Safety and health and their importance for sustainability

Dr Annik Nanchen

ETH/EPFL September & October 2024

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01	Introduction – Sustainable Development
02	Health - REACH
03	Safety – Process Safety
04	Case Study - Discussion

Sustainability – google «news 29.8.2023»

Bass Coast mum completes 100 Day Dress Challenge with focus on sustainability

ABC Gippsland / By William Howard

Posted Yesterday at 1:30am, updated Yesterday at 1:35am

Forbes

FORBES › INNOVATION › TRANSPORTATION

EDITORS' PICK

Current Climate: GOP Presidential Candidates' Missed Opportunity On Sustainability

Alex Knapp Forbes Staff

I'm a senior editor at Forbes covering healthcare & science.

Alan Ohnsman Forbes Staff

I cover advanced transportation and climate-oriented technology.

Aug 26, 2023, 08:00am EDT

*This week's **Current Climate**, which every Saturday brings you the latest news about the business of sustainability. Sign up to get it in your inbox every week.*

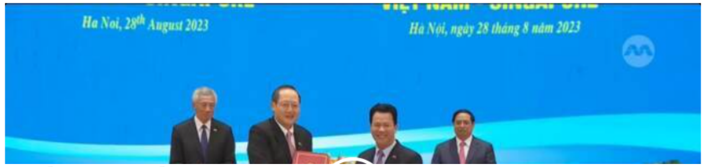
YETI CMO ON THE BRAND'S NEW VIRAL ADS—AND PRODUCT AS THE PROOF POINT OF SUSTAINABILITY

The company's clever outdoor boards have been getting lots of attention, but they're only part of the story

By Tim Nudd, Published on August 28, 2023.

Singapore

Singapore and Vietnam expand scope of economic cooperation, sign deals on sustainability, innovation



Ng Hong Siang

28 Aug 2023 06:01PM
(Updated: 28 Aug 2023 10:29PM)

News | 26 Aug, 2023

IUCN welcomes new Biodiversity fund and strengthens partnerships for conservation and sustainable development at Seventh GEF Assembly

These projects are implemented with Members throughout the regions, countries, and offices where IUCN works and cover themes including: biodiversity conservation, sustainable forest and land management, restoration, International Waters, climate adaptation, IPLC-led conservation, and more.

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The proposal is designed to help speed the country's transition to electric vehicles, one of the president's signature efforts to fight climate change. By Coral ...

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Dubai's real estate market needs sustainable pricing for middle-income families

Dugasta Properties is launching a scheme that offers 8% guaranteed returns

Introduction – 17 UN Sustainable Devlopment Goals

Which of those goals are linked to chemistry or chemical engineering?

Introduction – Sustainable process engineering

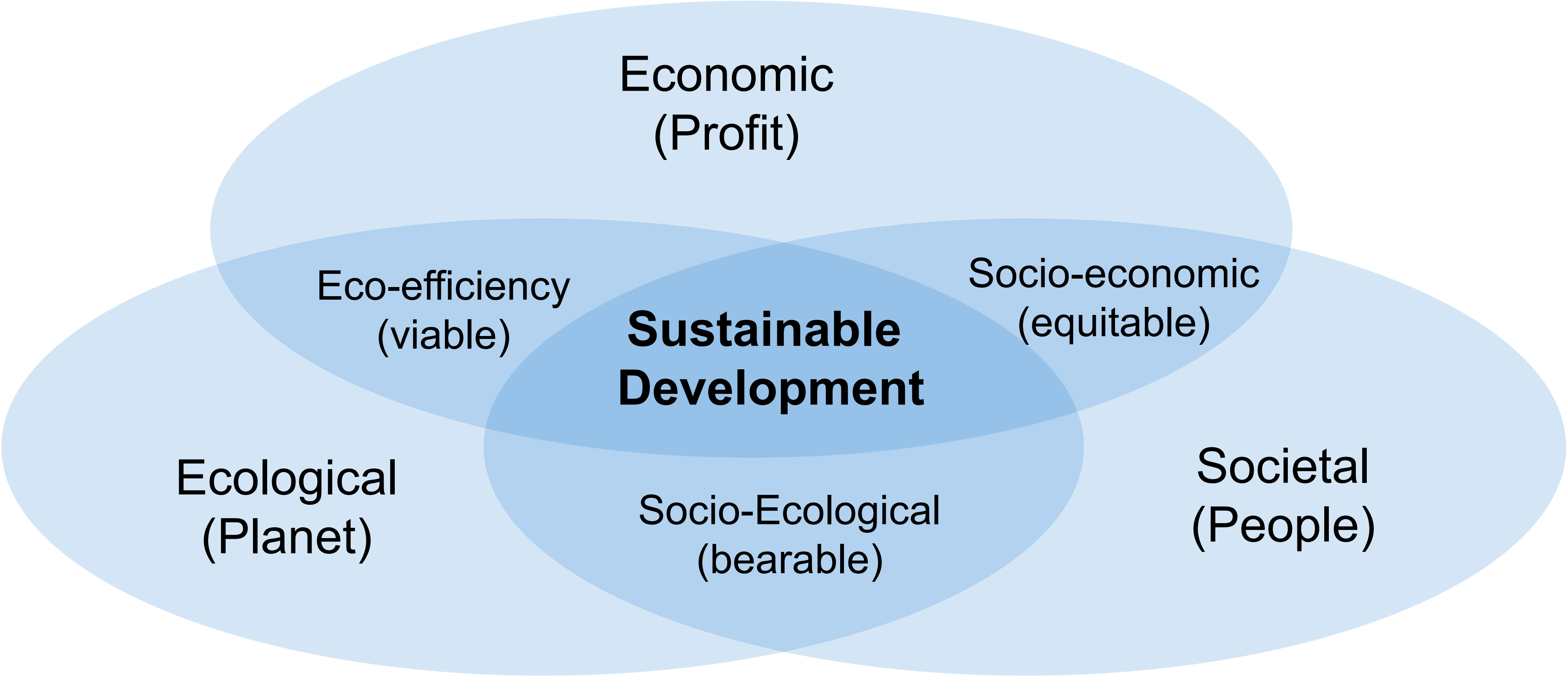
- Sustainable development
  - Meets the needs of the present without compromising the ability of future generations to meet their own needs (definition of the Brundtland Report (1987))[1]

  - Sustainable development depends on the extend of utilized resources and generated waste
    - Natural resources need to be utilized sustainably to prevent depletion of supplies in the long run
    - Any waste should be generated at lower rates than the natural environment can readily assimilate them

- 25 w% of natural resources extracted from earth comes out as goods and services (Charpentier, 2016, Procedia Engineering 138)

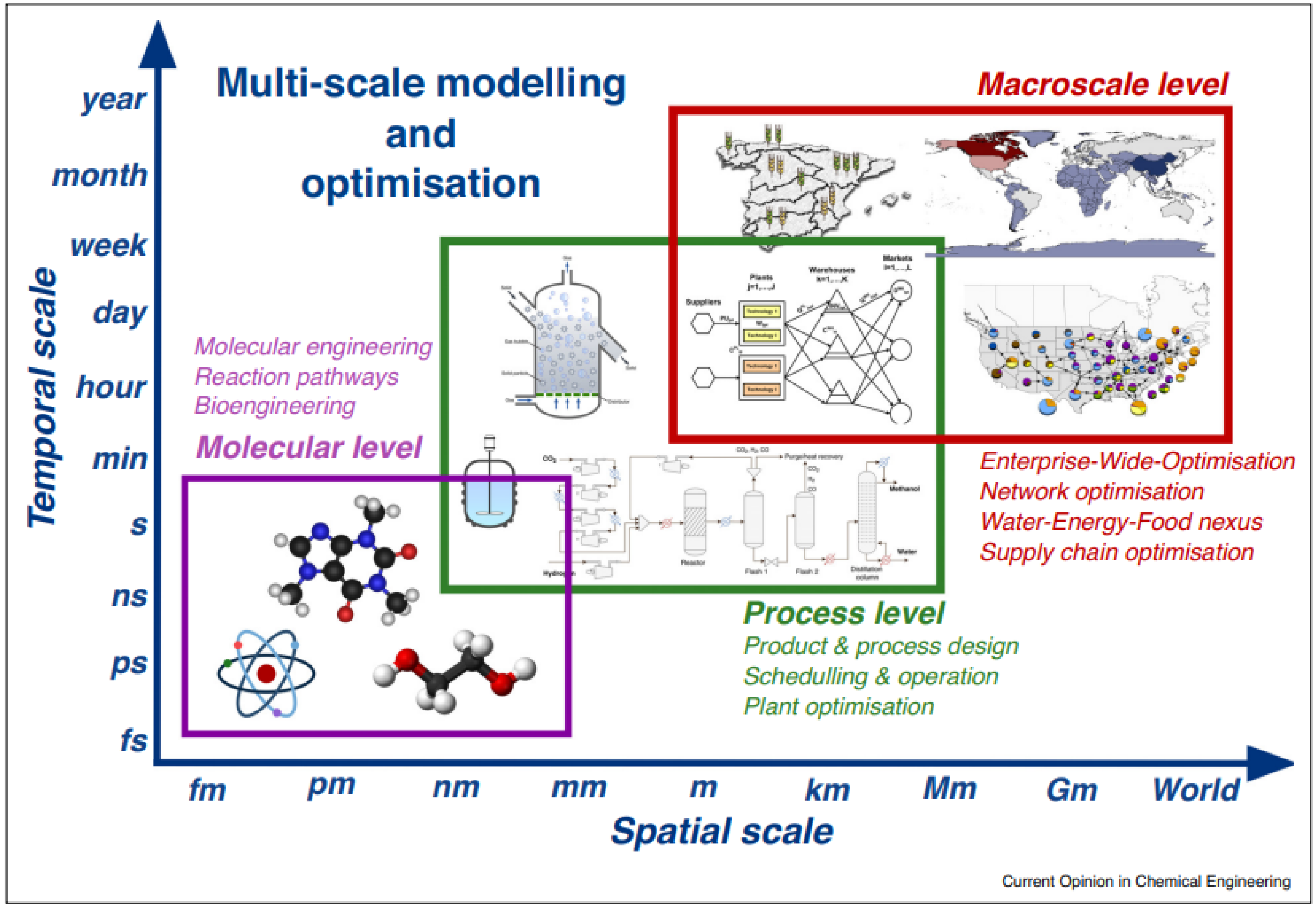
[1] Brundtland report: developed guiding principles for sustainable development

Introduction – 3P pillars



Reference: Sheldon, R.A (2018), Szekely, G (2021)

Introduction – Sustainable development



Green chemistry
Green engineering
Sustainability

Transferring processes from one scale to the other: temporal and spatial challenges/interdependance

Reference: Guillén-Gosálbez et al (2018)

Introduction – Green chemistry and sustainable chemistry

- **Green chemistry** is the design of chemical products and processes that reduce or eliminate the use or generation of hazardous substances. Green chemistry applies across the life cycle of a chemical product, including its design, manufacture, use and ultimate disposal. Definition from EPA (environmental protection agency)

- **Sustainable chemistry** is a subset of green chemistry
  - Incorporates the design, manufacture, and use of efficient, effective, safe, and more environmentally benign chemical products and processes.
  - Incorporate the concept of sustainability into production and use of chemicals and chemical products
  - Enable industrial processes to produce better products, mitigate pollution and increase profit margins.

- **Green engineering** is the design, commercialization and use of processes and products in a way that reduces pollution, promotes sustainability and minimizes risk to human health and the environment without sacrificing economy viability and efficiency. Definition from EPA (environmental protection agency)

Improve sustainability of a chemical process

The 12 principles of green chemistry	The 12 principles of green engineering
Prevention	Inherent rather than circumstantial
Atom economy	Prevention instead of treatment
Less hazardous chemical syntheses	Design for separation
Designing safer chemical	Maximize efficiency
Safer solvents and auxiliaries	Output-pulled versus input-pushed
Design for energy efficiency	Converse complexity
Use of renewable feedstocks	Durability rather than immortality
Reduce derivatives	Meet need, minimize excess
Catalysis	Minimize material diversity
Design for degradation	Integrate material and energy flows
Real-time analysis of pollution prevention	Design for commercial «afterlife»
Inherently safer chemistry for accident prevention	Renewable rather than depleting

Introduction – Health and Safety: link to sustainability

- Health:

- Safety

Program

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European regulations and efforts

- REACH (**R**egistration, **E**valuation, **A**uthorisation and Restriction of **Ch**emicals)

- EU Green Deal – becoming climate neutral by 2050
  - Chemical Strategy for Sustainability (CSS) towards a toxic-free environment

- Seveso Directive (major accident prevention)

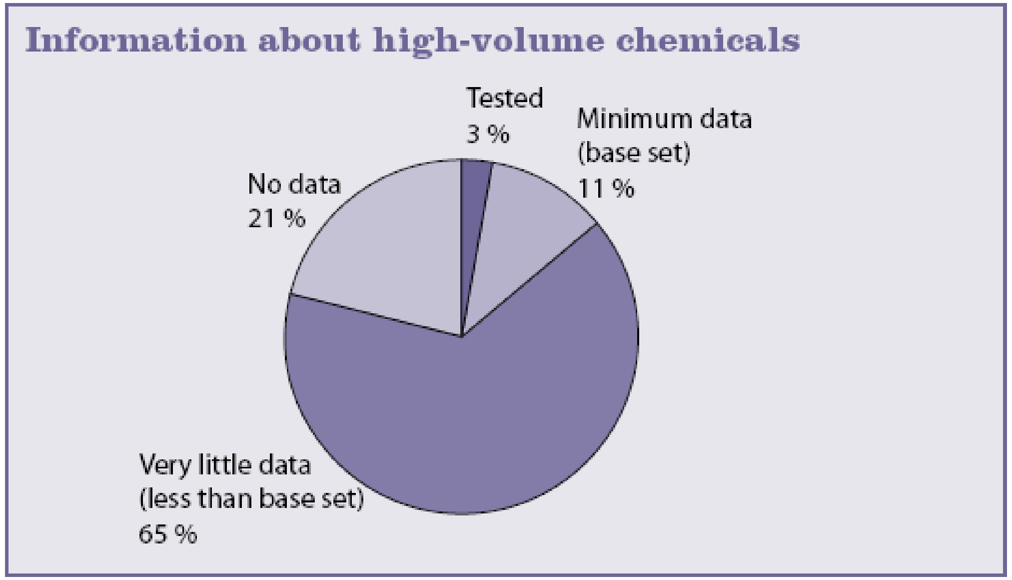
REACH objectives

- Ensure a high level of protection of human health and the environment against harmful substances
- Assess the safety of chemical substances in use in the EU
- Promote innovation and competitiveness
- Promote alternative (non-animal) methods for the assessment of the hazards of substances

- REACH Regulation (EC 1907/2006) entered into force in 2007
- Currently under revision

Why REACH?

