A new paradigm for chemical engineering?

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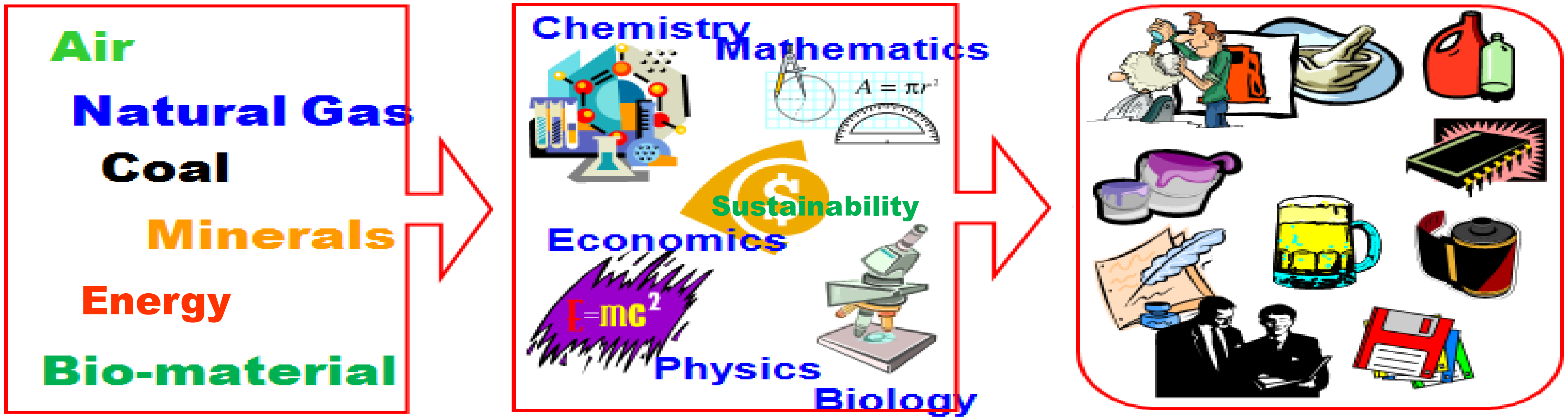
What is chemical engineering? **Definition**

Chemical engineering is the application of science, mathematics and economics to the process of converting raw materials or chemicals into more sustainable forms. The terms economics & sustainability are very important here.



What chemical engineers do? **Highlights**

- **Work with unit operations** for purposes of chemical synthesis and/or separation (chemical reaction, mass-, heat- and momentum- transfer operations)
- **Apply physical laws** of conservation of mass, energy and momentum
- **Apply principles** of thermodynamics, reaction kinetics and transport phenomena
- **Solve problems** – design & operate processes
- **More than just process engineering** – applies chemical knowledge to create better materials and products that are useful to our modern society

Paradigm and Paradigm shift

Paradigm is a constellation (of ideas) that defines a profession and an intellectual discipline

Paradigm shift: The Structure of Scientific Revolution - scientific advancement is not evolutionary, but rather a "series of peaceful interludes punctuated by intellectually violent revolutions", and in those revolutions "one conceptual world view is replaced by another"

Thomas Kuhn 1962

Scientific revolution through paradigm shift

Paradigm Shift points to a change from one way of thinking to another. It's a revolution, a transformation, a sort of metamorphosis. It just does not happen, but rather it is **driven by agents of change**.

Examples:

- Agriculture changed early primitive society
- Printing press changed the culture of people
- Scientific theory changed Newtonian physics to Relativity and Quantum Physics
- Personal computer & internet is effecting personal & business environment

The quantum leaps in ChE development

Significant changes through paradigm shifts

1. The first paradigm - *Unit Operations*, 1923

"Unit Operations should be the foundation of chemical engineering"

2. The second paradigm - *Transport Phenomena*, 1960

- A new burst of creative research activities.
- The chemical industry dominated world, companies like DuPont, ICI, and Exxon content to recruit academically educated graduates, willing to teach them technology.

3. The third paradigm - ??

Entering a golden age for ChE?

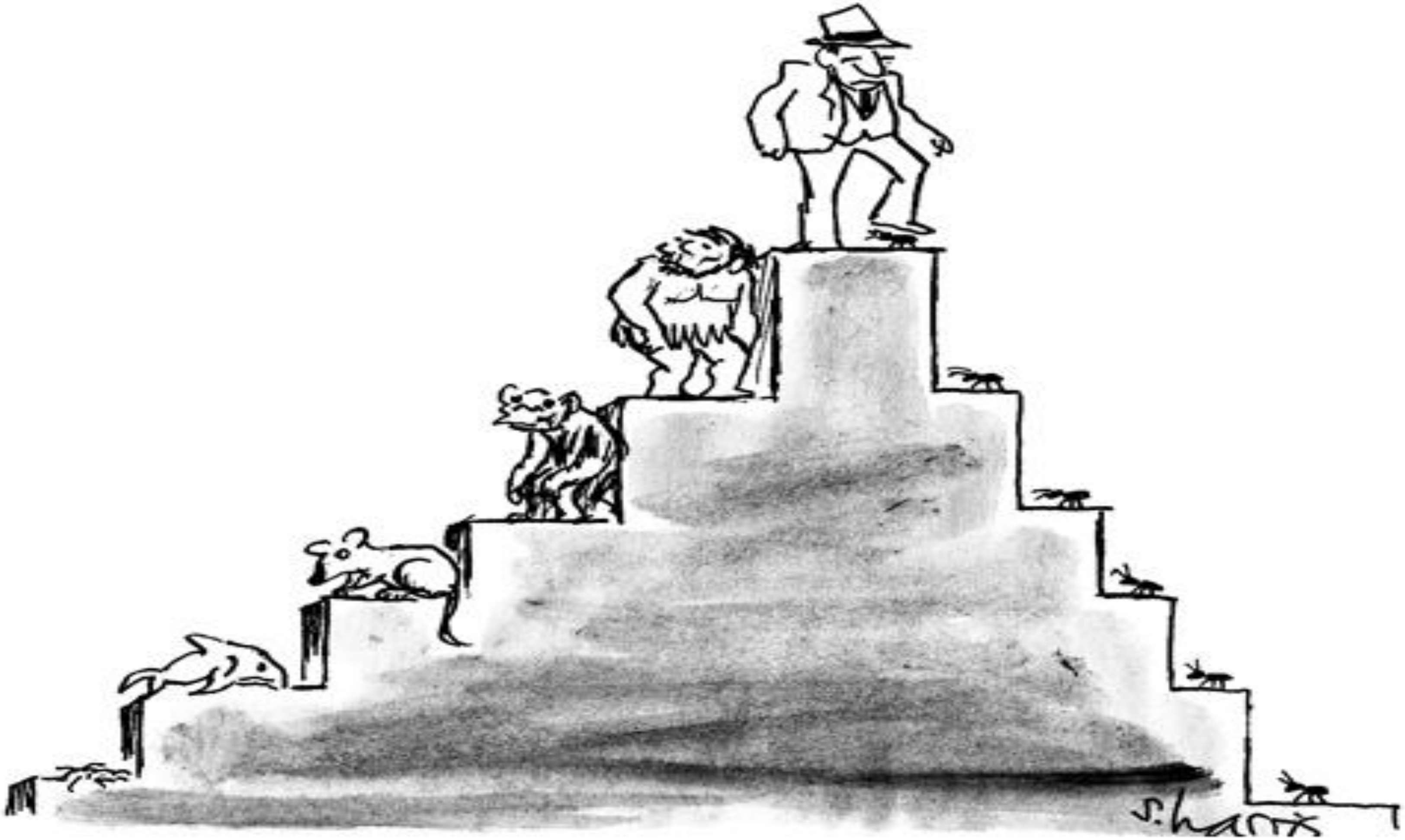
Adopted from Phil Westmoreland's* 5 reasons

