hydrogenious TECHNOLOGIES

Transport and logistics of solar fuels via LOHC

SolarChemieR Innovationsforum

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Agenda

LOHC Technology from Hydrogenious Technologies

Commercial Projects all over the world

Outlook on future developments

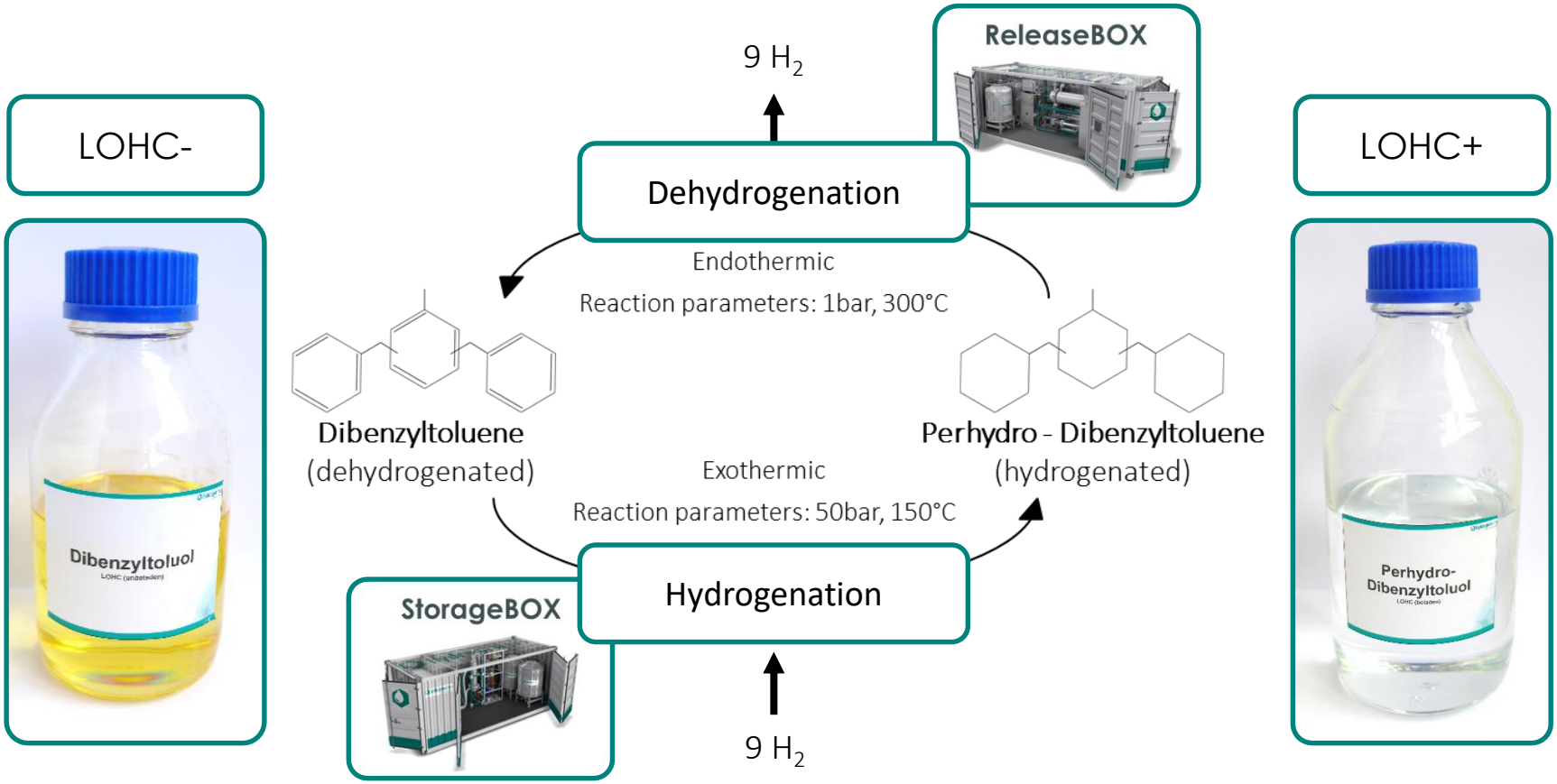
Hydrogenious Technologies GmbH – a pioneer in chemical hydrogen storage

