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Process intensification and electrification of the chemical industry

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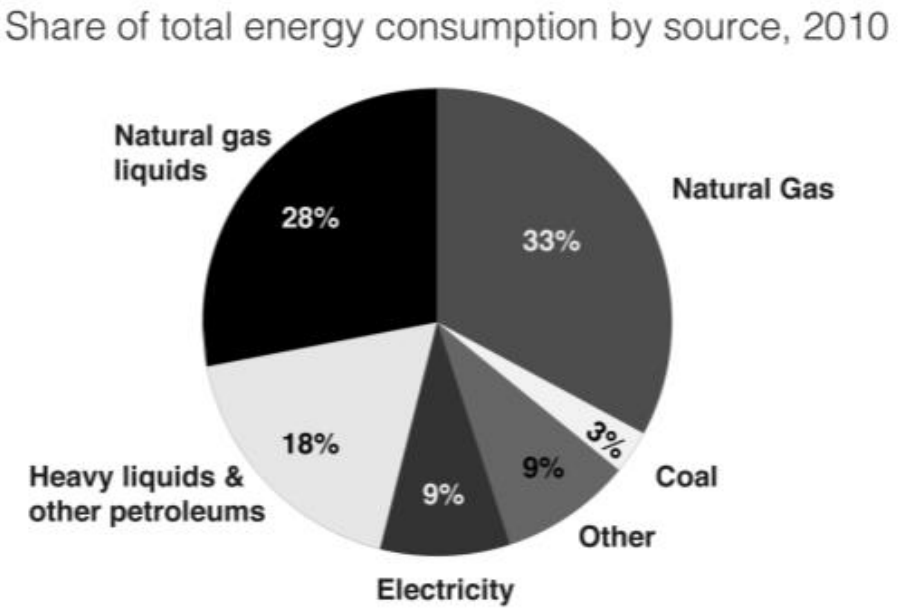
Current energy use in chemical industry

- Chemical industry, metal, pulp & paper, textile and similar sectors are energy-intensive industries
  - In Germany energy-intensive industries consume ca. 70% of the industrial energy consumption
  - Worldwide chemical industry produces ca. 10-15% of the anthropogenic emissions of greenhouse gases (excluding electricity usage)

Source: https://energy.gov/eere/amo/chemicals-industry-profile

Current energy use in chemical industry

- Contemporary chemical industry is predominantly based on fossil fuels as energy source
- Transition towards electrification is only desired when electricity is generated from renewable energy sources

