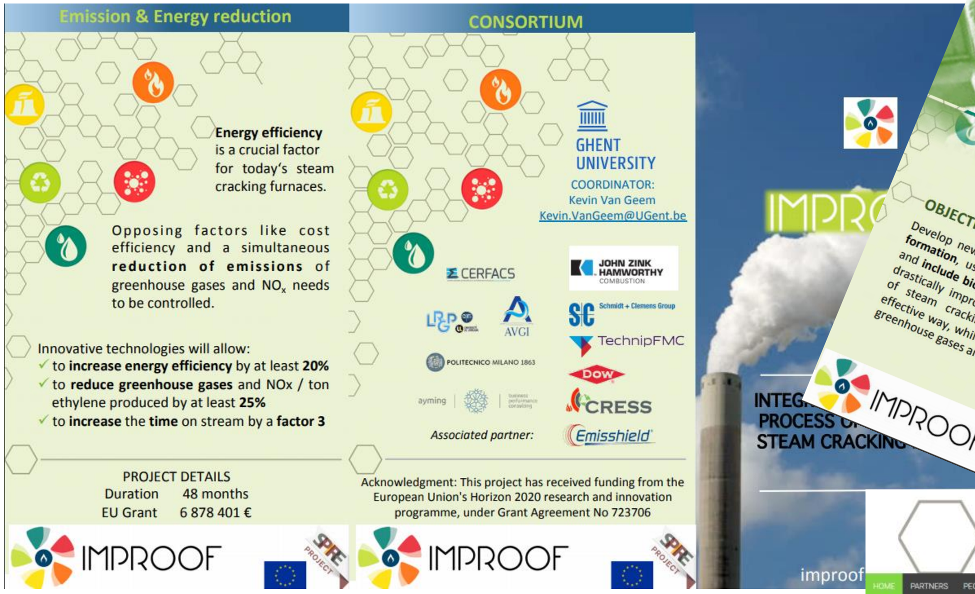
Welcome to the IMPROOF Stakeholder meeting

Please consider muting your microphone throughout the presentation

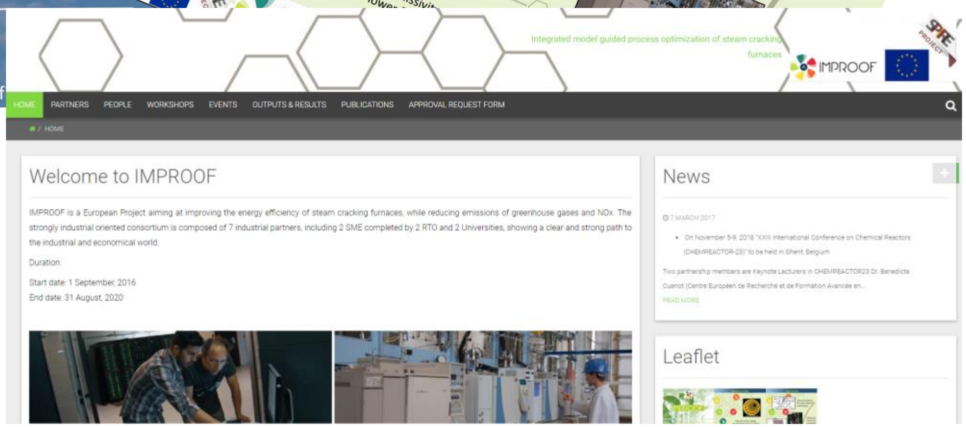
Q&A will be held at the end of the presentations
Questions can be posed continuously in the chat

IMPROOF



Emission & Energy reduction
Energy efficiency is a crucial factor for today's steam cracking furnaces.
Opposing factors like cost efficiency and a simultaneous reduction of emissions of greenhouse gases and NO_x needs to be controlled.
Innovative technologies will allow:
✓ to increase energy efficiency by at least 20%
✓ to reduce greenhouse gases and NOx / ton ethylene produced by at least 25%
✓ to increase the time on stream by a factor 3
PROJECT DETAILS
Duration 48 months
EU Grant 6 878 401 €
CONSORTIUM
GHENT UNIVERSITY
COORDINATOR:
Kevin Van Geem
Kevin.VanGeem@UGent.be
CERFACS
JOHN ZINK HAMWORTHY COMBUSTION
AVGI
TechnipFMC
POLITECNICO MILANO 1863
Dow
ayming
CRESS
Associated partner:
Emisshield
Acknowledgment: This project has received funding from the European Union's Horizon 2020 research and innovation programme, under Grant Agreement No 723706
IMPROOF
SPIRE PROJECT
INTEGRATED PROCESS OPTIMIZATION OF STEAM CRACKING
improof

IMPROOF
OBJECTIVE
Develop new techniques to reduce coke formation, use high emissivity coatings, and include biogas and bio-oil as fuels to drastically improve the energy efficiency of steam cracking furnaces in a cost effective way, while reducing emissions of greenhouse gases and pollutant emissions.
INNOVATIONS
New 3D reactor design for improved process control and increased run length
Heat Flux on ID surface
Renewable fuels (biogas and bio-oil) for lower net CO_2 production
High emissivity
METHODS
Chemical kinetics for oxy-combustion and biofuels
Advanced numerical simulation
IMPROOF



Integrated model guided process optimization of steam cracking furnaces
IMPROOF
HOME
PARTNERS
PEOPLE
WORKSHOPS
EVENTS
OUTPUTS & RESULTS
PUBLICATIONS
APPROVAL REQUEST FORM
Welcome to IMPROOF
IMPROOF is a European Project aiming at improving the energy efficiency of steam cracking furnaces, while reducing emissions of greenhouse gases and NOx. The strongly industrial oriented consortium is composed of 7 industrial partners, including 2 SME completed by 2 RTO and 2 Universities, showing a clear and strong path to the industrial and economical world.
Duration:
Start date: 1 September, 2016
End date: 31 August, 2020
News
Leaflet

Agenda

Meeting Name: Stakeholder meeting
Meeting Date: Sunday 16 August 2020, 17h CET
Meeting Venue: online

Stakeholder meeting				
	Remark	**Leader**	**Starting Time**	**Duration**
	Introduction, Presentation of the expected results and outcomes: new capacity / improvements of the plant, productivity	Kevin Van Geem	17:00	00:25
	Materials, pilot results and tube production	Marko Djokic, Steffen Heyland	17:25	00:30
	Low emission furnaces	Georgios Bellos, Peter Oud	17:55	00:15
	Conclusion + Q&A session	Kevin Van Geem	18:10	00:45
	meeting closed		**18:55**	


Q&A

IMPROOF

Technical field

Industrial furnace design - SPIRE04-2016

Integrated model guided process optimization of steam cracking furnaces

Academy

Technology developers

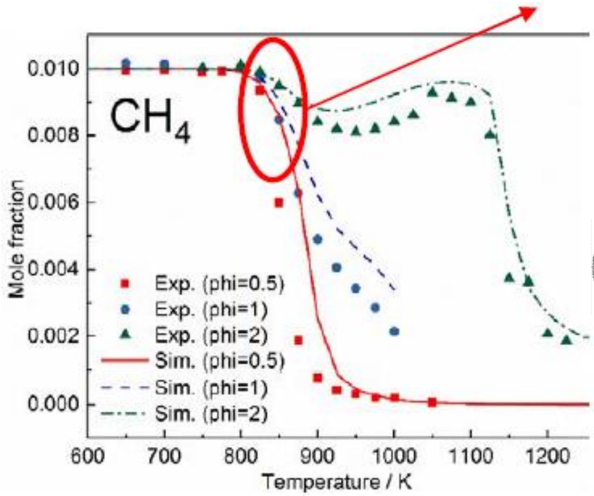
End user

Project
September 2016-August 2020
6.8 MM€ consortium grant

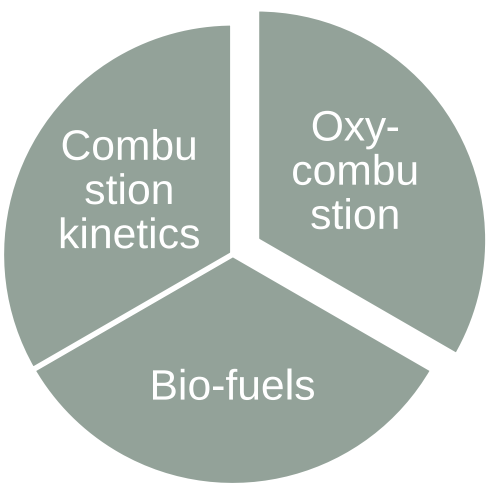
Reducing greenhouse gas emissions and NOx by 20% per ton of C2=

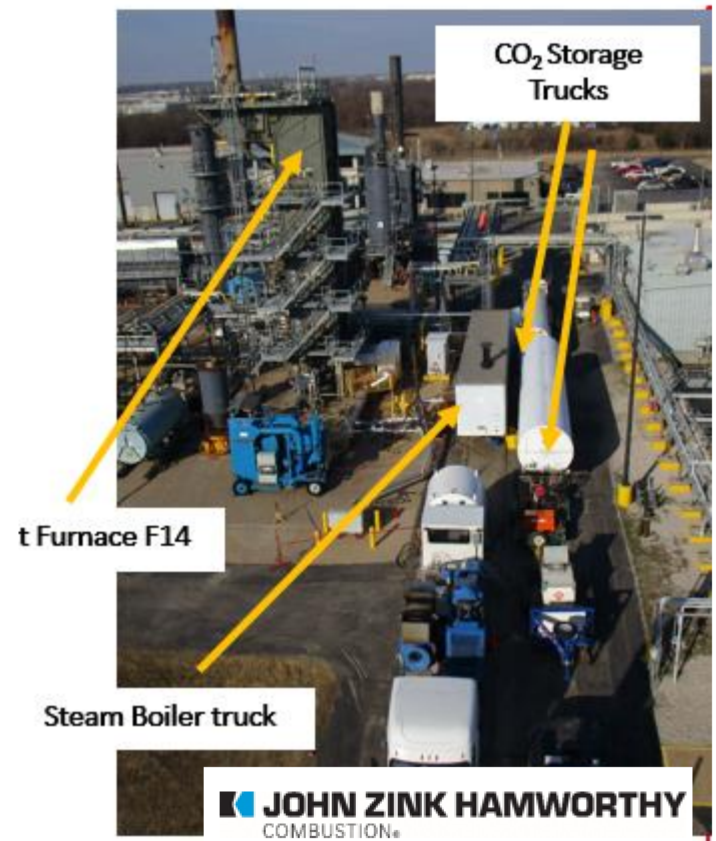
- Biofuels combustion
- Ultra low NOx burners
- Oxy-fuel combustion
- High emissivity coatings on walls
- New radiant coil metallurgy
- New radiant coil morphology

