Resource Efficiency Benchmarks in the Chemical Industry

IAMC Toolkit

Innovative Approaches for the Sound Management of Chemicals and Chemical Waste

UNITED NATIONS
INDUSTRIAL DEVELOPMENT ORGANIZATION

Introduction

Raw materials and waste are often the highest costs of production in the chemical industry. Improving material efficiency and reducing waste can significantly improve economic performance at a company and improve its environmental performance.

This presentation provides:

- Formulas for calculating material, energy work and plant efficiency;
- Example resource and pollution intensity benchmarks for selected chemical subsectors;
- Example benchmarks for chemical consumption and waste for the production of specific chemicals (e.g. polystyrene).

Contents

Introduction to Resource Efficiency in the Chemical Sector

Definition of Resource Efficiency

$$\text{Resource efficiency* = Productivity} = \frac{\text{Product output}}{\text{Resource input}}$$

**at full load*

Resource efficiency

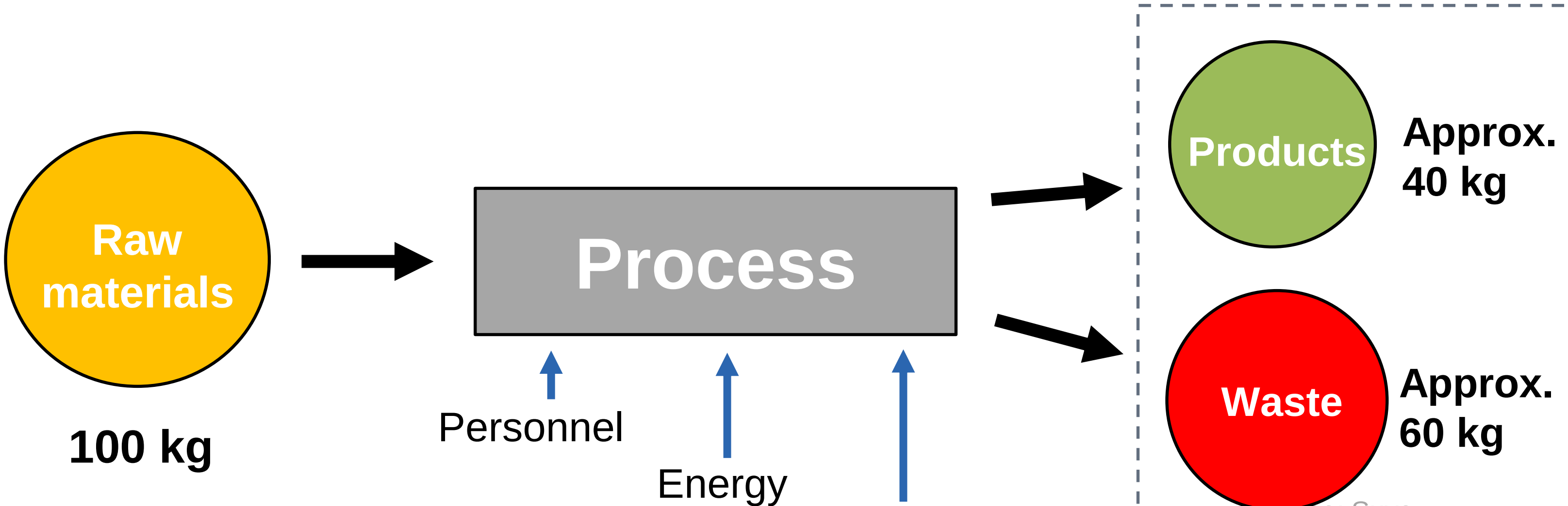
- Material efficiency (e.g. kg/kg): *higher potential in core techniques*
- Energy efficiency (e.g. kg/kWh): *higher potential in peripheral techniques*
- Work efficiency (e.g. kg/personnel hour)
- Plant efficiency (e.g. kg/plant hour)

Source: Suva

The amount of resources used is the basis of resource efficiency.

Resource Efficiency Potential of the Chemical Industry

Example: The stoichiometric efficiency for this process is 90%.
However, the material efficiency is only 40%.