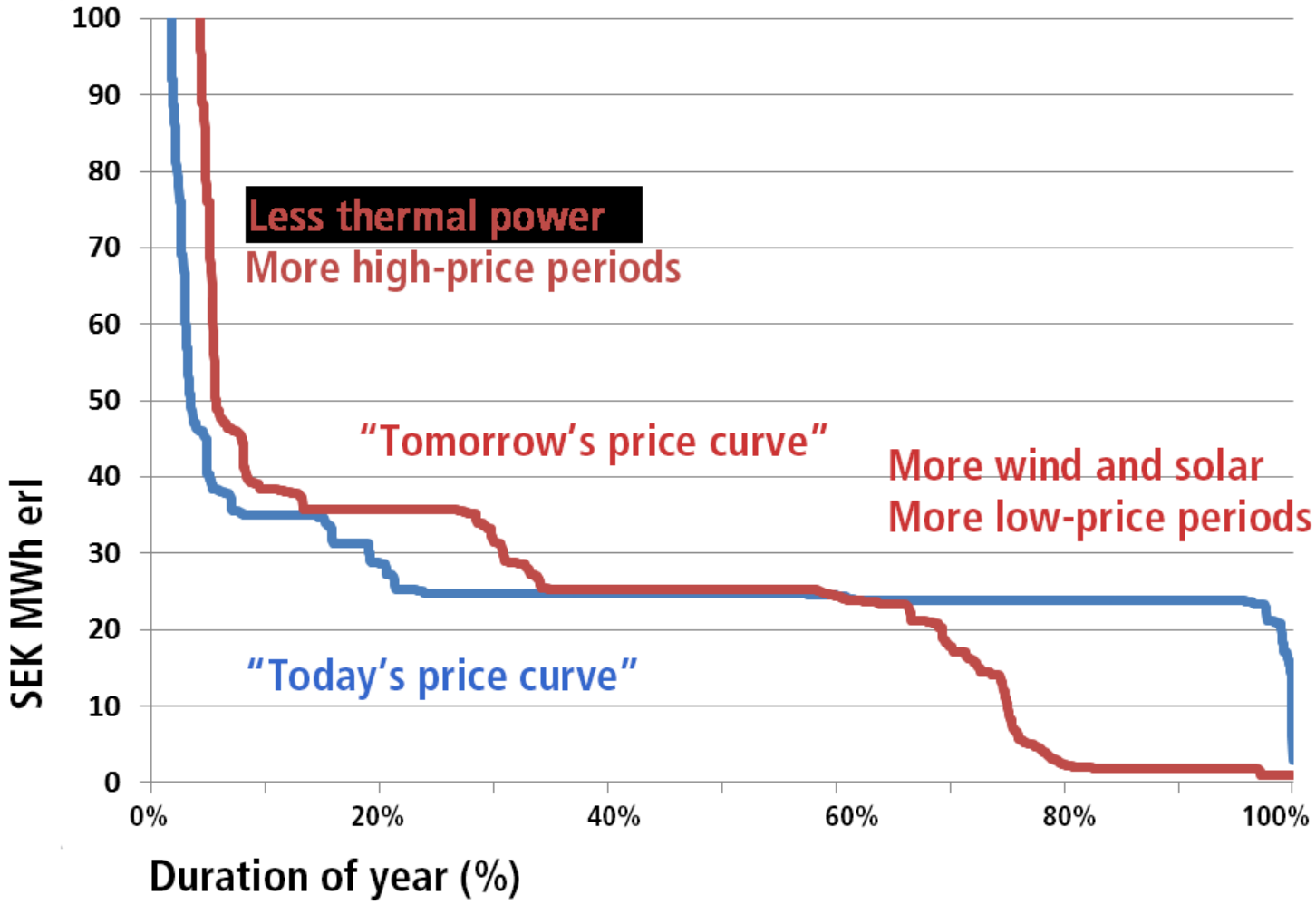


Source: https://energy.gov/eere/amo/chemicals-industry-profile

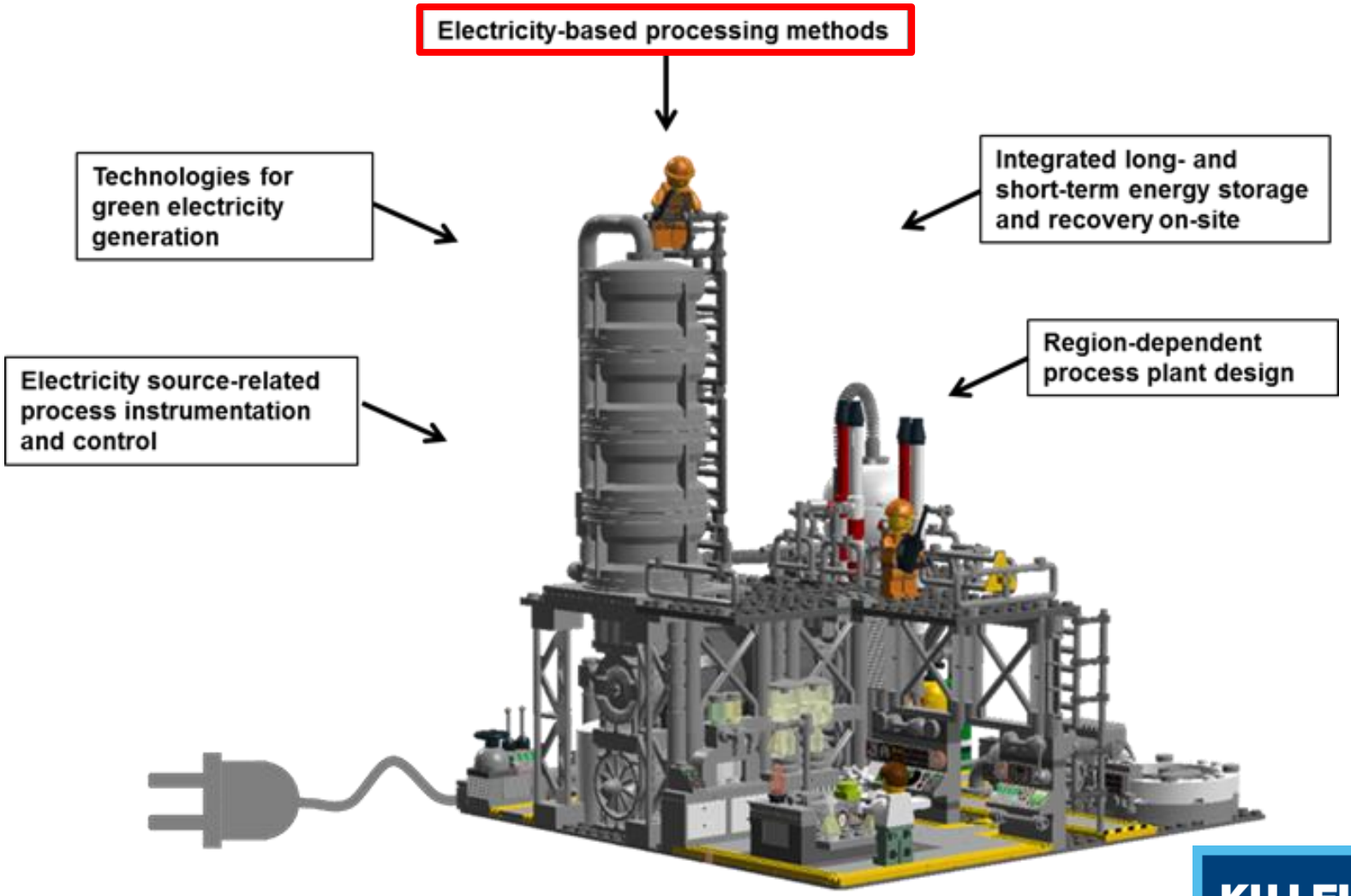
Variability of renewable energy

- Variability exists over years, seasons, days/week and hours/day, but variation is more or less **predictable**
- Storage is being developed, but **direct consumption** by production processes and strategies would be beneficial
- Implementation of electricity-intensive energy forms, coupled with advanced process control, can **shave** electricity production
- As a consequence, use of electricity-intensive energy forms will **facilitate** the development of more renewable electricity, since the major problem of over-production at some period of time would be managed by more electricity-consuming processes

Variability of renewable energy



The chemical plant of the future



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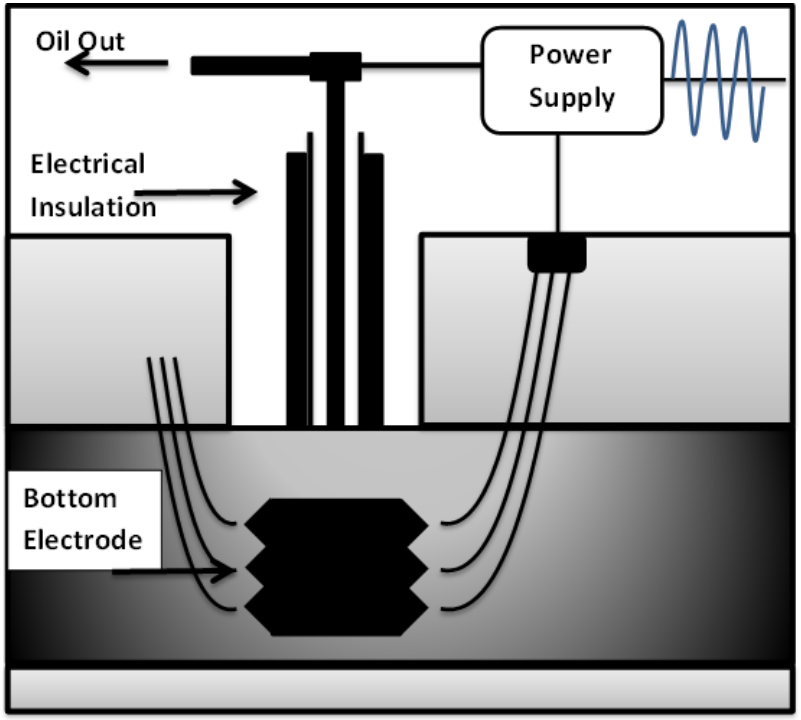
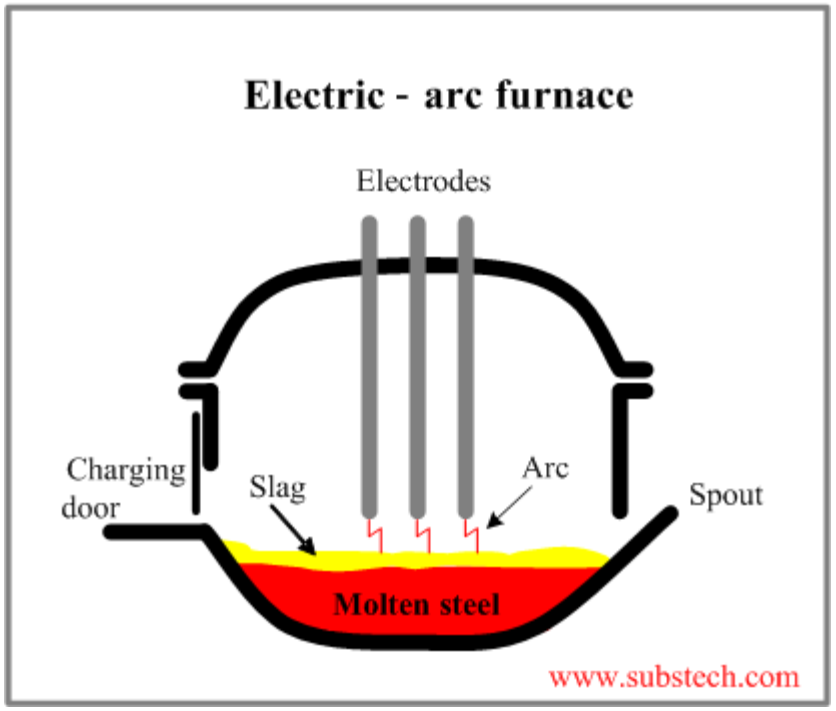
Electricity-based processes are not new