Combustion kinetics



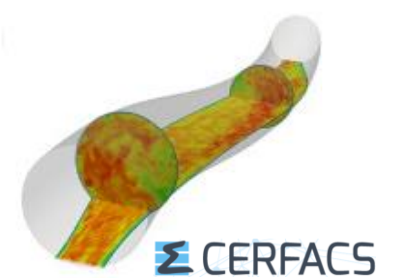
POLITECNICO DI MILANO

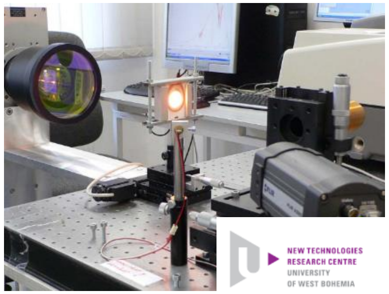


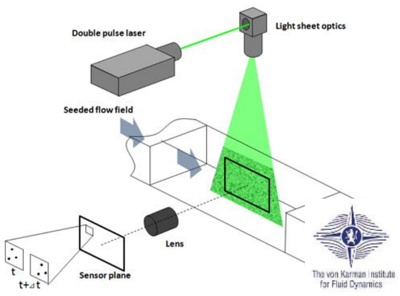


Demonstration of new technologies

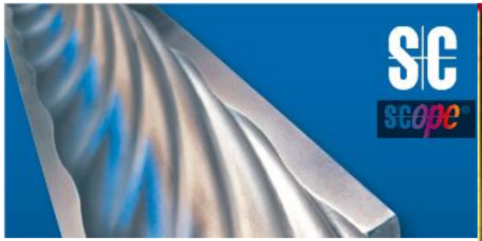
Modeling & TRL5

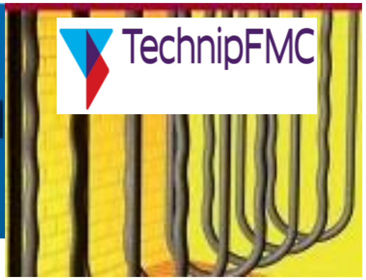






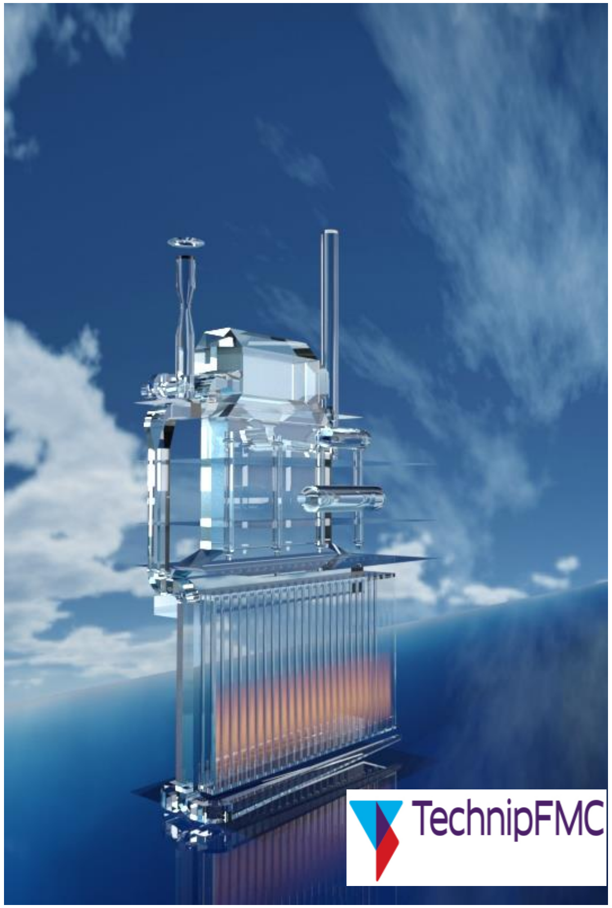
TRL6 demonstration

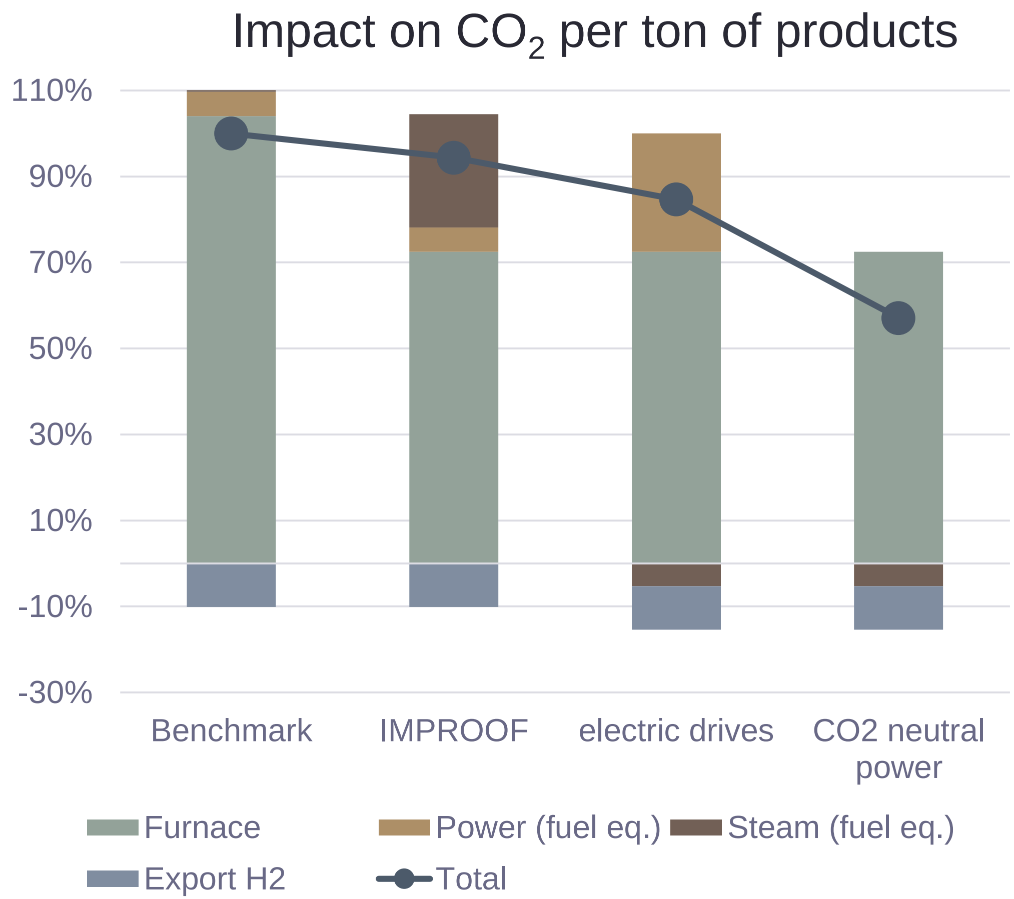




Emisshield CRESS

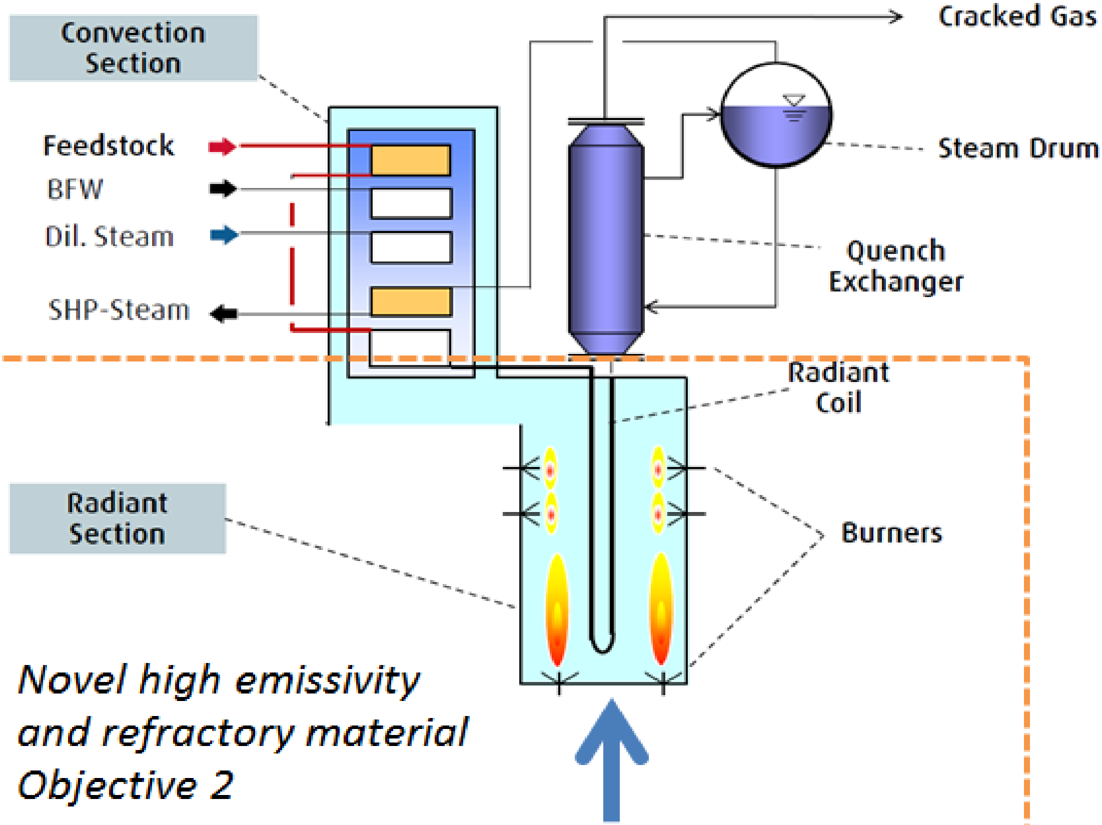
LCA on new process design



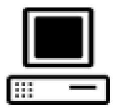


Objective: Furnace of the future

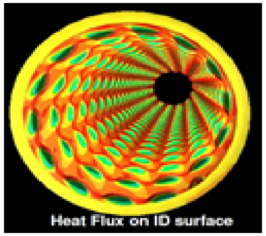
Novel furnace design - Objective 3



Novel high emissivity and refractory material Objective 2



3D modelling Objective 4

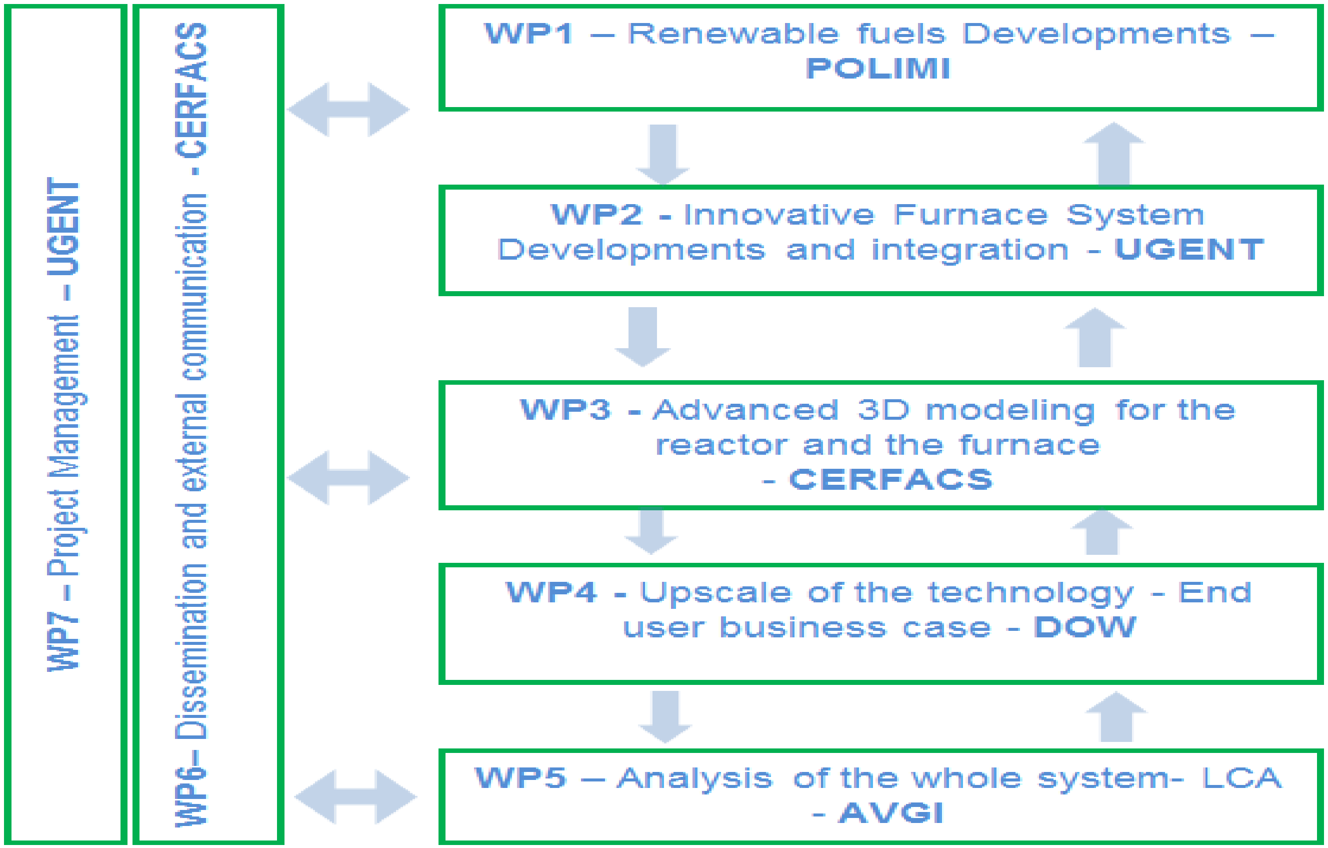


Alternative fuels – Oxy-fuel Objective 1

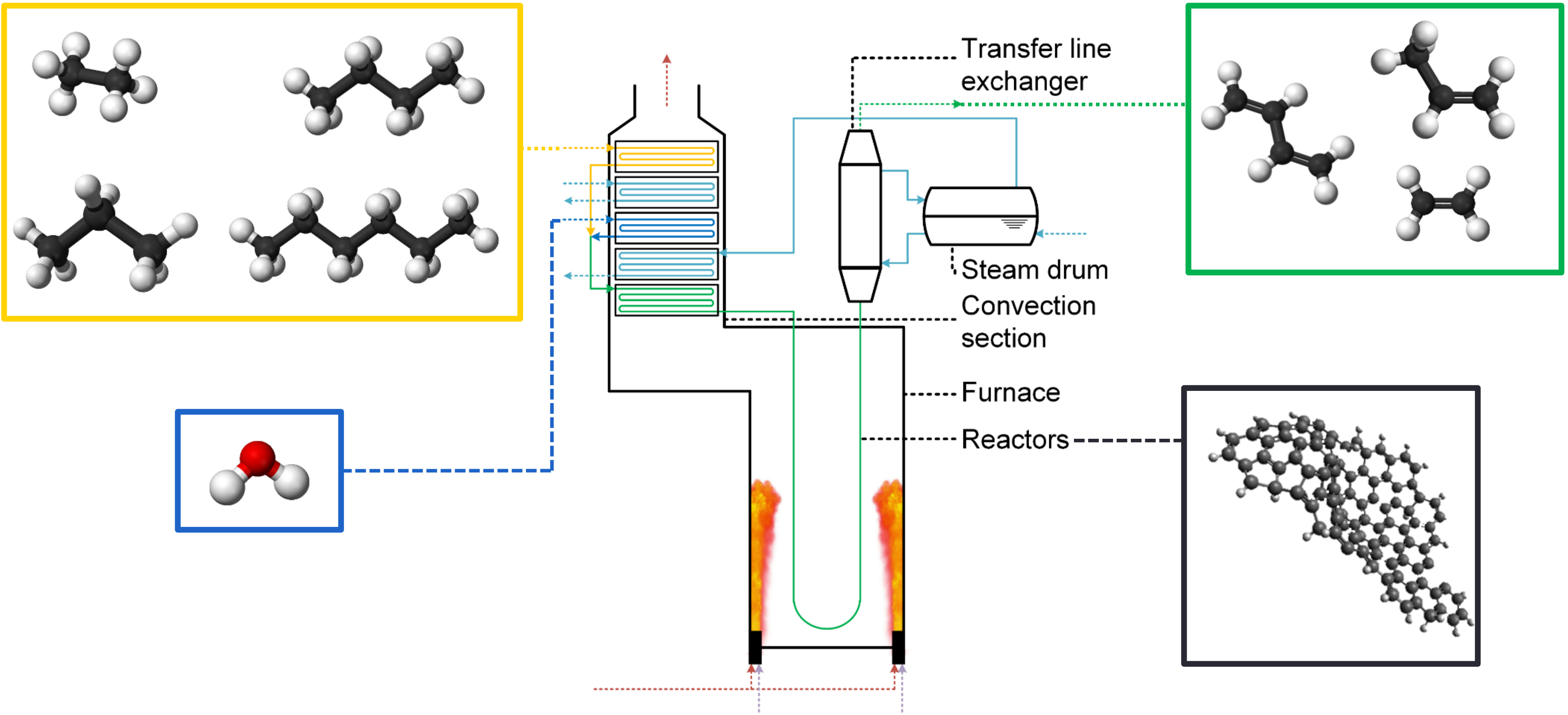
5 sub-objectives

1. Demonstrate the individual impact of **novel emissive, reactor and refractory materials** on pilot scale (TRL5)
2. Demonstrate the power advanced process simulation (**high performance computing and CFD**) for furnace design and optimization
3. Demonstrate the technical, economic and environmental sustainability of the IMPROOF furnace at **TRL6**
4. **Coke formation reduction** and real time optimization
5. Novel combustion technology using **alternative fuels and oxy-fuel** combustion.

WP structure with related WP leaders



state-of-the-art



Furnaces have had no spectacular advances for the last 10-20 years

S. Vangaever, P. A. Reyniers, C. Visser, D. Jakobi, G. J. Heynderickx, G. B. Marin, *et al.*, "Computational Fluid Dynamics-Based Study of a High Emissivity Coil Coating in an Industrial Steam Cracker," *Industrial & Engineering Chemistry Research,* vol. 57, pp. 120782-120794, 12018.

Review articles

I&EC research
Industrial & Engineering Chemistry Research

Review

Cite This: Ind. Eng. Chem. Res. 2018, 57, 16117−16136 pubs.acs.org/IECR

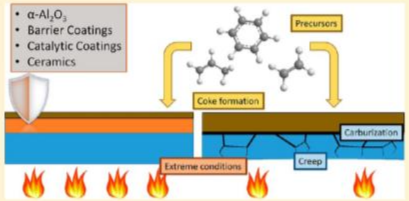
State-of-the-art of Coke Formation during Steam Cracking: Anti-Coking Surface Technologies

Steffen H. Symoens,[†] Natalia Olahova,[†] Andrés E. Muñoz Gandarillas,[‡] Hadiseh Karimi,[‡] Marko R. Djokic,[†] Marie-Françoise Reyniers,[†] Guy B. Marin,[†] and Kevin M. Van Geem*[,†]

[†]Ghent University, Laboratory for Chemical Technology, Technologiepark 914, 9052 Gent, Belgium
[‡]AVGI bvba, Technologiepark 19, 9052, Gent, Belgium

Supporting Information

ABSTRACT: Although steam cracking is a mature technology, mitigation of coke formation remains one of the main challenges in the petrochemical industry. To increase the olefin output of existing plants, coil materials that can withstand higher temperatures are desired. This work reviews material technologies that were developed and tested in the past three decades to minimize the rate of coke deposition and extend the furnace run length. The material not only determines the mechanical properties of the coil but also affects the coking rate substantially. In some cases, differences in coking rates by more than a factor 10 have been observed. SiC materials could be operated at significantly higher temperatures, and this leads to higher olefin selectivity if one includes acetylene hydrogenation; however, the mechanical joints make it currently impossible to take advantage of their superior temperature resistance. On the industrial scale, operational improvements have been reported with advanced reactor surface technologies such as high-performance alloys and coatings during the past decade. Catalytic coatings go a step further than barrier coatings by actively removing coke that is deposited on the coils. Another trend is to add aluminum to the coil material, which forms a protective aluminum oxide layer on the reactor wall during operation and results in reduced carburization. To optimize the coking mitigation capabilities of the coils, the state-of-the-art materials and/or coatings should be combined with 3D reactor technologies, which is not always possible for all materials because of the advanced machining that is needed.



1. INTRODUCTION

Steam cracking is the most important petrochemical process ...

Commercial steam cracking of hydrocarbons is performed almost exclusively in fired tubular reactors. The hydrocarbon feed stream enters the furnace and is preheated by heat exchange ...

pubs.rsc.org/en/content/articlelanding/2020/re/...

Publishing Journals Books Databases

Network access provided by: Ghent University Library

From the journal:
Reaction Chemistry & Engineering

Sustainable innovations in steam cracking: CO_2 neutral olefin production

Check for updates

Ismaël Amghizar,[a] Jens N. Dedeyne,[a] David J. Brown,[b] Guy B. Marin [a] and Kevin M. Van Geem *[a]

Author affiliations

...s://pubs.rsc.org/en/journals/journal/re

Evolution of the state-of-the-art

- a new wind is blowing: *IMPROOF is partly driving this*
  - *New concepts related to energy are being considered*
  - *Novel technologies are being vetted more quickly*

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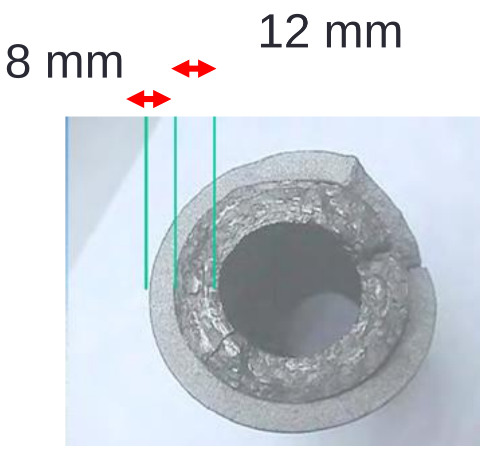
- Examples:
  - *Novel materials for high emissivity coatings*
  - *3D reactor technologies are being more and more embraced by industry*
  - *Reactor materials are revisited based on better understanding and better testing procedures*

Coke Formation



Coke Formation

↓

Reduce product yields
Loss of production capacity
Increase energy consumption
Shorten coil service life
Increase maintenance cost
Add operator load

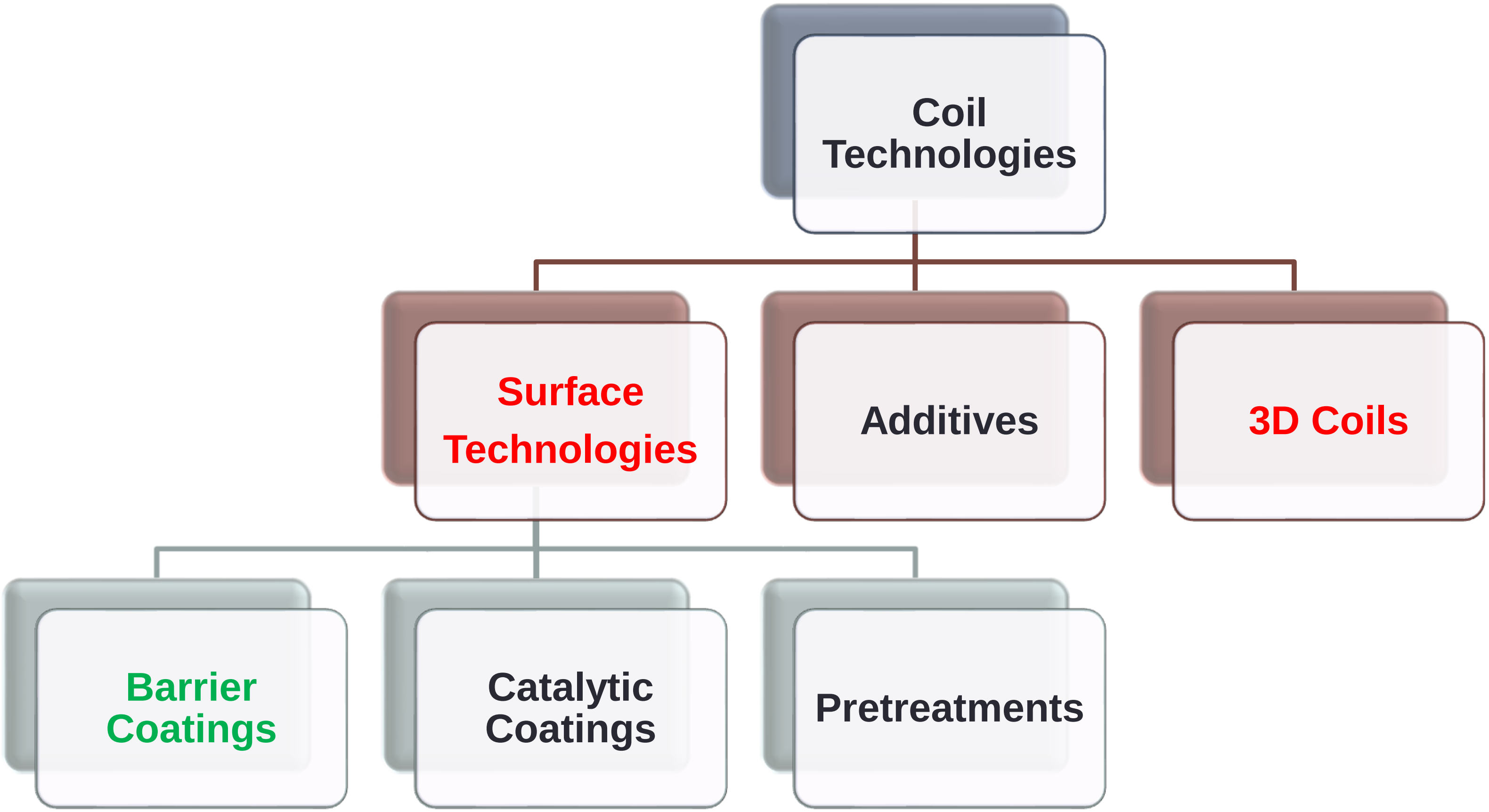
↓

Furnace Utilization ~ 90-95%

↓

Worldwide Production Loss:
10% Improvement = $ 2 Billion/yr

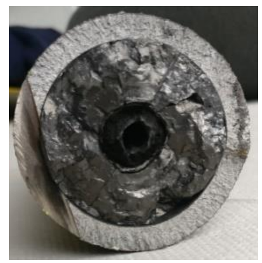
Technologies for Coke Reduction and Heat Transfer Improvements



Process Intensification in steam cracking

Improve reactor design by accelerating heat input

$$\dot{Q} = h\,A\,(T_{inner\ reactor\ wall} - T_{fluid})$$



- Thermal efficiency
- Product selectivity
- Decoking procedures

- More reactor material needed
- More friction with wall ~ Δp

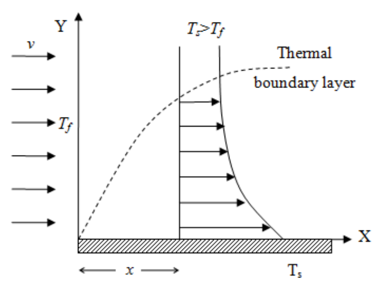
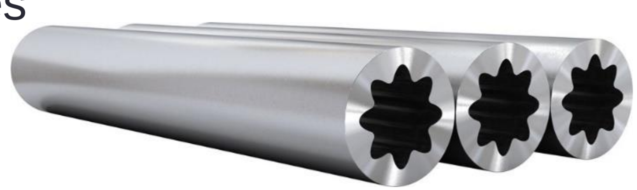


Fig.4.3: Thermal boundary layer flow past a flat surface

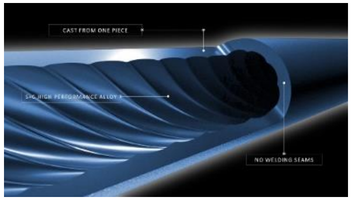
- Disrupt the boundary layer

3D Coils

- 3D geometries to enhance heat transfer by
  - Increased internal surface area
    - Fin-like structures

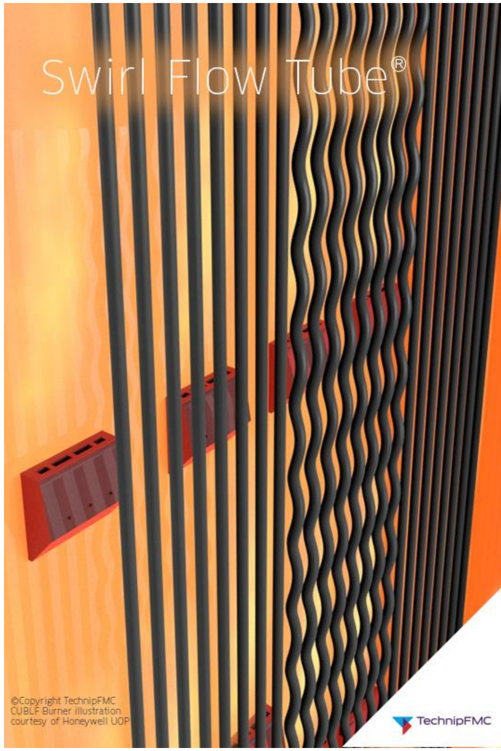


  - Enhanced mixing
    - SCOPE (S+C)
    - Swirl Flow Tube (SFT)



