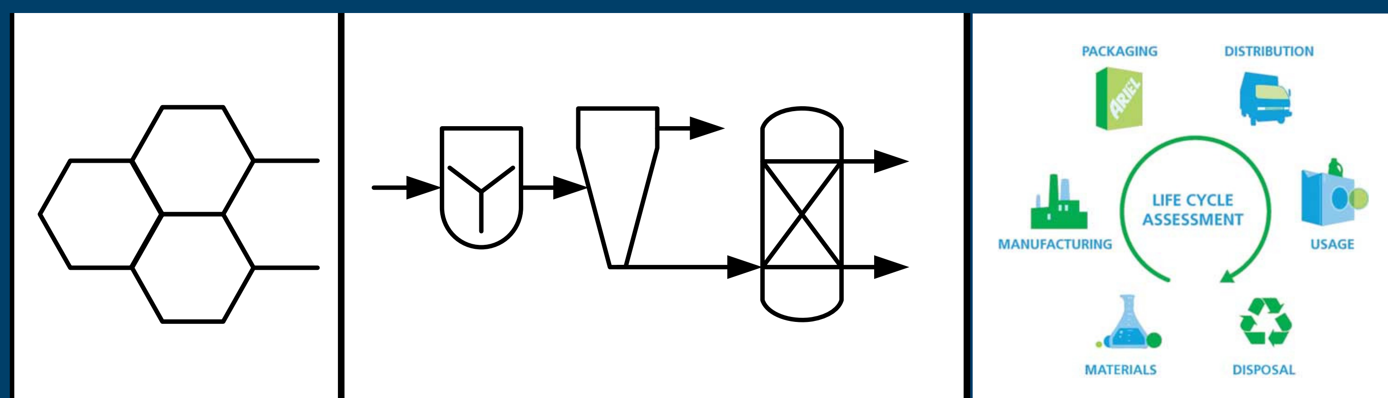
Evaluating the Sustainability of Manufacturing: Process and Life Cycle Assessments

Raymond Smith



Office of Research and Development
National Risk Management Research Laboratory
Land and Materials Management Division

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United States Environmental Protection Agency

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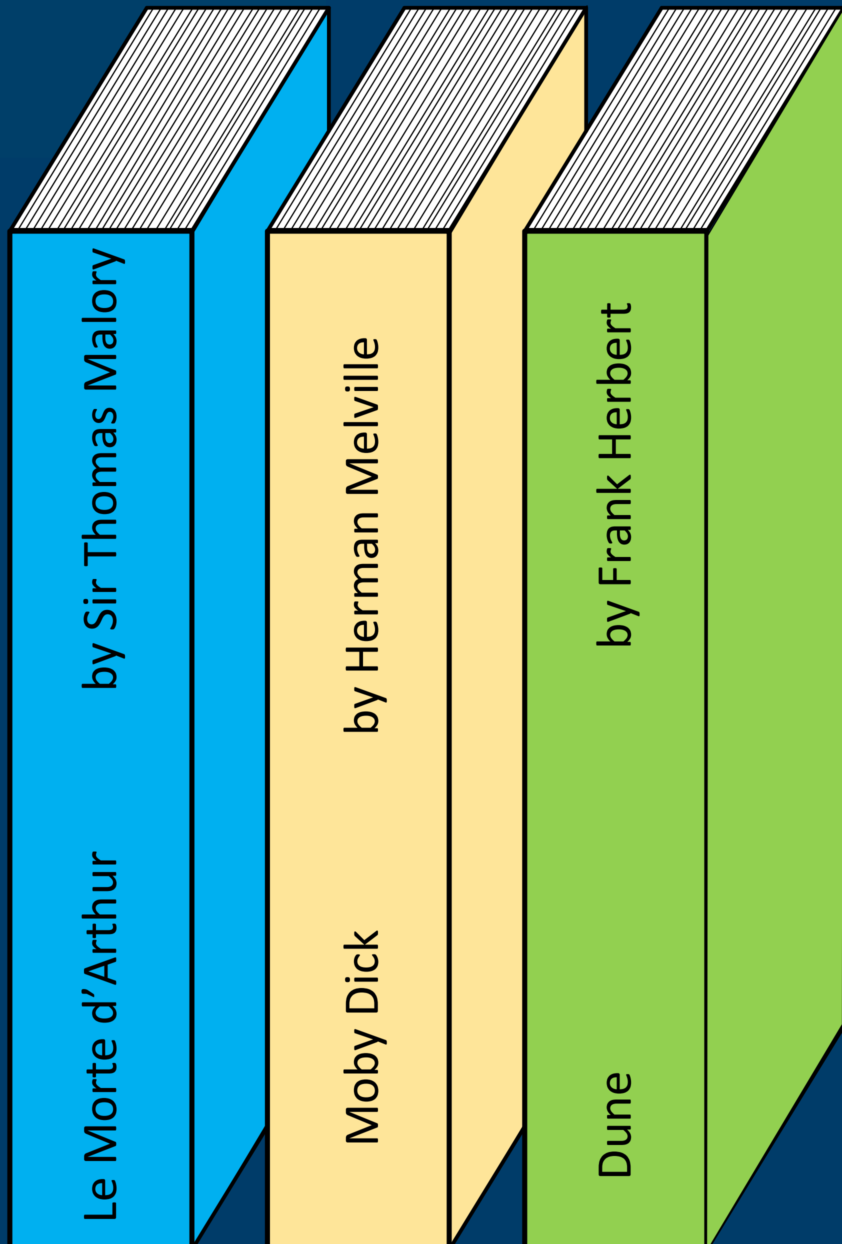
- The views expressed in this presentation are those of the author and do not necessarily reflect the views or policies of the U.S. Environmental Protection Agency.



Stories of Sustainability

- Horses
- Whale Oil
- "Spice," i.e., salt

The Story of Waste

"One man's waste is another man's treasure"

Circular Economy

Waste type	Avg. U.S. (%)	Tonnes per year for 100,000 people
Paper and paperboard	27.4	19,834
Glass	4.6	3,344
Metals	8.9	6,469
Plastics	12.7	9,177
Rubber and leather	3.0	2,176
Textiles	5.7	4,142
Wood	6.3	4,573
Food, other	14.5	10,530
Yard trimmings	13.5	9,816
Other materials	1.8	1,329
Misc. inorganic wastes	1.6	1,127
Total	100.0	72,517

EPA (2014) Municipal Solid Waste Generation, Recycling, and Disposal in the United States: Facts and Figures for 2012. EPA-530-F-14-001.

Margins

Refining margin (crack spread) is the difference between the value of the products a refinery produces and the value of the crude oil feedstock on a per barrel basis.

For corn to ethanol processes, the **grind margin** is ethanol and co-product net value minus feedstock and energy costs on a per gallon basis.

For MSW to X processes, what's the **X-MSW margin**, or sometimes an **X-RDF** (Refuse-Derived Fuel) **margin**?

Technologies for Portions of MSW

Facility / Technology Type	Metals	Glass	Paper and Paperboard	Plastics "1" and "2"	Plastics "3" - "7"	Organics: Food	Organics: Fats, Oils and Grease	Organics: Yard Waste	Other Trash
Specific Recycling Process[a]	●	●	●	●	◍				
Dirty MRF[b]	●	●	●	●	●	●	●	●	○
Clean MRF[b]	●	●	●	●					
WTE - Anaerobic Digestion[c]			○			●	●	●	
WTE - Gasification[d]			●	●	●			●	
WTE - Fermentation[e]								◍	
WTE - Incineration[f]	○	○	●	●	●	●	●	●	●

