VOLTA CHEM

Accelerating industrial electrification

Welcome at Community of Practice meeting

Power to chemicals

Program

10.00	**Arrival**
10.30	Introduction by Prof. Dr. Earl Goetheer – Principal Scientist
11.00	In depth Presentations & Questions • Power-2-Commodities based on CO_2 – Dr. Anca Anastasopol/Earl Goetheer • Power-2-Specialties – Dr. Amanda Garcia • Electrochemical process development. Bio-based plastics monomers – Dr. Roman Latsuzbaia
12.30	Lunch Meet the VoltaChem scientists and informal poster session
13.30	Parallel session: • Round table discussion; and • Tour laboratory facilities: from fundamentals to continuous reactions
14.30	Closure & Drinks

VOLTA CHEM

Accelerating industrial electrification

Introduction

Power to Chemicals & VOLTACHEM

Earl Goetheer

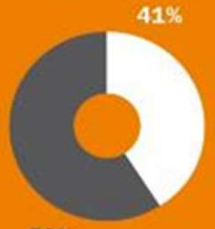
TNO

NUMBER OF EMPLOYEES

2,843 TOTAL WORKFORCE

TNO'S REVENUE (INCL. GOVERNMENT FUNDING)

€ 431 MILLION

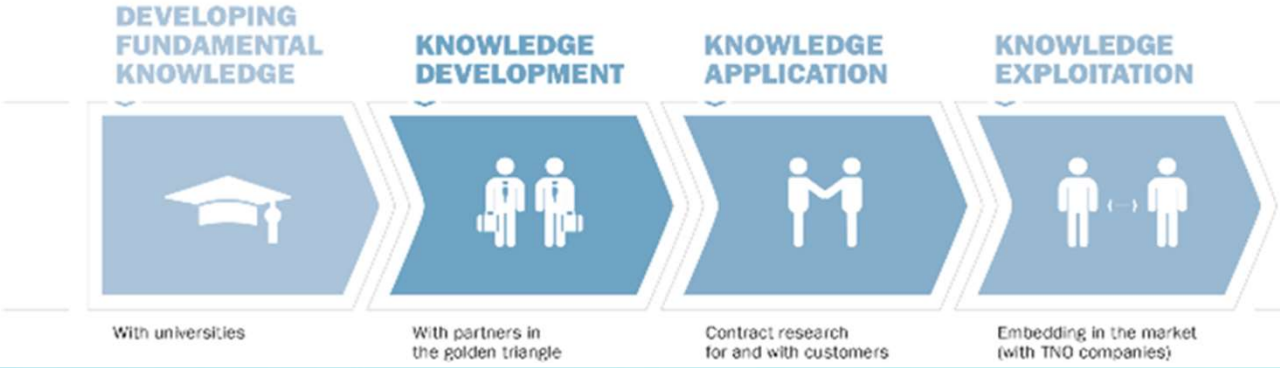


Contribution from the national government **€ 176 million**

Private-sector and public-sector contracts **€ 255 million**

2015

€ 416 million
€ 15 million*
3.6%*

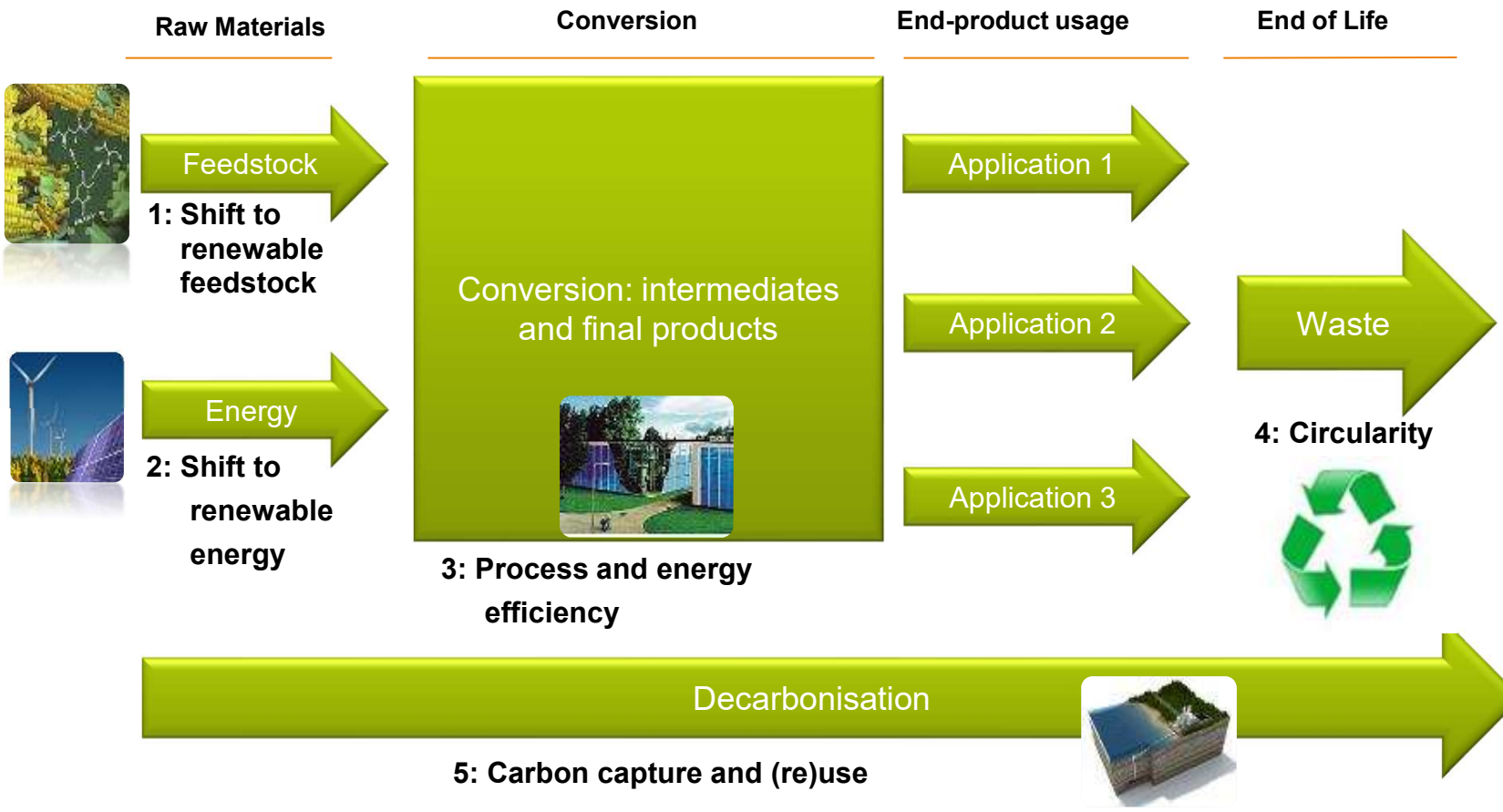


We are working for approx.

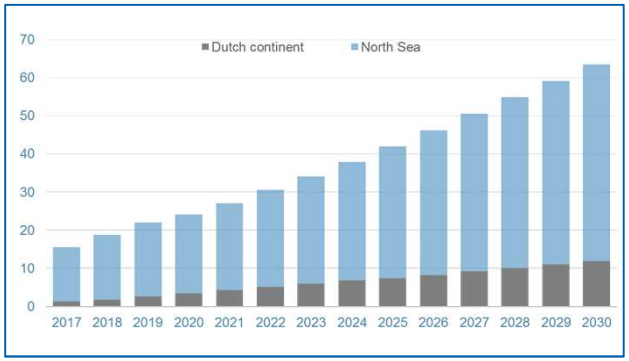
3000

companies

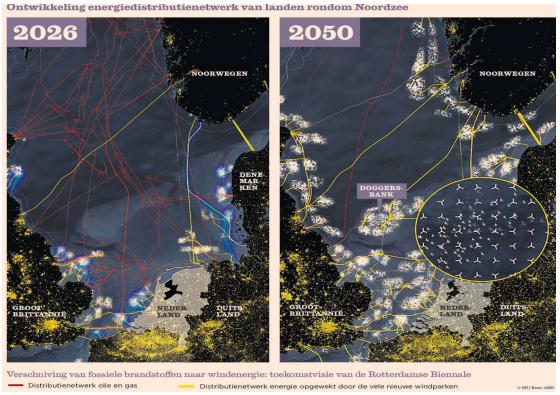
Transition of Energy Sector and Chemical Industry