Significant amounts of feedstock and residual waste result in:

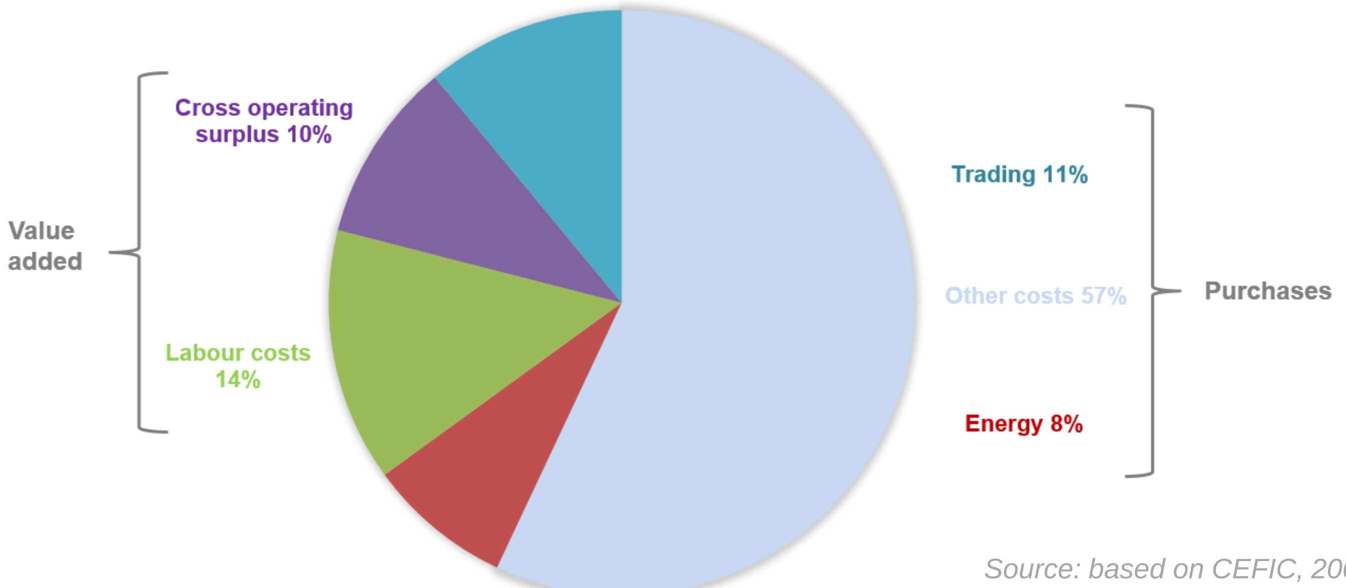
- Low productivity
- High costs
- Disposal/environmental issues
- Influence of state and society

Source: based on Steinbach

Resource Efficiency Potential of the Chemical Industry

Common characteristics and challenges in the chemical industry:

- High amount of input resources and high related costs
- High amount of by-products and waste



Source: based on CEFIC, 2009

Example: Wasted Potential in the Pigment and Dyestuff Industry

The potential for reducing resource consumption and costs in the chemical industry is high.

Example: Wasted potential in the pigment and dyestuff industry:

1 ton of product…

Requires 700 kg of solvent

Produces 100 kg of organic residual waste to be incinerated

Generates 72,500 kg of process wastewater

⇨ Potential to improve material efficiency, reduce the amount of waste, improve profitability and sustainability performance