- Founded in 2013 by Dr. Daniel Teichmann and Profs. Arlt, Schlücker and Wasserscheid; staff of 65; 30 patent families filed
- Global technology leader for Liquid Organic Hydrogen Carriers (LOHC) – the revolution in hydrogen storage and transport
- Focus on commercialization of hydrogen storage and release systems for industrial and mobile applications

Key Partners:

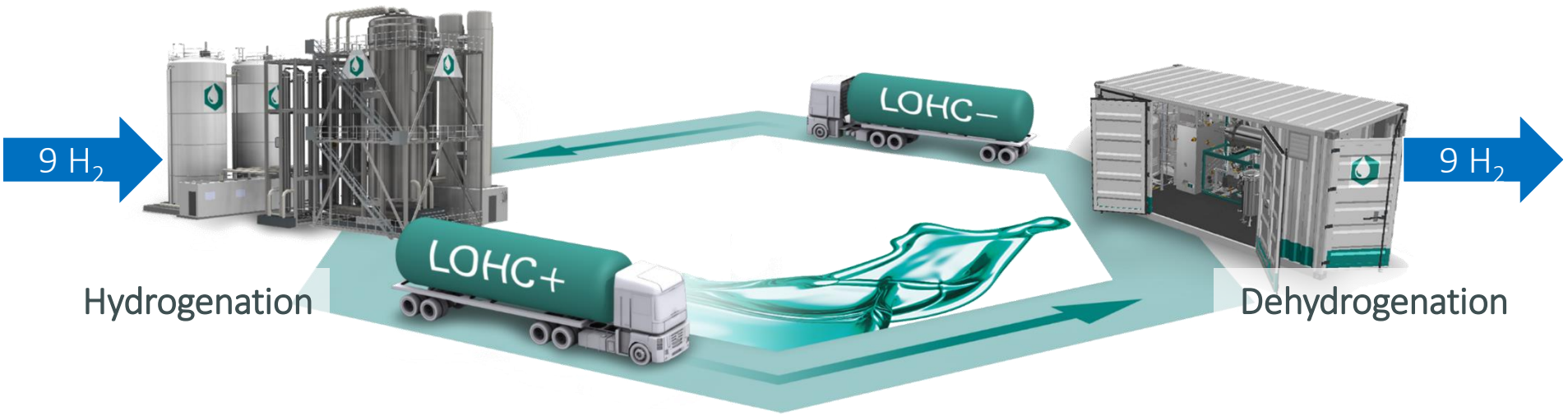
APVentures ADVANCE & PIONEER
FAU
MAN
CLARIANT
sasol
United Hydrogen FUELING THE FUTURE
HI ERN Helmholtz-Institut Erlangen-Nürnberg

LOHC enables safe and efficient storage of hydrogen through molecular binding



Chemical hydrogen storage in LOHC oils

Liquid Organic Hydrogen Carrier (LOHC) enable a safe and efficient transport of hydrogen at ambient conditions



The LOHC technology uses basic chemical processes to eliminate the complexities of today's hydrogen handling

Our LOHC technology has significant advantages in performance and handling compared to competing technologies

57 kg =

Our LOHC is…

- **Efficient**
  - 630 Nm^3 H_2 / m^3 LOHC → 6.23 wt%
  - 57 kg H_2 / m^3 LOHC
- **Safe**
  - Non-explosive
  - Not classified as dangerous good (ADR, etc.)
- **Easy to handle**
  - Diesel-like liquid
  - Ambient conditions
- **Low priced**
  - <5 €/kg
  - Reusable

Our LOHC is hardly flammable and non-explosive

We build systems to chemically bind hydrogen to a carrier liquid

Numerous applications can easily, safely and efficiently be connected by our LOHC technology to enable a sustainable hydrogen world

hydrogenious TECHNOLOGIES

Industrial Hydrogen

Renewable Energies

Electrolysis

Hydro-genation

Dehydro-genation

Industry supply

Hydrogen demand of 3 – 50 kg/h
Medium to long distance supply

Mobility

Large capacity refueling stations
buses, trains, captive fleets

Hydrogenious has realized the first LOHC-based renewable hydrogen storage and transport project

