VOLTA CHEM

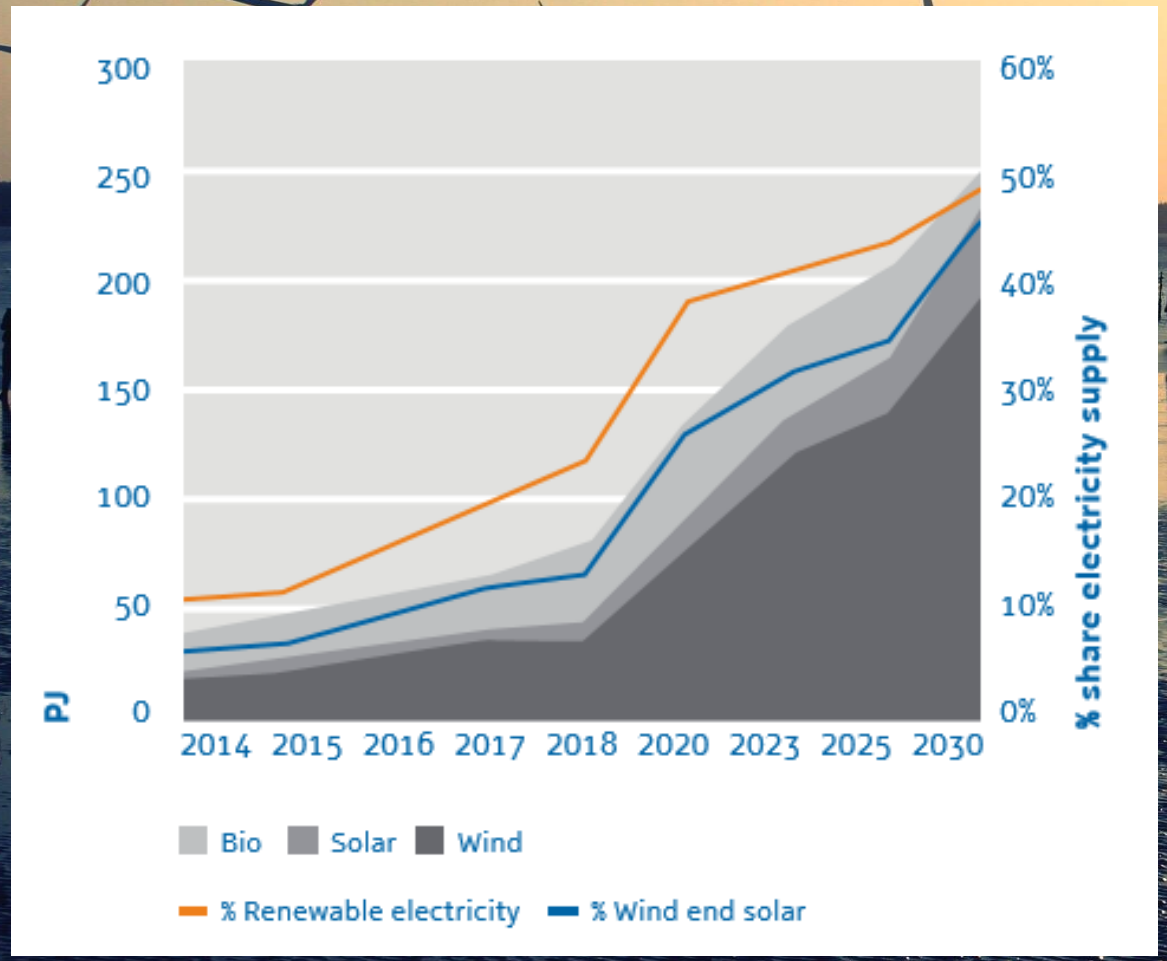
Sustainable Electrification of the Chemical Industry

Power-2-Chemicals: Selective electrochemical conversions for production of bio-based chemicals

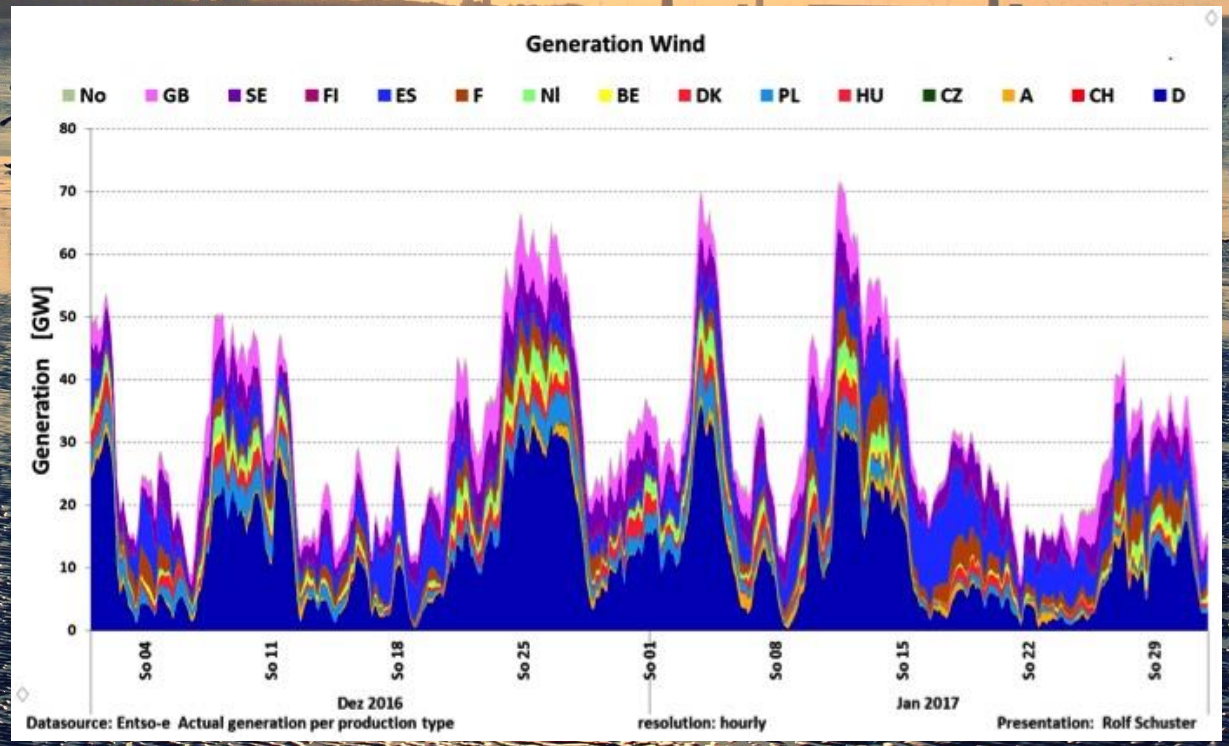
Roman Latsuzbaia, TNO

Powered by: TNO innovation for life ECN

Shift towards renewable energy & chemicals



Electrification in the Dutch process industry, Berenschot, 2017



https://www.wind-watch.org/documents/hidden-consequences-of-intermittent-electricity-production/