- Manufacturing's shift to emphasize processes and properties (smart manufacturing)
- New abundance of hydrocarbon resources in the US (a game changer)
- Biology's turning into a molecular science (multi-disciplinary)
- Computing, evolved into a cyberinfrastructure (knowledge and data management)
- ChEs' breadth and problem-solving approaches (contribute to the society)

* President of the AIChE, 2013

Development of our modern society

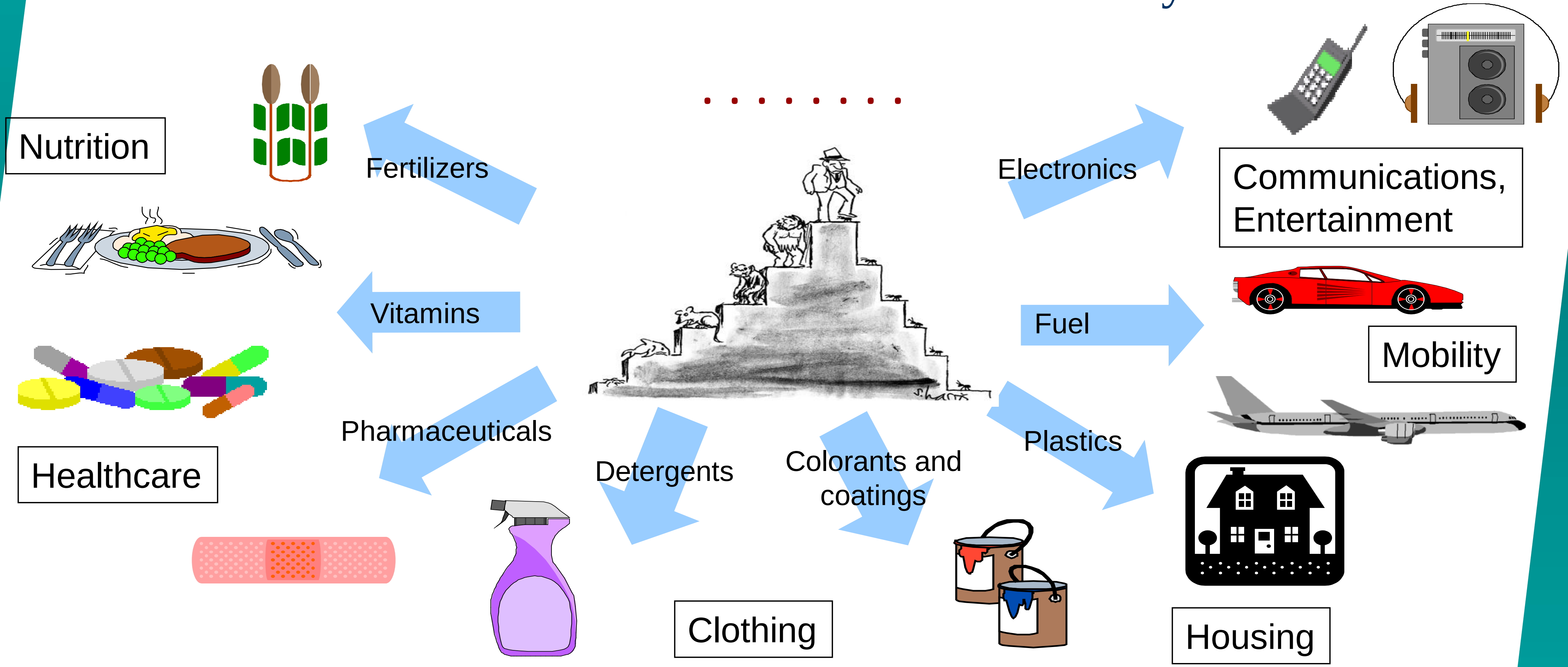
Humans are the master of this planet



But, how did we get there? Or, what are the problems now? Or, how do we stay there?

Master of the planet – how did we get there?

Positive contribution to our modern society



Survival of our modern society depends on the products from ChE

Master of the planet – how did we get there?

