INDUSTRIAL SCALE-UP IN CARBON2CHEM® – DESIGN OF TEST CAMPAIGNS WITH THE DEMONSTRATION PLANT

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3rd Carbon2Chem® Conference, October 27th-28th, 2020

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AGENDA

Part 1: Matthias Krüger, tkIS

- From laboratory to large scale plants: Problem definition and challenges during scale-up
- Summary of criteria for this project: towards the vision of a large scale Carbon2Chem® plant

Part 2: Tim Schulzke, Fraunhofer UMSICHT

- Results from experimental facilities with clean (bottle) gases and real steel mill gases (Phase 1)
- Design of test campaigns with demonstration plant

Slides of Dr. Matthias Krüger

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For a personal copy of Dr. Krüger's slides (3-11) please contact:

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Experimental facilities I

LCTS – Lab Catalyst Test Set-up

- Maximum operating conditons
  T = 400 °C, p = 100 bar
- Reactor
  $\varnothing_i$ 9.7 mm; length 270 mm
- Catalyst key indicators
  ground commercial tablets
  sieve fraction 250 – 500 µm
  amount: up to 5 g
- Gas Feed
  4 feed gases (CO, CO_2, H_2, N_2)
  ~6 - 60 $Nm^3/(kg_{cat}\ h)$

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Experimental facilities II

Pilot plant

- Maximum operating conditons
  T = 350 °C, p = 100 bar
- Reactor
  $\varnothing_i$ 19 mm; length 1,100 mm
- Catalyst key indicators
  ground commercial tablets
  sieve fraction 1 – 3 mm
  amount: 20 – 100 g
- Gas Feed
  5 feed gases (CO, CO_2, H_2, N_2, Ar)
  ~5 - 10 $Nm^3/(kg_{cat}\ h)$

Experimental facilities III

Demonstration plant

- Maximum operating conditons
  T = 270 °C, p = 89 bar
- Reactor
  $\varnothing_i$ 34.3 mm; Length ≈ 6,000 mm
- Catalyst key indicators
  commercial tablets ∅ 6 x 4 mm
  amount: ≈ 6.5 kg
- Gas Feed
  4 feed gases (CO, CO_2, H_2, N_2)
  ~5 $Nm^3/(kg_{cat}\ h)$

Experimental facilities

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Commonalities and Differences

	LCTS	Pilot plant	Demonstration plant
T measurement	Reactor inlet + exit; 1 point in catalyst bed	16 points along reactor axis	36 points along reactor axis
T control	Electrical trace heating * Oil cooling jacket		Boiling-water cooling jacket
Plant set-up	Once through * Gas recycle		Gas recycle
Catalyst	Commercial methanol catalyst		
Catalyst size	Fine powder	Fragments	Commercial tablets
Online analysis, sample point	Reactor outlet		Condenser outlet
Online analysis	GC-MS/FID/TCD	GC-FID/TCD	TCD (H_2) NDIR (CO, CO_2, CH_4, C_2H_4)
Reaction regime	Primarily kinetic	Primarily kinetic; additionally equilibrium	equilibrium
Object of investigation	Catalyst performance; reactor model validation		Plant performance; plant model validation