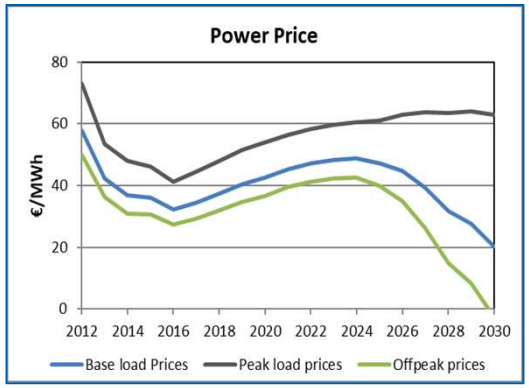


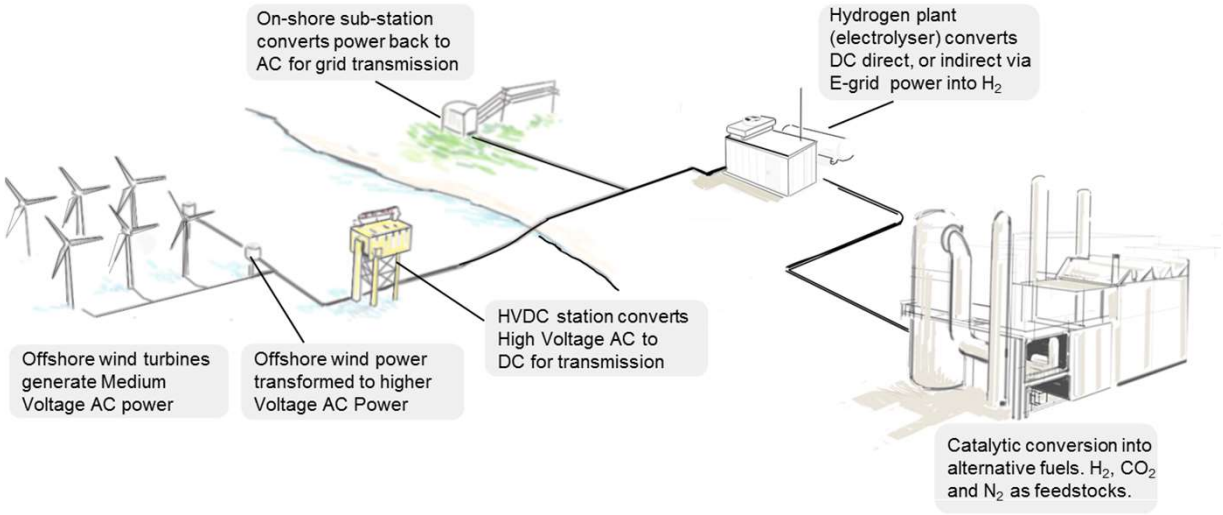
Renewables will create opportunities…



0.9 GW (2016) → 4.5 GW (2023) → 250? GW (2050)



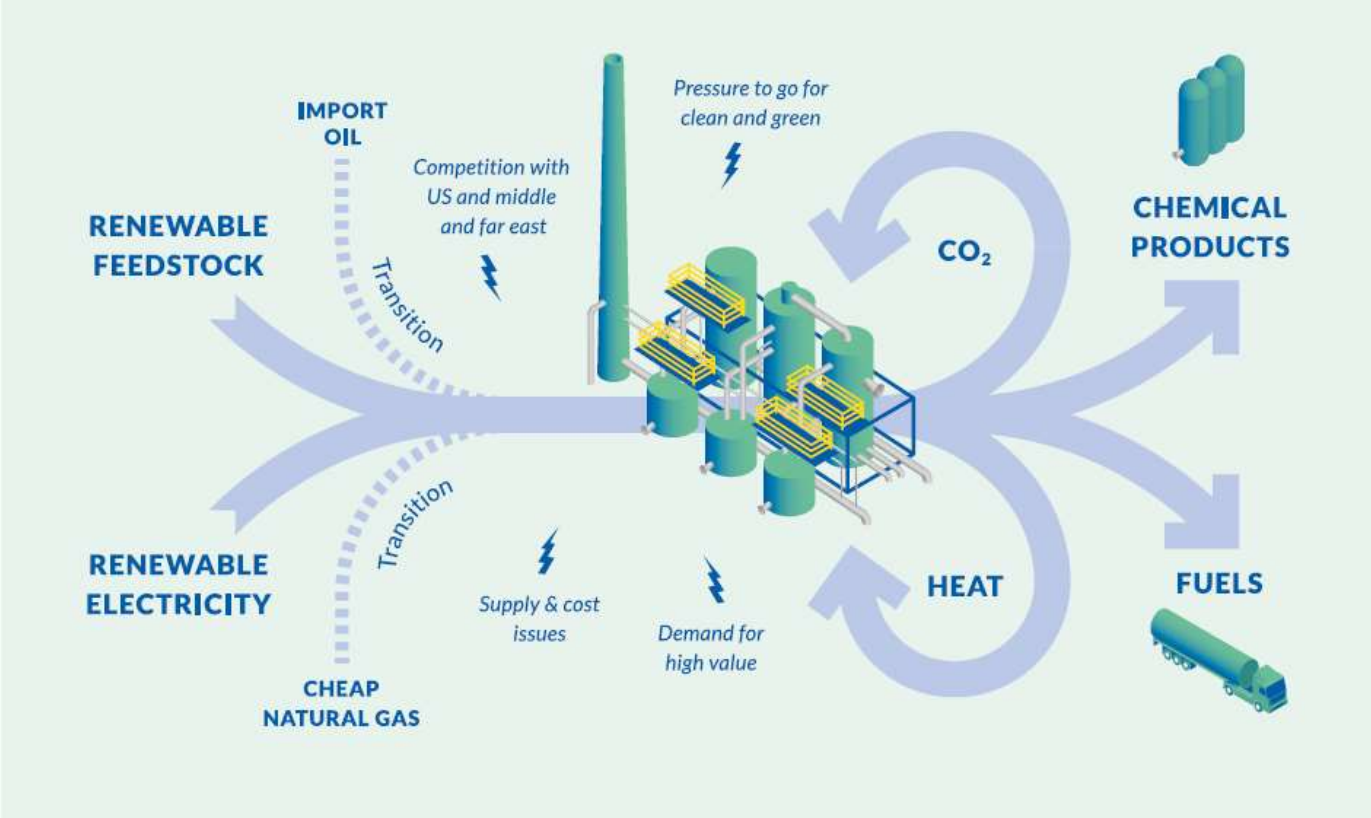




VOLTA CHEM

… employing industrial electrification …

From fossil feedstock to renewable electricity as primary energy source



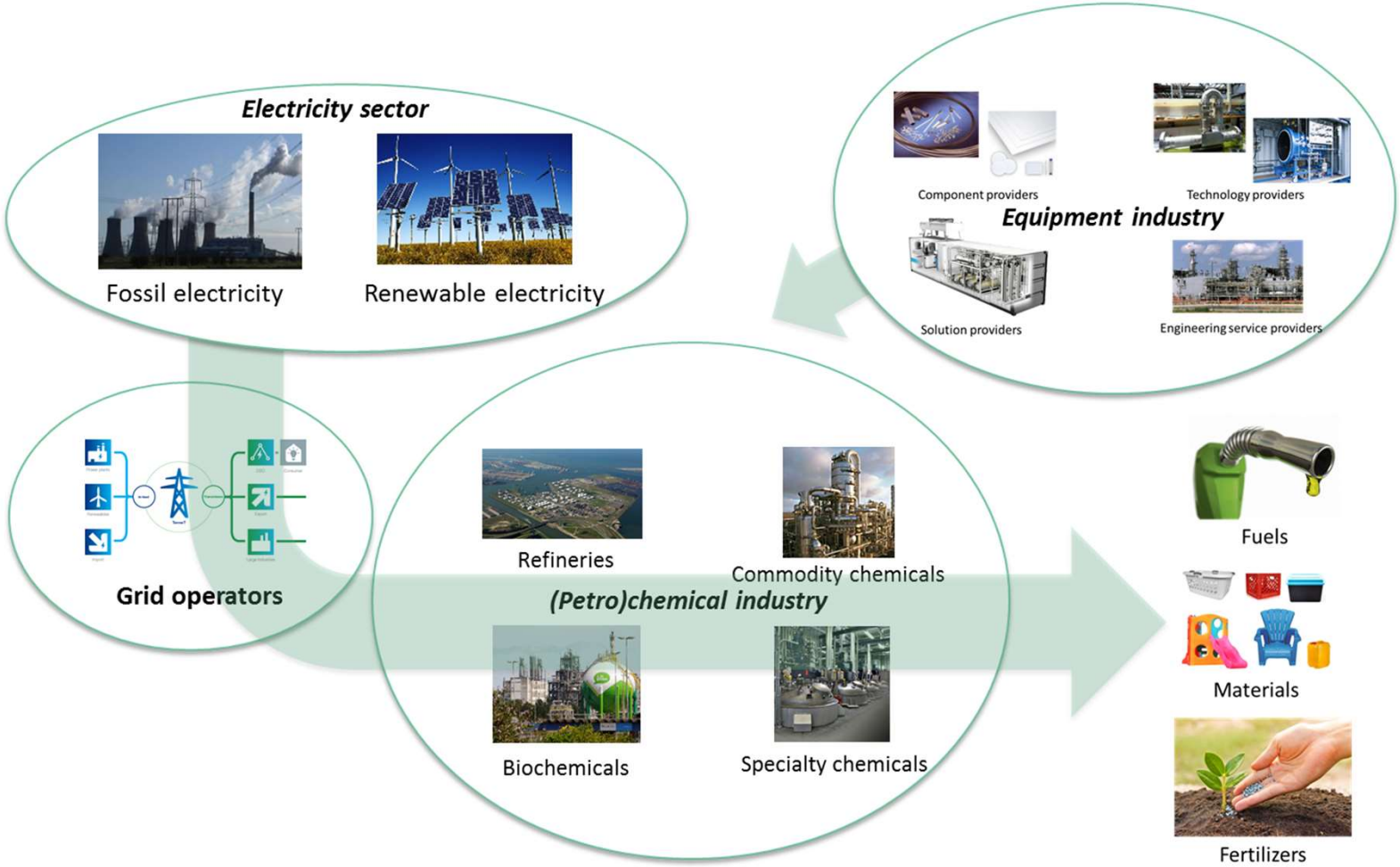
TOPSECTOR ENERGIE
Empowering the new economy

