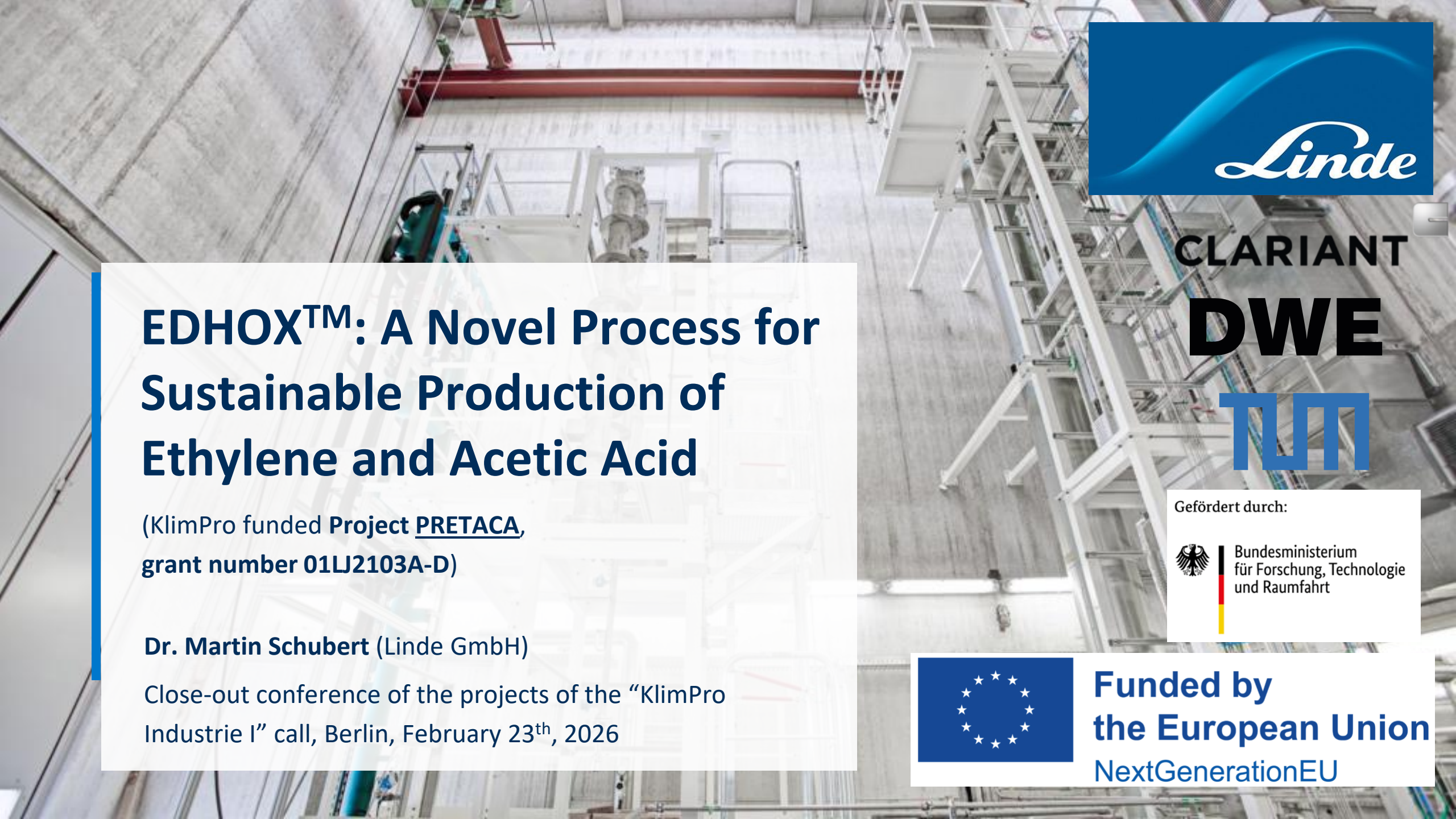


EDHOX™: A Novel Process for Sustainable Production of Ethylene and Acetic Acid

(KlimPro funded **Project PRETACA**,
grant number 01LJ2103A-D)

Dr. Martin Schubert (Linde GmbH)

Close-out conference of the projects of the "KlimPro Industrie I" call, Berlin, February 23th, 2026

Gefördert durch:
Bundesministerium für Forschung, Technologie und Raumfahrt

Funded by the European Union
NextGenerationEU

Agenda

01

Background & Motivation

02

PRETACA – Project Overview and Strategy

03

Main Achievements

04

Summary & Conclusions

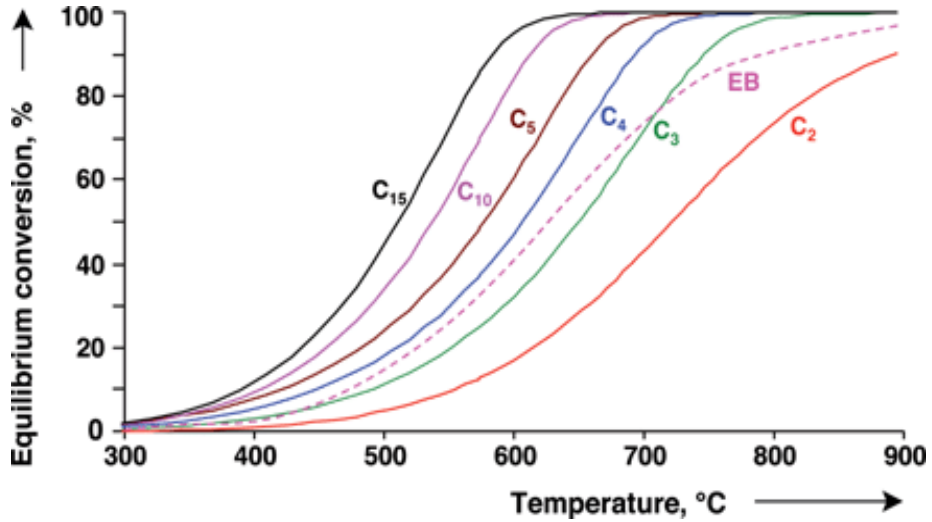
01

Background & Motivation

Alternative to Ethane Steam Cracking or Dehydrogenation?

