Technologies and innovations shaping the future of petrochemical industry

Saeed Sahebdelfar

Petrochemical Research and Technology Co.

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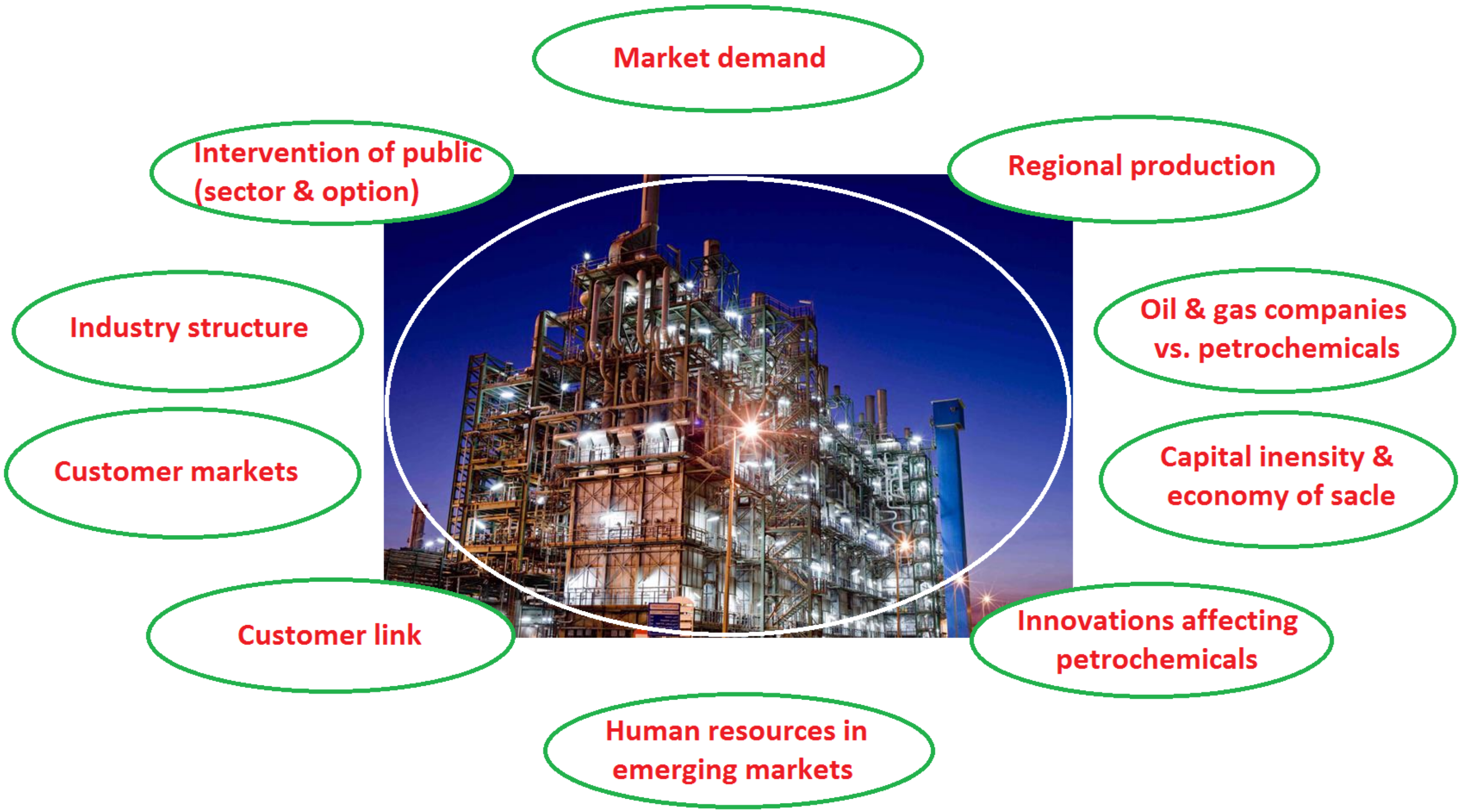
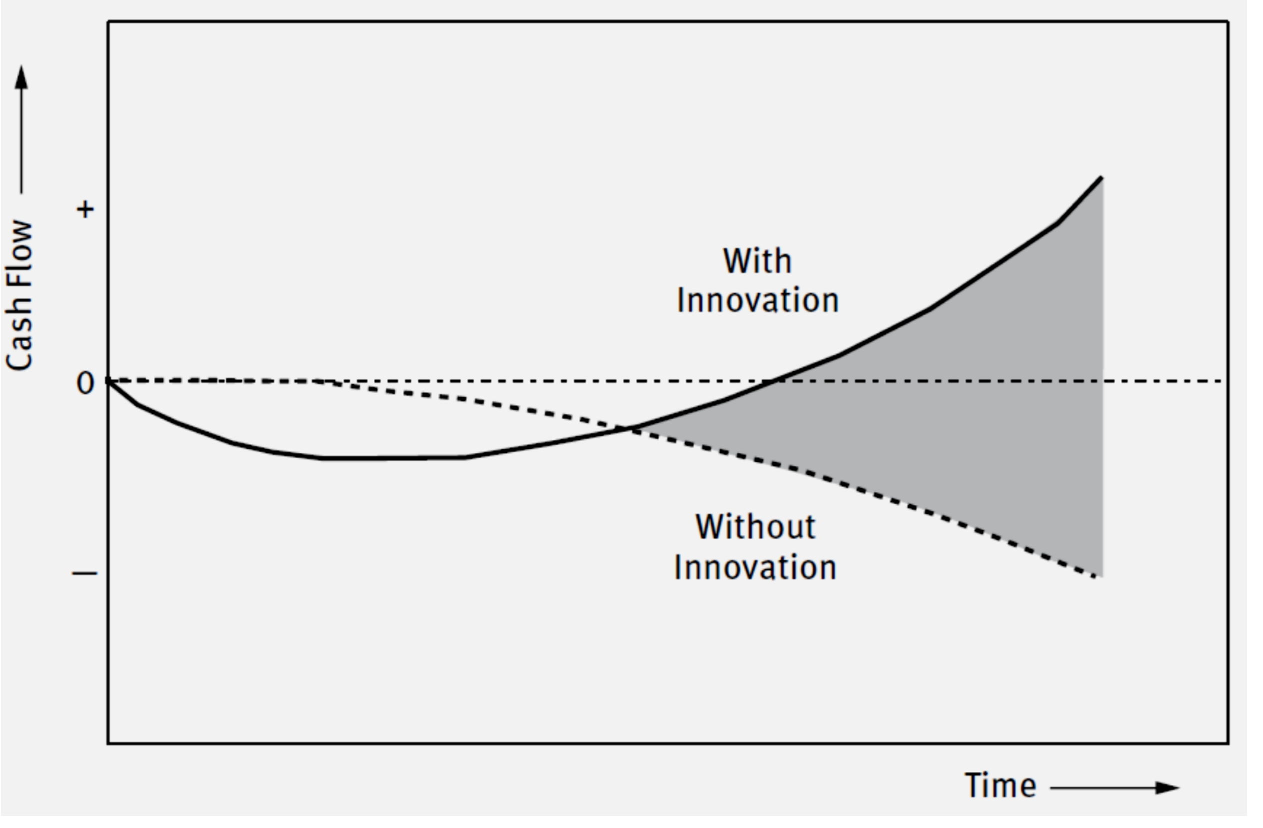
Agenda