Electrical enhanced oil recovery



Steel production

Source: Gill, 1983; www.substech.com

Direct/indirect use of electricity

- Power-to-heat: use of electricity to generate or upgrade heat

  Challenge: load-following at intermittent electricity supply, possibility of retrofitting

- Power-to-gas: use of electricity for direct chemical transformations via hydrogen/methane

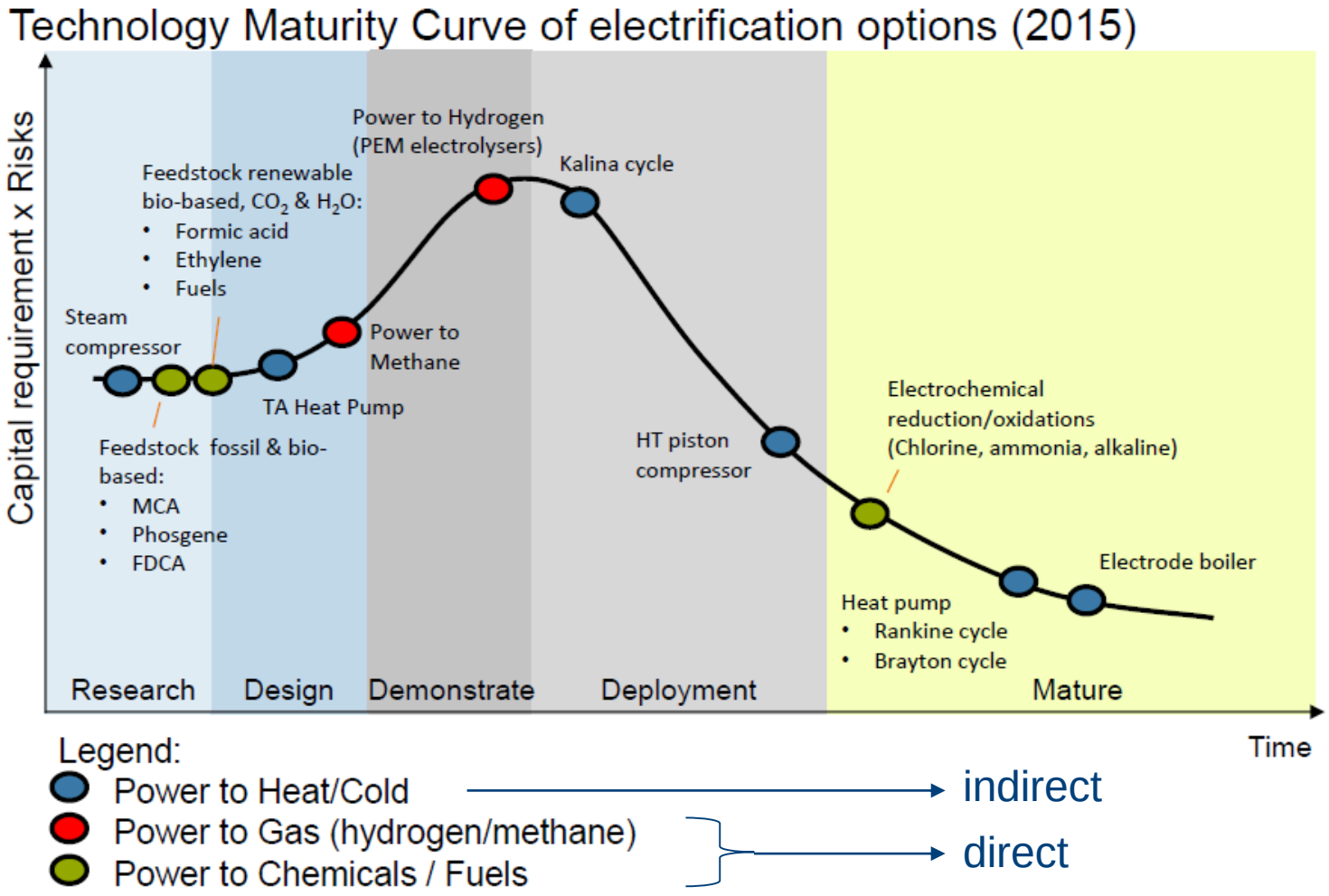
  Challenge: development of low-cost electrolyzers

- Power-to-chemicals: use of electricity for direct synthesis of intermediates and higher-value products

  Challenge: development and selection of low-cost technologies

Source: Rob Kreiter, ECN-L-15-049; www.voltachem.com

Direct/indirect use of electricity



Source: Rob Kreiter, ECN-L-15-049

Direct/indirect use of electricity

	Short term 0-5 years	Medium term 5-10 years	Long term 10-30 years
Breakthrough of electrification categories & promising technologies	High potential: Power to Heat • Steam recompression / Mechanical Vapour Recompression (baseload) • Electric boilers (flex) • Electromagnetic radiation (baseload / flex) • HT heat pumps (baseload / flex) →		
	Limited potential: Power for Mechanical Drive • Replacement of steam drive by electric drive (baseload)		
		High potential: Power to Chemicals • Electrolysis for chemical production, i.e. chlorine / ammonia (DSM)* (flex)	
		Limited potential: Power for Separation • Ultra filtration/Nano filtration/Reversed osmosis (baseload)	
			High potential: Power to Hydrogen • Electrolysis (flex)
			Limited potential: Power to Gas • Electro synthesis (baseload/flex)

Roadmap for electrification in the Dutch process industry

Source: RVO-TKI, Report on the Electrification in the Dutch process industry, 2017

