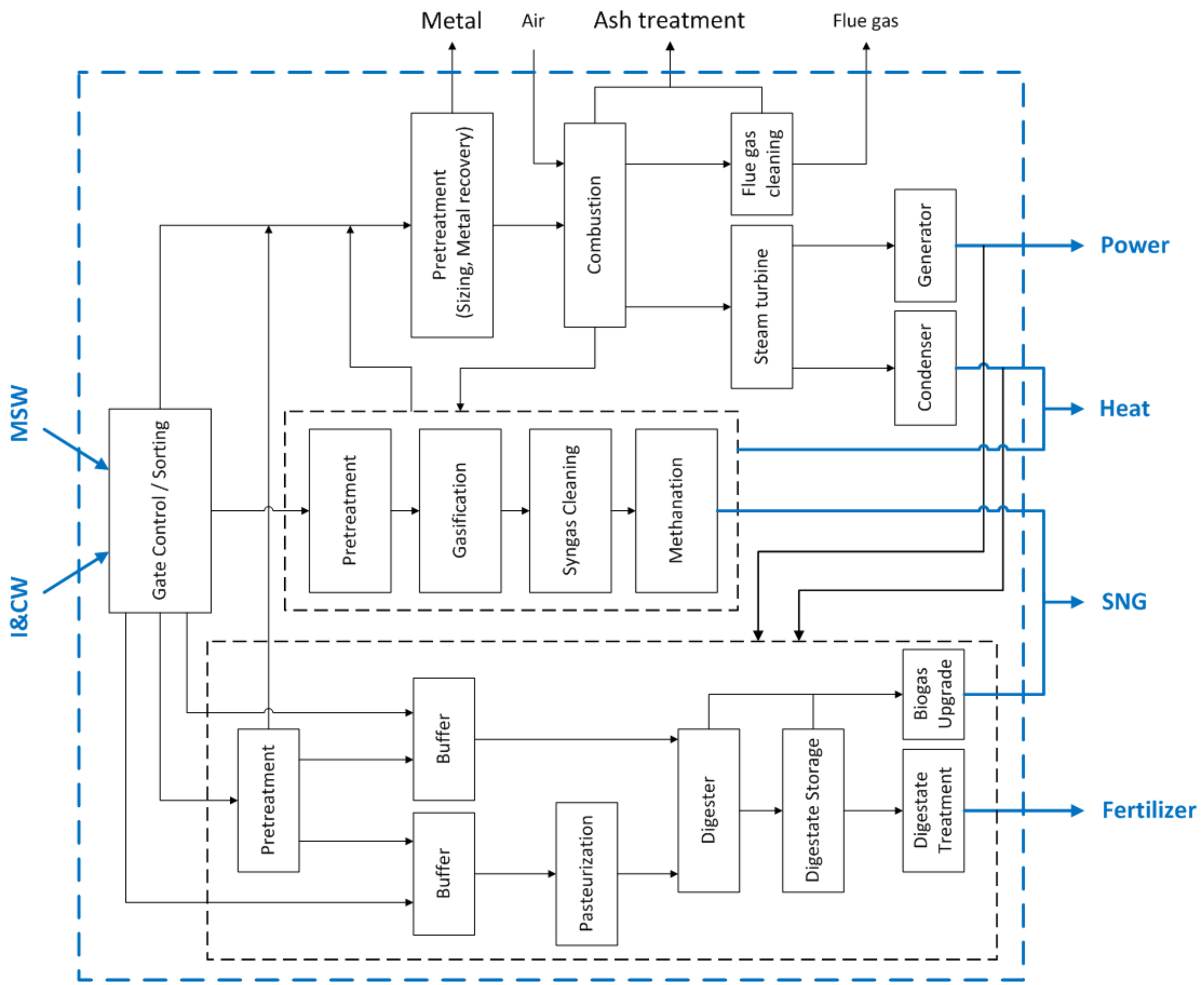


IAWARE Scenario 1



- State of the Art Scenario
  - AD of digestible waste streams (separated at source or on-site) with biogas upgrade to SNG
  - Incineration of residual waste coupled with steam cycle
  - Heat supply from steam cycle to biological processes (pretreatment, AD, upgrade)
- Simulation Data Examples (based on data from WtE-facilities in a midsized Swedish municipality)
  - Waste streams: AD 30.000 t/y (LHV 3.5 MJ/kg), Incineration 100.000 t/y (LHV 11 MJ/kg)
  - Biogas yield: 87 $Nm^3_{CH_4}/t_{Waste}$
  - Incineration plant efficiency (net, based on LHV)
    - CHP: electrical ca. 15%, overall ca. 85%
    - Power configuration: electrical ca. 23%