Steam Cracking & Dehydrogenation of alkanes

- $C_2H_6 \rightarrow C_2H_4 + H_2$
  - Highly endothermic equilibrium-limited reaction
  - Low pressures and high temperatures are favored
  - By-product formation
  - Catalytic dehydrogenation of ethane not feasible



Sanfilippo, D. and Rylander, P. N., "Hydrogenation and Dehydrogenation", in: Ullmann's Encyclopedia of Industrial Chemistry (2009).

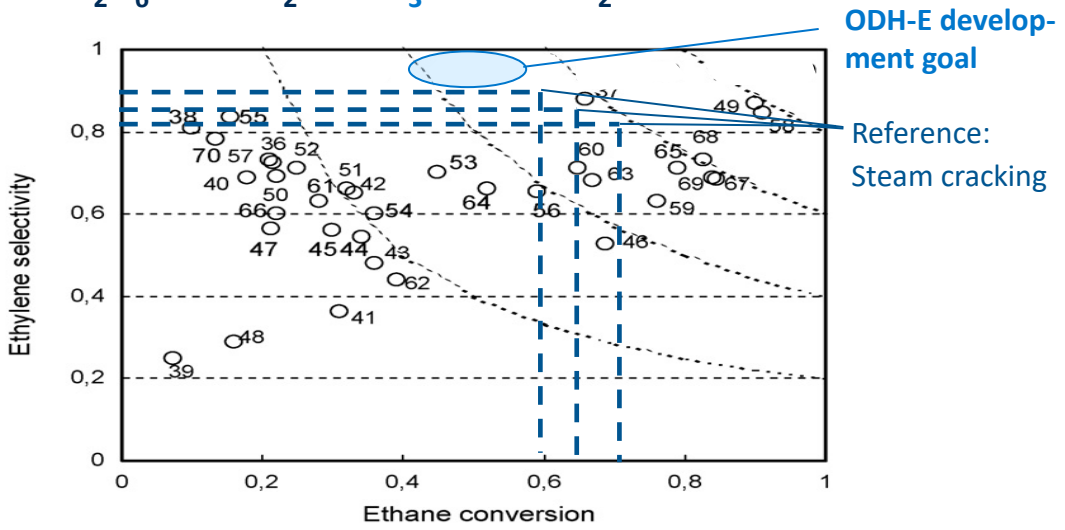
Alternative

Oxidative Dehydrogenation of Ethane (ODH-E)

- Exothermic, catalytic reaction → no thermal cracking
- Mild conditions: 300-400°C
- **MoVNbTe** oxides promising **catalyst** systems
- **Valuable products**: **Ethylene** & **Acetic Acid**

$C_2H_6 + 0.5\ O_2 \rightarrow C_2H_4 + H_2O$

$C_2H_6 + 1.5\ O_2 \rightarrow CH_3COOH + H_2O$



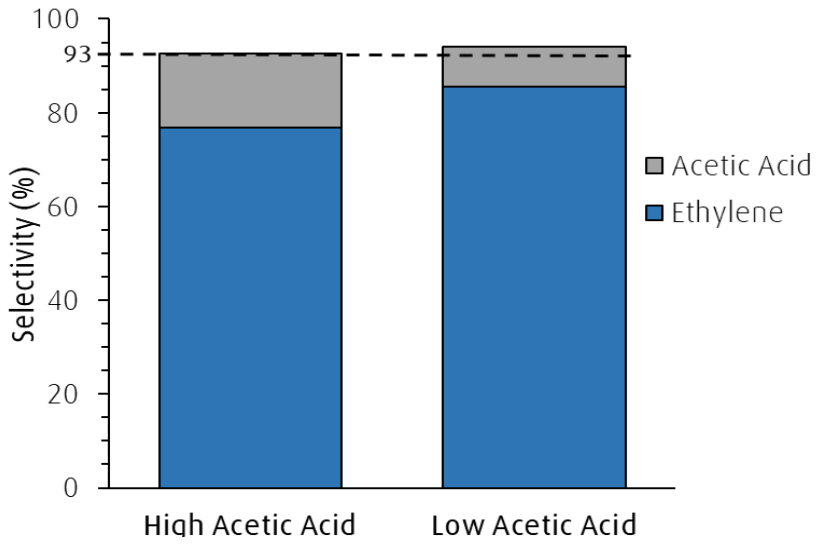
F. Cavani, N. Ballarini, A. Cericola; Catalysis Today (2007), 127, 113.

Summary of previous ODH-E development

Since 2014 joint ODH-E process and catalyst development at Linde and Clariant

- **Development** of a **$MoVNbTeO_x$-based catalyst recipe from economic raw materials available for large scale production**[1] **at Clariant** including first scale-up of the active material to ton scale. Tableting recipe for mechanical stable catalyst shapes with defined activity levels yet to be adapted for large scale production.
- **Process design development at Linde** including erection & operation of dedicated lab equipment and ODH-E pilot plant.
- **Since 2020 Linde's ODH-E technology** listed under trade name **EDHOX™** (EDHOX = Ethane DeHydrogenation, Oxidative).