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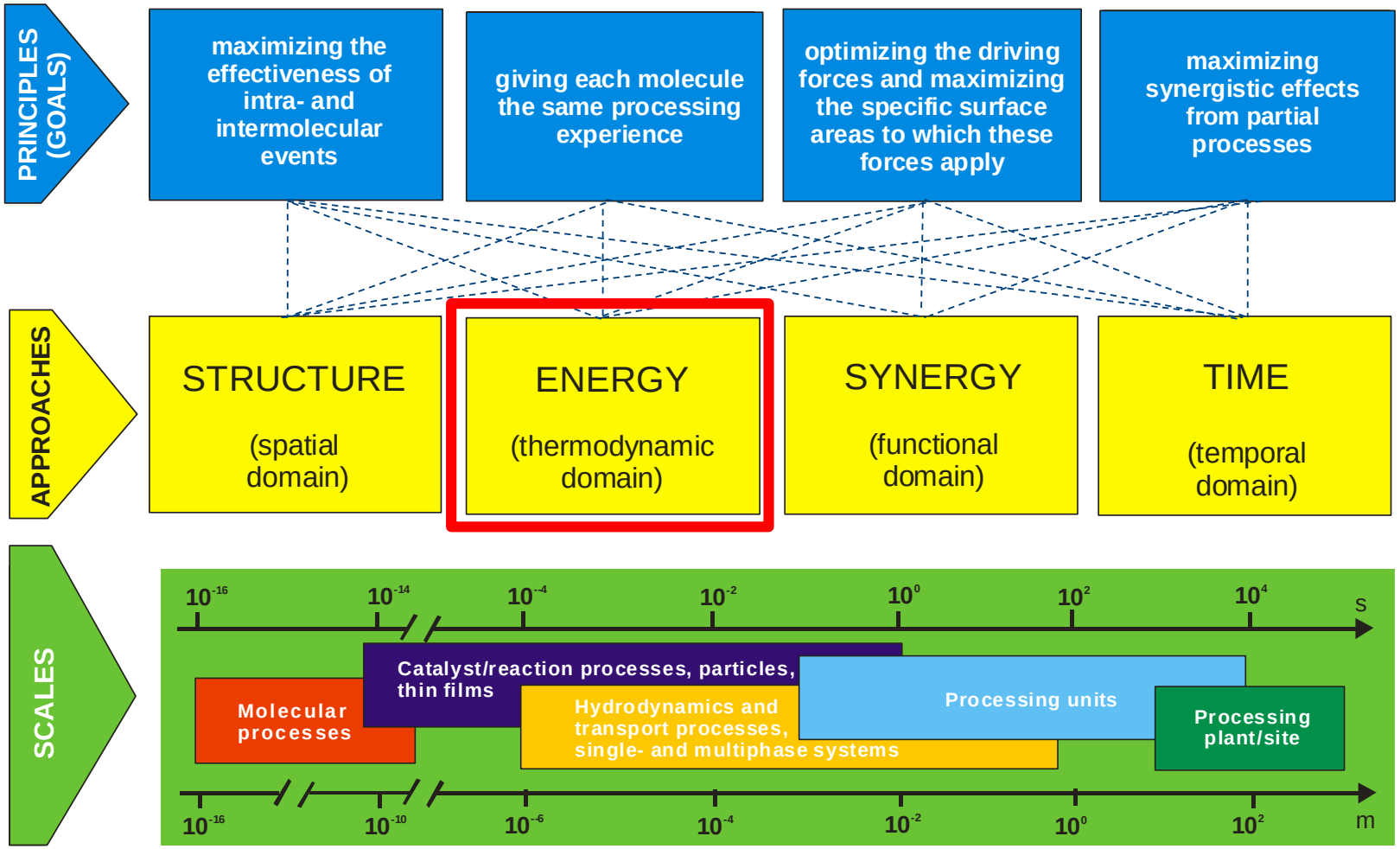
Process Intensification (PI)



Van Gerven & Stankiewicz (2009), I&ECR *48* (5), 2465-2474

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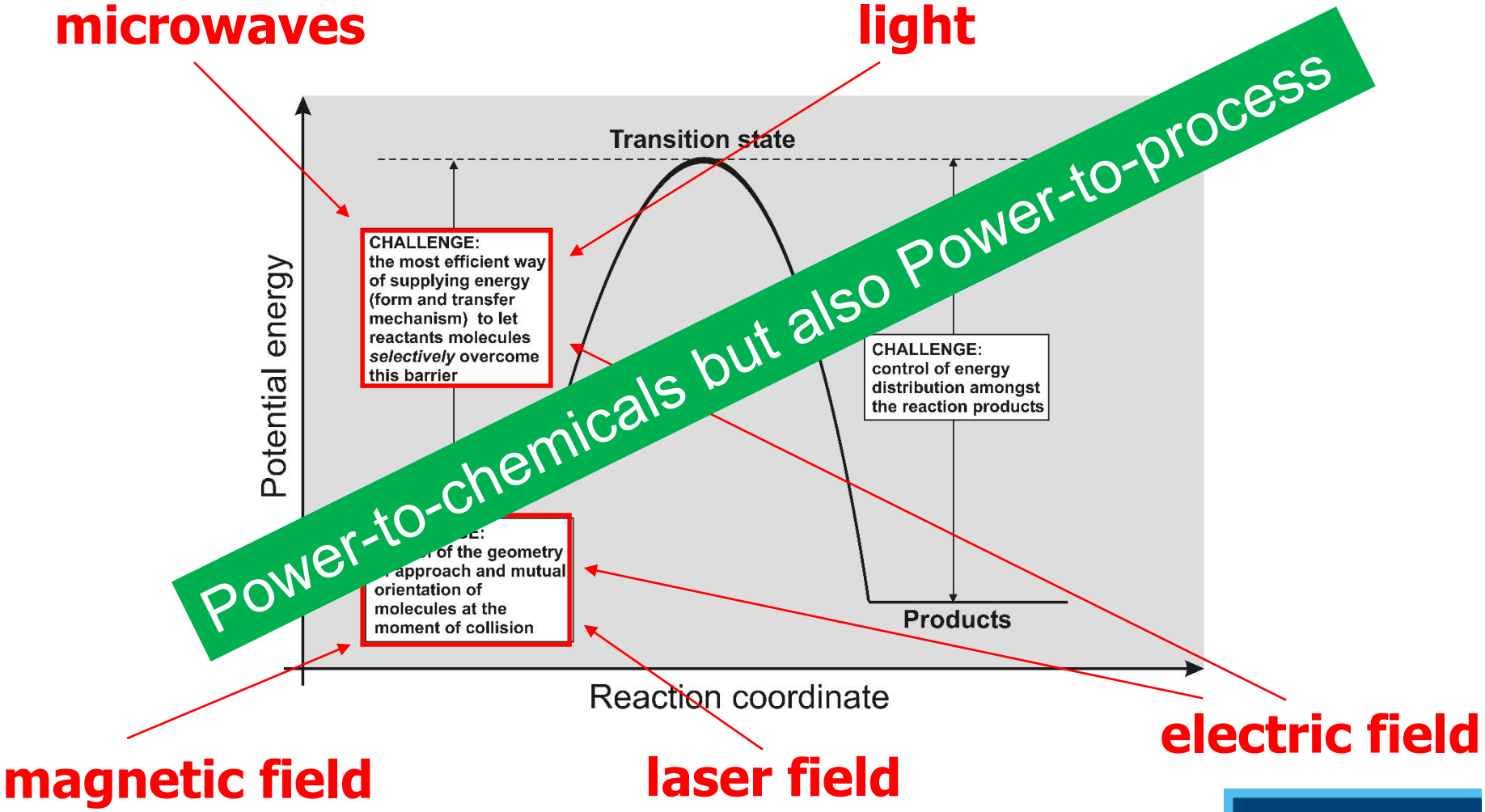
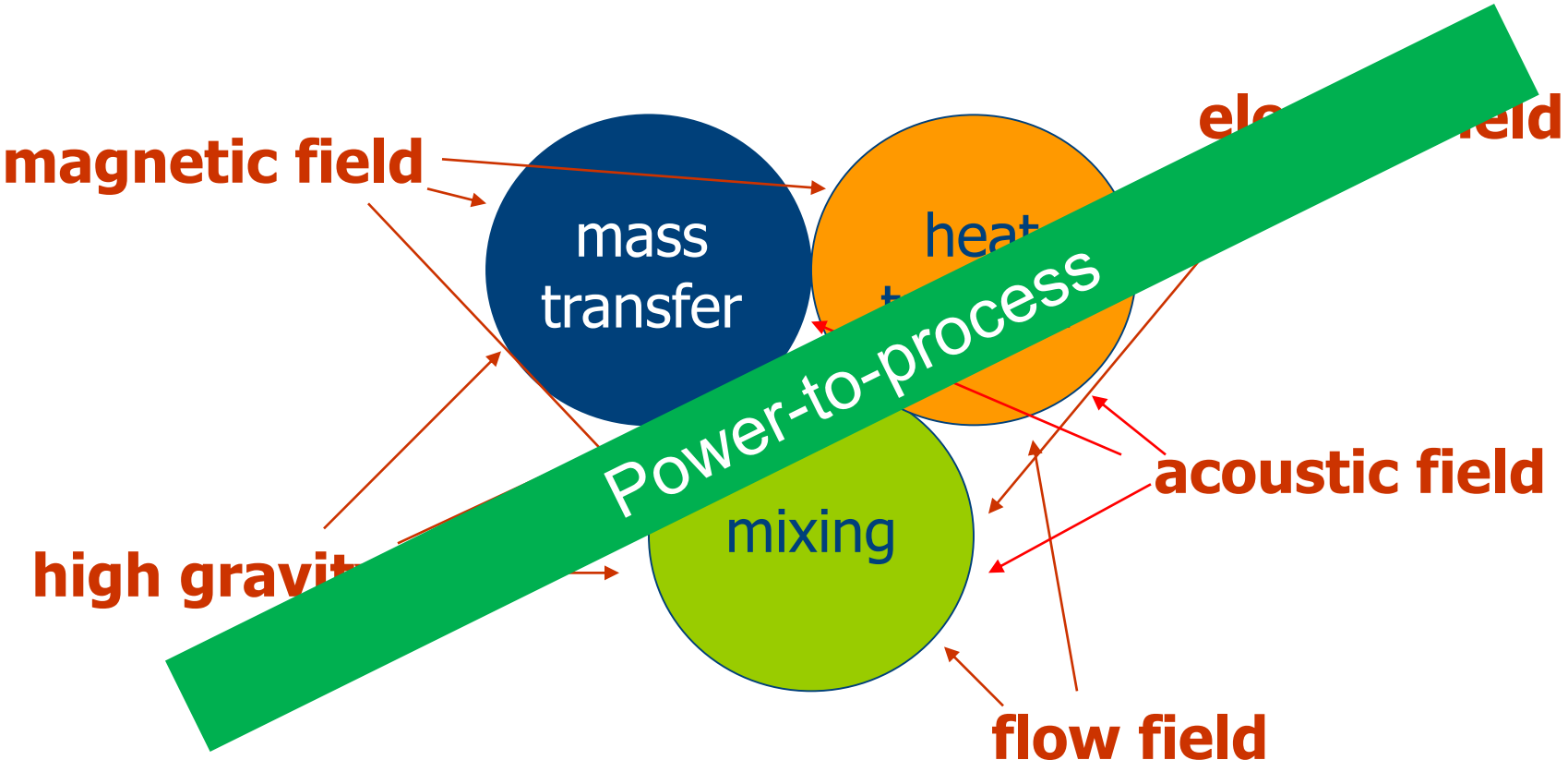
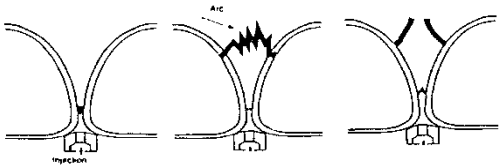
Direct energy transfer to molecules