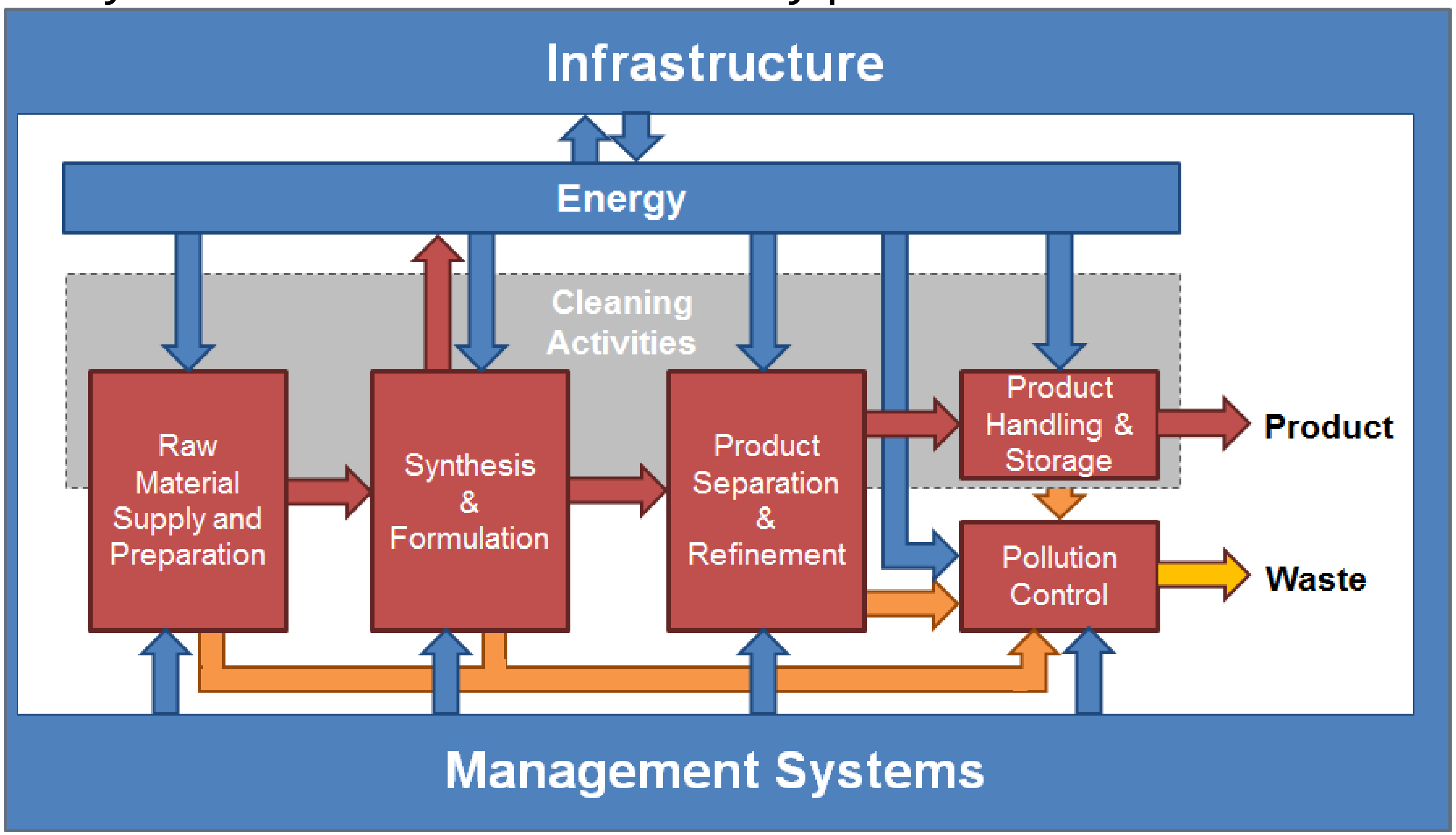
Example Benchmarks

- Chemical sector overview
- Specific chemical processes

Resource Efficiency Potential at a Chemical Plant

The entire chemical plant production system should be considered to identify areas with resource efficiency potential.

Source: ISSPPRO



Example Benchmarks for Chemical Synthesis

High amounts of waste in the chemical industry even when applying best practice

Example: stoichiometric and material efficiency in selected German chemical subsectors (synthesis):

Selected subsectors	Stoichiometric conversion (%)	Material efficiency (%)
Pharmaceuticals	86	20
Pigments and dyestuffs	88	26
Plant protection	89	36
Other specialty chemicals	90	62
Commodity chemicals	90	76
Average	88	38

Source: based on Steinbach

Material Efficiency in the Chemical Sector

Average solvent and water consumption and halogen input as waste

Selected subsectors	Solvent consumption [kg/t of product]	Water consumption [kg/t of product]	Halogen [Input, kg/t of product; per cent input as waste]
Pharmaceuticals	3,200	5,400	363 kg; 78%
Pigments and dyestuffs	700	71,200	368 kg; 88%
Agrochemicals	250	6,400	364 kg; 74%
Specialty chemicals	100	1,500	59 kg; 75%
Basic chemicals	0	1,900	--

Source: based on Steinbach

⇨ Material efficiency can still be improved.

