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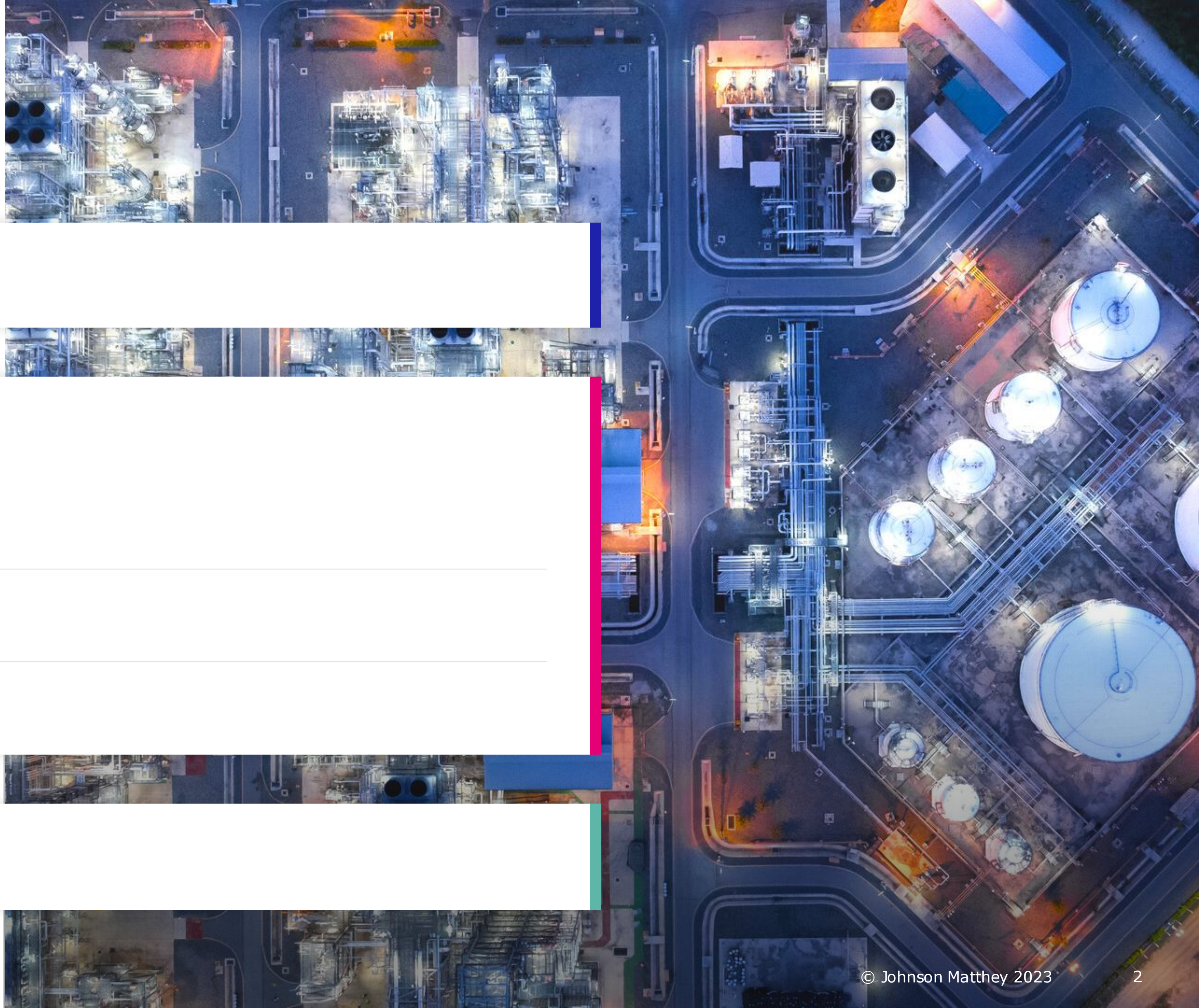
Johnson Matthey
Inspiring science, enhancing life