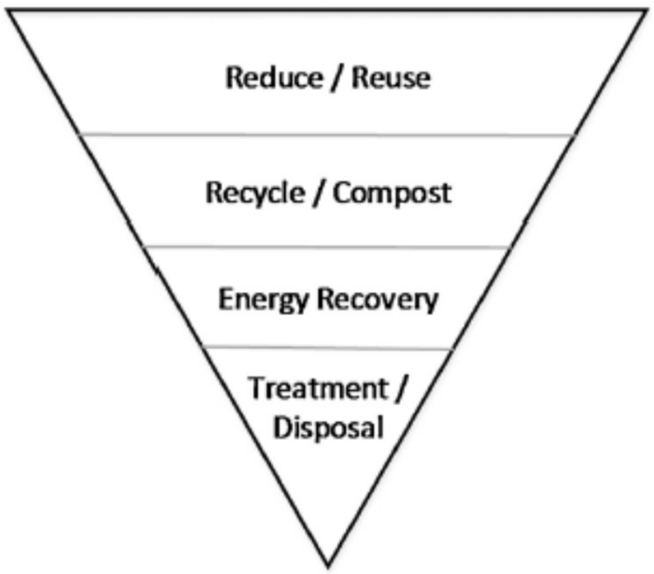
● = commercialized process

◍ = demonstrated process

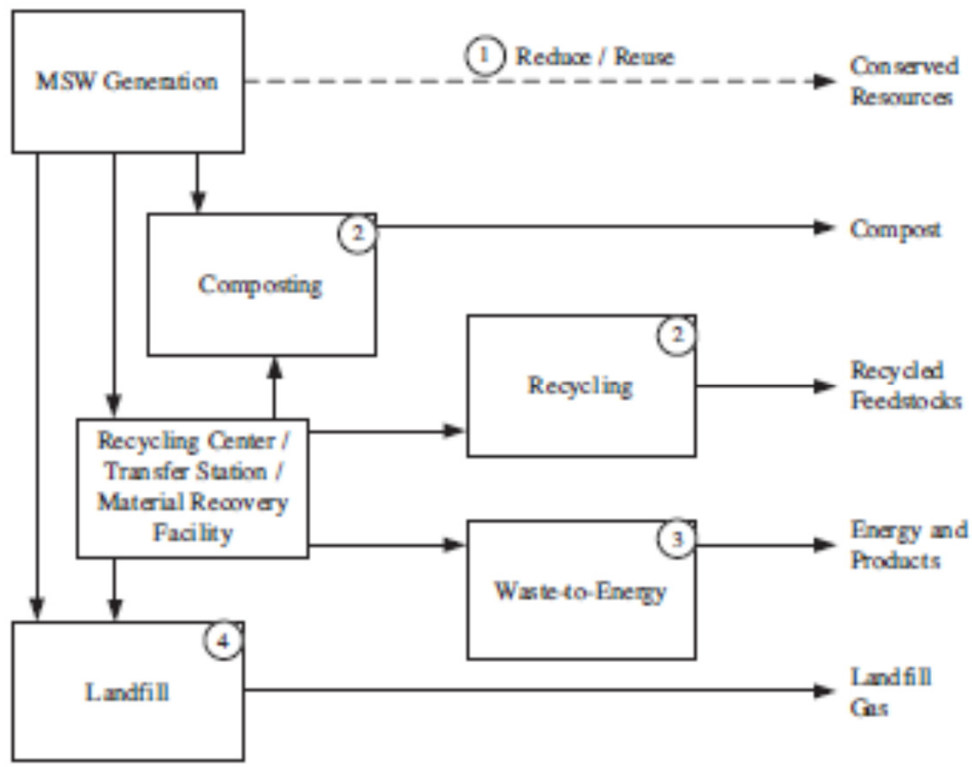
○ = technology that can handle feedstock without using it productively

Smith R.L. et al, An Industrial Ecology Approach to Municipal Solid Waste Management: I. Methodology, Resource Conservation Recycling 104, 311-316 (2015)

Waste Management Options



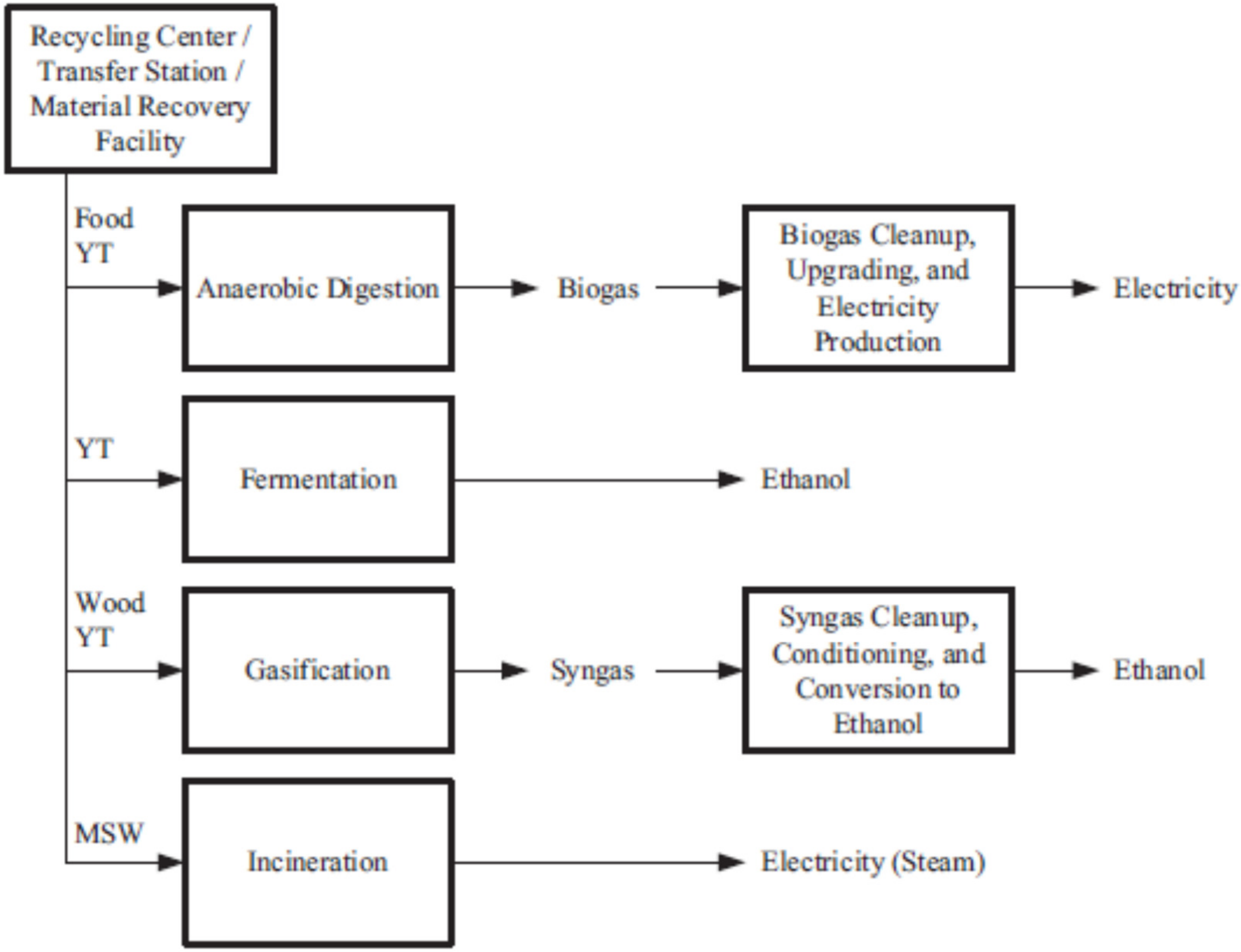
EPA's Waste Management Hierarchy



Smith R.L. et al, An Industrial Ecology Approach to Municipal Solid Waste Management: I. Methodology, Resource Conservation Recycling 104, 311-316 (2015)

MSW Process	Product(s)	Residuals	Use for Residuals
MSW generation	Compostable and recyclable materials	Non-compostable, non-recyclable materials	Heat value, recycling research opportunity
Composting	Compost	Contaminants (glass, plastics)	Glass and plastic recycling, heat value
Recycling center/ transfer station/ MRF	Separated recyclable materials	Non-compostable, non-recyclable materials	Heat value, recycling research opportunity
WTE—lignocellulosic fermentation	Ethanol	Lignin; CO2	Heat value, products; beverages, algal process
WTE—gasification (with conversion to ethanol)	Syngas, then ethanol	Ash/slag	Construction materials
WTE—anaerobic digestion	Biogas, then power	Digestate slurry	Composting, fertilizer
WTE—incineration	Power	Ash	Construction materials

Waste to Energy Products and Processes



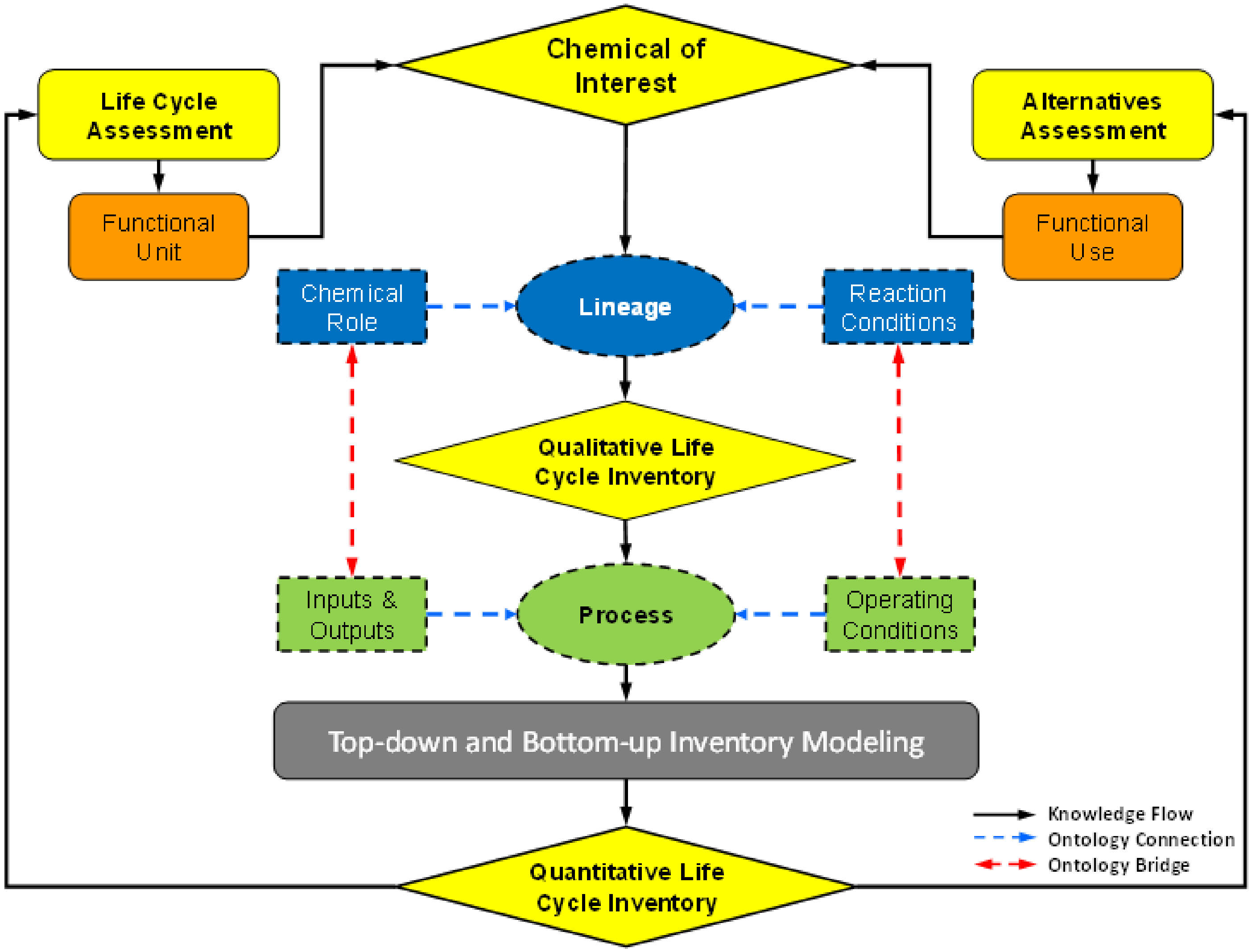
Smith R.L. et al, An Industrial Ecology Approach to Municipal Solid Waste Management: II. Case Studies... Resources Conserv. Recycl. 104, 317-326 (2015)