Topsector Chemie

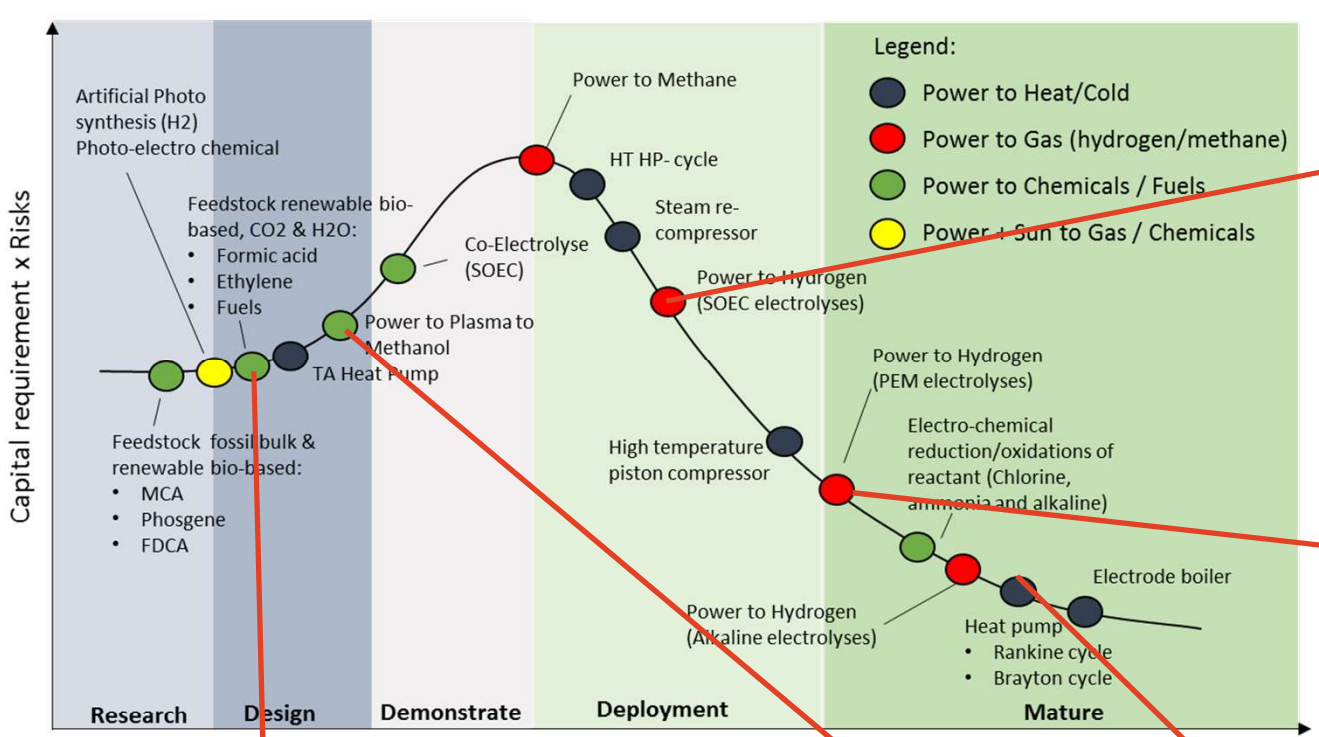
Holland High Tech
High Tech Solutions for Global Challenges