Americas hydrogen and syngas technical training seminar

Optimizing reformer performance

Michael Severance

Contents



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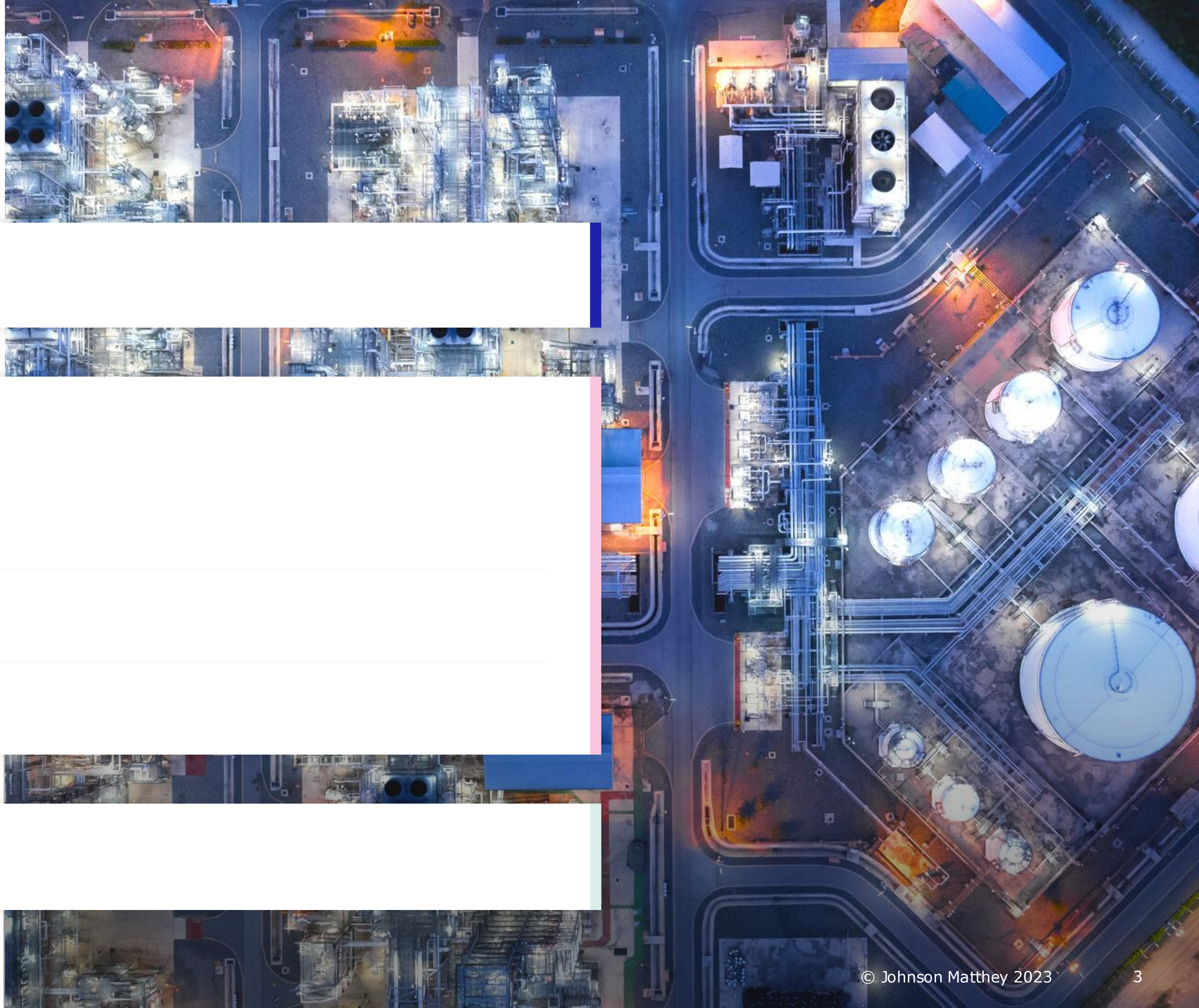