EDHOX™ Pilot Plant Performance



→ Combined ethylene + acetic acid **selectivity > 93%** (molar basis)

→ Ethane **conversion 50%**

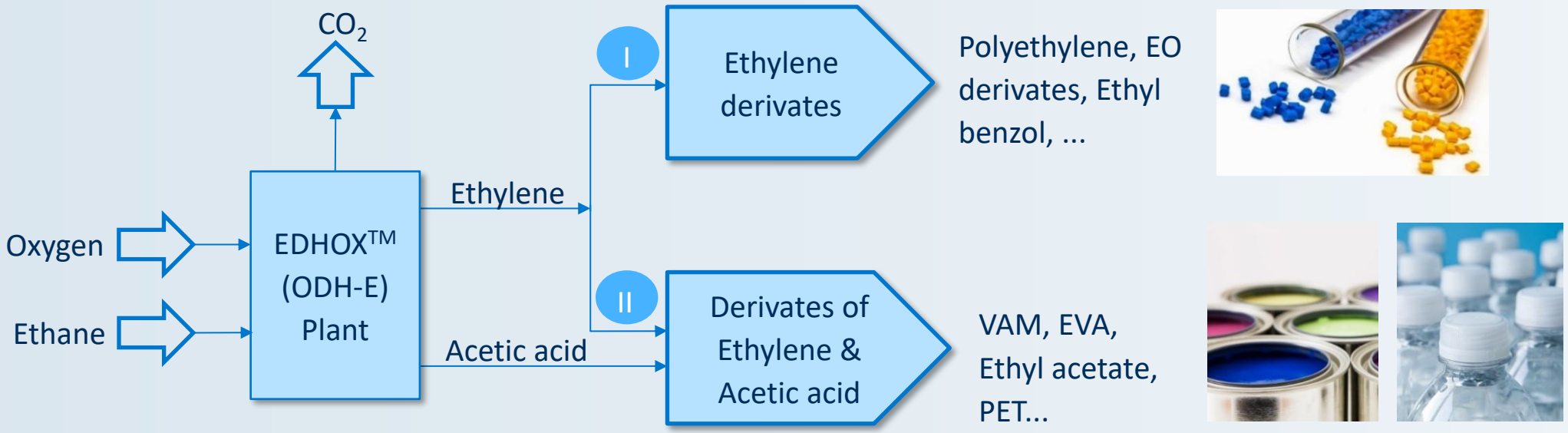
→ Produces ethylene/acetic acid ratios in the range of **2.5-4.5 $t_{ethylene}/t_{acetic\ acid}$**

→ **EDHOX™** is a **on-purpose ethylene** & **acetic acid technology!**

[1] DE 10 2011 109 816
DE 10 2011 109 774
DE 10 2017 000 861
D. Melzer ,et al., Nature Comm. 10 (2019) 4012

Continuation of EDHOX™ Development

Motivation for Public Funded Project



Targets of the Project PRETACA (acronym for Production of Ethylene & Acetic Acid)

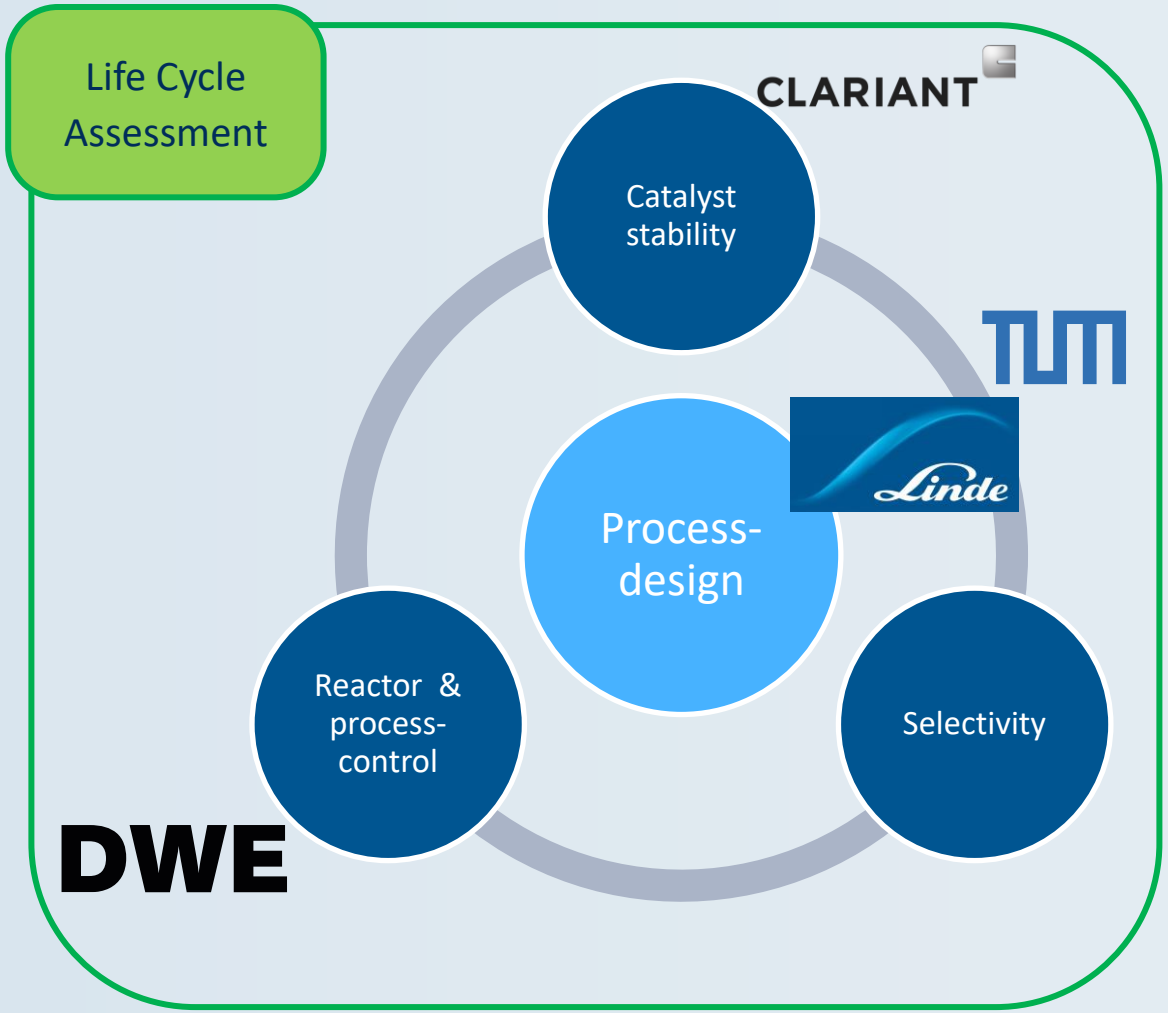
- Widening the ethylene to acetic acid product range:
  - I. ODH-E process with very high selectivity to ethylene (nearly negligible amount of acetic acid)
  - II. ODH-E process with high selectivity to acetic acid
- Reduction and minimization of process related CO_2 emissions
- Verification of catalyst scale-up to large-scale catalyst production