VoltaChem

Power to chemicals

Electro-organic synthesis

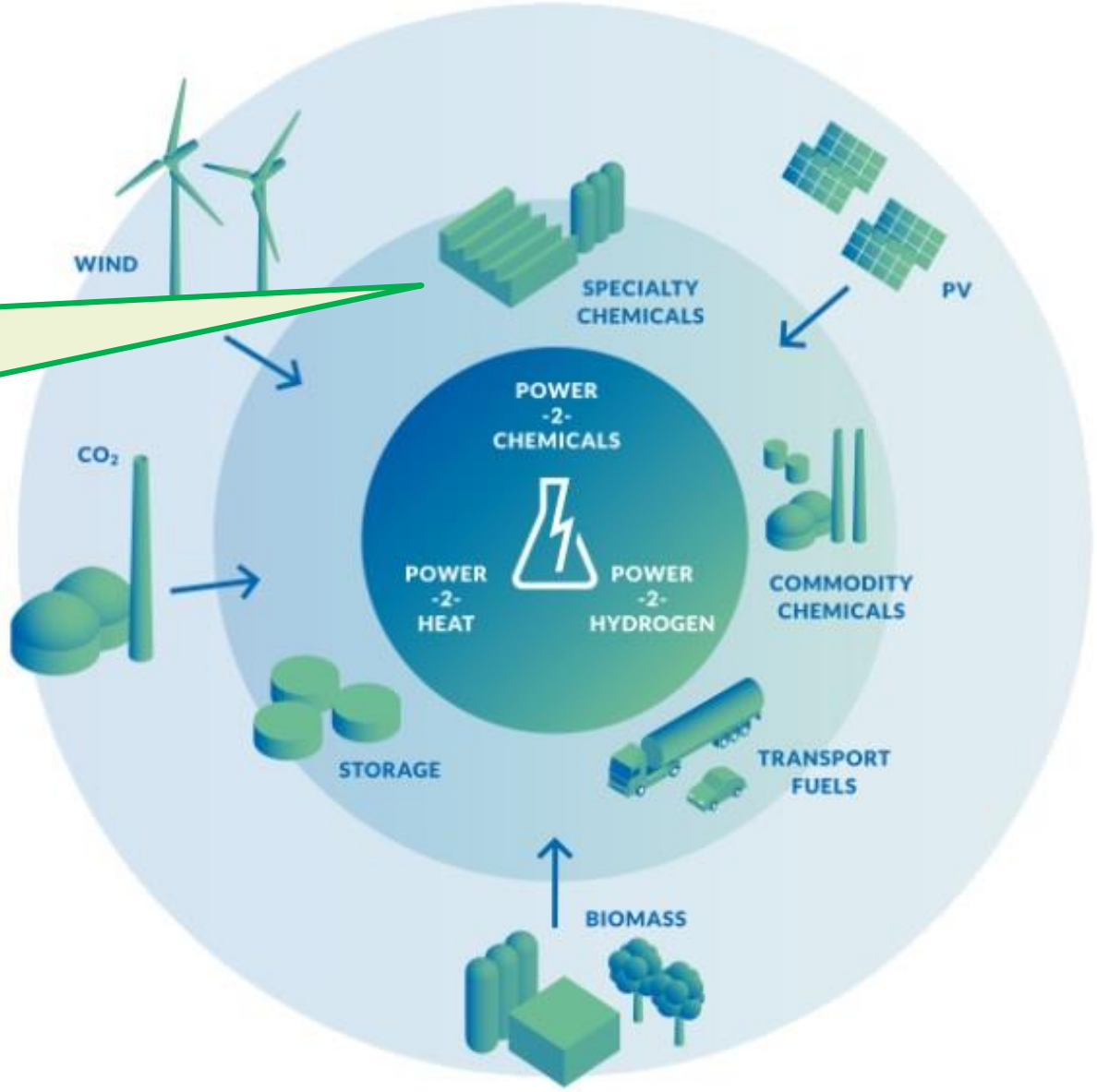
CO_2 electro-reduction

Electro-oxidation

Electro-reduction

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

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



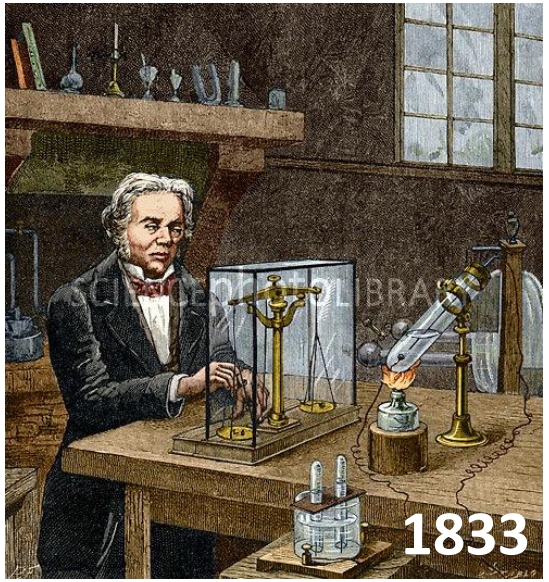
Electrochemical production

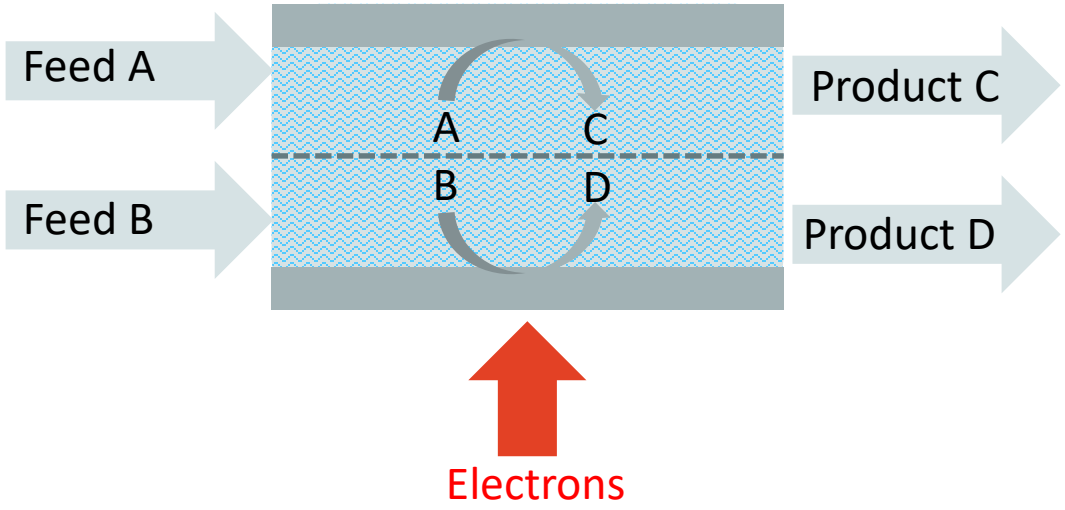
Why electrochemical?

- 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

Why is it limited on the market?

- High costs: CAPEX & OPEX
- Stability of membranes & electrodes
- Knowledge: electrochemical process development