* will be modified in phase 2

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Results from Phase 1

Benchmark tests

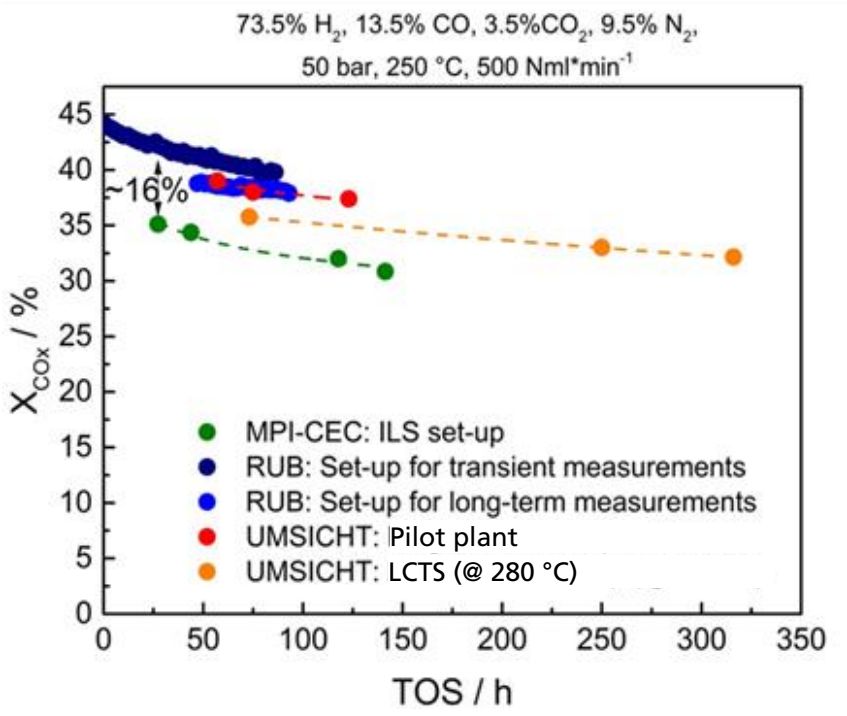
Comparison of different test set-ups operated by different consortium partners

⇒ good overall consistency

Definition: Carbon Oxide Ratio

COR = CO / (CO + CO_2)

Benchmark: COR = 13.5 / 17 = 0.79



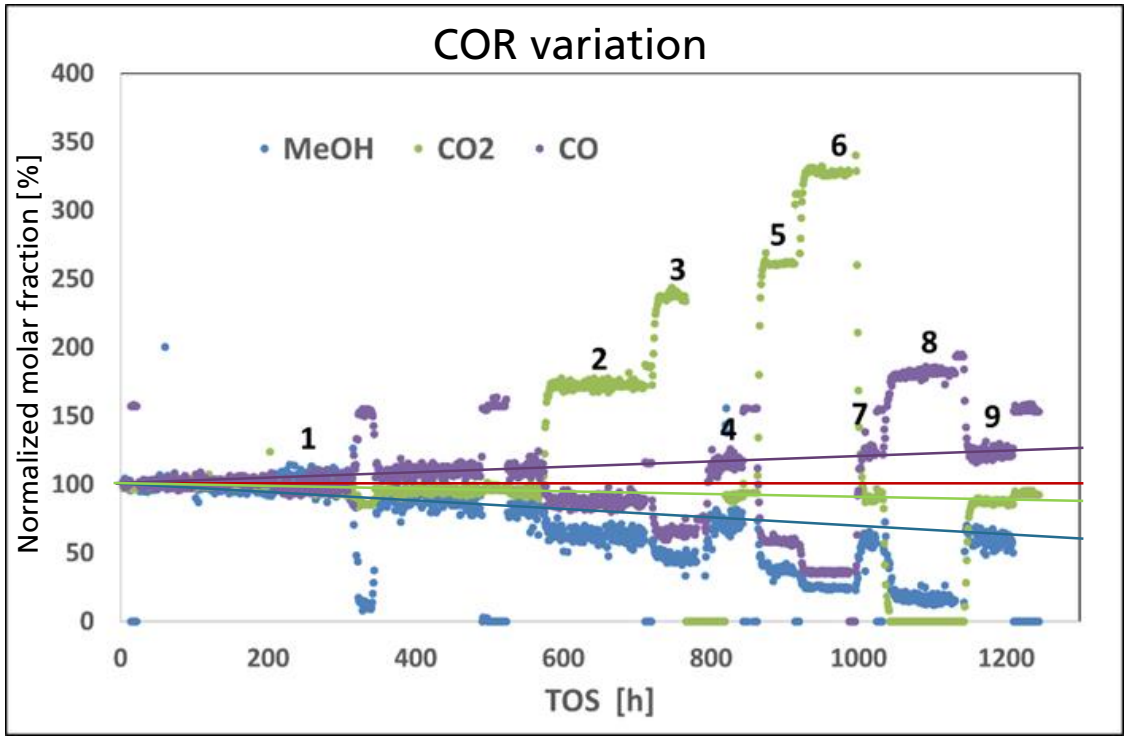
Results from Phase 1

LCTS, bottle gases

73.5 % H2, 9.5 % N2

280 °C, 50 bar

Step	CO_2 [Vol. %]	CO [Vol. %]	COR
1	3.5	13.5	0.79
2	7	10	0.59
3	10.5	6.5	0.38
4	3.5	13.5	0.79
5	12	5	0.29
6	17	0	0
7	3.5	13.5	0.79
8	0	17	1
9	3.5	13.5	0.79