SCOPE®

SFT®

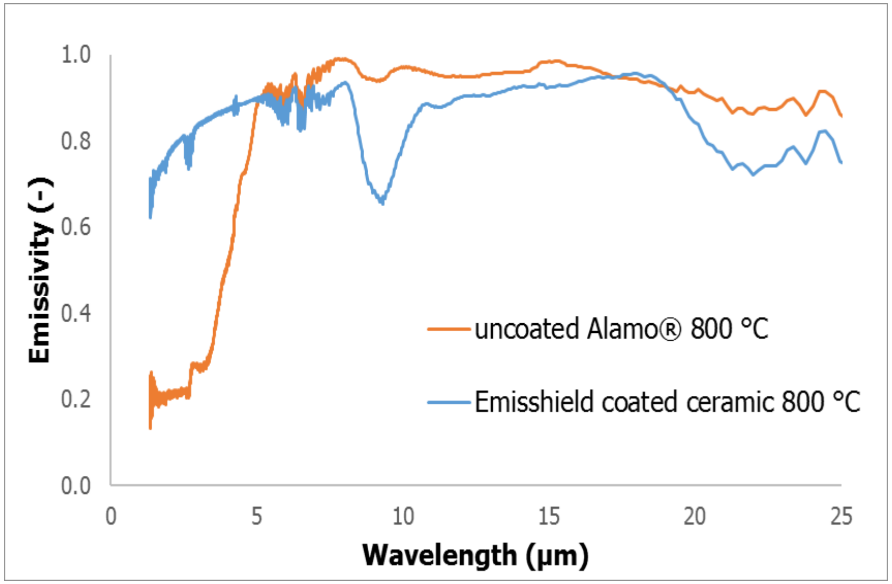


- Major drawback: Increased pressure losses

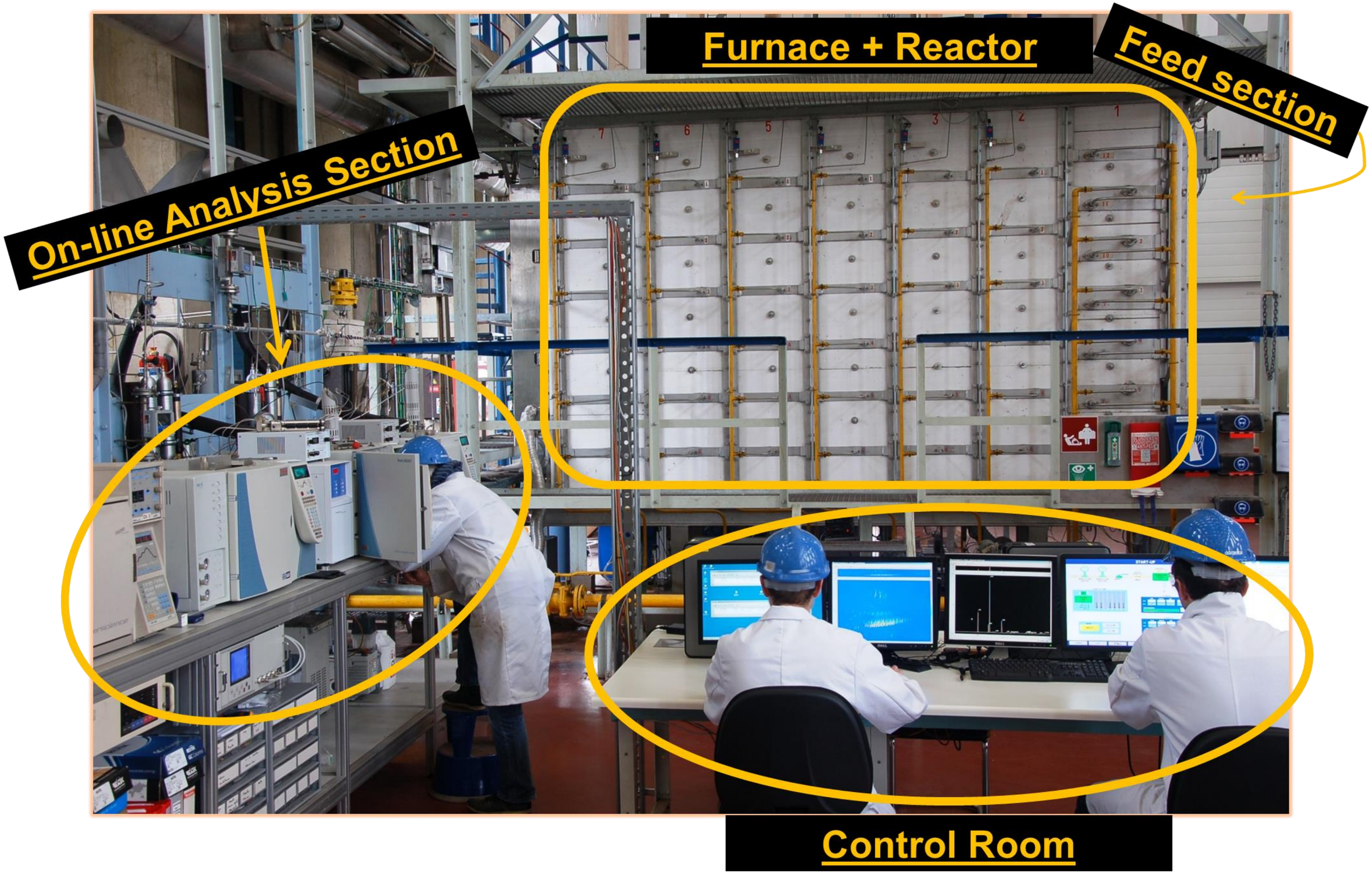
High Emissivity Coatings

- Application of high-emissivity coatings:
  - on furnace walls improves heat transfer and thermal efficiency of furnace
  - on reactor tubes increases capacity of reactor tube to transfer heat to process gas
- Emissivity of a high-emissivity ceramic coating increases with temperature
- CFD modeling showed:

  Application of high-emissivity coatings on walls of a naphtha furnace increased thermal efficiency (~1%) & improved yield of ethylene(~0.5%)



Pilot tests proved there value



Techniques for Lowering NOx

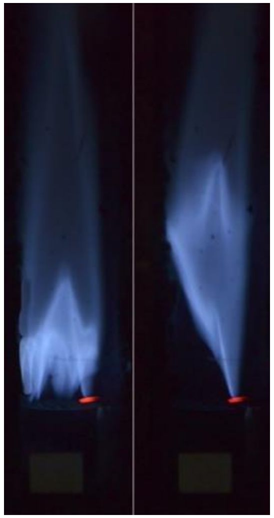
- Steam injection in the combustion zone
- Modifications to create a larger flame
  - Produces a lower flame temperature and lower NOx
- Low or ultra-low NOx staged fuel burners
- Selective Catalytic Reduction (SCR) system
  - NOx and ammonia react on a titanium-vanadium based catalyst to produce nitrogen and water
- Improved Combustion
  - Oxy-fuel combustion
  - Moderate or Intense Low-oxygen Dilution (MILD) combustion

Bussman, W., Poe, R., Hayes, B., McAdams, J. & Karan, J. *Environ. Prog.* **21,** 1–9 (2002).
Walker, J. S. & Salbilla, D. L. Analysis of NO x Reduction Techniques on an Ethylene Cracking Furnace.
Zimmermann, H. & Walzi, R. in *Ullmann's Encyclopedia of Industrial Chemistry* 547–572

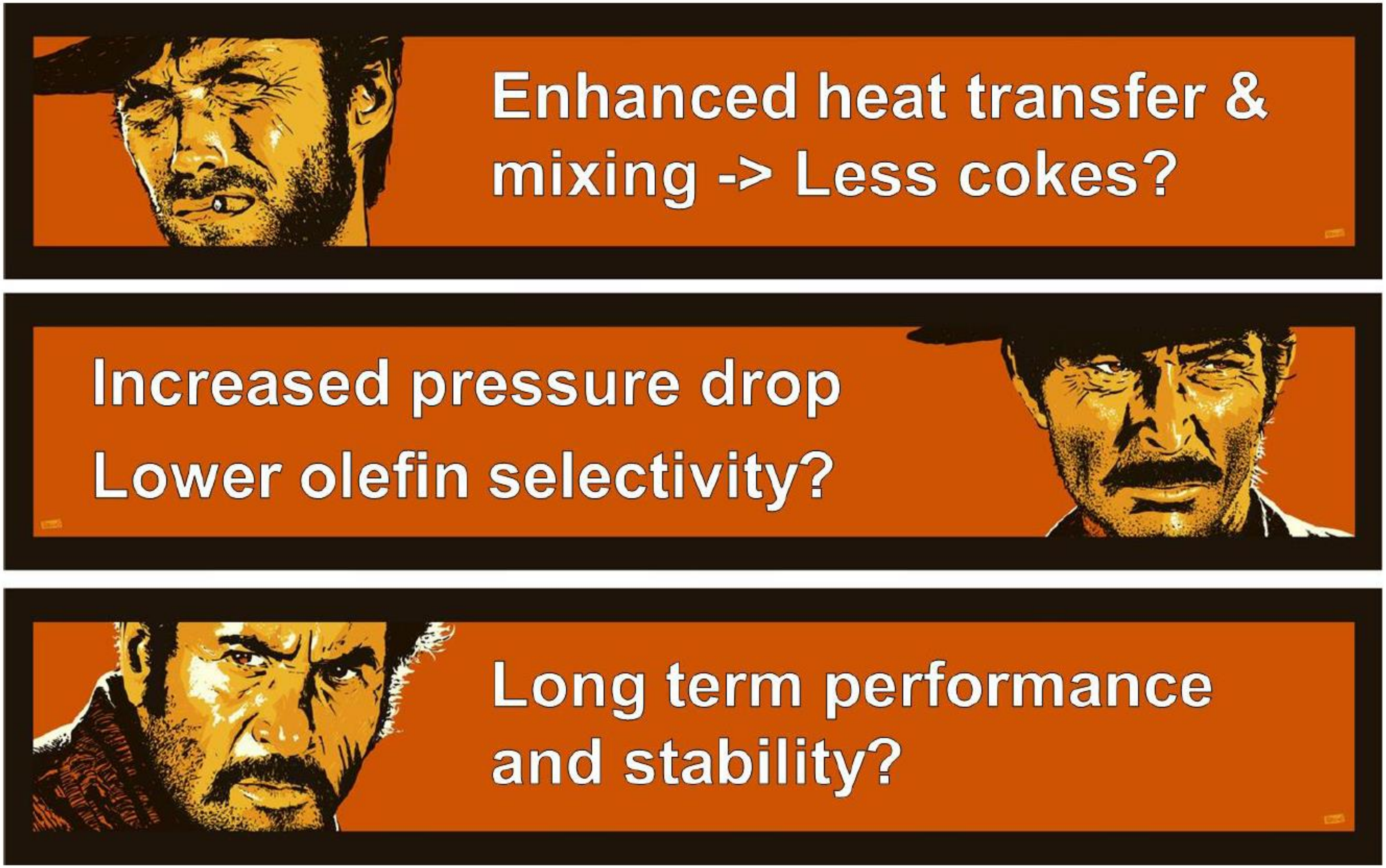
Improved Combustion

- Oxy-fuel process is based on removal of nitrogen from air to carry out combustion with nearly pure oxygen and part of the flue gases

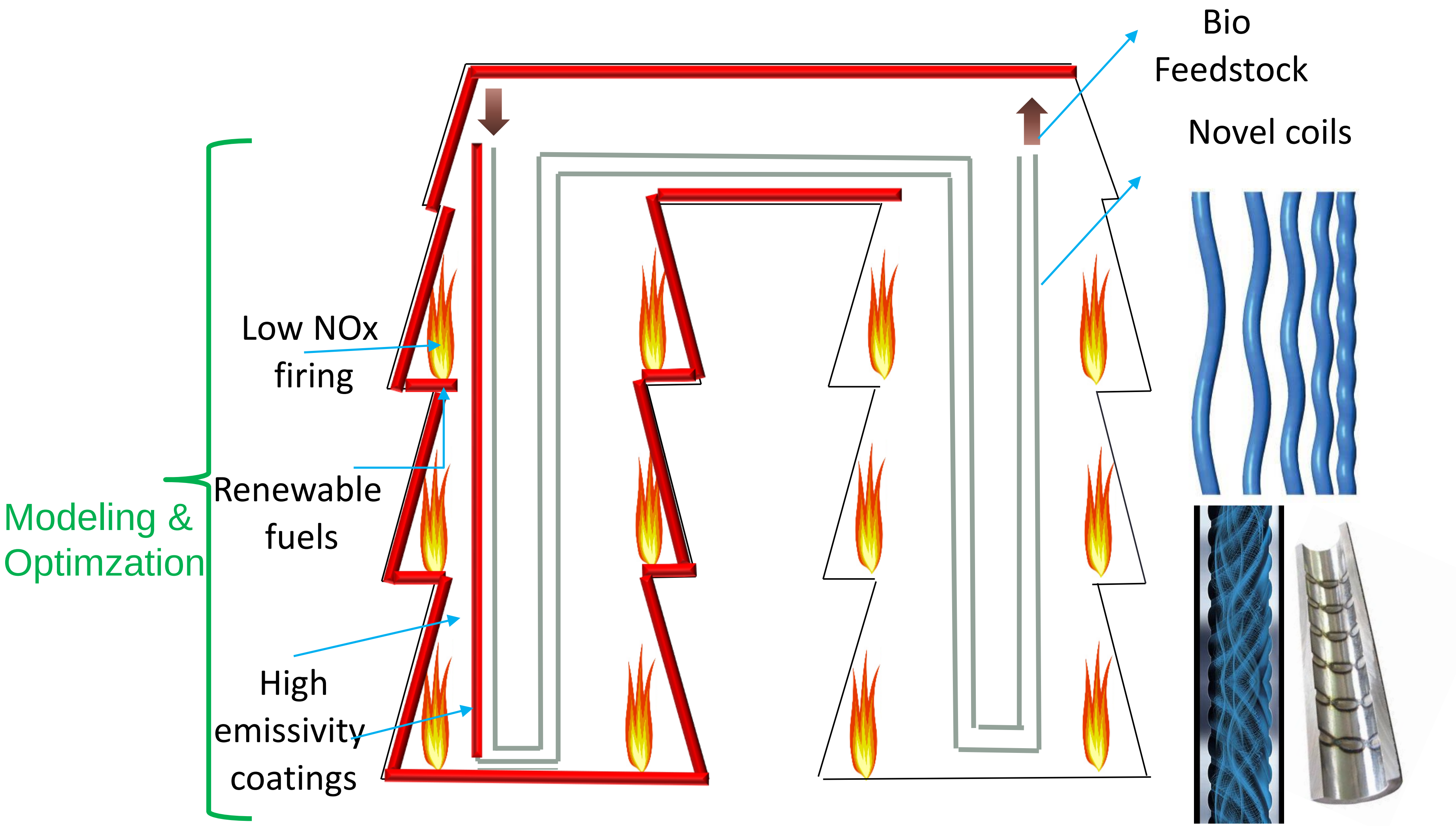
  - Advantages:
    - Production of a highly concentrated stream of CO_2, ready for capture and storage (CCS).
    - Significantly reduce size of combustor unit
    - Higher adiabatic flame temperature
    - Reduce NO_x



Only results will tell how ugly things get



On 31 August 2020 it does not stop: Models are essential to make further progress



General project progress

- *Regarding the objectives defined:*

1. *Demonstrated the individual impact of novel emissive, reactor and refractory materials on pilot scale (TRL5)*
2. *Demonstrate the power advanced process simulation (high performance computing and CFD) for furnace design and optimization*
3. *Demonstrate the technical economic and environmental sustainability of the IMPROOF furnace at TRL6*
4. *Coke formation reduction*
5. *Novel combustion technology using alternative fuels and oxy-fuel combustion*

General project progress

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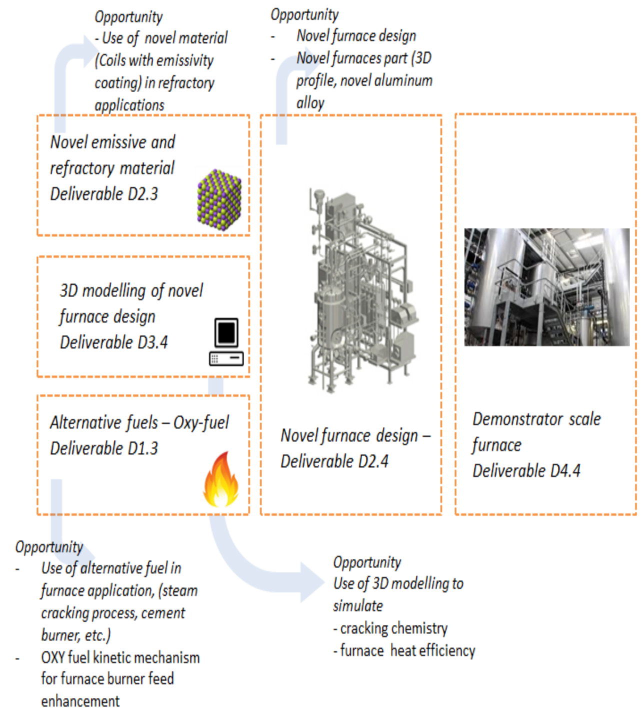
IMPROOF risk mitigation plan



Questions

FACULTY OF ENGINEERING AND ARCHITECTURE

ADVANCEMENTS IN RADIANT COIL TECHNOLOGY

M.R. Djokic, S. Vangaever, K.M. Van Geem, D. Jakobi, S. Heyland/ EPC Workshop/ 16-Aug-2020

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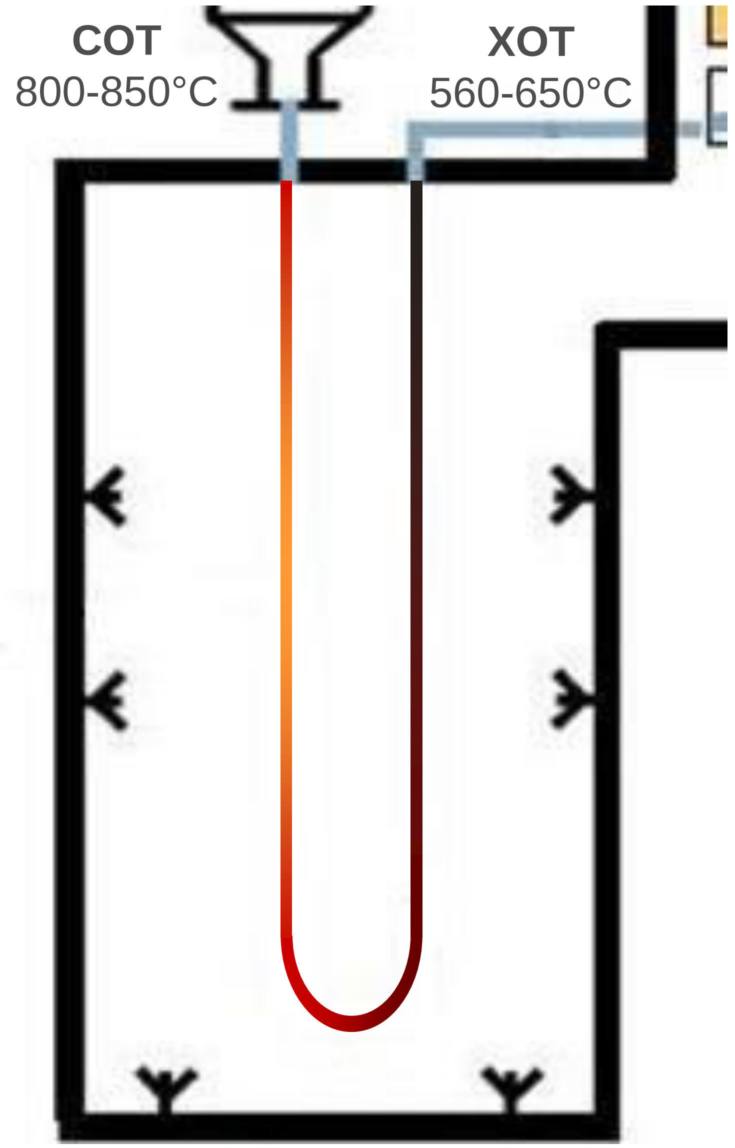
IMPROOF

INTRODUCTION

- Main target of the IMPROOF-Project is to increase the energy efficiency of steam cracking furnaces by at least 20%
- A substantial efficiency increase can be achieved by optimizing the radiant section, the “core” of the steam cracker

INTRODUCTION

Steam Cracking Process



Outer Tube Surface heated by Firebox

- Max. Tube Metal Temperature: 1100-1150°C
- Oxidizing flue gas atmosphere

Inner Tube Surface with Alternating Corrosive Conditions

- Oxidizing conditions (furnace start-up & decoking)
- Reducing conditions (after coke deposition on inner tube surface)