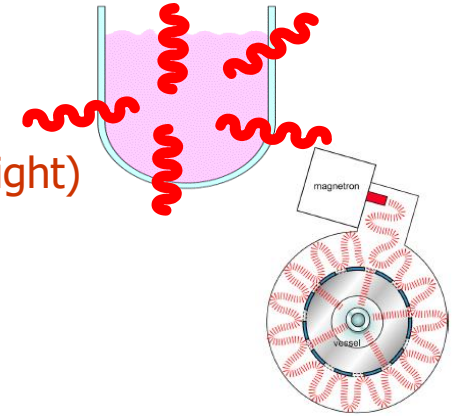
Direct energy for transport phenomena

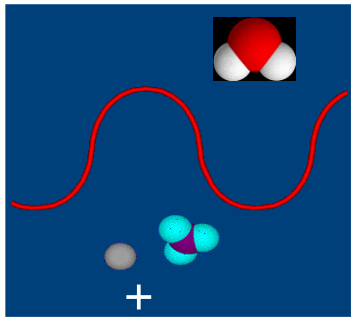


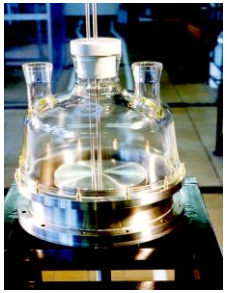
Power-to-process

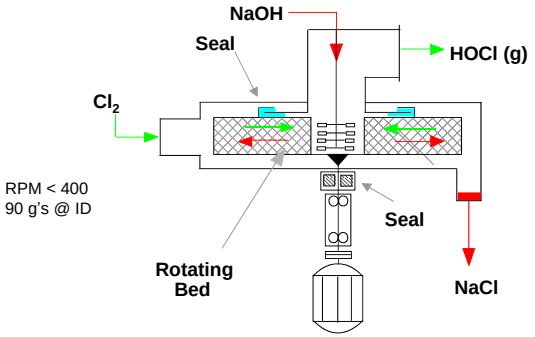


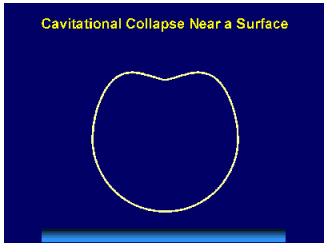
- Energy of electric field (EHD, arcs)
- Energy of magnetic field (MHD, induction)
- Energy of electromagnetic field (microwaves, plasma, light)
- Energy of acoustic field (ultra-/infrasound)
- Energy of flow field (cavitation, supersonic shockwave)
- Energy of high gravity (rotating packed bed reactors, spinning disc reactors)