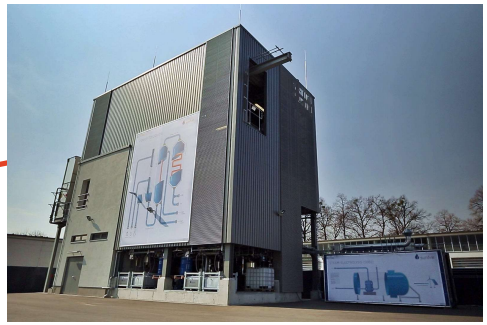
… in important industry clusters

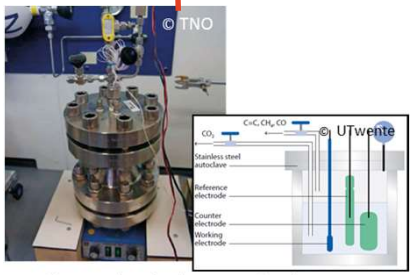
A new value chain will be developed…



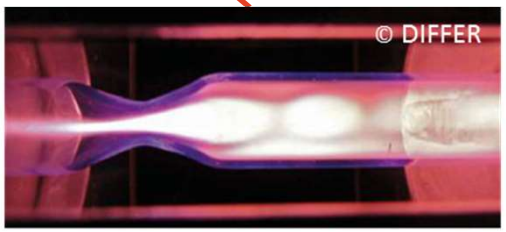
… using existing and new technology …







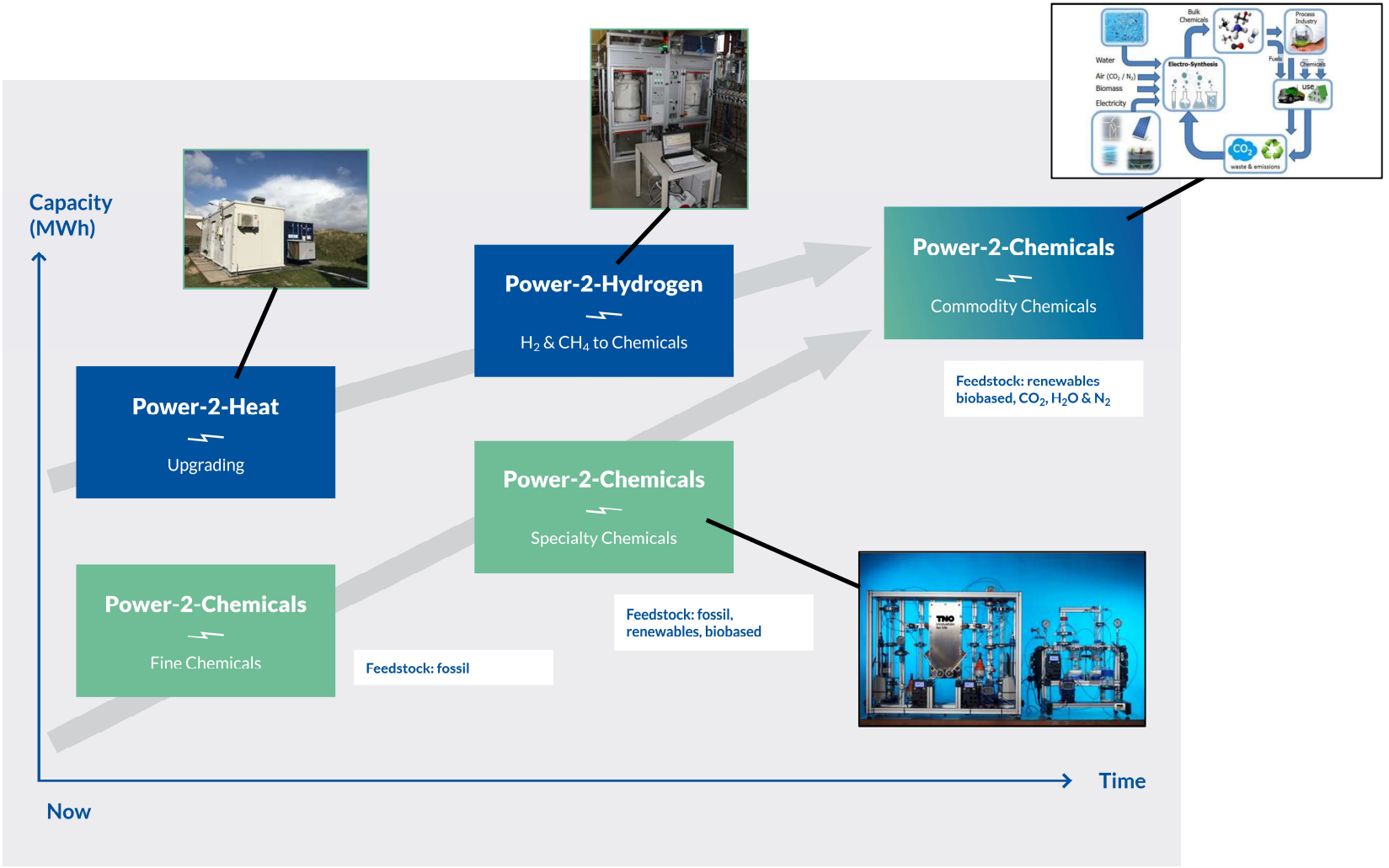
Electrochemical reactor development



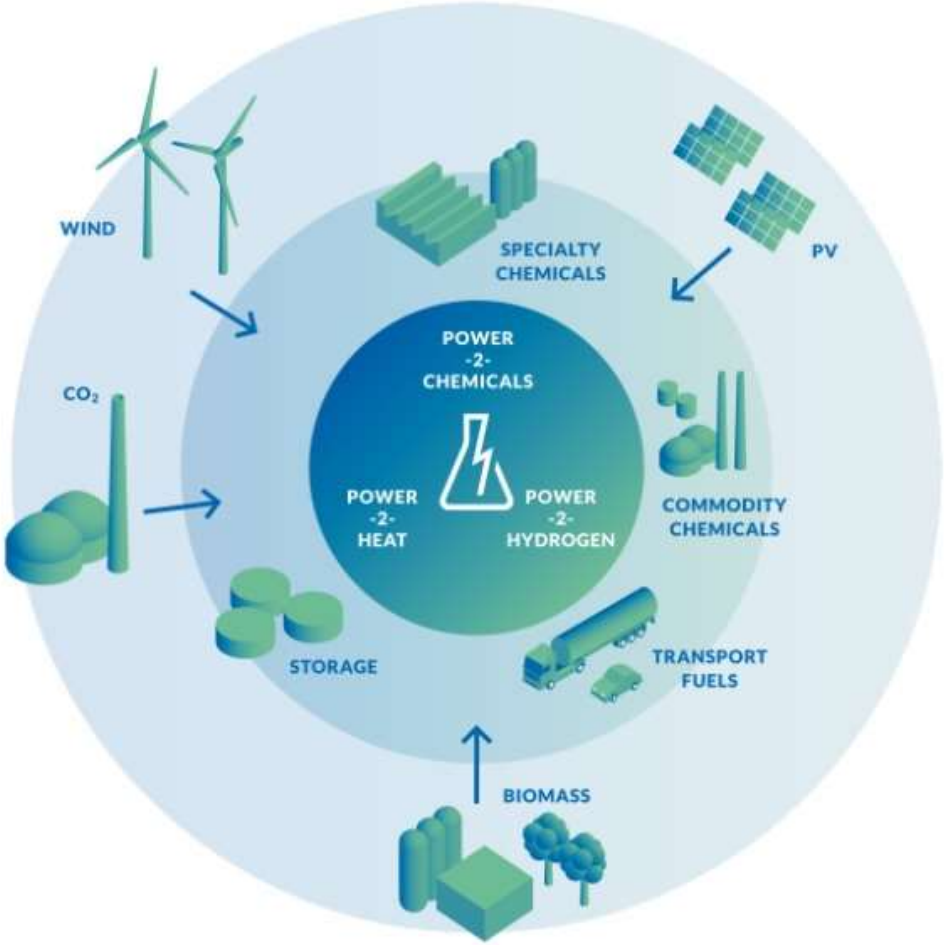
Upcoming technologies: Plasma

Extension of operating windows in heat upgrading

… following a high-level roadmap

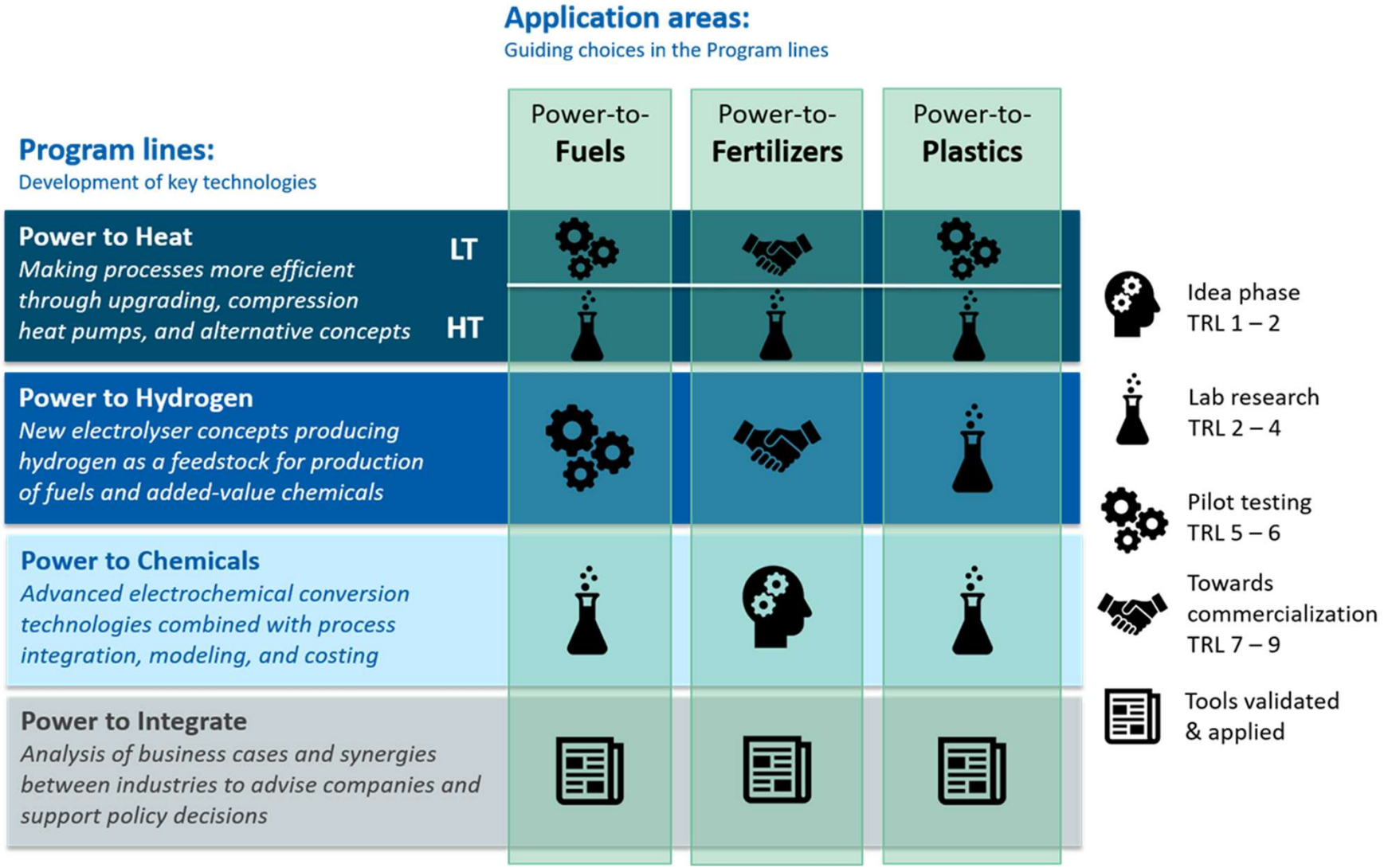


VoltaChem in 1 slide



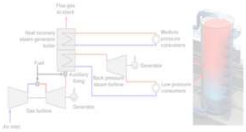
- Public-Private ***Shared Innovation Program*** of 6M/year initiated in 2015 by TNO, ECN and Topsector Chemistry.
- *Accelerate innovation and implementation* of ***electrification for achieving decarbonization*** in chemicals.
- Initiate and facilitate ***collaborative development*** *of technology and associated business models*.
- Addresses both the *indirect and direct use of electricity* within the chemical industry, involving stakeholders from ***chemicals***, ***energy & equipment supply***.

Introducing our program lines



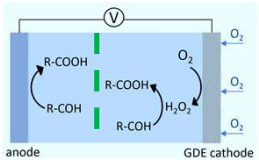
VoltaChem development focus

Power-2-Integrate
Technology scouting & developing ***economic, life-cycle & system models*** to better understand electrification opportunities.