Example: Effluent Load Typical of LVOC* Processes

					Emission prior to biological treatment												
	Wastewater volume				COD				AOX								
Product	m³ / t				Kg / t				g / t					mg / t			
	<0.1	0.1-1	1-10	>10	<0.1	0.1-1	1-10	>10	<0.1	0.1-1	1-10	10-100	>100	<0.3	<1	1-10	>10
L. Olefins																	
C1=;C2=;C3=		X				X											
1.3-Butadiene		X			X												
Acetylene			X				X										
2. BTX																	
Benzene /Toluene	X				X												
Ethylbenzene/Cumene		X			X				X								
Styrene			X		X												
3. EDC/VC, organochlorides																	
EDC	X				X				X						X	X	
EDC		X				X				X						X	
Methyl chloride			X			X	X			X					X		
Epichlorohydrin				X			X						X			X	

1. * LVOC = Large volume organic chemicals

Source: based on EC LVOC D1, 2014

Waste in the Chemical Sector

Average amount of residual waste incinerated

Selected subsectors	Inorganic material [kg/t of product]	Organic material [kg/t of product]	Water [kg/t of product]
Pharmaceuticals	150	3,600	1,400
Pigments and dyestuffs	1	100	5
Plant protection	90	330	620
Specialty chemicals	1	40	5
Commodity chemicals	5	20	130

Source: based on Steinbach

Waste in the Chemical Sector

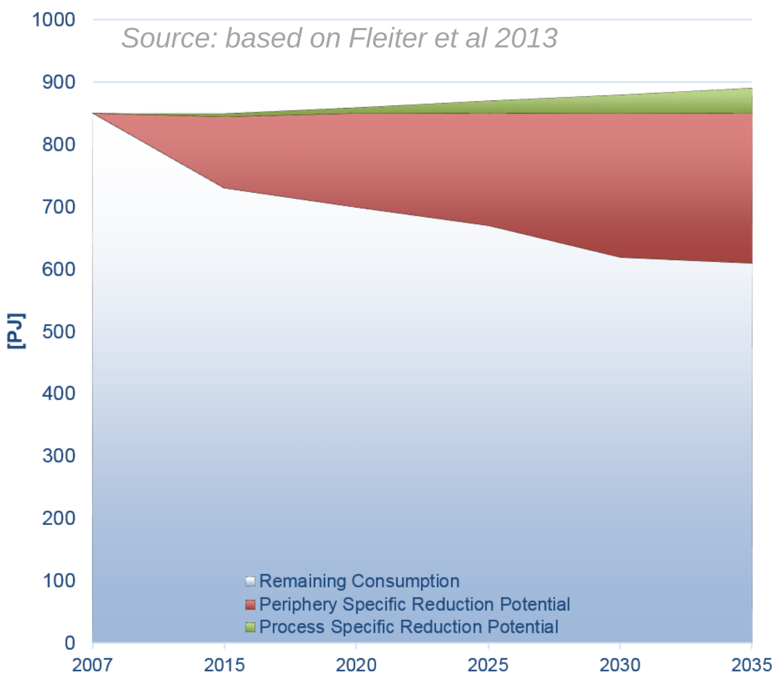
Average amount of process wastewater treated in wastewater treatment plants

Selected subsectors	Inorganic material [kg/t of product]	Organic material [kg/t of product]	Water [kg/t of product]
Pharmaceuticals	590	320	5,000
Pigments and dyestuffs	3,600	480	72,500
Plant protection	630	160	8,200
Specialty chemicals	120	40	1,400
Commodity chemicals	1	20	1,900

Source: based on Steinbach

Average amount of process wastewater treated in wastewater treatment plants

Example: consumption of electricity in process and peripheral technologies in Germany



- Process-specific reduction potential
- Periphery-specific reduction potential
- Remaining consumption

⇨ Energy efficiency potential exists mainly in **peripheral** technologies.