IAWARE Scenario 2

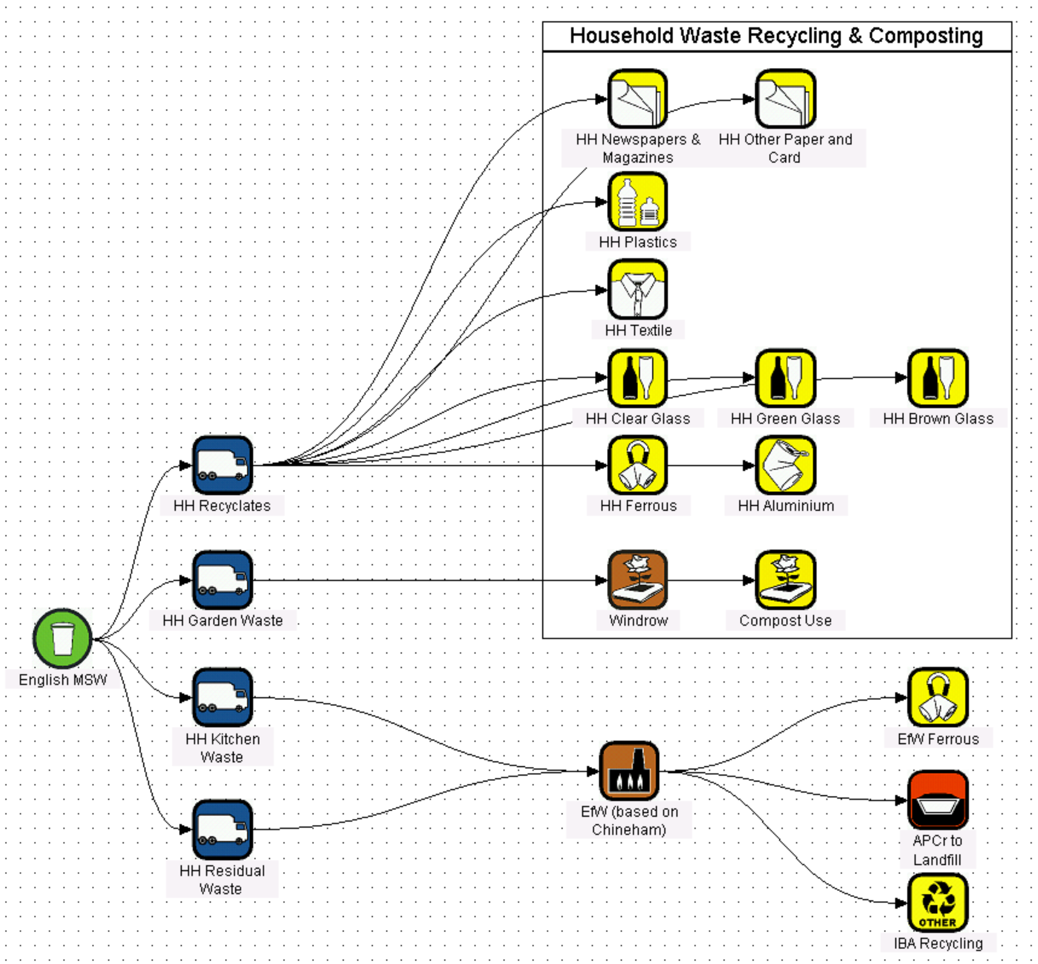


- Partial Gasification Scenario
  - AD of digestible waste streams (separated at source or on-site) with biogas upgrade to SNG
  - Gasification of separated waste stream with higher LHV, downstream methanation
  - Incineration of residual waste, steam cycle
  - Heat supply from incineration cycle to biological and gasification processes
- Simulation Data Examples
  - Gasification 25.000 t/y (LHV 15.5 MJ/kg)
  - Gasification/methanation efficiency (net, LHV)
    - SNG conversion 60%, overall 80%
  - Other figures same as Scenario 1