Power-2-Heat
Developing and testing a ***flexible electrically driven heat production system*** for *high temperature.*

Power-2-Hydrogen
Developing and testing ***electrochemical production of hydrogen and further conversion*** towards *fuels and added value chemicals.*



Power-2-Chemicals
Developing an ***electrosynthesis technology*** **platform** for:

- selective ***oxidation of biobased feedstock*** *to chemical intermediates for plastics (showcases: FDCA & LA).*
- direct ***conversion of CO2*** *to commodity chemicals & fuels (showcases: syngas & formic acid).*

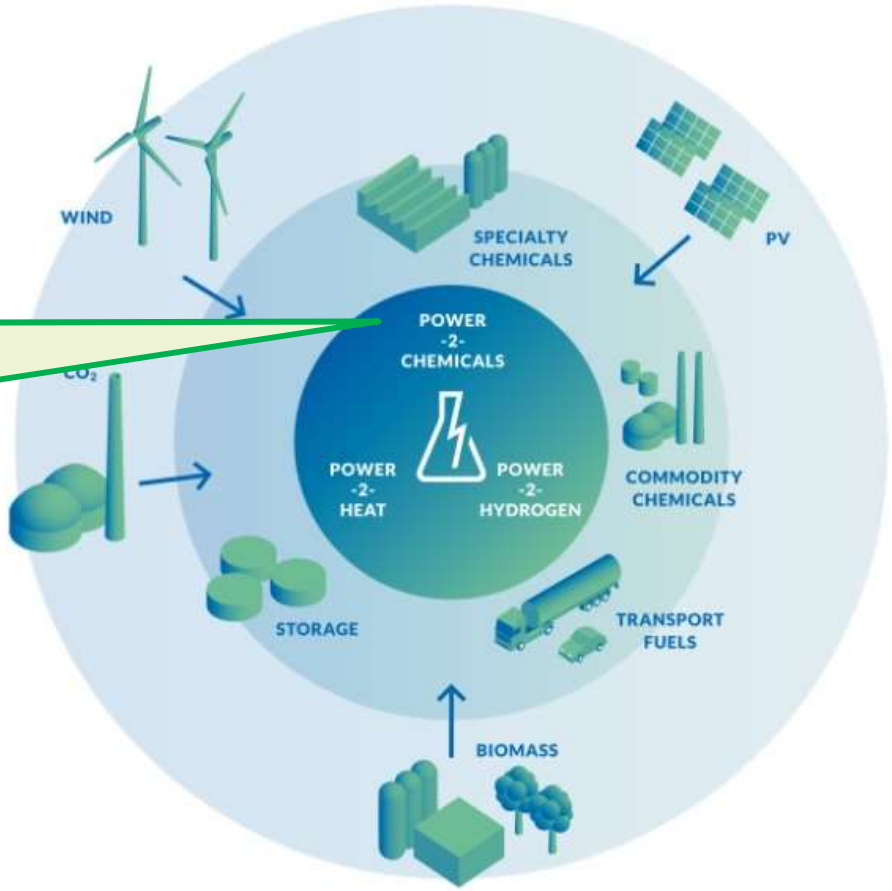
Power-2-Chemicals in VoltaChem

Power to chemicals

- Electro-organic synthesis
- CO_2 electro-reduction
- Electro-oxidation
- Electro-reduction

- ✓ Oxidation of furfural
- ✓ Oxidation of hydroxymethylfuran
- ✓ Oxidation of alcohols

- ✓ Reduction of furfural
- ✓ Reduction of hydroxymethylfuran
- ✓ Reductive amination
- ✓ Reduction of oxygen



9-7-2019

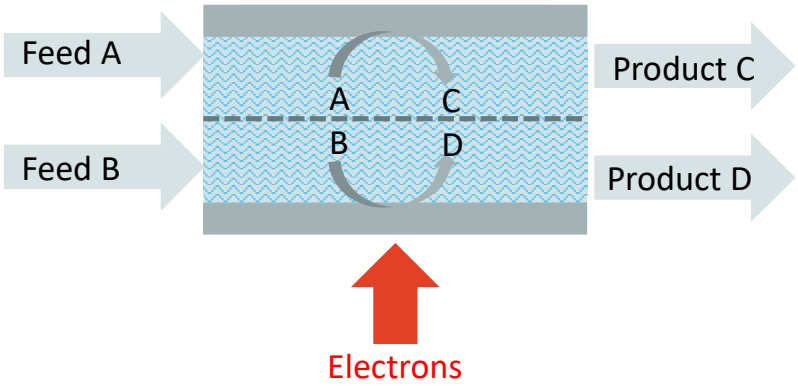
Why electrosynthesis

Advantages

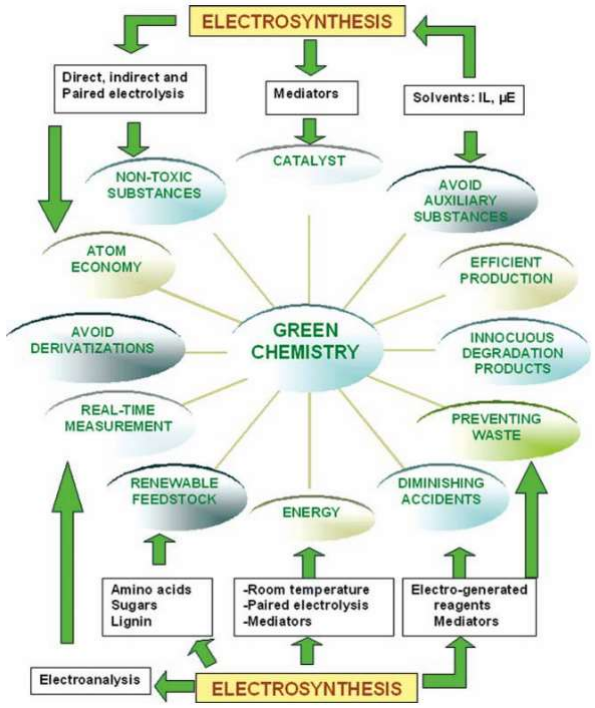
- High selectivity
- Direct electricity utilization
- Ambient conditions
- Satisfies at least 9 of the 12 postulates of sustainable or green chemistry
- Green conversion for biomass processing

Drawbacks

- High CAPEX
- Stability membranes & electrodes
- Knowledge gap electrochemical process development



Why is electrosynthesis a green methodology?