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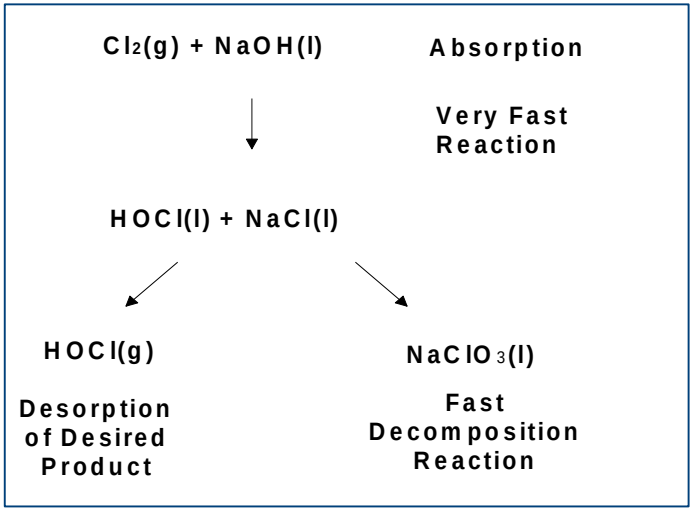
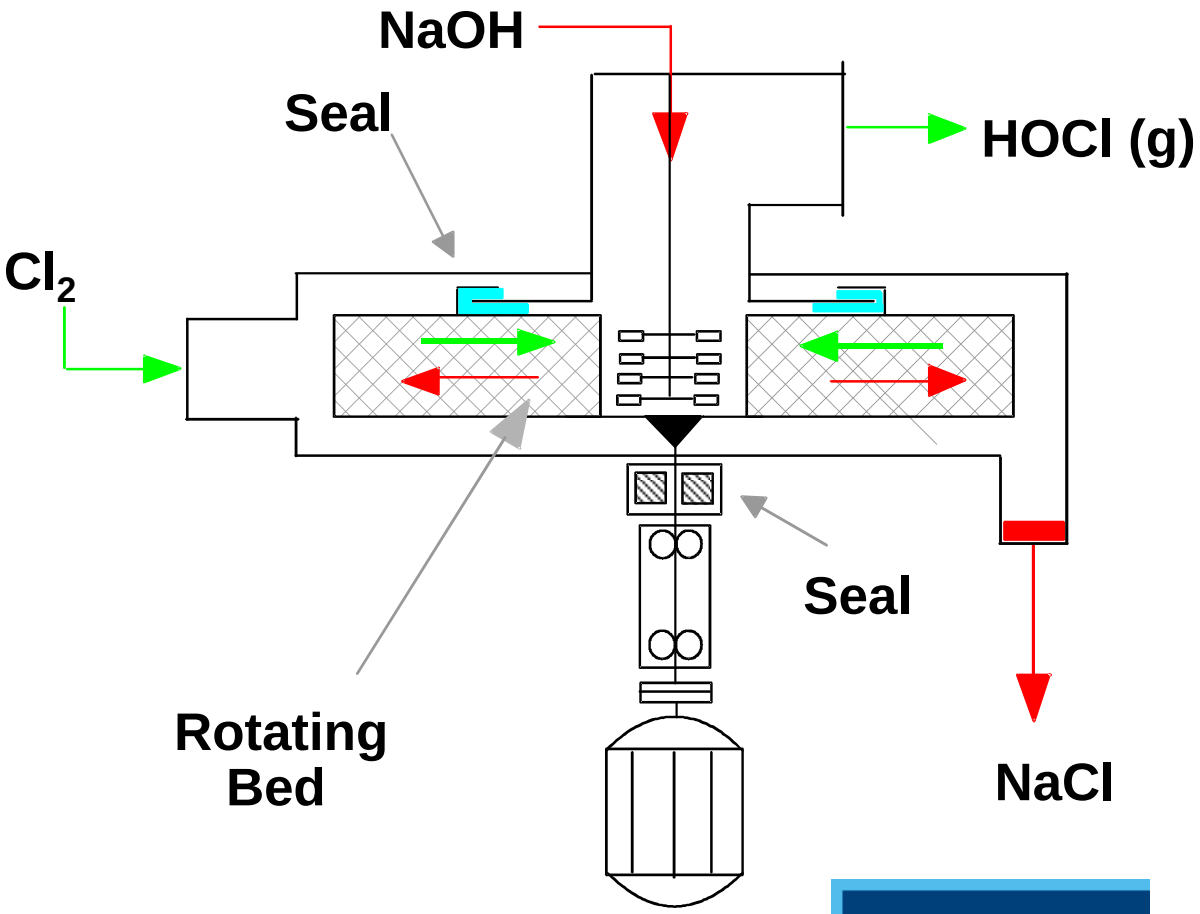
HOCl synthesis by RPBs at Dow Chemical



RPM < 400
90 g's @ ID



Source: D. Trent, in: *Re-Engineering the Chemical Processing Plant*, Marcel Dekker, 2003

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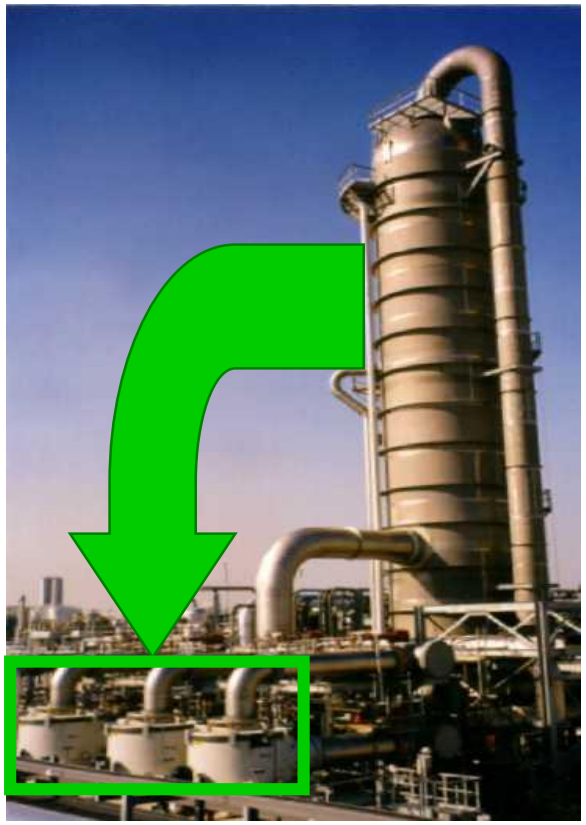
HOCl synthesis by RPBs at Dow Chemical



The three RPBs shown in the lower left of the picture process the same volume of gas and liquid as the tall absorber tower to the right!

- **Yield = 94-96% (80% conventional)**
- **Equipment size decreased by a factor of ca. 40**
- **50% reduction of the stripping gas**
- **1/3 reduction in waste water & chlorinated byproducts**
- **Same processing capacity**

Source: D. Trent, in: *Re-Engineering the Chemical Processing Plant*, Marcel Dekker, 2003

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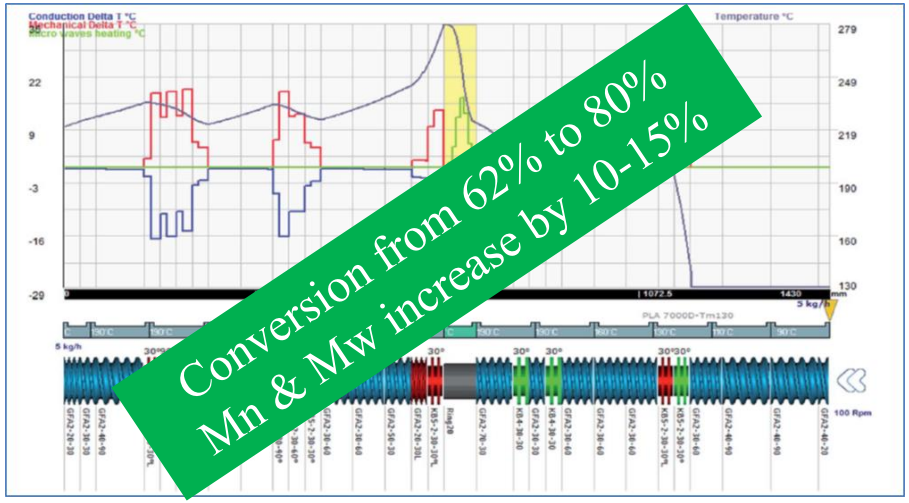
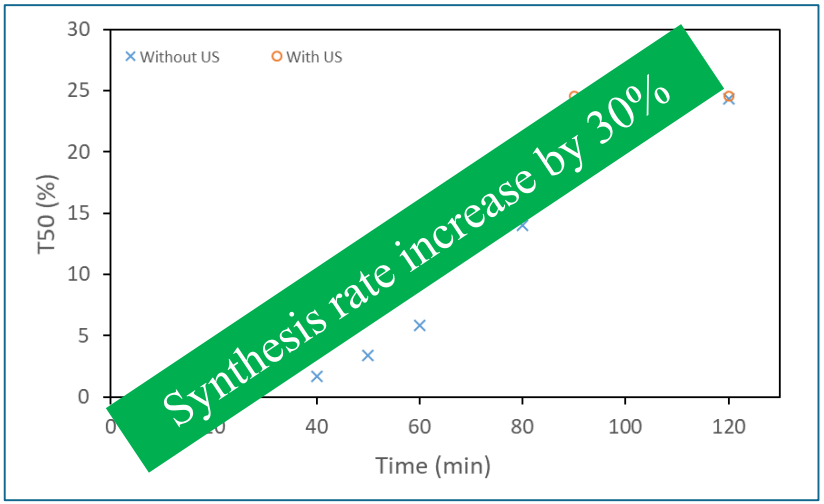
Example: Reactors

