

CHEMISTRY THAT MATTERS™



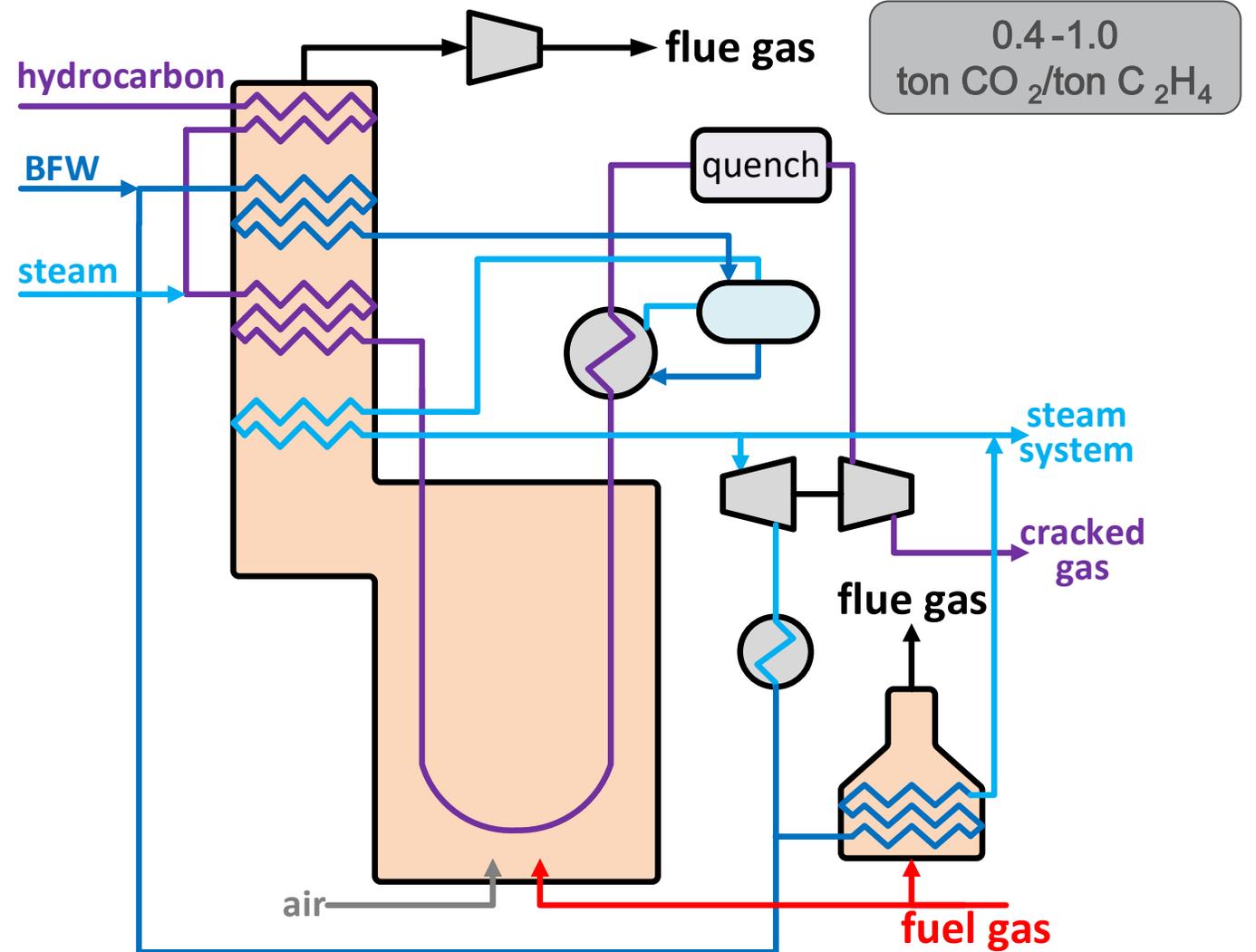
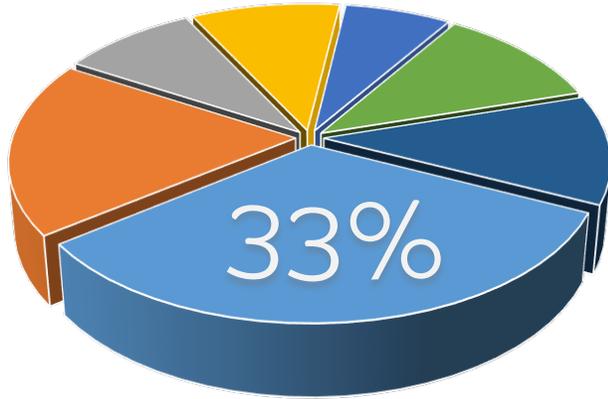
DEMONSTRATION OF ELECTRIC CRACKING FURNACES BY SABIC, BASF AND LINDE

I PER TECHNOLOGY WORKSHOP – JANUARY 2025

Speaker: Robert Broekhuis



EMISSIONS DOMINATED BY CRACKING AND REFORMING FURNACES



FURNACE DECARBONIZATION OPTIONS

CARBON CAPTURE

Operate furnace as before
 Capture CO₂ from stack
 (dilute, low pressure)
 Purify, compress, sequester