- Change drivers
- Innovation role
- Foresight
- Centralized vs. distributed production
- Electrification and intensification
- Circular economy
- Technology foresight by patent analysis
- Research and innovation needs
- Conclusions

Main drivers of petrochemical industries

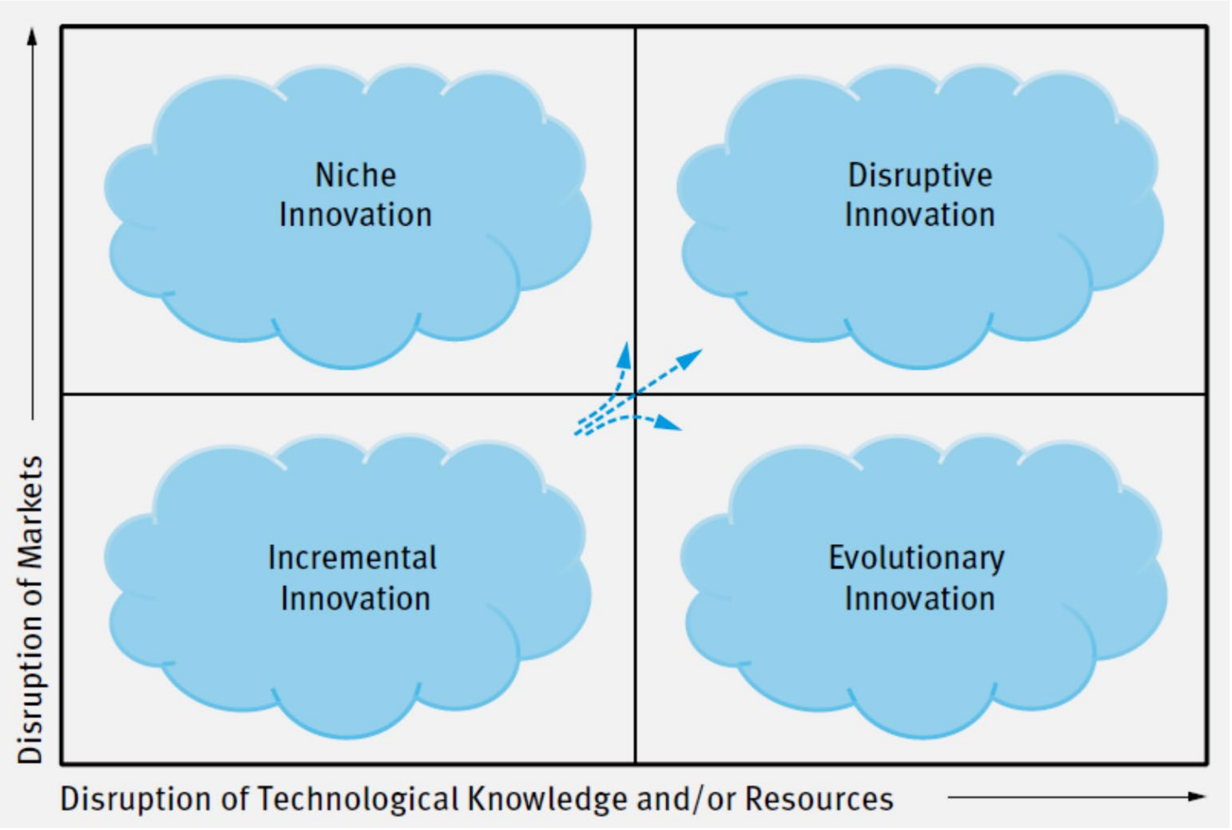


Effect of innovation on cash flow in a competitive market



"No innovation" net cash flow projection is negative rather than zero

Abernathy and Clark's model



A "Transilience Map" Illustrating Abernathy and Clark's Forms of Technological Innovation and Their Influence on an Organization's Prior Technological Knowledge and Resources (horizontal axis) and on the Competitive Marketplace (vertical axis).