- Sonication and Microwave Processing of Material Feedstock (H2020-SPIRE-02-2018, **SIMPLIFY**, TRL4-6)
- Based on previous EU projects (AlterEgo, Innorex, COSMIC)
- Specialty processes involving viscous fluids/suspensions



MW-assisted reactive extrusion

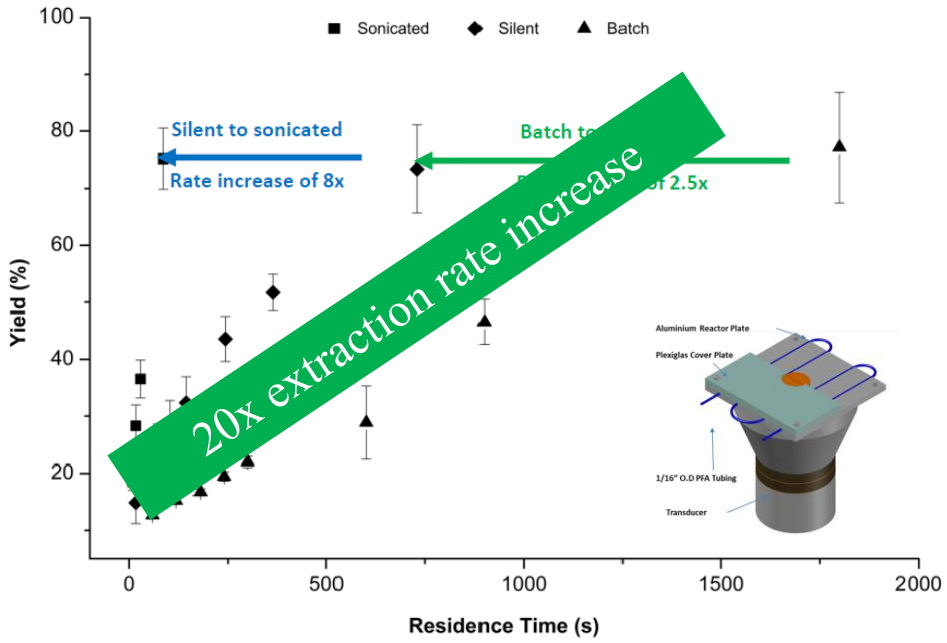


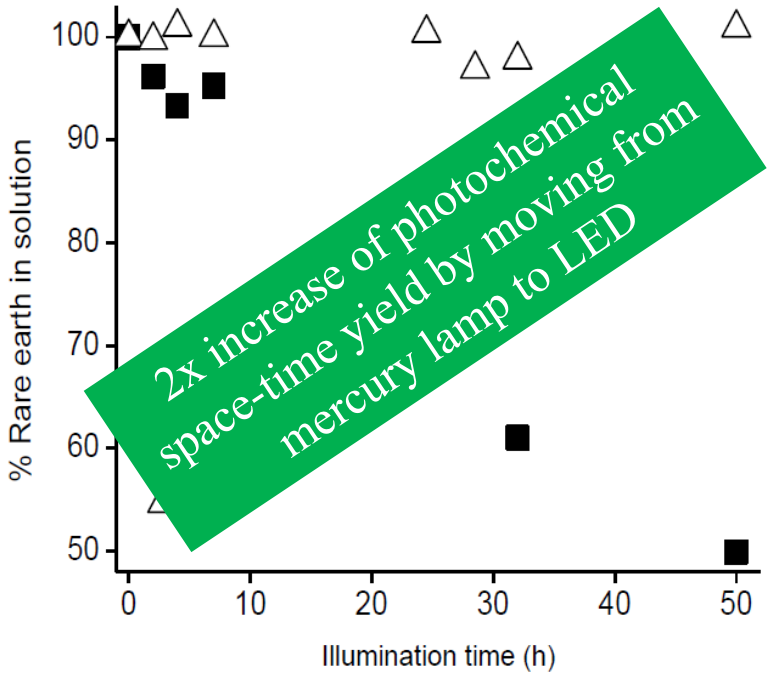
US-assisted reactive crystallisation

ARKEMA INNOVATIVE CHEMISTRY
COLOROBBIA CONSULTING
MUEGGE
UNIMORE UNIVERSITÀ DEGLI STUDI DI MODENA E REGGIO EMILIA
technische universität dortmund
KU LEUVEN
COATEX ARKEMA GROUP
WEBER ULTRASONICS
engage Key Technology Ventures
Quantis
Fraunhofer ICT

Example: Separators

- US-assisted solvent extraction in flow (TRL3-4)
- UV-based metal (Eu/Y) separation (TRL 3-4)

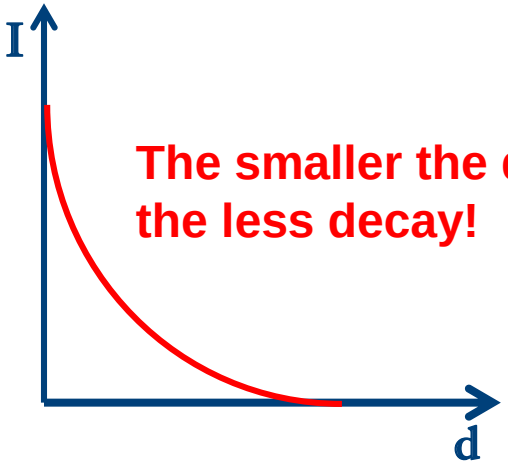




Energy forms enable transition to flow

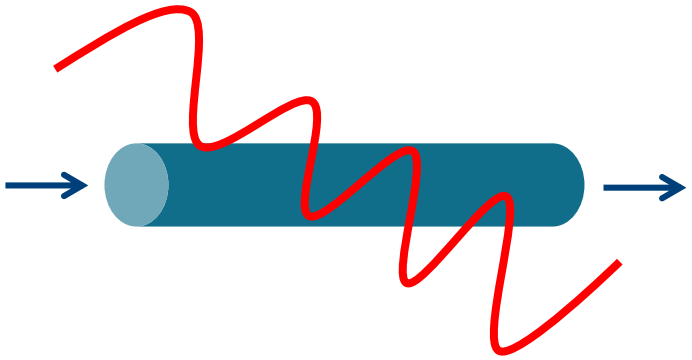
Energy waves and small-scale flow are partners in crime!

Waves  Miniaturisation



The smaller the distance, the less decay!

Miniaturisation  Waves



Waves are non-contact activators and actuators!