Features

Energy intensive
 Retro fitable

Carbon abatement

Up to 95%

Resource requirements

CO₂ storage infrastructure

HYDROGEN FIRING

Import clean H₂ to fire cracker
 Modify furnace for H₂ burning
 Reconfigure heat integration

Features

Energy intensive
 Retro fitable

Carbon abatement

Depends on H₂ source

Resource requirements

H₂ supply
 CO₂ storage infrastructure at H₂ production site

ELECTRIFICATION

Import electricity to heat furnace
 Modify/replace furnace
 Reconfigure heat integration

Features

Energy efficient
 Sometimes retro fitable

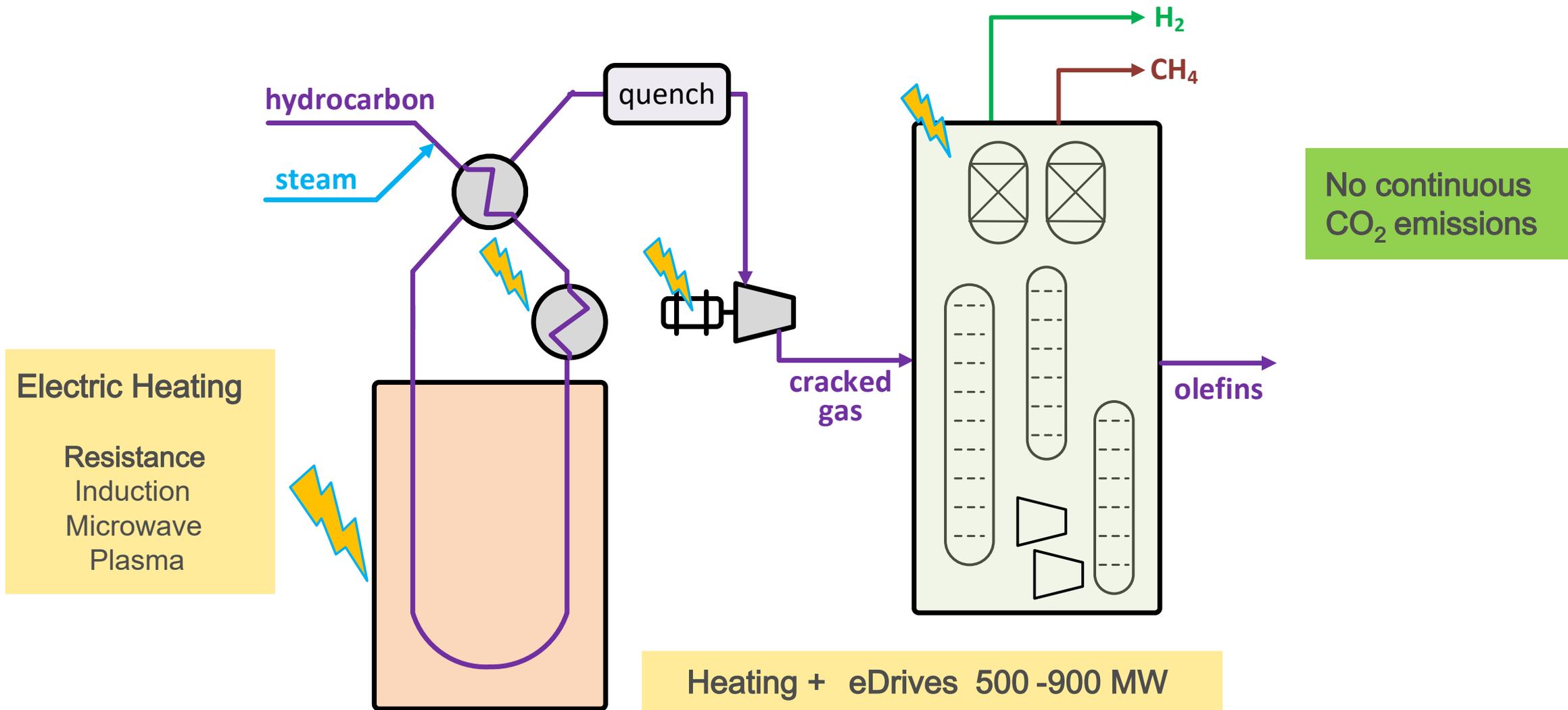
Carbon abatement

>95%

Resource requirements

Large-scale clean electric power

CRACKER PLANT ELECTRIFICATION



PARTNERSHIP WITH BASF AND LINDE: STARBRIDGE™ FURNACE TECHNOLOGY

Jointly developing eFurnace technology since 2021

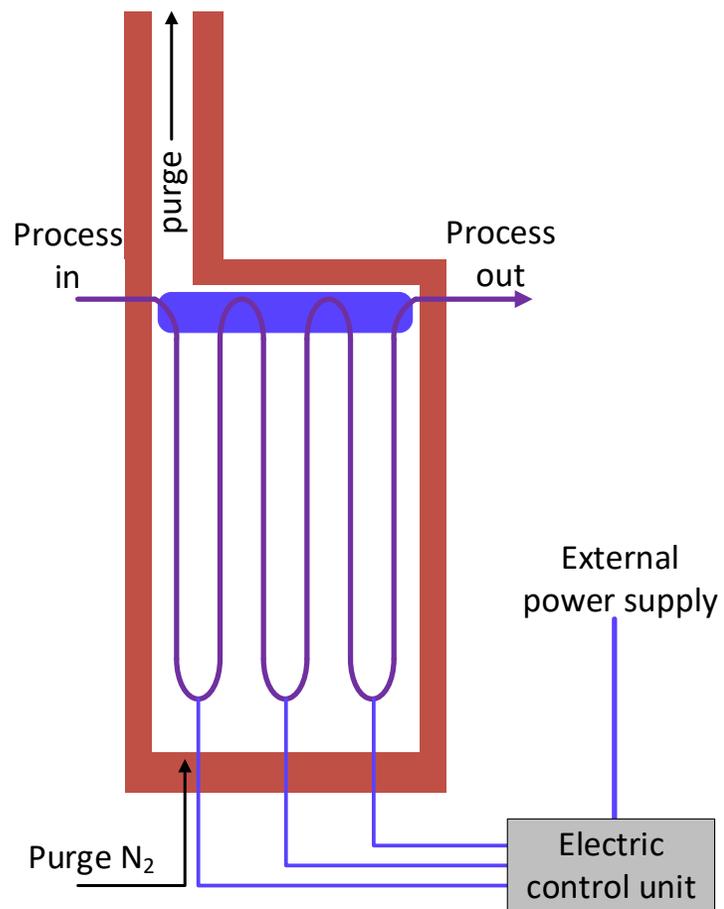
- Selected two electric heating technologies for large -scale demonstration
- Investment by SABIC and BASF with funding support from German government grant
- Linde acts as EPC contractor and licensor of STARBRIDGE™ furnace technology to petrochemical industry
- Demonstration plant integrated into BASF cracker at Ludwigshafen