Disruptive innovation

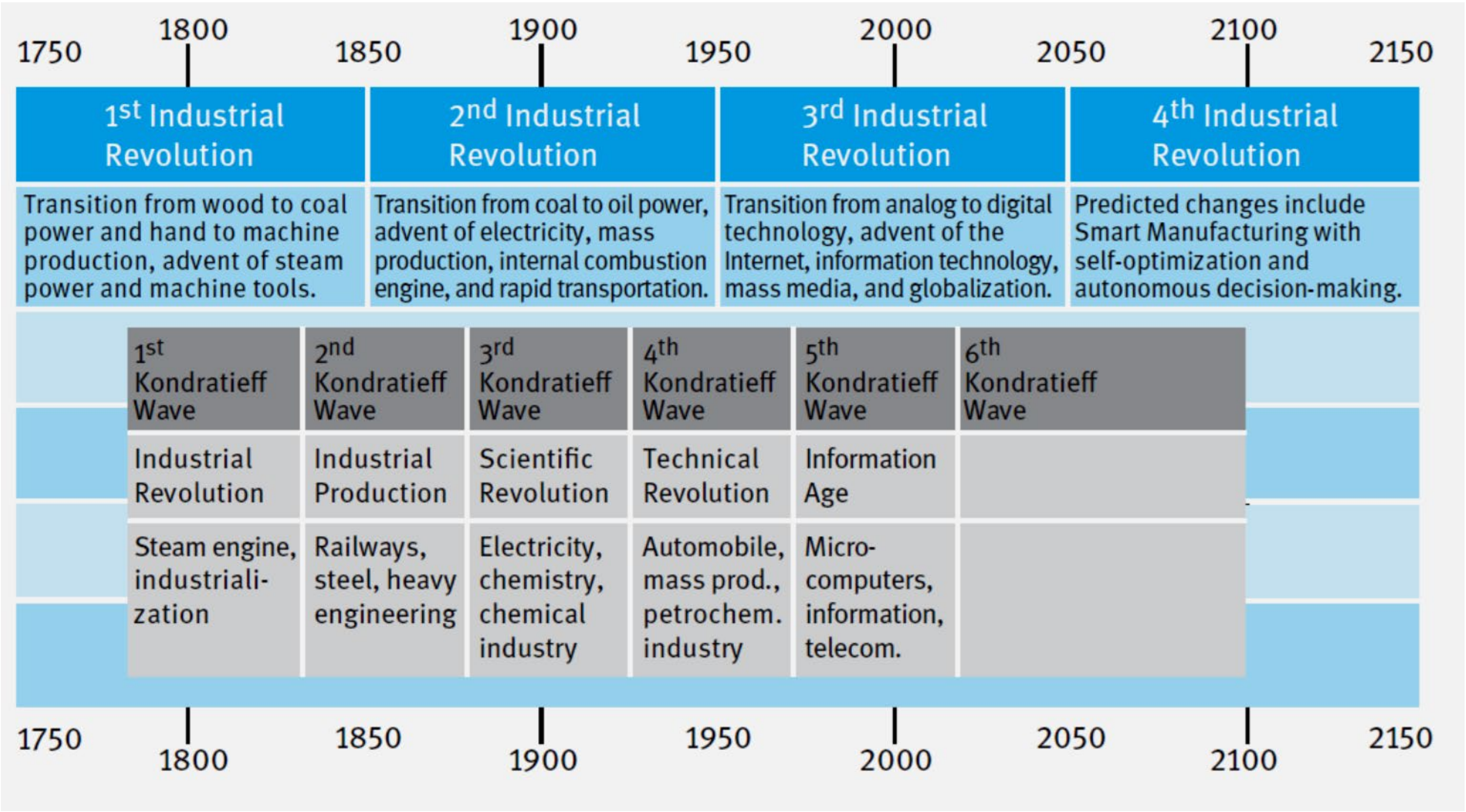
- An innovation displacing an earlier commercial product, process, or service and significantly changing (disrupting) a market niche, or even an entire market.
- Also termed catalytic innovation, disruptive technology, discontinuous innovation, fundamental innovation, radical innovation, technology-push innovation, transformational innovation, or revolutionary innovation.
- Unexpected in the marketplace and different from evolutionary or incremental innovations.
- Typically very R&D intensive and may require discovery research.

Ongoing trends affecting the petrochemical industry

- Feedstock change
- Greener production
- Integrity (petrochemical & refineries)
- Circular economy
- Energy transition

But what about the future?

Kondratieff Waves and the Industrial Revolutions



The 6th and 7th Kondratieff waves

- The 6th wave, spanning the current era, predicted to last from about 2010 to about 2050. Key developments during might include environmental technology, genetic engineering, nanotechnology, robotics, and health technologies.
- The 7th wave, spanning a future era, predicted to last from about 2050 to about 2090. The speculated developments may be driven by a merging of technology and intelligence to create autonomous robots, whether at nanoscale, microscale, or macroscales, that are capable of independent action, self-repair, and replication.