Introduction

01

Safety

02

Environment

03

Efficiency

04

Reliability

05

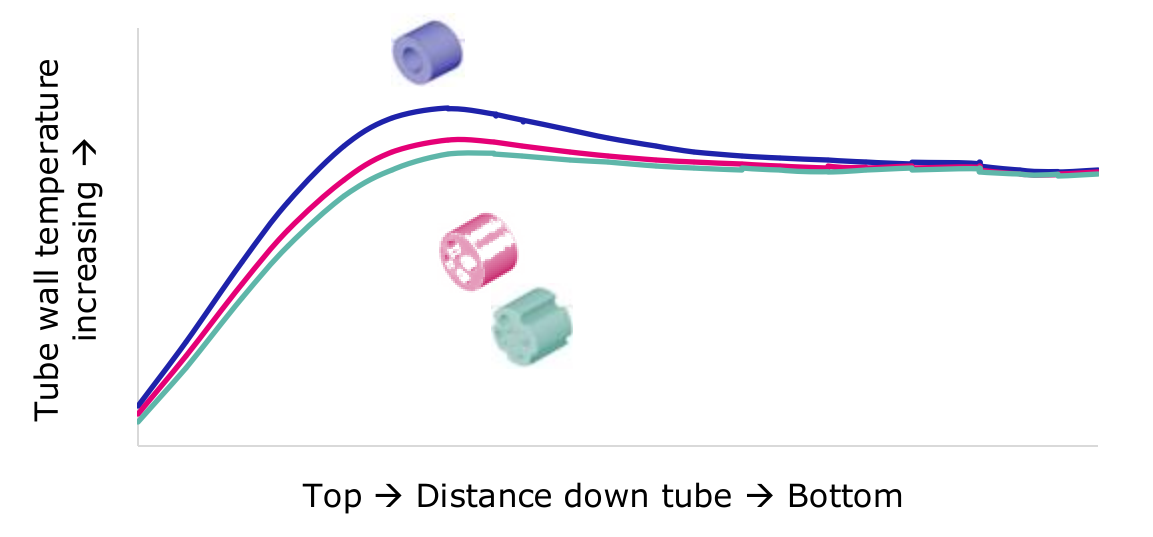
Throughput

Catalyst life and turnaround around planning

Catalyst life extension

Improvements eliminating catalyst changes

Catalysts | Tube materials | Tube inspection | Plant Operations



Year	SOR	1	2	3	4	5	6	7	8
1970-80's									
↓									
2010-20's									

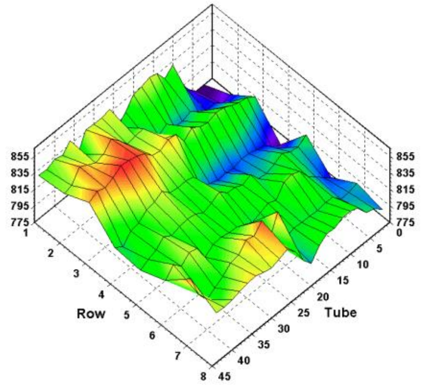
Potential reformer issues

Poisoning 1

Carbon formation 2

Tube failure and replacement 3

Fluegas maldistribution 4

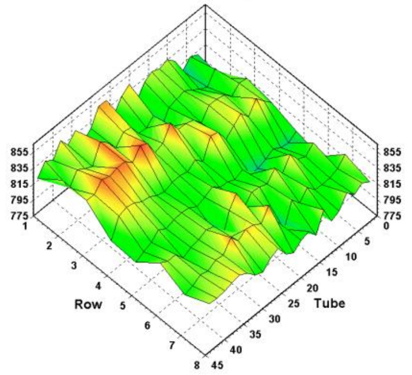


Burner problems 5

Refractory and tunnel damage 6

Combustion air maldistribution 7

Mechanical integrity 8



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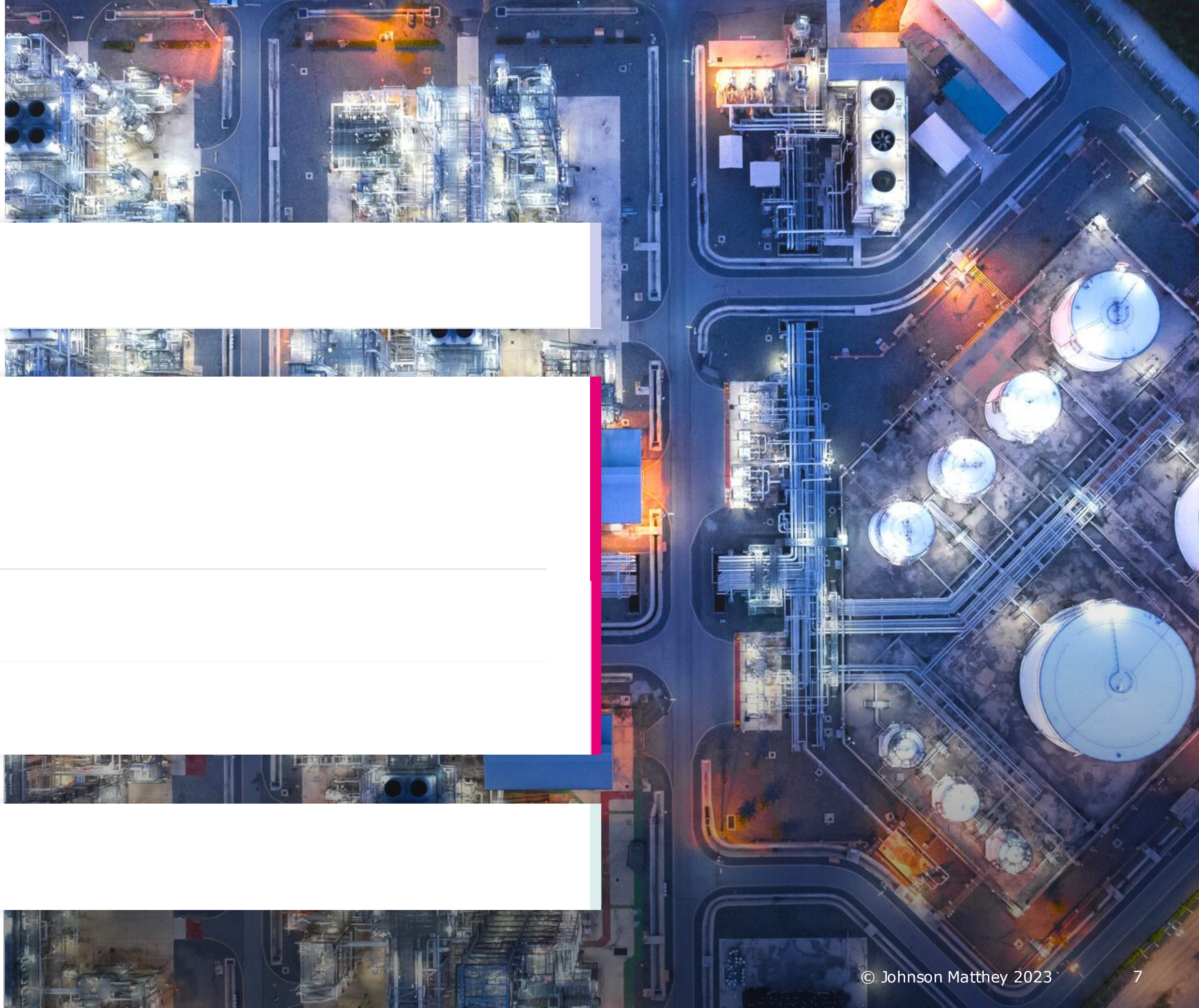