- Insufficient information on chemicals

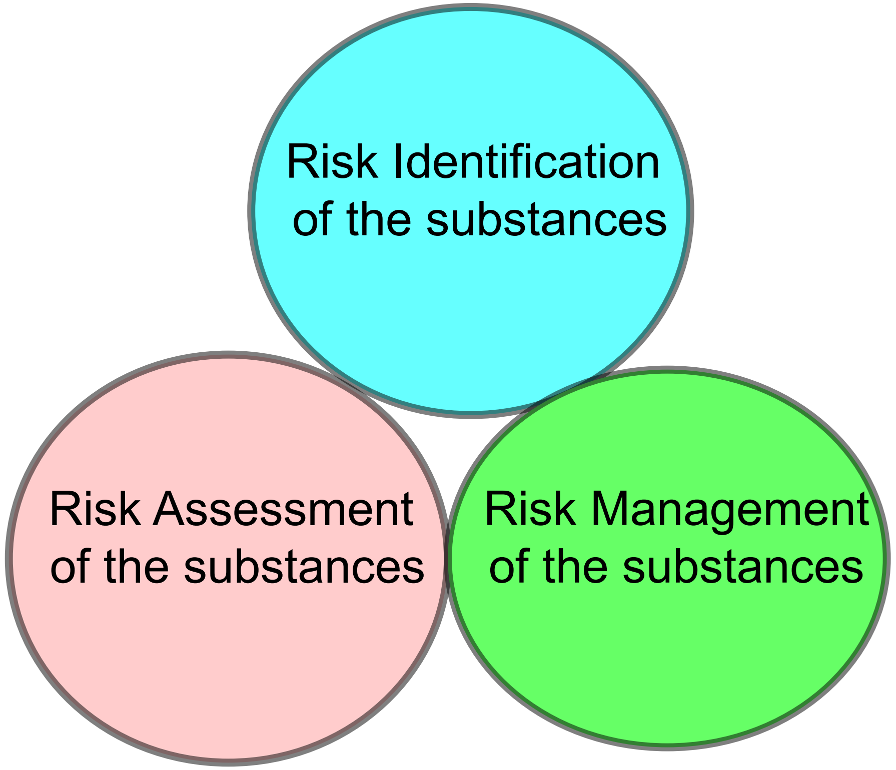


Global production of chemicals evolution:

Year	1930	2005
Tonnes/y	1 million	400 million

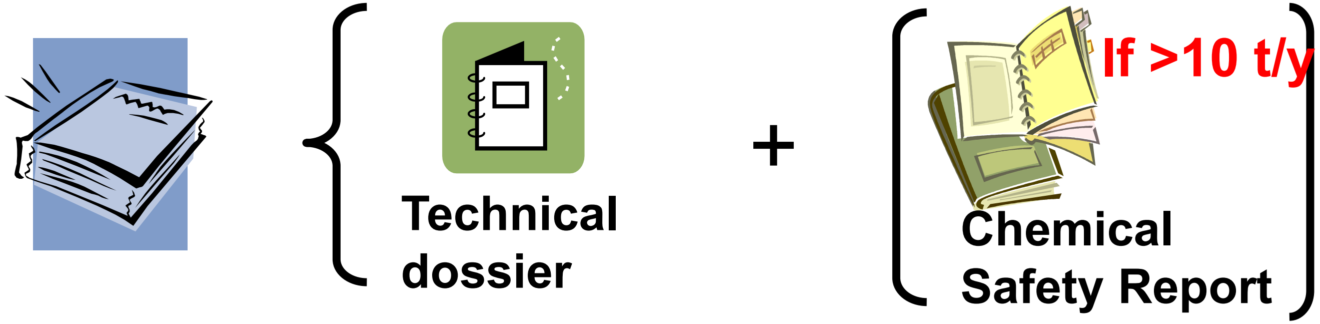
REACH: how to reach the objectives?

- **R**egistration
- **E**valuation
- **A**uthorisation
- Restriction of **Ch**emicals



REACH registration dossier

- **Registration dossier** is the set of information submitted electronically by a registrant for a particular substance



Technical dossier consists of two main components:

- **technical dossier**, always required for all substances subject to the registration obligations
- **chemical safety report**, required if the registrant manufactures or imports a substance **in quantities of 10 tonnes or more per year.** The chemical report is the documentation of the chemical safety assessment (CSA)

REACH registration dossier – Chemical safety assessment

- Human health hazard assessment
    - Goal define the DNEL (derived no effect level) for humans: level of exposure above which humans should not be exposed
- Physicochemical hazard assessment
    - Classification and labelling
- Environmental hazard assessment
    - Goal define the PNEC (predicated no-effect concentration) below which adverse environmental effects are not expected to occur for the environment
- Persistent, bioaccumulative and toxic (PBT) and very persistent and very bioaccumulative (vPvB) assessment

- Depending on the results of the assessment
    - Exposure assessment
        - Generation of exposure scenario(s)
        - Exposure estimation
    - Risk characterisation

→ Register a substance and uses

REACH registration dossier – Uses

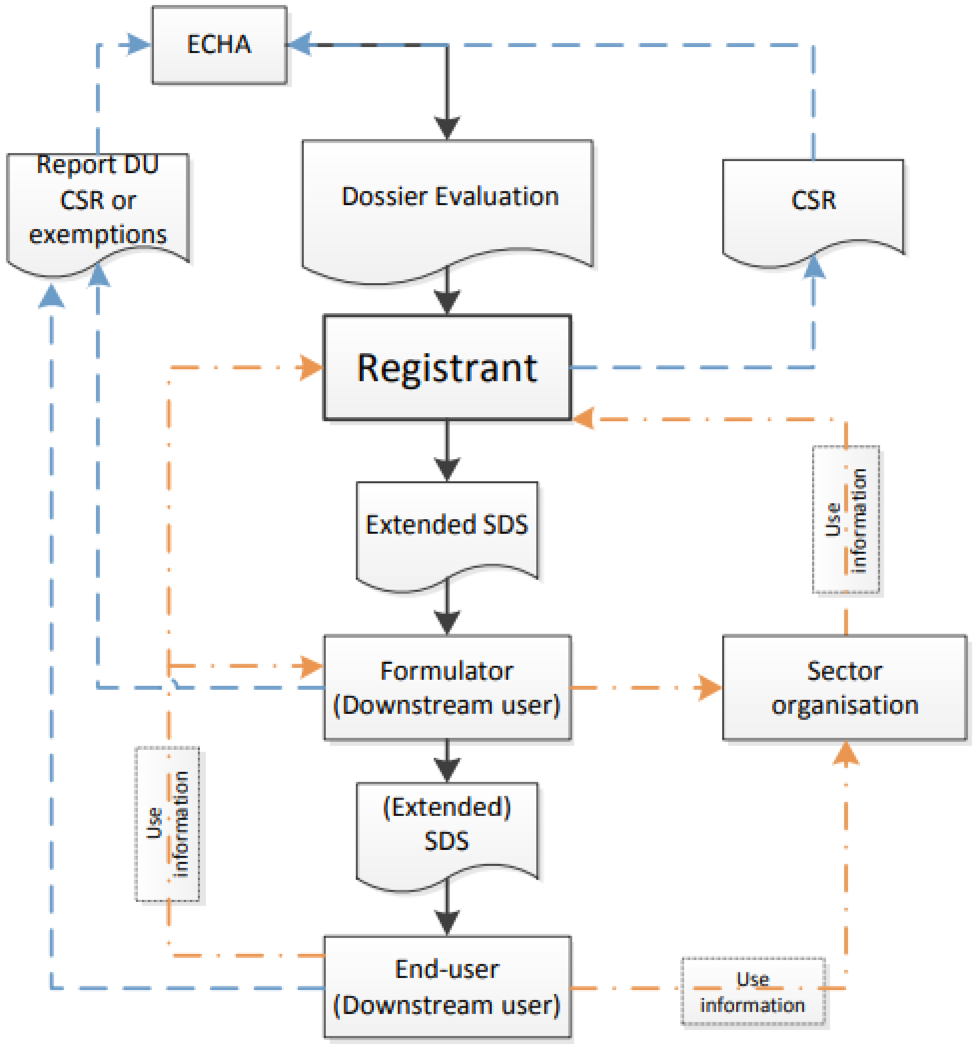
Example of uses

Formulation of a paint	Substances and mixtures are used in a mixing process. The use consists of several activities, such as the handling of raw materials and loading of vessels, the mixing process and the filling of paint into containers. In addition, vessels may have to be cleaned
Electroplating of metal	Electrolytes (substances or mixutres) are used to cover metals. The use consits of several activities, such as the preparation of the electroplating baths (filling and adjustment), the immersion of parts into the baths and the drying of parts. Cleaning and maintenance activities are also part of the use.
Blowing of plastic films	Raw materials of polymer compuonds are mixed, filled into the extruder, heated and blown, the material is cooled and packaged

Reference: ECHA Guidance for downstream users Version 2.1 october 2014

Exposure assessments

- Use
  - Exposure scenario based on:
    - Substance properties
    - Frequency of application (operational conditions: OC)
    - Risk management measures (RMM)



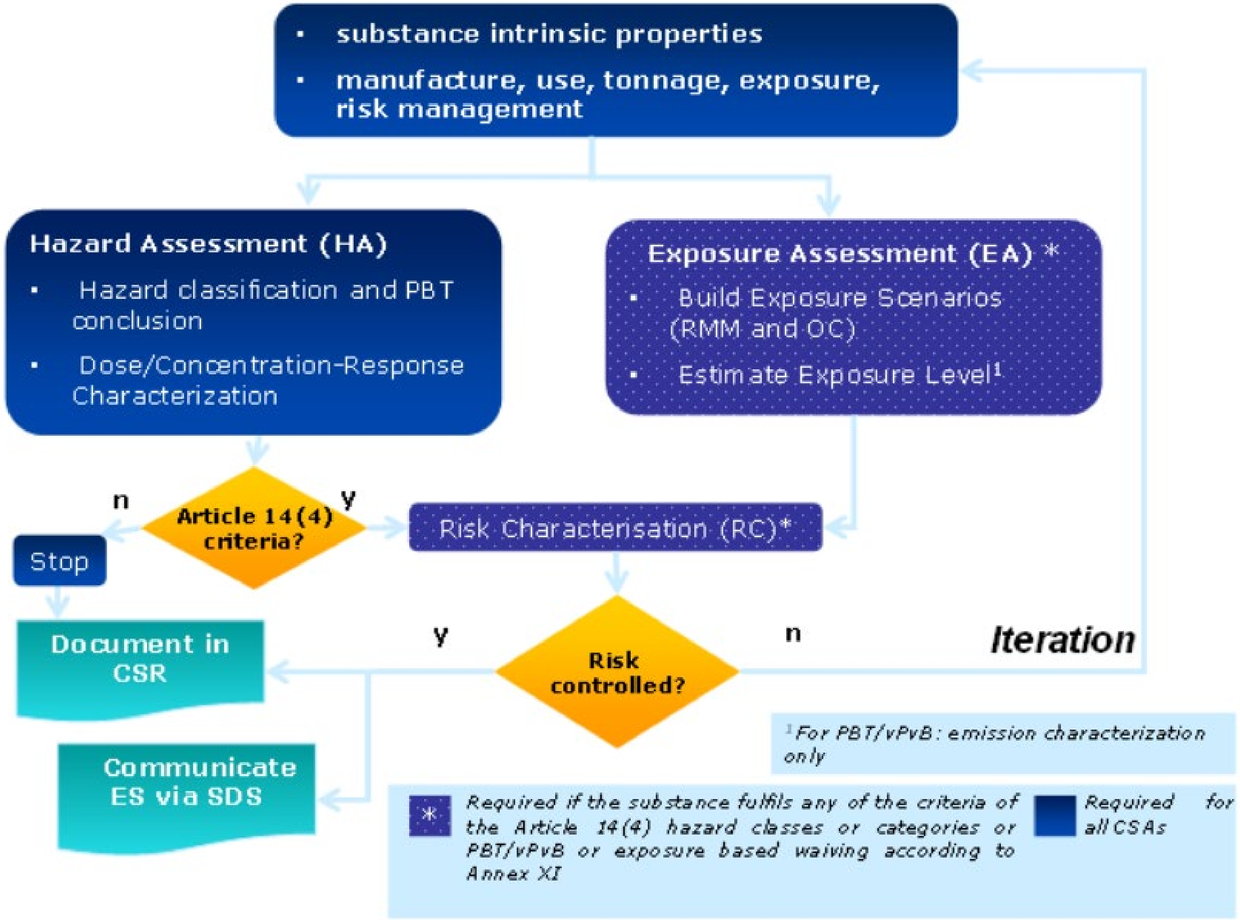
Reference: ECHA Guidance for downstream users Version 2.1 october 2014

Example of operational conditions and risk management measures

	Example 1	Example 2
Identified use	Industrial use of a hard surface cleaner Washing and cleaning product	Industrial use of a hard surface cleaner Washing and cleaning product
Type of activity/use	• Dilution of a concentrated solution • Spray onto surfaces to be cleaned. • Wiping off surface with a cloth.	• Dilution of a concentrated solution • Spray onto surfaces to be cleaned. • Wiping off surface with a cloth
Operational condition		
Concentration	> 25%	> 25%
Duration	1 hrs/day	8 hrs/day
Frequency	5 workdays/week	5 workdays/week
Risk Management Measures		
Ventilation conditions	The application takes place indoors Normal air exchange of 0.5/hr	The application takes place outdoors
Containment	Open process	Open process

Reference: ECHA Guidance for downstream users Version 2.1 october 2014

REACH chemical safety assessment



RMM: risk management measures
OC: operational controls
PBT: persistent bioaccumulative and toxic
vPvB: very persistent and very bioaccumulati
CSR: chemical safety report
ES: exposure scenario
SDS: safety data sheet
CSA: chemical safety assessment

Reference: ECHA Guidance for downstream users Version 2.1 october 2014

Example of use registration

Safety data sheet Safety data sheet
acc. to Regulation (EC) No. 1907/2006 (REACH)

Benzene ROTIPURAN® ≥99,5 %, p.a.

article number: **7173**
Version: **3.0 en**
Replaces version of: 2019-09-24
Version: (2)

date of compilation: 2017-09-29
Revision: 2022-08-03

SECTION 1: Identification of the substance/mixture and of the company/ undertaking

1.1 Product identifier

Identification of the substance	**Benzene** ROTIPURAN® ≥99,5 %, p.a.
Article number	7173
EC number	200-753-7
CAS number	71-43-2

1.2 Relevant identified uses of the substance or mixture and uses advised against

Relevant identified uses:	Laboratory chemical Laboratory and analytical use
Uses advised against:	Do not use for products which come into contact with foodstuffs. Do not use for private purposes (household).