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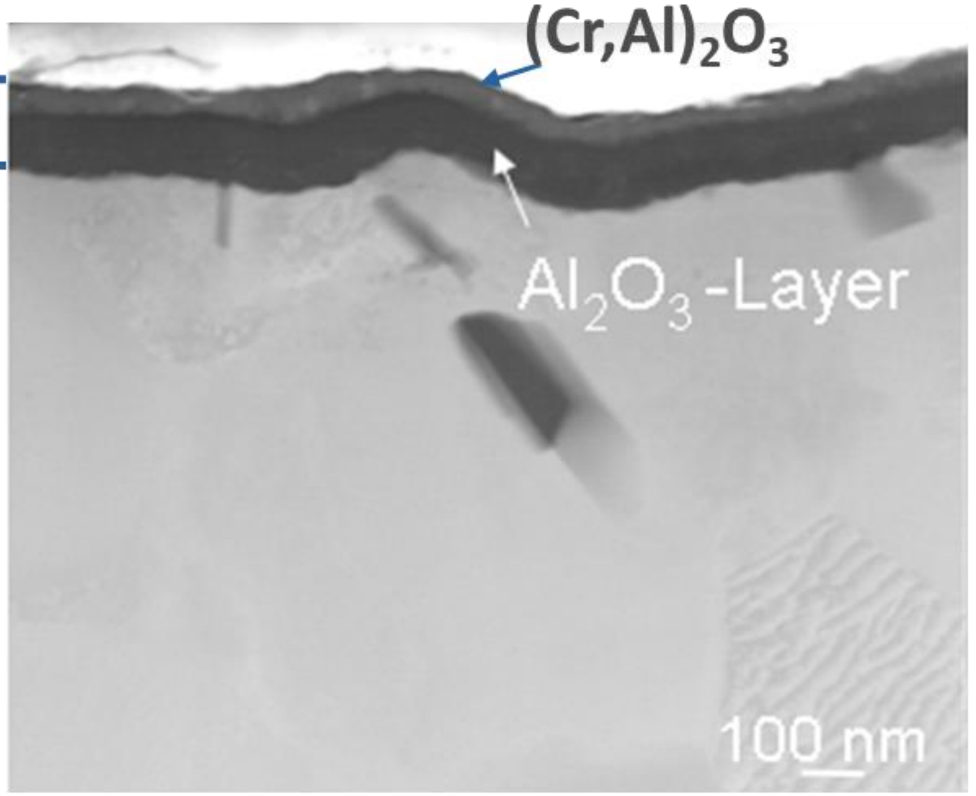
MATERIALS

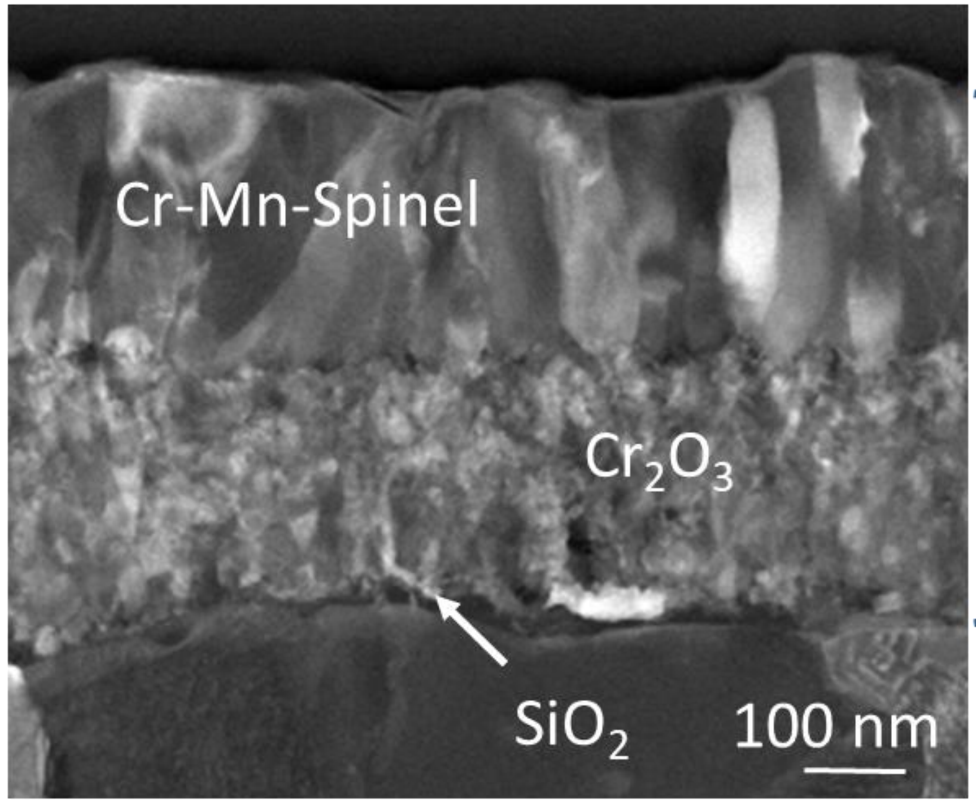
Initial Oxide Layer after Start-Up

Centralloy® HT E Alumina Former	Common Chromia Forming Alloys

Oxide Scale: **0.15 µm**

transient aluminum oxide;
transformed during 1^{st} run
into stable α-Al_2O_3





Oxide Scale: 0.7 µm

composed of
Cr-Mn-spinels
chromium oxide and
silicon dioxide

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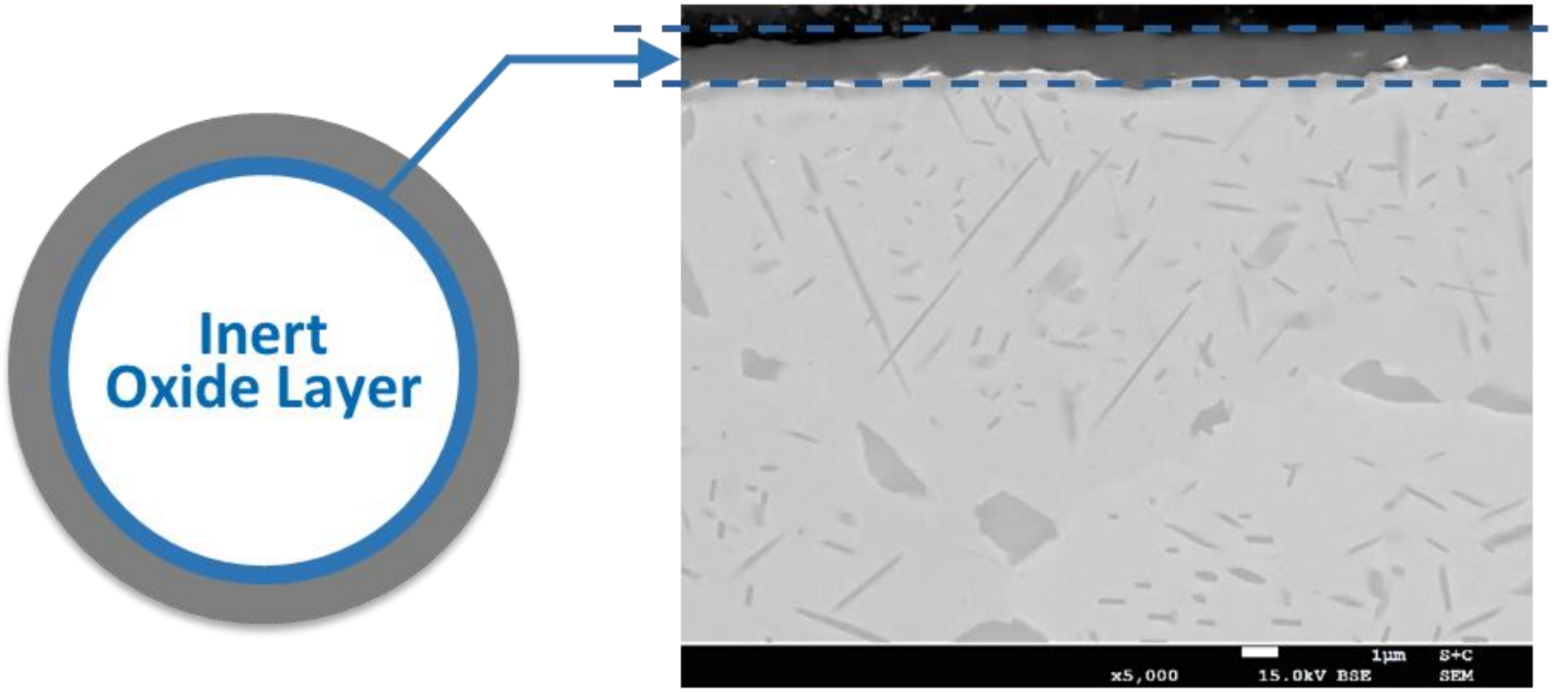
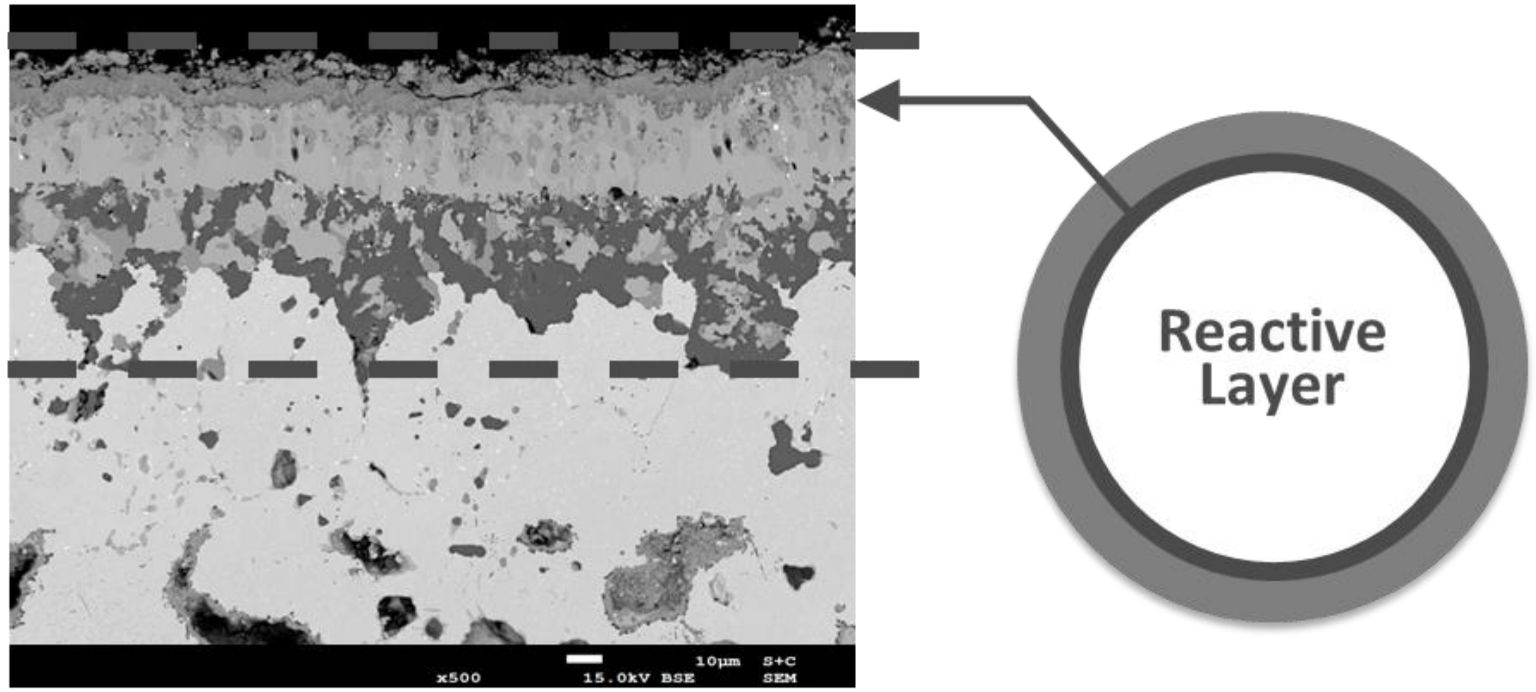
MATERIALS

Oxide Layers after Cyclic Operation

Centralloy® HT E Alumina Former	Common Chromia Forming Alloys





+ Dense inert Aluminium Oxide layer – 1 µm
+ Complete protection, no carburization
+ Low coking rate

– Destroyed Chromium Oxide layer – reaction zone 90 µm
– Open structure, causing carburization
– High coking rate

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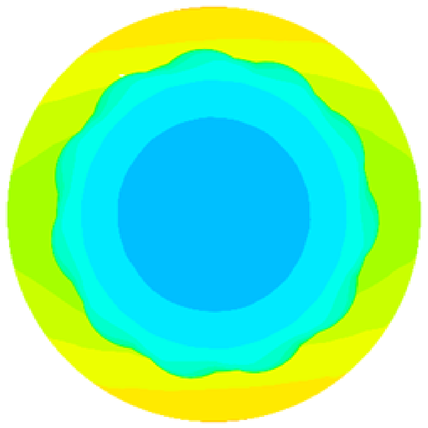
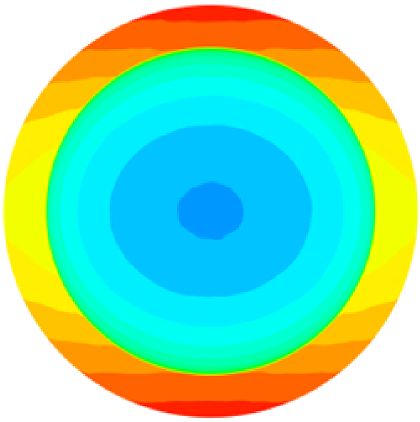
IMPROOF

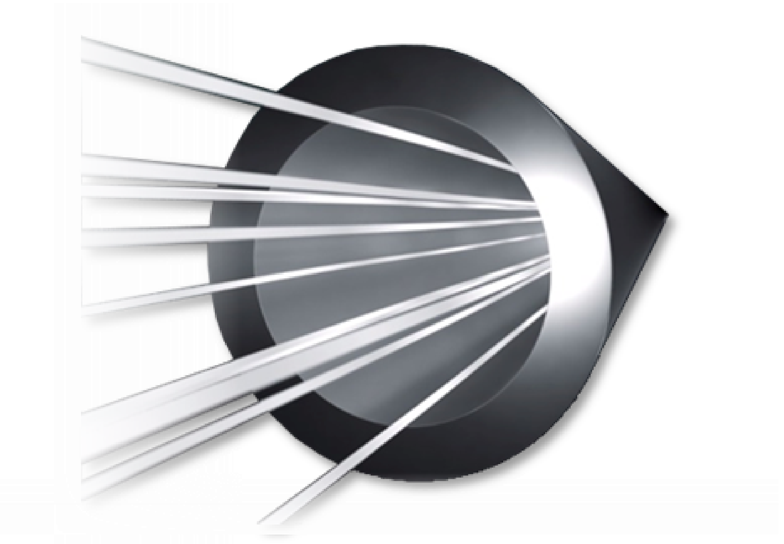
ENHANCED HEAT TRANSFER

Inner Profiled Tubes

S+C SCope®	Common Bare Tube







Rotating flow pattern

+ Improved heat distribution across tube shell
+ Reduced gas temperature gradients
+ Balancing of sunny/shady sides
+ Less carburization/maintenance
+ Customizable profile (amount of fins & profile depth)

Linear flow pattern

– Local heat concentration
– Internal stresses due to temperature difference
– Imbalance of sunny/shady sides
– More carburization/maintenance

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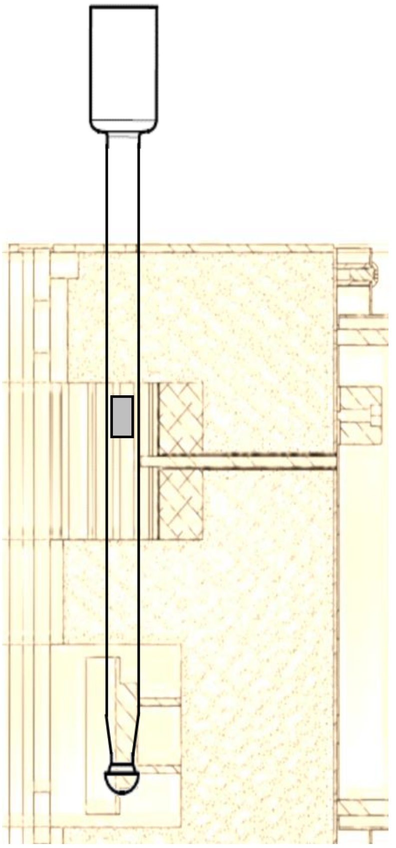
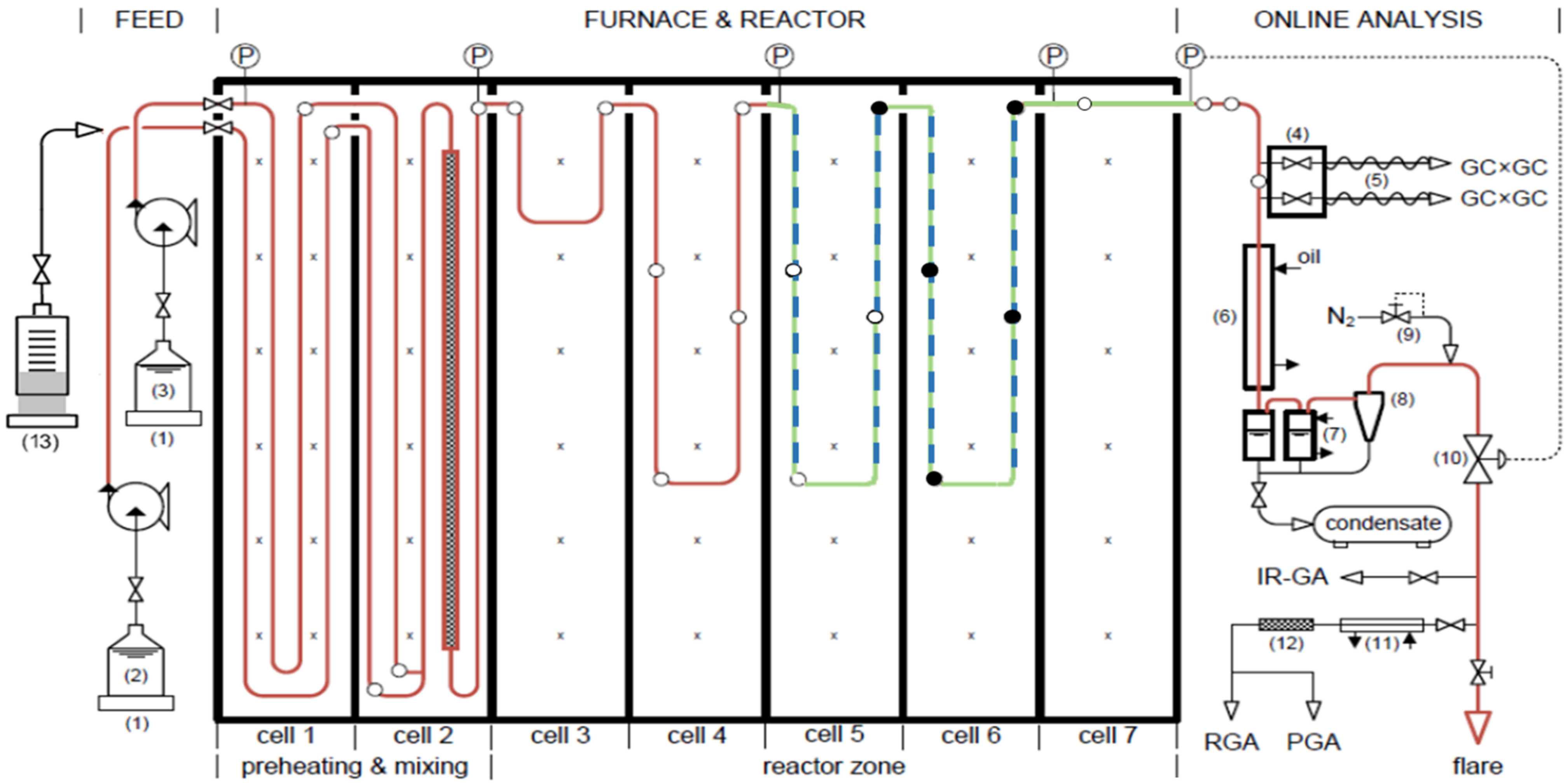
TEST RIGS

Plug-Flow-Reactor + Electrobalance



A. Muñoz Gandarillas, K. Van Geem, M.-F. Reyniers, and G. Marin, “Influence of the reactor material composition on coke formation during ethane steam cracking,” *INDUSTRIAL & ENGINEERING CHEMISTRY RESEARCH*, 2014.