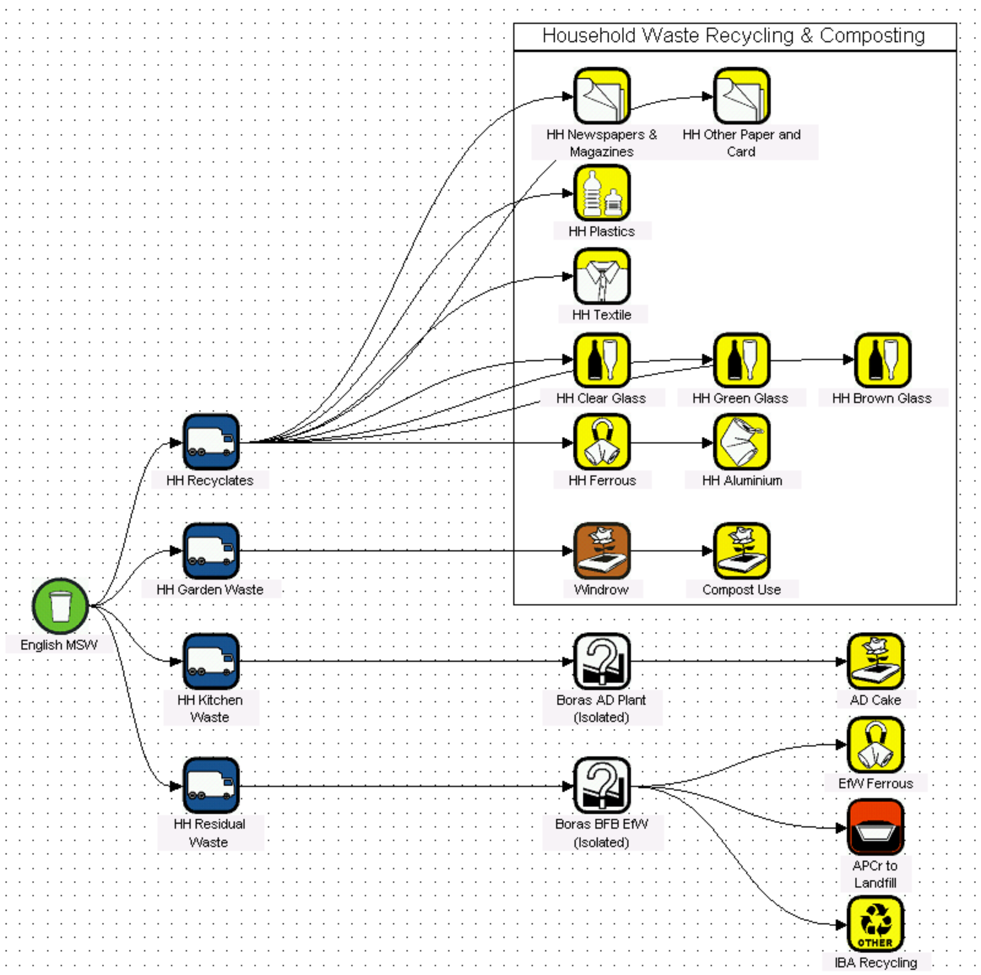
Results from Energy Balance Calculation

Case	Electricity [GWh]	Heat [GWh]	SNG [GWh_{LHV}]	other	Notes
Scenario 1 (CHP)	41,9	206,0	25,8	Fertilizer	
Scenario 1 (Power)	66,7 (64,0)	0	18,8 (25,8)	Fertilizer	() Heat for Upgrade process from incineration
Scenario 2 (CHP)	16,9	152,1	90,4	Fertilizer	
Scenario 2 (Power)	32,9	0	90,4	Fertilizer	
Comparison A Incineration CHP	48,4 (46,3)	234,6 (214,1)	0	- (Compost)	() Digestible Waste composted, without consideration of power demand
Comparison B Incineration Power	75,3 (70,9)	0	0	- (Compost)	() Digestible Waste composted, without consideration of power demand
Comparison C Advanced Incineration	100,4 (91,7)	0	0	- (Compost)	() Digestible Waste composted, without consideration of power demand