1. Identification

Product identifier

Benzene (REACH region)

Chemical name: Benzene
CAS Number: 71-43-2

Relevant identified uses of the substance or mixture and uses advised against

Relevant identified uses: Only to be used as intermediate according to the REACH Regulation (EC) No 1907/2006, art. 18

Example of use registration

Safety data sheet

according to Regulation (EC) No. 1907/2006 (REACH)

Ethanol 96 %, Ph.Eur., extra pure

article number: **P075**
Version: **7.0 en**
Replaces version of: 2021-05-12
Version: (6)

date of compilation: 2015-07-27
Revision: 2022-12-16

SECTION 1: Identification of the substance/mixture and of the company/ undertaking

1.1 Product identifier

Identification of the substance	**Ethanol** 96 %, Ph.Eur., extra pure
Article number	P075
Registration number (REACH)	01-2119457610-43-xxxx
Index number in CLP Annex VI	603-002-00-5
EC number	200-578-6
CAS number	64-17-5
Alternative name(s)	Ethyl alcohol

1.2 Relevant identified uses of the substance or mixture and uses advised against

Relevant identified uses:	Laboratory and analytical use Laboratory chemical Industrial uses Professional uses
Uses advised against:	Do not use for products which come into contact with foodstuffs. Do not use for private purposes (household).

1.2. Relevant identified uses of the substance or mixture and uses advised against

Relevant identified uses: process chemical, solvent(s)

For the detailed identified uses of the product see appendix of the safety data sheet.

Example of extended SDS

Contributing exposure scenario	
Use descriptors covered	PROC8a: Transfer of substance or mixture (charging and discharging) at non-dedicated facilities Use domain: professional
Operational conditions	
Concentration of the substance	2-(2-butoxyethoxy)ethanol Content: >= 0 % - <= 100 %
Physical state	liquid
Vapour pressure of the substance during use	2,91976 Pa
Process temperature	20 °C
Duration and Frequency of activity	480 min 5 days per week
Indoor/Outdoor	Indoor
Risk Management Measures	
Provide a good standard of general or controlled ventilation (5 to 10 air changes per hour)	Effectiveness: 70 %
Use suitable chemically resistant gloves.	Effectiveness: 80 %
Use suitable eye protection.	
Exposure estimate and reference to its source	
Assessment method	EASY TRA v4.1, ECETOC TRA v3.0, Worker
	Worker - dermal, long-term - systemic
Exposure estimate	2,7429 mg/kg bw/day
Risk Characterization Ratio (RCR)	0,033046
Assessment method	EASY TRA v4.1, ECETOC TRA v3.0, Worker
	Worker - inhalation, long-term - systemic
Exposure estimate	50,6958 mg/m³
Risk Characterization Ratio (RCR)	0,75105
Assessment method	EASY TRA v4.1, ECETOC TRA v3.0, Worker
	Worker - inhalation, long-term - local
Exposure estimate	50,6958 mg/m³
Risk Characterization Ratio (RCR)	0,75105
Guidance to Downstream Users	
For scaling see: http://www.ecetoc.org/tra	

SDS

REACH evaluation

- Dossier evaluation: ECHA checks that registration dossiers contain the information on chemicals required by the legislation.
- Substance evaluation: Member states evaluate substances after they have identified specific concerns.

- Following the assessment, registrants may be required to submit or generate additional information on the substance.

REACH authorisation

- REACH Regulation sets up a system under which the use of substances with properties of very high concern and their placing on the market can be made subject to an authorisation requirement. Such substances are included in Annex XIV of the Regulation and may not be placed on the market or used without an authorisation. This authorisation requirement ensures that risks from the use of such substances are either adequately controlled or outweighed by socio-economic benefits. An analysis of alternative substances or technologies will be a fundamental component of the authorisation process.
- 59 substances (June 2023)

- Candidate List of substances of very high concern for Authorisation: Candidate List of substances of very high concern for Authorisation - ECHA (europa.eu)
- 233 substances (including the ones already in Annex XIV) (June 2023)

REACH restriction

- Any condition for or prohibition of the manufacture, use or placing on the market of a substance. The substances restricted under REACH and the conditions of their restrictions are included in Annex XVII of the Regulation.

- The restrictions procedure is a safety net to address unacceptable risks to human health or the environment, arising from the manufacture, use or placing on the market of substances, which need to be addressed on a Community-wide basis.

▼M5

Column 1 Designation of the substance, of the group of substances or of the mixture	Column 2 Conditions of restriction
▼M67 76. *N,N*-dimethylformamide CAS No 68-12-2 EC. No 200-679-5	1. Shall not be placed on the market as a substance on its own, as a constituent of other substances, or in mixtures in a concentration equal to or greater than 0,3 % after 12 December 2023 unless manufacturers, importers and downstream users have included in the relevant chemical safety reports and safety data sheets, Derived No-Effect Levels (DNELs) relating to exposure of workers of 6 mg/m^3 for exposure by inhalation and 1,1 mg/kg/day for dermal exposure. 2. Shall not be manufactured, or used, as a substance on its own, as a constituent of other substances, or in mixtures in a concentration equal to or greater than 0,3 % after 12 December 2023 unless manufacturers and downstream users take the appropriate risk management measures and provide the appropriate operational conditions to ensure that exposure of workers is below the DNELs specified in paragraph 1. 3. By way of derogation from paragraphs 1 and 2, the obligations laid down therein shall apply from 12 December 2024 in relation to placing on the market for use, or use, as a solvent in direct or transfer polyurethane coating processes of textiles and paper material or the production of polyurethane membranes, and from 12 December 2025 in relation to placing on the market for use, or use, as a solvent in the dry and wet spinning processes of synthetic fibres.

REACH restriction

74. Diisocyanates, O = C=N-R-N = C=O, with R an aliphatic or aromatic hydrocarbon unit of unspecified length	1. Shall not be used as substances on their own, as a constituent in other substances or in mixtures for industrial and professional use(s) after 24 August 2023, unless: (a) the concentration of diisocyanates individually and in combination is less than 0,1 % by weight, or (b) the employer or self-employed ensures that industrial or professional user(s) have successfully completed training on the safe use of diisocyanates prior to the use of the substance(s) or mixture(s).

72. The substances listed in column 1 of the Table in Appendix 12	1. Shall not be placed on the market after 1 November 2020 in any of the following: (a) clothing or related accessories; (b) textiles other than clothing which, under normal or reasonably foreseeable conditions of use, come into contact with human skin to an extent similar to clothing; (c) footwear; if the clothing, related accessory, textile other than clothing or footwear is for use by consumers and the substance is present in a concentration, measured in homogeneous material, equal to or greater than that specified for that substance in Appendix 12.

REACH - Summary

Health and Sustainability - Summary

- What role plays health?
- What can be done to improve health?

Improve sustainability of a chemical process

The 12 principles of green chemistry	The 12 principles of green engineering
Prevention	Inherent rather than circumstantial
Atom economy	Prevention instead of treatment
Less hazardous chemical syntheses	Design for separation
Designing safer chemical	Maximize efficiency
Safer solvents and auxiliaries	Output-pulled versus input-pushed
Design for energy efficiency	Converse complexity
Use of renewable feedstocks	Durability rather than immortality
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Catalysis	Minimize material diversity
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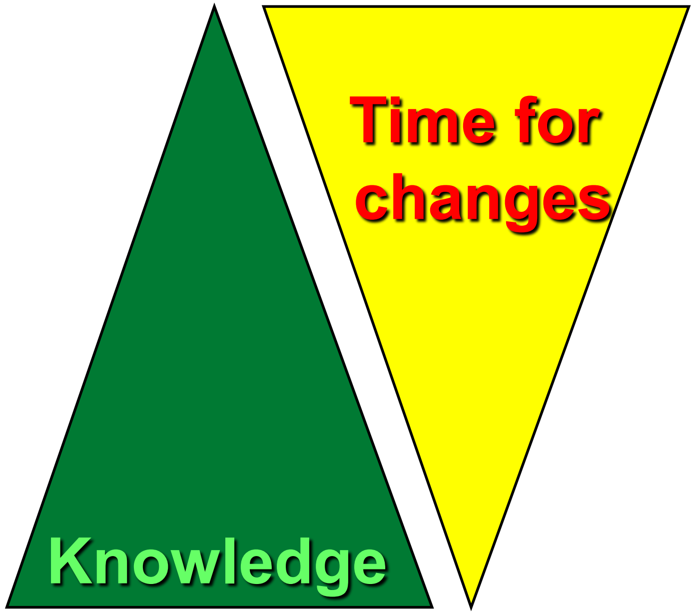
Improve sustainability of a chemical process

- Discovery, Innovation
- Feasibility Study
- Laboratory Study
- Study in Pilot Plant
- Engineering
- Building and Start Up
- Process in Production
- Process Death



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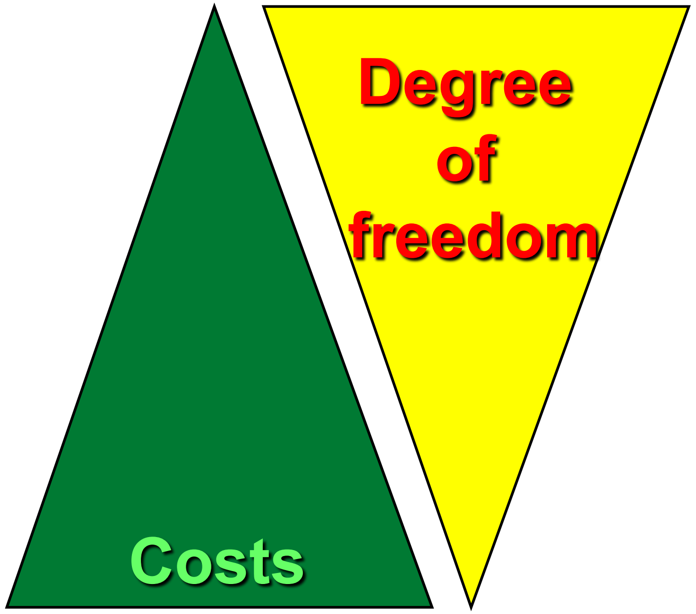

European regulations and efforts

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- Seveso Directive (major accident prevention)

Chemical strategy for sustainability

- Objectives
  - better protect citizens and the environment
  - boost innovation for safe and sustainable chemicals
- Actions
  - banning the most harmful chemicals in consumer products - allowing their use only where essential
  - account for the cocktail effect of chemicals when assessing risks from chemicals
  - phasing out the use of per- and polyfluoroalkyl substances (PFAS) in the EU, unless their use is essential
  - boosting the investment and innovative capacity for production and use of chemicals that are safe and sustainable by design, and throughout their life cycle
  - promoting the EU's resilience of supply and sustainability of critical chemicals
  - establishing a simpler "one substance one assessment" process for the risk and hazard assessment of chemicals
  - playing a leading role globally by championing and promoting high standards and not exporting chemicals banned in the EU

Chemical strategy for sustainability

22 April 2024 — Commission proposes criteria to define the essential use of most harmful chemicals

Communication can be found here.

7 December 2023 — Commission proposes 'one substance, one assessment' chemicals assessment reform for faster, simplified and transparent processes

Find out more

14 July 2023 — **Proposal to ban all remaining intentional uses of mercury in the EU**

Proposal, Delegated act and News

19 December 2022 — **Commission proposed a revised Regulation on classification, labelling and packaging of chemicals (CLP) and introduced new hazard classes**

Find out more

8 December 2022 — **Recommendation on a framework for safe and sustainable by design chemicals**

Find out more

10 June 2022 — **Commission clarifies definition on nanomaterials**

Find out more

25 April 2022 — **Commission publishes REACH Restrictions Roadmap**

Find out more

20 January 2022 — **Commission launches public consultation on REACH revision - now available in all EU languages**

Find out more

9 August 2021 — **Commission launches public consultation on CLP revision**

Find out more

14 October 2020 — **Publication of chemicals strategy** → 85 actions

9 May 2020 — **Publication of chemicals strategy roadmap**

For more information on the roadmap and feedback, visit here.

Hide 6 items

11 December 2019 — **Publication of the European Green Deal**

Reference: https://environment.ec.europa.eu/strategy/chemicals-strategy_en#timeline

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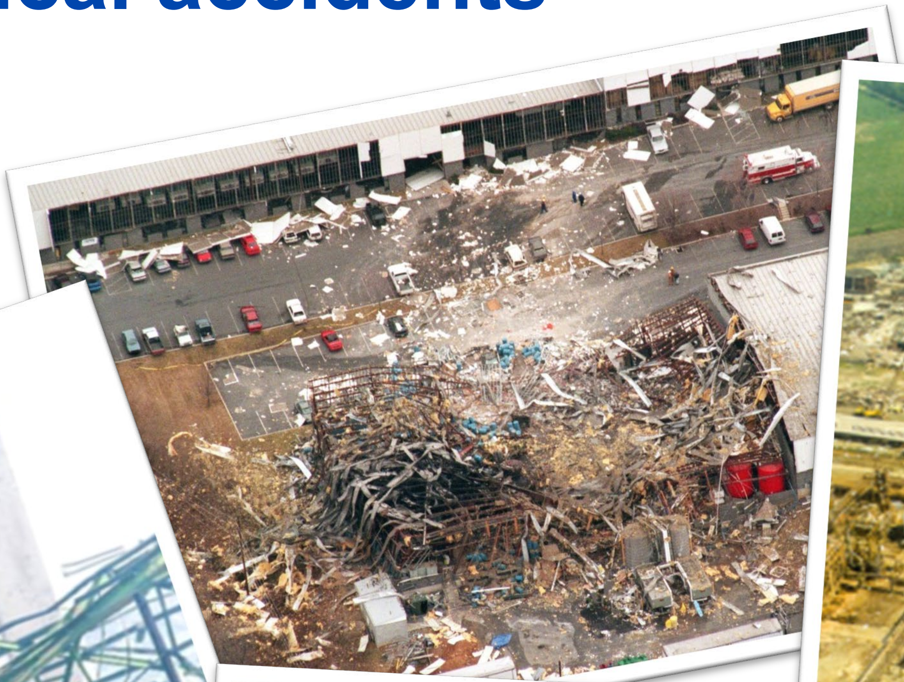
Major chemical accidents



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- Seveso Directive (major accident prevention)

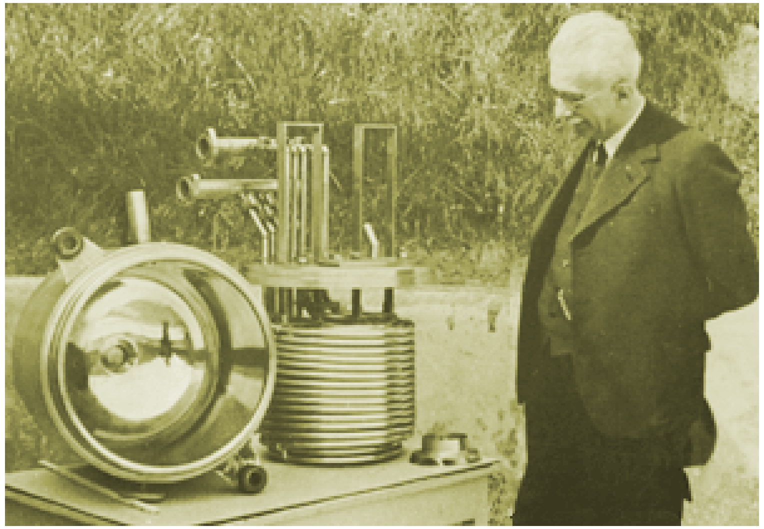
Seveso Directive

- Major accidents are threats for humans and the environment
- The Directive applies to more than 12 000 industrial establishments in the European Union where dangerous substances are used or stored in large quantities