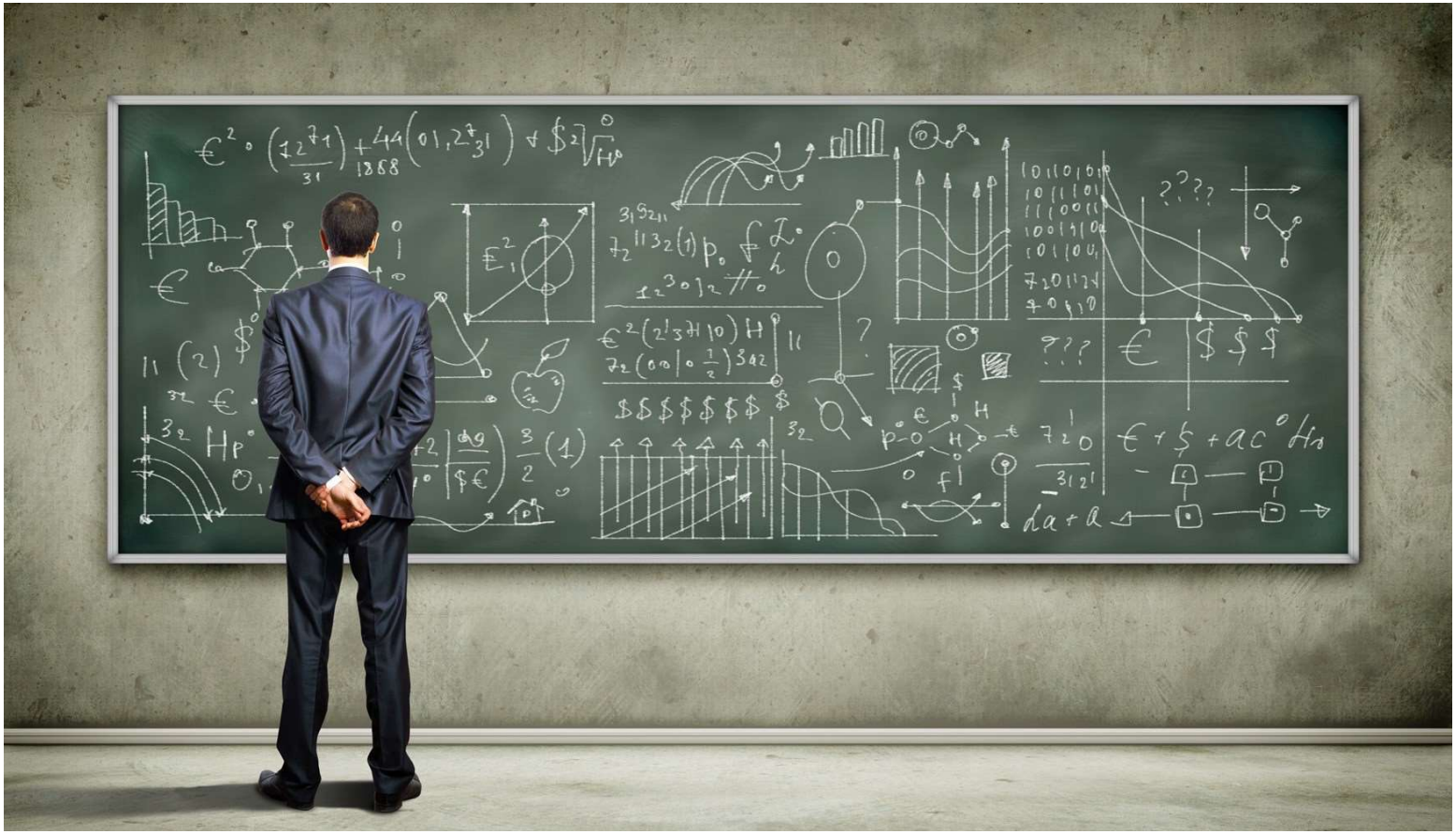


Green Chem., 2010, 12, 2099–2119 | 2099

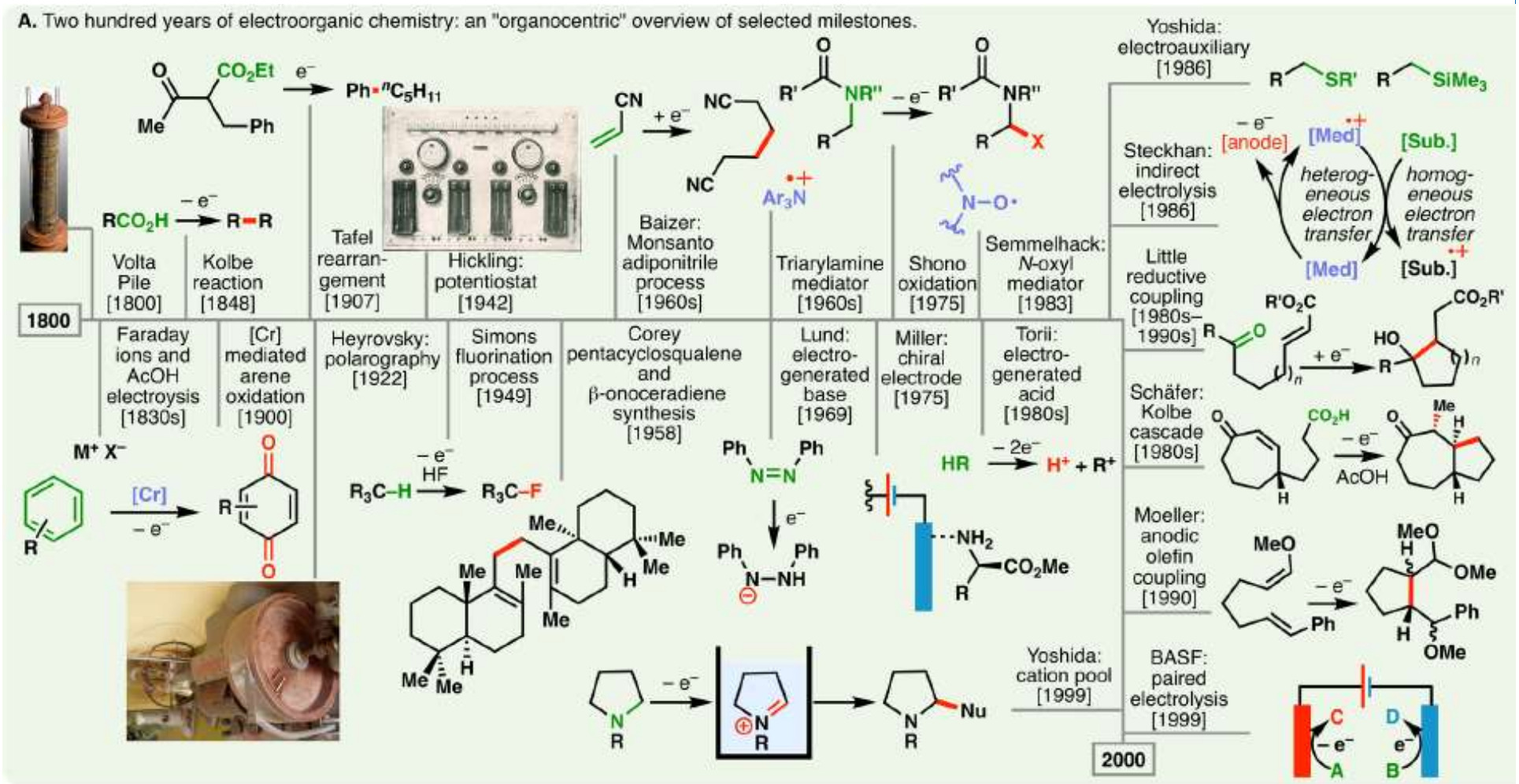
Organic electrosynthesis and its direct relationship to the green chemistry postulates

The main advantage of electrosynthesis over an ordinary redox reaction is avoidance of the potential wasteful other half-reaction and the ability to precisely tune the required potential.

The past



Long history



Starting material	Product	Company
Butanone	Acetoin (3-hydroxybutanone)	BASF
1,4-Butynediol	Acetylenedicarboxylic Acid	BASF
Acrylonitrile (hydrodimerization)	Adiponitrile (> 200.000 tons/year) (production of nylon 66)	Monsanto, BASF, Asahi Chemical
4-Cyanopyridine	4-Aminomethylpyridine	Reilly Tar
Anthracene	Anthraquinone	L. B. Holliday, ECRC
Nitrobenzene	Azobenzene	Several
Glucose	Calcium Gluconate	Sandoz, India
L-Cystine	L-Cysteine	Several
Diacetone-L-sorbose	Diacetone-2-ketogulonic Acid	Hoffman-LaRoche
Naphthalene	1,4-Dihydronaphthalene	Hoechst

Pros

1. Replacement of inorganic redox reagents with electrochemical processes often reduces the total number of laboratory steps.
2. Electrode reactions are selective and present direct routes to products otherwise difficult to make (*via* 'umpolung').
3. Electrons are cheap and are easy to transport. Electricity can be made from many different natural resources.
4. Green and safe technology; no toxic wastes, no fire or explosion hazards, no storage/handling of aggressive reagents, mostly room temperature chemistry.
5. Electrochemical synthesis is easily scalable to the industrial level.

Cons

1. Organic electrochemistry is (still) considered a specialists topic and is usually not a part of the chemistry curriculum.
2. Reaction mechanisms are often complex and require insight into radical ion and radical chemistry. Products may be difficult to predict.
3. Requires equipment (electrodes, cells and current sources) that often is not available in an organic chemistry laboratory.
4. Electron transfer is a heterogeneous process and for that reason takes time (1 mole of e^- = 1*F* = 96485 C = 96485 A·s = 26.8 A·h).
5. Occasionally, electrode fouling occurs. Requires cleaning of electrodes and cells.

Ole Hammerich

Why electrosynthesis

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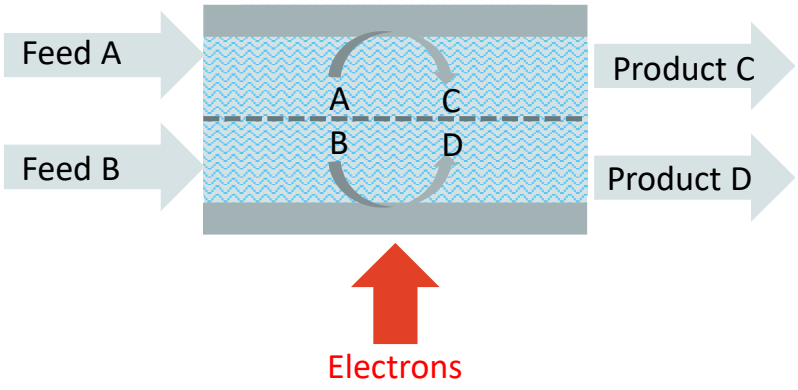