Focus of TNO: upscaling of electrochemical production processes & TEA

Literature study and expert opinion

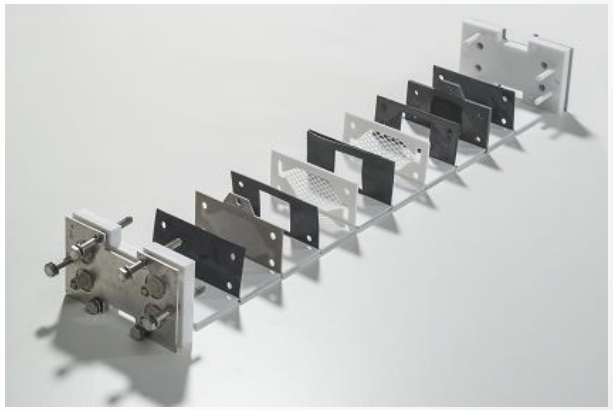
Downstream processing

Techno-economic evaluation

Electrochemical systems

Design of electrochemical process and development
TRL 1-2 to TRL 5

System integration, pilot construction & demonstration

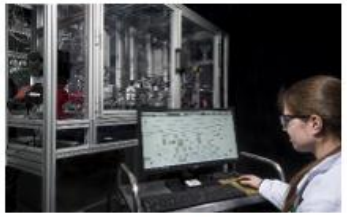


Our unique knowledge & infrastructure

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

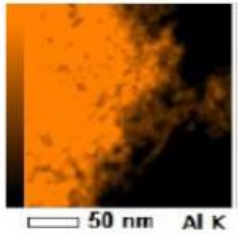
Thermo-acoustic heat pump pilot

Electrolyzer test stations

Hydrogen separation and conversion long term test rig

High pressure hydrogen conversion test rig

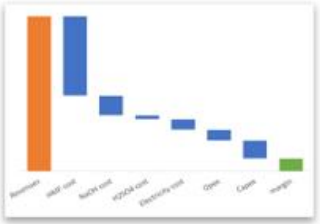
TNO labs Eindhoven



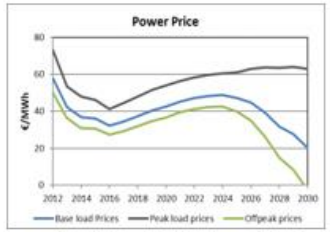
Catalyst development lab

Catalyst synthesis equipment

Common tools & know-how

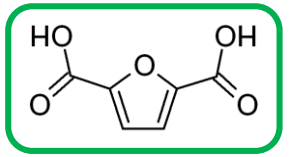