Process Safety

- Process safety definitions (CCPS):
  - a discipline that focuses on the prevention of fires, explosions, and accidental chemical releases
  - Prevention of, preparedness for, mitigation of, response to, or restoration from catastrophic releases of chemicals or energy from a process
- ≠ occupational safety: focus on personal safety (prevent harms from falls, cuts, sprain, strains, being stuck by objects, repetitive motion injuries etc)

Nitroglycerine nitration reactor in 1875
https://www.nobelprize.org/alfred-nobel/alfred-nobel-in-scotland/

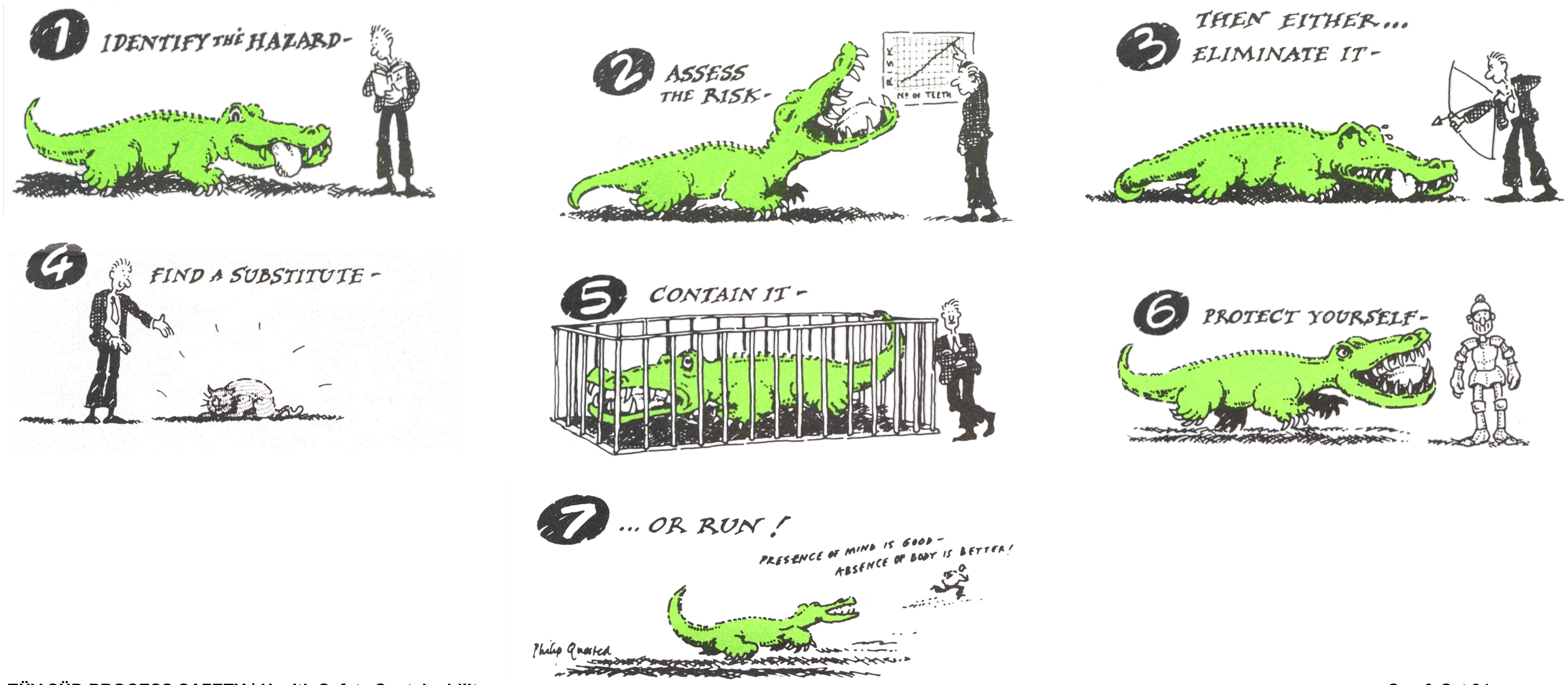


Continuous nitroglycerine reactor in 1935(Biazzi)
http://www.biazzi.ch/page/history.php/

Process safety

- What could lead to fires, explosions, and accidental chemical releases?
- What are the hazards and what are the risks (for fire, explosions, and accidental chemical releases)?

Goal/objectives of risk analysis- process safety



Hierarchy of risk reducing measures

1. Inherent safety

Find examples linked to process safety for all of them

2. Prevention
   - Technical measures:
     I. Passive
     II. Active
   - Organizational measures

3. Mitigation

Hierarchy of risk reducing measures – inherent safety

- Intensification
  - Inventory reduction
- Substitution
  - Use safer material
- Attenuation
  - Use material in the less hazardous form
- Simplification
  - Avoid complex plants or systems
- Tolerance
  - Robust equipment, error tolerant processes

Find examples linked to chemical processes

Improve safety of a chemical process

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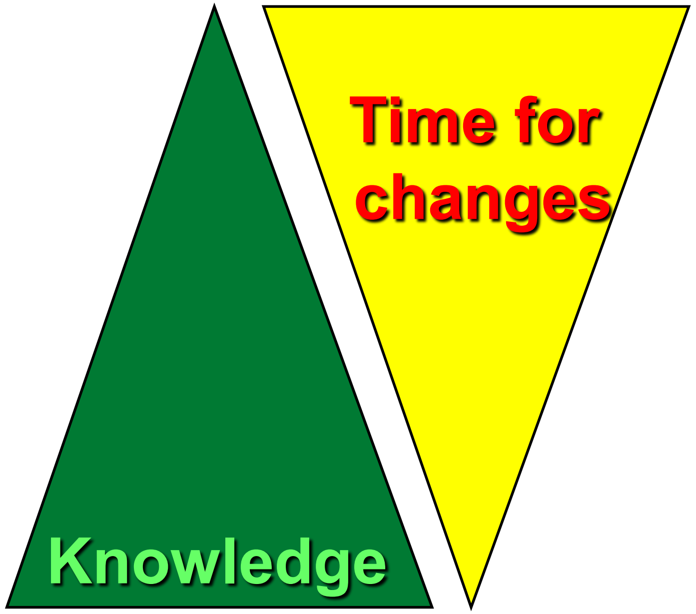

Improve safety of a chemical process

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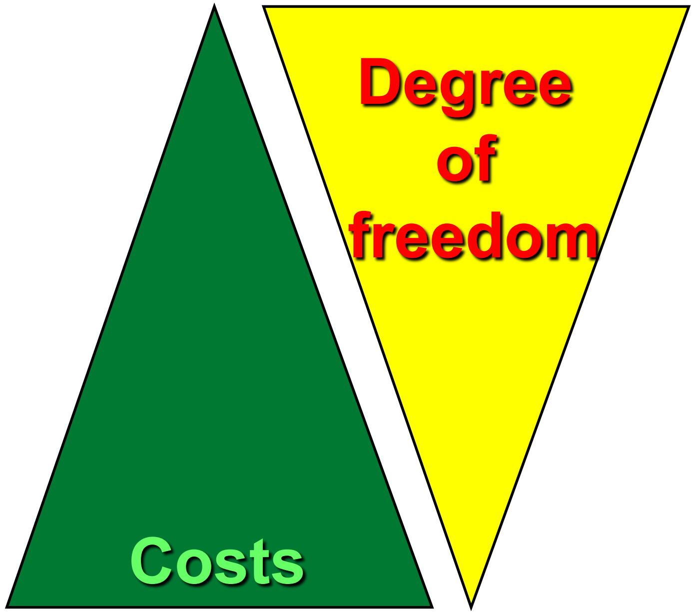
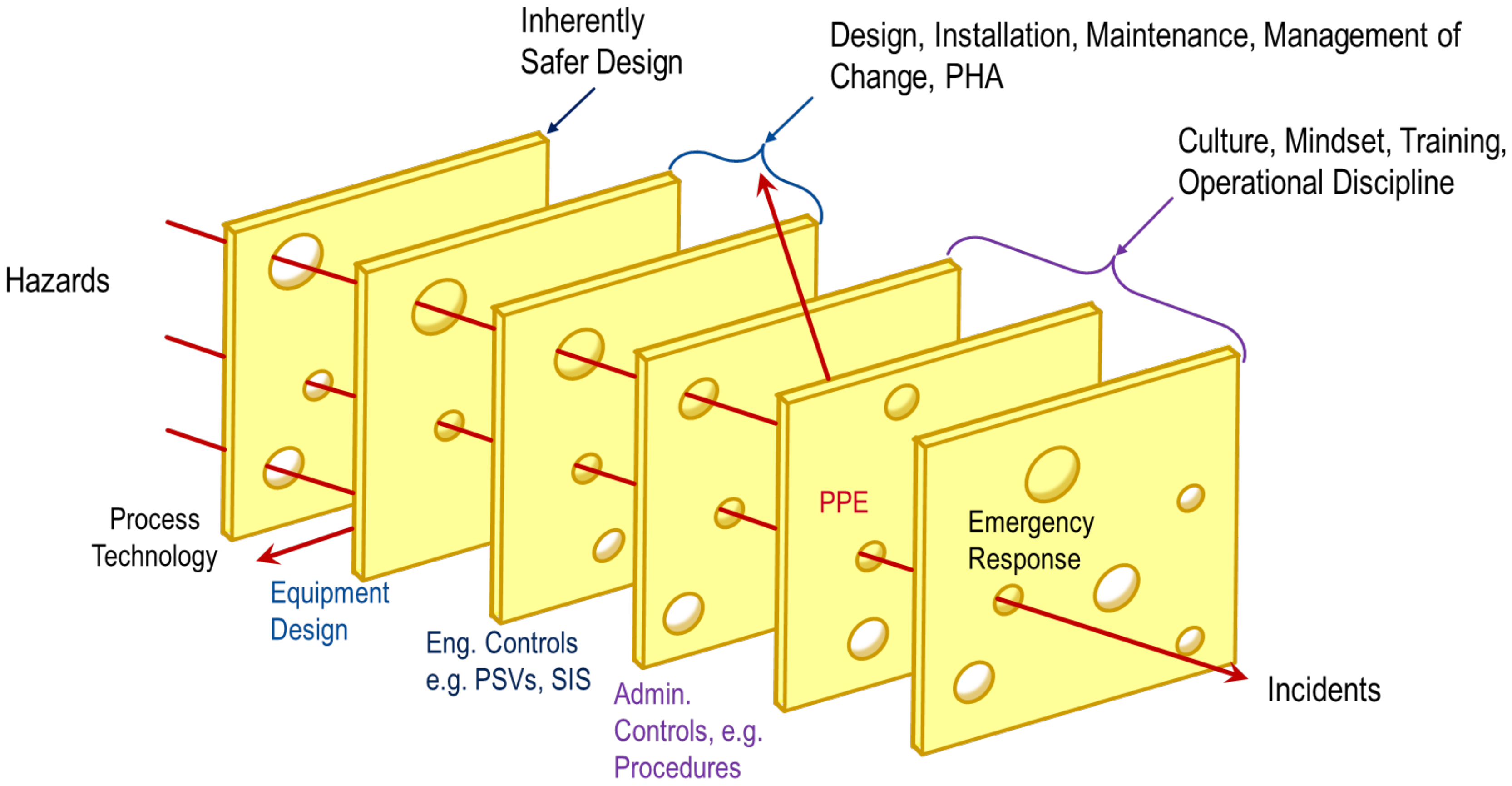
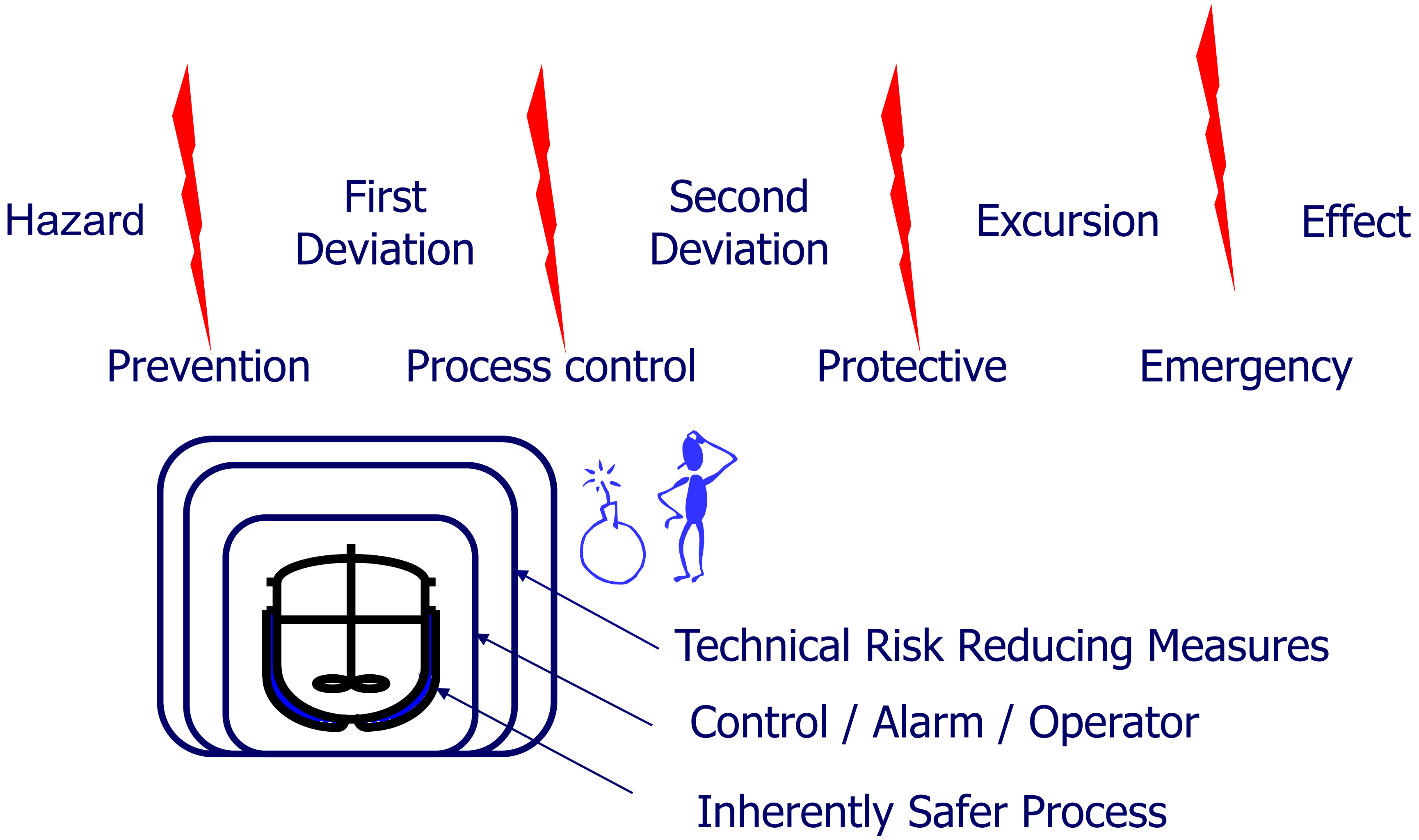


What is a Safe Process ?