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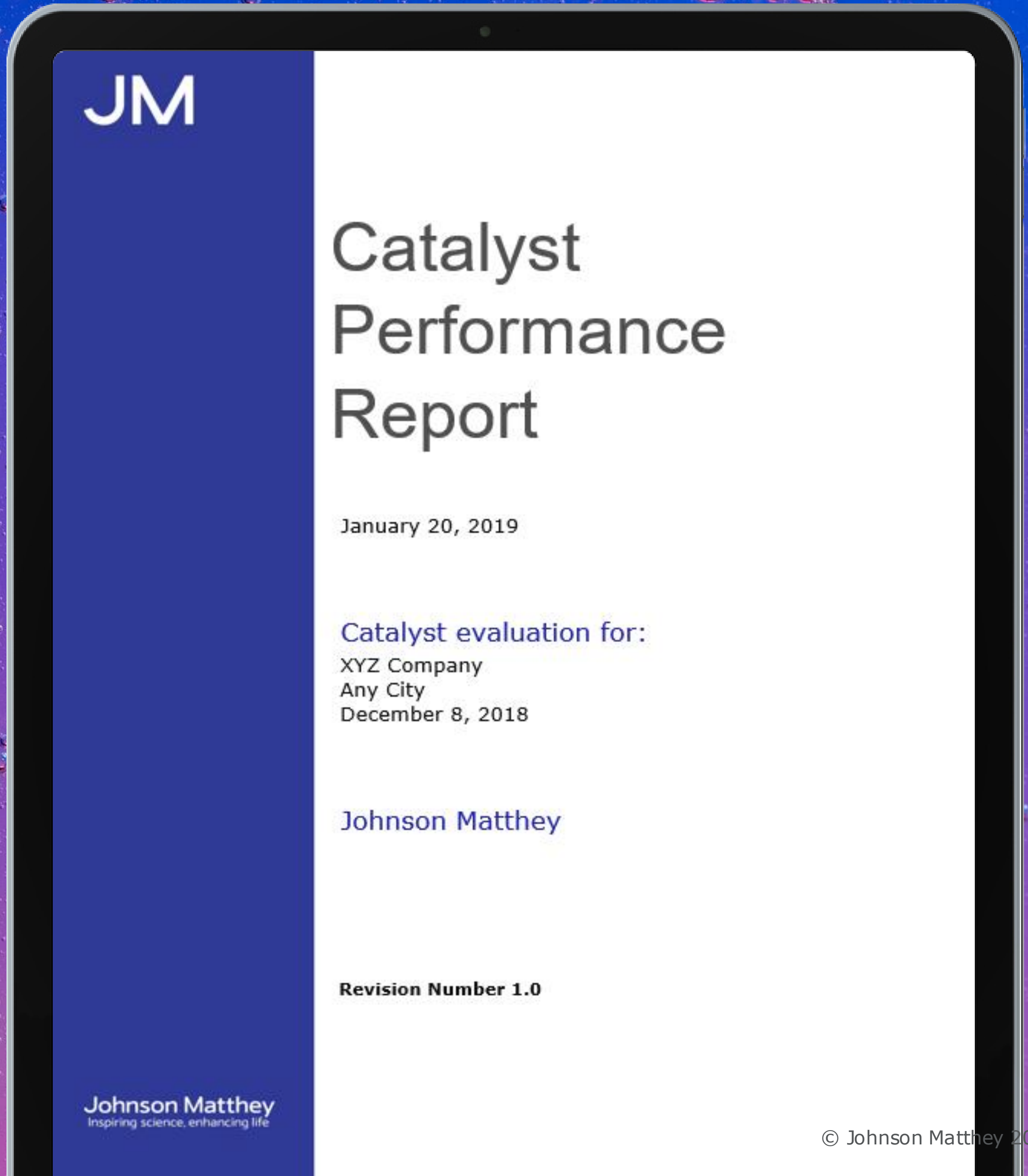
Process modelling