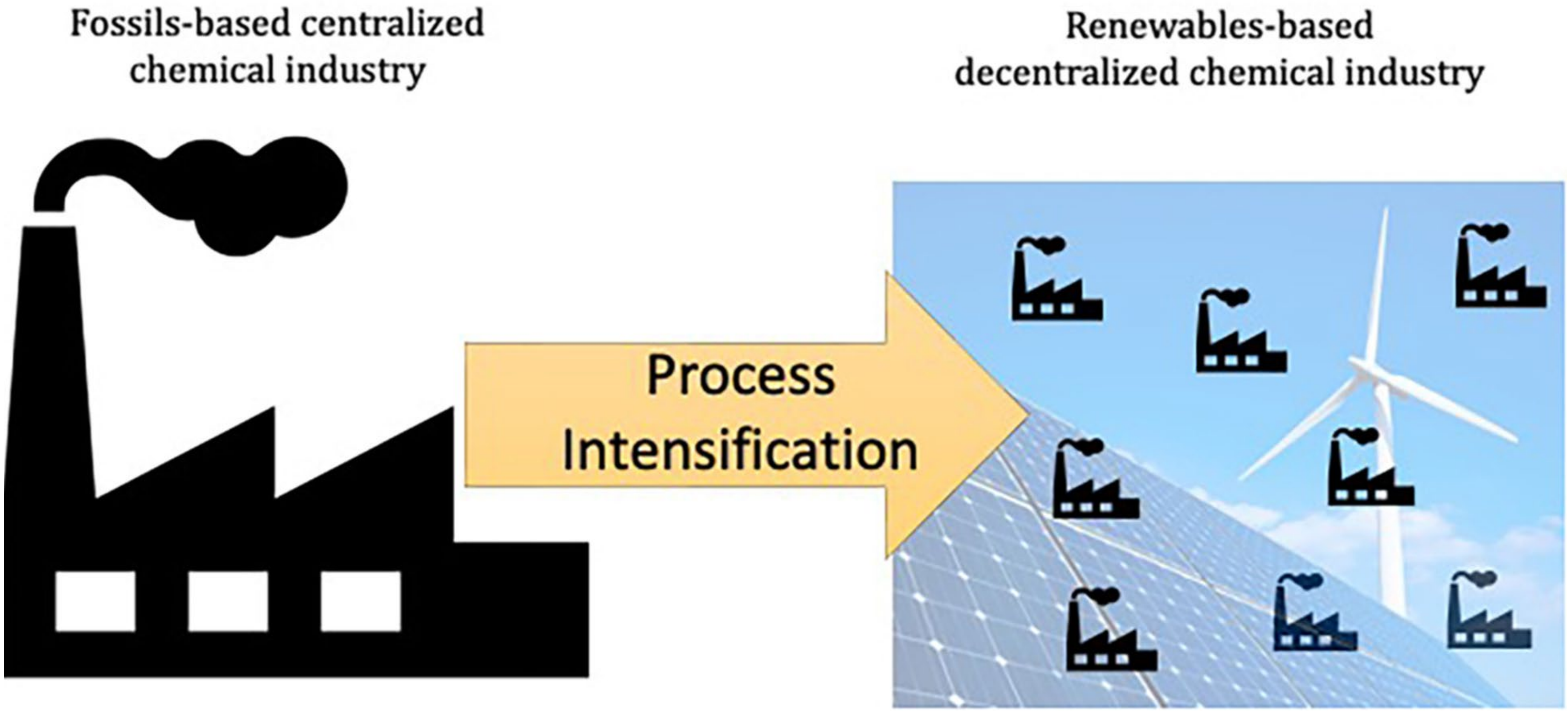
Ref.: Wilenius, M.; Kurki, S., University of Turku: Helsinki, December 2012, 127 pp.

Conventional petrochemical industry

- Rigidly hierarchical with few building blocks (mainly light olefins, aromatics and syngas/methanol)
- Requiring a sequence of steps, often many, to obtain the final chemicals
- Largely associated with the concept of scale economy
  - significant local impact on the environment
  - intrinsic low flexibility and adaptability

What would change?

Centralized vs. distributed production



Drivers to shift to delocalized production

- Geopolitical circumstances,
- The need to rely on renewable power sources,
- The need to treat distributed waste
- And others
- Process intensification technologies have the potential to make this transition an economically viable path

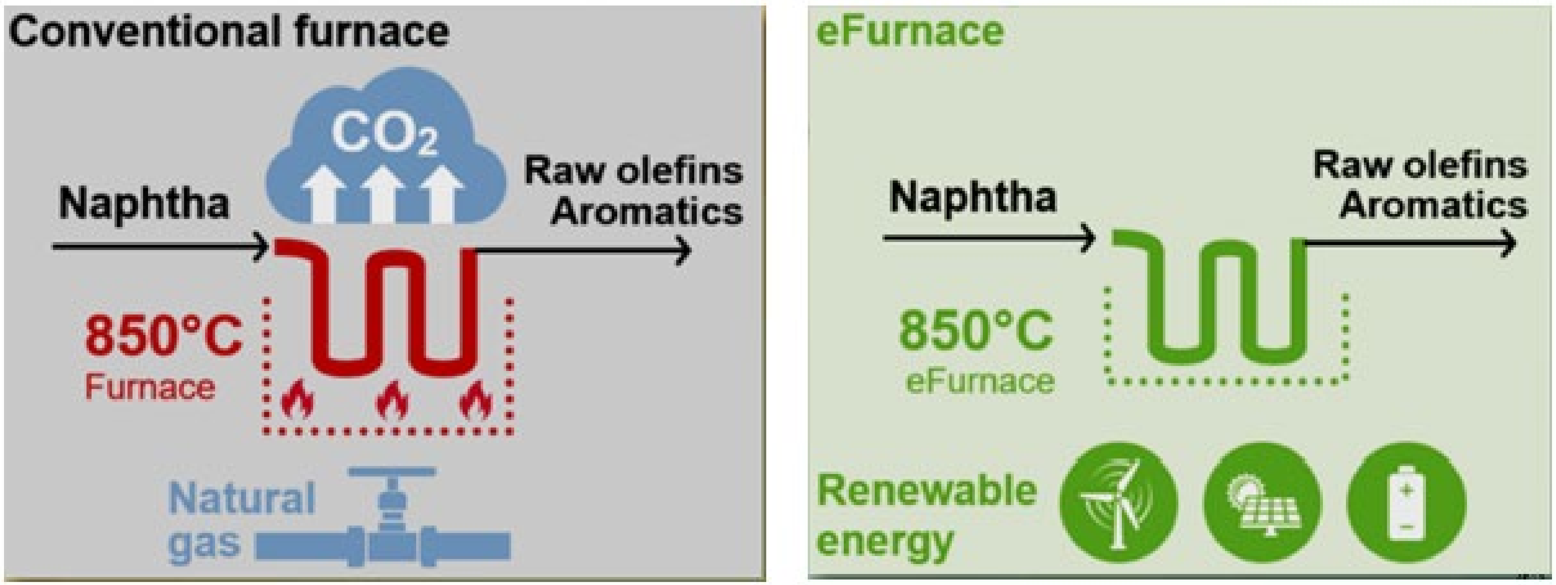
Requirements for distributed production

- Efficient small-medium scale plants
- Good integration with the territory and the local resources/needs
- Modular plant scheme allowing for a faster time to market and great flexibility in operations (e-chemistry technologies)