- Remaining risks can be accepted
- The risks must be known
- Risk analysis was performed

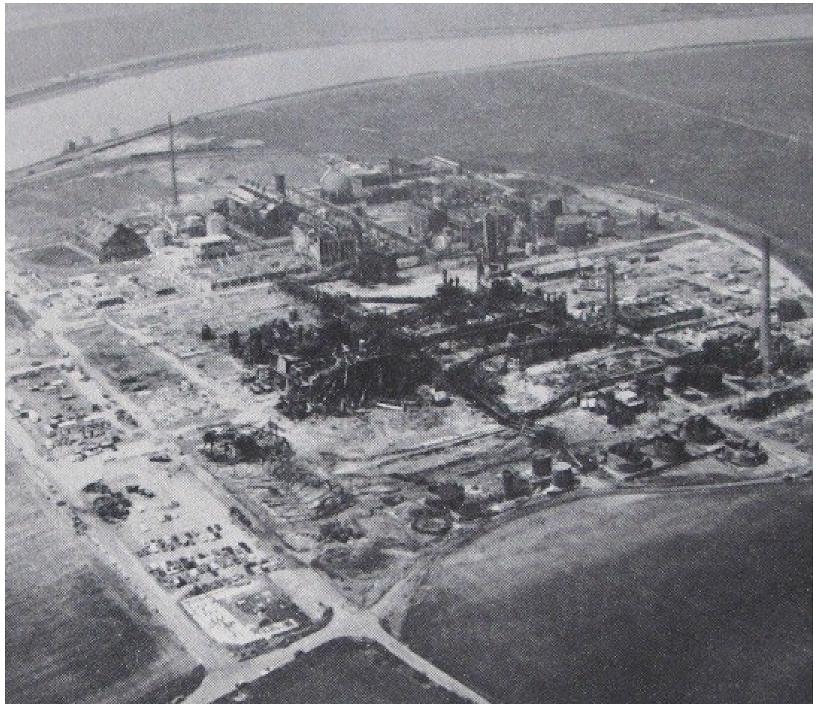


What is a Safe Process ?



Flixborough

- June 1st 1974 16:58
- Killed 28 people, injured 36 onsite and > 57 off site
- Lead to development of safety and loss prevention
- Increased efforts in industry and demand from the public controls on such plants
- https://youtu.be/8A1xSCUtB-M

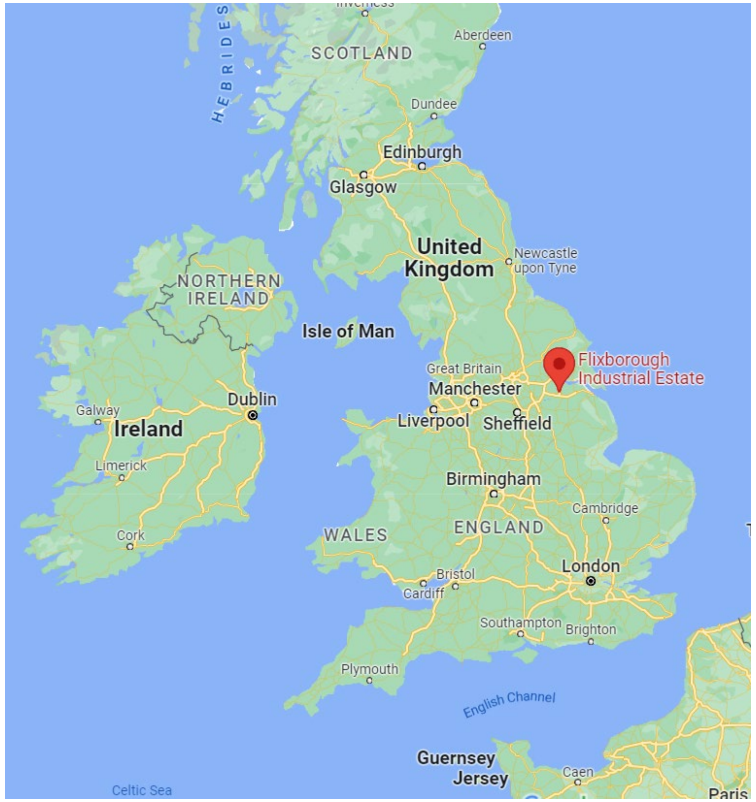


Flixborough (accident site)

- Farmland, 260 km north of London, 800m from villages of Flixborough and Amscott, 3-5 km from larger towns

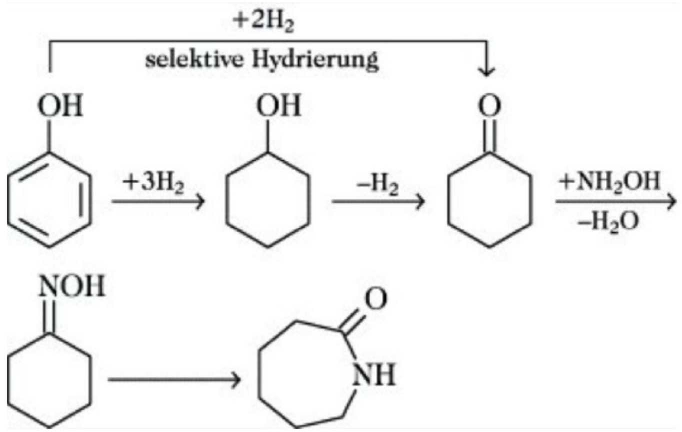
- 1974: occupied 550 people
- Plant built in 1938 to produce fertilize
- 1964 changed ownership with the aim to produce caprolactam (owned by DSM and National Coal Board (NCB))

- Produced first 20’000 t/y caprolactam by means of phenol hydrogenation (1967)
- 1972 increased capacity (70’000 t/y) with construction of a new unit: this unit uses cyclohexane oxidation

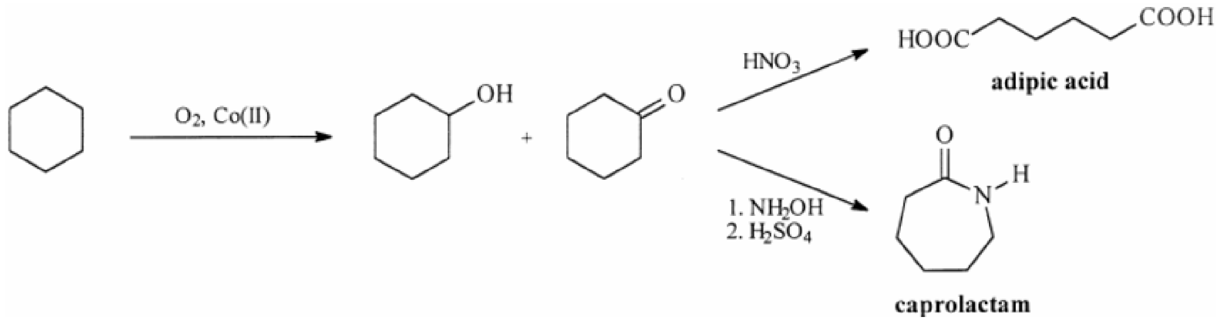


Flixborough - Chemistry

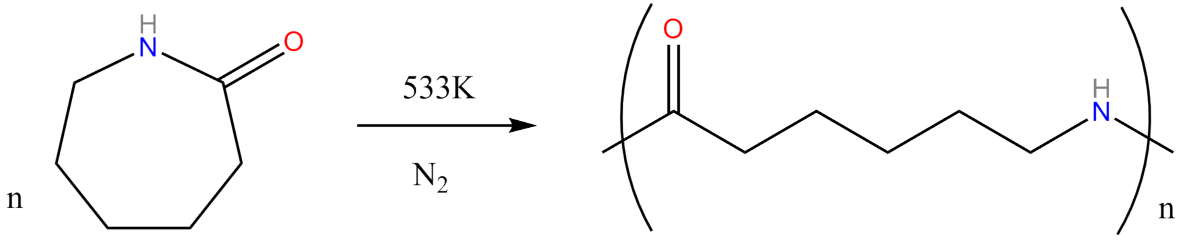
- Phenol hydrogenation:



- Cyclohexane oxidation

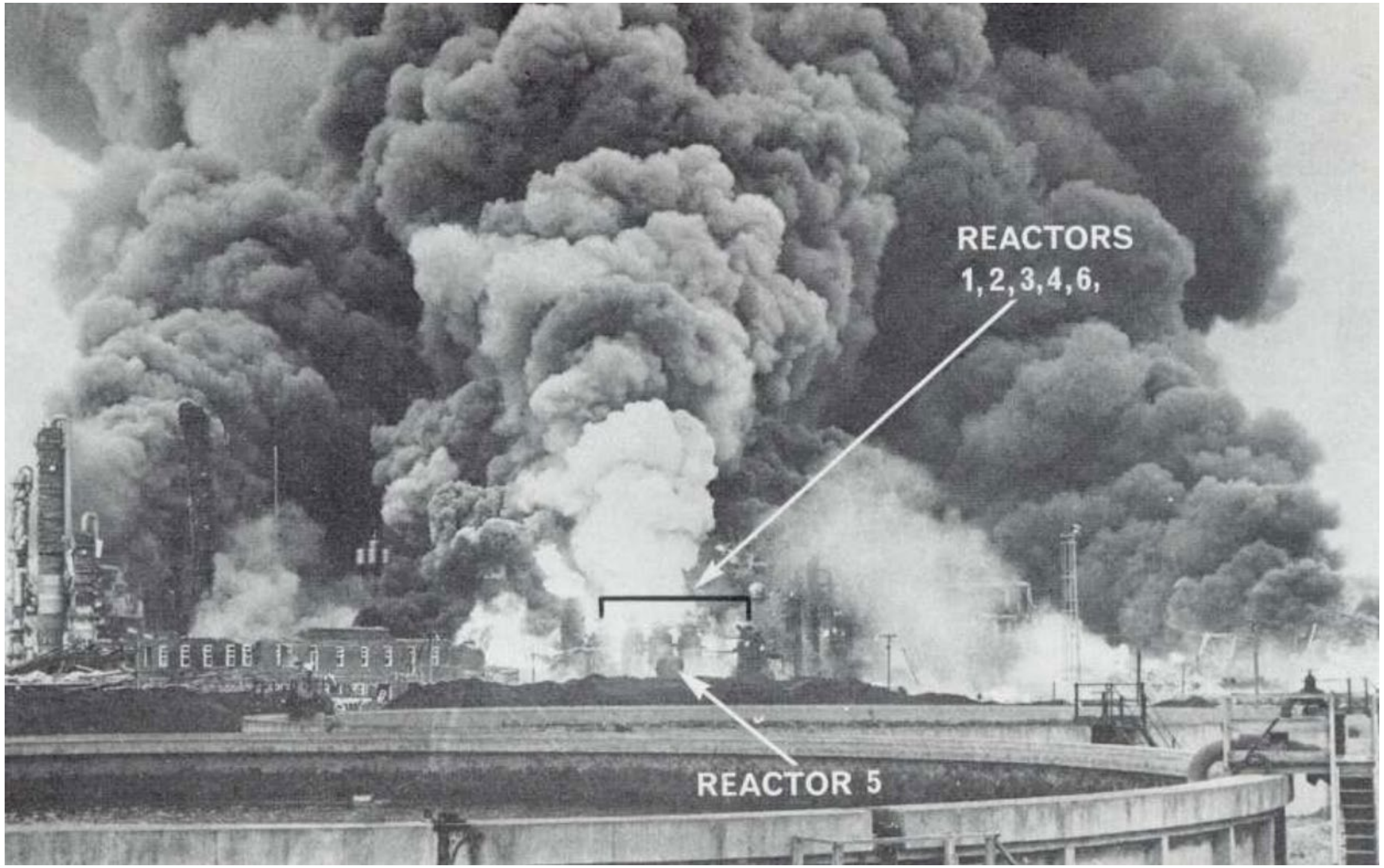


- Caprolactam use → nylon production

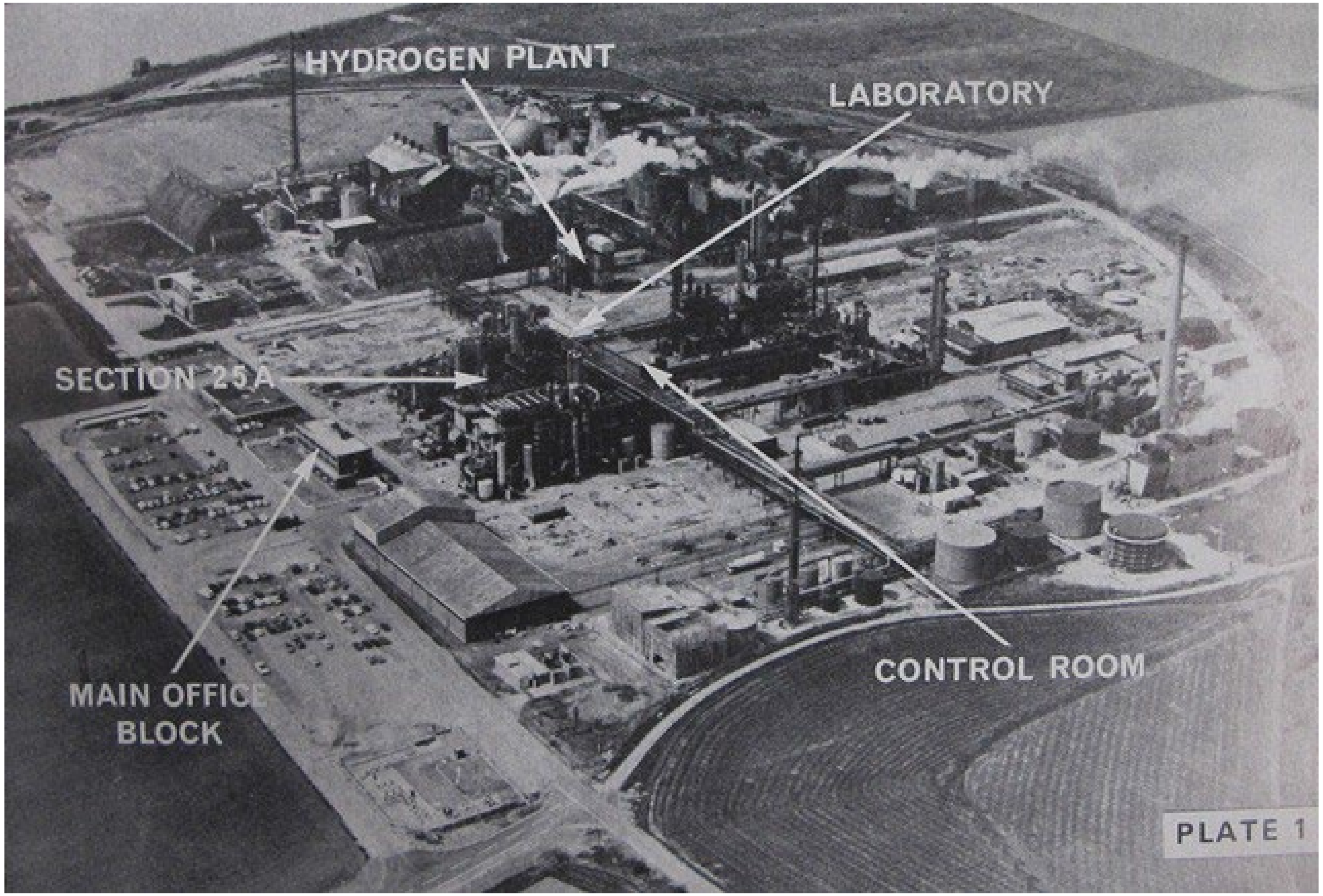


Flixborough - The accident

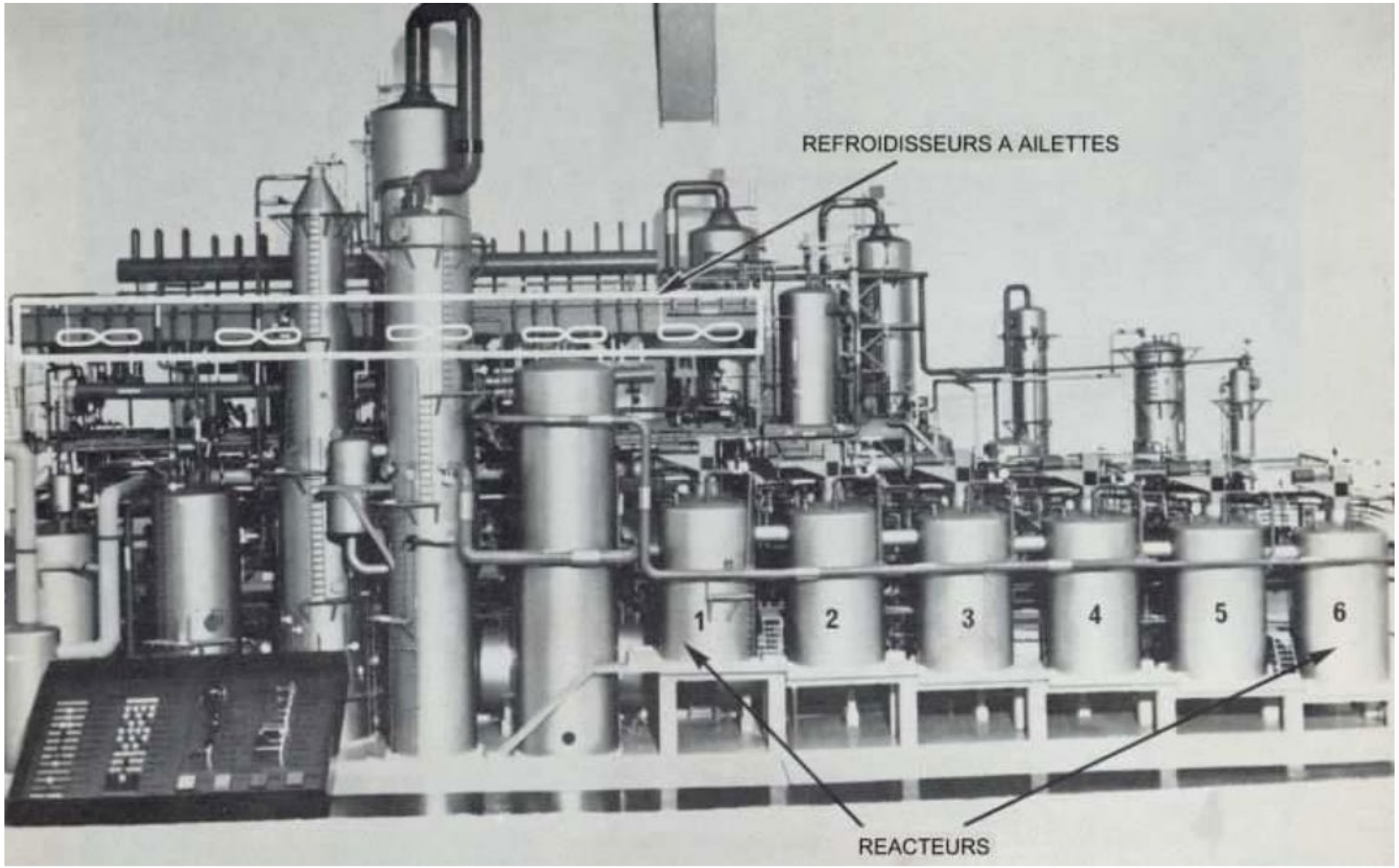
- June 1st 4:53 pm deflagration
  - Noticeable 50 km away
  - Flames 70-100m high
  - Pressure of the explosion destroyed stationary fire fighting equipment
  - All building within 600m were destroyed
  - 72 individuals present on the site: 28 killed, 36 injured (lucky it was week-end)
  - 1987 houses and retail businesses were damaged (72 of 79 houses in Flixborough, 73 from 77 in Amscott, 644 of 756 in Burton)
  - Large piece of equipment found 6 km away, debris up to 32 km away



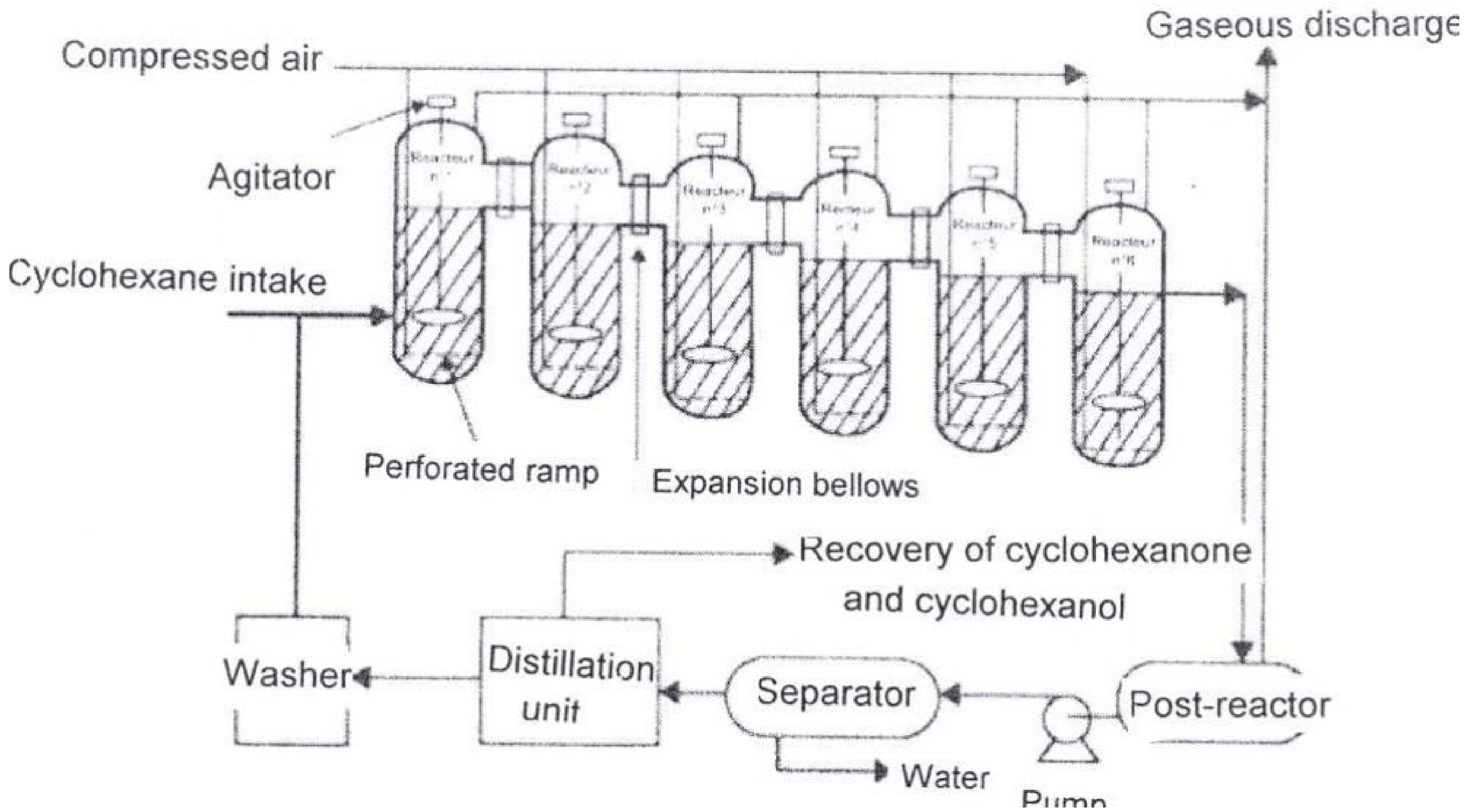
Plant layout



Process



Flixborough - Process



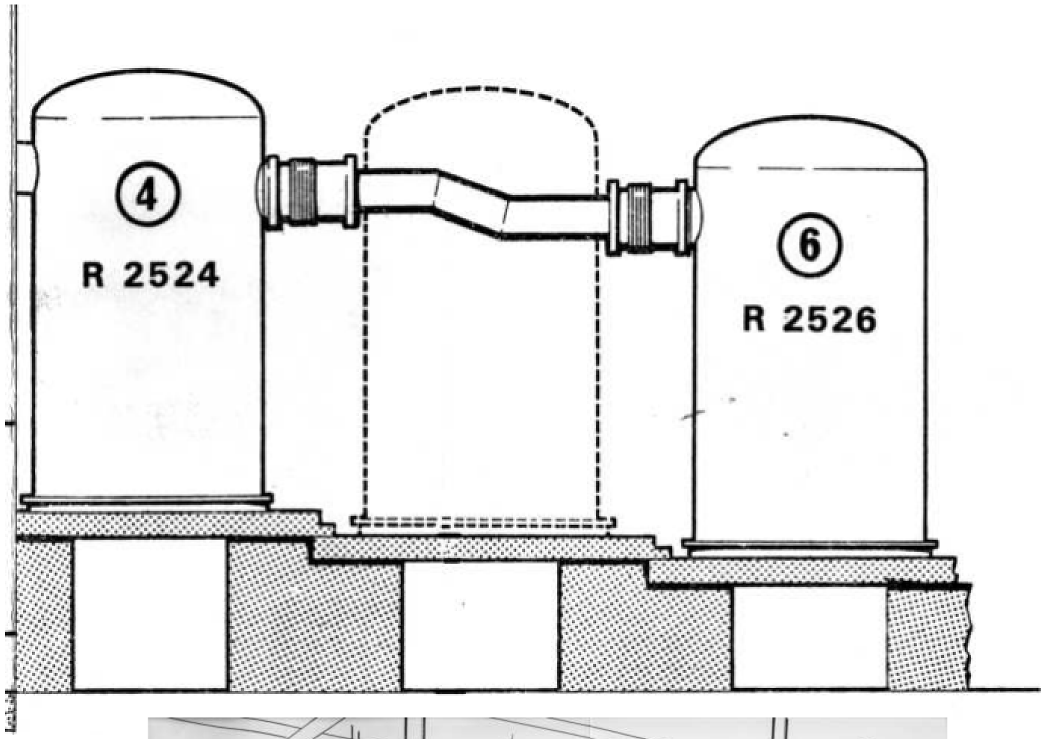
- 6 reactors of 45 m^3 each
- Compressed air injected through perforated ramp
- 25m^3 cyclohexane in the reactors at 155°C and 8.8 bar of pressure (+ catalyst)
- Low output of cyclohexanone and cyclohexanol → recirculation of cyclohexane
- 250 -300 m^3/h liquid flow between reactors via 711 mm diameter pipes fitted with expansion bellows
- Installation inert (nitrogen)
- PRV 11 bar

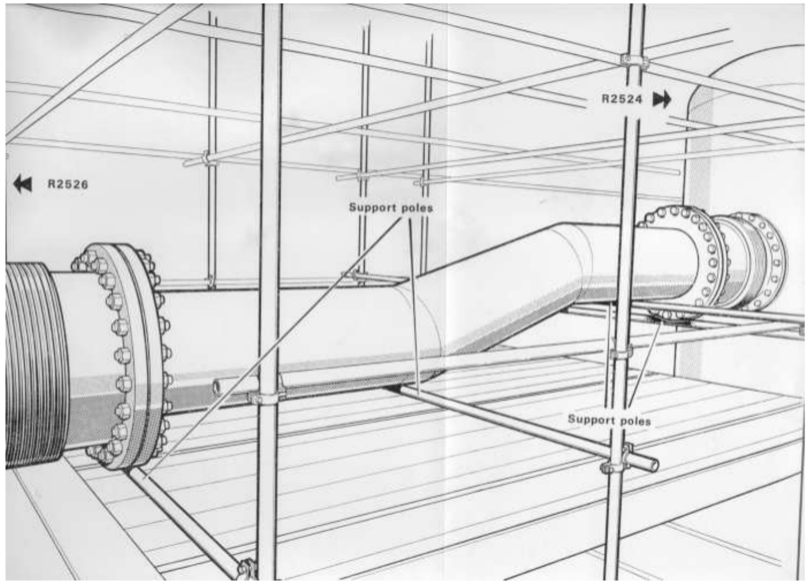
The context

- New caprolactam unit at full capacity since beginning of 1974
  - technical and labour problems before:
    - miner strikes, only 3 day of power per week (November 1973 to January)
    - Plant can't adapt → work on backup energy generation → reactor agitation turned off
    - Agitation of reactor 4 deteriorated and was not put back on
  - Beginning of 1974 plant produced 47'000 tones/year → prospect of financial loss →ask Government's pricing commission to authorize 48% price increase but was refused
  - Considerable economic and commercial pressure
- Personnel
  - Plant maintenance engineer post vacant since beginning of 1974
    - Former maintenance engineer's subordinate (technician with 10 years experience in electricity and 4 years in maintenance)
    - Mechanical engineering competence in the plant low (Director and Technical Director are chemists/chemicl engineers, no qualification in mechanical engineering)