Sustainable Manufacturing Results

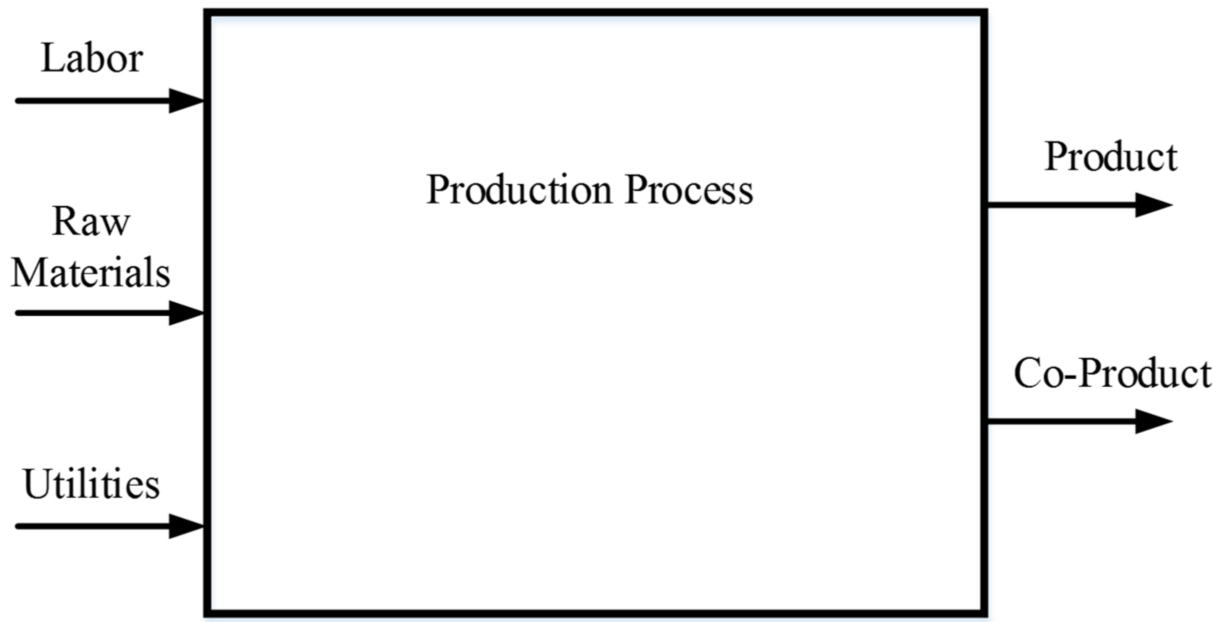
The results of analyses (see publications) show that gasification, anaerobic digestion, and fermentation have positive economics.

Anaerobic digestion improves seven emissions (out of seven explored), while fermentation, gasification, and incineration successively improved fewer emissions.

Identifying Chemicals, Reactions, and Processes in a Life Cycle



Process Model



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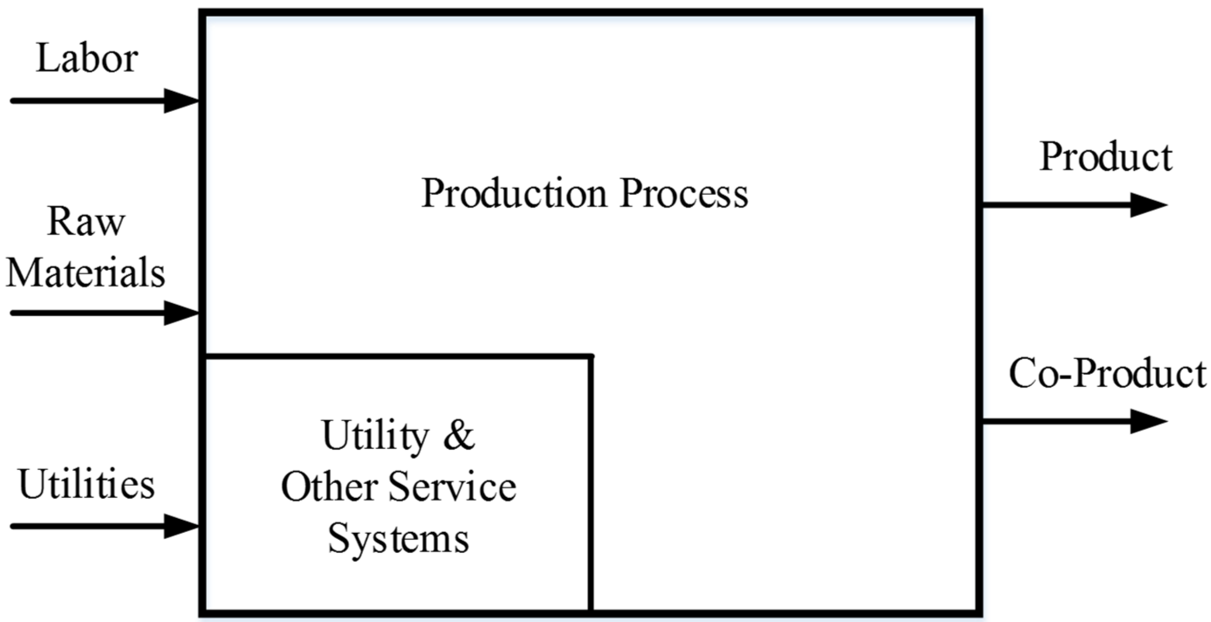

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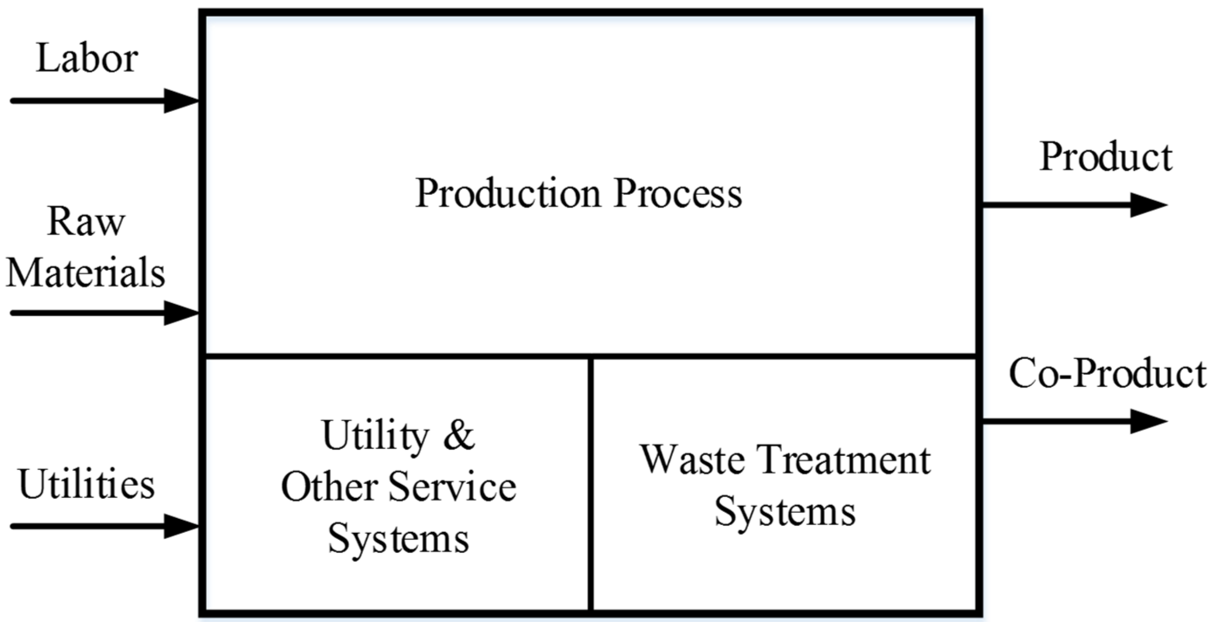