Sustainability Issues: Current and future survival

World population is expected to reach 11 billions by 2050

Increase in water, energy & commodities demand

6-7 x		Global GDP growth over next ~50 years (in constant dollars)
5-6 x		Production capacity for most commodities (steel, chemicals, lumber, etc.)
3.5 x		Energy demand **7 x** Electricity demand
Increase		Water demand
Increase		GHG emissions

Siirola, PSE-2012

Is our future sustainable? Process Industry Growth*

Region	2000 Prod	2000-25 Growth New Plant	%Tot	2025-50 Growth New Plant	%Tot
North America	1.0	0.6	5	0.8	5
Latin America	0.4	1.1	9	1.6	10
Europe	1.1	1.1	9	0.5	4
Africa	0.2	1.5	12	3.2	21
Asia	1.4	8.2	65	9.3	60
World	4.1	12.6		15.4	

* Current North America = 1.0

Siirola, PSE-2012

PSE for SPEED Sustainable Product-Process Engineering, Evaluation & Design

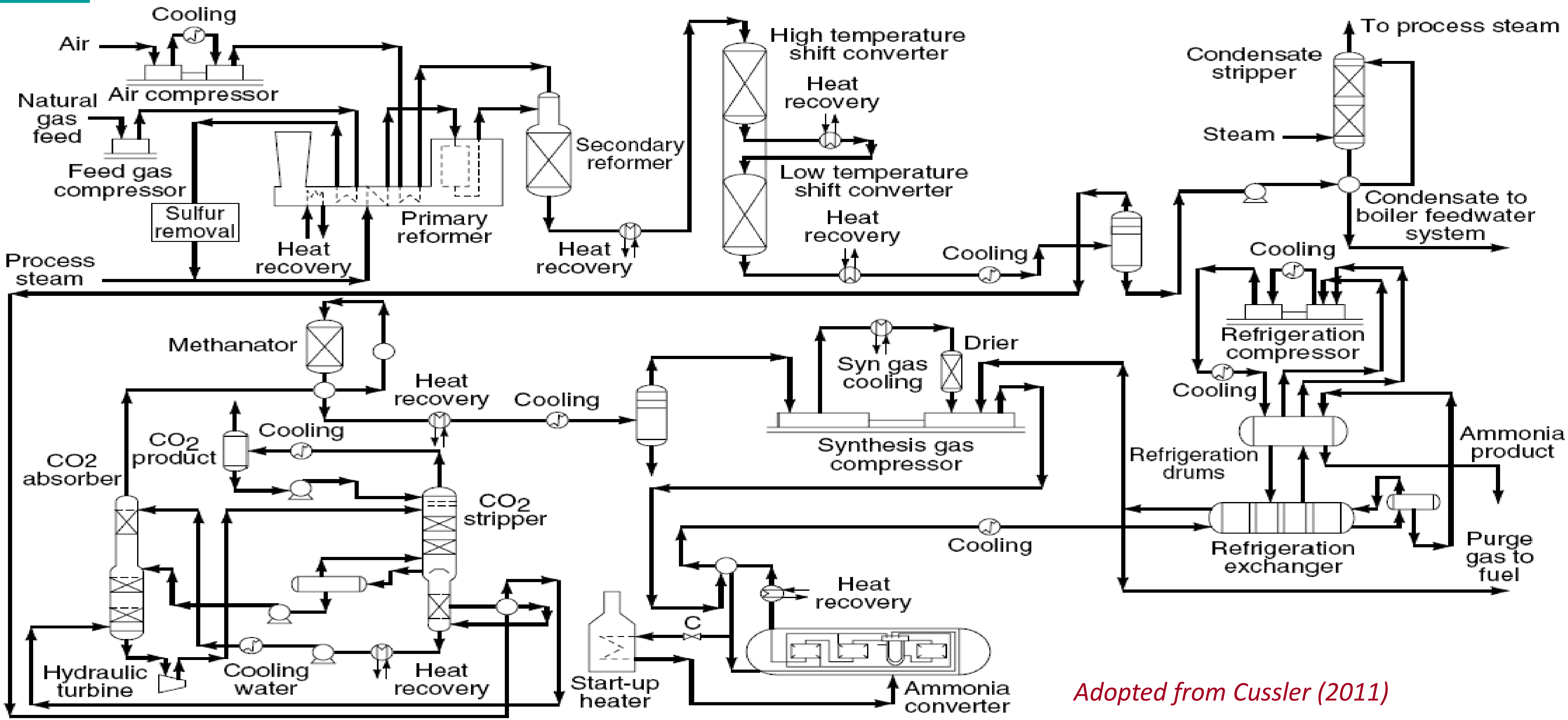
Paradigm shifts in ChE: **The key products**

	Commodities	Molecules	Microstructures
Key	Cost	Speed	Function
Basis	Unit Ops	Chemistry	Microstructure
Risk	Feedstock	Discovery	Science

What skills are required?

Adopted from Cussler (2011)

For commodities, ”**manufacture**” is the key



Adopted from Cussler (2011)

