POWER-2-OLEFINS: SUPERSONIC OLEFIN PRODUCTION

Mike Bonheure[1], Rejish L. Johnson[1,2], Tom Verstraete[2], Georgios D. Stefanidis[1], and Kevin M. Van Geem[1]

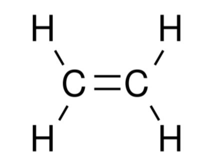
[1]Laboratory for Chemical Technology
Technologiepark 125, 9052 Ghent, Belgium
https://www.lct.ugent.be

[2]von Karman Institute for Fluid Dynamics
Waterloosesteenweg 72, B-1640 Sint-Genesius-Rode, Belgium
https://www.vki.ac.be/

Light olefins are essential for our civilization

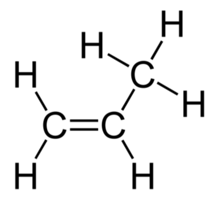

FEEDSTOCKS

CHEMICAL



270 Mt/year

6.2% growth rate annually

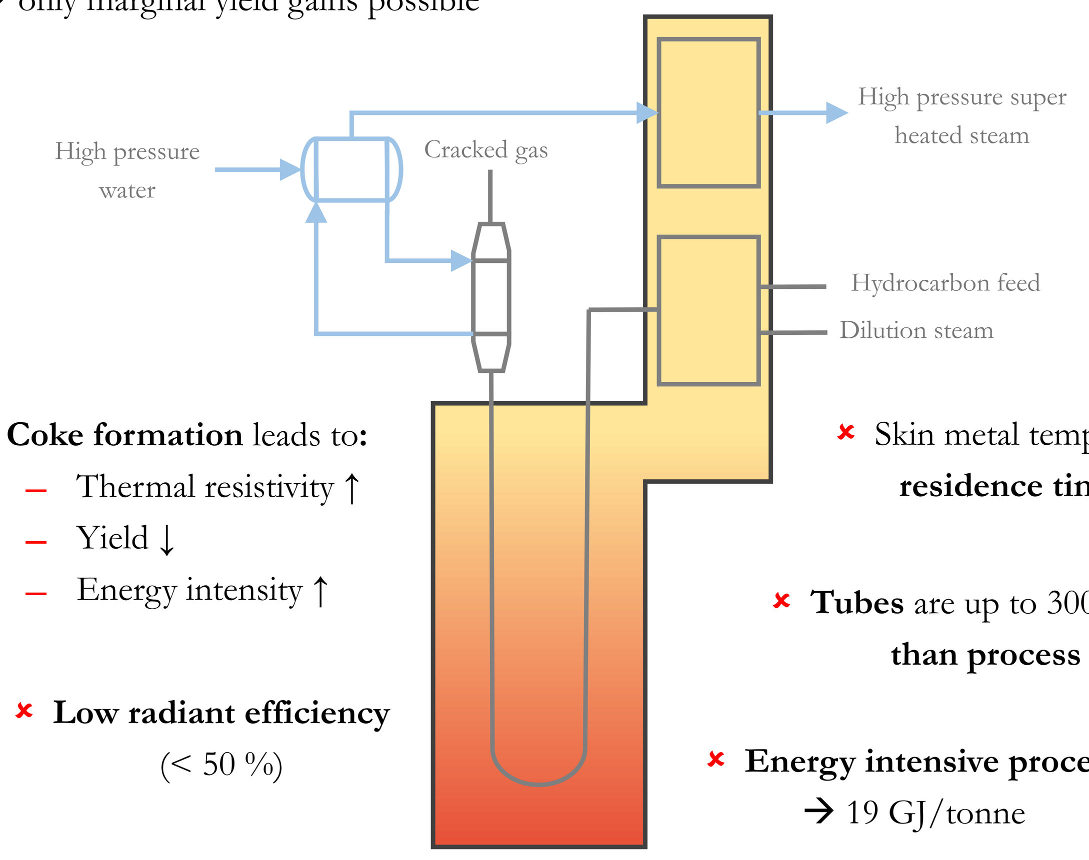


PROCESS

CONSUMER GOODS

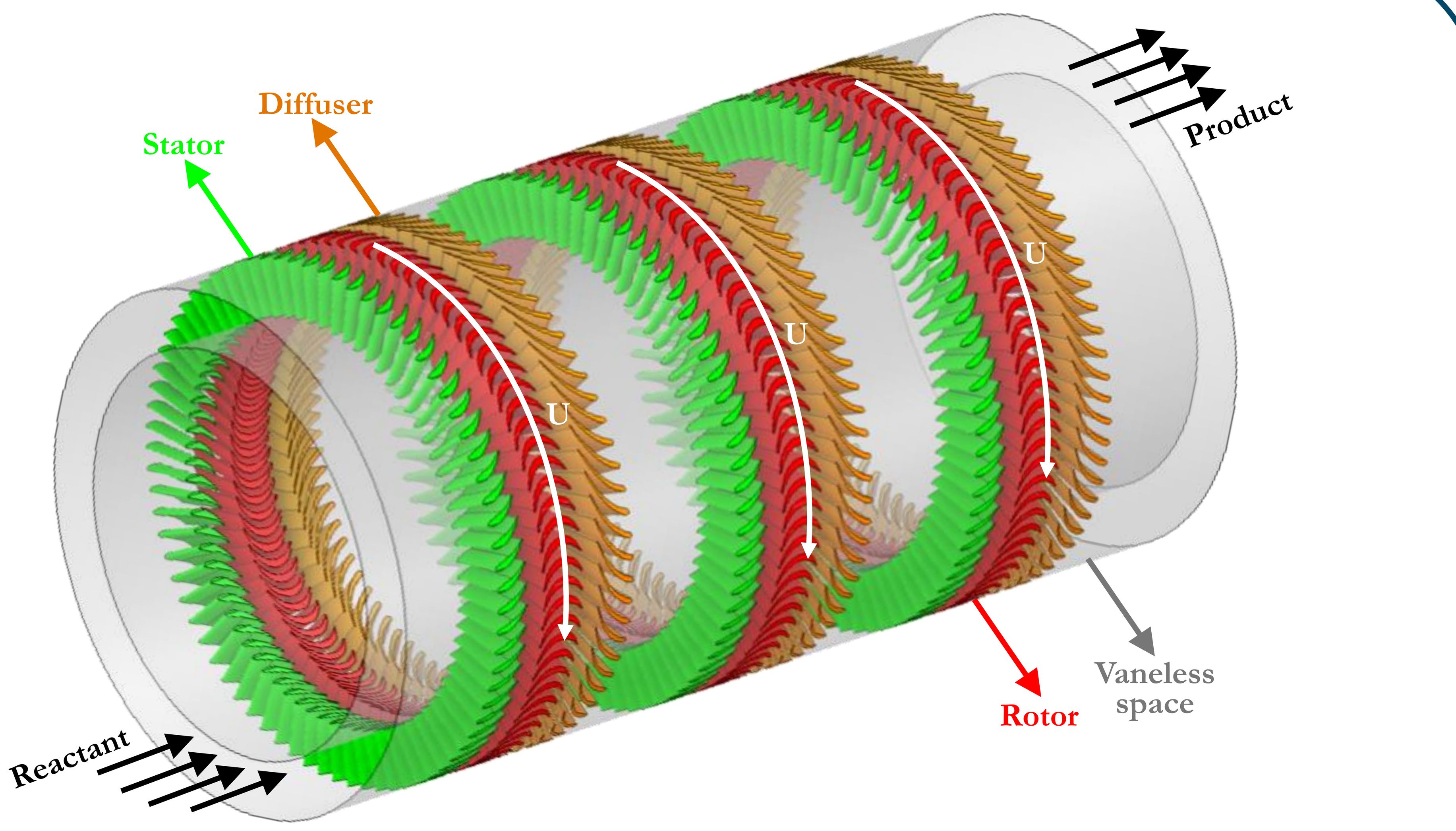

From a classic concept …

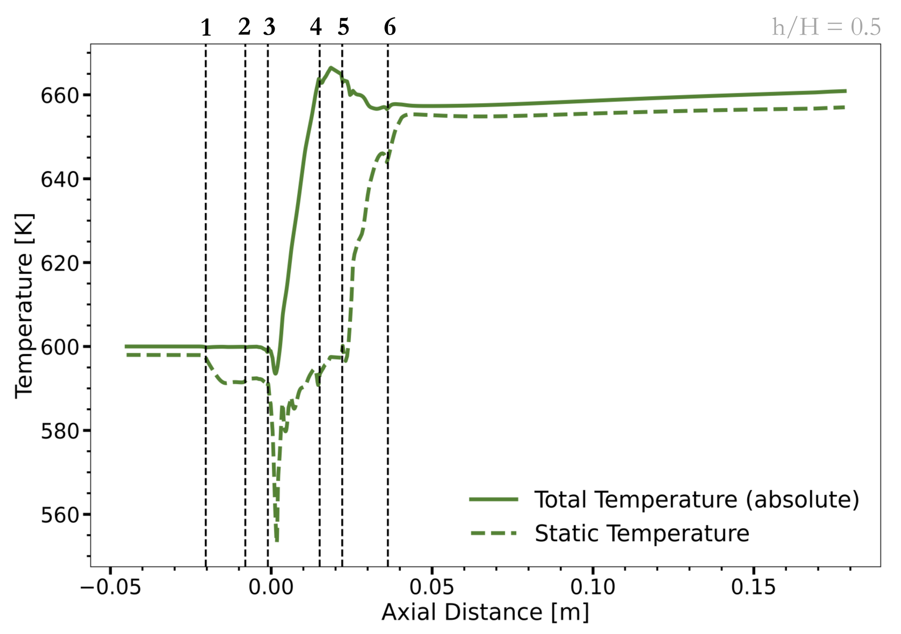
- ✗ **Fully developed** → only marginal yield gains possible
- ✗ > 400 Mt $CO_{2,eq}$ annually on global scale