Pilot Plant



K. Van Geem, S. Pyl, M.-F. Reyniers, J. Vercammen, J. Beens, and G. Marin, “On-line analysis of complex hydrocarbon mixtures using comprehensive two-dimensional gas chromatography,” *JOURNAL OF CHROMATOGRAPHY A*, 2010.

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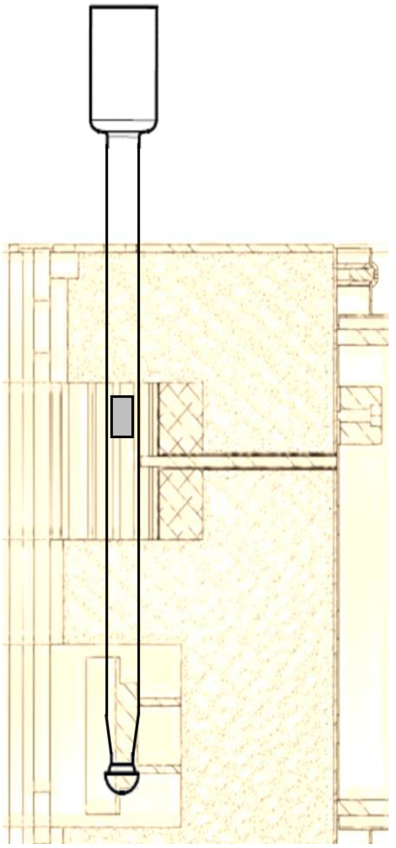
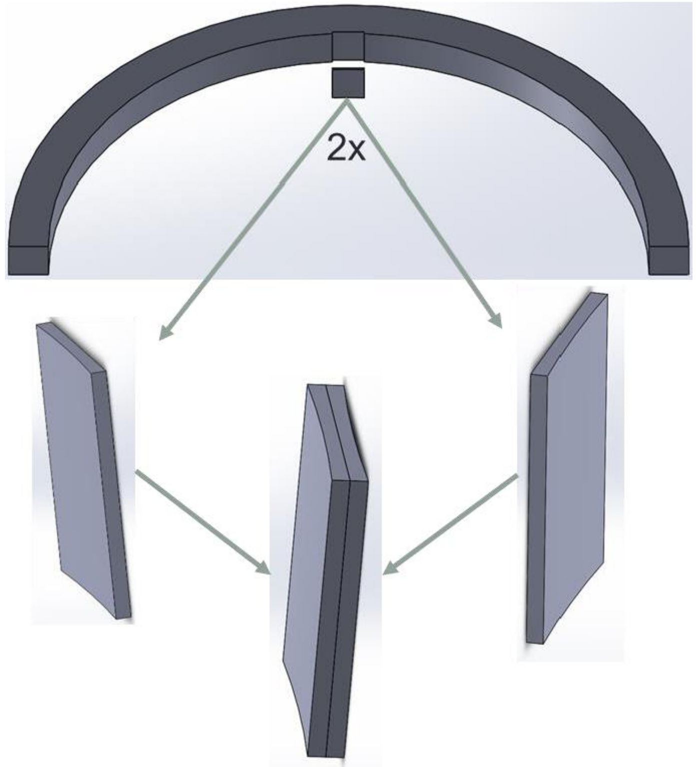
TEST RIGS

Plug-Flow-Reactor + Electrobalance

…can measure exact coking rates of real tube surfaces under industrial steam cracking conditions

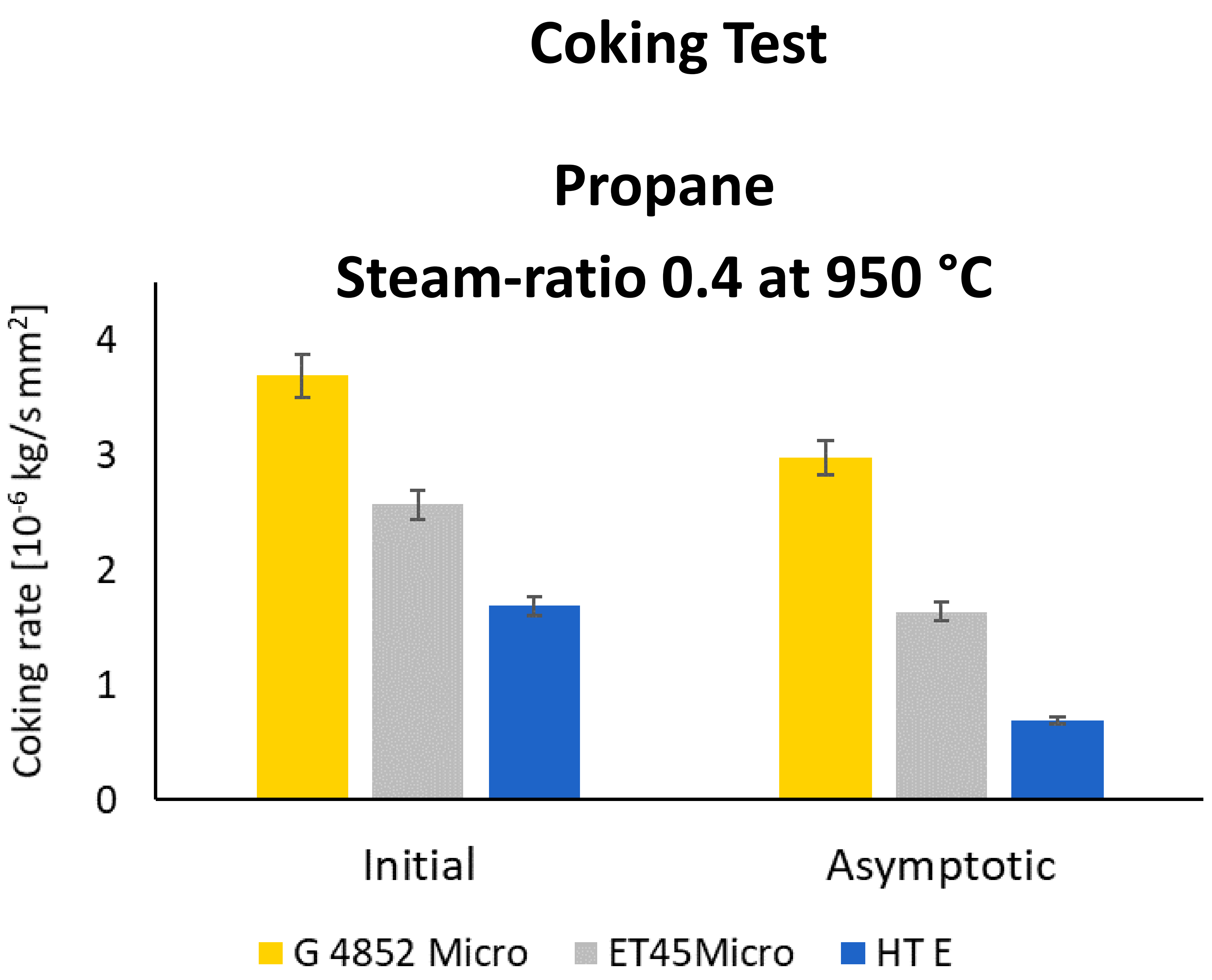


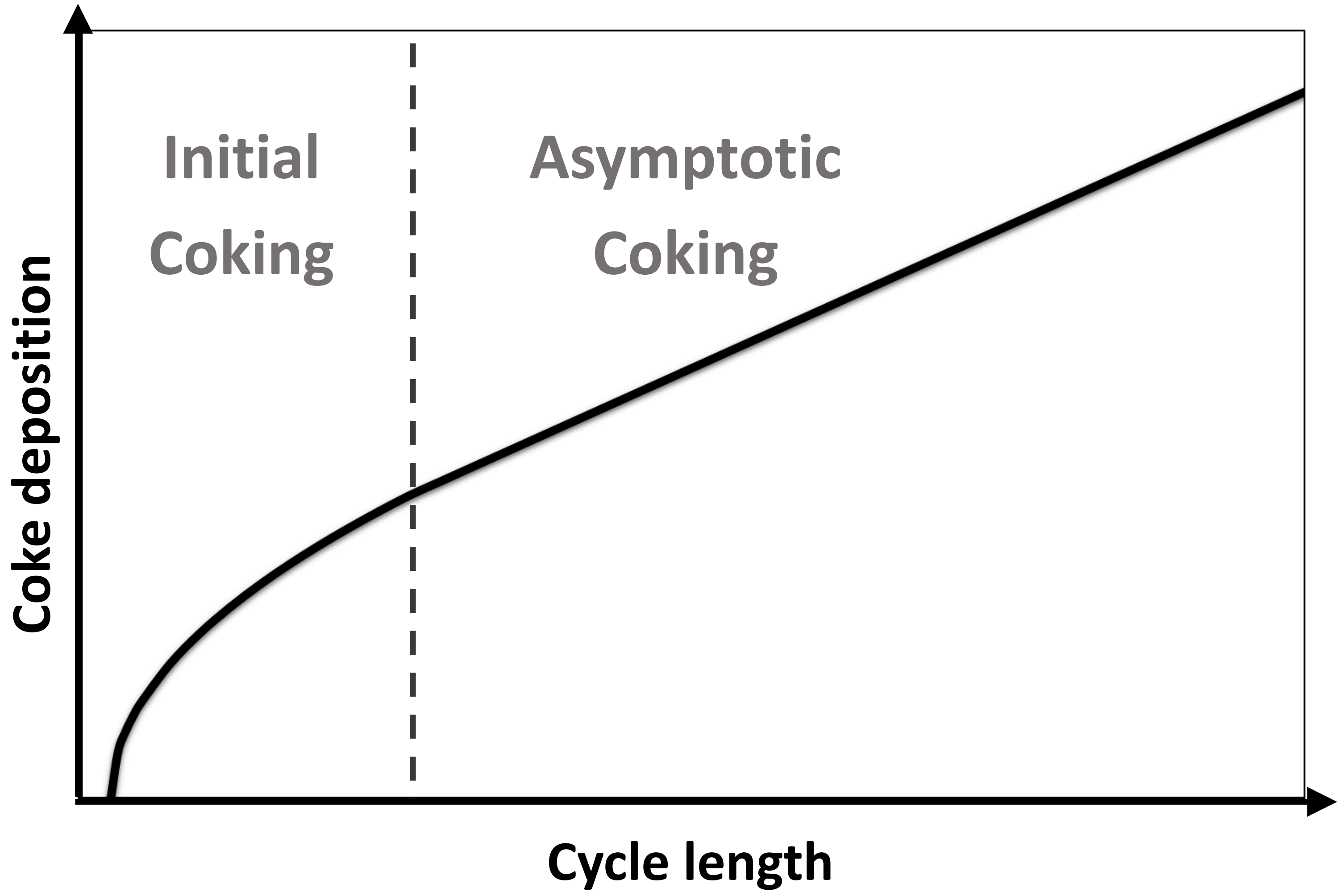


Process:

1. Start-up with steam
2. Ageing Procedure (TMT 1050°C)
3. Cracking/Coking test

COKING RATES PFR





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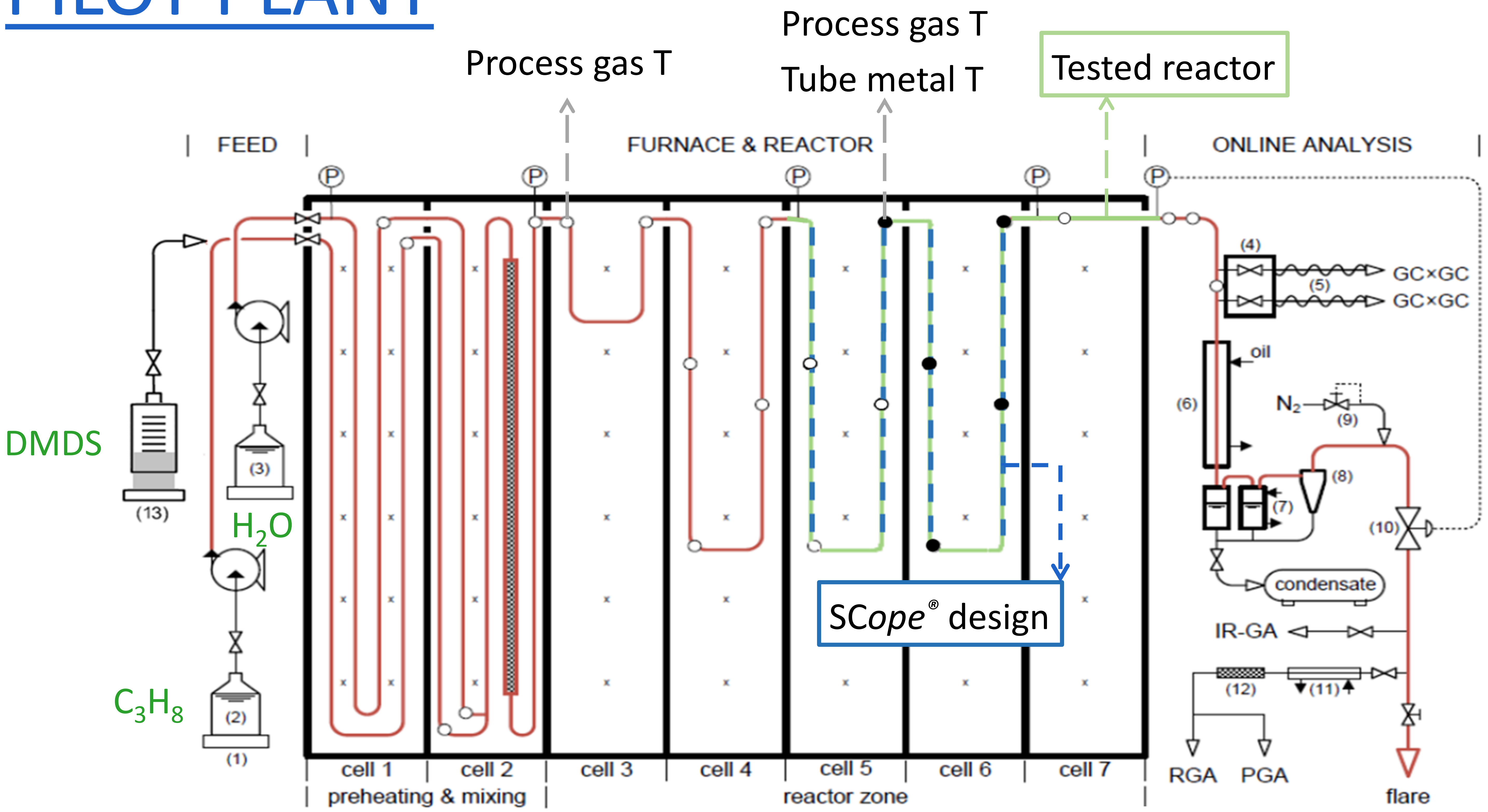
PILOT PLANT



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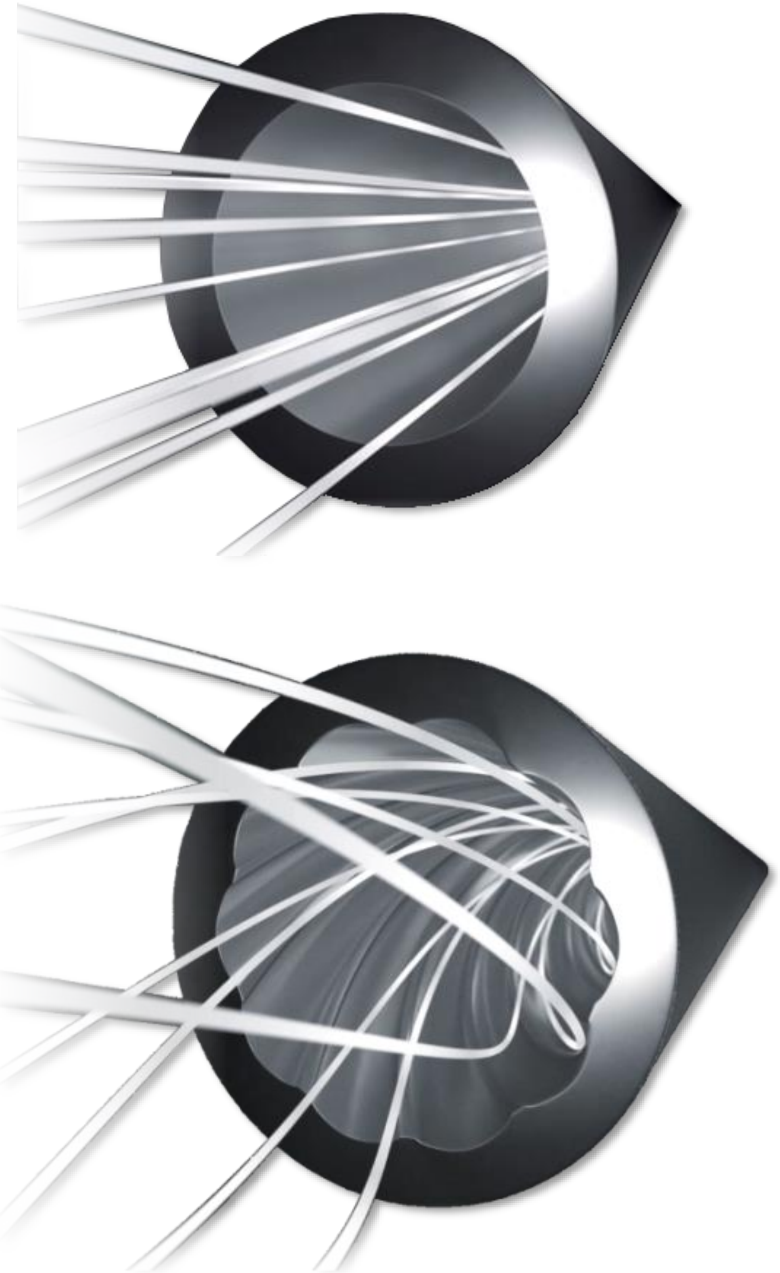

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EXPERIMENTAL PROGRAM

- 6 h Cracking
- Decoke
- 2 h Cracking
- Decoke
- 6 h Cracking
- Decoke
- 1.67 h Cracking (TMT Controlled)
- Decoke
- 12 h Cracking

✓ Prior to each Cracking Cycle (CC) a presulfiding step was performed

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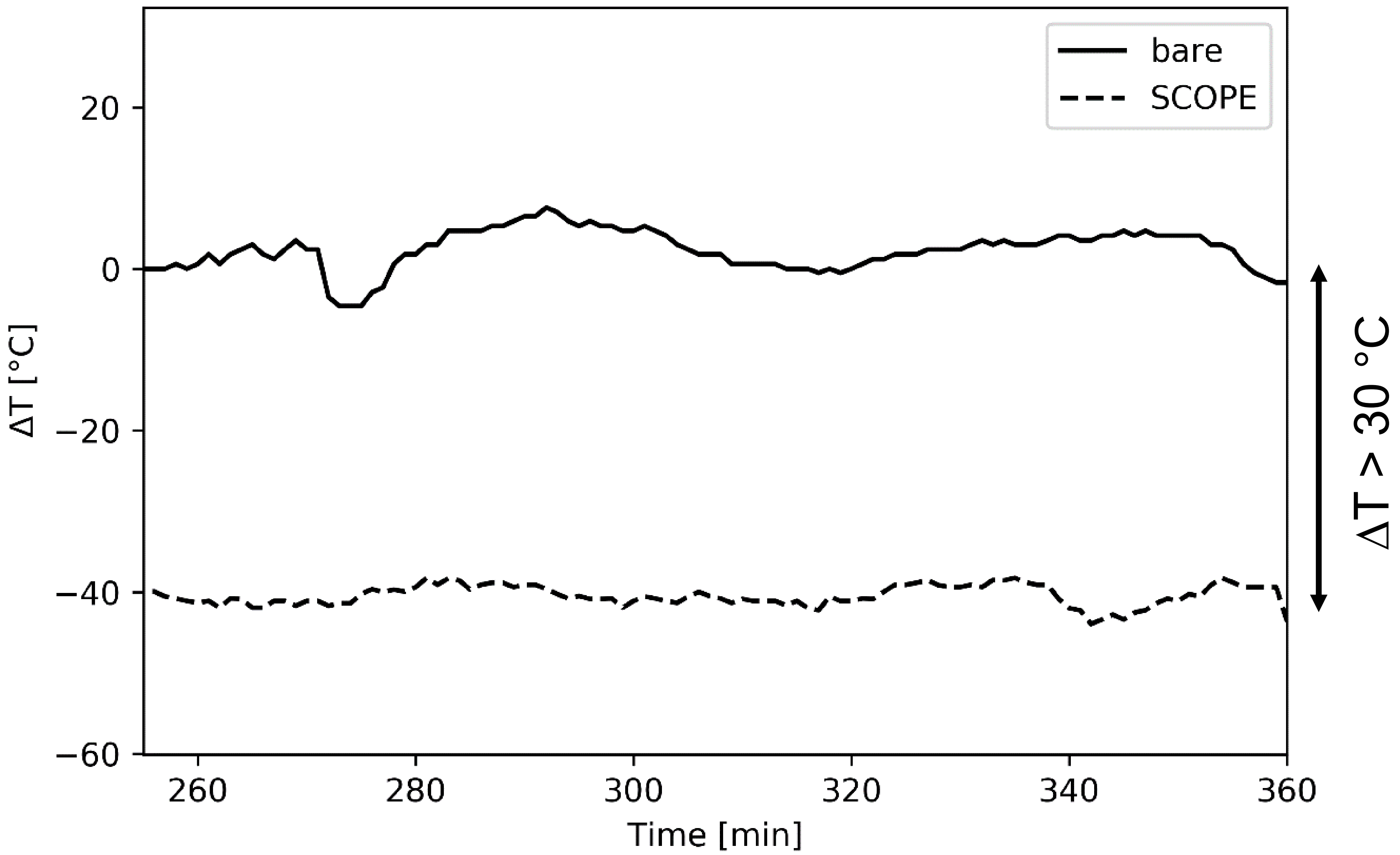
TUBE METAL TEMPERATURES