02

PRETACA – Project Overview and Strategy

PRETACA: Project Overview

Project Consortium, Work Split and Interactions between the Project Partners. Project duration: 01/2022-09/2025



- Consortium lead
- Process design incl. Process safety
- Catalyst & pilot plant testing

CLARIANT

- Catalyst development for different ethylene to acetic acid product ratios
- Demonstration of catalyst production scale-up
- Investigation of catalyst recycling

DWE*)

- Reactor design for a commercial large-scale reactor
- Development of suitable safety and reactor control concepts

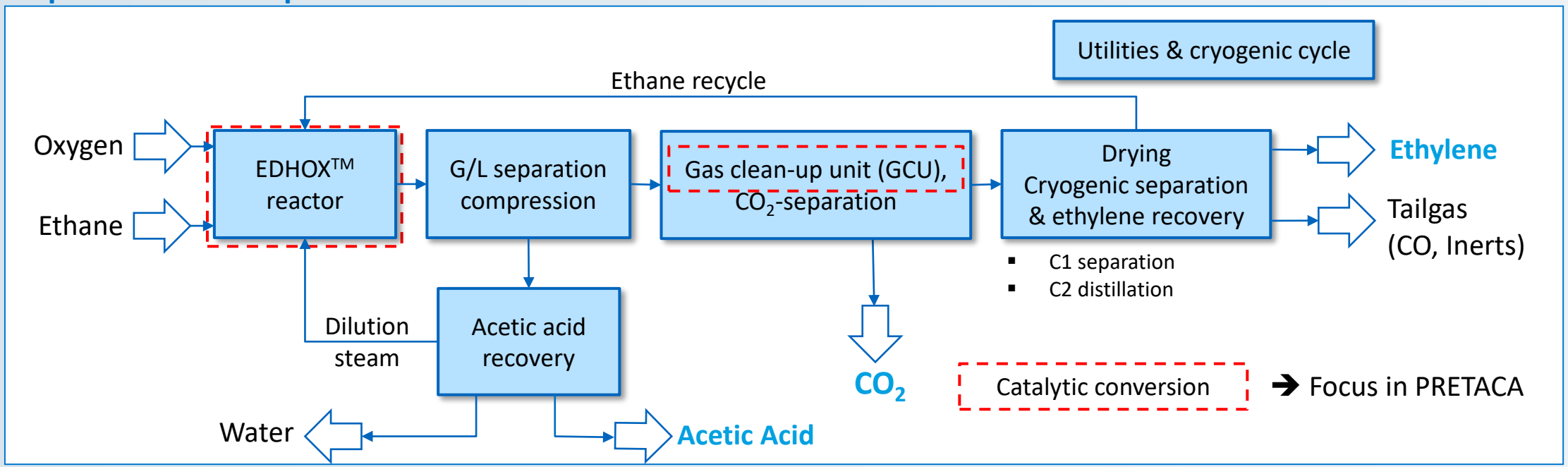
*) Since Jan. 2026: DWE GmbH
MAN Energy Solutions until 05/2025
Everllence from 06/2025-12/2025

Lehrstuhl für Anlagen- und Prozesstechnik

- Process analysis and process optimization
- Investigations of catalyst stability (under extreme conditions)
- Life Cycle Assessment

PRETACA: Project Overview

Simplified EDHOX™ process overview



EDHOX™ reactor: Product formation (ethylene & acetic acid)

	Reaction	Reaction equation
Main reaction	**Ethylene formation**	**$C_2H_6 + 0.5\ O_2 \rightarrow C_2H_4 + H_2O$**
Main reaction	**Acetic acid formation**	**$C_2H_6 + 1.5\ O_2 \rightarrow CH_3COOH + H_2O$**
Side reaction	CO-formation	$C_2H_6 + 2.5\ O_2 \rightarrow 2\ CO + 3\ H_2O$
Side reaction	CO_2-formation	$C_2H_6 + 3.5\ O_2 \rightarrow 2\ CO_2 + 3\ H_2O$

Gas clean-up unit (GCU): Simultaneous removal of acetylene & oxygen

Reaction	Reaction equation
Acetylene removal	$C_2H_2 + 2.5\ O_2 \rightarrow 2\ CO_2 + H_2O$
O_2-removal	$CO + 0.5\ O_2 \rightarrow CO_2$