Results from Phase 1

LCTS, cleaned blast furnace gas, balance hydrogen from bottles

250 °C, 84 bar

Cleaned BFG:

≈ 25 % CO

≈ 23 % CO_2

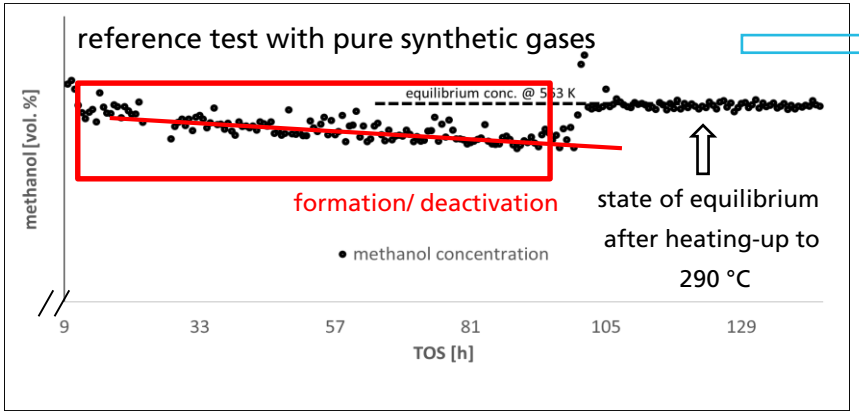
≈ 4 % H_2

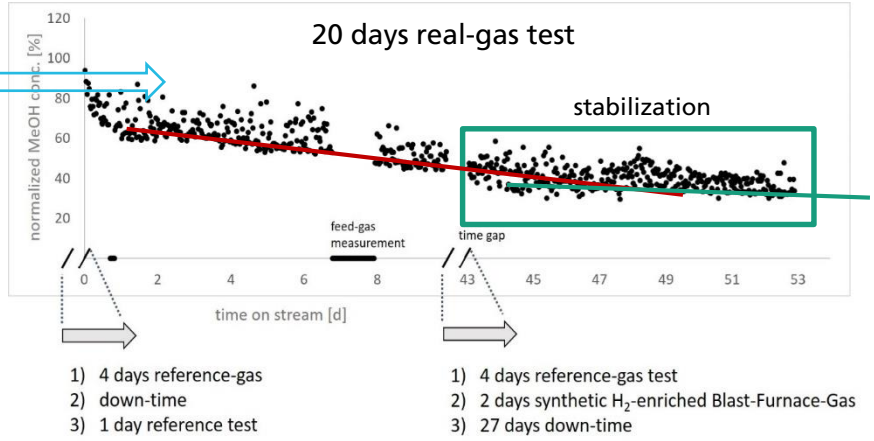
≈ 48 % N_2

325 Nml/min BFG

425 Nml/min H_2

SN ≈ 2.4



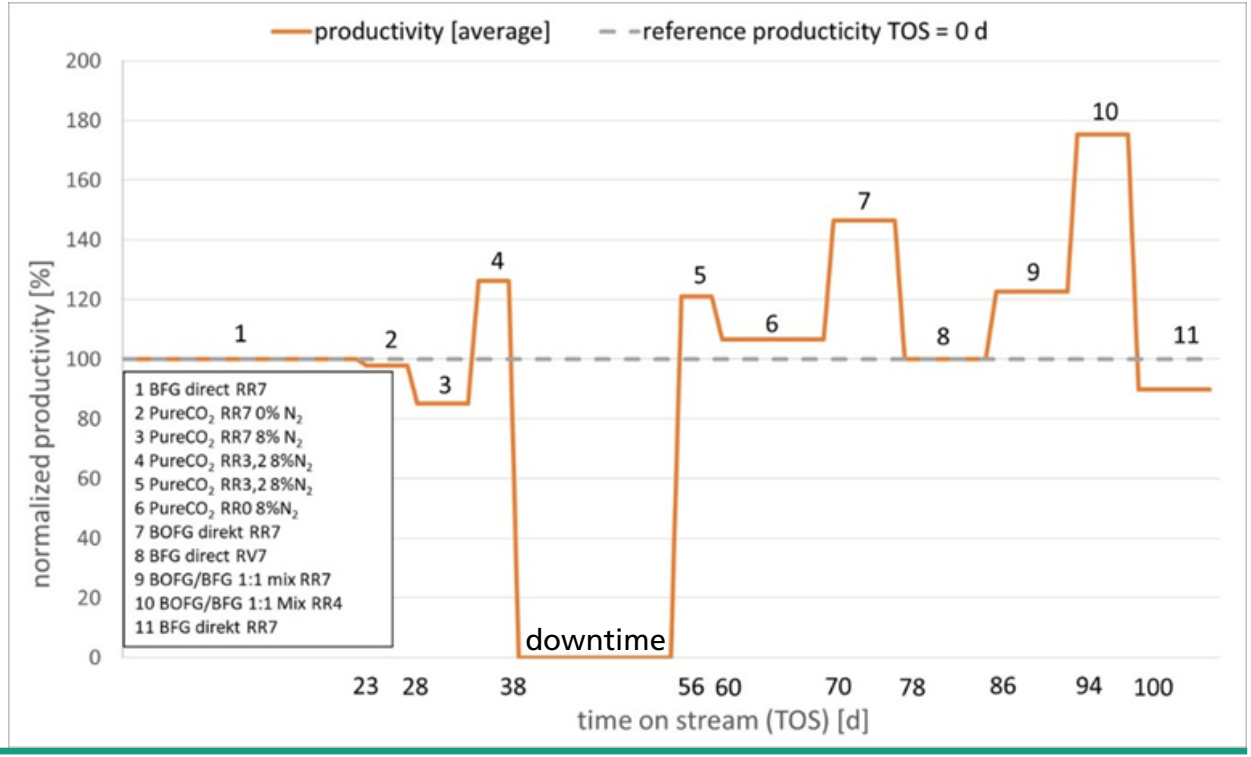


Results from Phase 1

Pilot plant, bottle gases

Scenario comparison

SN ≈ varying

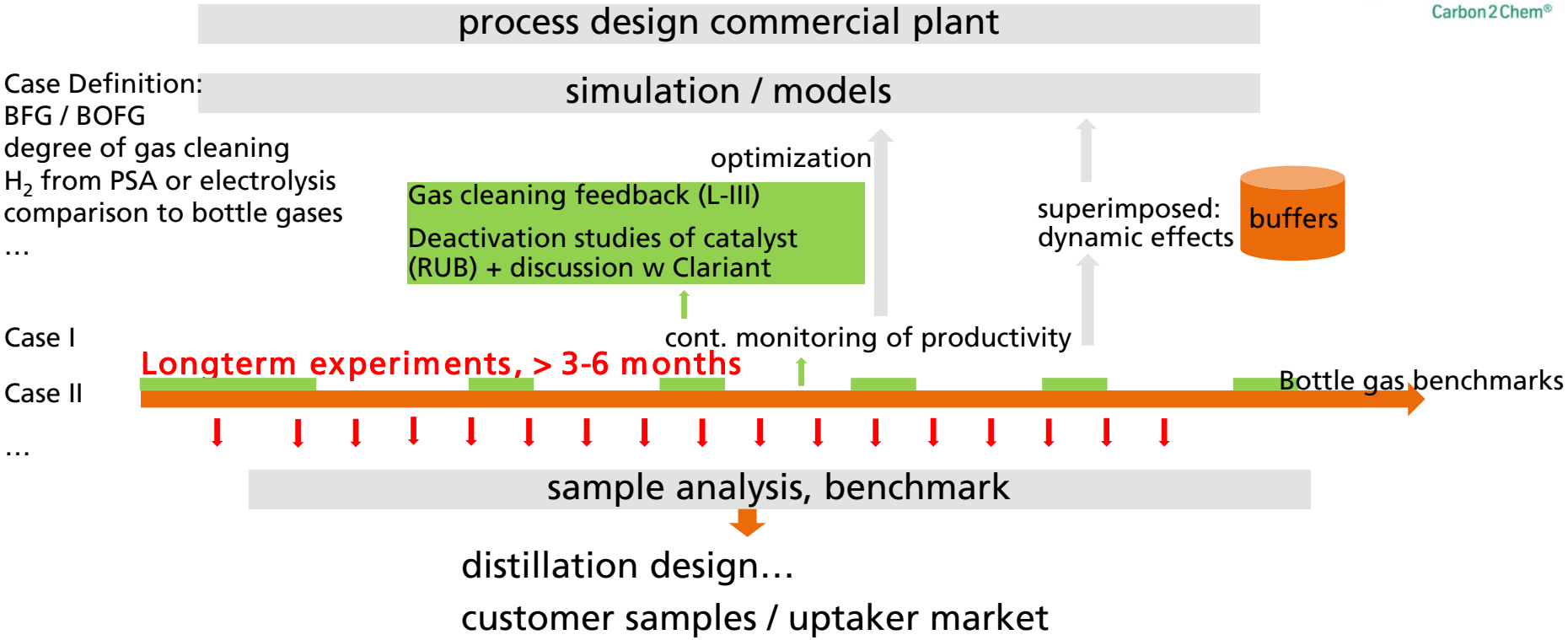