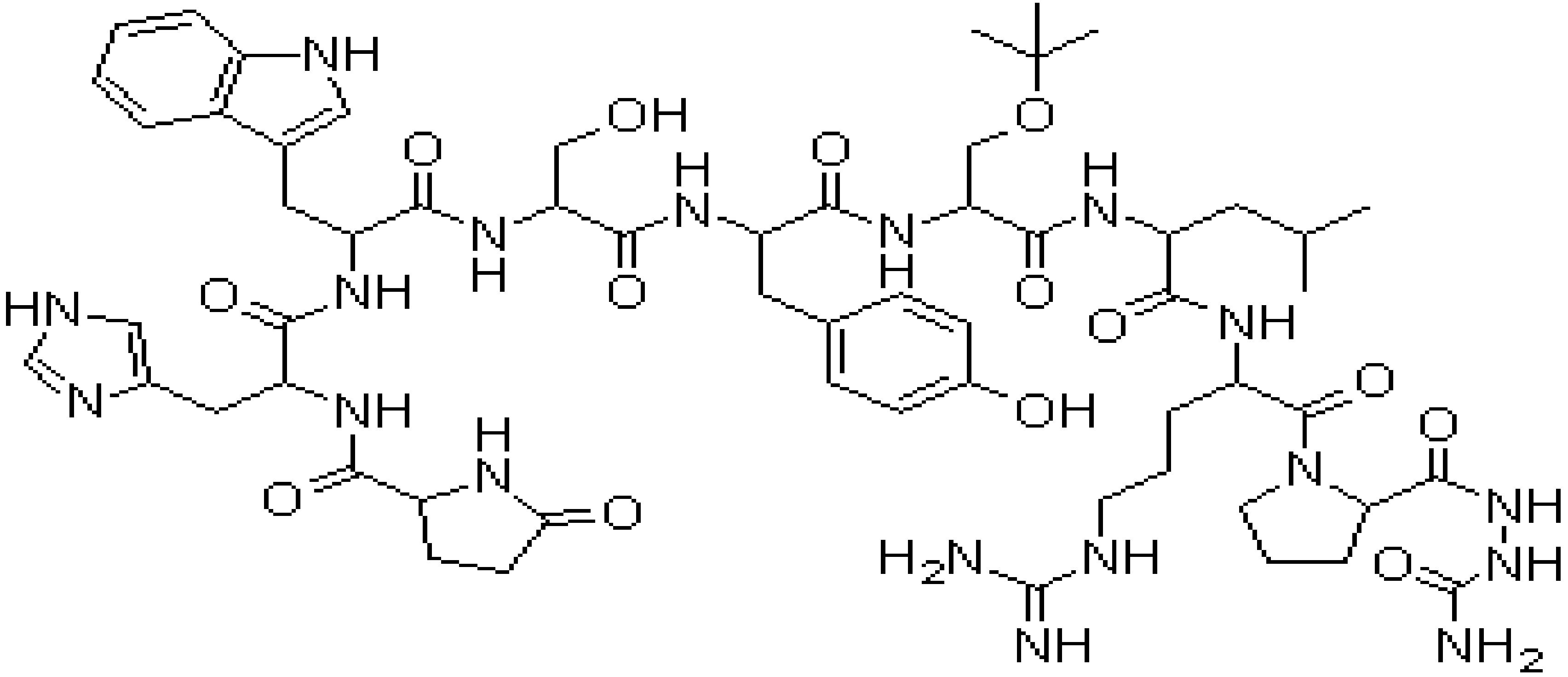
The future is unclear! **Risky feedstock**

Fight for survival!

Adopted from Cussler (2011)

For molecules, “**selection**” is key

46 Kilos = $800 M



Pyr-His-Trp-Ser-Tyr-D-Ser(tBu)-Leu-Arg-Pro-Azagly-NH_2

Adopted from Cussler (2011)

For microstructures, ”**need**” is the key

Jet-fuel blend

Gasoline blend

Scientifically specified

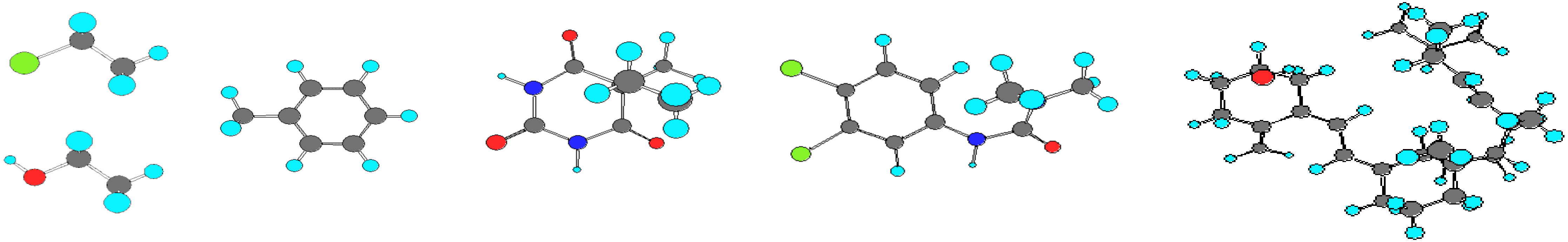
Liquid formulations & emulsions

Consumer reactions

Problem dimension - molecules

How do we find the new molecules?

solvents, fuels, … **drugs, pesticides, aroma, ….**

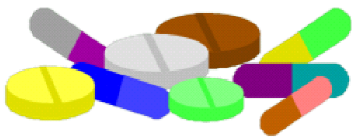


Low	← **Value** →	**High**
Preservation		***Creation***
Large	← **Production rate** →	**Small**
Easy	← **Finding candidates** →	**Difficult**

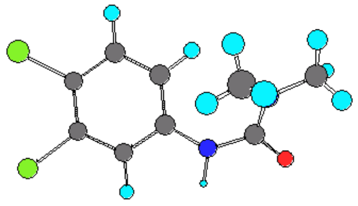
Innovative solutions need new molecules or new uses of the existing molecules

Achieving sustainability through product-process

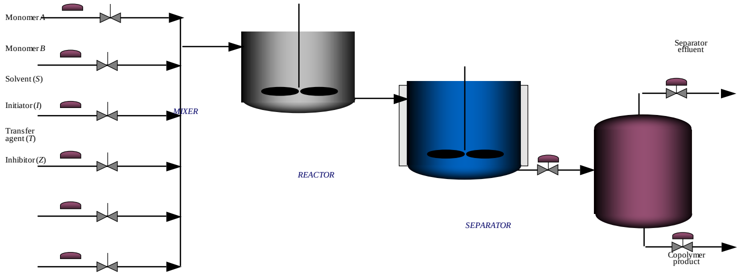
Product



Product function



Process function



Process

What is the best way to identify, design, develop,

....

the chemicals based products & their processes?