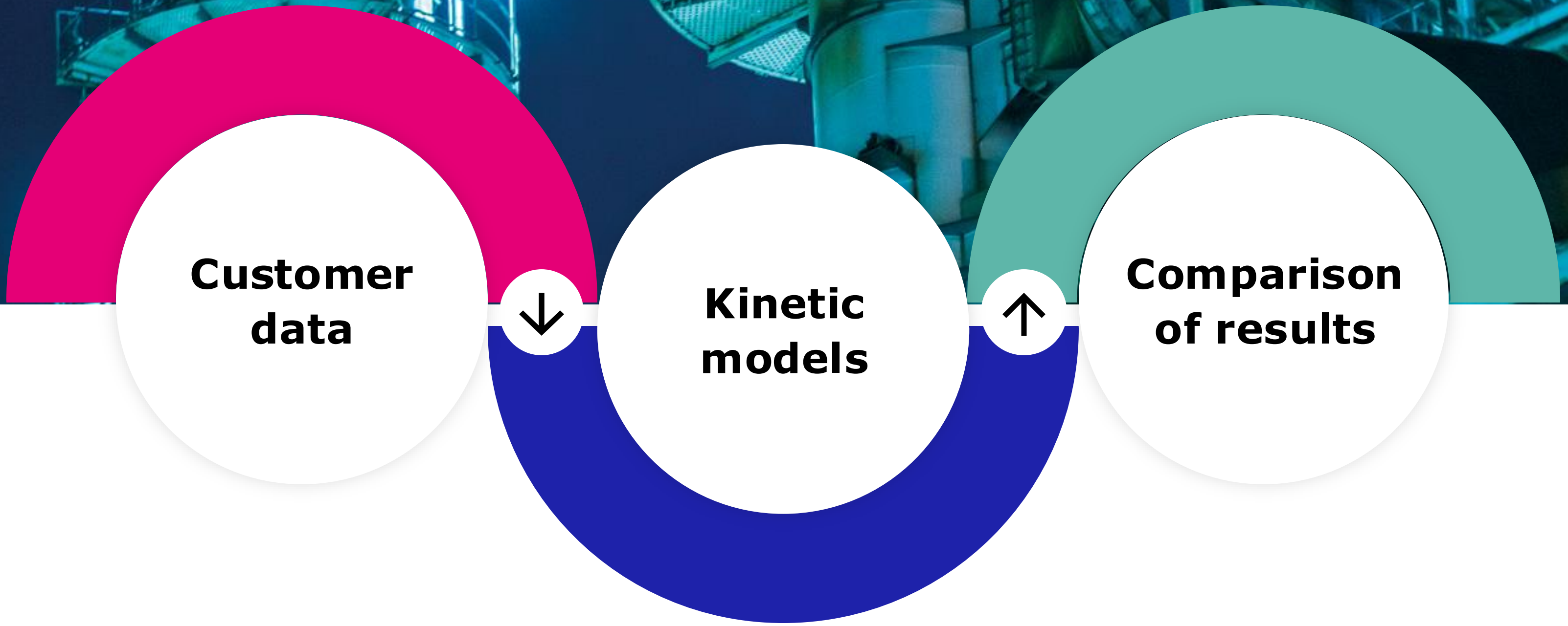
Catalyst evaluation

Catalyst performance

Turnaround planning



Process modelling



Reaction kinetics

Hydrocarbon reaction rates

Time dependency of performance

Carbon deposition kinetics

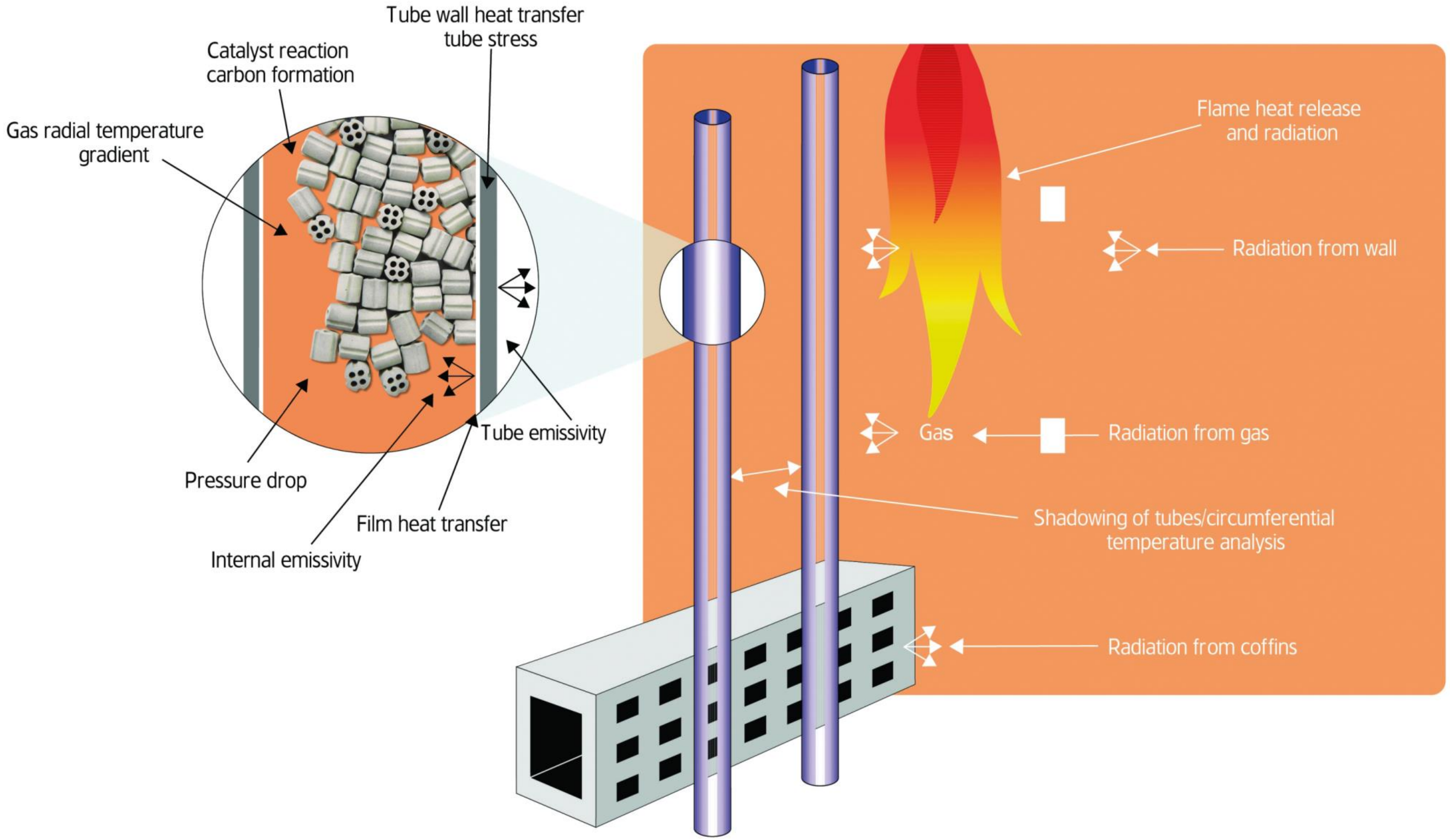
Feedstock characteristics

Composition of feed

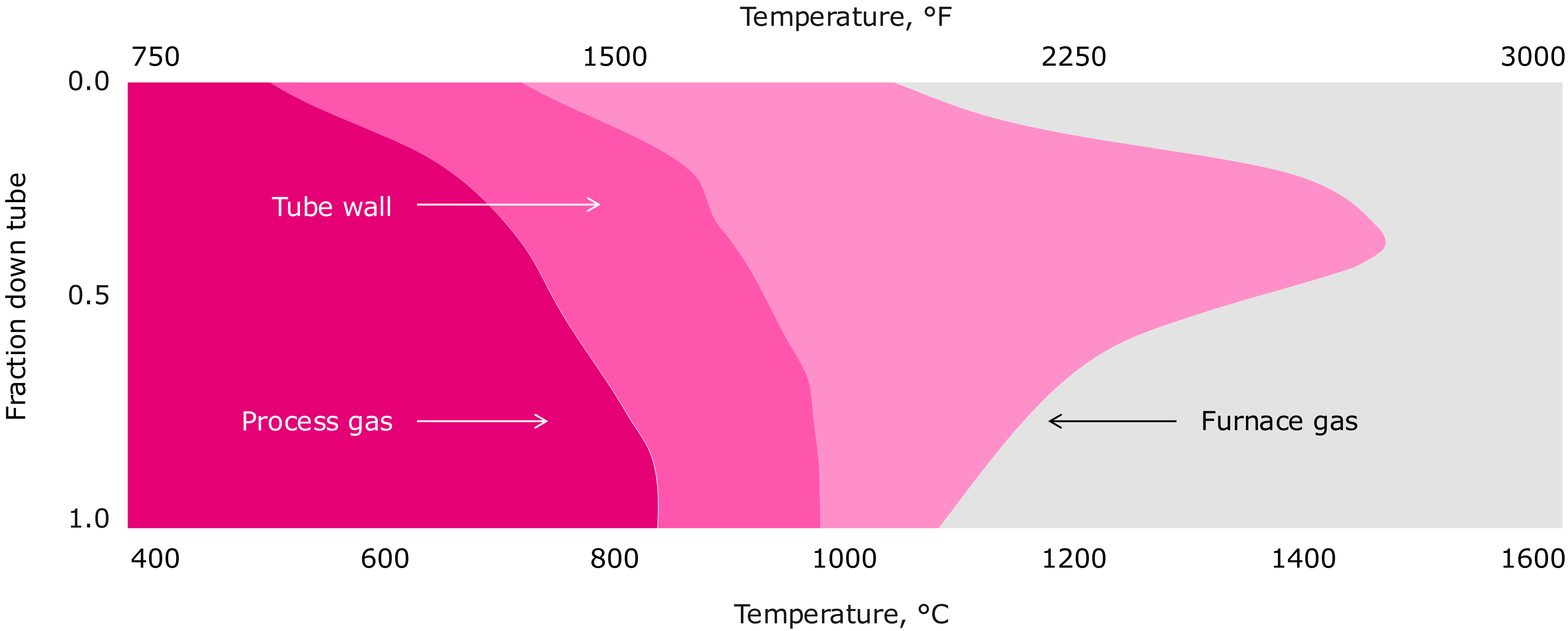
Catalyst type and loading

Shape and size of catalyst

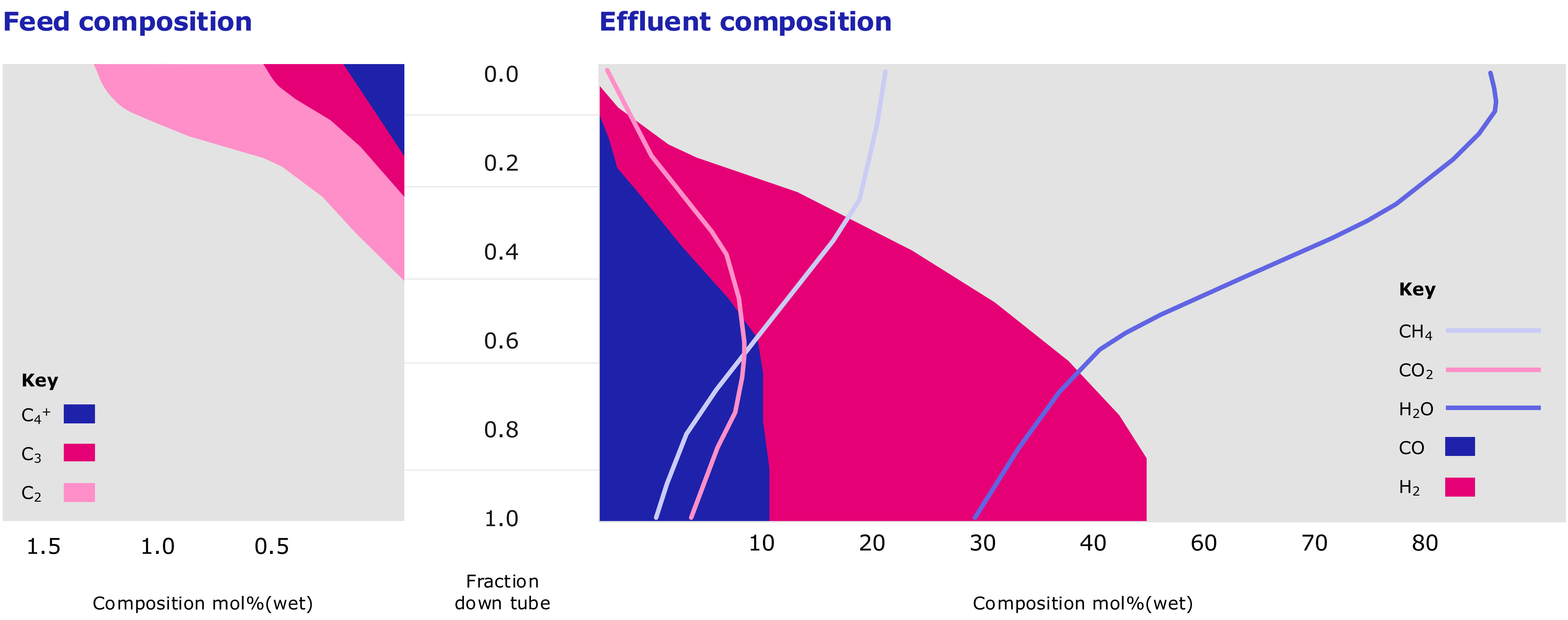
Process modelling



Process modelling – outputs: temperatures



Process modelling – outputs: composition



Primary – modelling outputs

PRIMARY 1.4.3

HYDROCARBON CRACKING