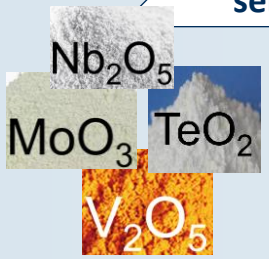
03

Main Achievements

Catalyst Development & Scale-up at Clariant

Successful demonstration of commercial scale of Clariant's OxyMax™ E catalyst production

Raw material selection



- Purity
- Phys./chem. Properties

Raw material preparation

- Calcination
- Milling

Suspension aging

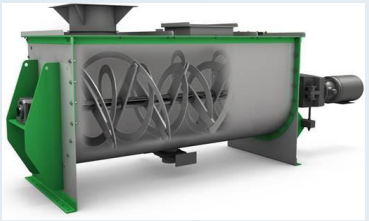
Crystallization (20 m³)

Filtration

Drying

Activation

Mixing with binder



Tabletting

Calcination

OxyMax™ E catalyst

Achievements

- ✓ **Scaleable catalyst recipe w.r.t.** active material & **especially tabletting / shaping to achieve mechanically stable tablets without altering performance** for each activity layer (based on pre-defined activity layering & testing together with Linde)
- ✓ **Successful demonstration of large-scale catalyst production (2 tons scale)** using commercial-scale equipment

EDHOX™ Pilot Plant at Linde

Validation of Catalyst Performance & Crucial Process Units under Representative Process Conditions

**In operation since May 2019

*In operation since Feb 2017

- ✓ **Linde pilot plant features all crucial process units**:
  - Molten salt cooled EDHOX™ reactor
  - Staged activity catalyst bed filling of the pilot reactor[1]
  - Gas clean-up unit (GCU)
  - Ethane recycle

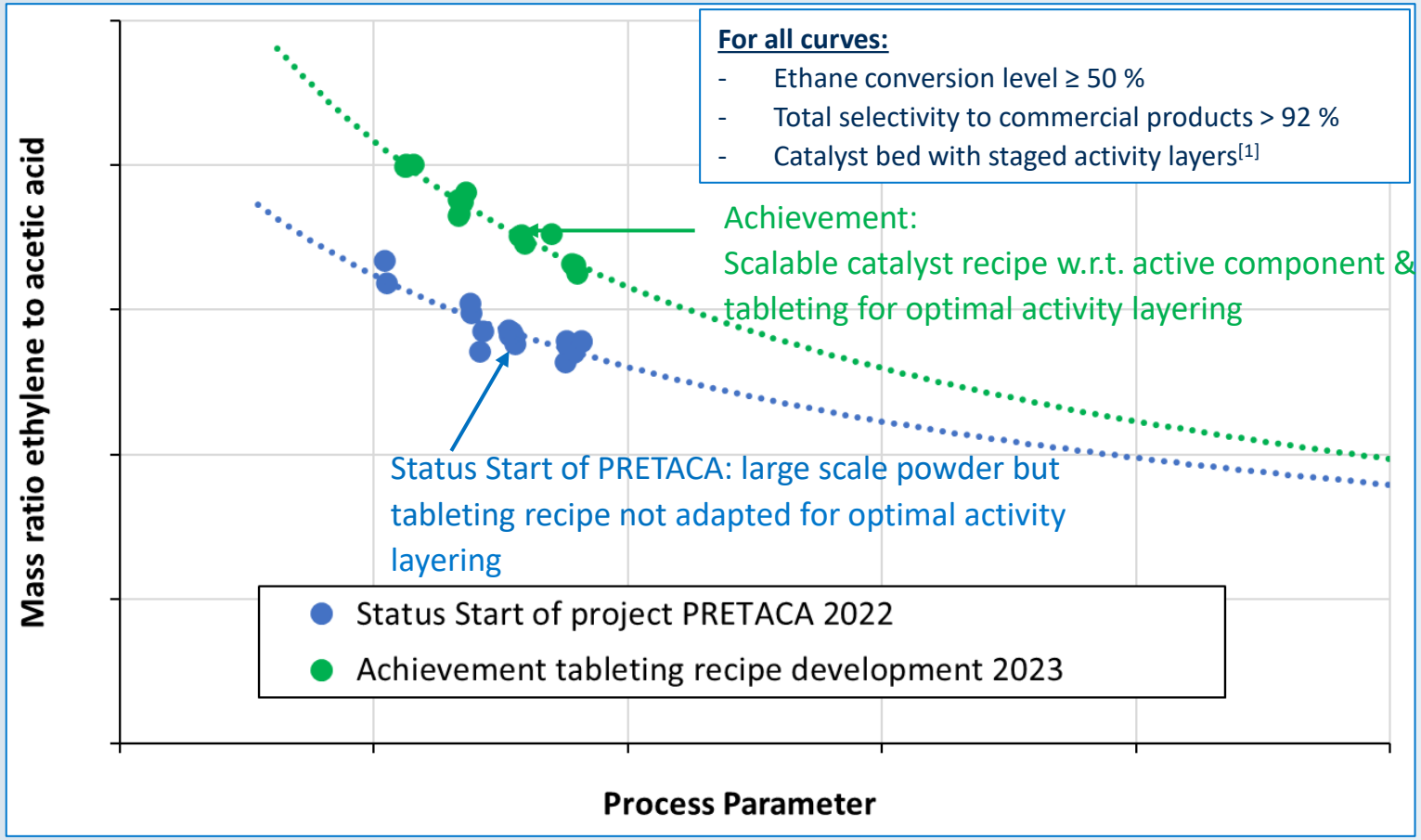
[1] WO 2019 243480 A1

- ✓ **Scale-up demonstrated**:
  EDHOX™ pilot plant reactor tube geometry corresponds to geometry of a single tube of commercial size reactor (L_{eff} = 8.4 m; tube ID= 26 mm)