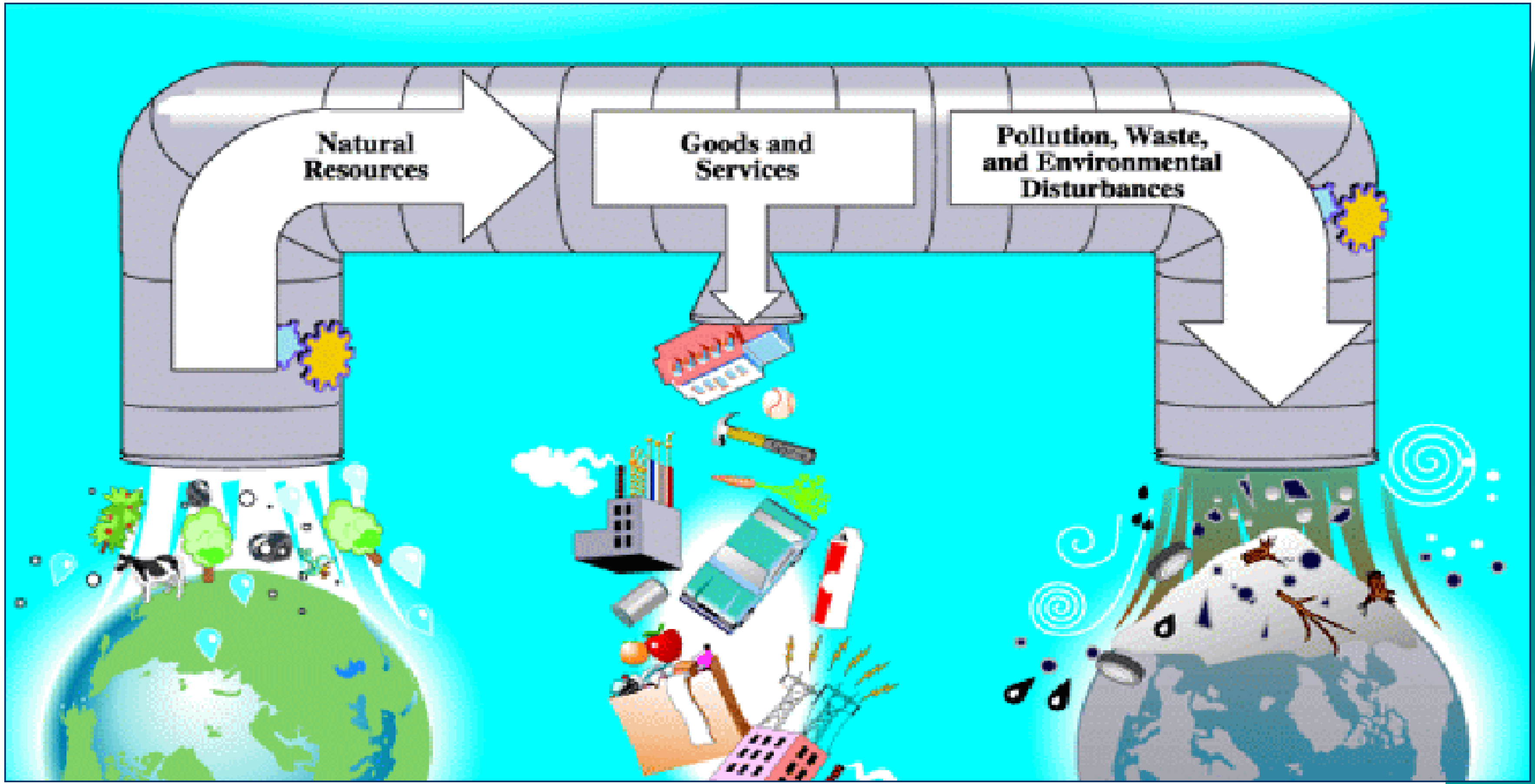
Is our future sustainable? The **challenge** facing us

Convert resources to products

Use energy, **water, ….**

Environmental Impacts (GWP, **OD, HTTP, …)**

Produce waste



Only 25% converted; must be > 40% (Driolli 2007)

Wrong use? Issue of concern - **Innovation**

G. Agricola, *De Re Metallica*, 1556

Innovations in Unit operations

Chemical Process Industry, 2006

Is it possible to achieve more improvements in design for these equipment?

Adapted from Stankiewicz, 2008

Paradigm shift in education - 1

Which skills, outcomes and knowledge are common and should not be ignored in new study programs?

Besides the core, which are other, non-traditional topics, engineering fields and non-engineering knowledge necessary for engineers to manage problems of specific current and future (bio)chemical and process related industries?

EFCE Education WP, 2005-2010

Paradigm shift in education - 2

Which are other, non-traditional topics, engineering fields and non-engineering knowledge necessary for engineers to manage problems of specific current and future (bio)chemical and process related industries?

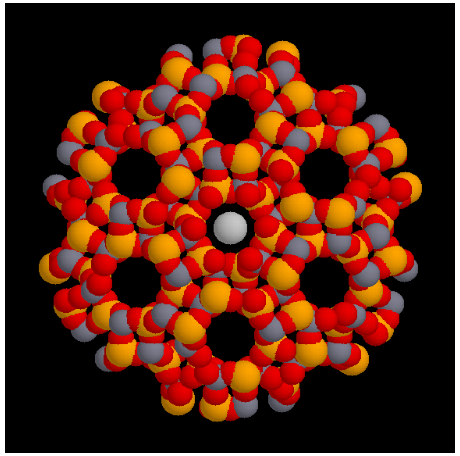
"Chemical engineering should be redefined to cope with innovative technologies rather than new disciplines outside ChE"

EFCE Education WP, 2005-2010

Curriculum vs role & scope of ChE

1. What is the role of Chemical & Biochemical Engineering in "commodity" industry vs. "new emerging" technologies?

Value preservation vs. Value creation



2. What is the future scope for fundamental contributions in Chemical & BioChemical Engineering ? ***Engineering vs. Science***

3. What are the major real world challenges

Globalization, energy, environment, health

Paradigm shift in education - 3

1. Need to keep core Chemical Engineering Knowledge; Need to emphasize fundamentals: basis is life-long learning

2. Need to modernize curriculum and add flexibility
   - Increase exposure at molecular level
   - Increase exposure to energy (alternative/renewable) and sustainability issues
   - Expose students to new process technology
   - Introduce product design as complement of process design
   - Emphasize process operations, enterprise planning
   - Increase link to other industrial sectors (pharma, electronics)

Grossmann 2014

Paradigm shift in education - 3

3. Need to recognize that “bio-area” & “nano-area” will be important but not dominant force in Chemical Engineering

4. Environmental Engineering increasingly important and requires chemical engineering (water use efficiency, pollution control.) : Civil Eng. ownership?