x m	Catalyst	Tube inner wall temp C	R	Carbon onset C	Margin below carbon onset C	Carbon laydown
0.000	57-4Q	537.0				
0.301	57-4Q	535.7	0.035	750.0	214.4	UNLIKELY
0.301	57-4Q	624.4	0.171	750.0	125.6	UNLIKELY
0.767	57-4Q	662.7	0.306	750.4	87.6	UNLIKELY
1.233	57-4Q	695.0	0.480	751.1	56.1	UNLIKELY
1.699	57-4Q	719.6	0.656	752.5	32.9	UNLIKELY
2.048	57-4Q	733.1	0.763	754.3	21.2	UNLIKELY
2.514	57-4Q	745.5	0.852	758.0	12.5	POTENTIAL
2.980	57-4Q	753.2	0.876	763.3	10.1	POTENTIAL
3.446	57-4Q	758.1	0.846	770.3	12.1	POTENTIAL
4.028	57-4Q	762.2	0.757	781.0	18.8	POTENTIAL
4.610	57-4Q	765.6	0.627	793.6	28.0	UNLIKELY
5.076	57-4Q	768.4	0.505	804.7	36.3	UNLIKELY
5.659	57-4Q	772.5	0.338	819.4	46.9	UNLIKELY

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Example of carbon on tube wall

Process modelling: carbon formation and removal

Formed from **hydrocarbon cracking**	$CH \rightleftharpoons C_{(s)} + 2H_2$
	$C_2H_6 \rightarrow 2C_{(s)} + 3H_2$
	$C_3H_8 \rightarrow 3C_{(s)} + 4H_2$ etc.

Removed by **steam, carbon dioxide** and **hydrogen**	$C_{(s)} + H_2O \rightleftharpoons CO + H_2$
	$C_{(s)} + CO_2 \rightleftharpoons 2CO$
	$C_{(s)} + 2H_2 \rightleftharpoons CH_4$

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Process modelling: carbon formation and removal