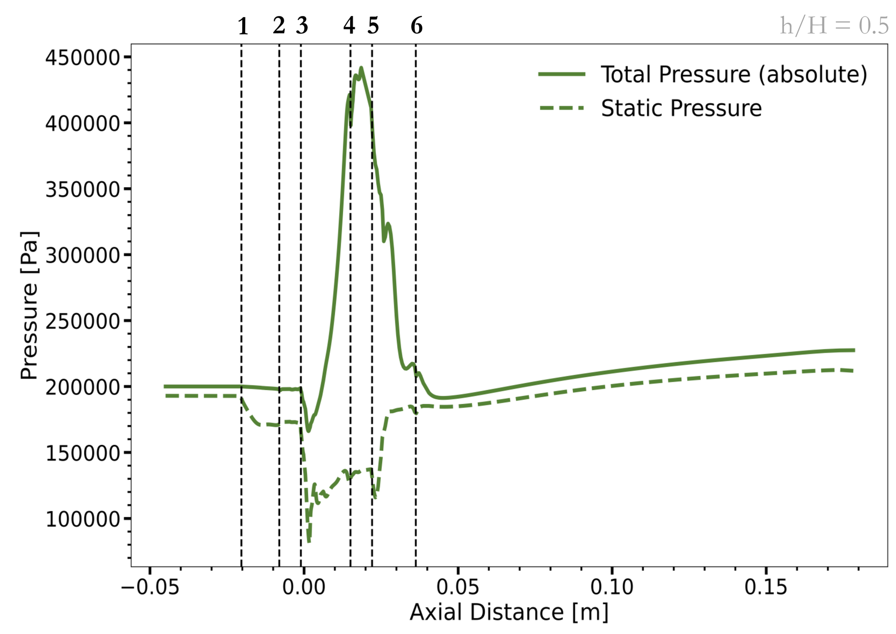


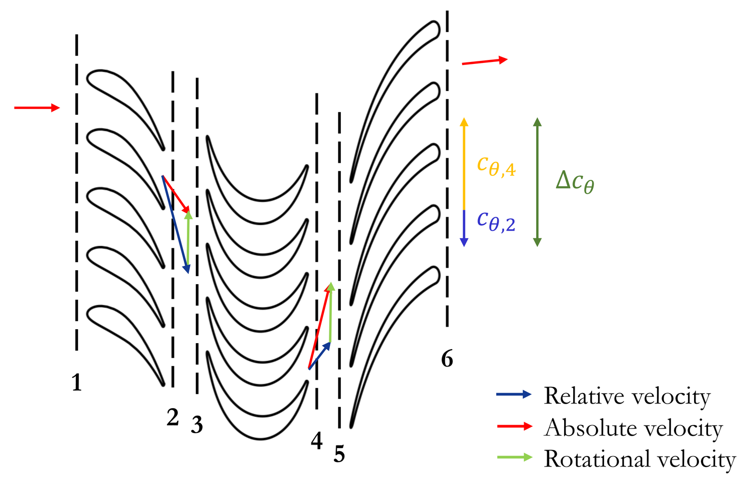
- ✗ **Coke formation** leads to:
  - Thermal resistivity ↑
  - Yield ↓
  - Energy intensity ↑
- ✗ **Low radiant efficiency** (< 50 %)
- ✗ Skin metal temperature **limits residence time** (> 50 ms)
- ✗ **Tubes** are up to 300 °C **hotter than process fluid**
- ✗ **Energy intensive process** → 19 GJ/tonne