The accident

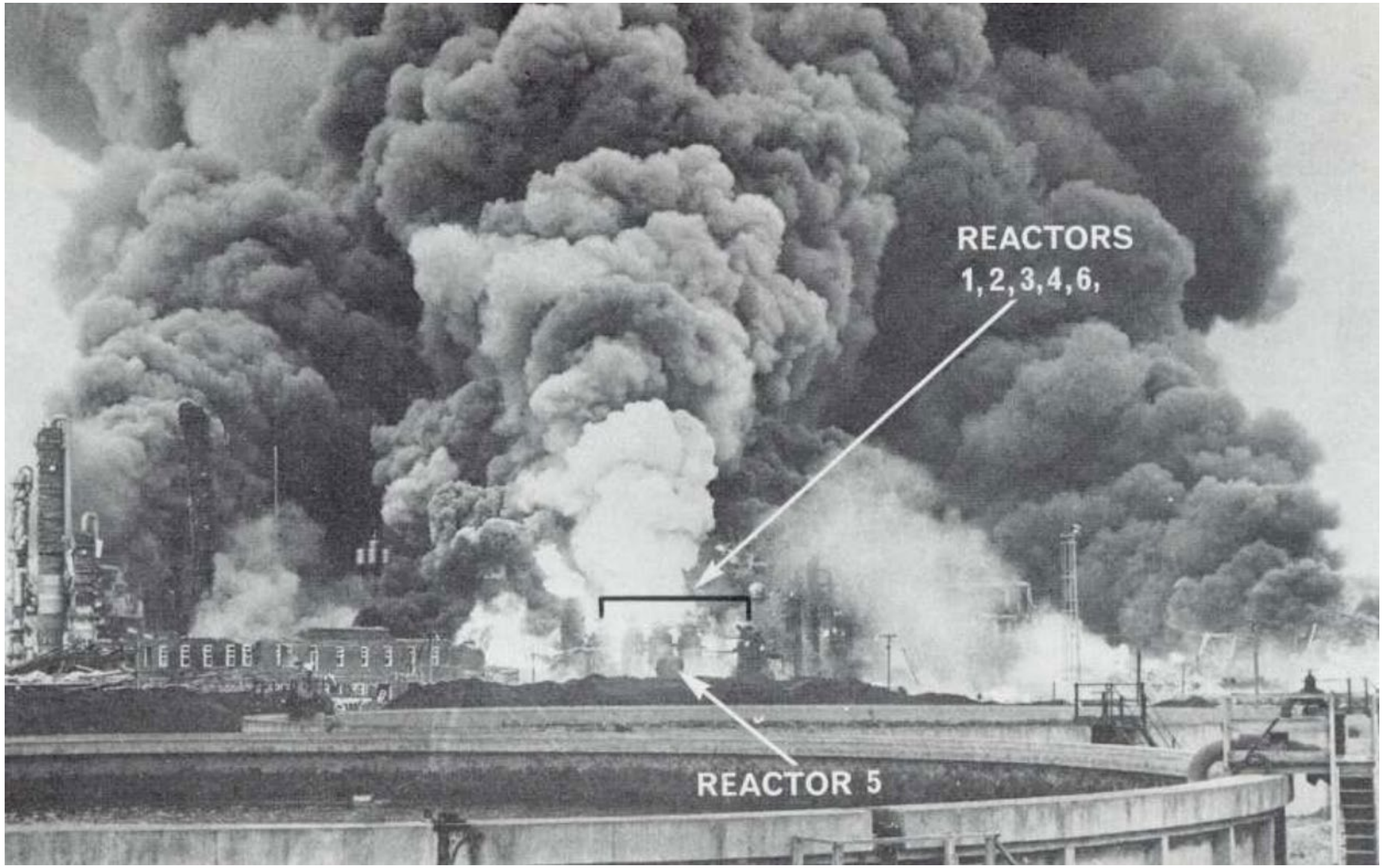
- March: new difficulties
  - March 27th cyclohexane leak on reactor 5 (vertical crack)
  - March 28th crack is 2 meter long
  - Stop and inspection of reactor 5 scheduled
  - Resume production quickly → build a bypass between Reactors 4 and 6
  - Leak test on 1st of April, restart process with 508 mm elbow pipe (fabricated onsite) connecting the two expansion bellows on Reactors 4 and 6 via a plate flange. Entire assembly supported by scaffolding
  - Until May 29th installation operated without any special problem
  - May 29th: cyclohexane leak --> shut down, repair, test restart early morning 1st June
  - June 1st 4:00: new cyclohexane leak, followed by several others → installation stopped and restarted 1 hour later
  - Shortly after: new leak → stop production





The accident

- June 1st 7 am back into service but problems with T and P
- June 1st 4:53 pm deflagration
  - Noticeable 50 km away
  - Flames 70-100m high
  - 2 bar pressure at the epicentre → destroyed stationary fire fighting equipment
  - All building within 600m were destroyed
  - 72 individuals present on the site: 28 killed, 36 injured (lucky it was wk)
  - 1987 houses and retail businesses were damaged (72 of 79 houses in Flixborough, 73 from 77 in Amscott, 644 of 756 in Burton)
  - Large piece of equipment found 6 km away, debris up to 32 km away



The causes of the accident

- Difficult to determine exactly because
  - absence of witnesses (all staff present in the control room died in the accident)
  - Destruction of all unit instrumentation
- According to the investigation report:
  - Failure at the level of the two connecting bellows on the temporary pipe placed between reactor 4 and reactor 6
  - Massive leak of hot and pressurized cyclohexane
  - Release of of 40-60 ton cloud of cyclohexane ignited 25 to 35 seconds later (ignition: reforming tower of the hydrogen unit)
  - Cause: amateurism by removing reactor 5 and constructing bypass.
    - No verification (only leak test with nitrogen 9 bar)
    - No calculation, no drawings
    - No reference to standard or guidelines
    - Nothing to prevent movements of the bypass (scaffolding inadequate)
      - No account of turning moment that would be placed on the pipe due to flow of fluid and proces P
      - No account for shear forces on the bellows (not designed for that)
    - Leak on reactor 5 not investigated
  - Other causes also described in literature

The actions taken and lessons learnt

- Need to strengthen public authority control → Health and Safety at Work Act was introduced in the UK
- Together with Seveso accident in 1976 led to the «Seveso directive»
- 18 people died in the control room → carefully design the layout and location of control rooms (occupied building)
- Limit the hazard potential onsite
- Any modification, no matter how small, can engender risk –> MOC
- Preventive maintenance preferable to emergency intervention
- Management of feedback (cracks in other reactors reported but escaped investigation) → safety culture
- Competence from staff crucial (only a well-skilled and experienced workforce will be able to recognize precursor signals of an accident → competence and organisational changes
- Personnel should not be faced with having to chose between safety and productivity. Goal of a company must be to produce under safe conditions

Hierarchy of risk reducing measures – inherent safety

- Intensification
  - Inventory reduction
- Substitution
  - Use safer material
- Attenuation
  - Use material in the less hazardous form
- Simplification
  - Avoid complex plants or systems
- Tolerance
  - Robust equipment, error tolerant processes

Bhopal

- 2nd-3rd December 1984 in Bhopal India, pesticiede plant.
- Release of methyl isocyanate (immediate deaths 2259, many more in the weeks/years after, more than 500’000 injuries)

- Intermediate storage of methylisocyanate
- Many parts of the installation malfunctionning
- Water introduced in the tank → runaway reaction
- Pressure increase and release of methylisocyanate (direct release to the atmosphere should have been prevented by 3 risk reducing measures (cooling of methylisocyanate,, a flare tower to burn released gas, vent scrubber), which were malfunctioning, insufficiently sized or otherwise inoperable

- Intermediate storage convenient, but not essential (reduce inventories)

Hierarchy of risk reducing measures – inherent safety

- Intensification
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- Substitution
  - Use safer material
- Attenuation
  - Use material in the less hazardous form
- Simplification
  - Avoid complex plants or systems
- Tolerance
  - Robust equipment, error tolerant processes

Hierarchy of risk reducing measures

Reference: Kletz & Amyotte, Process Plants, a handbook for inherently safer design (2010)

Comparing methods to improve EHS

	Safety	Health	Environment
Inherent Safety	√√√	√√	√
Pollution prevention		√	√√√
Green chemistry	√√	√	√√√
Green technology	√		√√√
Design for the environment		√	√√√

√ √ √ : primary focus   √ √ secondary focus   √ directly linked benefit

Reference: Kletz & Amyotte, Process Plants, a handbook for inherently safer design (2010)

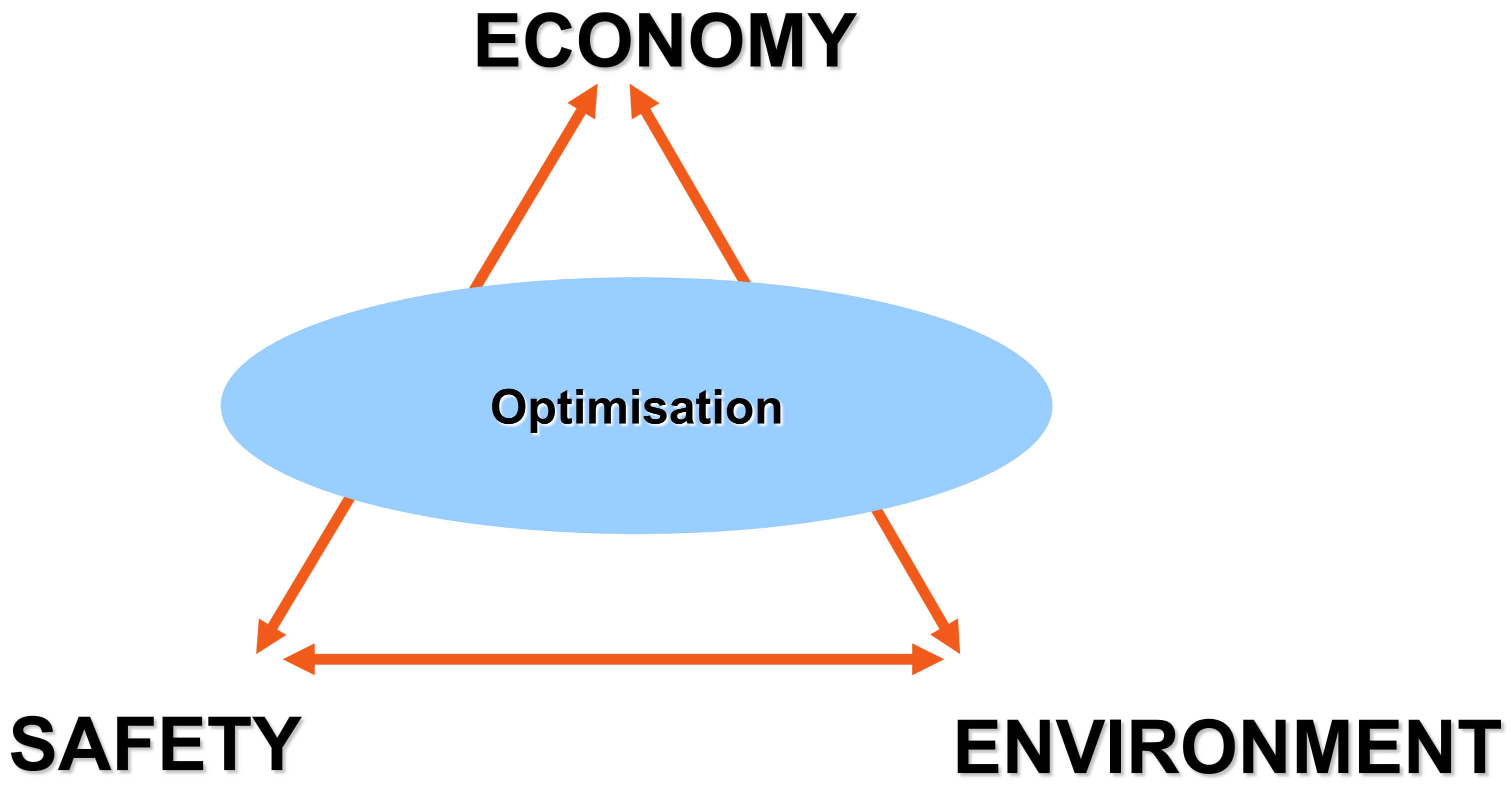
Improve sustainability of a chemical process

The 12 principles of green chemistry	The 12 principles of green engineering
Prevention	Inherent rather than circumstantial
Atom economy	Prevention instead of treatment
Less hazardous chemical syntheses	Design for separation
Designing safer chemical	Maximize efficiency
Safer solvents and auxiliaries	Output-pulled versus input-pushed
Design for energy efficiency	Converse complexity
Use of renewable feedstocks	Durability rather than immortality
Reduce derivatives	Meet need, minimize excess
Catalysis	Minimize material diversity
Design for degradation	Integrage material and energy flows
Real-time analysis of pollution prevention	Design for commercial «afterlife»
Inherengly safer chemistry for accident prevention	Renewable rather than depleting

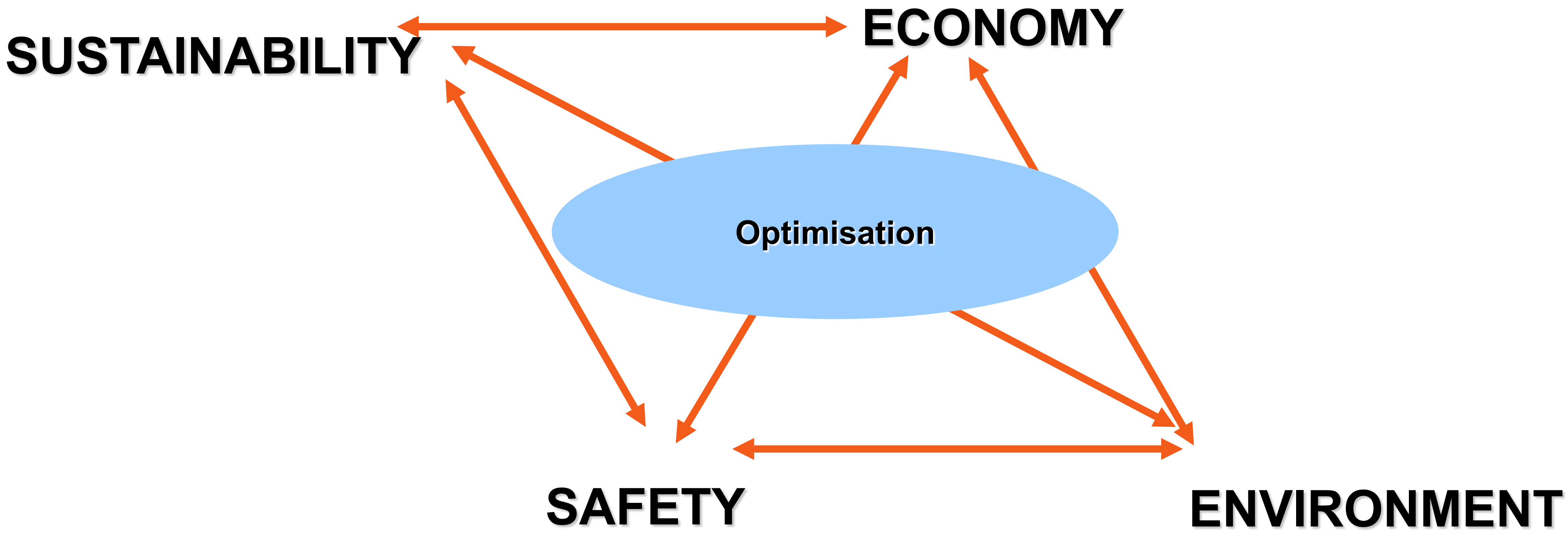
Improve sustainability of a chemical process

- What could one do (at an early stage?)