Process Simulation using Life-Cycle Assessment tool WRATE

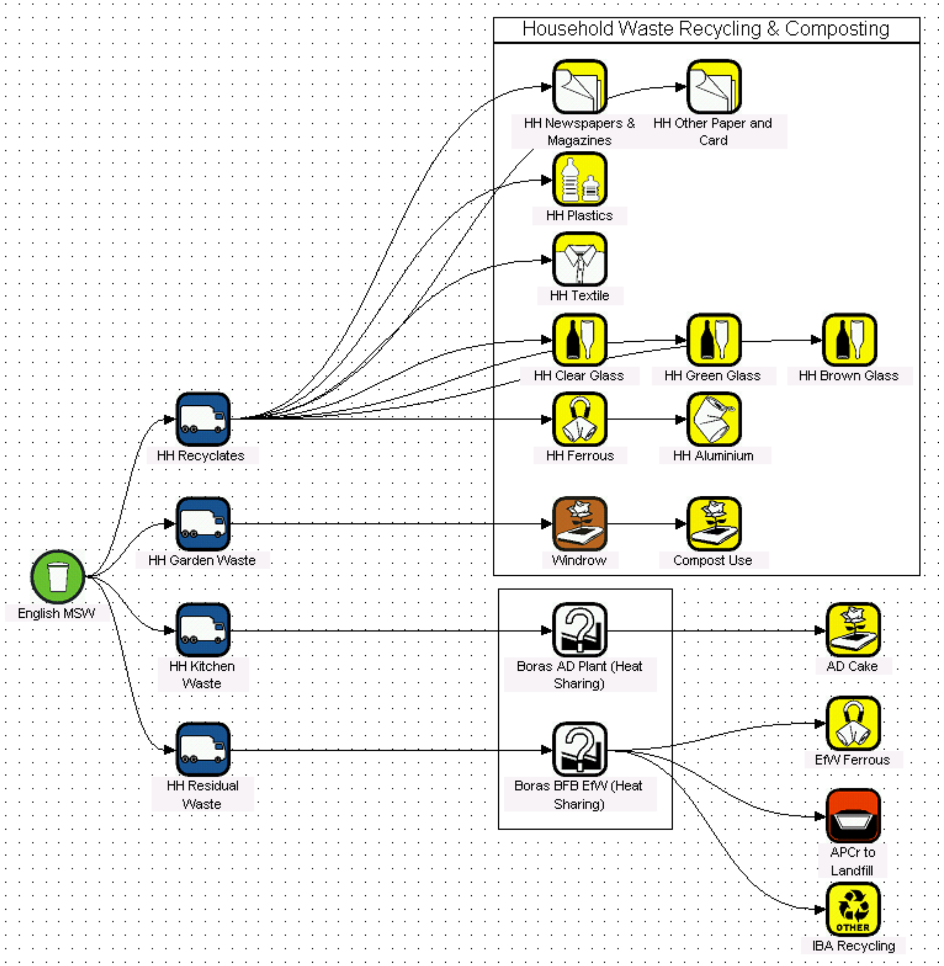


WRATE simulation Scenario 0a: Energy from Waste incineration plant only

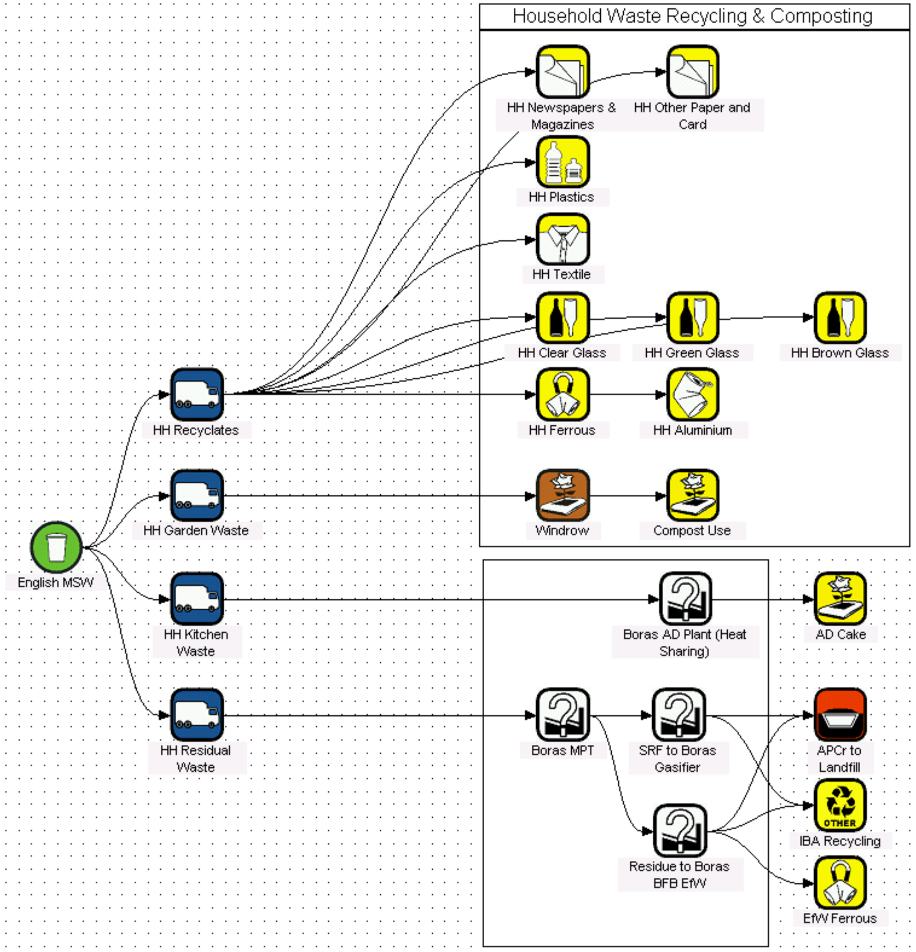


WRATE simulation Scenario 0b: AD and incineration plant without connection

Process Simulation using Life-Cycle Assessment tool WRATE

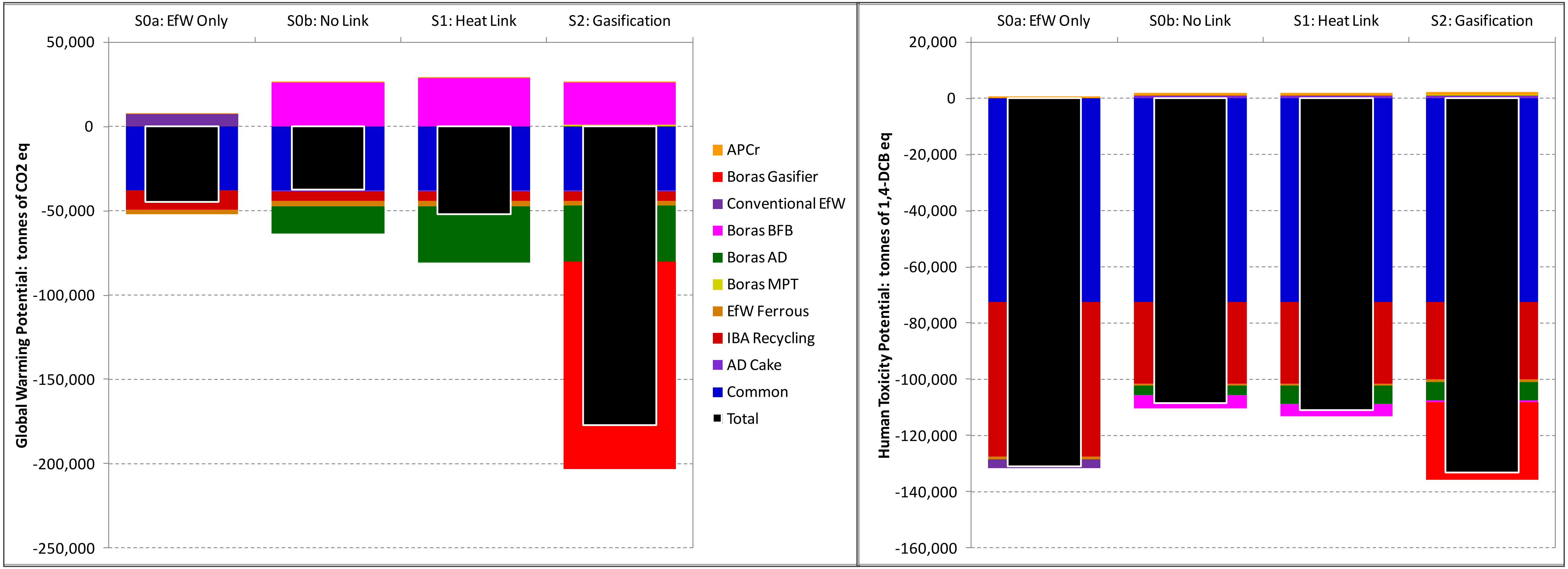


WRATE simulation Scenario 1



WRATE simulation Scenario 2

Results from LCA simulation



Impact on Global Warming Potential (left) and Human Toxicity Potential (right) with respect to single parameters

Results from LCA simulation

Indicator	Units	S0a: EfW Only	S0b: No Link	Scenario 1	Scenario 2
Climate Change	te CO2-Eq	-44,552	-37,353	-51,997	-177,132