… to a revolutionary design



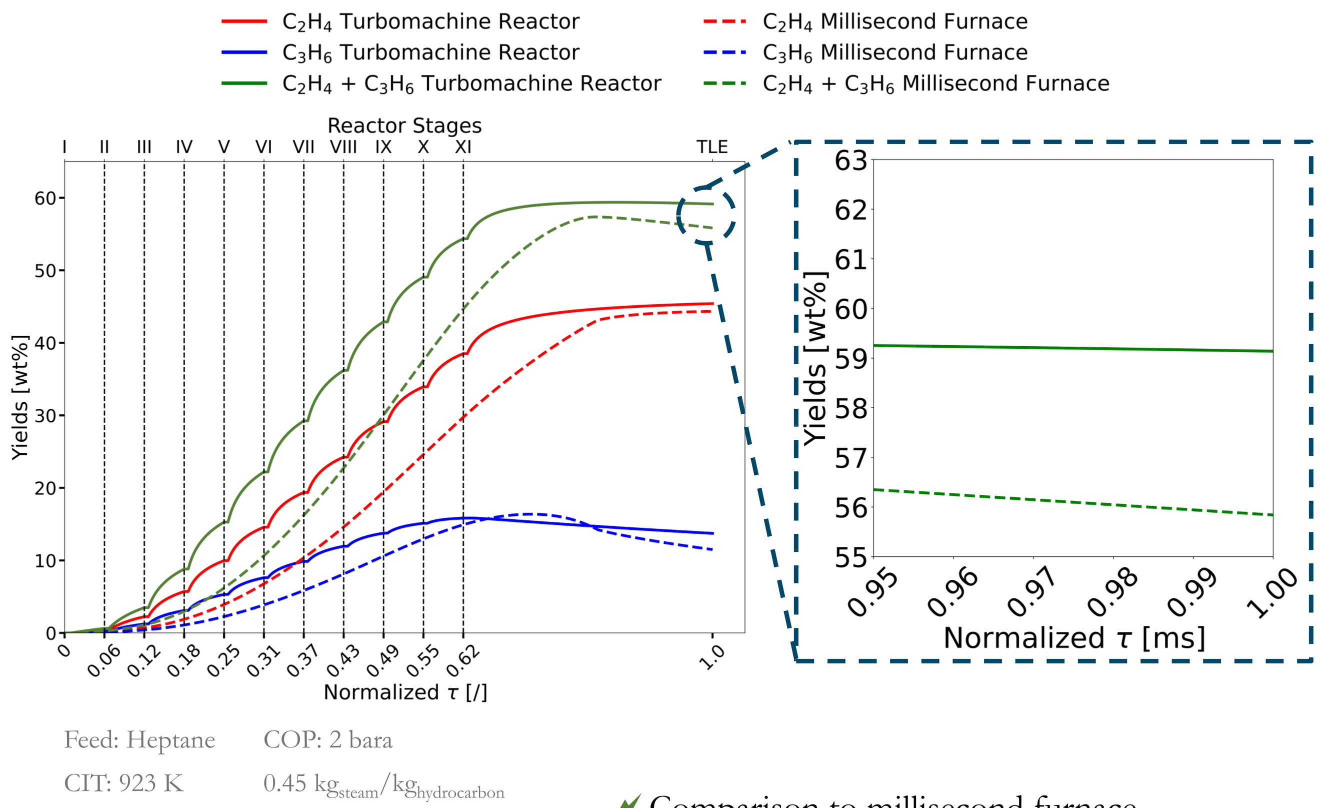






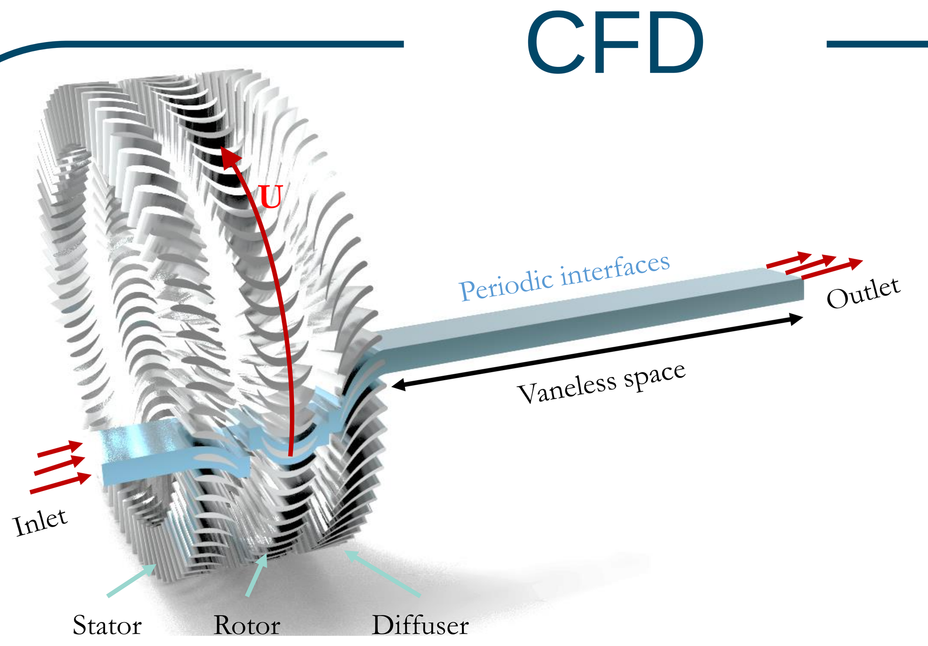
- Turbomachine reactors apply a **revolutionizing heating method**, circumventing heat transfer limitations
  - ✓ **High turning in rotor** $[\Delta H_0 = \Delta(Uc_\theta)]$
  - ✓ Oblique **shock structures** in both rotor and diffuser zone
    - Heating in nanosecond timescale
  - ✓ Purposely-designed diffuser
    - **Conversion of kinetic energy into turbulence**
    - Controls the pressure drop across the stage
    - Maintains the temperature for the next stage
  - ✓ Vaneless space further diffuses the flow for the next stage