Hydrogenious HQ (Erlangen)

98kWp PV
@ Hydrogenious HQ

Excess heat
10kW

50kW Siemens
PEM Electrolyzer

StorageBOX 10

Transport of loaded LOHC

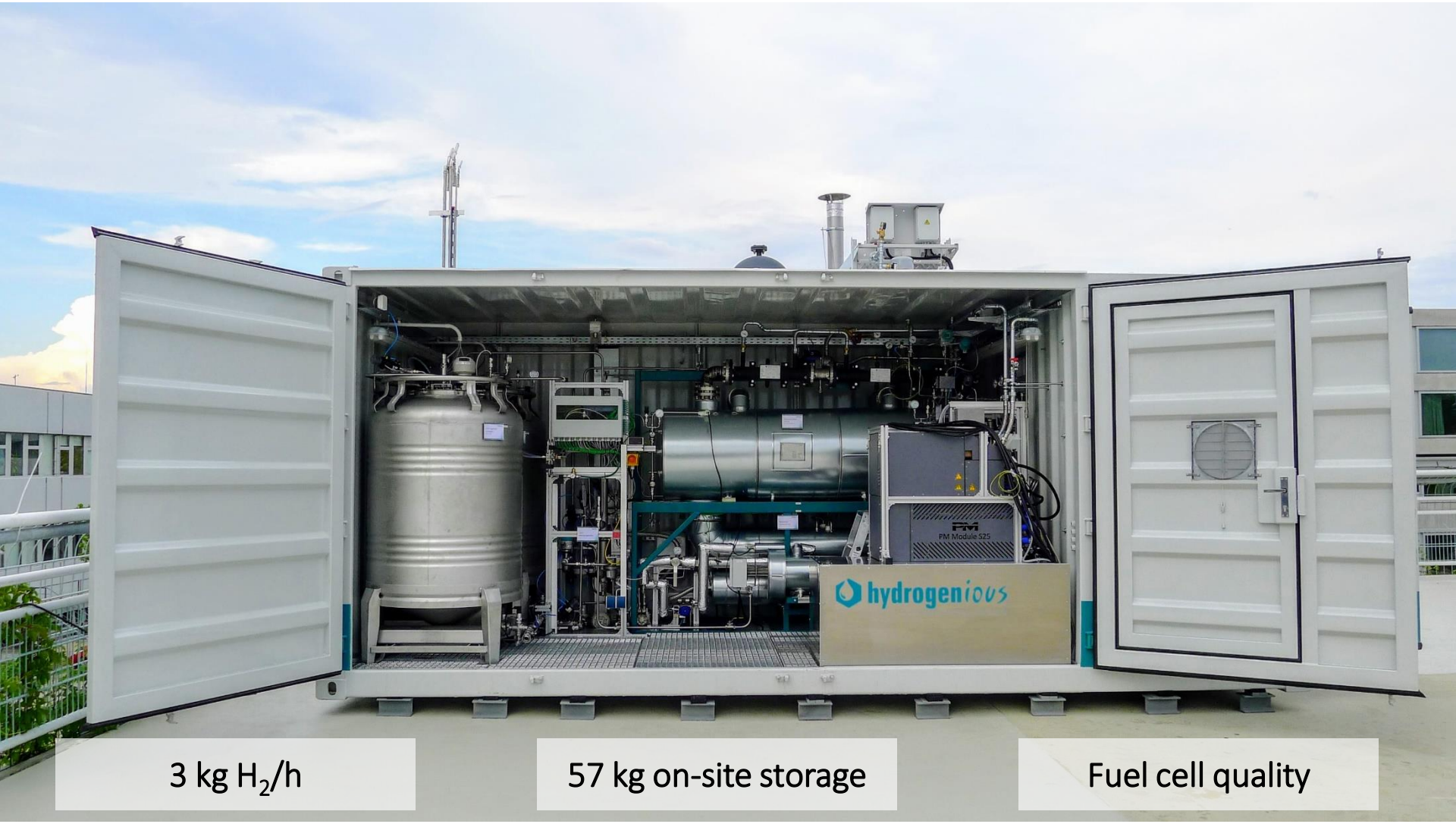
Fraunhofer IAO (Stuttgart)