February 2nd, 2017: Successful first feed-in together with collegues from Clariant

EDHOX™ Pilot Plant at Linde

Pilot Reactor Validation of OxyMax™ E Catalyst Performance at Representative Process Conditions

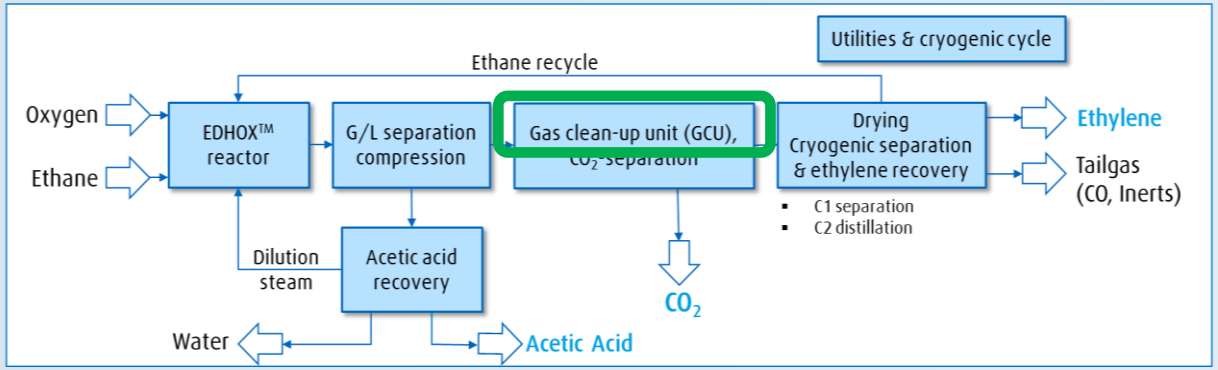


- ✓ **Improved Performance of advanced catalyst recipe** compared to catalyst from start of PRETACA **successfully validated**
- ✓ **Validation** of **mechanical stability** of the catalyst (due to improved tableting recipe)
- ✓ **Stable longtime performance** of catalyst **validated**
- ✓ **Demonstration of catalyst scale-up** and performance of catalyst from large-scale production
- ✓ **Validation of catalyst operational robustness** by investigation of upset / stress operation
- ✓ **Validated mechanical robustness** – basis for catalyst loading into a commercial reactor

[1] WO 2019 243480 A1

EDHOX™ Pilot Plant at Linde

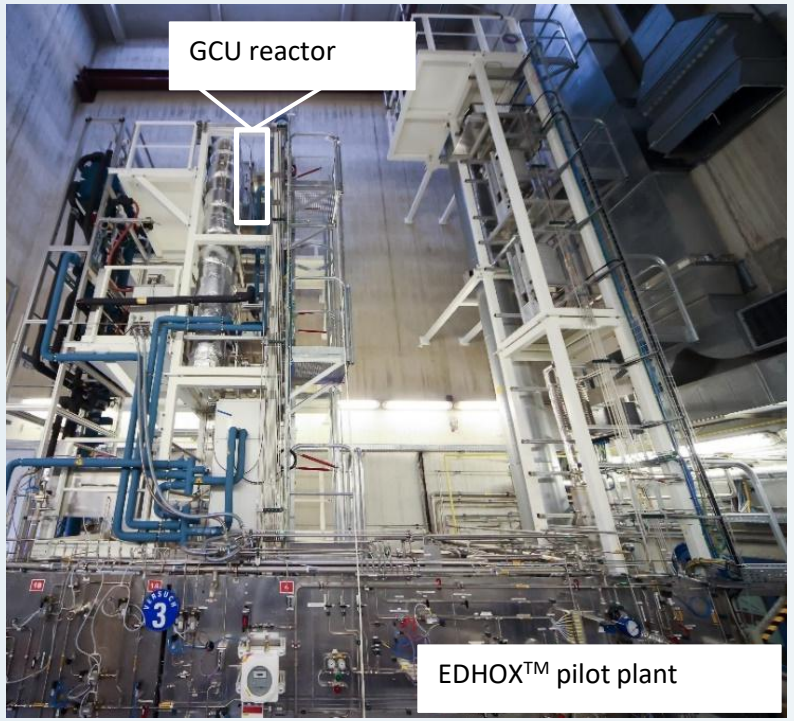
Gas Clean-up Unit (GCU) Design Concept Validation



Achievements

- ✓ **Definition & validation of GCU design concept**
- ✓ Adiabatic reactor with Clariant's Cu-based OxyMax™ 288 catalyst
- ✓ **Definition & validation of GCU design boundaries**
- ✓ **Definition of operational concept**
- ✓ Two patent applications filed (EP25152012.8 & EP25215956.1) for GCU operation & design with in PRETACA