1D model



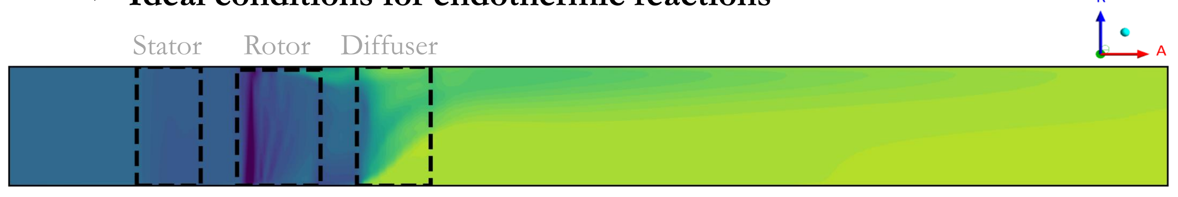
- Assumptions
  - ✓ Same residence time in each stage
  - ✓ Plug flow behavior in vaneless space
  - ✓ Fixed power input for every stage
  - ✓ Static pressure is constant
- Comparison to millisecond furnace
  - ✓ Residence time decreased by a factor up to 3
  - ✓ No need for drastic downstream adaptations
  - ✓ **Turbomachine reactors outperform conventional technology** (e.g., +3.3 wt% for heptane cracking)