ReleaseBOX 33

Fuel Cell

Micro smart grid network

Hydrogenious has the first LOHC-based hydrogen project in operation since June 2016 at the Fraunhofer IAO



3 kg H_2/h

57 kg on-site storage

Fuel cell quality

Competing transport technologies have significant shortfalls regarding costs, transport capacities and safety…

Industrial H_2 production

Industrial supply

H_2 filling stations

	H_2 per truck	Transport capex (Tractor and trailer)	Hazardous	Energy required / kg H_2 (excl. transport)	Boil-off
LOHC (Perhydro-DBT)	up to 1,800kg	~250,000EUR	no	1.5 – 10 kWh[1] (th.)	0%
CGH2 (@ 250bar)	up to 350kg	>400,000EUR	yes	1.5 – 2 kWh (el.) (eq. to ~ 6 kWh th.)	0%
CGH2 (@ 500bar)	up to 1,100kg	>1,000,000EUR	yes	4 – 5 kWh (el.) (eq. to 15 kWh th.)	0%
LH2 (@ -253°C)	up to 3,300kg	>1,400,000EUR	yes	10 kWh (el.) (eq. to ~ 30 kWh th.)	1-3% / day

1. Actual value fully dependent on usage of exothermic heat produced in hydrogenation process

Commercial project: US market entry started with industrial demo project together with United Hydrogen Group

United Hydrogen
FUELING THE FUTURE

- U.S. based hydrogen distributor
- Hydrogen source is by-product hydrogen from chlor-alkaline electrolysis; Delivery of 6.300 kg H2 per day to 35 customers (Industrial supply)
- **Current situation:** Limited economical distribution radius due to low transport capacities of pressure tube trailer technology
- **Targeted setting:** Expansion of supply radius from ca. 300 km to up to 700 km through use of high-capacity LOHC technology
- Pilot LOHC system were installed near Charleston, Tennessee

System delivery:
December 2017

Expansion of supply radius from ca. 300 miles to up to 700 miles through utilization of LOHC technology

Customers of LOHC-supplied hydrogen:
- Power plant operators
- Food industry
- Metal refining industry, etc.

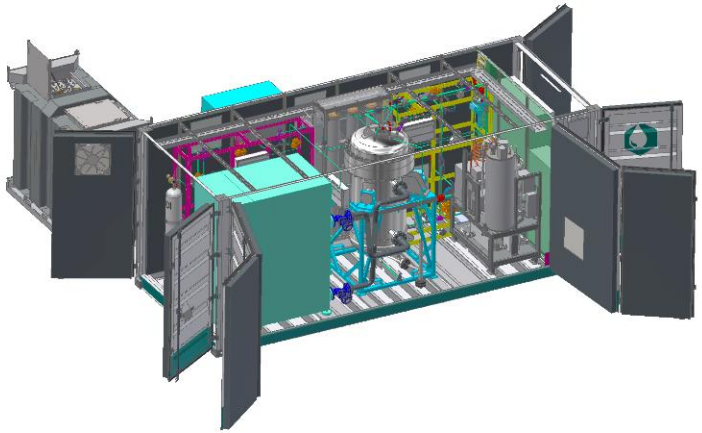
Commercial project: US market entry started with industrial demo project together with United Hydrogen Group

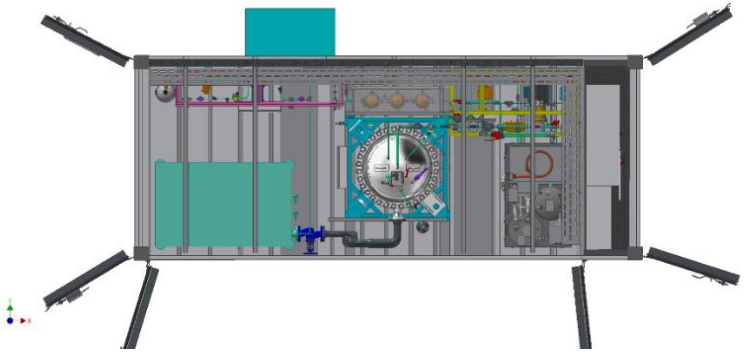
Delivery of 3 systems

StorageBox100 (100 Nm³/h hydrogen uptake)
- LOHC loading at Charleston facility
- Usage of by-product hydrogen from chlor-alkaline electrolysis