TWO EFURNACE HEATING CONCEPTS

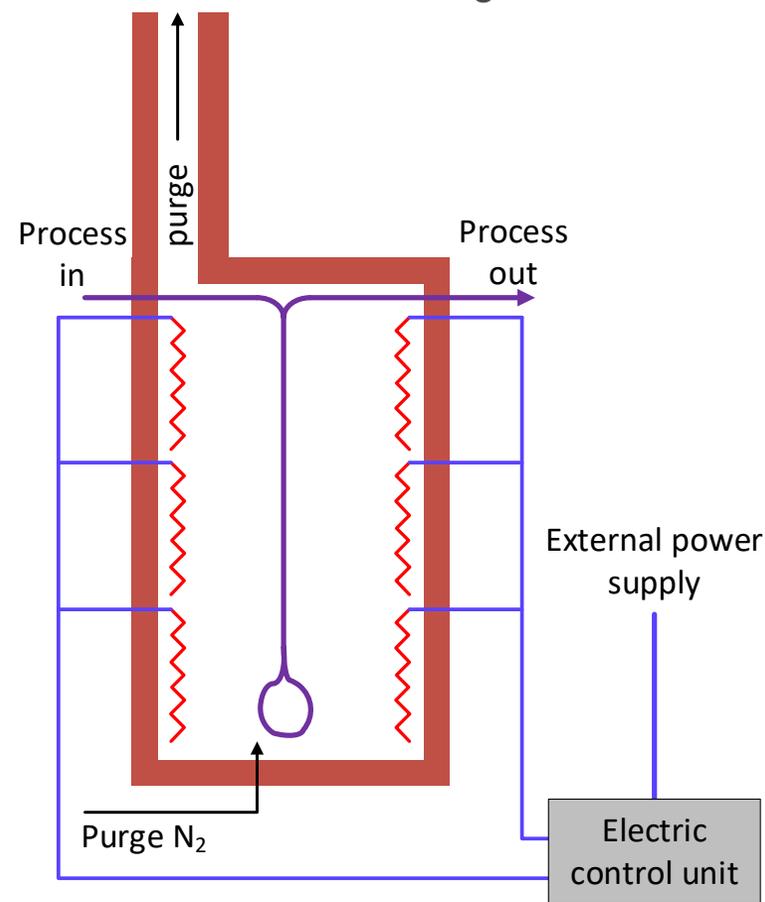
DIRECT Impedance heating

current passes through cracking coils

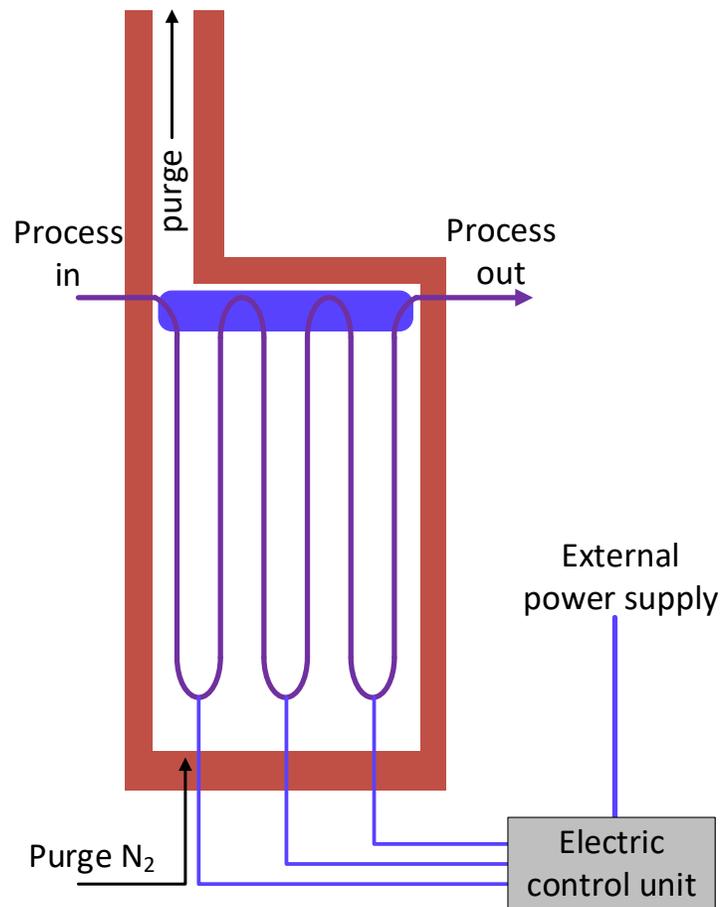


INDIRECT radiative heating

current passes through resistive modules, heat radiates to cracking coils



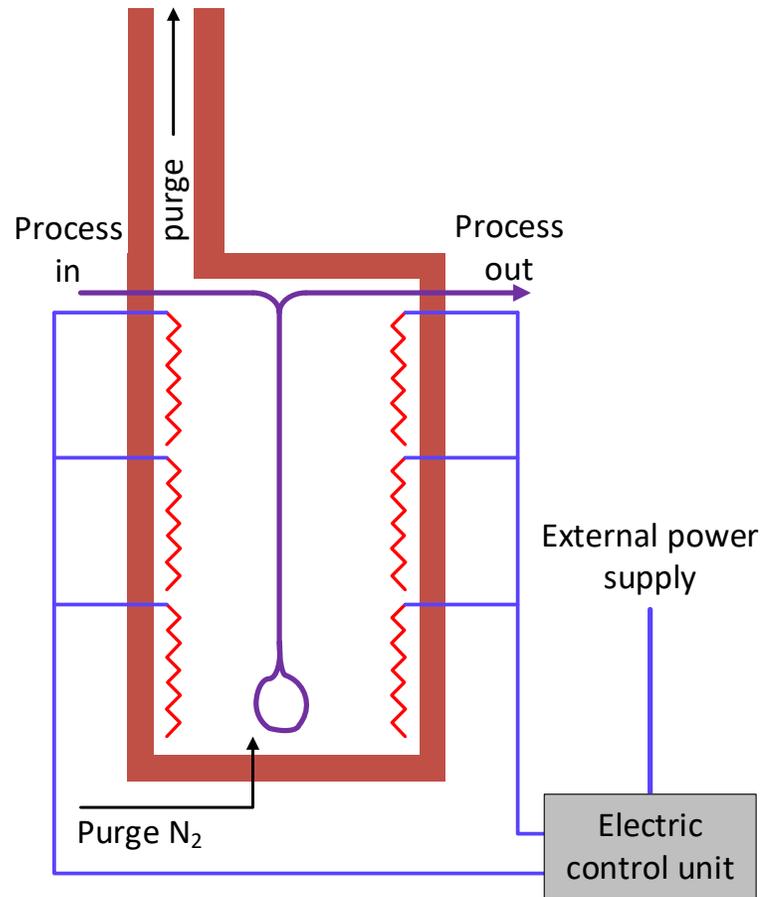
DIRECT HEATING CONCEPT



Innovation and know-how development in many areas

- Heating concept demonstrated at pilot scale since 2018
- Mechanical design – thermal growth, bottom pin connections
- Electrical supply concept (diagram at left illustrative)
- Detailed electrical phenomena, including inductive effects
- Furnace safety concept
- Configurations for scale – up beyond demo developed and patented

INDIRECT HEATING CONCEPT



Select from various heating element technologies

- Metallic (FeCrAl) – to 1300 ℃
- SiC – to 1500 ℃
- MoSi₂ – to 1800 ℃
- Durability, element layout and furnace design, electrical supply concepts vary
- Conventional coil arrangements can be maintained

Other know -how developed

- Modular configurations
- Furnace safety concept
- Furnace configurations for scale -up beyond demo developed