Pyrometer

Manual T

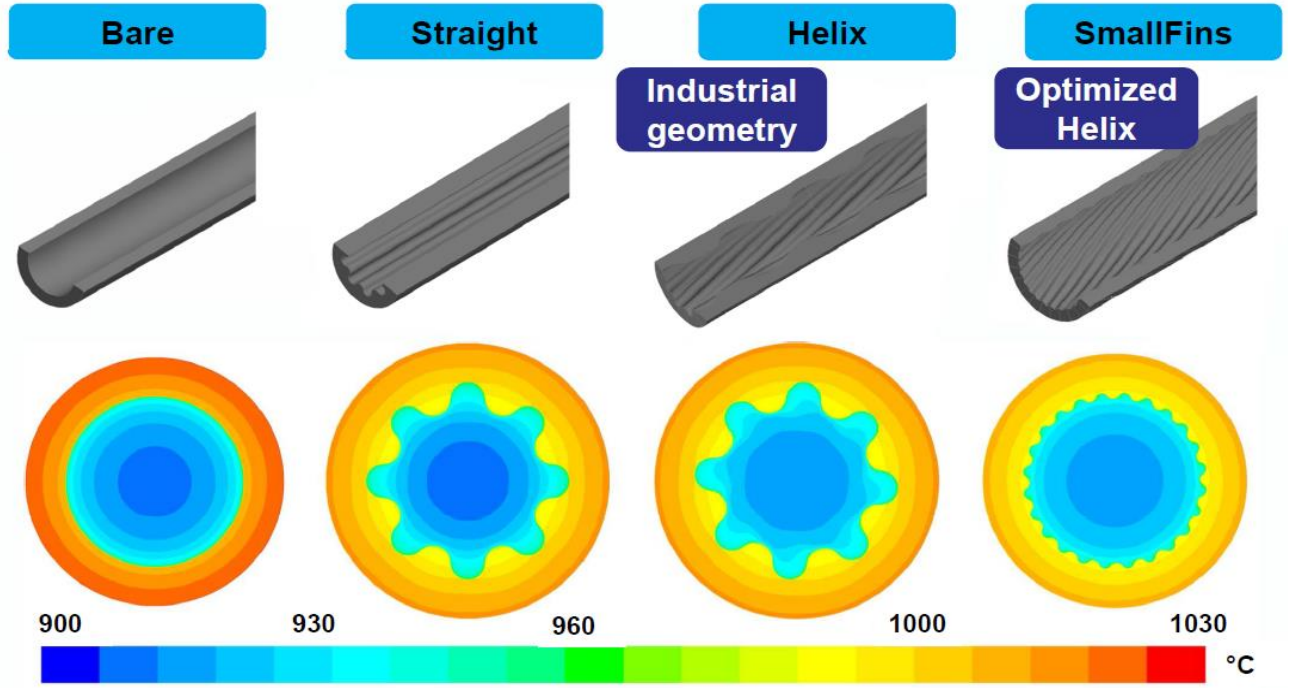
Weld-on

TC's

Result

~10% lower

Fuel gas consumption



C. Schietekat, K. Van Geem, and G. Marin, "Computationally efficient CFD simulations with detailed free-radical mechanisms," in *American Institute of Chemical Engineers Annual Meeting, Abstracts*, San Francisco, United States, 2013.

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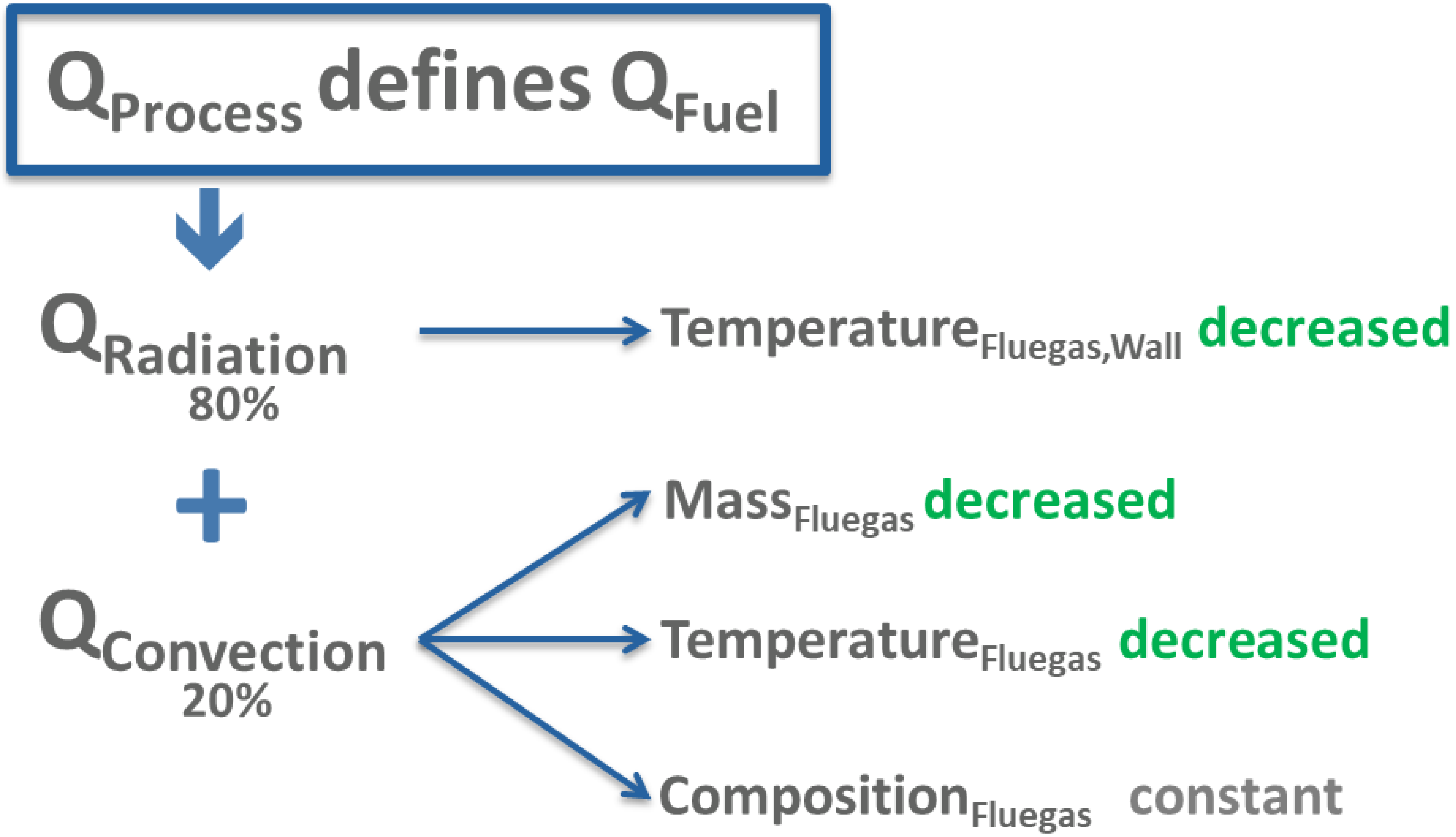
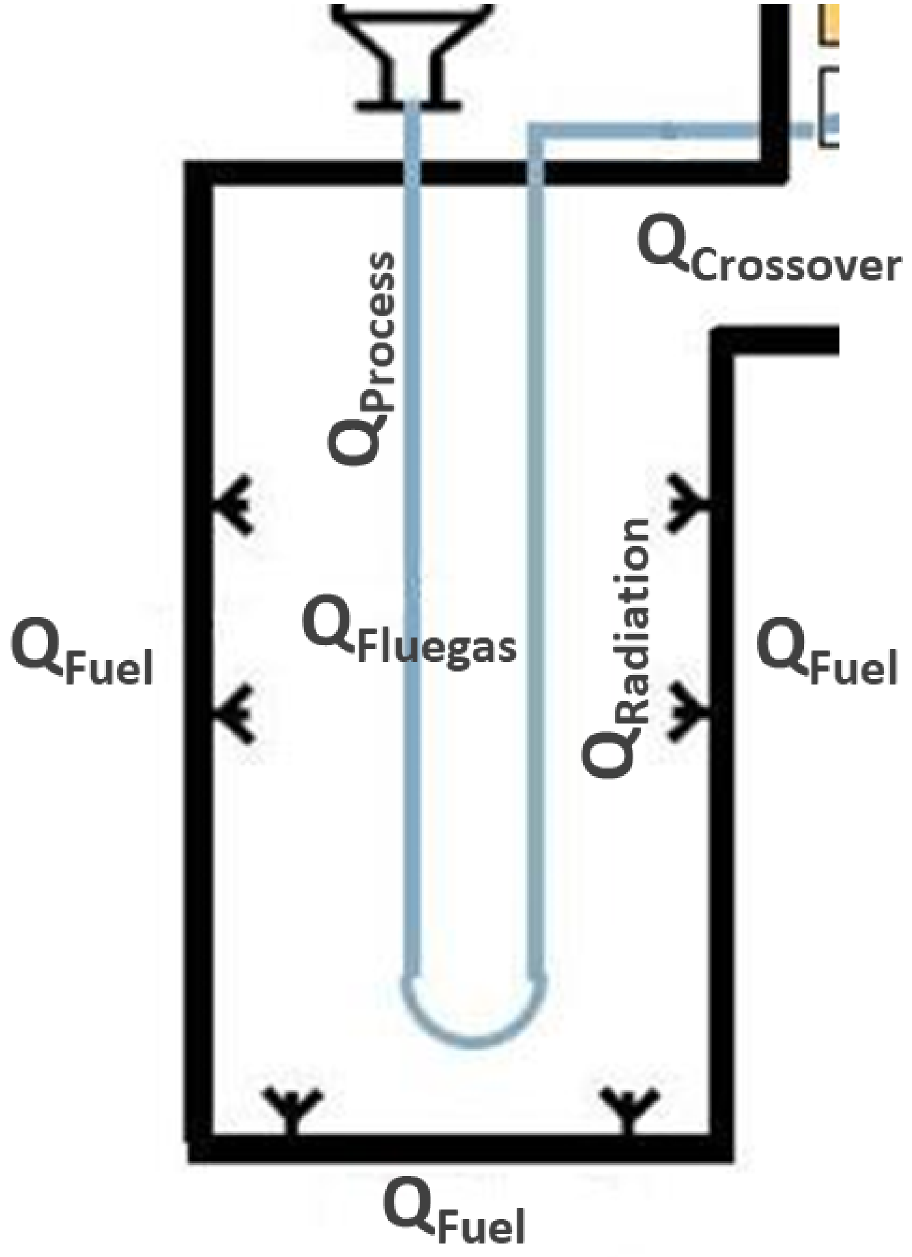
TUBE METAL TEMPERATURES

30 °C lower tube metal temperature reduces fuel consumption by ~ 10 % (based on Pilot Plant measurement)





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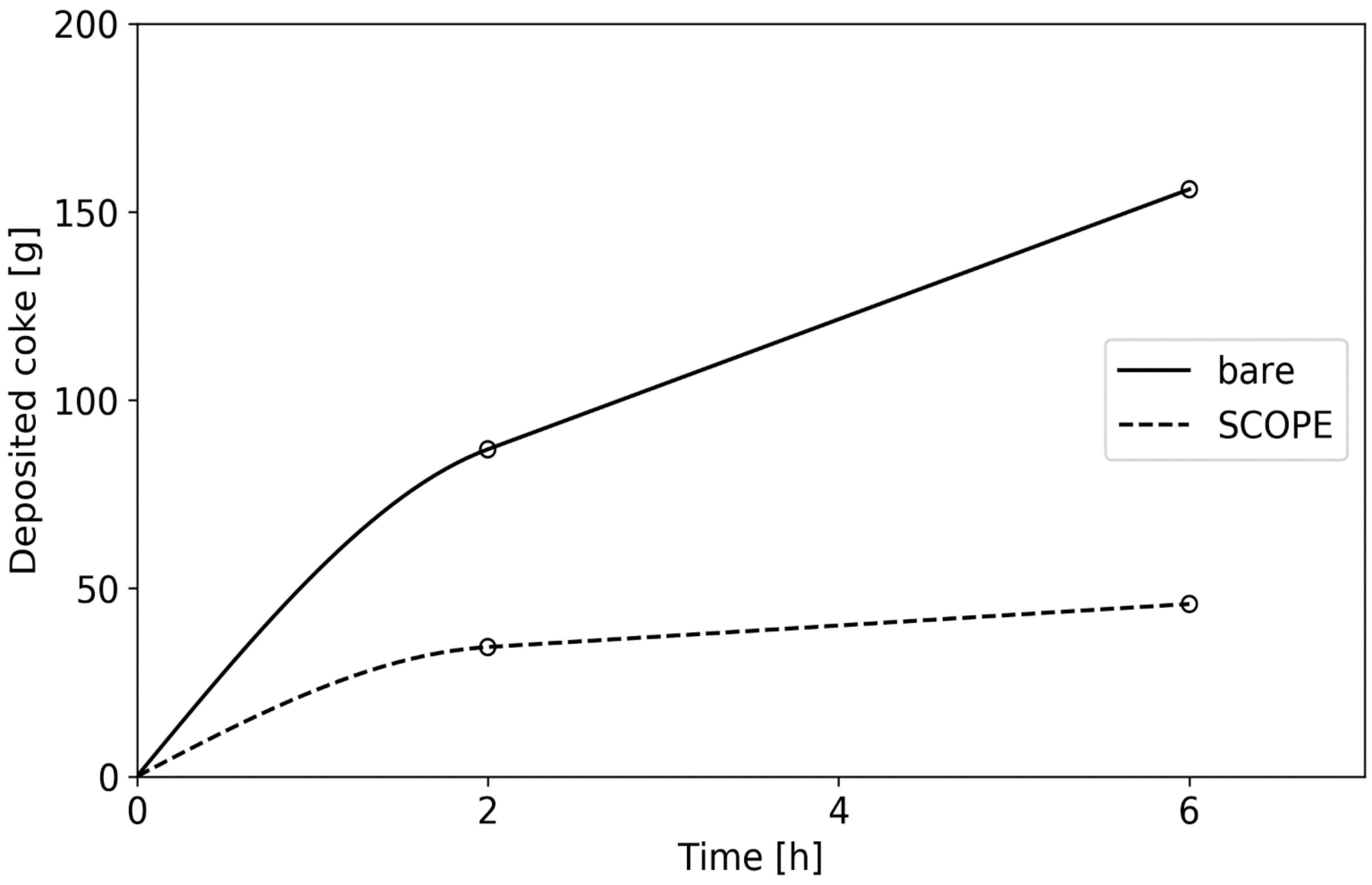
COKE DEPOSITION



- Homogenisation of the cracking gas temperature due to better mixing
  → reduced coke formation
- Better mixing in combination with increased heat transfer leads to lower tube metal temperatures, while maintaining the same cracking severity
  → reduced firebox firing rate
- Overall positive effect on initial and asymptotic coking rate

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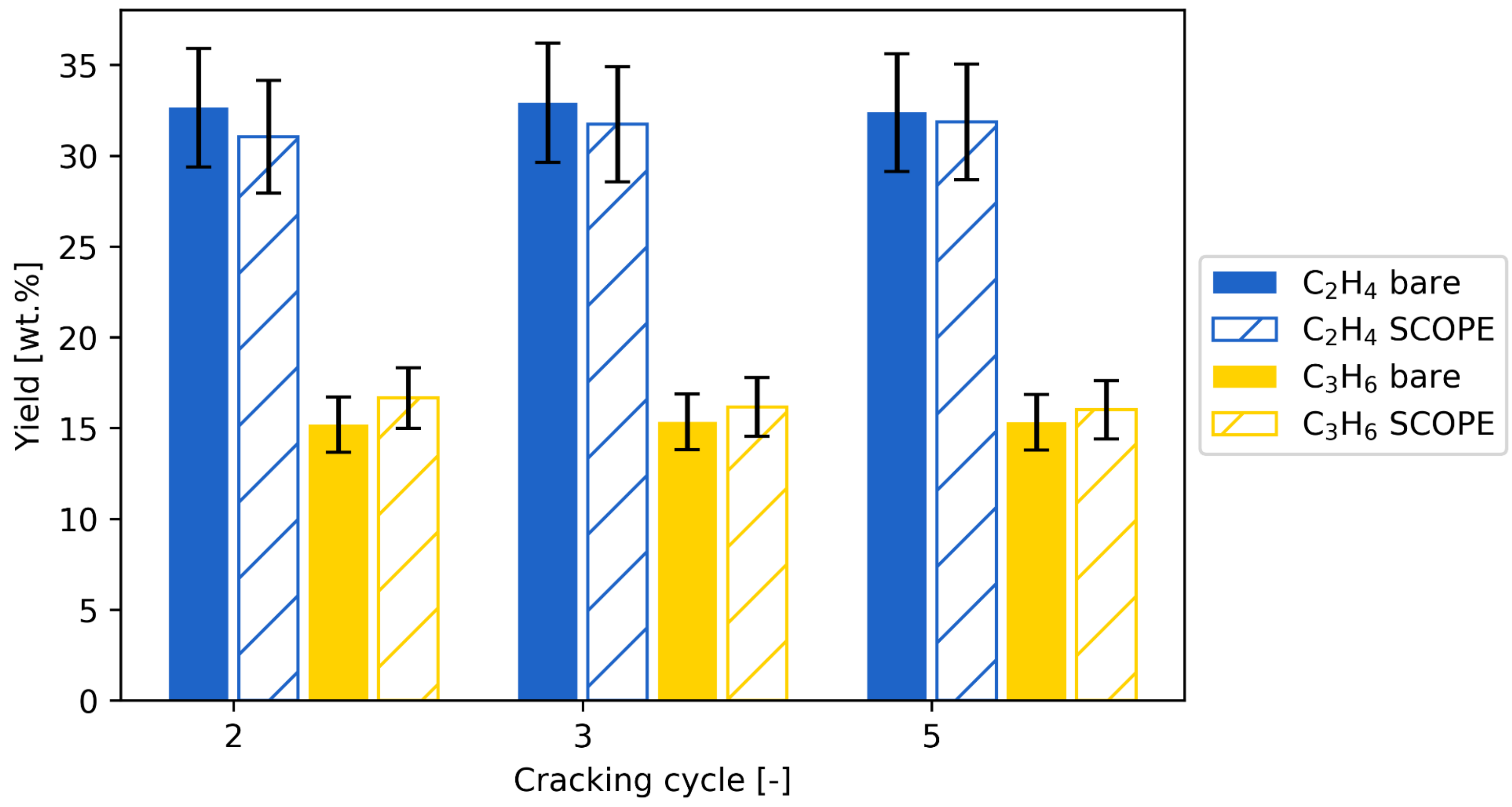
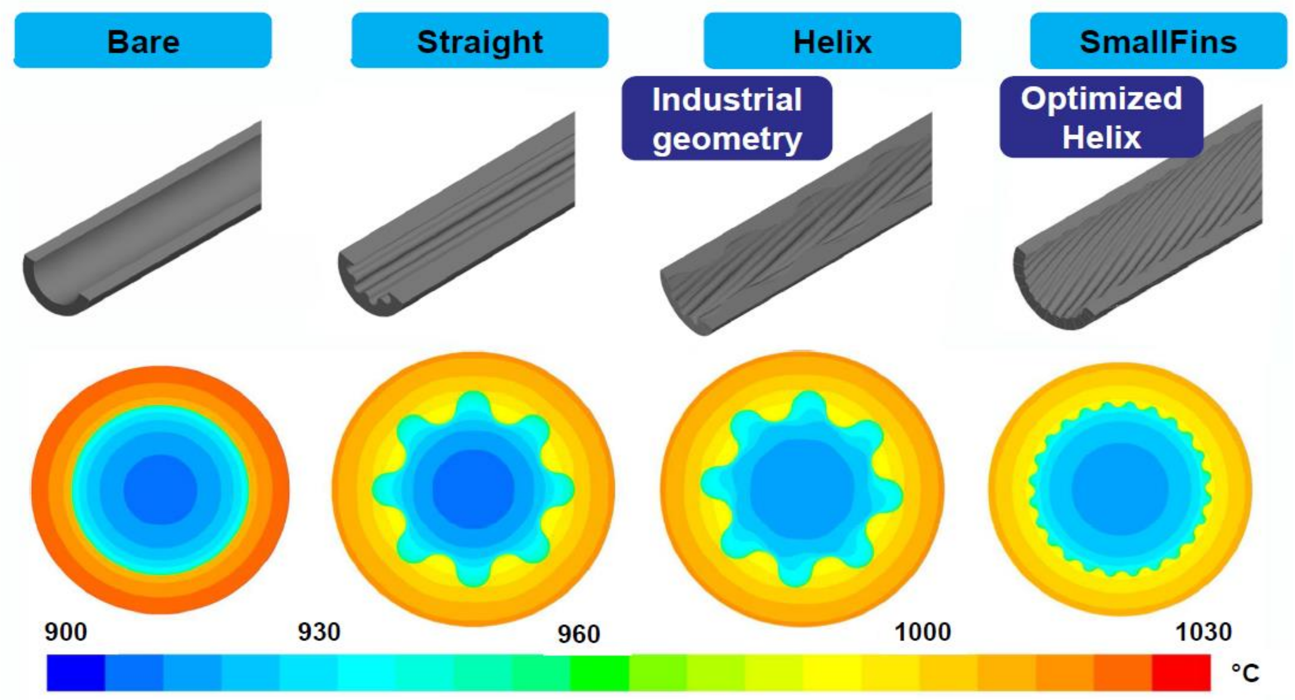
PRODUCT YIELDS