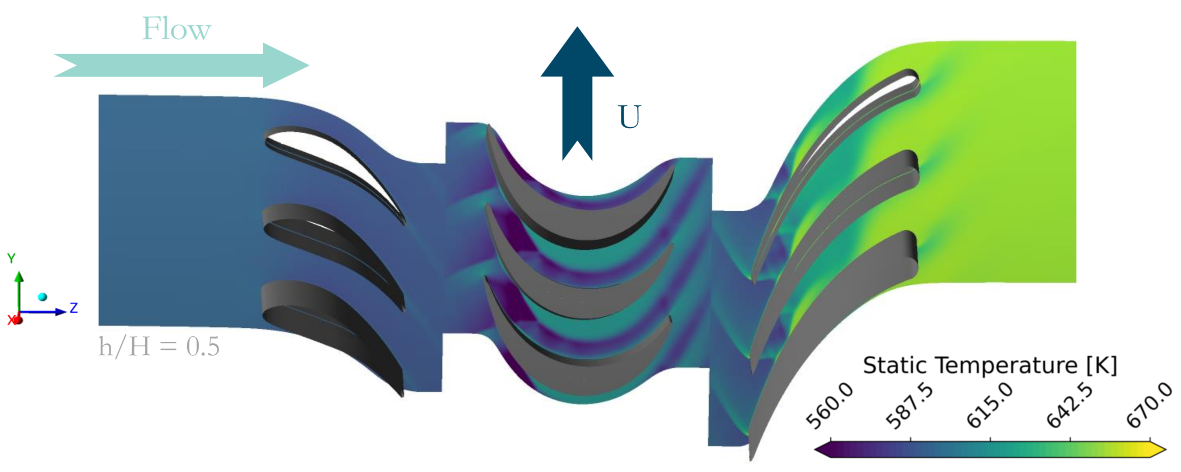
CFD

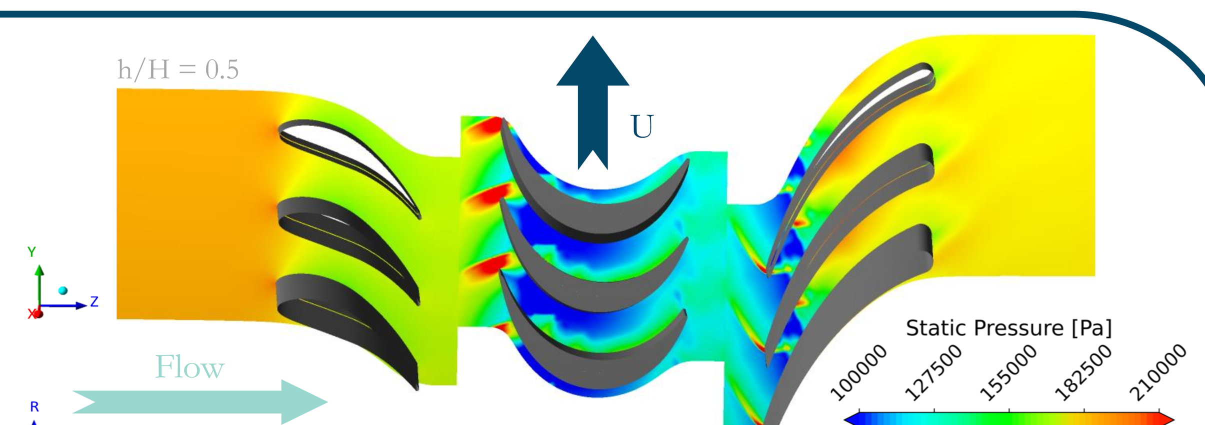


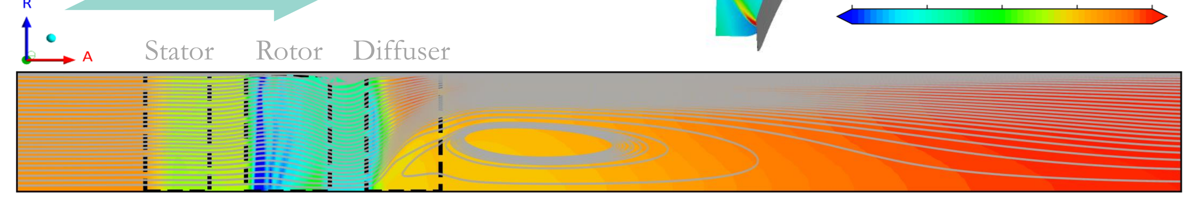
- Rotational motion
  - ✓ Mixing plane
  - ✓ Rotational speed: 30 000 rpm
- Boundary conditions
  - ✓ Feedstock: ethane
  - ✓ Inlet total pressure: 2 bara
  - ✓ Inlet temperature: 600 K
  - ✓ Outlet static pressure: 2.1 bara

- Higher static temperature region at suction side rotor
  - ✓ Due to boundary layer separation to control pressure increase
- After three axial diffuser chord lengths, radially uniform static temperature distribution in vaneless space
- High temperature, high turbulence and low velocity in vaneless space
  - ✓ **Ideal conditions for endothermic reactions**









- The **dedicated blade design** maintains an almost **constant static pressure** across one stage
  - ✓ **Introducing losses** at desired locations
    - Mixing
    - Boundary layer separation
    - Secondary flow structures (e.g., tip leakages)
  - ✓ **Large separation bubble starting at shroud diffuser**
    - Increase in entropy (pressure reduction)

Turbomachine reactors outperform classic furnaces

- Higher Yields (> 1 wt%)
- Maximal exergy utilisation
- Reduced residence times