Electrification

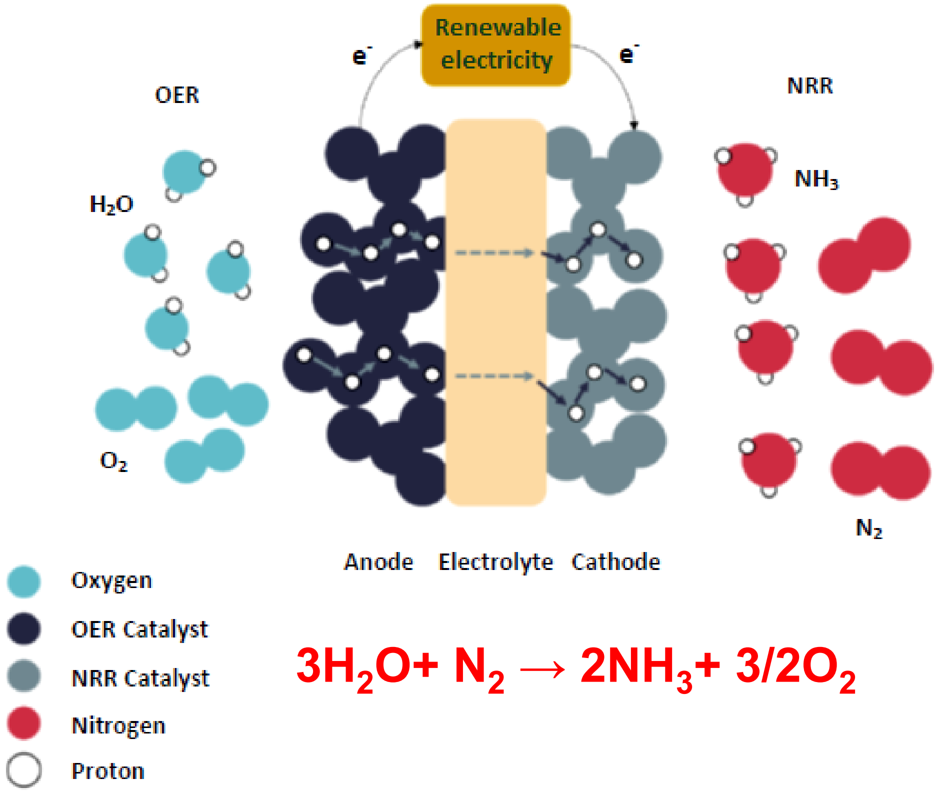
- The direct electrification of heat production (electric furnaces)
- Indirect electrification through electrochemical routes to products, fuels, or feedstock from less problematic feedstocks such as water, nitrogen, and carbon dioxide (from CCUS).
- Among the chemical, steel, and cement industry, the chemical industry has the largest electrification potential as it primarily consumes energy for heating and cooling

Direct electrification of naphtha crackers



e.g.: The "*Cracker of the Future*" consortium launched by six chemical companies (BASF, Borealis, BP, LyondellBasell Industries, Sabic, and Total) in 2019. Two members, BASF, Sabic, plant to developed an electrically heated cracker supported by Linde Engineering (a 6MW electric cracker is in demo stage in Germany).

Electrical synthesis of ammonia (e.g., Proton Ventures NFUEL® mini-ammonia plants)

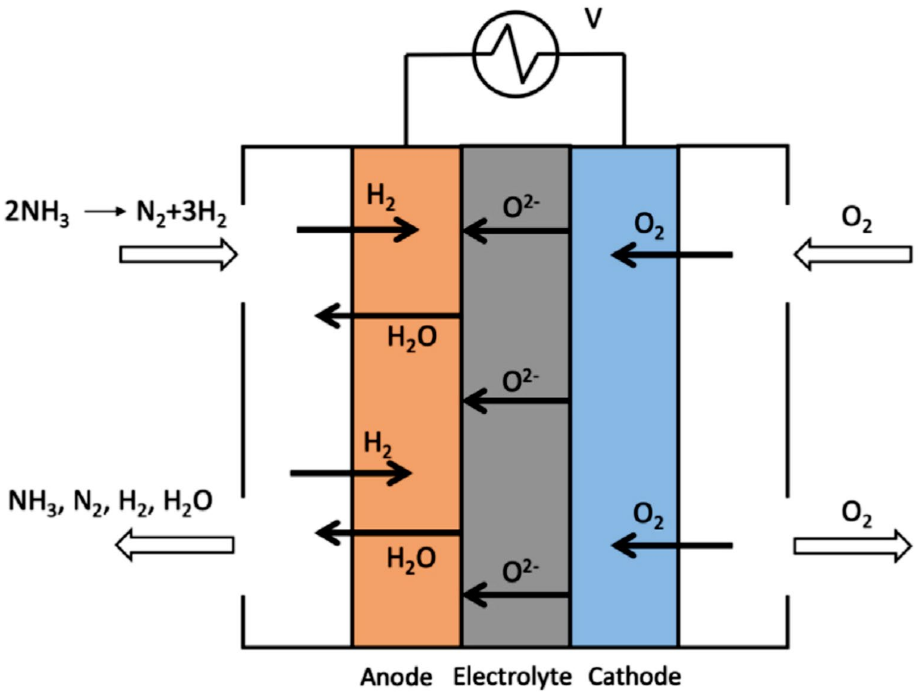


$$3H_2O + N_2 \rightarrow 2NH_3 + 3/2O_2$$

Schematic of NH_3 synthesis in a protonic ceramic electrolysis cell (PCEC) wherein H_2O and N_2 are transformed into NH_3