Reduced over-cracking near wall



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CONCLUSIONS

- HT E features the lowest coking rates due to formation of stable α-Al_2O_3 scale (initial and asymptotic)
- After high temperature (end-of-run) exposure HT E performs better

  (S. Symoens et al. EPC 2018 [ref])

- Combining the advanced coil material (HT E) and novel 3D reactor design (SCOPE®) leads to:
  - ✓ Increased run lengths
  - ✓ Improved product selectivity
  - ✓ Longer lifetime of the reactor coils
  - ✓ Higher energy efficiency of the furnace

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S. Symoens *et al.*, "IMPROOF : Integrated model guided process optimization of steam cracking furnaces," presented at the 30th Ethylene producers' conference (30th EPC), Orlando, USA, 2018.

HT E & SCOPE – APPLICATIONS IN INDUSTRY

HT E: 365

No. of Furnaces	Design	Feed
10	SRT I	Gas
1	PC 1-1	Gas
7	USC M	Gas
1	HS-I	Gas
3	MS	Gas
64	SRT III	Gas / Naphtha
9	SRT IV (HC)	Gas / Naphtha
30	SRT IV (HS) / V	Gas / Naphtha
16	PC 2-2	Gas / Naphtha
11	PC 4-2	Gas / Naphtha
28	USC U	Gas / Naphtha
16	USC W	Gas / Naphtha
18	MK	Gas / Naphtha
42	SMK	Gas / Naphtha
33	Individual	Gas / Naphtha
13	UDC	Gas / Naphtha
21	SRT VI	Gas / Naphtha
2	SRT 1.5	Naphtha
21	PC 1-1	Naphtha
4	GK2	Naphtha
3	GK3	Naphtha
5	GK4	Naphtha
7	GK5	Naphtha
365		

SCOPE: 17

No. of Furnaces	Design	Feed
2	MS	Gas
1	1-Pass	Gas
2	2-Pass	Gas / Naphtha
1	U-Coil	Naphtha
1	Individual	Gas
3	PC 1-1	Naphtha
1	PC 2-2	Naphtha
1	GK2	Naphtha
1	GK4	Naphtha
4	SRT V	Naphtha
17		

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ACKNOWLEDGMENT

This project has received funding from the European Union’s Horizon 2020 research and innovation programme (H2020-SPIRE-04-2016) under grant agreement No 723706.

Thank you for your attention!

Low-Emission Cracking Furnace

Peter Oud – Product Development Manager Ethylene
Georgios Bellos – Senior Research Scientist, Dow
Bert-Jan Massop – Finance Director, Dow

IMPROOF workshop
32nd Ethylene producers conference

Sunday 16 August 2020

Agenda

1. IMPROOF project
2. Conventional cracking furnace flow sheet
3. Low-emission cracking furnace flow sheet
4. Benefits of low-emission cracking furnace
5. Shaping a new integration concept
6. Impact on ethylene plant flow sheet
7. Energy balance across the ethylene plant
8. Relative CO_2 emission per ton of products
9. Operational expenditure evaluation
10. Conclusion

TechnipFMC

SPIRE IMPROOF project*

IMPROOF is a European project aiming at improving the energy efficiency of steam cracking furnaces, while reducing emissions of greenhouse gases and NOx.

Objectives

- Reducing specific emissions of greenhouse gases and NOx by at least 25%
- Cost effective

*** Website: https://improof.cerfacs.fr/**

« The work leading to this invention has received funding from the European Union H2020 (H2020-SPIRE-04-2016) under grant agreement n°723706 ».

Conventional furnace

Convection section:

- Preheating, evaporation and superheating hydrocarbon feedstock (FPH, HTC I&II)
- Dilution steam superheating (DSSH)
- Boiler feed water (BFW) preheating (ECO)
- High pressure steam superheating (HPSSH I&II)

Radiant coil:

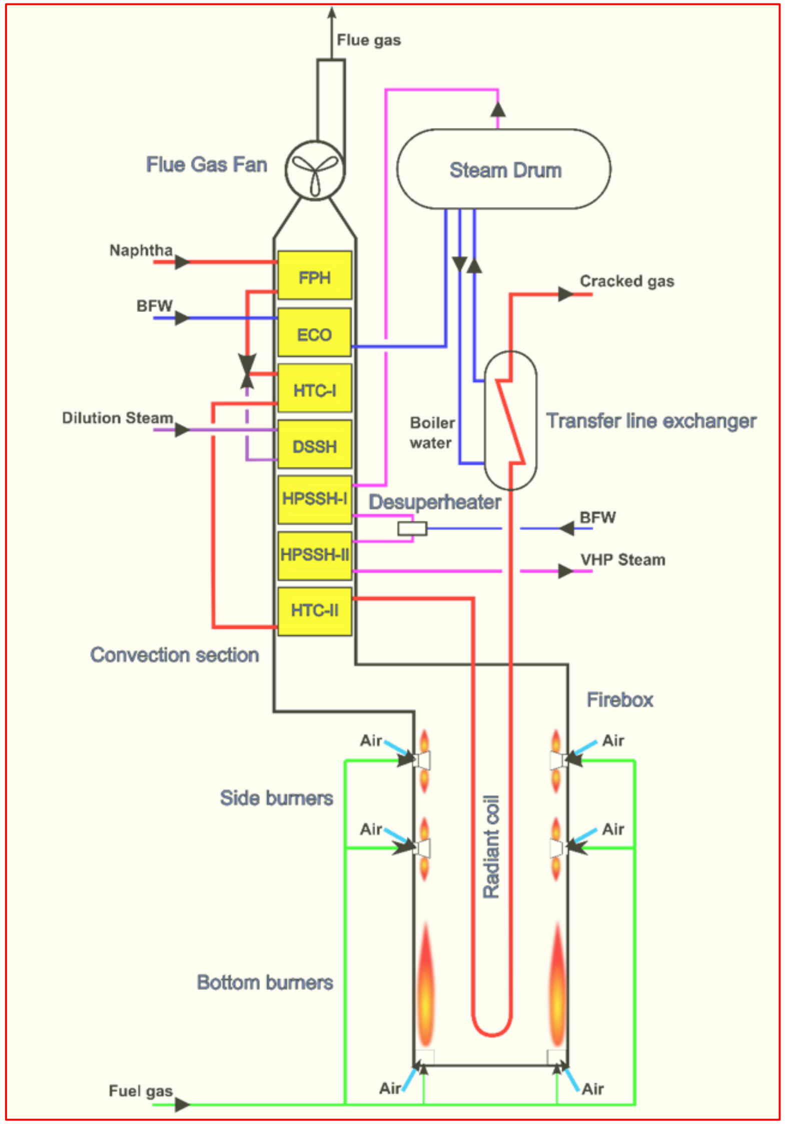
- Pyrolysis of feedstock

Effluent:

- Saturated steam generation (Transfer line exchanger, TLE)

Firebox:

- Combustion of fuel gas firing (Bottom and side burners)



Low-emission cracking furnace

Convection section:

- *Air preheat (APH)*
- Preheating, evaporation and *initial* superheating hydrocarbon feedstock (FPH,HTC)
- Dilution steam superheating (DSSH)
- High pressure steam superheating (HPSSH I&II)
- *Saturated steam generation (BOILER)*
  No BFW preheat

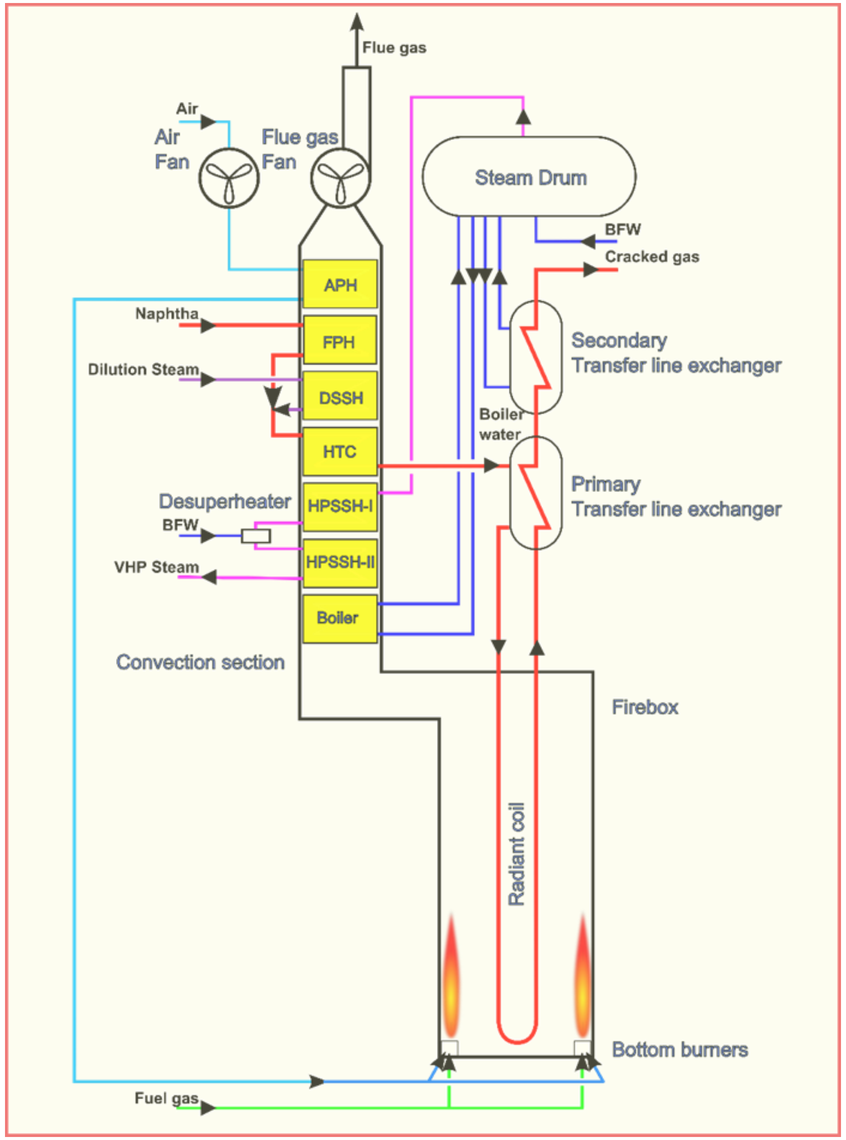
Radiant coil: Pyrolysis of feedstock

Effluent:

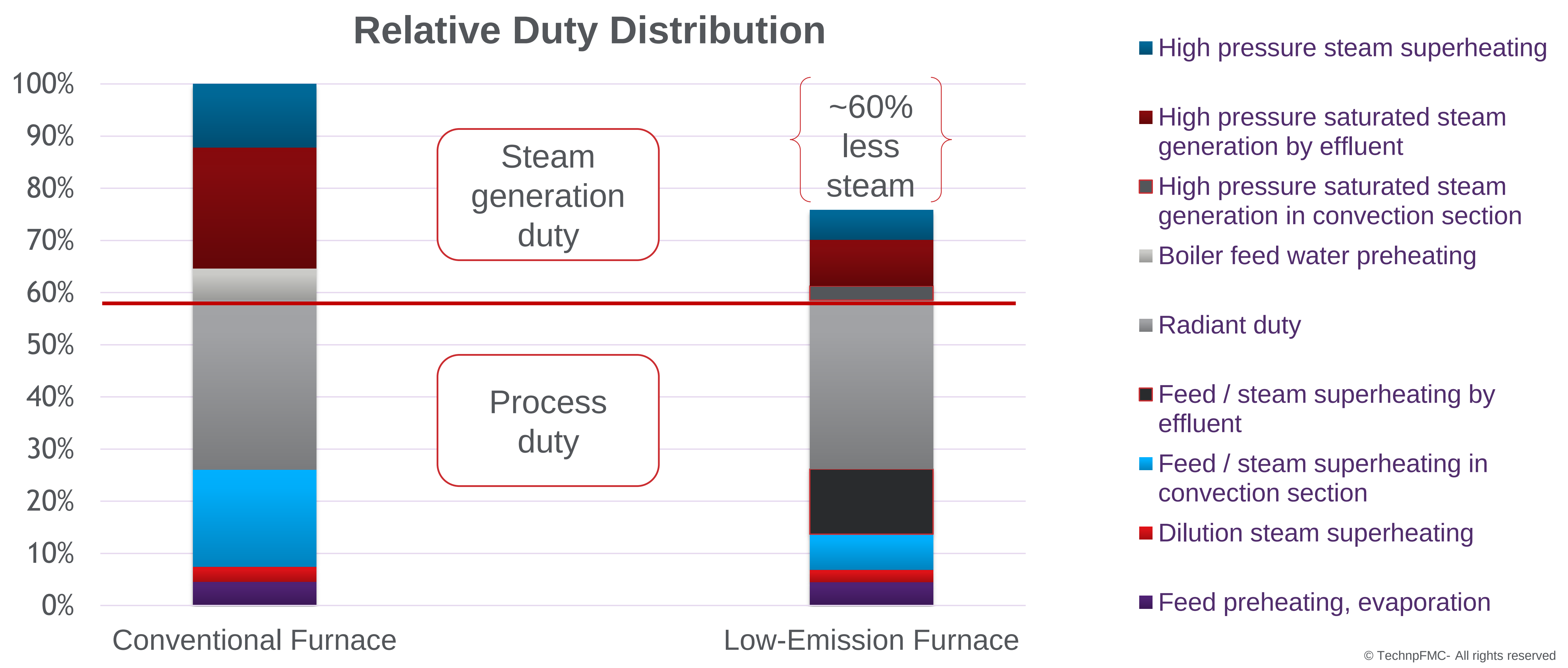
- Final feedstock superheating (Primary TLE)
- Saturated steam generation (Secondary TLE)

Firebox:

- Combustion of fuel gas firing (*Bottom burners only*)



Redistribution of duties in favor of process duty



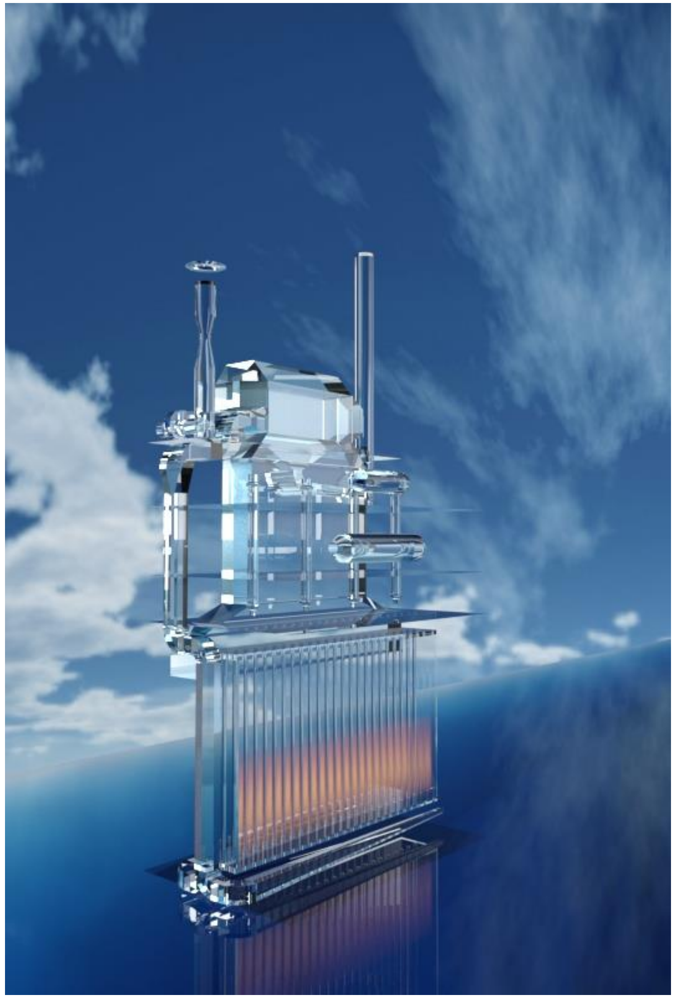
IMPROOF project targets achieved

Low-emission cracking furnace

- **CO2 emissions can be reduced by 30%**
  - Exceeding expectations
- **Design is cost effective.**
  - Estimated pay-back time roughly 1 year
  - Improved operating margins, especially under difficult market conditions

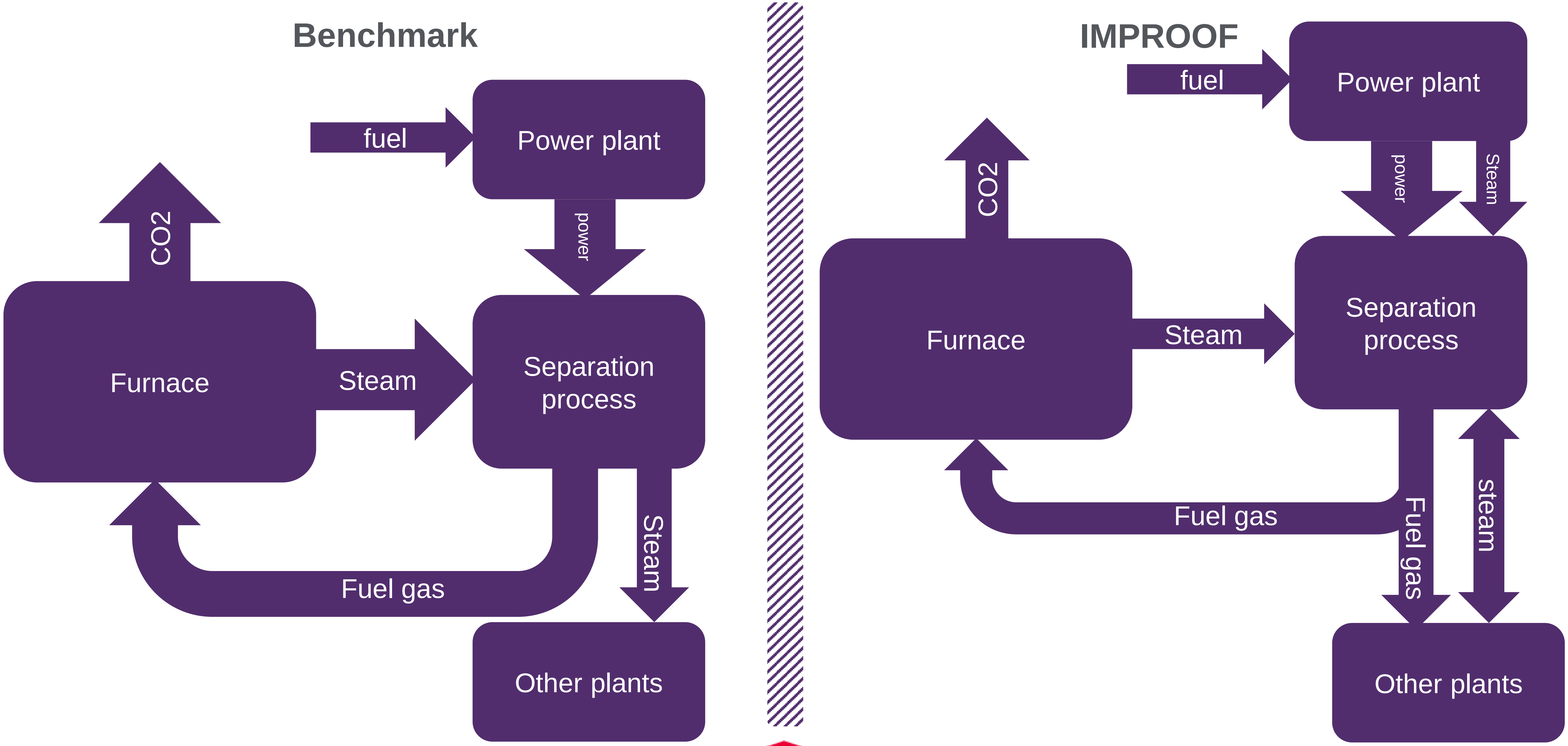
☑ **Objectives Achieved**

TechnipFMC patented design.