FURNACE DEMONSTRATION

Demo facility at BASF Ludwigshafen

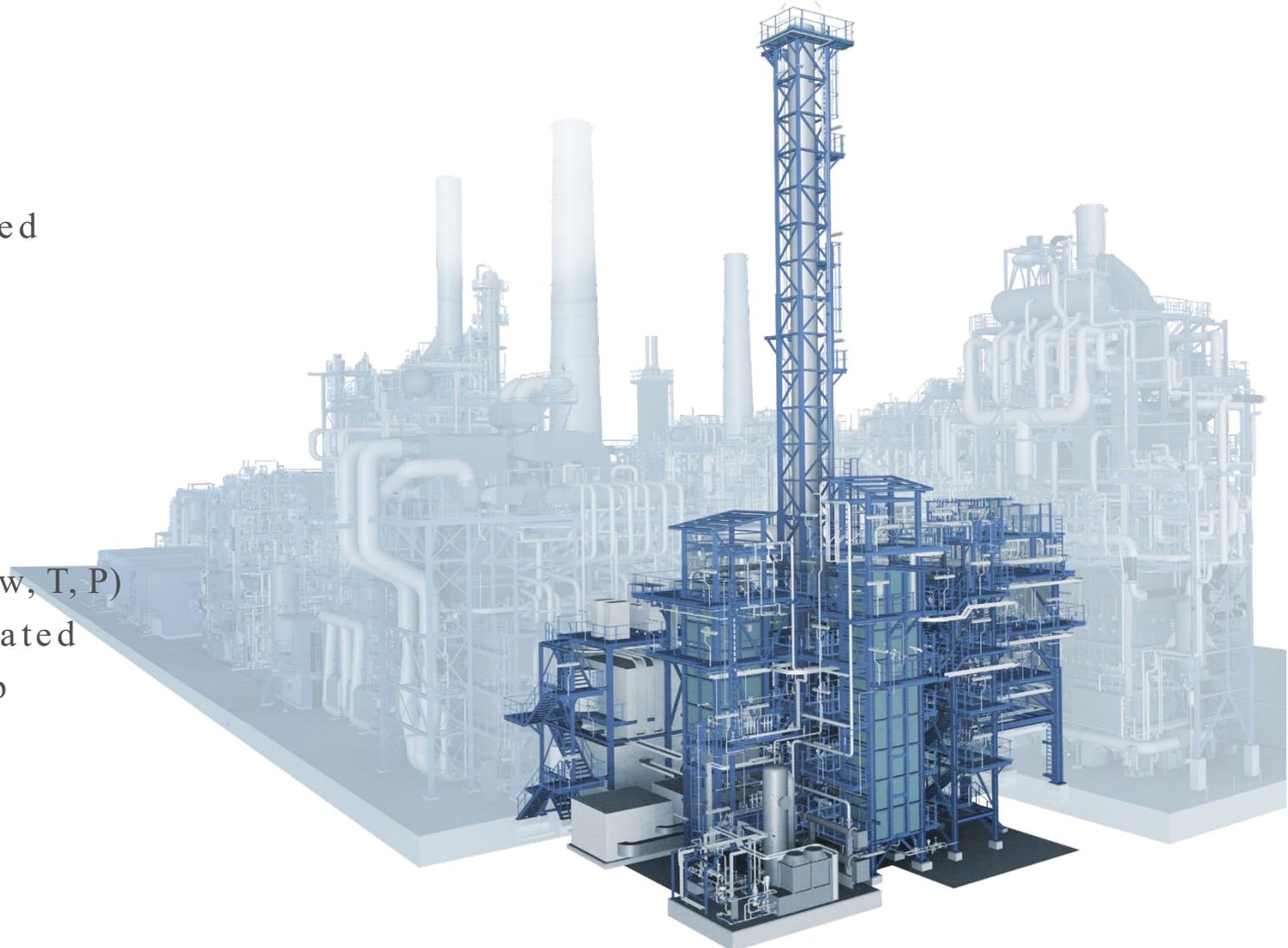
- engineering kicked off 2021

Both furnace technologies to be demonstrated

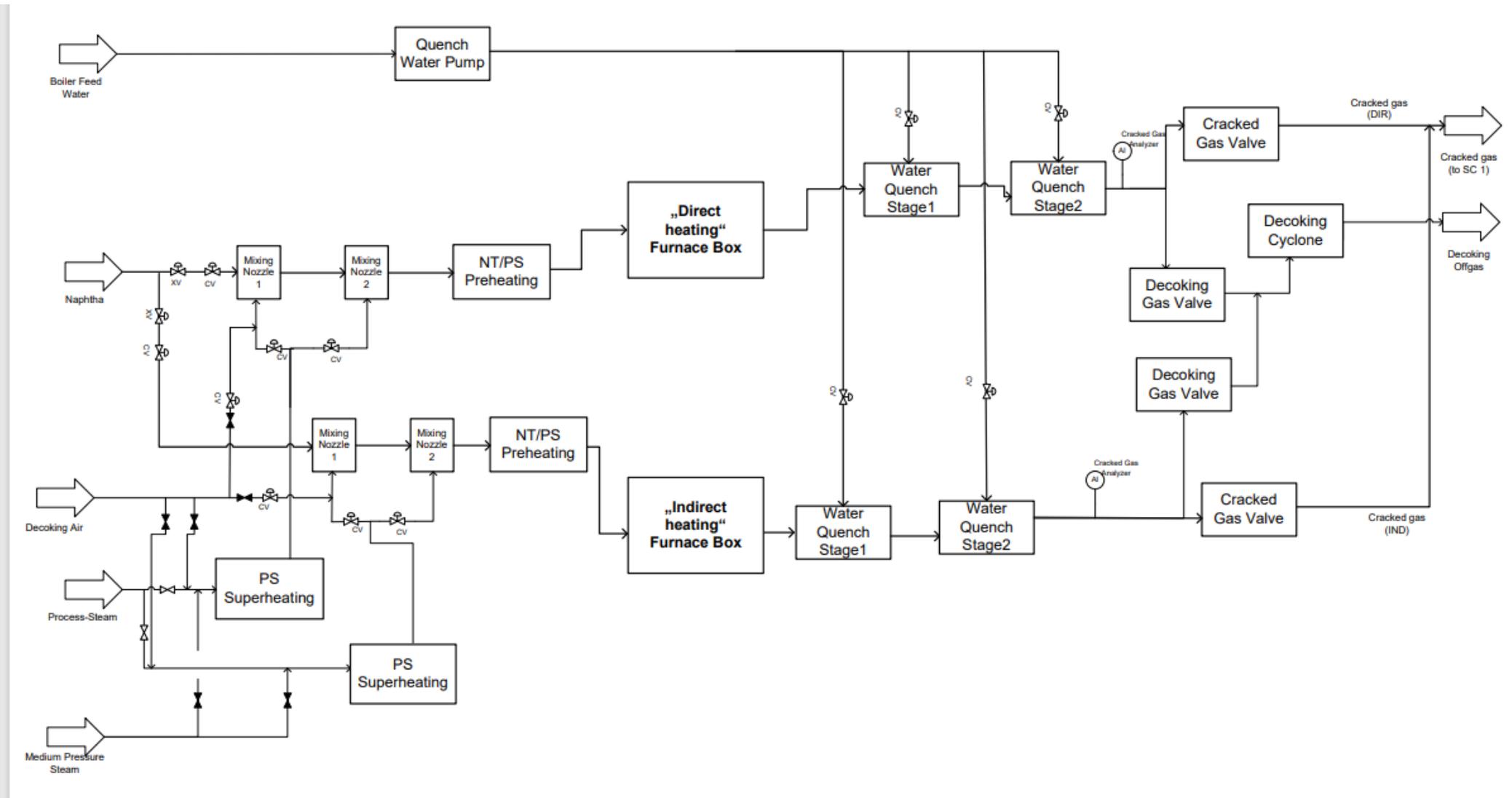
- each 3 MW for preheating and cracking
- each ~2 t/h naphtha
- cracked gas tied to existing cracker

Furnace operation

- Commercial size cracking coils
- Conventional operating parameters (flow, T, P)
- Modest run length improvement anticipated
- Layout enables straightforward scale-up



E-FURNACE DEMO PLANT – PROCESS FLOW DIAGRAM



FURNACES STARTED UP MID-2024

Construction completed early 2024

Phased commissioning through spring of 2024:

- Demonstrate subsystems, including electrical preheaters
- Establish integration with BASF cracker
- Thermal demonstration of furnace heating with steam and electrical heat

Both furnaces brought online in June 2024

- Naphtha feed near design rates
- Successful operation through a coking cycle of two months
- Extensive learnings will be incorporated into commercial designs