KEY Performace indicators

1. Current density
2. Faradaic efficiency
3. Life time
4. System integration

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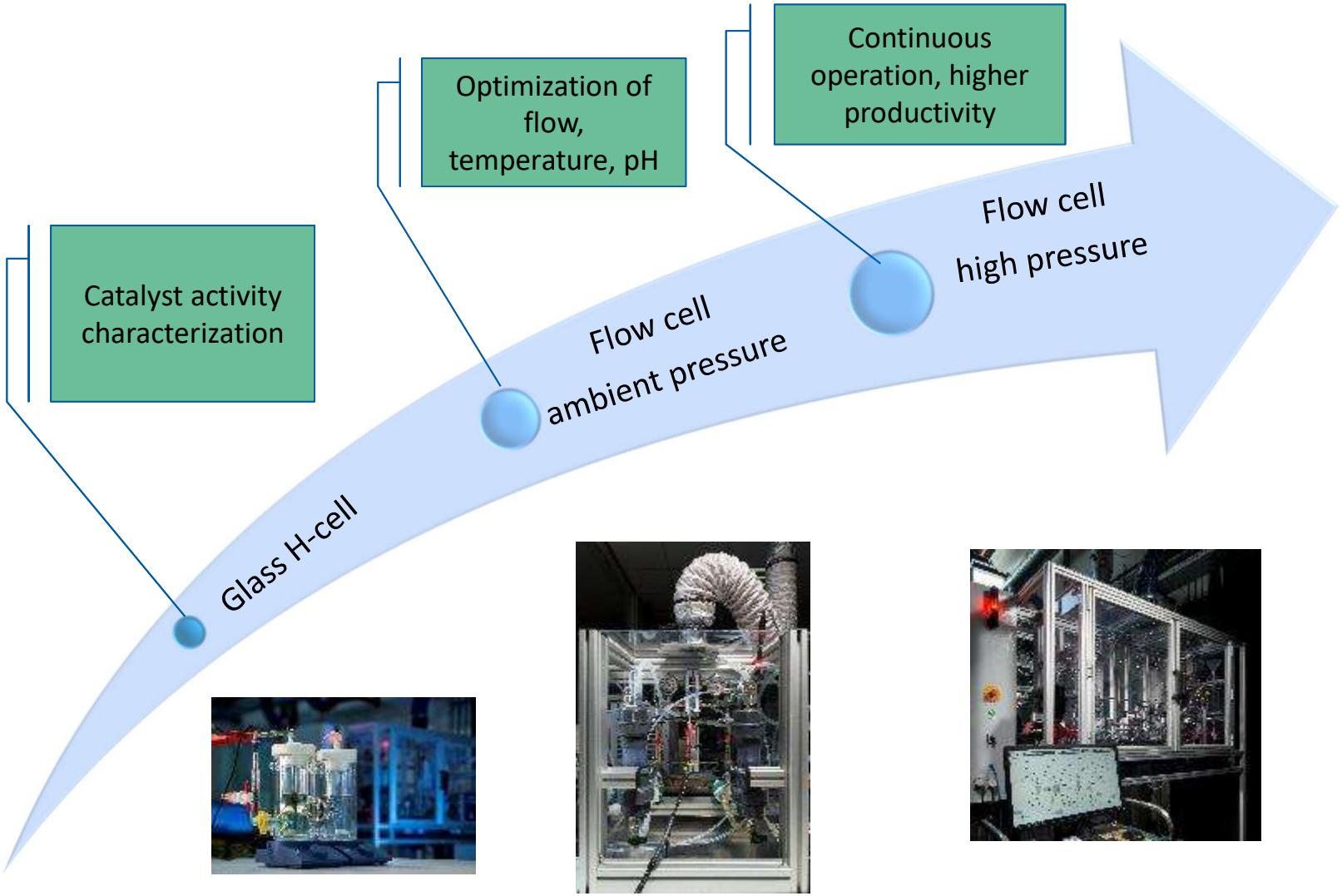
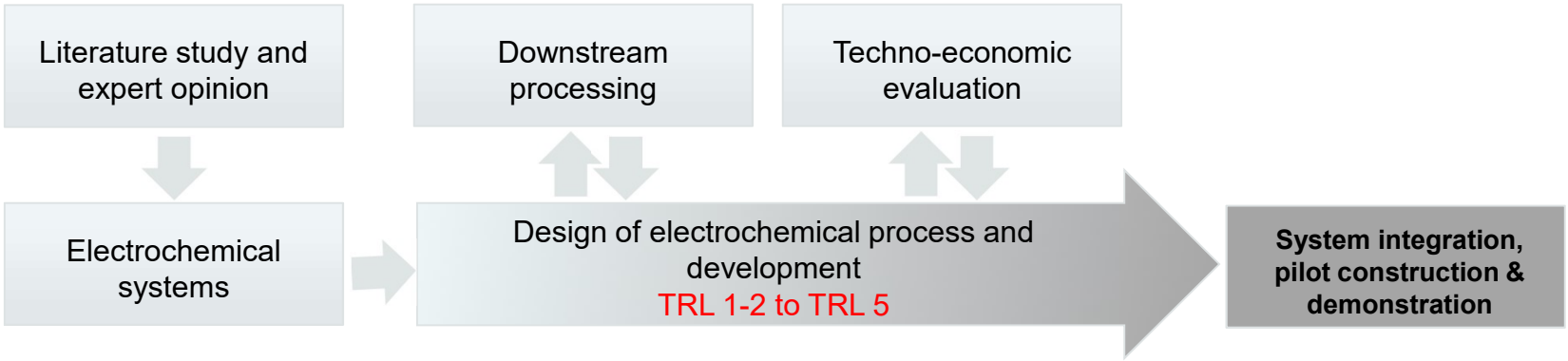
Accelerating industrial electrification

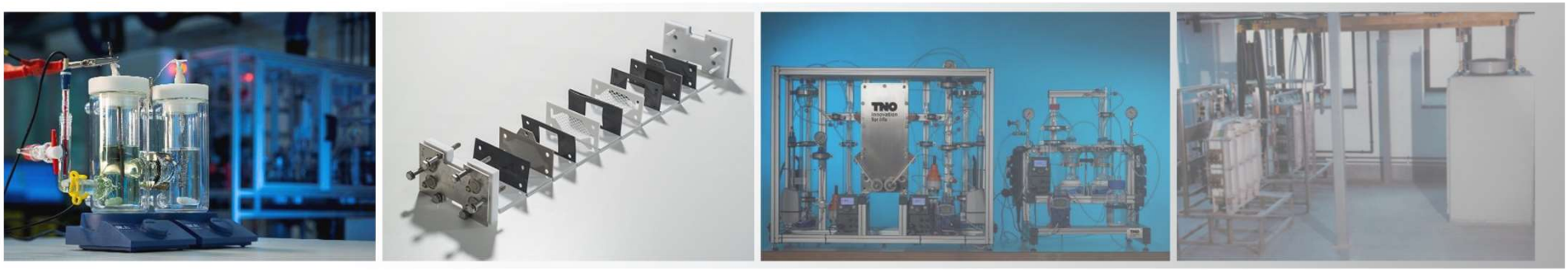
Our approach

Focus on development and scale-up



Structured approach including TEA



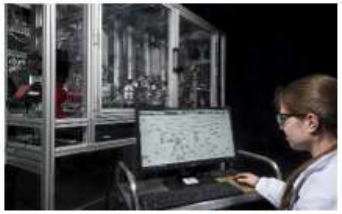


Our unique knowledge & infrastructure

TNO labs Delft

Electrochemical lab equipment

Bench-scale atmospheric electrochemical test bed



Bench-scale high-pressure electrochemical test bed

ECN (part of TNO) labs Petten

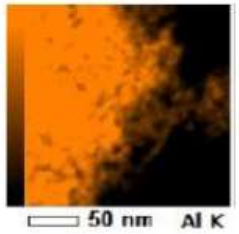
Thermo-acoustic heat pump pilot

Electrolyzer test stations

Hydrogen separation and conversion long term test rig

High pressure hydrogen conversion test rig

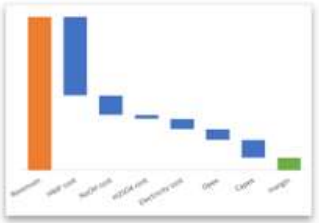
TNO labs Eindhoven



Catalyst development lab

Catalyst synthesis equipment

Common tools & know-how



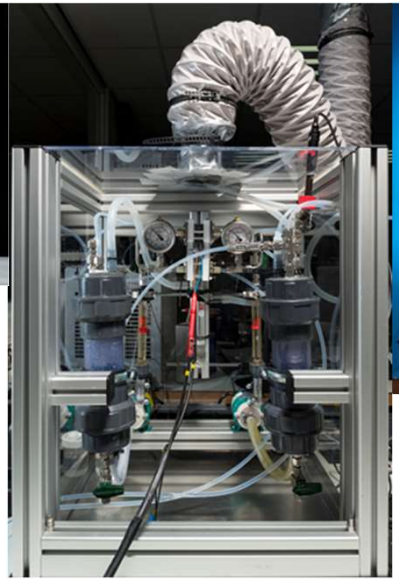
Business case assessment tools

Energy market analysis tools

Infrastructure TNO SPES (Delft)

Electrolysis conditions: glass electrolysis cell

- Electrolyte volume 0.1-0.3 L
- Varying electrode shapes (Graphite, RVC, Sn, Au, Pt,)



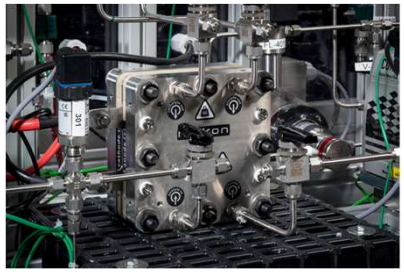
Flow cell electrolyzer batch bench scale system

- Electrolyte volume 0.1-0.3 L
- Electro Syn Cell®
- 10 cm^2 electrode (Graphite, RVC, Sn, Au, Pt,)
- Ambient pressure
- Inline gas analysis