Applications of green ammonia

- A chemical feedstock for petrochemical industry
- Hydrogen carrier or clean energy material



High temperature oxygen ion conducting solid oxide fuel cell

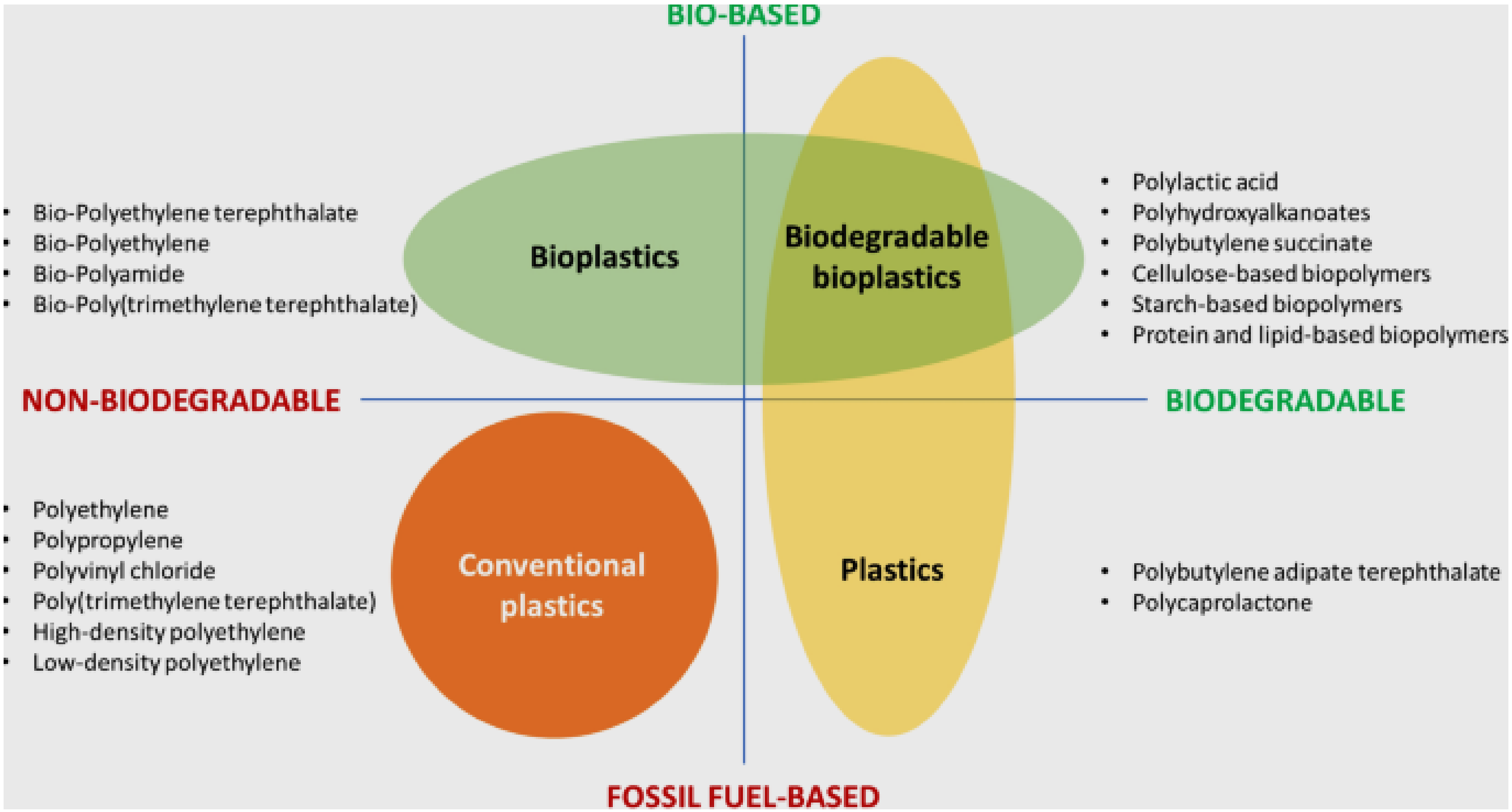
Potentials and challenges of e-technologies

- Intensification by reducing the number of steps
- Lowering fixed and operative costs, and introducing new modalities of production
- Better use of the local resources (distributed production).
- Technological challenges that prevent electrochemical routes from operating at high production rates, selectivity, stability, and energy conversion efficiency