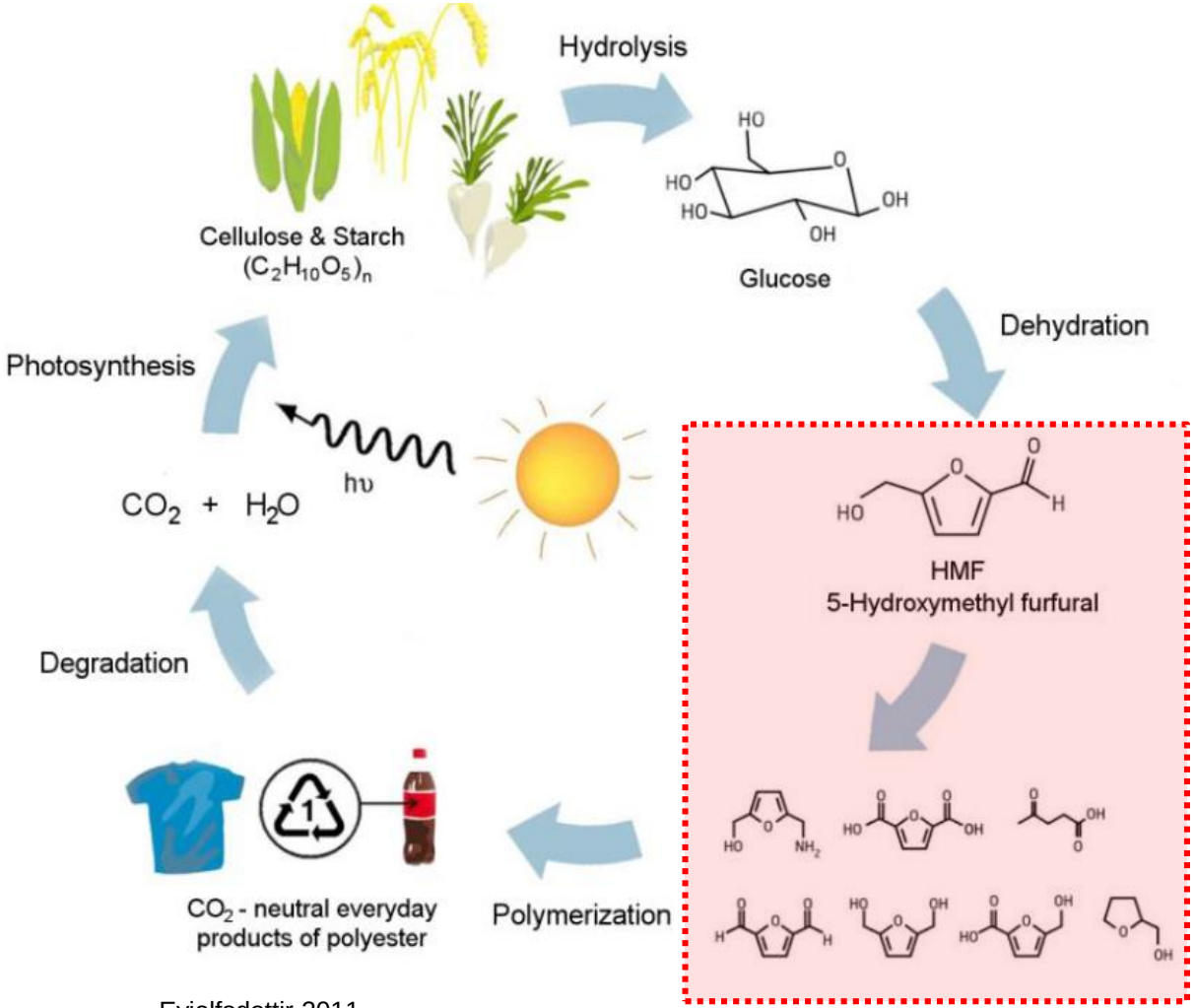
Business case assessment tools



Energy market analysis tools

Electrochemical production of FDCA from HMF





Eyjolfsdottir 2011

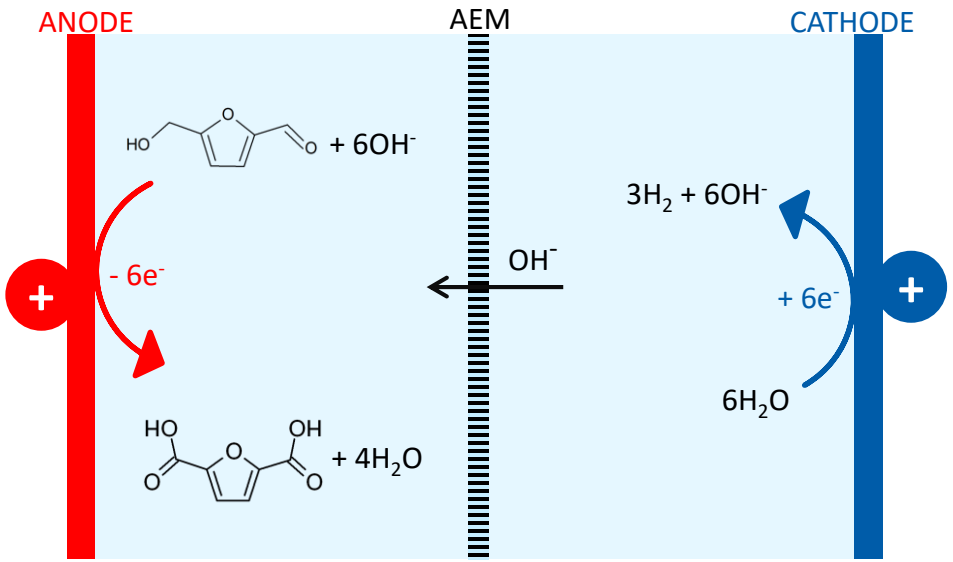
research topic

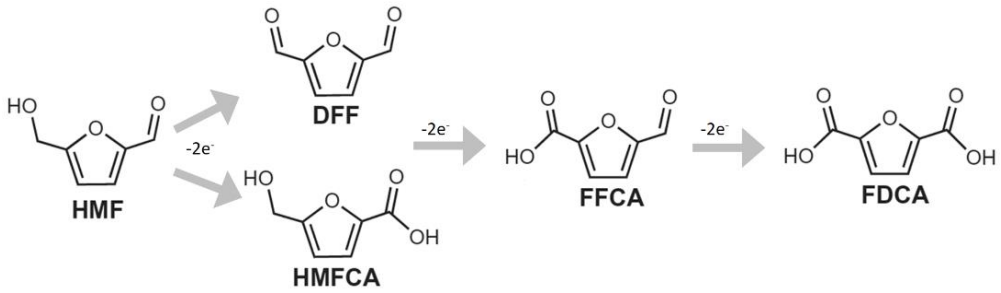
Driver:

- HMF sustainable feedstock
- FDCA building block of future for production of chemicals and plastics
- FDCA → PEF: potential replacement of PET. Higher barrier and mechanical stability.
- PET – 27.8 mln tonnes in 2015*
- PTA 750 – 1450 USD/tonne
- No existing commercial process
- Waste minimization

*https://www.plasticsinsight.com/global-pet-resin-production-capacity-overview/

Why electrolysis of FDCA?





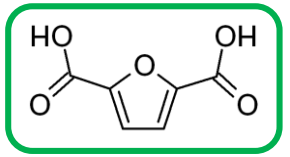
Conventional oxidation process

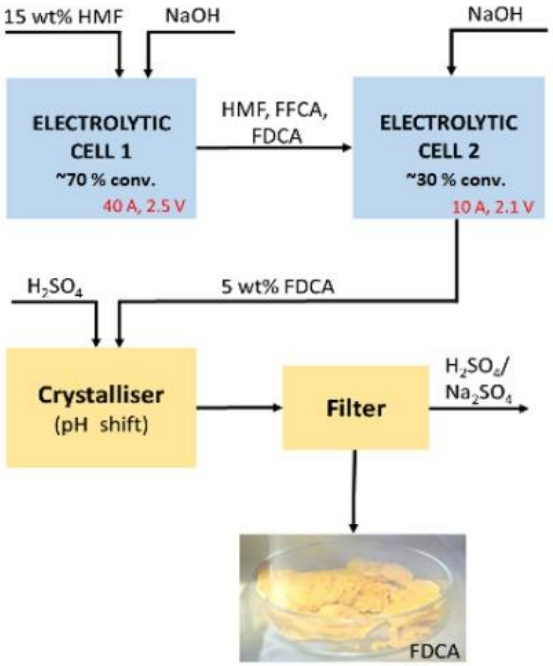
- Use of O_2
- 30-130 ^{0}C
- Pressure of O_2 3-40 bar
- Noble metal catalysts, high catalyst loadings (20-80% wt% of HMF)