Several years of operation planned

- Performance optimization
- Reliability demonstration



CFD MODELING IN SUPPORT OF INDIRECT FURNACE

Predict temperatures of heating elements and cracking coils

At anticipated operating parameters of demo and commercial furnaces

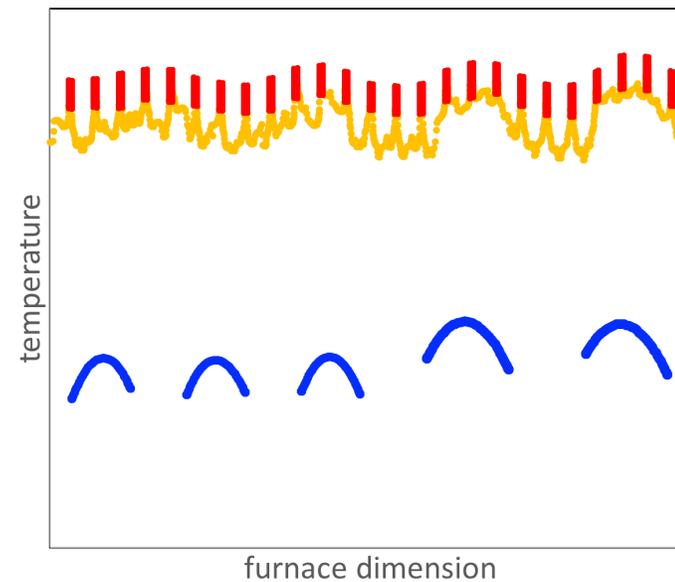
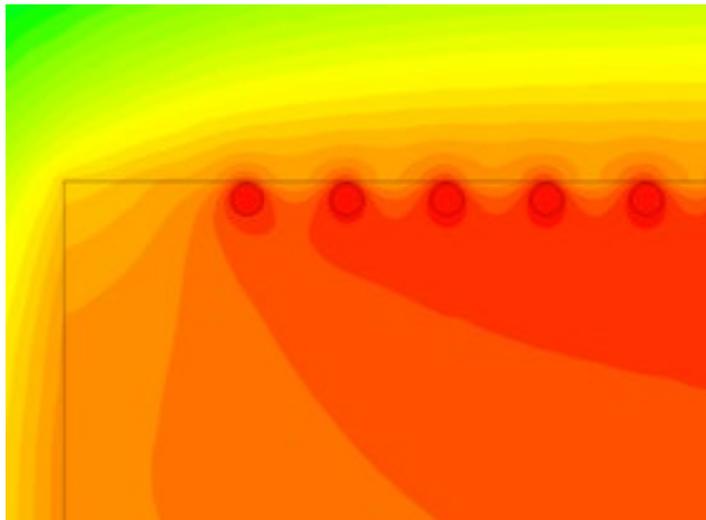
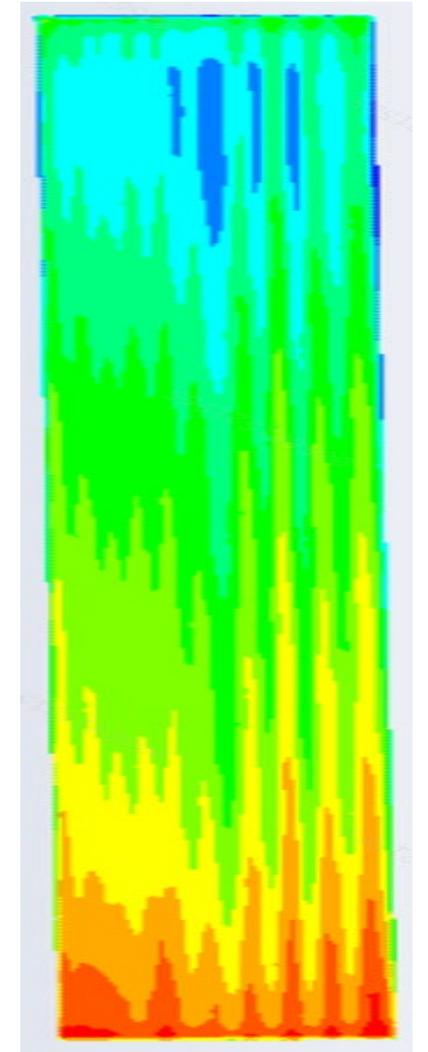
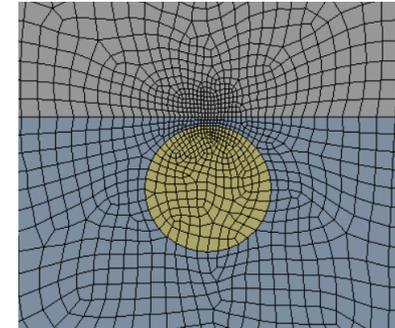
Compare alternative heating configurations

Relate maximum temperatures to material and design parameters

Evaluate configuration and control strategies

Individual or zoned control of heating elements

Placement on heating walls (density, spacing, coverage)