Acidification	te SO2-Eq	-250	-267	-316	-772
Eutrophication	te PO4-Eq	-9	-11	-14	-52
Freshwater Aquatic EcoToxicity	te 1,4-DCB-Eq	-10,876	-9,476	-10,499	-18,785
Human Toxicity	te 1,4-DCB-Eq	-130,867	-108,342	-111,091	-133,132
Resource Depletion	te antimony-Eq	-741	-1,479	-2,339	-9,388

Summary

- WtE-plants based on incineration provide an important contribution to the current energy supply
- Energy recovery in current WtE plants is limited, regarding both the electrical and overall efficiency
- The key to maximization of energy recovery is heat utilization
- IAWARE is a concept aiming for integration of several waste treatment technologies into one facility with internal heat, power and material exchange
- The aim is to minimize unused heat generation by generating high quality products
- Key technologies are anaerobic digestion and gasification, both enable the production of fuel or chemicals with potential further benefits (e.g. fertilizer from AD process)
- Survey for various IAWARE example configurations has been carried out, based on energy balance calculation as well as through more detailed life-cycle assessment simulation
- Results show that the IAWARE concept can offer advantages in resource recovery, depending on the final use of the products and the heat utilization possibilities in an alternative WtE incineration plant

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Ingmar Schüßler
SP Technical Research Institute of Sweden
Ingmar.Schussler@sp.se

Simon Gandy
AEA Group
simon.gandy@aeat.co.uk