Flow cell electrolyzer
Continuous bench scale system

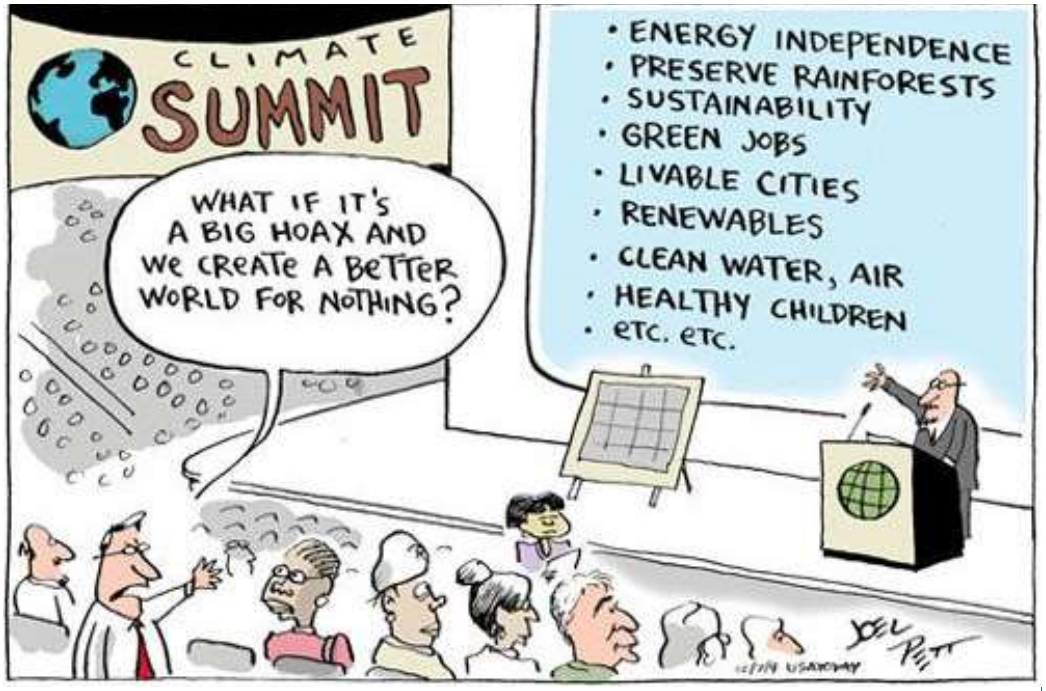
- Electrolyte volume 0.7-1.2 L
- Electro Syn Cell®
- 0.16 m^2 electrode (Graphite, RVC, Ni foam, Pt, …)
- Throughput: 0.4 L/hr FDCA (~5wt% aq.)
- Ambient pressure

Flow cell electrolyzer continuous autonomous bench scale system



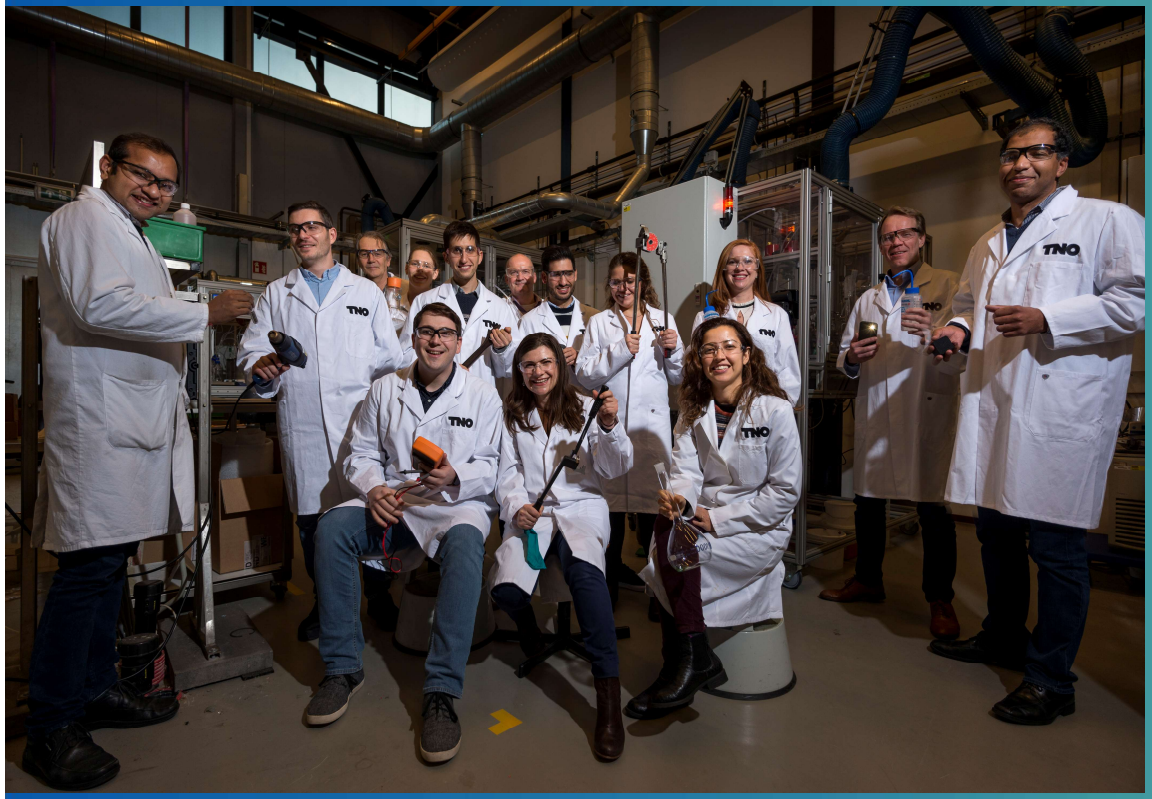
- Electrolyte volume 0.7-1.2 L
- Hydron Cell
- 100 cm^2 electrode (Graphite, RVC, Sn, Au, Ag, Ni foam, Pt)
- Pressure 1-60 bar
- Inline gas analysis

Technology Lines



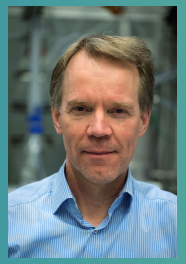
- CO2 to Commodity chemicals
- Power to Specialties
- Electrochemical process development.
  Showcase Bio-based plastics monomers

Let’s energize innovation together!



Ir. Martijn de Graaff
Business development
martijn.degraaff@tno.nl

Prof. dr. ir. Earl Goetheer
Principal scientist TNO
Earl.Goetheer@tno.nl



Dr. ir. Erwin Giling
Project manager power to chemicals
Erwin.giling@tno.nl

www.voltachem.com

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VoltaChem Community

There are multiple ways to engage with VoltaChem

1. **Community membership and Community of Practice membership [“bilateral”]**
   Exclusive discussion group, roadmap updates, high-level results and (inter)national events.

2. **Multi-annual shared R&D program membership [“srp”]**
   Pre-competitive R&D within a collaborative program with a duration of 2-4 years. Participants get rights to the results and can influence and change the scope of the program along the way.

3. **Co-funded R&D project [“sponsoring”]**
   Pre-competitive linear development; small projects with predefined scope/time/budget. Participants get certain rights to the results and scope is determined upfront.

4. **Bilateral project (consultancy, contract R&D) [“bilateral”]**
   Exclusive bilateral consultancy or contract R&D project with pre-defined scope/time/budget.

5. **Subsidized research collaboration [“subsidy”]**
   VoltaChem participates in publicly funded consortium projects (e.g. RVO, EU) and fundamental research programs (e.g. NWO). The funding rules of the specific programs determine the rights to the results and scope is determined up-front by partners together.

VoltaChem community: Nice to meet you!

A platform for open innovation and cross-fertilization of the energy, chemical & equipment sector focused on electrification:

- ***brings together stakeholders*** from relevant sectors, like chemicals, energy, equipment industry and service providers ***in an exclusive forum***.

- *Performs* ***collaborative technology & business scouting*** *and uses the results to* ***develop and update a multi-year high-level roadmap*** for implementation of in the industry and society as a whole.

- ***works together on specific high-level projects*** that are needed for implementation of the roadmap.

The community gives you the latest insights in technology & market opportunities

- Quarterly Business community meetings
  - Interaction and networking with industry peers on strategic topics
  - Direct feedback from VoltaChem RD&I and BD activities
  - Direct influence on and participation in VoltaChem roadmap
- Community of Practice (CoP) meetings
  - Tailor-made program with industry peers - with a technological orientation
  - Direct feedback from VoltaChem RD&I and BD activities
  - Direct influence on and participation in VoltaChem roadmap
  - Possibility to participate in VoltaChem technology developments
- International business & technology scouting
  - Conference and trade-fair reports
  - International technology and business scouting overview
- Bilateral consulting & interaction (~2 days)

Our current members and partners

… and growing

We look forward to meeting you!

Monique Rijkers
Program manager Power-2-Integrate
Community manager
Monique.Rijkers@tno.nl

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