GCU lab plant



EDHOX™ pilot plant

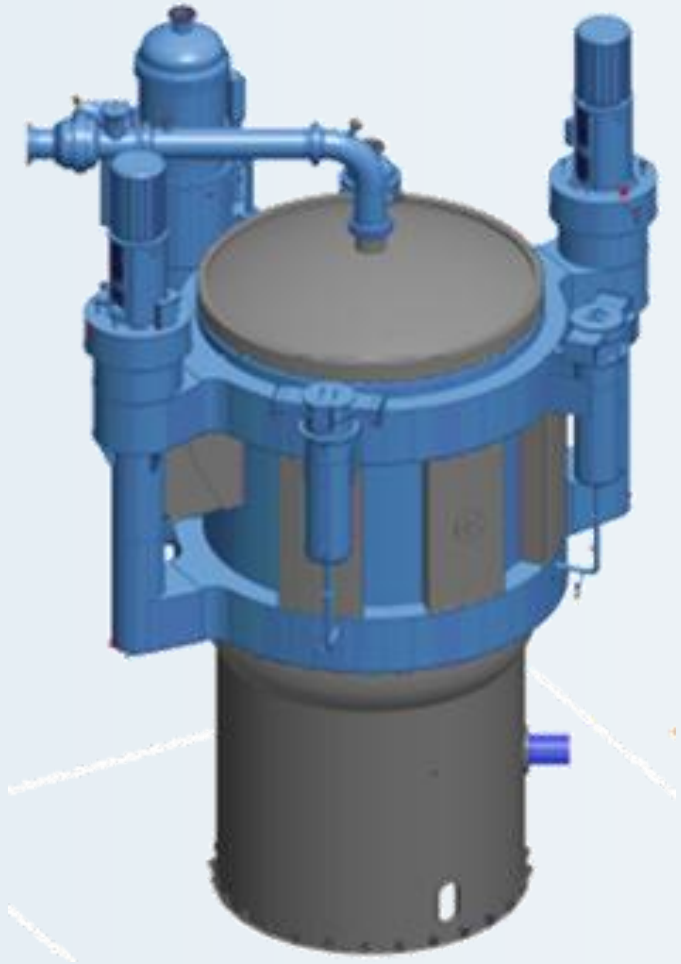
Experimental Validation

More than **880 hours on-spec GCU operation** (i.e. C_2H_2 & O_2 removal) in pilot plant **with representative ODH-E process gas**

Design of a Technical Scale Reactor System by DWE

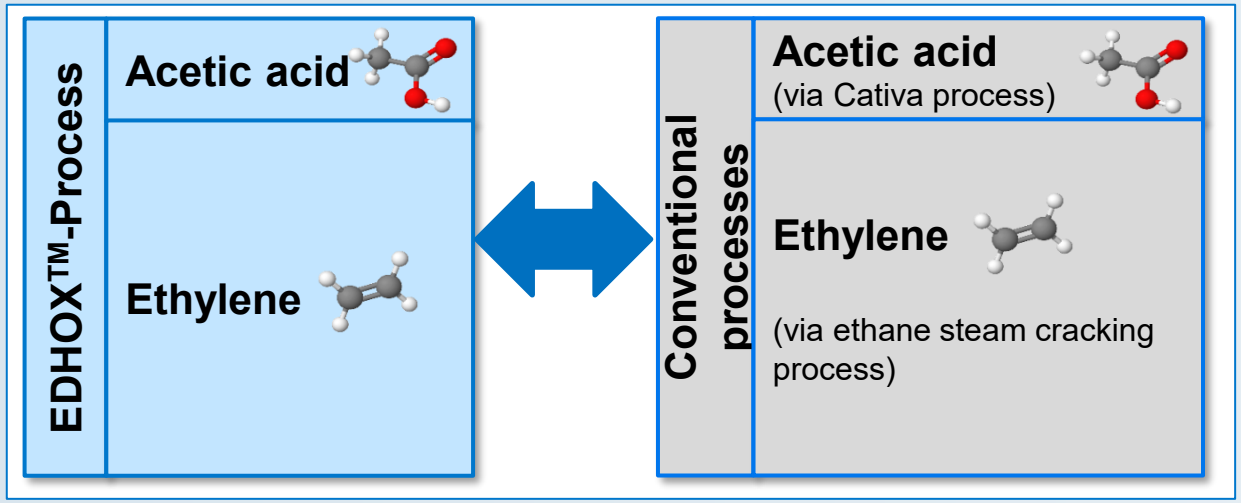
Design of a technical scale reactor system by DWE

- ✓ **Molten salt cooled** multi-tubular **reactor**
- ✓ Definition of max. constructable reactor size
- ✓ **Special design of reactor inlet dome** to meet safety requirements (pressure containment requirements for deflagration case)
- ✓ Design of salt and steam system for optimal heat removal
- ✓ **Special design of feed dosing and mixing system** upstream of reactor inlet (together with Linde)
- ✓ **Design validation based on determined safety- & operational-relevant data** by experimental simulation of special upset conditions