5. Need closer interaction with industry; otherwise risk being irrelevant

6. Need to provide excitement to recruit the very best young people to join Chemical Engineering

Grossmann 2014

Paradigm shifts within ChE: Resources & renewables

- Natural gas replacement for coal as the primary early carbon management technique (source reduction)
- Increased deployment of highly efficient NGCC plants
- Use of synthetic fuels
- For many intermediates competition between C1 (methane) and C2 (ethane) feedstocks resulting from advances in catalysis, energy efficiency, process design
- ……..

Adopted fromSiirola, PSE-2012

Development of ChE – new directions

Unique opportunities and formidable challenges

Probe the frontiers of technological innovations to bring

- New categories of abundant resources
- Substitute and/or improve resources that become scarce
- Deliver sustainable solutions (energy, water, food …)
- Contribute to staving off disaster (global climate change, a viral pandemic, oil spills, …)
- 3rd Paradigm (P-P-P integration)

Problem solution versus managing the complexity

Problems

Design

Synthesize

Operate

Plan

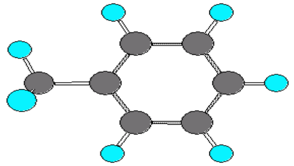
Problem defined by

- System boundary
- Models (of different types, sources, ...)
- Data (from different sources,)
- Multi-objectives & multi-disciplines
- ....

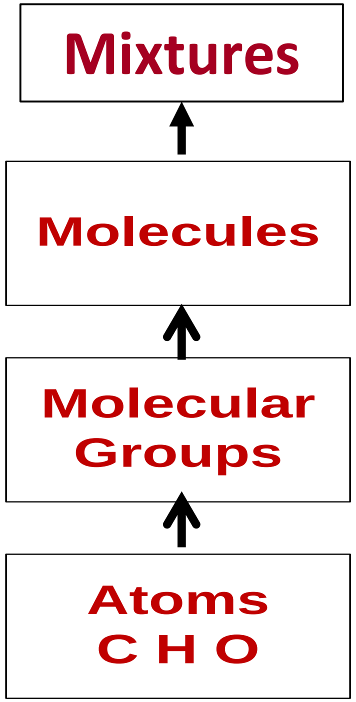
ChE = *systematic solution of problems by efficient management of the complexity*