Electrochemical oxidation process

- No Use of O_2 or oxidants
- Water as a solvent
- Ambient conditions
- Cheap materials (Ni, Co)
- 100% conversion, >90% select.
- Low product concentration
- Stability of electrodes
- High current densities required to reduce CAPEX

FDCA continuous electrochemical production

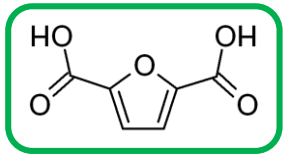


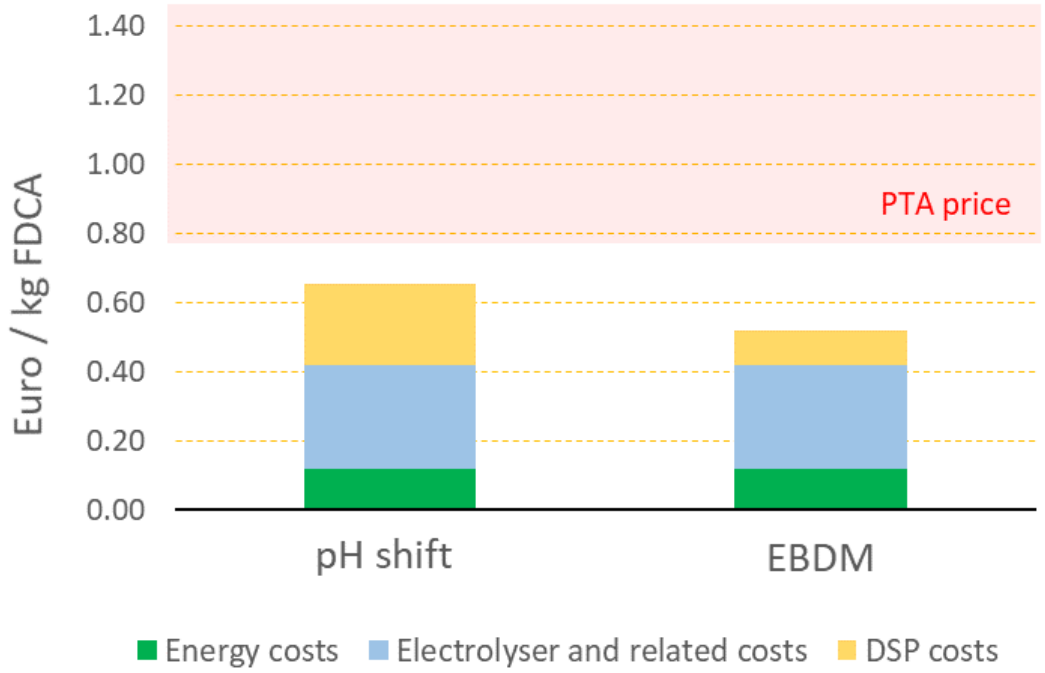


- 0.08-0.16 m^2 electrolyser
- Ni foam electrodes
- 1L reactor volume
- 50-100 g/h FDCA
- KGs of crude product made

Latsuzbaia, R. et al, Continuous electrochemical oxidation of biomass derived 5-(hydroxymethyl)furfural into 2,5-furandicarboxylic acid. Appl. Electrochem. 2018

Costs of electrolysis





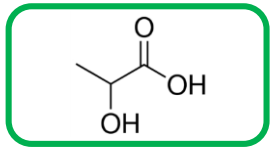
70-80% yield FDCA, 84% CE
DSP: 90-95% yield

0.5 – 0.7 €/kg FDCA
1.13 €/kg FDCA (Triebl 2013)

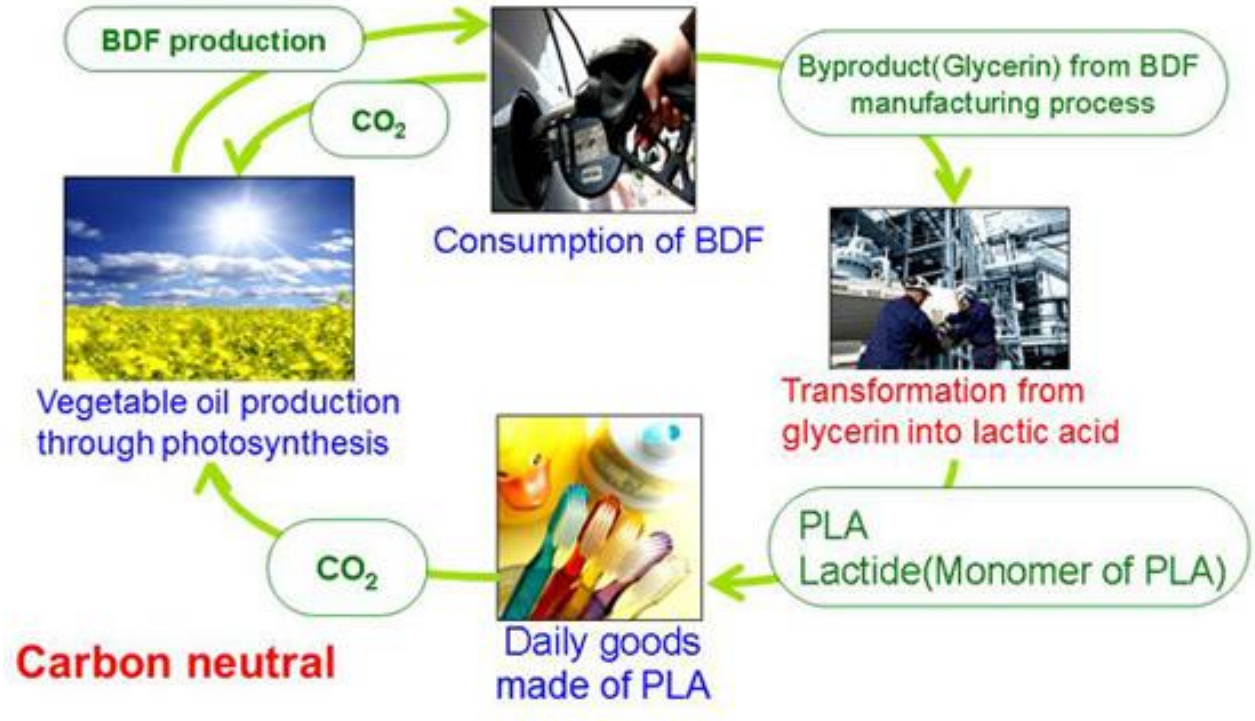
Energy saving ~20-30%, if paired 60-70%
0.200 kg CO2/kWh heat production
0.396 kg CO2/kWh electricity production
EU av.