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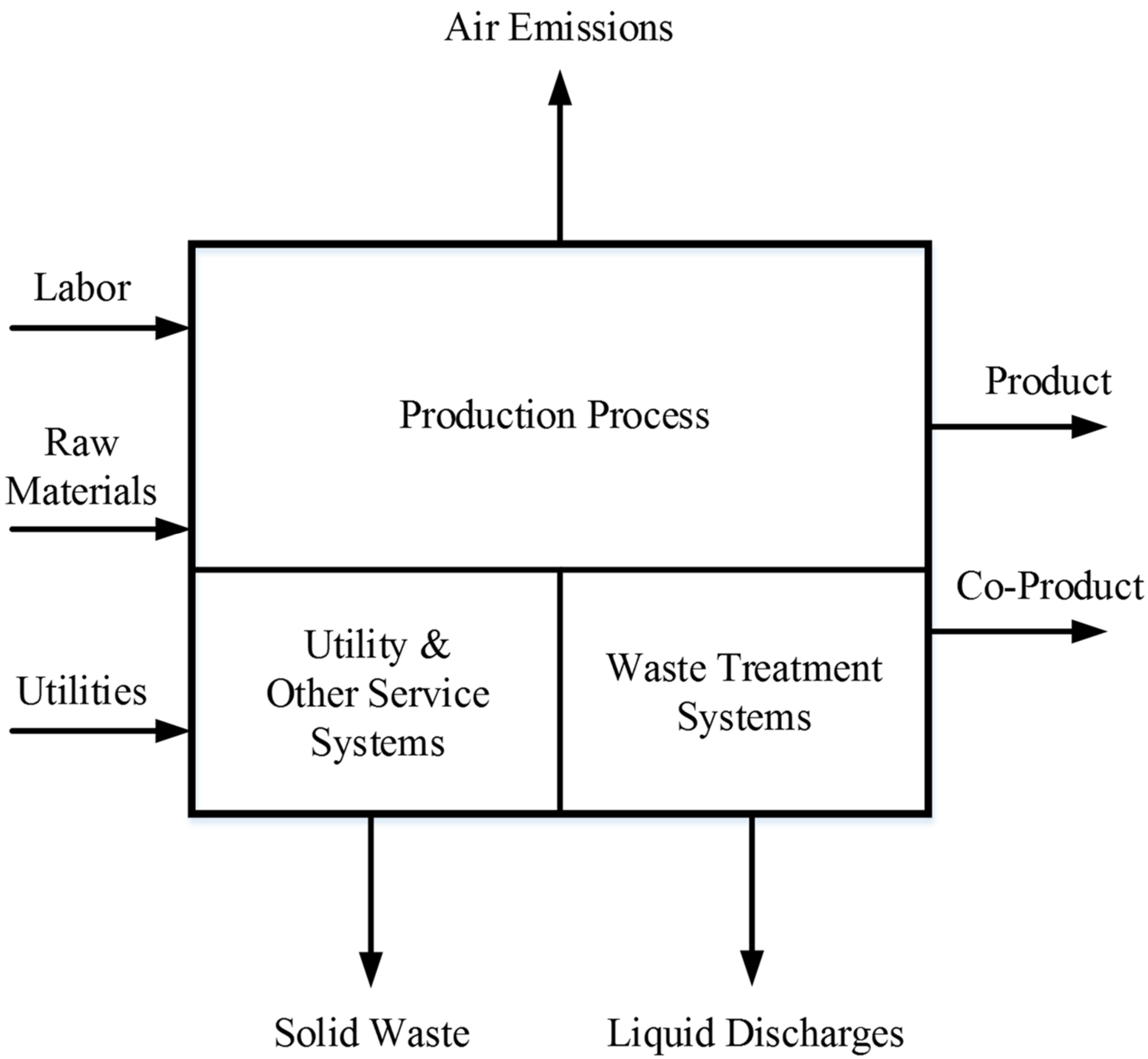
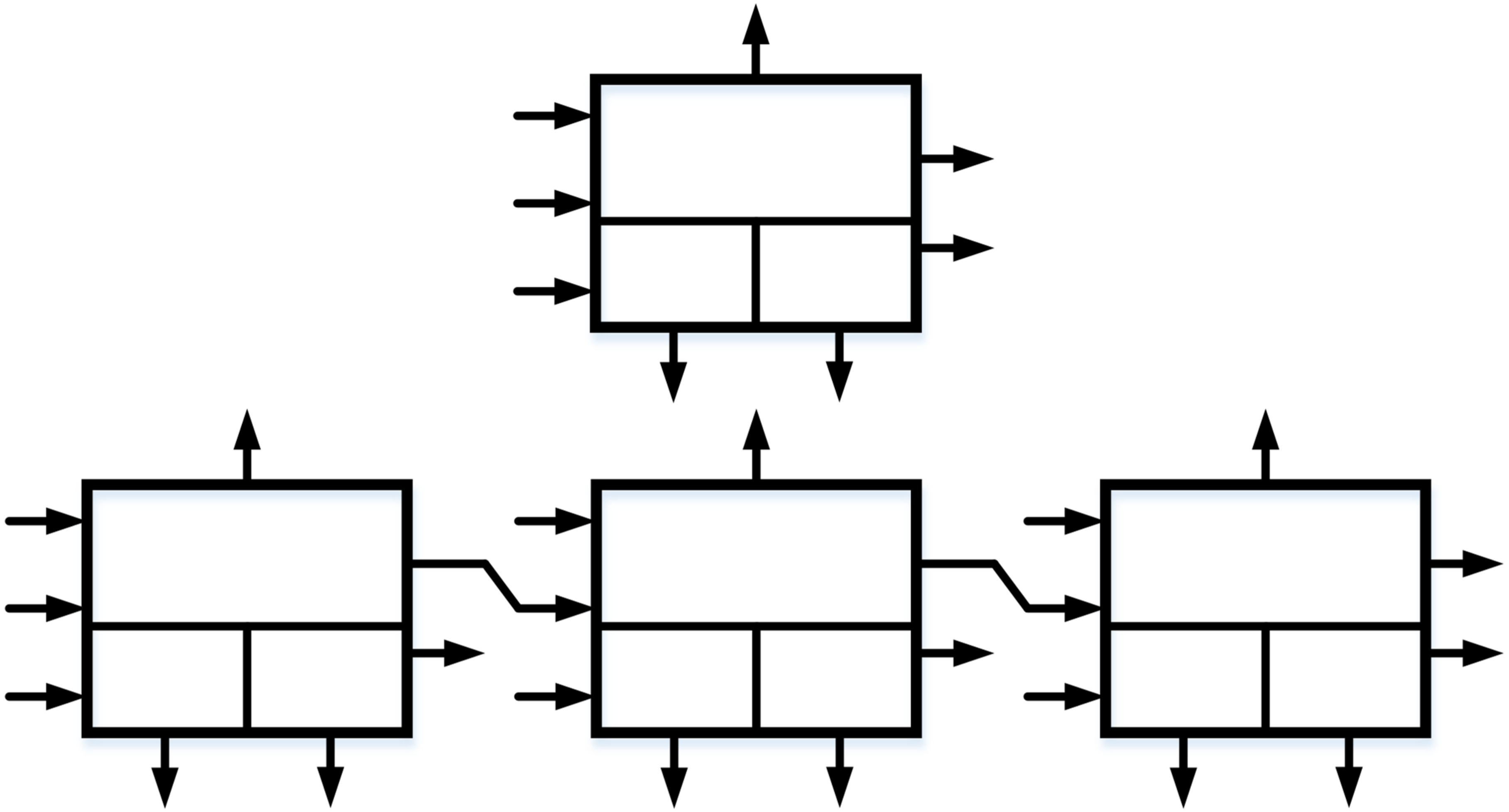
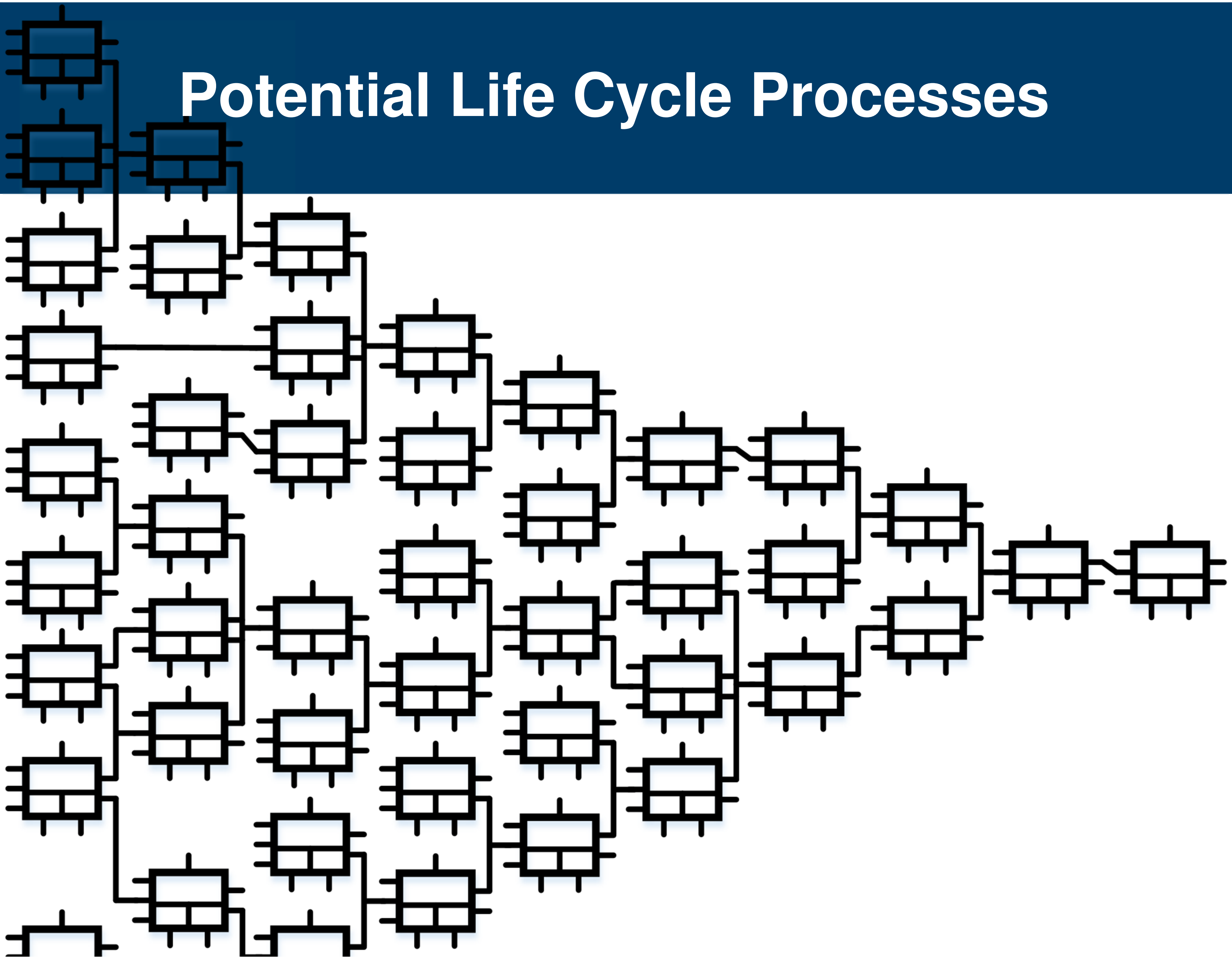