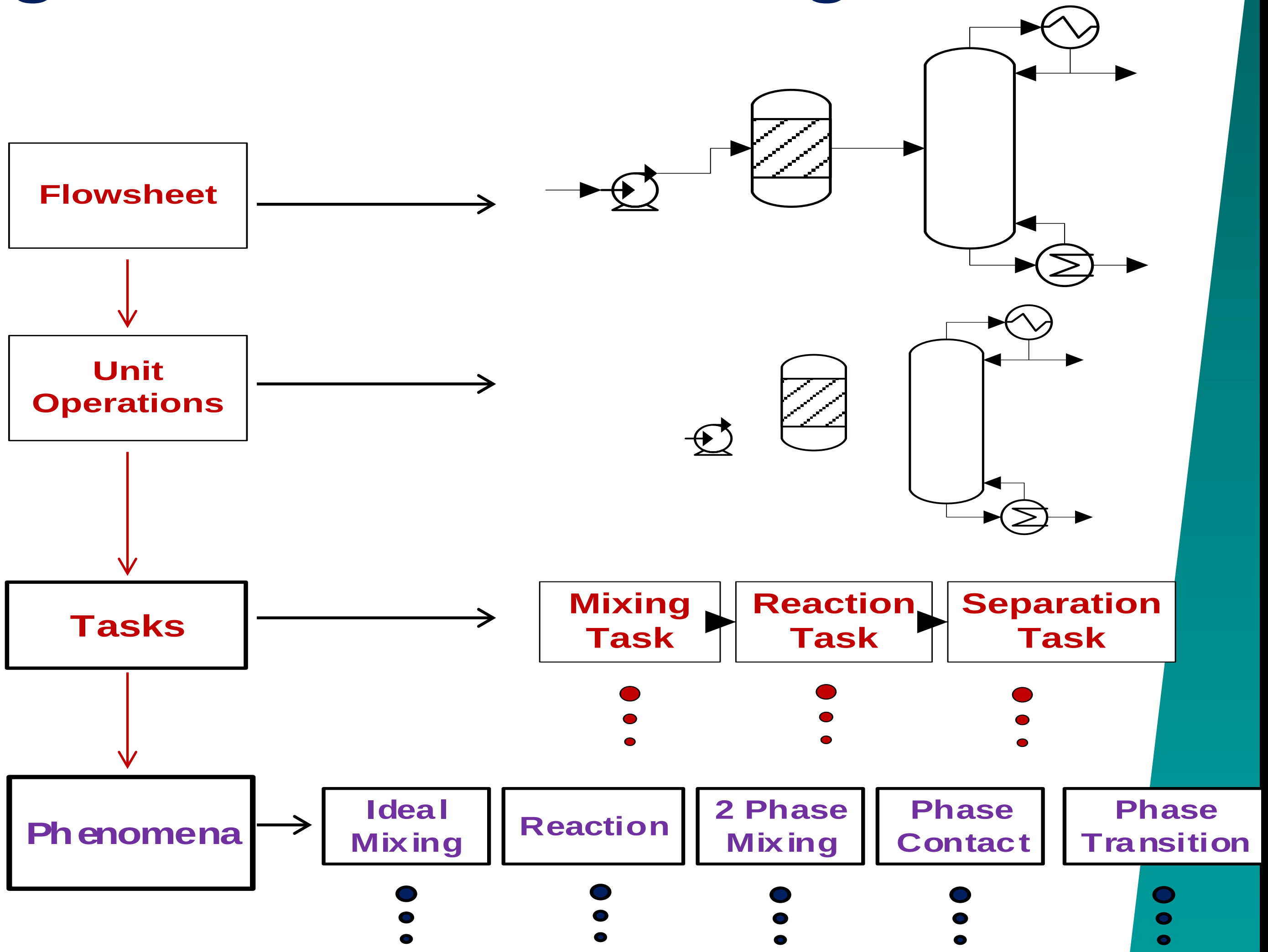
Flowsheet design as molecular design

Key concept: Design processes in the same way as molecules



Lower level of aggregation

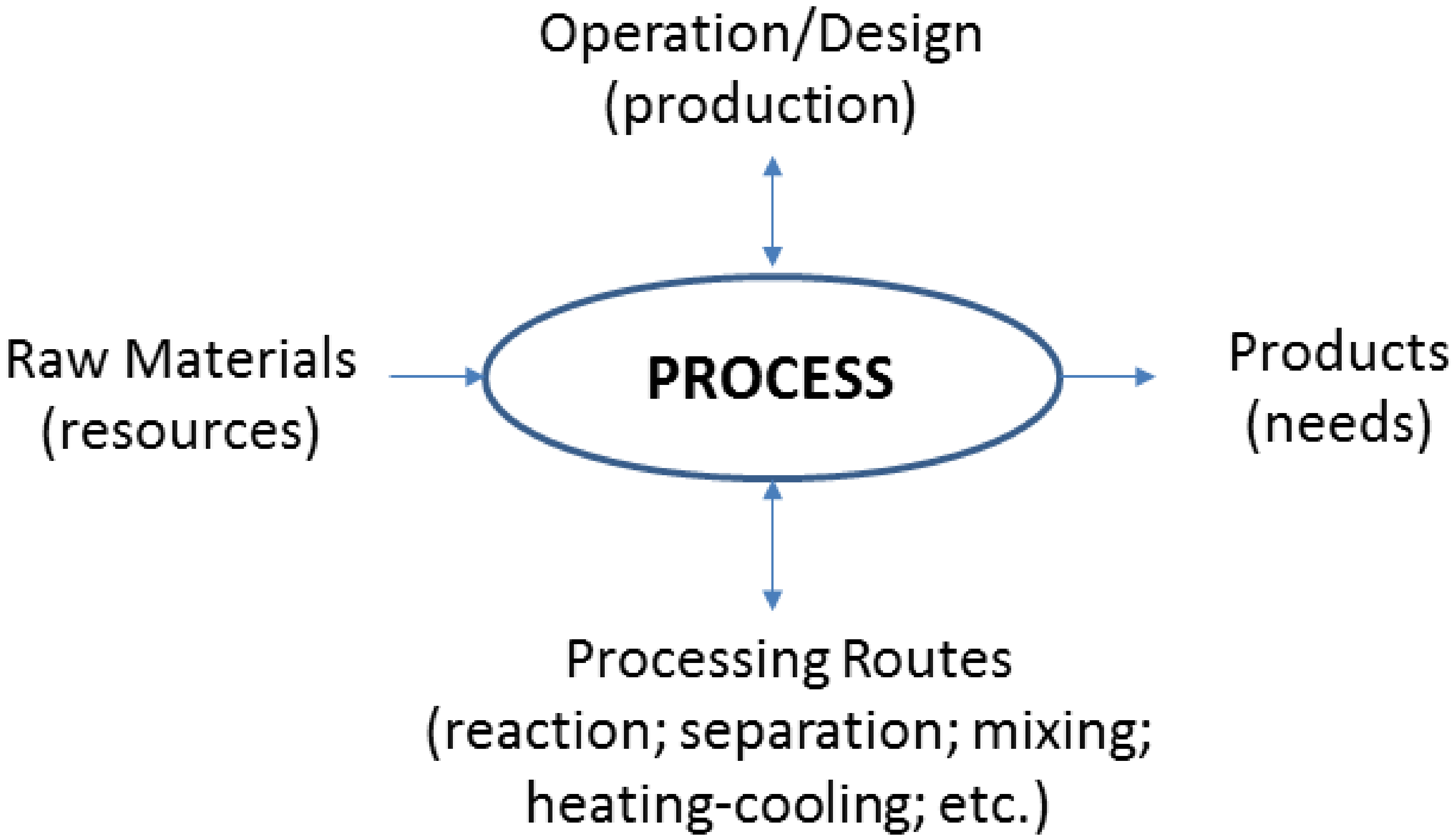




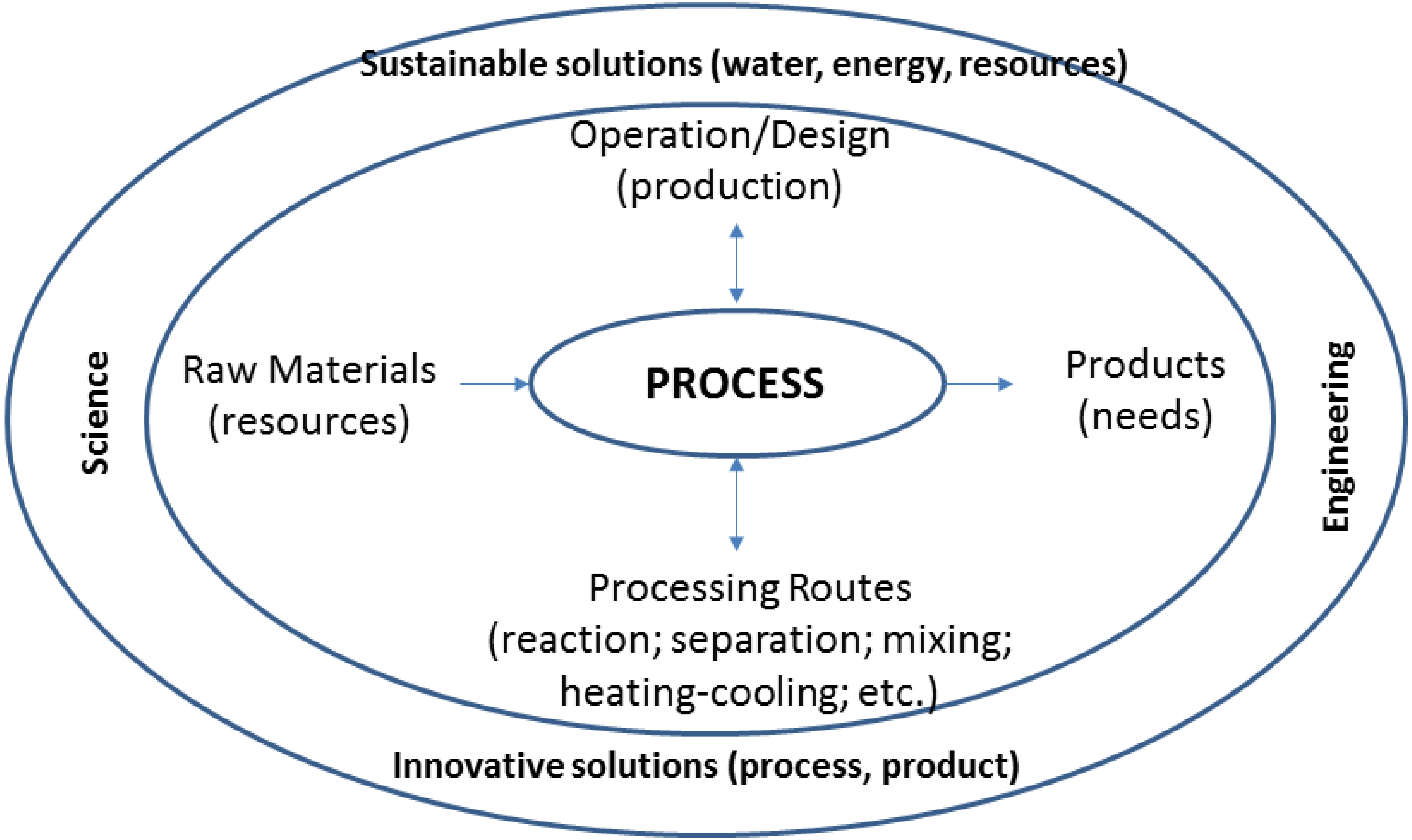
Gani et al. (1994)