Latsuzbaia, R. et al, Continuous electrochemical oxidation of biomass derived 5-(hydroxymethyl)furfural into 2,5-furandicarboxylic acid. Appl. Electrochem. 2018

Lactic acid for biobased polymers



GOAL: demonstration of industrially feasible electrochemical continuous lactic acid production from a renewable feedstock



Energy Procedia. Volume 56, 2014, Pages 195–200

- Renewable feedstock: biobased glycerol derived 1,2-propanediol (PDO)
- LA demand to increase 5-8% yearly, ~400kt/year
- Selective oxidation of alcohol groups is challenge.

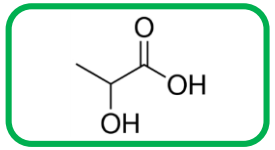
Conventional oxidation process

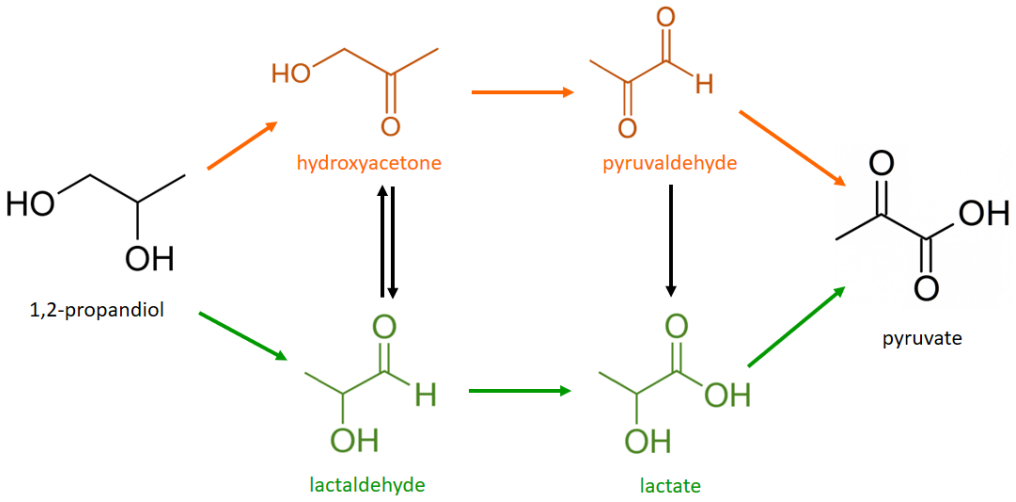
- Fermentation (70-90% in 2009)
- Thermocatalytic oxidation on noble metals (Au, Pt, Pd & alloys)
- Electrochemical oxidation on noble metals (Pt, Au) in strong alkaline medium

Electrochemical production

- Selective oxidation on cheap graphite materials at ambient conditions
- Chirality

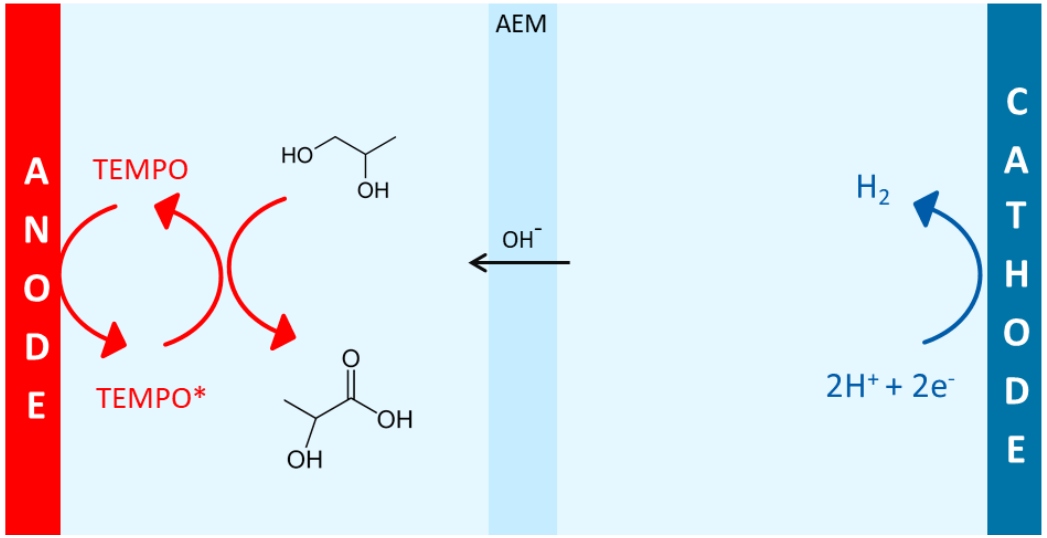
Lactic Acid Electrolysis





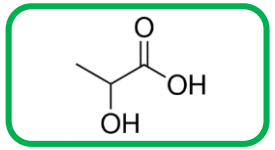
Adapted from Chadderdon, ACS Catal. 2015, 5, 6926−6936