Process Model in the Value Chain

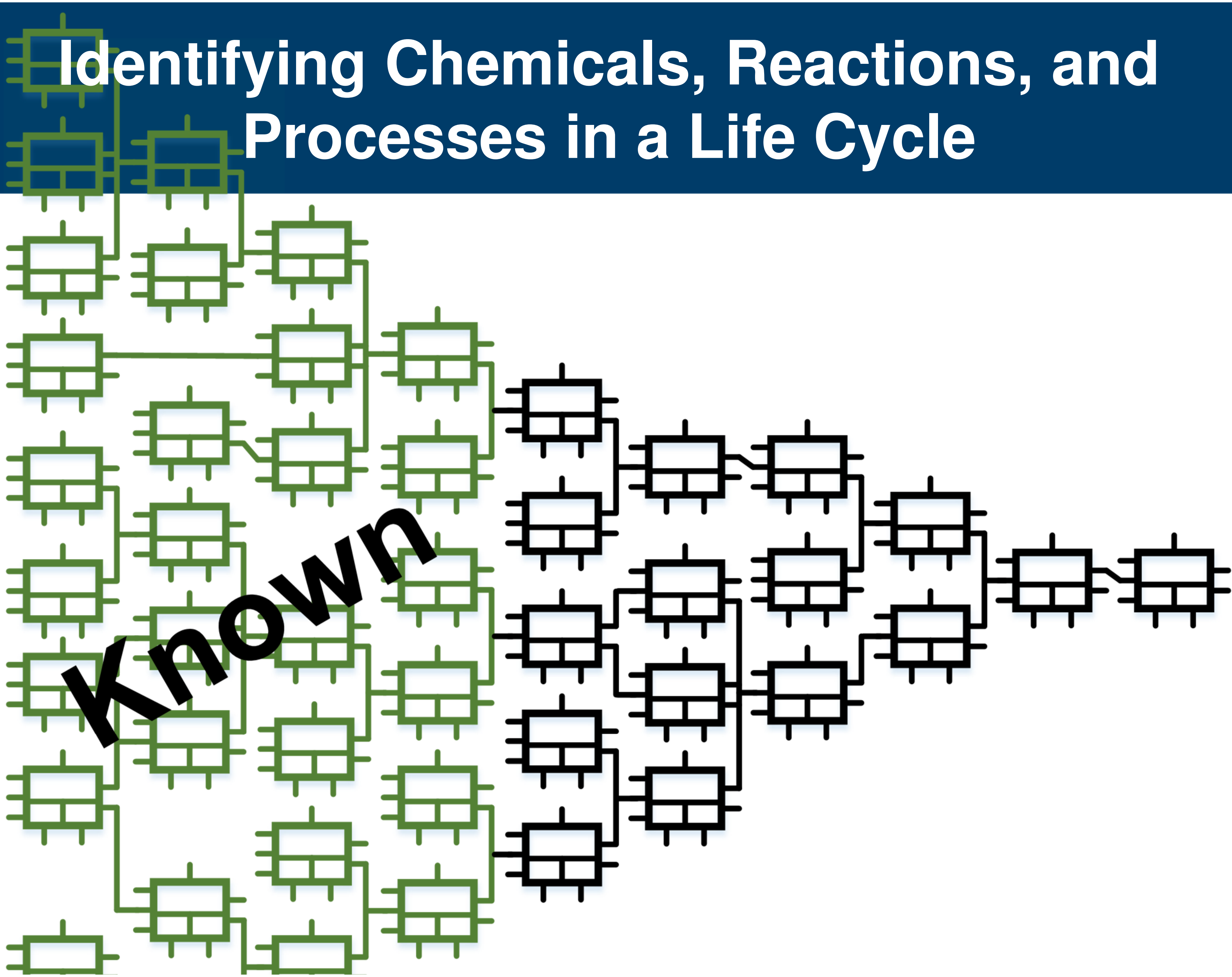


Potential Life Cycle Processes



Identifying Chemicals, Reactions, and Processes in a Life Cycle

Identifying Chemicals, Reactions, and Processes in a Life Cycle



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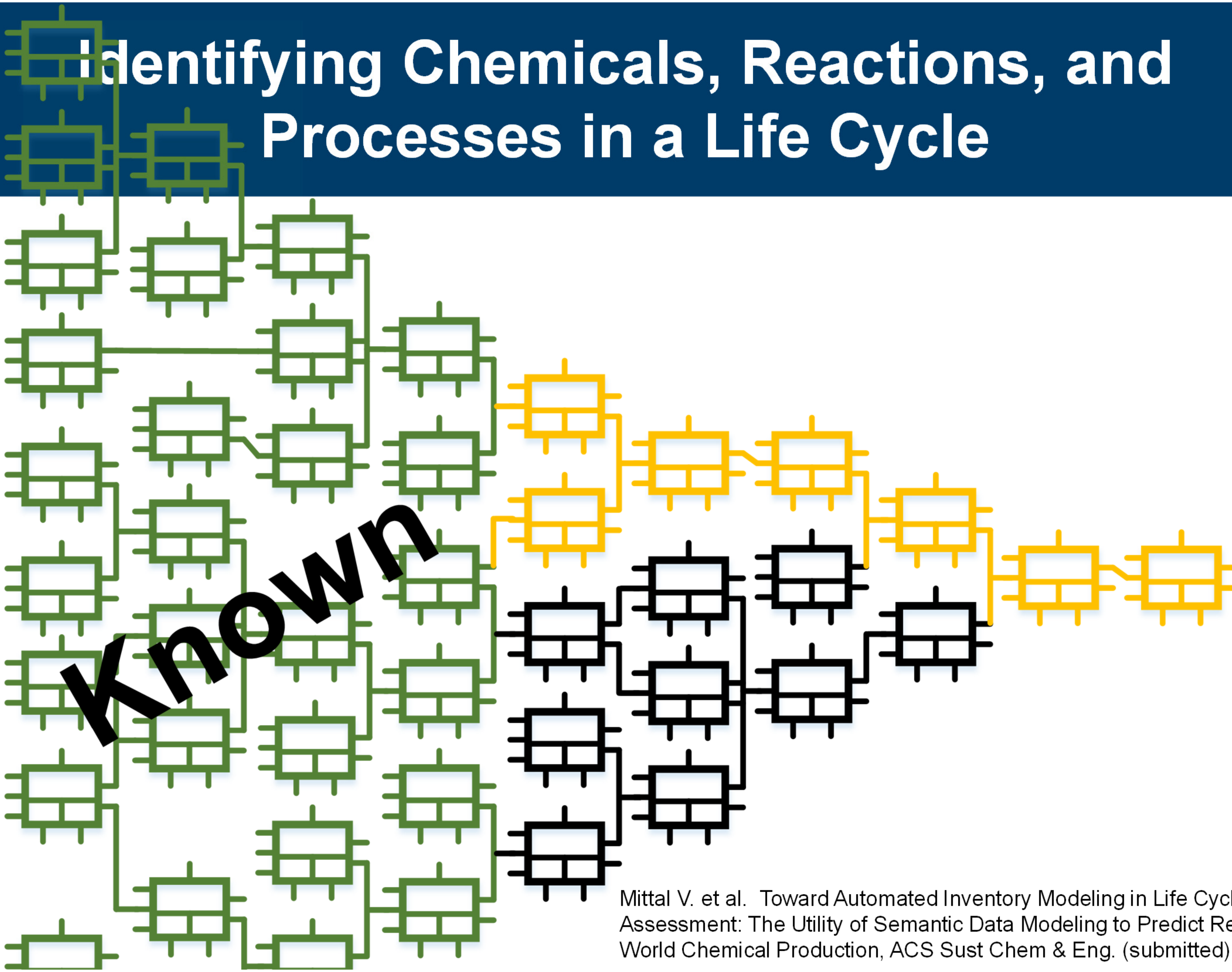
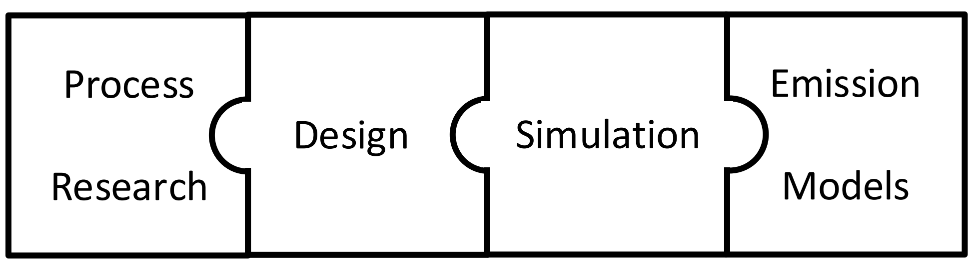