EDHOX™ Life Cycle Assessment

Techno-economic Analysis & Life Cycle Assessment

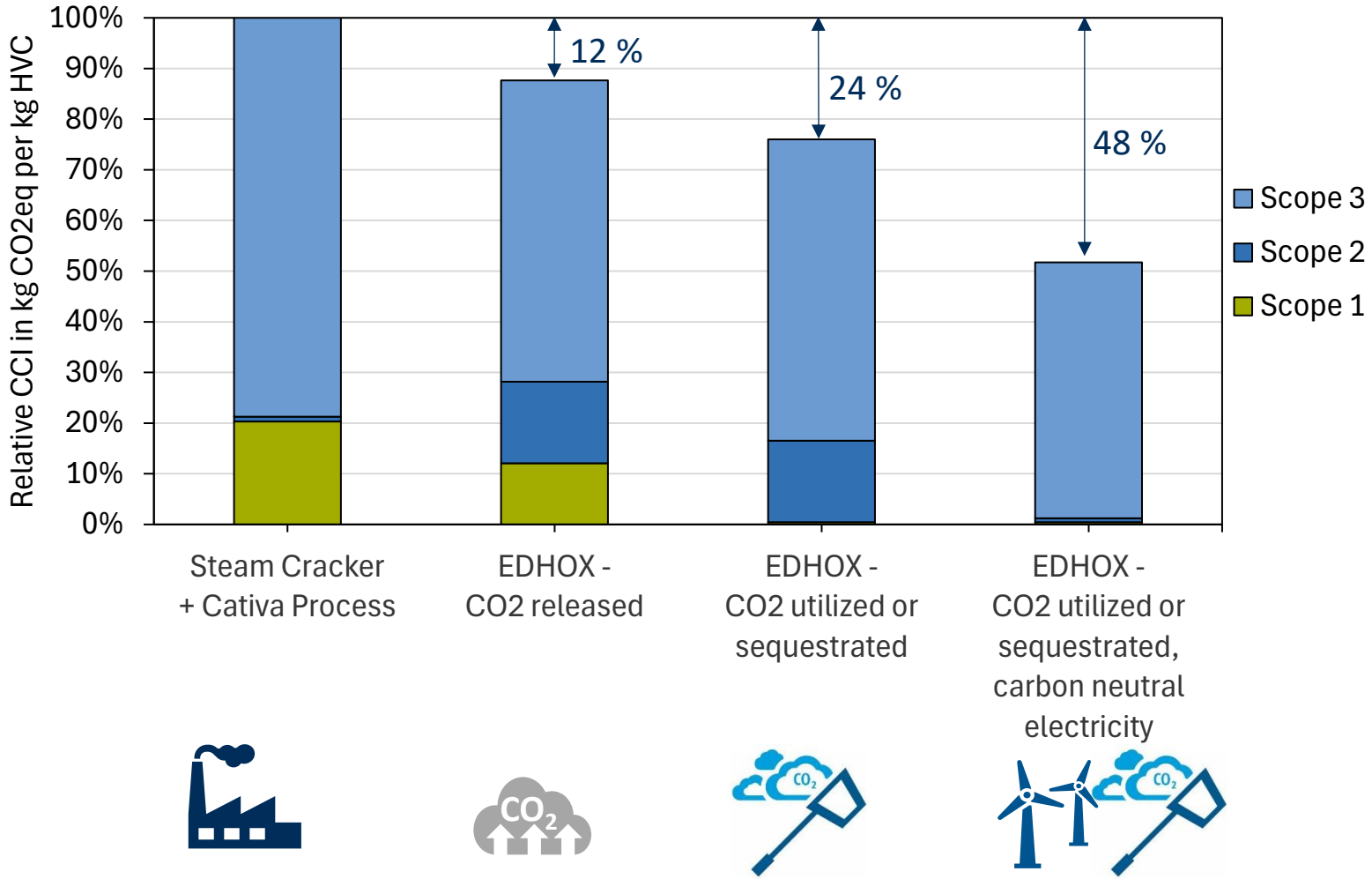


Targets & Methodology

- Economical and ecological assessment and comparison of different ODH-E / EDHOX™ process variants
- Highlight CO2 saving potentials
- Cradle-to-gate life cycle assessment of the EDHOX™ process on the scale of an envisaged commercial plant
- Comparison of the EDHOX™ process to the conventional state-of-the-art ethane steam cracking technology
- System expansion with a conventional production process for acetic acid to solve the multifunctionality problem of combined ethylene & acetic acid production

EDHOX™ Life Cycle Assessment – First Results

Climate change impact (CCI) of EDHOX™ decreasing with the evolving energy mix



- ✓ Significantly lower **Direct** (Scope 1) **CO_2 emissions by 40%** compared to conventional Ethane Steam Cracker + Acetic Acid Plant
- ✓ **Further CO_2 saving potential** by **sequestration or further utilization** of **captured CO_2 emissions**
- ✓ **Zero Scope 2 emission possible** by application of renewable energy

Data for LCA retrieved from:
Ecoinvent v3.10 database, location US-TRE

PRETACA: Exploitation of Project Results

EDHOX™ technology is ready for commercial application

Implementation of EDHOX™ technology

- **Global implementation of EDHOX technology**, e.g. as substitute to steam crackers for new plants or for increasing capacity of existing plants (e.g. steam crackers), however:
  - **Linde: Full EPC project execution in Germany**
  - **Clariant: Catalyst production in Germany**
  - **DWE: Reactor manufacturing in Germany**
- **Marketing of EDHOX™** started with **positive feedback from the market**, contact to potential clients around the globe
- **Promising opportunity for first implementation of EDHOX™** technology is **in China**

Communication & Knowledge Transfer

- **TUM:** Project **findings and developed methodologies** will be **implemented in selected lectures and further research projects**
- **TUM**: **Publication** of findings **in international journals** currently **in preparation or submitted/under peer review**, respectively
- Presentation at conferences: to date 5 contributions; further contributions already scheduled
- **IP protection**: To date, **5 patent applications filed form PRETACA results** (3 Linde; 1 DWE & 1 Linde/TUM); further applications are currently in preparation

04

Summary & Conclusions

Summary & Conclusions

Novel Process for Sustainable Production of Ethylene & Acetic Acid

- **EDHOX™**: Novel process for **sustainable production of ethylene and acetic acid** via oxidative dehydrogenation of ethane (ODH-E) → **ready for commercial application!**
- Public funded project PRETACA: Jan 2022 until June 2025 as part of EDHOX™ technology development
- Joint development of Linde, Clariant, DWE and Technical University of Munich within public funded project PRETACA
- **Fixed bed, multi tubular salt bath-cooled catalytic reactor** operating under mild conditions
- **Very high selectivity** to valuable products: **ethylene** + additional **acetic acid**
- **Product ratio** of **ethylene and acetic acid** can be adjusted by **process conditions** and **catalyst formulation**
- **Significantly lower Scope 1 CO_2 emissions compared to state-of –the art ethylene & acetic acid production process** (even with venting of captured CO_2); further significant CO_2 reduction potential (especially Scope 2) identified; **CO_2 captured** as **pure component** by the process, **ready for utilization or sequestration**

Thank you for your attention

More information on EDHOX™ Technology
www.linde-engineering.com

Linde Engineering
Dr. Martin Schubert
martin.schubert@linde.com
www.linde.com

Making our world more productive