Energy Efficiency in the Chemical Sector

Energy efficiency potential in peripheral technologies

(analysis from selected German companies)

Area	Average (%)	Range (%)
Compressed air (n*=4)	22.5	5-50
Motors (n*=2)	19	2-50
Pumps (n*=3)	30	5-50
Heat and cooling utilities, heat integration (n*=3)	17.5	5-30

*n= number of companies analyzed

Source: based on BiPRO et al.

⇨ The potential for improvement is still high.

Example Benchmarks

- Chemical sector overview
- Specific chemical processes

BAT Specific to Polystyrene (PS) Production (GPPS Method)

Chemicals consumption and waste produced in PS production

GPPS	Unit per ton of product	BAT AEL
Air emissions		
Dust	g	20
VOC, total	g	85
Water emissions		
COD	g	30
Suspended solid	g	10
Hydrocarbons total	g	1.5
Wastewater	t	0.8
Cooling tower purge water	t	0.5
Waste		
Hazardous	kg	0.5
Non-hazardous	kg	2
Consumption		
Total energy	GJ	1.08
Styrene	t	0.985
Mineral oil	t	0.02
Cooling water (closed circuit)	t	50
Process water	t	0.596
Nitrogen	t	0.022
Diluent	t	0.001
Additives	t	0.005

Notes:

1) The emission values in the water are measured after treatment. Wastewater can either be treated at an in-plant facility or at a centralized location.
2) Cooling water, purge water not included
3) Hazardous waste (for treatment or incineration) in kilograms per ton of product (kg/t)
4) Inert waste (for landfilling) in kilograms per ton of product (kg/t)

Source: based on EC 2007, page 263

Energy and water consumption and emissions

UP	Unit	BAT AEL range	
Consumption			
Energy	GJ/t	2	3.5
Water	m^3/t	1	5
Emissions to air			
VOC to air	g/t	40	100
CO to air			50
CO_2 to air	kg/t	50	150
NO_X to air	g/t	60	150
SO_2 to air	g/t	~0	100
Particles to air	g/t	5	30
Waste			
Hazardous waste for external treatment	kg/t		7

Source: based on EC 2007, page 269

Styrene from Ethylbenzene (EB) Dehydrogenation

VOC emissions from shared end-of-pipe abatement:
Composition: VOCs, CH_4, SO_2, NO_X, CO_X, dust, NMVOCs
Monitoring: normally after abatement device, spot samples

VOC emissions in grammes per ton of styrene monomer (SM)	
SO_2	1.4–3
NO_X	130–160
CO	4–7
PM	5–9
NMVOC	2–3

Source: based on EC LVOC 2014, page 502

VOC emissions from fugitive emissions:
Composition: CO, CO_2, NMVOCs, methane, EB, styrene, aromatics
Monitoring: kg per ton of EB or kg per year, using the method described in the CWW BREF
Amount: 3–16 g per ton of styrene monomer

Styrene from Ethylbenzene Dehydrogenation

Emissions to water: ethylbenzene, styrene, benzene

Monitoring: TSS, pH, COD

Effluent concentration after pretreatment prior to wastewater treatment plant

	Analytical method MN 31147 (mg/l)	
Ethylbenzene	0.75	0.1
Styrene	1.25	0.0
Benzene	0.1	0.0
TSS	5	100
pH	n/a	7.6

Source: based on EC LVOC 2014, page 504

Styrene from Ethylbenzene Dehydrogenation

Energy consumption:

Values of energy-related utilities in kWh per ton of EB	
Electricity	70-170
Steam	1,350-2,300
Total	1,500-2,350
Energy recovery	0-800

Source: based on EC LVOC 2014, page 505

Raw material consumption:

- The main raw materials used are ethylbenzene and the catalyst.