Mittal V. et al. Toward Automated Inventory Modeling in Life Cycle Assessment: The Utility of Semantic Data Modeling to Predict Real-World Chemical Production, ACS Sust Chem & Eng. (submitted)

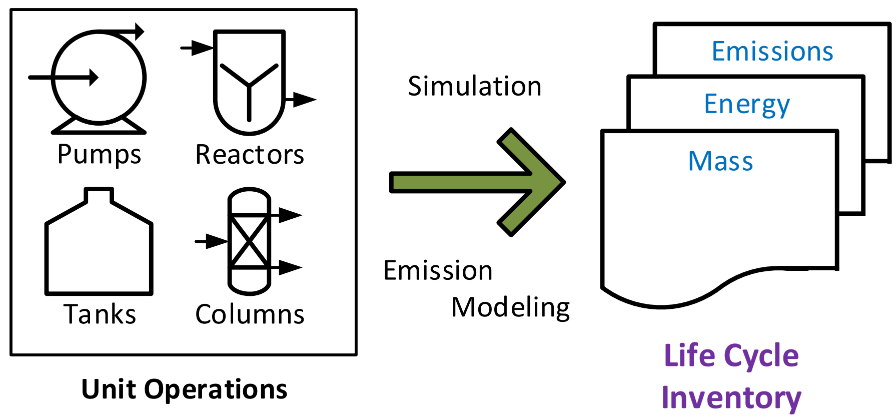
Rapid Estimation of Life Cycle Inventory

1. Existing inventory databases
2. Top-down inventory data mining
3. Bottom-up inventory development



Bottom-Up Simulation

Advantages: potential for improved LCI; process specific; inputs naturally in results; storage, vent, and fugitive emissions included



ACS Sustainable Chemistry & Engineering

Research Article

pubs.acs.org/journal/ascecg

Coupling Computer-Aided Process Simulation and Estimations of Emissions and Land Use for Rapid Life Cycle Inventory Modeling

Raymond L. Smith,* Gerardo J. Ruiz-Mercado, David E. Meyer, Michael A. Gonzalez, John P. Abraham, William M. Barrett, and Paul M. Randall

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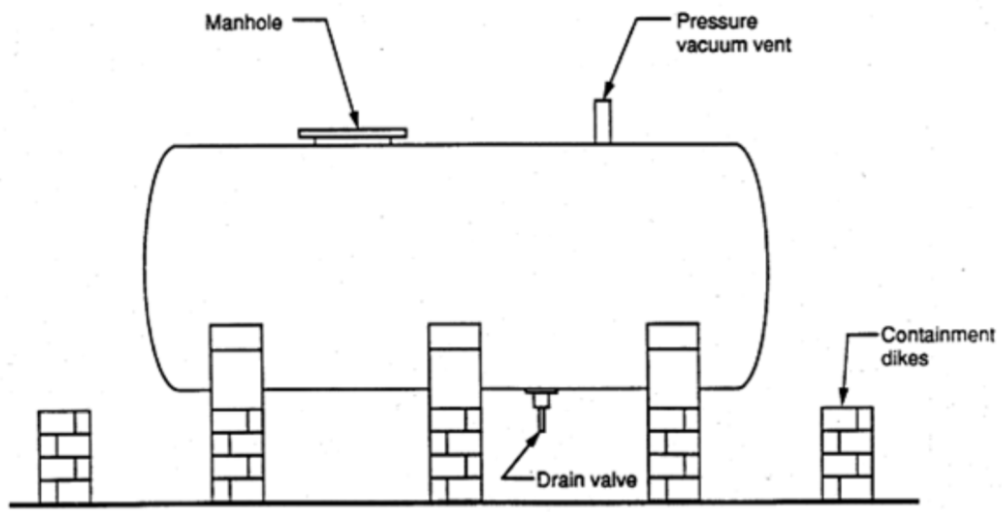
Challenges: knowledge of engineering design; need for chemical synthesis details; uncontrolled emissions

Bottom-Up Simulation



Working Losses

$$L_W = \frac{\dot{V}}{22.4}\left(\frac{273.15}{T}\right)\left(\frac{P_i^{sat}}{760}\right)(MW)K_N K_P$$

Breathing Losses

$$L_B = 16.3V_V\left(\frac{273.15}{T}\right)\left(\frac{P_i^{sat}}{760}\right)(MW)\left(\frac{T_R}{T}\right)$$

Process Vents

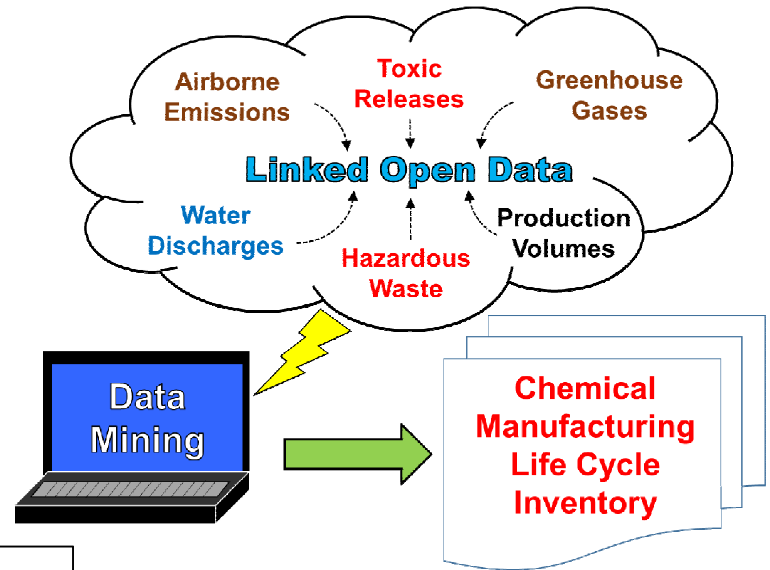
$$S_i = \frac{P_i^b}{x_i \gamma_i P_i^{sat}} = \frac{k_i A}{k_i A + F}$$

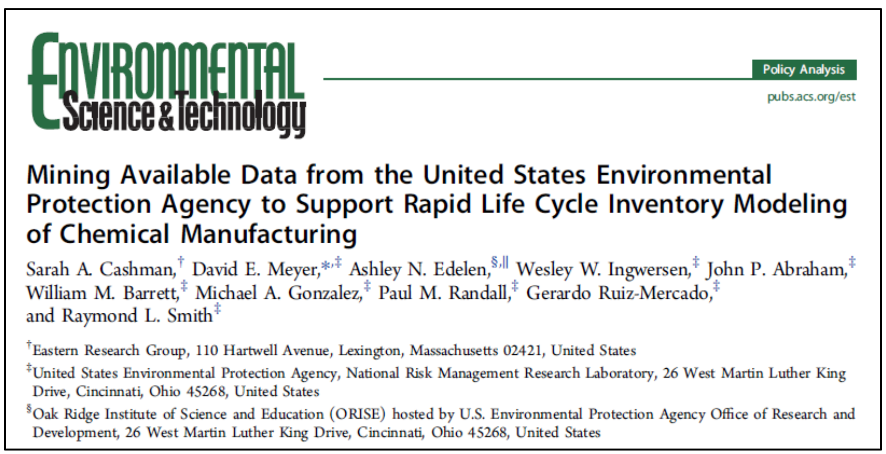
$$E_i = \frac{F x_i \gamma_i P_i^{sat}}{RT} S_i (MW_i)$$

Equipment Type	Service	Emission Factor (kg/h/source)
Pumps	Light liquid	0.0199
	Heavy liquid	0.00862
Compressors	Gas	0.228
Valves	Gas	0.00597
	Light liquid	0.00403
	Heavy liquid	0.00023
Connectors (e.g., flanges)	All	0.00183
Open-ended lines	All	0.0017
Sampling connections	All	0.0150
Pressure relief valves	Gas	0.104