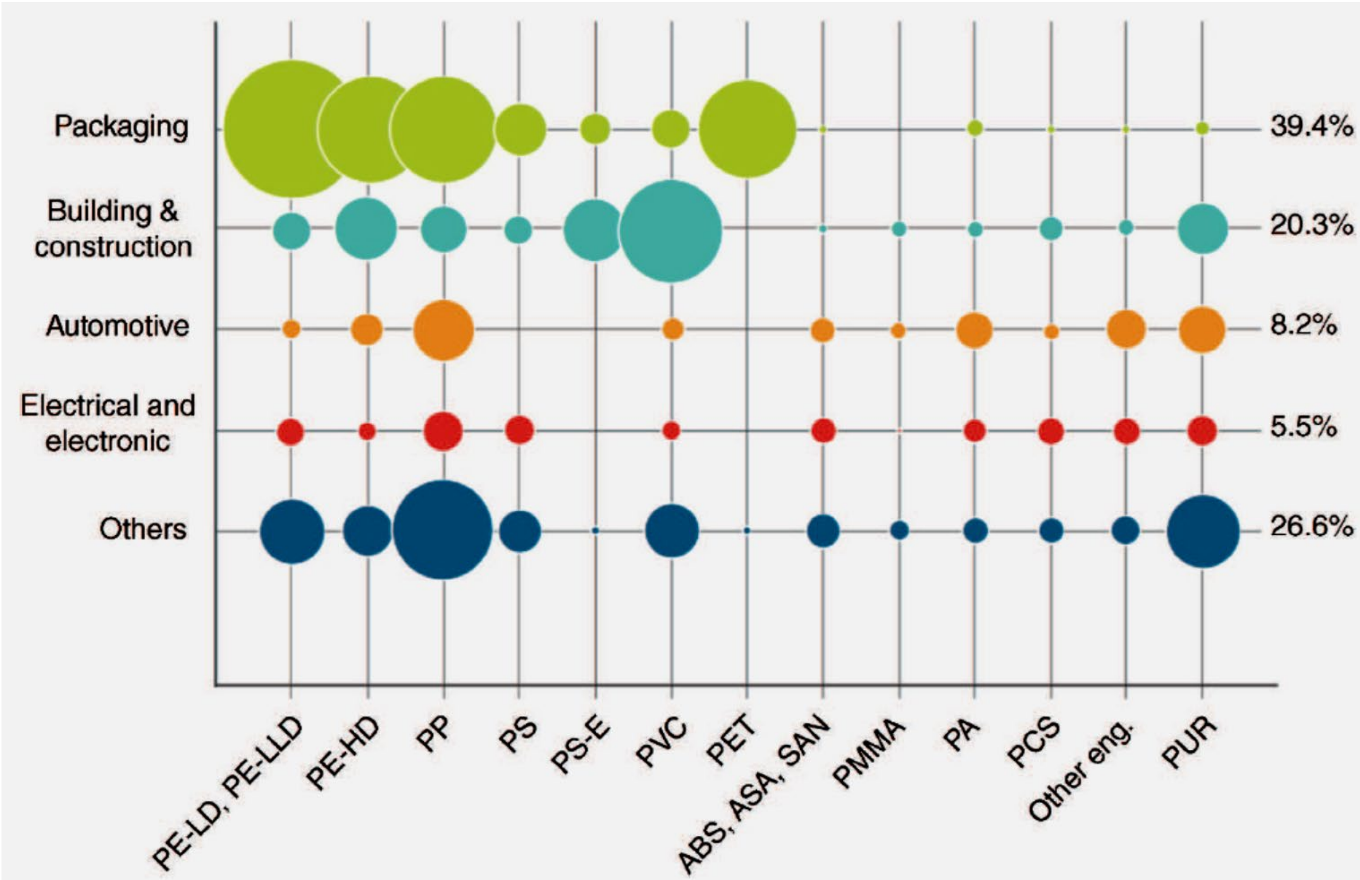
Challenges in unconventional catalysis

- Control of in-situ generated "highly-reactive" charged species to avoid side reactions
- Introducing electro-, photo- and plasma catalytic processes on a commercial scale
- Development of unconventional, potentially disruptive catalysts