Demonstration plant modification

- Operation at UMSICHT in Oberhausen with
  - changing ratio of CO / CO_2 (originally designed for pure CO_2)
  - changing addition of N_2 to makeup gas
  - changing recycle ratio and makeup gas flow rate
  - ⇒ Determination of operating window

- Application for building permit at Carbon2Chem test facility in Duisburg
- Relocation of demonstration plant to Duisburg

Design of campaigns at steel mill



Summary

- Scale-up is a complex topic, not straight forward
- Carbon2Chem partners are experienced with successful scale-up
- First basis for scale-up is longterm stability of lab and pilot plants and experimentally validated reaction / reactor / plant models
- Stepwise transfer of results and campaigns to larger plants towards the vision of Carbon2Chem first-of-its-kind plant

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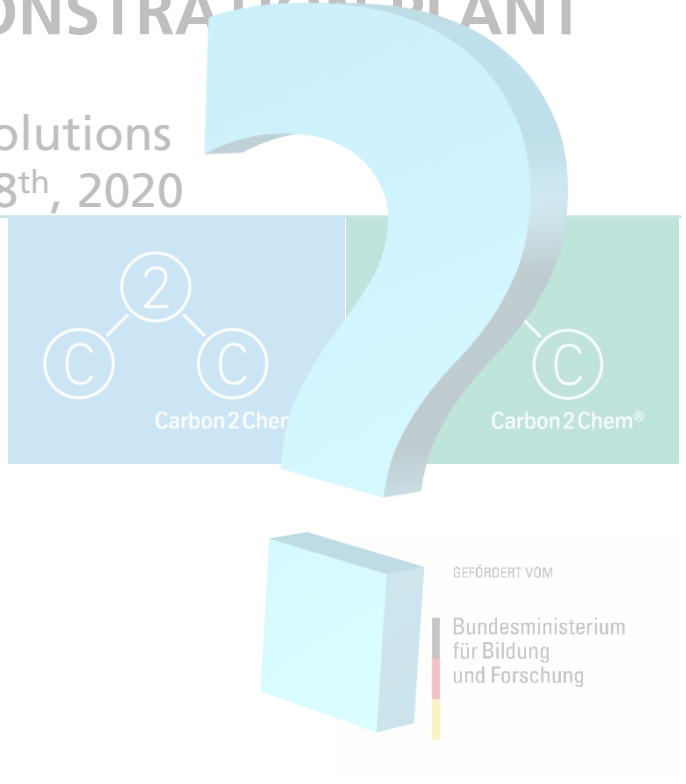

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