Top-Down Data Mining

Advantages: primary data reported by industry and States; detailed release profiles; automation capabilities (linked open data)





ENVIRONMENTAL Science & Technology

Policy Analysis

pubs.acs.org/est

Mining Available Data from the United States Environmental Protection Agency to Support Rapid Life Cycle Inventory Modeling of Chemical Manufacturing

Sarah A. Cashman,[†] David E. Meyer,[*,‡] Ashley N. Edelen,[§,∥] Wesley W. Ingwersen,[‡] John P. Abraham,[‡] William M. Barrett,[‡] Michael A. Gonzalez,[‡] Paul M. Randall,[‡] Gerardo Ruiz-Mercado,[‡] and Raymond L. Smith[‡]

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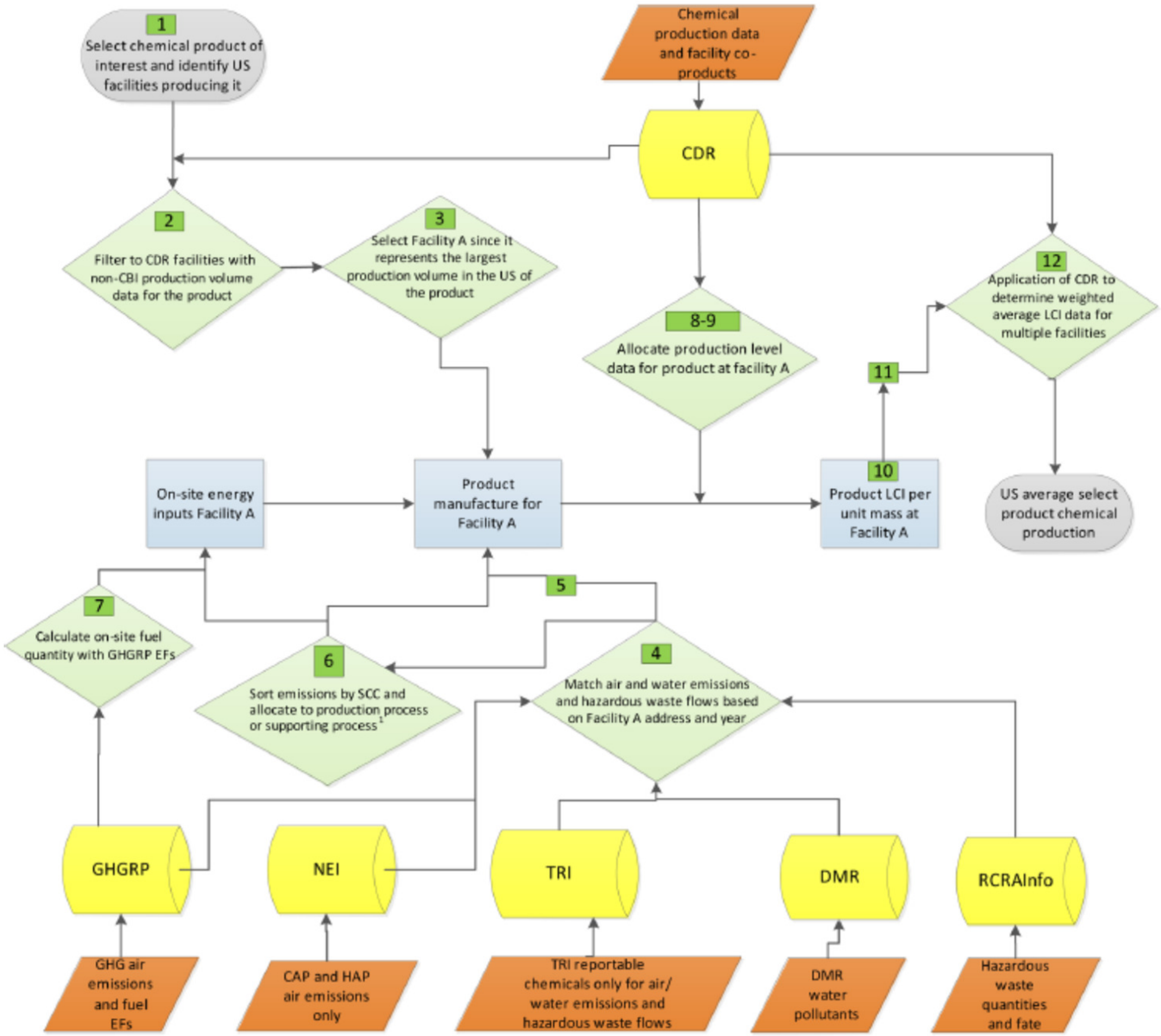
[‡]United States Environmental Protection Agency, National Risk Management Research Laboratory, 26 West Martin Luther King Drive, Cincinnati, Ohio 45268, United States
[§]Oak Ridge Institute of Science and Education (ORISE) hosted by U.S. Environmental Protection Agency Office of Research and Development, 26 West Martin Luther King Drive, Cincinnati, Ohio 45268, United States

Challenges: multi-chemical facility-level allocation; input data gaps; currently limited to TSCA CDR chemicals

Top-Down Data Mining



Life Cycle Inventory Methods

Analysis of a chemical of interest leads to identification of the chemical lineage, defining processes of interest.

Methods for bottom-up and top-down life cycle inventories have been developed with capabilities aimed at providing quick and accurate results.

United States Environmental Protection Agency

Return to the Story of Sustainability

United States Environmental Protection Agency

United States Environmental Protection Agency

References

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- Smith, R.L. et al. "An Industrial Ecology Approach to Municipal Solid Waste Management: II. Case Studies for Recovering Energy from the Organic Fraction of MSW," *Res. Conserv. Recycl.* 104, 311-316 (2015).
- Mittal, V. et al. "Toward Automated Inventory Modeling in Life Cycle Assessment: The Utility of Semantic Data Modeling to Predict Real-World Chemical Production," *ACS Sust Chem Eng* (accepted).
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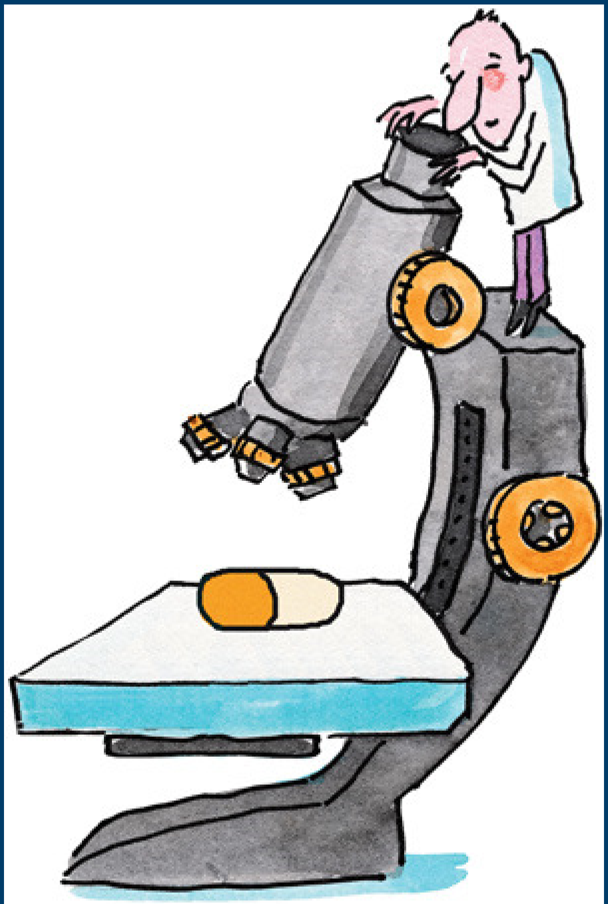
- Cashman, S. et al. "Mining Available Data from the United States Environmental Protection Agency to Support Rapid Life Cycle Inventory Modeling of Chemical Manufacturing," *Environmental Science & Technology*, 50(17), 9013-9025 (2016).

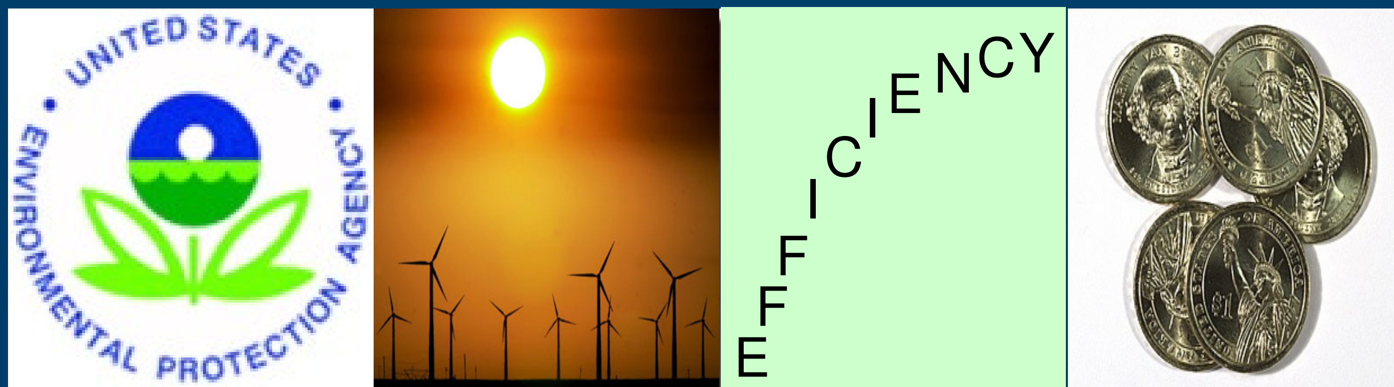
GREENSCOPE Tool



Gauging Reaction Effectiveness for ENvironmental Sustainability of Chemistries with a multi-Objective Process Evaluator