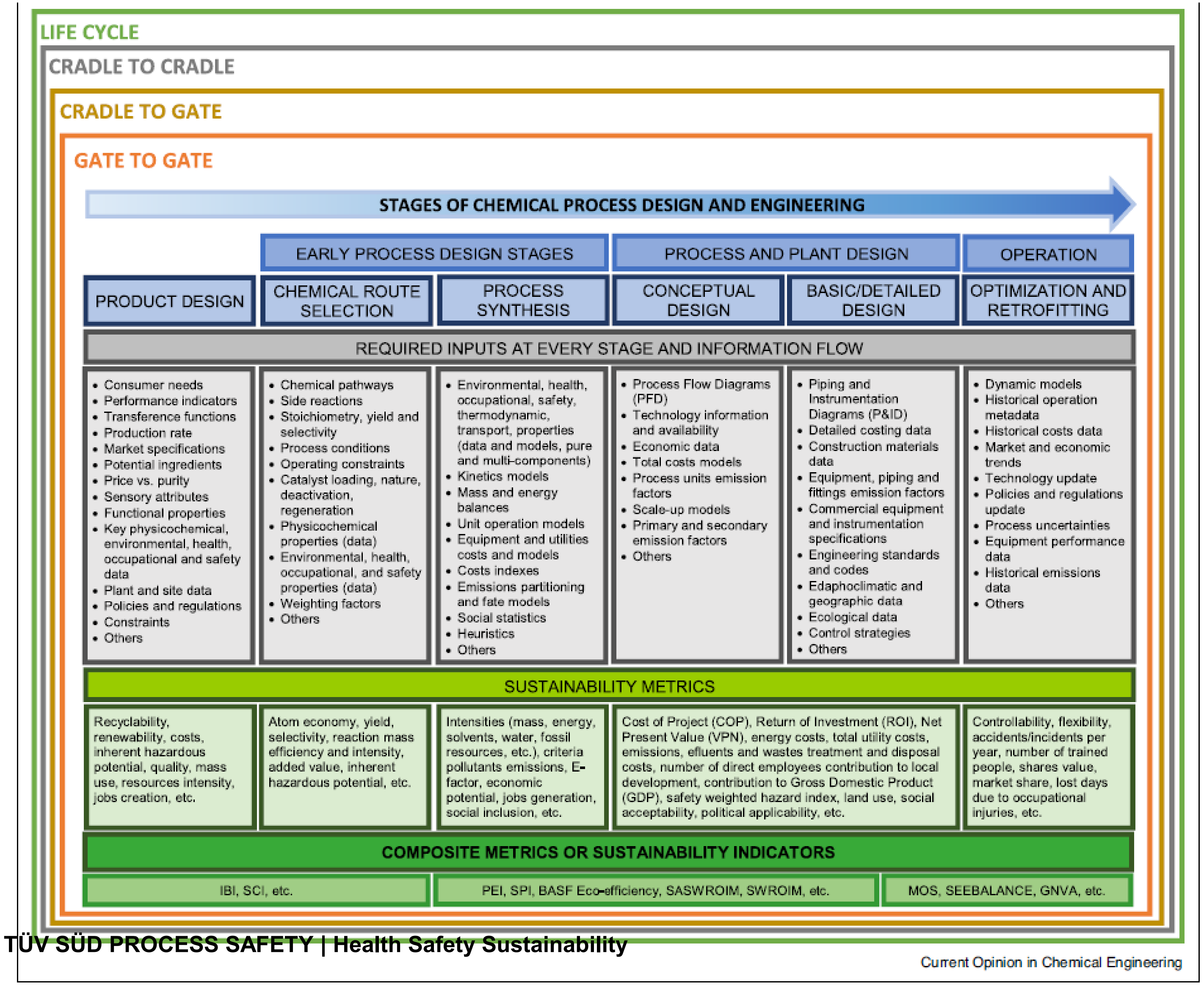
Process Development



Process Development



Process Development and Sustainability



Reference: A. Argoti et al, 2019, Current opinion in chemical engineering, Challenges and opportunities in assessing sustainability during chemical process design

Process Intensification

Equipment		Methods			
Equipment for carrying out chemical reactions	Equipment for operations not involving chemical reactions	Multifunctional reactors	Hybrid separations	Alternative energy sources	Other methods
Spinning disk reactor	Static Mixers	Reverse-Flow Reactors	Membrane Adsorption	Centrifugal Fields	Supercritical Fluids
Static mixer reactor (SMR)	Compact Heat Exchangers	Reactive Distillation		Ultrasound	Dynamic Reactor Operation
Static mixing catalysis (KATAPAKs)	Microchannel Heat Exchangers	Reactive Extraction	Membrane Distillation	Solar Energy	
Monolithic reactors	Rotor/Stator Mixers	Reactive Crystallization		Microwaves	
Microreactors	Rotating Packed Beds	Chromatographic Reactors	Adsorptive Distillation	Electric Field	
Heat Exchange Reactors (HEX)	Centrifugal Adsorber	Periodic Separating Reactors		Plasma Technology	
Supersonic Gas/Liquid Reactor		Membrane Reactors			
Jet-Impingement Reactor		Reactive Extrusion			
Rotating Packed-Bed Reactor		Reactive Comminution			
		Fuel Cells			

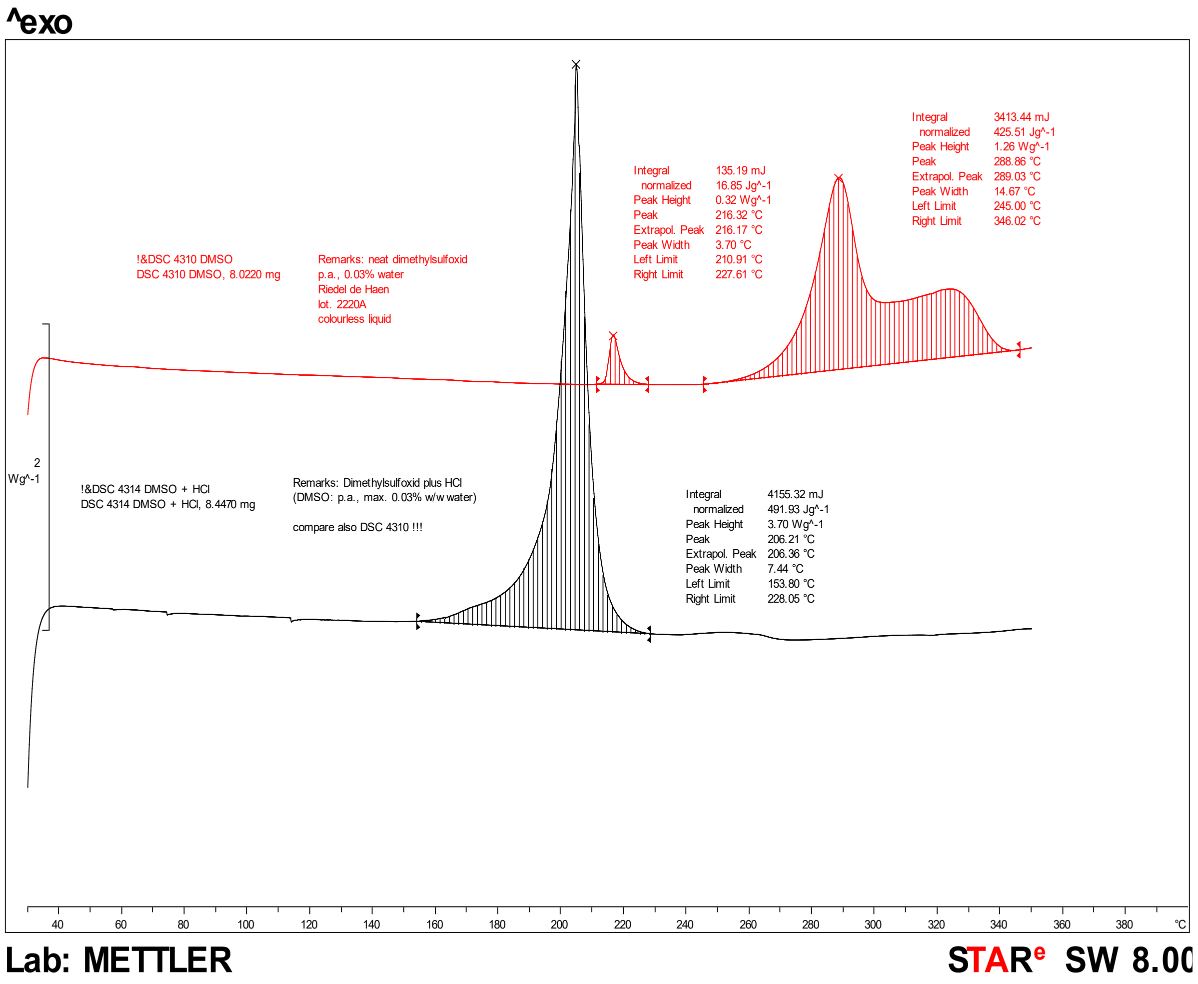
Improvement and drawbacks for safety

- What are the effects of these possible improvements on safety?

Case study - Solvent

- Solvents are widely used
  - Put species in contact
  - Make mass stirrable
- Cause a significant amount of waste
- What are the benefits of solvents? Why are solvent used?
- What can you do to improve sustainability with respect to solvents?

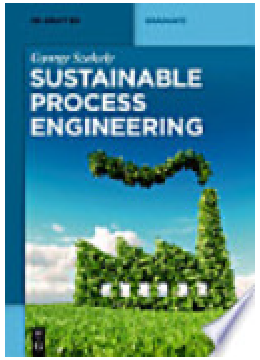
Effects of contaminants on DMSO



Effects of contaminants on DMSO

- DMSO Recovery
  - Batch destillation of DMSO
  - Solvent was contaminated with alkyl bromide
  - Storage during 1 year before destillation
  - Slow autocatalytic reaction destabilised DMSO

References



books.google.com › books

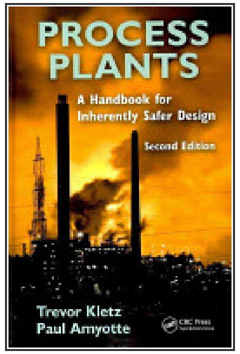
Sustainable Process Engineering

Gyorgy Szekely · 2021

The book provides a guide to sustainable process design applicable in various industrial fields. • Discusses the topic from a wide angle: chemistry, materials, processes, and equipment. • Includes state-of-the-art research achievements ...

Preview | More editions

Process Plants: A Handbook for Inherently Safer Design, Second Edition



Trevor A. Kletz, Paul Amyotte

Taylor & Francis, 17 May 2010 - Technology & Engineering - 384 pages

★★★★★

0 Reviews ⓘ

How far will an ounce of prevention really go? While the answer to that question may never be truly known, Process Plants: A Handbook for Inherently Safer Design, Second Edition takes us several steps closer. The book demonstrates not just the importance of prevention, but the importance of designing with prevention in mind. It emphasizes the role of inherent safety in process safety management systems and in ensuring an appropriate process safety culture. Keeping the easy to understand style that made the first edition so popular, this book clearly delineates practical, everyday issues and complex technical ones.

More »

References

- The Brundtland report

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Report of the World Commission on Environment and Development

Our Common Future

United Nations
1987

- R.A. Sheldon

ACS Sustainable Chemistry & Engineering

Perspective

Cite This: *ACS Sustainable Chem. Eng.* 2018, 6, 32−48

pubs.acs.org/journal/ascecg

Metrics of Green Chemistry and Sustainability: Past, Present, and Future

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Department of Biotechnology, Delft University of Technology, Section BOC, van der Maasweg 9, 2629 HZ Delft, The Netherlands

ABSTRACT: The first green chemistry metrics—the E factor (kgs waste/kg product) and atom economy (mol wt of product/sum of mol wts of starting materials)—were introduced in the early 1990s and were actually green chemistry *avant la lettre*. In the last two decades, these two metrics have been adopted worldwide by both academia and industry. The E factor has been refined to distinguish between simple and complete E factors, for example, and to define the system boundaries. Other mass-based metrics such as process mass intensity (PMI) and reaction mass efficiency (RME) have been proposed. However, mass-based metrics need to be augmented by metrics which measure the environmental impact of waste, such as life cycle assessment (LCA), and metrics for assessing the economic viability of products and processes. The application of such metrics in measuring the sustainability of processes for the manufacture of pharmaceuticals and other fine chemicals is discussed in detail. Mass-based metrics alone are not sufficient to measure the greenness and sustainability of processes for the conversion of renewable biomass vs fossil-based feedstocks. Various metrics for use in assessing sustainability of the manufacture of basic chemicals from renewable biomass are discussed. The development of a sustainable biobased production of chemicals meshes well with the concept of a circular economy, based on resource efficiency and waste minimization by design, to replace traditional linear, take−make−use−dispose economies.

KEYWORDS: *E factor, Atom economy, Carbon economy, Step economy, Circular economy, Biobased economy, Ethanol equivalent, Life cycle assessment*

Project & Assessment Sustainability (Health and Safety)

- Group of 2-3 people
- Sustainability and Health or Sustainability and Safety (linked with chemistry and/or chemical engineering)
  - Present & Discuss a Paper
  - Present & Discuss an Equipment
  - Present & Discuss a Methodology
  - …
- 2-3 pages
  - Summarize paper/Introduce methodology
  - Discuss impact (advantages, drawbacks…) on sustainability and Health and/or Safety
  - Conclude
  - References
- Due date EPFL: 6th October; ETH 29th October
- Hand-in via moodle
- Preferred language English
  - (German or French also possible)

Example of possible projects

- Sustainability and health
  - Banning of PFAS: trade-offs (https://environment.ec.europa.eu/strategy/chemicals-strategy_en#documents)
- Sustainability and safety
  - Discuss an equipment or a method (multifunctional reactors or hybrid separations)
    - Trade-offs, advantages, disadvantages (safety – sustainability)
  - Metrics for sustainable development and safety (e.g. paper of R.A. Sheldon (2018) & Kweku et al 2008 Comparison of methods for assesing environmental, health and safety (EHS) hazards in early phase of chemical process design)
- Present and discuss a paper on sustainability (linked to chemistry or chemical engineering)
  - E.g A. Argoti et al, 2019, Current opinion in chemical engineering, Challenges and opportunities in assessing sustainability during chemical process design
  - Webinar: Amidation Reaction - Calorimetric and Modeling Techniques (mt.com)

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Rotating Packed-Bed Reactor		Reactive Comminution			
		Fuel Cells			

Grading

Structure

What	Max points	Points	Comment
2-3 pages for 2 persons	0.25		
Structured paper (Titles, legends for figures etc)	0.25		
References, cited in the paper	0.25		
Total	**0.75**		

Topic

What	Max points	Points	Comment
Sustainability	0.5		
Health and or Safety	0.5		
Adv, dis, Trade offs	1		
Common thread	0.5		
Specific	0.5		
Grasp fundamentals/ big picture	0.5		
Clear Intro on methodology/paper etc	0.5		
Relevant References	0.25		
Total	**4.25**		

Thank you

TÜV SÜD Schweiz AG

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