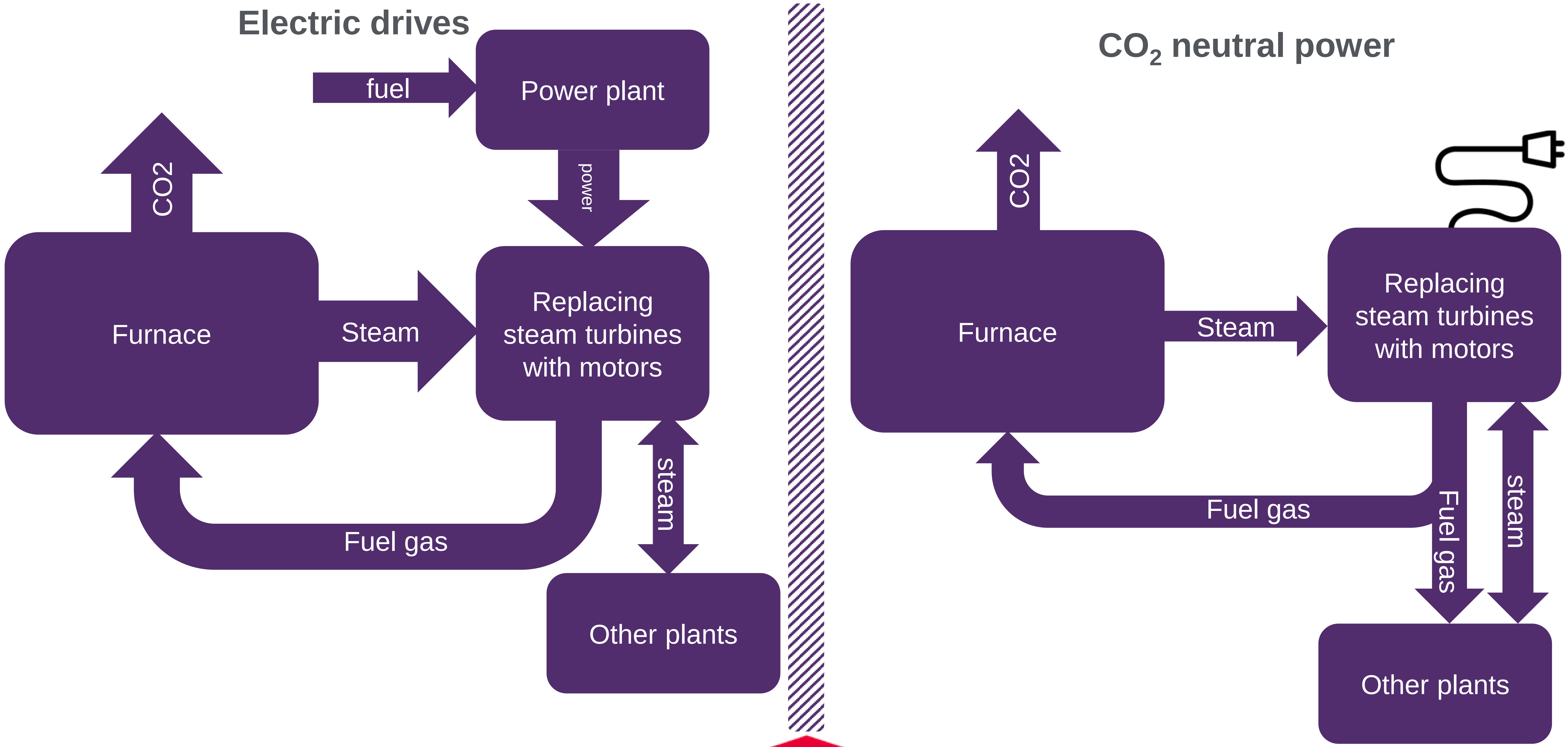


Low-emission cracking furnace

Shaping a new integration concept



Shaping a new integration concept



Impact on ethylene plant flowsheet

Existing plant

- Insufficient HP steam to drive all main machines
- Switch to electrical motors
- Adjust steam grid to maintain steam balance
- Effects on cooling water

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Due to drastic flowsheet changes, long payback times are expected at the current carbon prices

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Greenfield Plant

- Flowsheet changes can be implemented in an early stage of the project
- Steam and power integration can be anticipated

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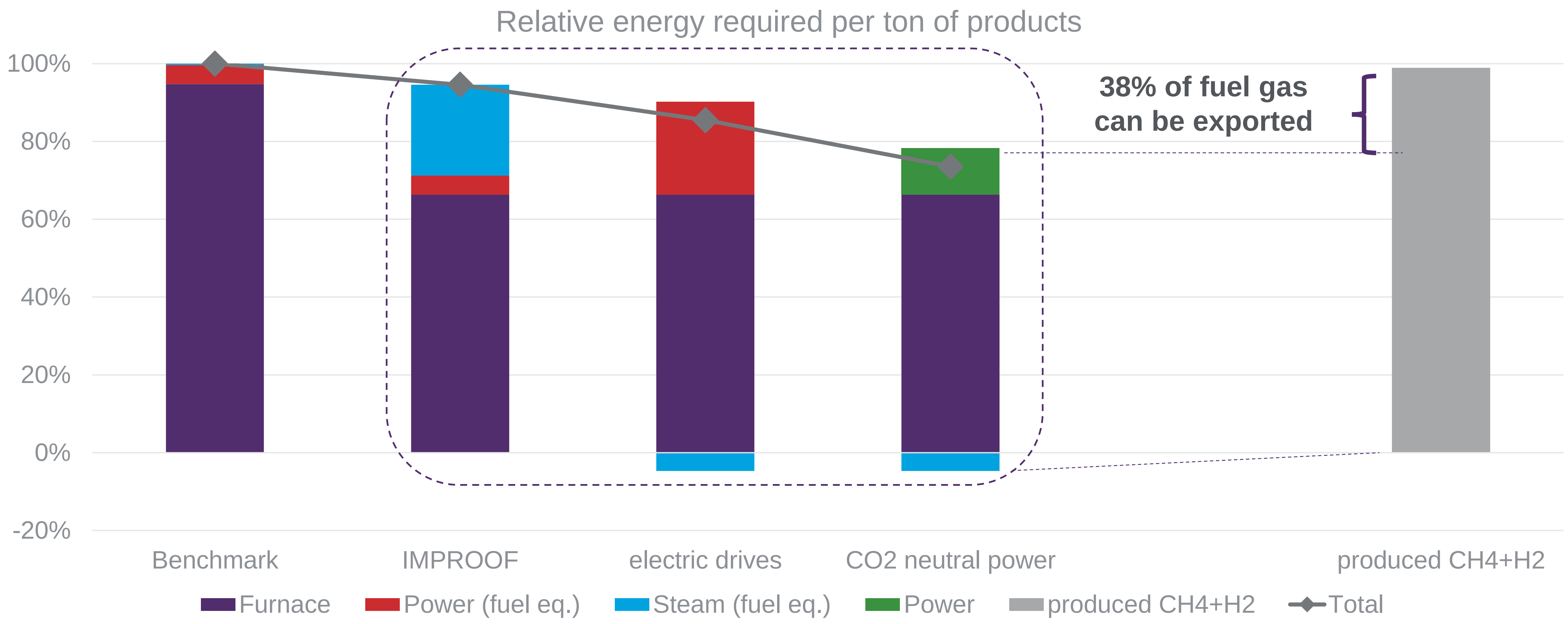
Greenfield Plant

- Flowsheet changes can be implemented in an early stage of the project
- Steam and power integration can be anticipated

Add-on cracking furnace

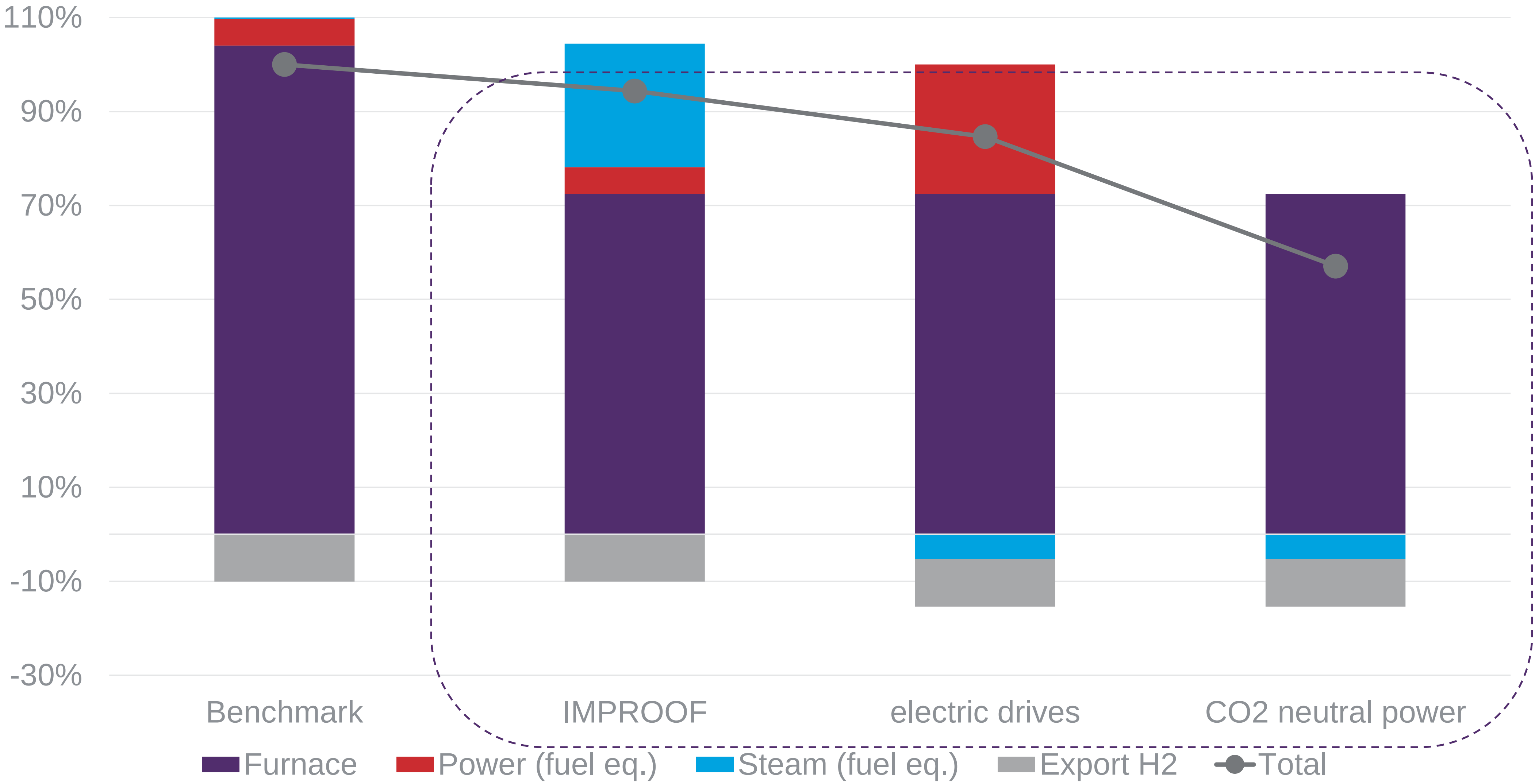
- Possible, especially in plant’s with excess high pressure steam production

Energy balance across the ethylene plant



CO_2 neutral power generated by solar panels or wind turbines
Electrical efficiency of solar or wind energy not included

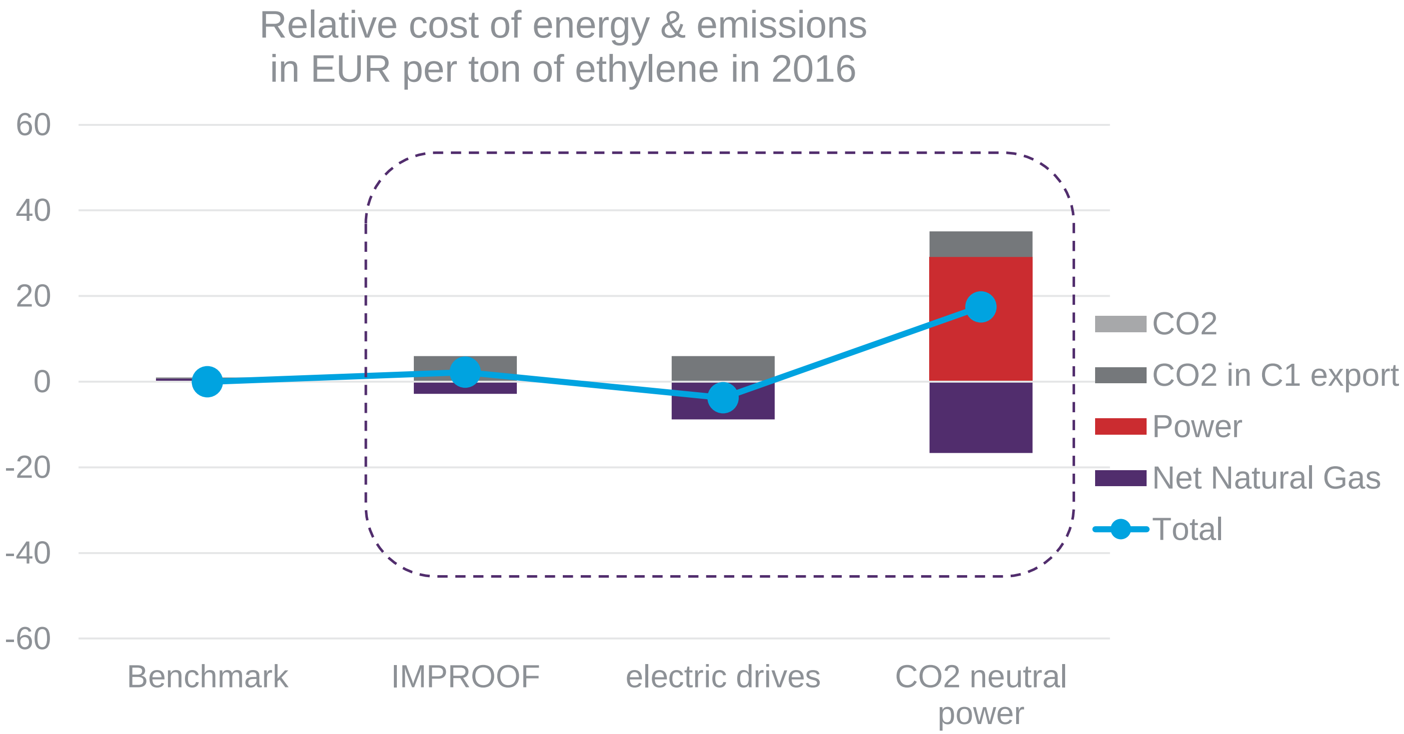
Relative CO_2 emission per ton of products

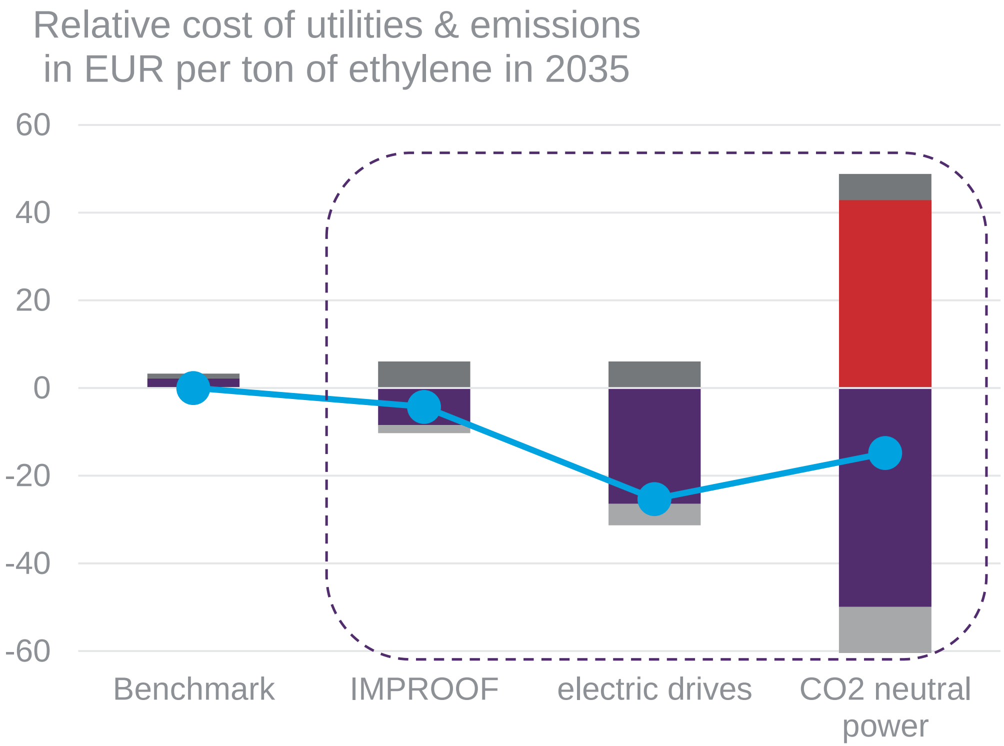


Operational expenditure evaluation

Cost elements contributing to the differentiation of cost for energy and emissions

CO2 cost for direct emissions is not included





*The evaluation relies on CO_2, natural gas and electric power prices for 2016 as reported by the Dutch Central office of Statistics

Price-set	Units	2016	2035
CO_2 Emissions	EUR/MT of CO_2	5.2	24.7
Power	Eur/MWh	33.7	49.6
Natural Gas	Eur/MWh	9.1	27.3

Conclusion

The Low-Emission Cracking Furnace

- Reduces CO_2 emissions at furnace stack by 30%
- If the low emission furnace is combined with motor drives, net CO_2 reduction is 15%
- Access to CO_2 neutral power can reduce CO_2 emissions by 40%
- Cost of energy depends largely on future natural gas and power prices

Seek Together™