EB consumption: 1,040-1,166 kg per ton of styrene monomer

Water consumption:

- Most of the water is used as boiler feed water to generate the steam needed in the reaction, up to 4 m^3 per ton of styrene monomer (Cefic).

Styrene from Ethylbenzene Dehydrogenation

Co-products and by-products:

Principal co-products and by-products in kg per ton of SM	
Hydrogen	up to 50
Benzene	up to 20
Toluene	16-94

Waste generation:

Waste streams in kg per ton of SM	
Spent catalyst waste	up to 0.4
Coke from the reaction	--
Tar	up to 22 (9-71)
Gums, oligomers of polystyrene	up to 5
Spent solvents	(1.5-6)

Source: based on EC LVOC, 2014, page 505

Introduction to EC BREF Documents

BREFs and Where to Find Them

What are BREFs?

- Best Available Techniques (BAT) reference documents

BREFs

- Increase process efficiency, rate of yield, etc.
- Reduce environmental pollution, chemical input, etc.

Where to find them?

http://eippcb.jrc.ec.europa.eu/reference/

Content of BREFs

- Each document provides information on a specific industrial/agricultural sector in the EU including
  - Techniques and processes used in the sector
  - Current emission and consumption levels
  - Techniques to consider in the determination of the best available techniques (BAT) and emerging techniques
- A list of references (background material) is quoted in the reference document.
- Links to websites containing relevant legislation/standards
- Additional technical information

Overview of Available BREFs

Title, acronym, year	Key chemicals addressed
Production of Chlor-alkali, CAK, 2014	Chlorine, brine
Production of Cement, Lime and Magnesium Oxide, CLM, 2013	Cement, lime, magnesium
Common Waste Water and Waste Gas Treatment, CWW, 2003 (Final draft 2014)	Wastewater and waste gas
Emissions from Storage, EFS, 2006	Liquids, liquefied gases and solids
Industrial Cooling Systems, ICS, 2001	
Large Volume Inorganic Chemicals – Ammonia, Acids and Fertilisers, LVIC-AAF, 2007	Ammonia, nitric acid, sulphuric acid, NPK (nitrogen, phosphorus, potassium) fertilizers, etc.
Large Volume Inorganic Chemicals – Solids and Others Industry, LVIC-S, 2007	Aluminium fluoride, calcium carbide, carbon dilsulphide, etc.
Large Volume Organic Chemical Industry, LVOC, 2003 (Draft 1, 2014)	Lower olefins, benzene, toluene, acrylonitrile, etc.
Manufacture of Organic Fine Chemicals, OFC, 2006	Dyes and pigments, organic explosives, pheromones

Overview of Available BREFs

Title, acronym, year	Key chemicals addressed
Production of Polymers, POL, 2007	Synthetic fibres and rubbers, etc.
Production of Pulp, Paper and Board, PP, 2001	Sulphate, sulphite
Refining of Mineral Oil and Gas, REF, 2015	Lower olefins
Production of Specialty Inorganic Chemicals, SIC, 2007	Silicones, specialty inorganic pigments, cyanides, etc.
Surface Treatment of Metals and Plastics, STM, 2006	
Surface Treatment Using Organic Solvents, STS, 2007	Metal coils, waterproofing, adhesive application, etc.
Tanning of Hides and Skins, TAN, 2013	
Textiles Industry, TXT, 2003	Fibre preparation, dyeing, etc.
Wood-based Panels Production, WBP, 2014 (only Final Draft available)	
Waste Incineration, WI, 2006	Incineration, pyrolysis, gasification
Waste Treatment, WT, 2006	Hazardous and non-hazardous

Key Messages

- Raw materials and waste are often the highest costs of production in the chemical industry.
- Improving material efficiency and reducing waste can significantly improve economic performance at a company and improve its environmental performance.
- Resource and pollution intensity indicators can be developed to drive continuous improvement and reduce costs at companies
- Industry and sector-specific indicators can be used as a benchmark
- Using the EC BREFS can
  - Increase process efficiency, rate of yield, etc.
  - Reduce environmental pollution, chemical input, etc.

Sources

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