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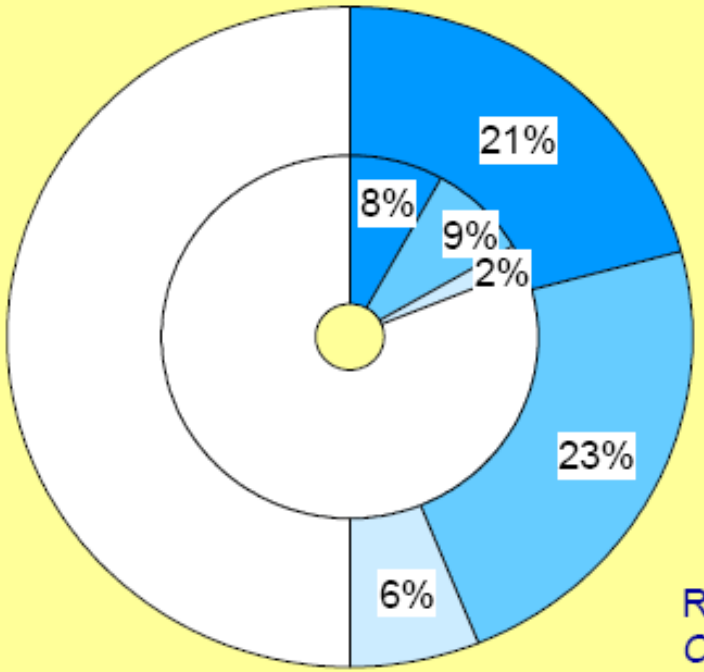
Potential applications of microreactors

Classification of 86 reactions campaigns carried out at Lonza

Lonza



- Type A reactions
- Type B reactions
- Type C reactions
- Remaining

Big circle:
based on kinetics only

Small circle:
based on kinetics & phases

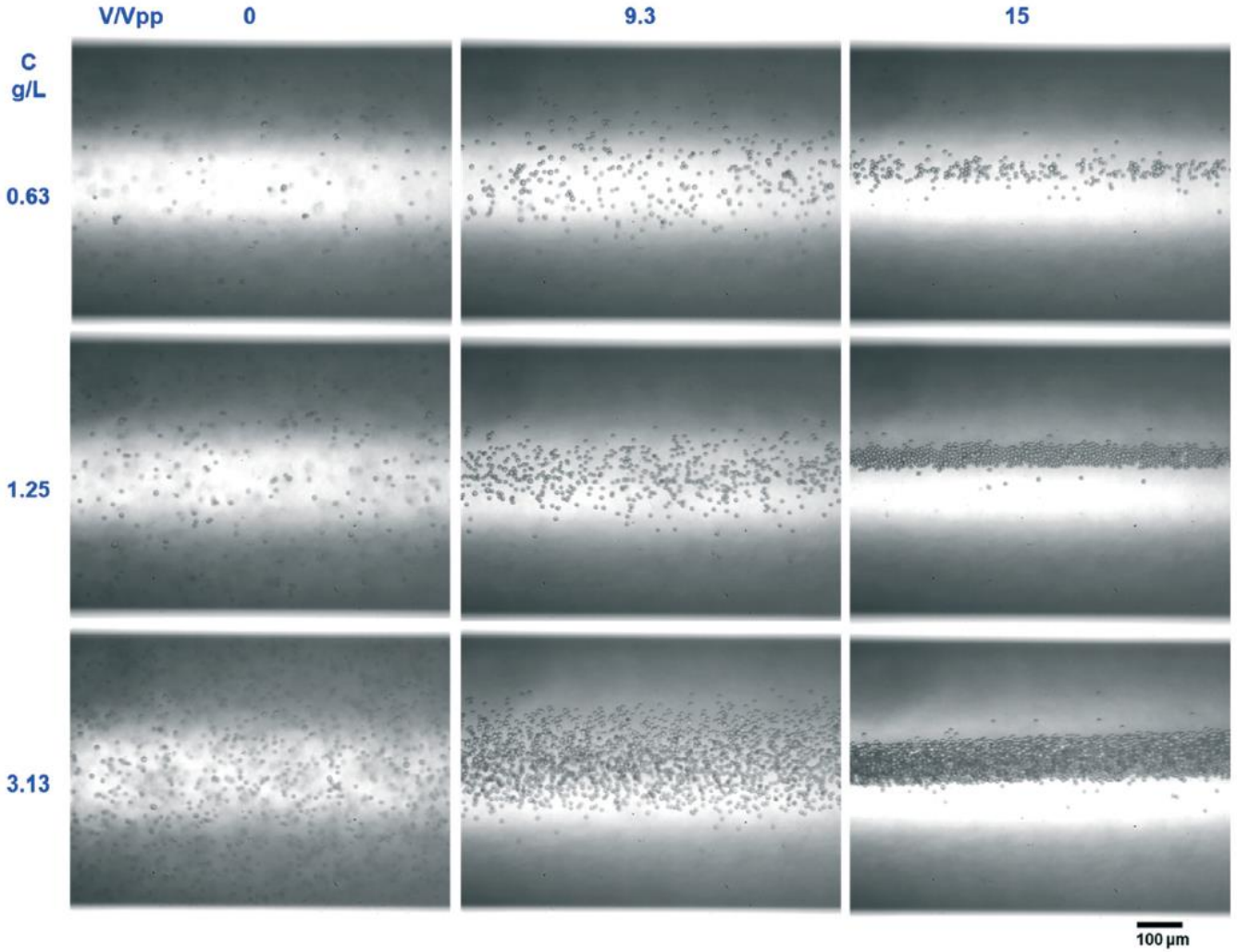
- **50% of the reactions to benefit from a continuous process**
- **63% not suited to current micro reactors due to solid carriage**

Roberge, D.M., Ducry, L., Bieler, N., Cretton, P., Zimmermann, B. *Chem. Eng. Tech.* **28**, 3 (2005) 318-323

Dominique Roberge (Lonza)

- **Type A reactions: very fast, < 1 s; mixing controlled**
- **Type B reactions: rapid, 1 s to 10 min; kinetically controlled**
- **Type C reactions: slow, > 10 min; safety and quality issues**

Acoustophoresis in microreactors



Source: Dong, Lab Chip, 2019, 19, 316

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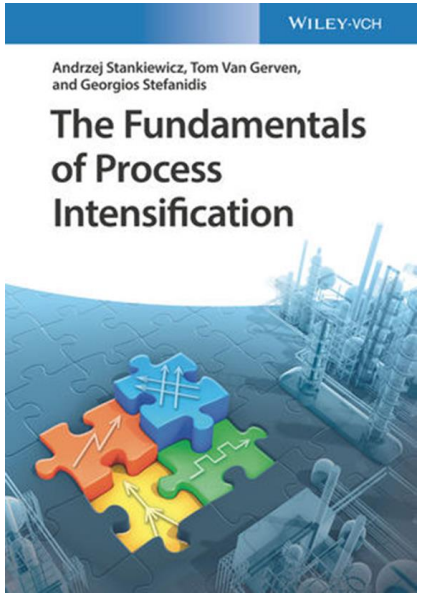
Take-home message



- Power-to-chemicals can mean
  - Electricity to run the chemistry
  - Electricity to run the process

- Chemistry side goes beyond electrochemistry (e.g., photochemistry)

- Process side should not be forgotten & can help realizing the transition to
  - renewable energy sources
  - continuous processes

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