Classification of plastic materials based on their origin and biodegradability



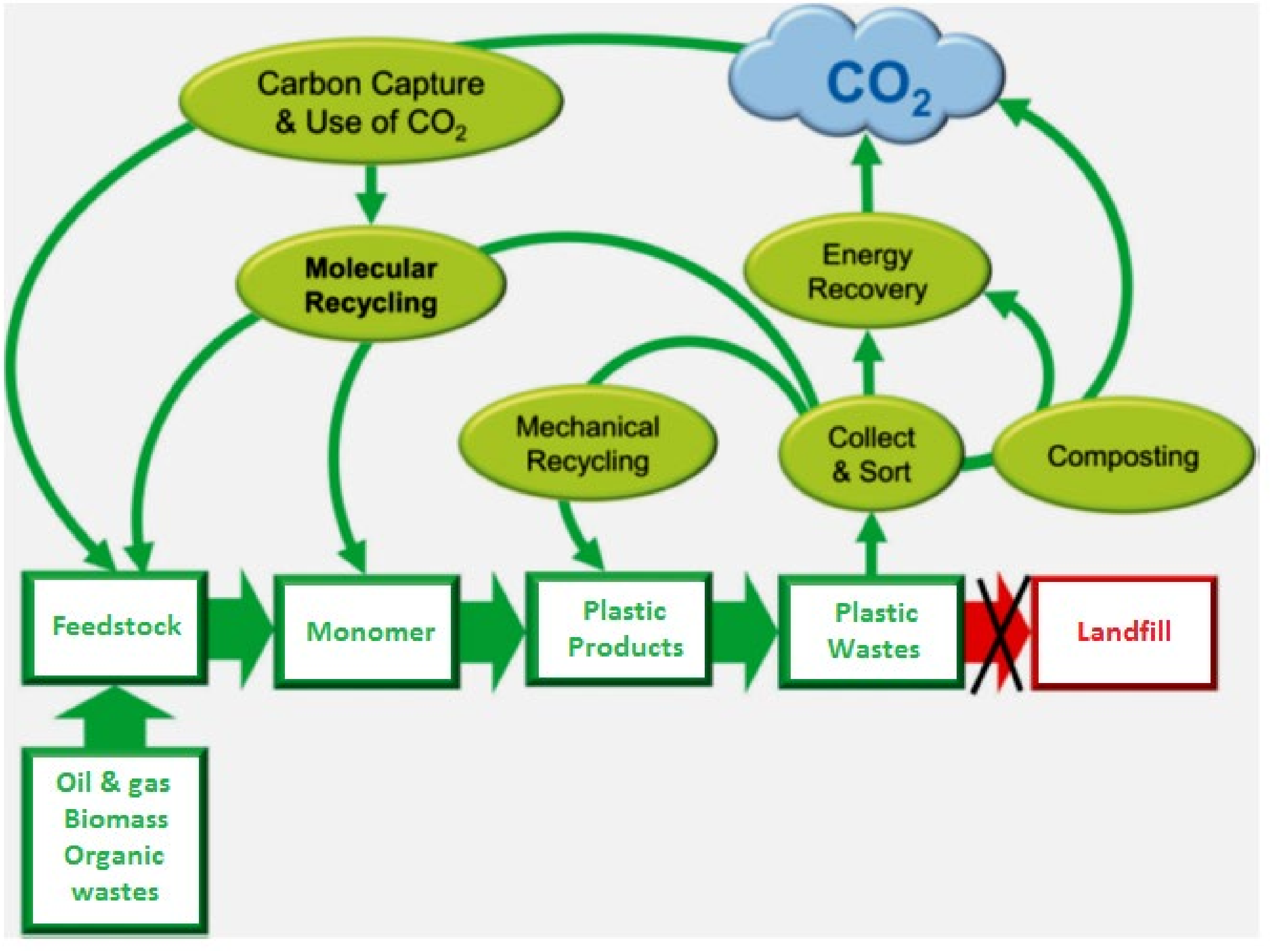
Typical applications of polymers



The sizes of the bubbles show the relative importance. PS-E=expanded PS; ASA=acrylonitrile–styrene–acrylate; SAN=styrene–acrylonitrile; other eng.=other engineering plastics

Ref. : http://www.plasticseurope.org/, accessed 2015.

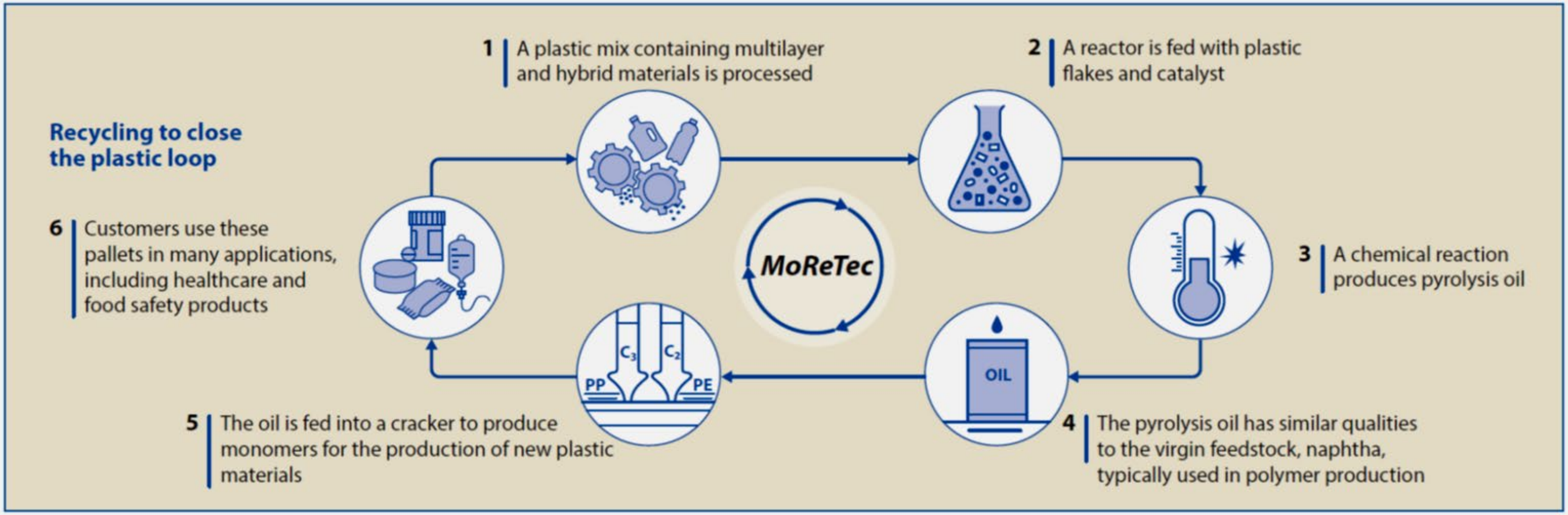
Closing the carbon loop in the circular plastics economy



Ref.: C.G. Schirmeister, R. Mülhaupt, Macromol. Rapid Commun. **2022**, 43, 2200247

LyondellBasell MoReTec (molecular recycling technology) Process

- Developed by LyondellBasell with cooperation of Karlsruhe University of Technology
- Uses a catalytic step to produce light olefins from waste plastics
- Plastic mix containing multilayer and hybrid materials is processed



Ref. : C. R. Dziedziak, J. J. Murphy, PTQ Q3 2023

Key areas where research and innovation are needed

- Sustainable feedstocks
- Recycling
- Green chemistry
- Biotechnology
- Advanced materials
- Digitalization and automation
- Energy efficiency
- Collaboration and interdisciplinary research

An three-step approach to forecasting promising technologies using patent analysis

- Clustering patent documents on the basis of the cooperative patent classification (CPC) into technology clusters, representing a more detailed technology classification system than the international patent classification (IPC).
- Examining the combination of CPCs of each formed clusters
- Analyzing patent indicators such as forward citations, triadic patent families, and independent claims to assess whether the technology clusters are promising.

Ref.: G. Kim, J. Bae, Technological Forecasting & Social Change, 117, 2017, 228-237

Suggested research topics (for oil and post-oil eras)

- Renewable feedstock (bio-based, CCSU)
- Electrification
  - Direct (furnace modeling & design)
  - Indirect (electrocatalysts, electrolytes, membranes)
- Process intensification (innovative reactor and process design, alternative fluids)
- Circular plastic economy
- Technology foresight from patent analysis

Conclusions

- Innovation is the key to the future of the petrochemical industry
- The chemical industry may shift to more decentralized production facilities
- Process intensification technologies have the potential to make this transition an economically viable path
- Technologies for a transition to circular economy have become available recently

Thanks for your kind attention!

Saeed Sahebdelfar, Consulatant
Petrochemical Research and Technology Co.
Email address: s.sahebdel@npc-rt.ir