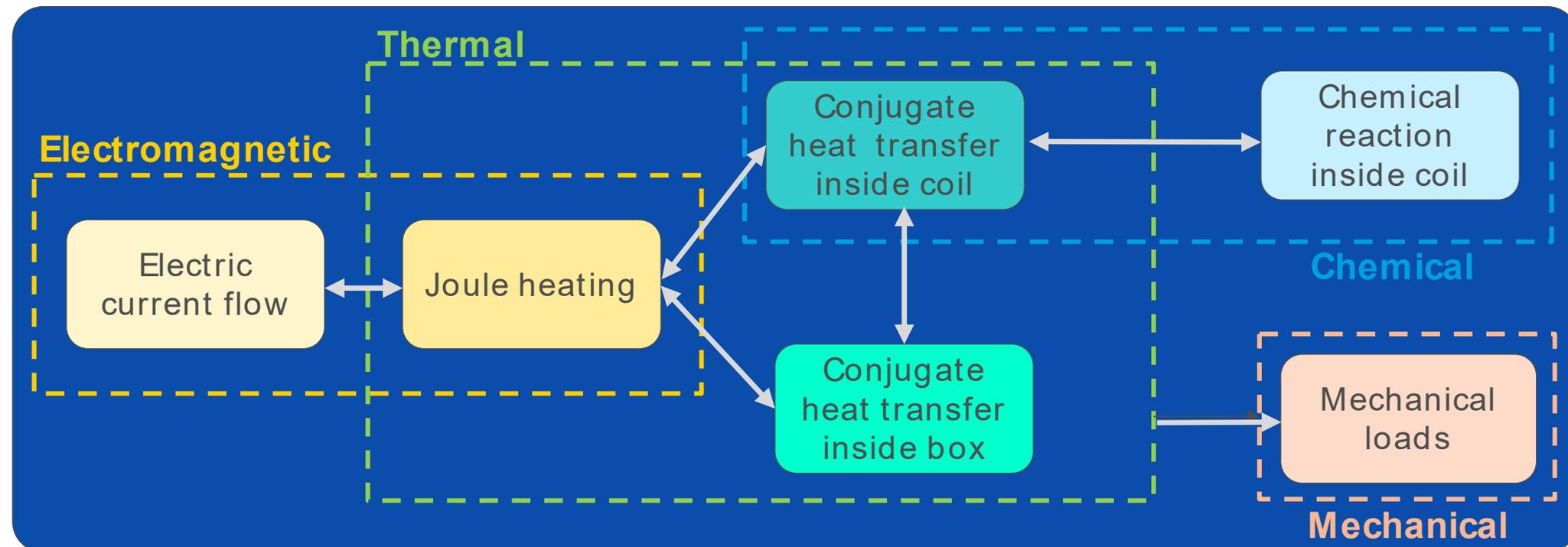
MULTI-PHYSICS MODELING TO SUPPORT DIRECT FURNACE DESIGN

Understanding the complementary process/electrical roles of the crating coils

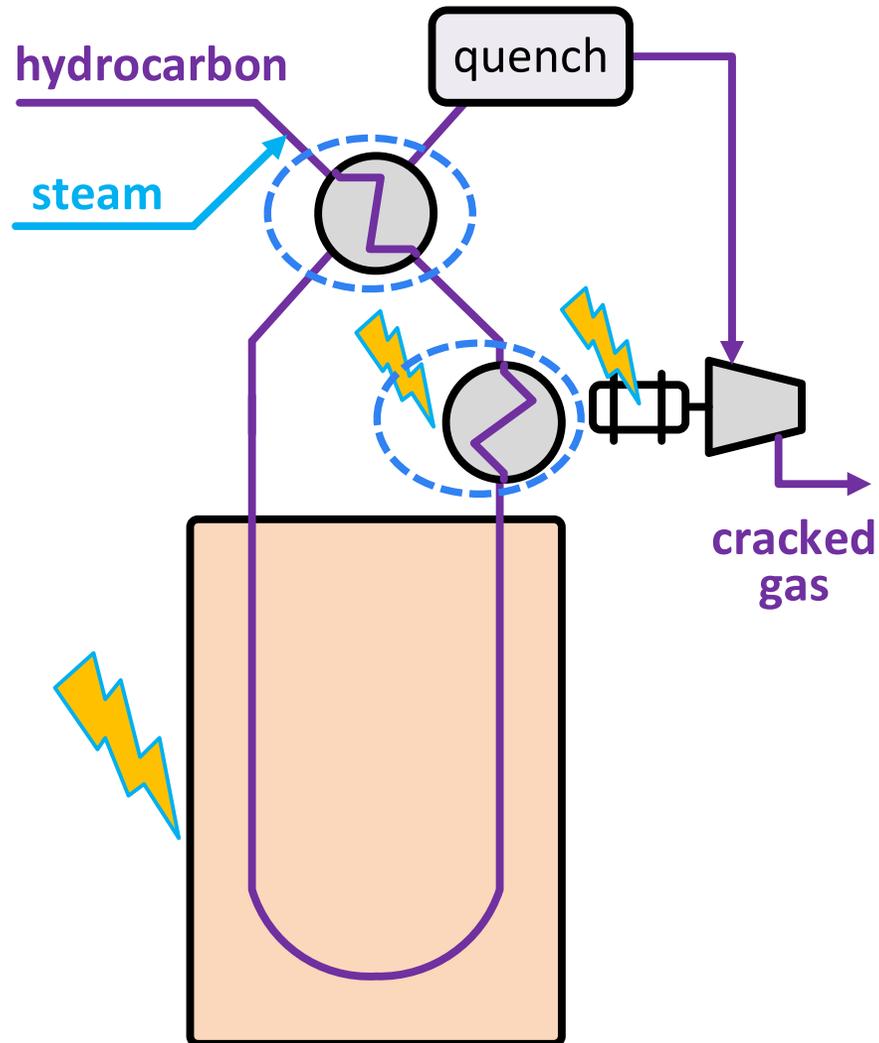
Coupled multi-physics simulations including electromagnetic aspects

Simulation results → Process and equipment definition

Chemical, thermal, and mechanical design, including control strategy and electric component sizing



REST OF PLANT CONSIDERATIONS



New heat integration methods

No flue gas → no convection section

New feed preheat strategies

JDA partners developing novel exchangers
with Arvos Schmidtsche Schack

SCHMIDTSCHESCHACK

ARVOS

Industry options for high-temperature eHeaters

Much less steam → electric drives for rotating equipment

→ energy intensity improvement by >30%

Co-products

Hydrogen

Partial furnace firing or export for energy/chemical value

Methane

Export (or use on-site) to support ongoing demand, displacing geologic natural gas

Blue and turquoise hydrogen production

TRANSFORMATION PATHWAY

Linde already offering commercial licenses to STARBRIDGE™ cracker technology

SABIC's climate commitments

CARBON NEUTRALITY
by 2050

in line with the
Paris Agreement goals

20% REDUCTION
by 2030

Interim Scope 1&2 GHG emissions
target compared to 2018

Translating these ambitious goals into decisive action

First -adopter full cracking eFurnace installation at SABIC site

Retrofit options and scenarios developed for SABIC's cracker fleet

Support large -scale electrical infrastructure and renewable generation initiatives



THANK YOU



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