ReleaseBox2.5 (2,5 Nm³/h hydrogen release)
- Location: Power plant operator, used for generator cooling
- 10 bar output pressure
- 99,95% hydrogen purity

ReleaseBox33 (33 Nm³h hydrogen release)
- Location: Food production company
- 30 bar output pressure
- 99,95% hydrogen purity





United Hydrogen
FUELING THE FUTURE

Impressions of installation and commissioning of US systems

Start-up of US plants have shown stable operating points over a long period of time

StorageBox100 (100 Nm³/h hydrogen uptake)

- Facility acceptance test for the StorageBOX in the U.S. has been completed in May 2018 and shows high performance
- Hydrogen Uptake of 100 Nm/h (11 kg/h) was proven during facility acceptance test
- Highly exothermic process can be handled safely within our StorageBOXes at different throughputs

ReleaseBox2.5 (2,5 Nm³/h hydrogen release)

- The hydrogen output can be adjusted dynamically according to actual demand by the customer10 bar output pressure
- Constant hydrogen output after 30 days time on stream and multiple load changes, ramp-up and shut down procedures
- Hydrogen outputs up to 3 Nm³/h exceeds customer demands

The LOHC technology offers significant advantages for large scale HRS – e.g. for bus, train or captive fleet supply…

Advantages of LOHC

- ✓ Low delivery frequency to HRS
- ✓ Lowest cost for H_2 bulk storage
- ✓ No boil-off losses / discharge
- ✓ Safe handling
- ✓ Small footprint through underground storage
- ✓ Highest social acceptance through oil handling

LOHC+ | ReleaseBOX | H_2

LOHC bulk storage (2,000+ kg H_2)

Dehydrogenation

Compression | Pressure cascade | Dispenser

hydrogenious TECHNOLOGIES + Standard HRS technology

Hydrogenious has gathered a strong consortium for the first European LOHC-based HRS project HYSTOC

Consortium partners

WOIKOSKI — Leading Scandinavian industrial gas company

HYGEAR — Specialist for gas purification units

FAU — Leading scientific facility on LOHC research

VTT — Research center focused on fuel cells and hydrogen technologies

This project has received funding from the Fuel Cells and Hydrogen 2 Joint Undertaking under the European Union's Horizon 2020 research and innovation programme under grant agreement No 779694

Hydrogenious and 11 partners focus on LOHC-based hydrogen refueling stations in the Kopernikus project

- The “Kopernikus Projects” form Germany’s largest coordinated research program
  - Funded by the German Ministry of Research
  - **> 90 companies and (research) institutes** involved
  - Four specific excellence clusters

- “Decentral H_2-logistics” project with focus on **LOHC based H_2 refueling stations**
  - Budget of **~4 Mio. EUR** over next three years
  - **12 partners involved** including Linde, ThyssenKrupp, Clariant and AREVA

SPONSORED BY THE
Federal Ministry of Education and Research

Hydrogenious' product portfolio: S-Series: The StoragePLANT

Interfaces

H_2 inlet pressure	30 – 50 bar
Electr. Connection	400V
Heat production	9 kWh / kg H_2

StoragePLANT 500

H_2 storage	500 Nm³ / h
LOHC production	800 l / h
Housing	skid-mounted

StoragePLANT 1500

H_2 storage	1,500 Nm³ / h
LOHC production	2,400 l / h
Housing	skid-mounted

StoragePLANT 5000

H_2 storage	5,000 Nm³ / h
LOHC production	8,000 l / h
Housing	skid-mounted

Customized plant sizes available >5.000 Nm³/h

Thank you for your interest!

Group Leader Team Reaction Engineering

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