- Lower GHG emissions
- No heat transfer limits
- Reduced coking rates
- Improved flexibility

Acknowledgements

Mike Bonheure acknowledges financial support from a doctoral fellowship from the Fund for Scientific Research Flanders (FWO) under application number 1SD7121N. The computational work was carried out using the STEVIN Supercomputer Infrastructure at Ghent University, funded by Ghent University, the Flemish Supercomputer Center (VSC), the Hercules Foundation, and the Flemish Government department EWI. The authors gratefully acknowledge the financial support of the Flemish Government and Flanders Innovation & Entrepreneurship (VLAIO) through the Moonshot project P2O (HBC.2020.2620). The research leading to these results has also received funding from the European Research Council (ERC) under the European Union's Seventh Framework Programme (FP7/2007-2013)/ERC grant agreement no. 818607(OPTIMA).

GHENT UNIVERSITY · LCT DRIVING CHEMICAL TECHNOLOGY · von KARMAN INSTITUTE FOR FLUID DYNAMICS · FLANDERS INDUSTRY INNOVATION MOONSHOT · FLANDERS INNOVATION & ENTREPRENEURSHIP · HPC UGENT · fwo · Vlaanderen is computing

E-mail: Mike.Bonheure@UGent.be

CRF-ChemCYS, Blankenberge, 12/10/2022