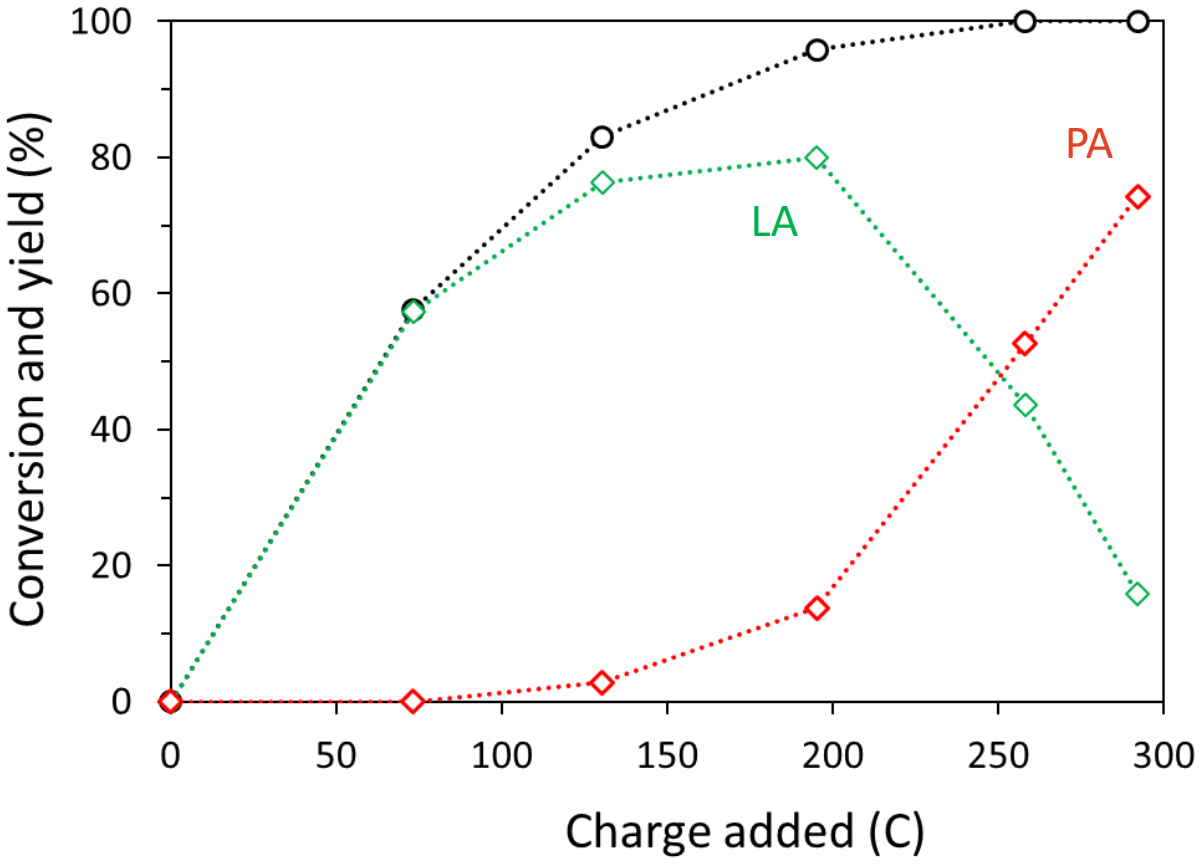
TNO patent



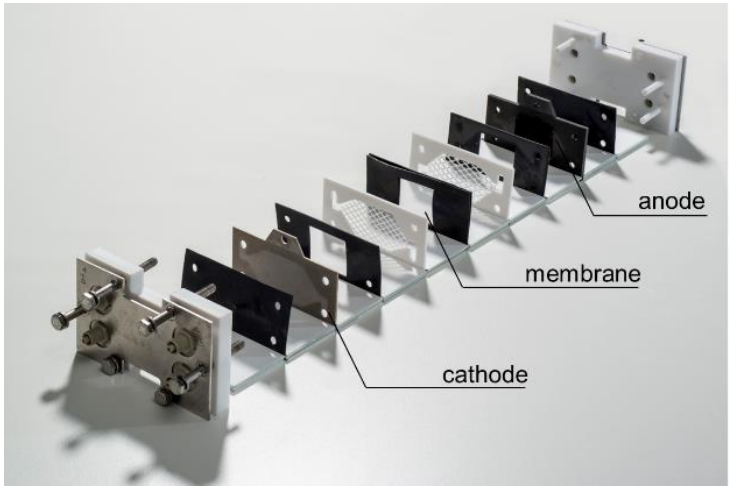
TEMPO: 2,2,6,6-Tetramethylpiperidin-1-yl)oxyl