EPA
United States
Environmental Protection
Agency

GREENSCOPE Tool



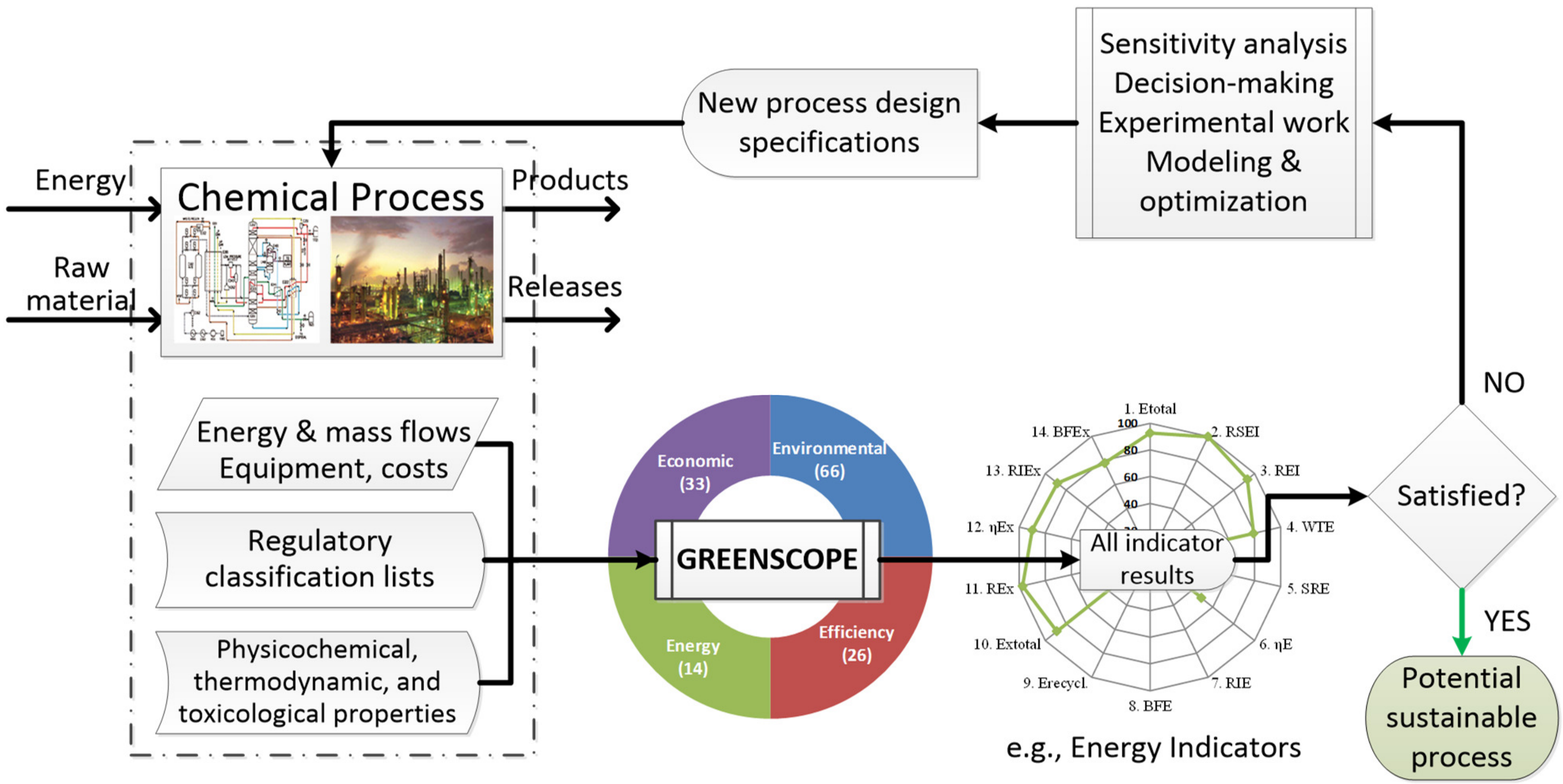
- Spreadsheet and online software tool, capable of calculating ~140 different indicators.
- User can choose which indicators to calculate.
- User can redefine indicator limits to fit circumstances.

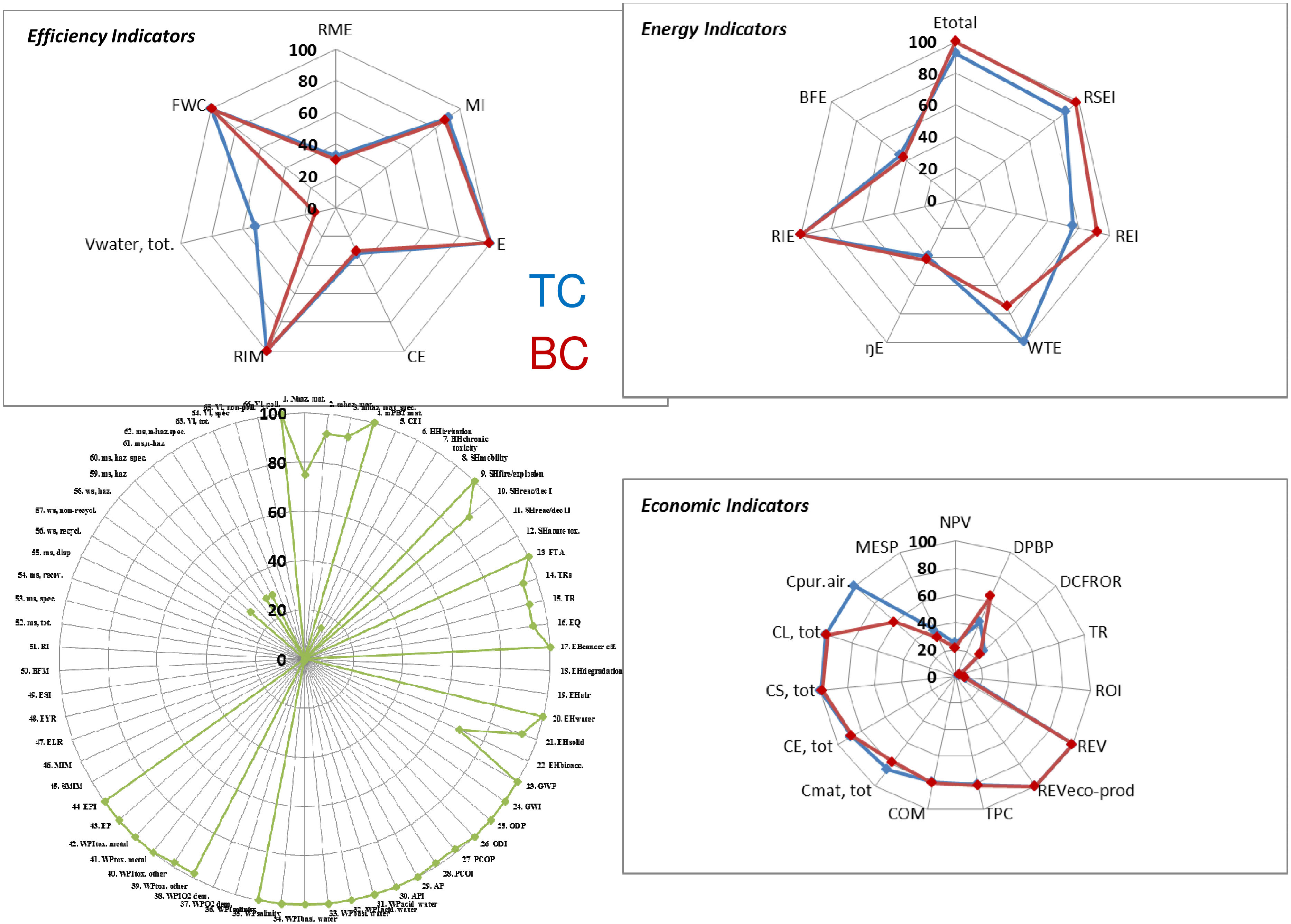
Sustainability Framework

- Identification and selection of two reference states for each sustainability indicator:
  - Best target: 100% of sustainability
  - Worst-case: 0% of sustainability
- Two scenarios for normalizing the indicators on a realistic measurement scale
- Dimensionless scale for evaluating a current process or tracking modifications/designs of a new (part of a) process

$$\text{Percent Score} = \%G_i = \frac{(\text{Actual-Worst})}{(\text{Best-Worst})} \times 100\%$$

Using GREENSCOPE





Efficiency Indicators
RME
MI
E
CE
RIM
Vwater, tot.
FWC
100
80
60
40
20
0
TC
BC
Energy Indicators
Etotal
RSEI
REI
WTE
ηE
RIE
BFE
Economic Indicators
NPV
DPBP
DCFROR
TR
ROI
REV
REVeco-prod
TPC
COM
Cmat, tot
CE, tot
CS, tot
CL, tot
Cpur.air
MESP