Lutze et al. (2013)

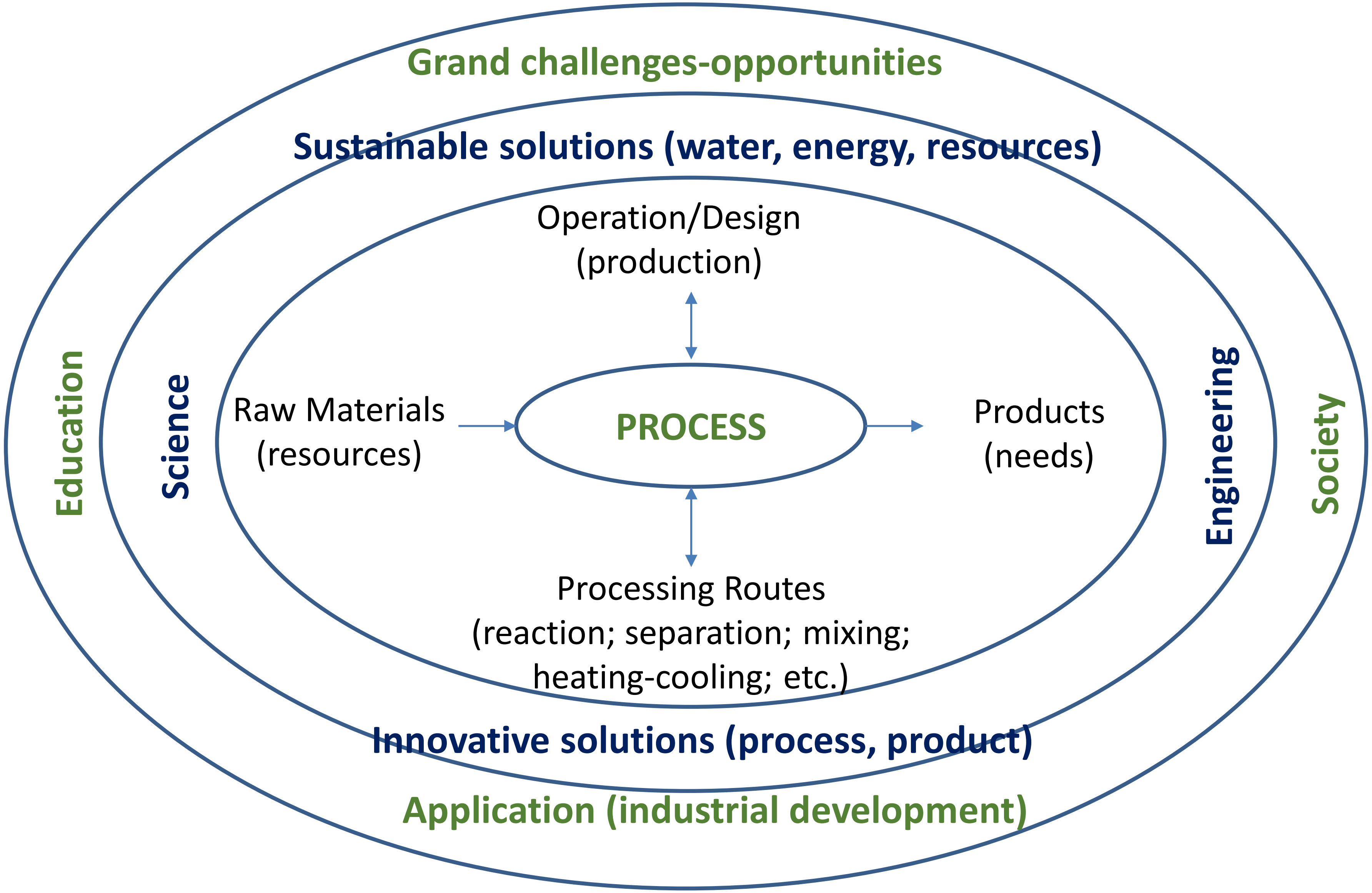
A multi-layered view of ChE: **Core** layer



A multi-layered view of ChE: **Interface** layer



A multi-layered view of ChE: Connecting layer



Dependent on the wrong people?

Why should others make decisions for us? How do we become decision makers?

Conclusions & future directions

ChE’s positive contribution to the modern society through P^3I

- Need to adapt to the needs of the modern society (questions of energy, water, environment, sustainability, responsibility, ... should be incoporated in the study)
- Courses need to adopt (introduction of new ideas, new methods, new tools, ...)
- Balance between engineering-science; commodity-value added; core-new need to be found (different solutions are possible)