Lactic Acid Electrolysis

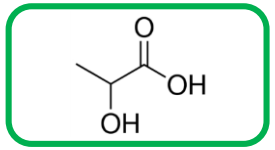


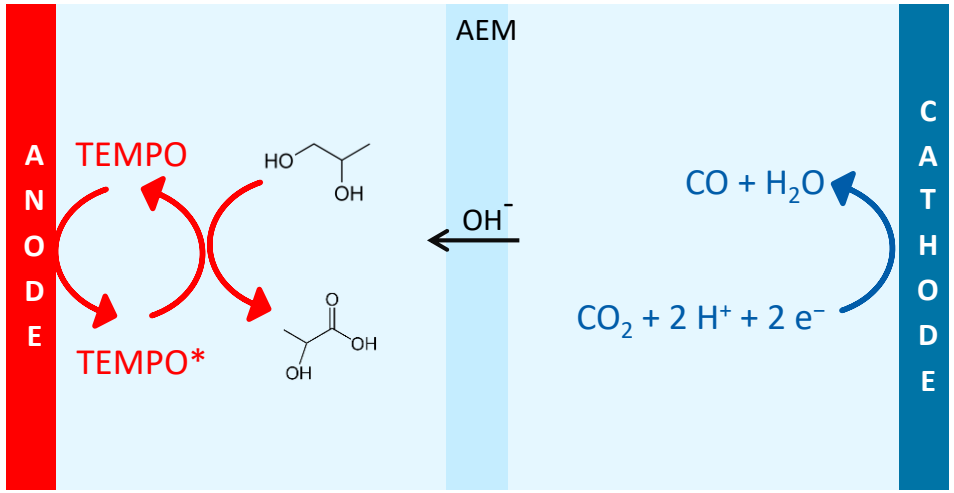


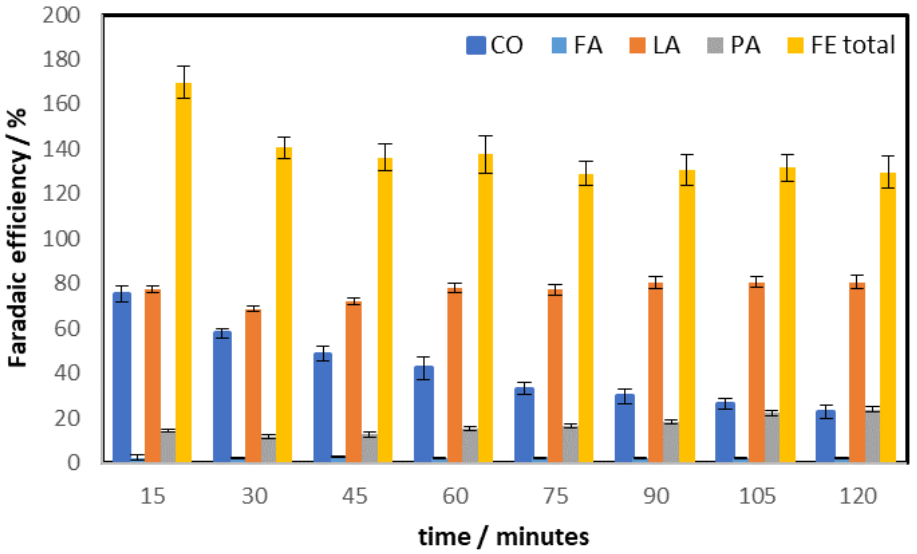
- Anode: carbon felt (1 cm2), TEMPO
- Anolyte: pH 10 borate buffer with 0.5 M Na_2SO_4
- RT
- Current density: 30-40 mA/cm2
- Current efficiency: 90% LA
- Yield LA: 80%
- ~0.1M LA

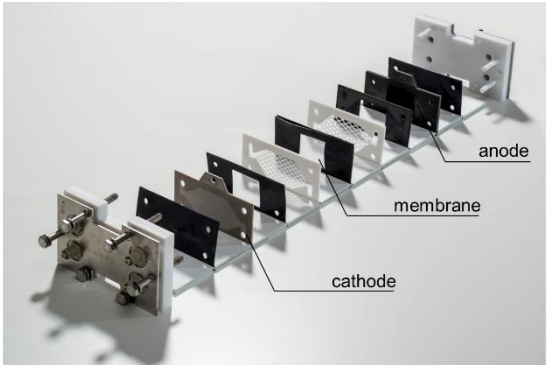


Paired Electrolysis with co-production of CO



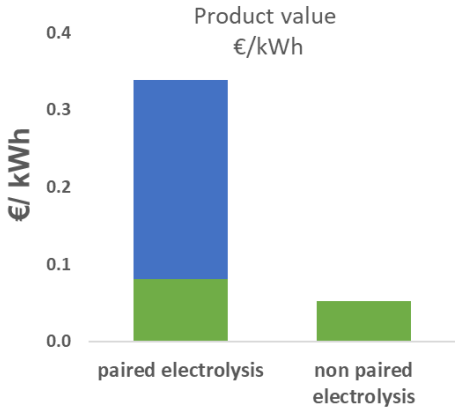






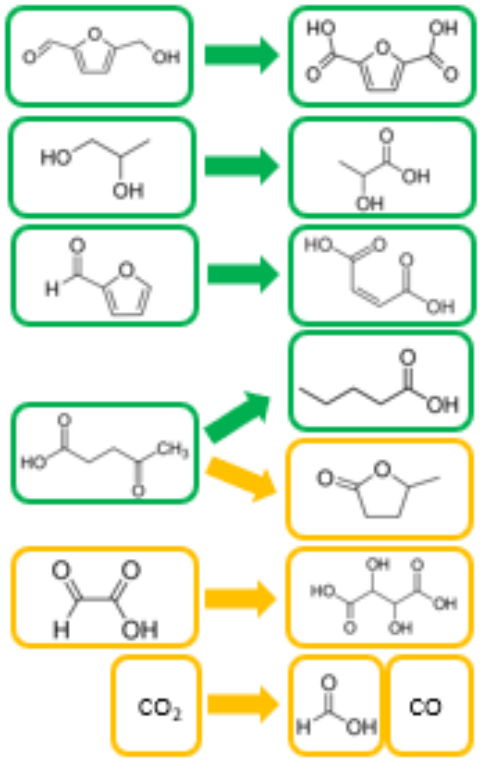
- Production of lactic acid with co-production of CO (TRL3)
- **Cell voltage lowered (40%)**
- **Pt anode replaced with Carbon felt**
- **3.5 kwh/kg LA, 6.2 kwh/kg CO**

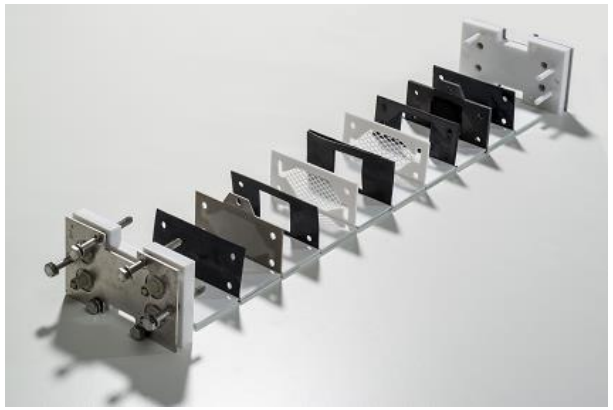
- DSP of lactic acid



Summary

- Shift towards renewable energy and chemicals: decarbonization
- **Selective electrochemical conversions** can be economically feasible
- Efficient production of monomers for polymers and platform chemicals: FDCA, Lactic acid, maleic acid, valeric acid, and many more





Thank you for your attention!

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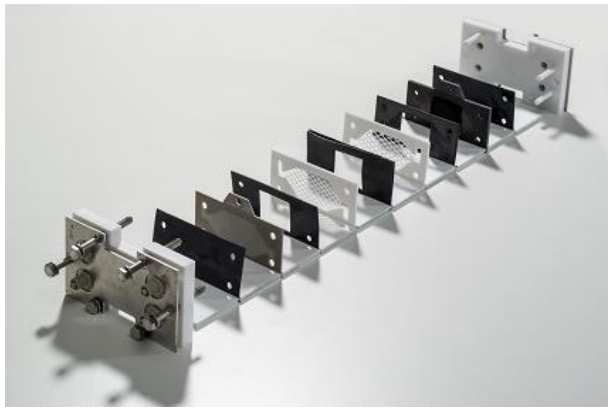
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