Carbon **formation** and **removal** rates can be calculated

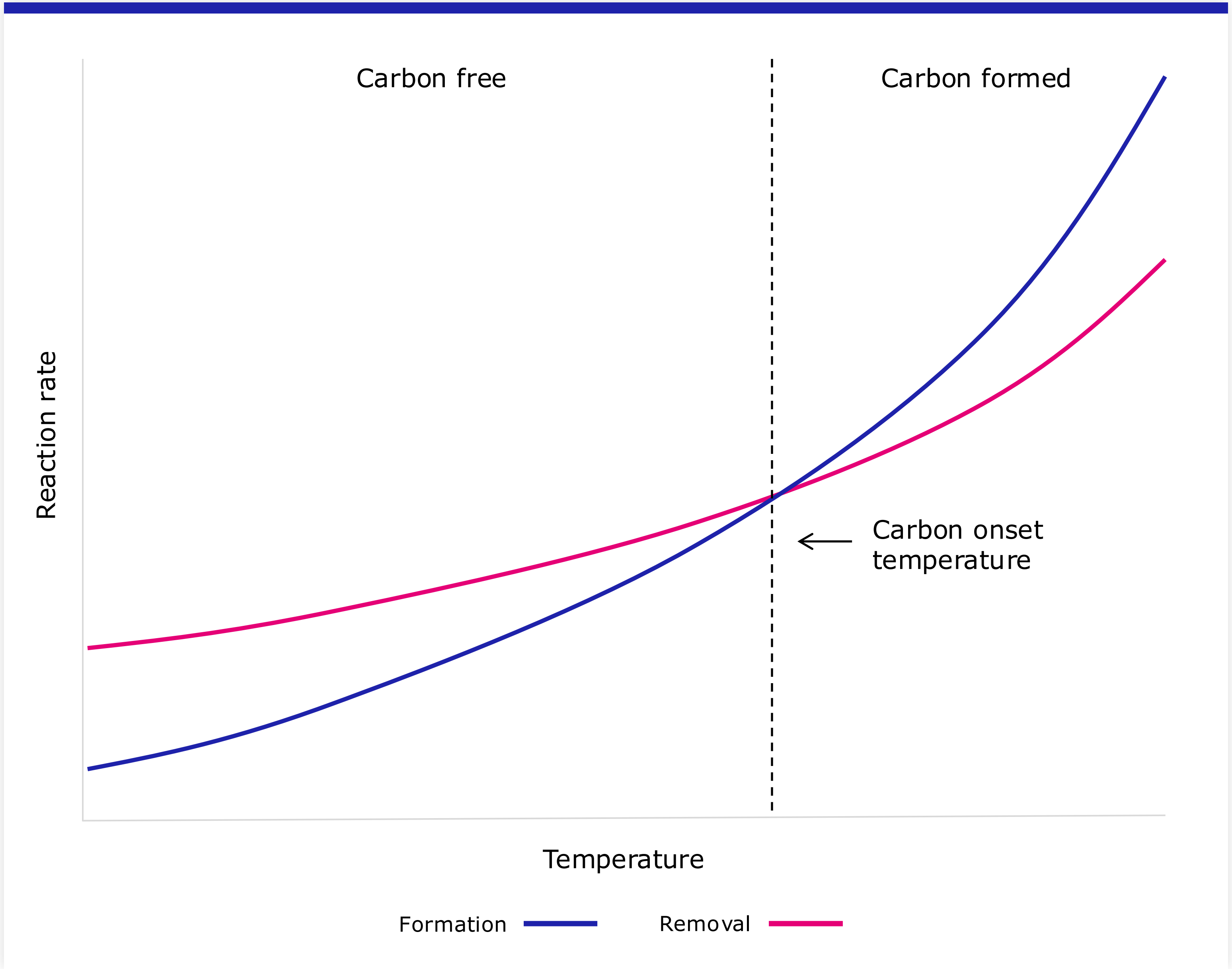
$R_{formation}$

Fn{T, P, [CH_4], [C_2H_6], [C_3H_8], etc.}

$R_{removal}$

Fn{T, P, [H_2O], [CO_2], [H_2]}

Allows carbon onset temperature to be predicted



Carbon prevention and removal

Carbon formation will always occur to some extent

If rate of removal exceeds rate of formation then there is no net carbon formed

Addition of potash (alkali) is highly effective:

This makes the support more basic and less prone to carbon

Potash is bound into the support material and released at a controlled rate

Catalyses the reaction of carbon with steam

$$C_{(s)} + H_2O \rightleftharpoons CO + H_2$$

Case studies: when should the primary catalyst changed?

Plant improvement

Plant capacity increase (bigger tubes)

Reliability project (retube)

Routine catalyst change

Catalyst showing signs of failure

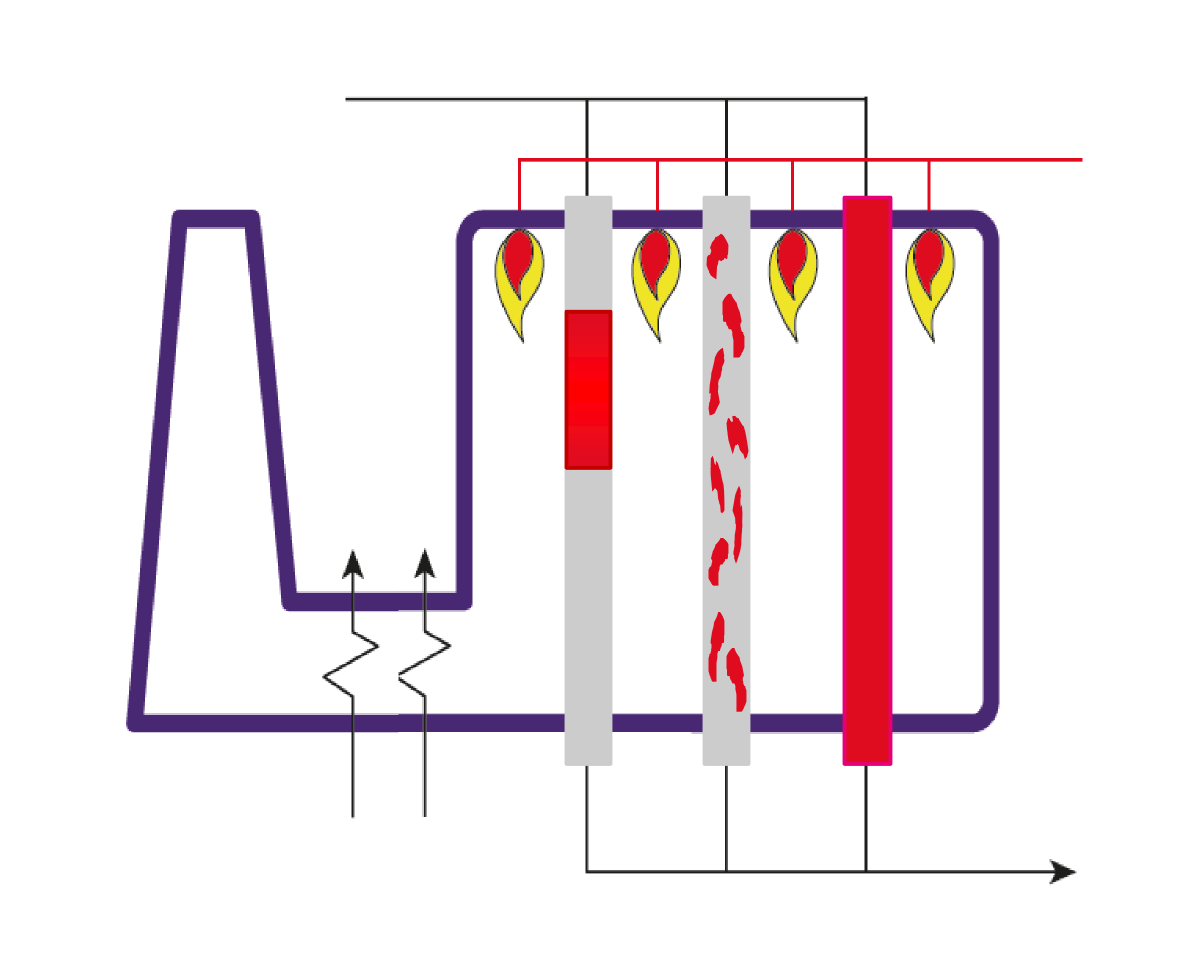
Reduce risk of failure in next campaign

Typical catalyst failure causes

Activity loss: hot tubes, carbon

Poisoning: hot tubes, carbon

Pressure drop: thermal cycles, carbon or wetting



Turnaround planning

North American Hydrogen Plant

Four-year turnaround cycle | Tied to Hydrocracker | New catalyst

KATALCO™ 25-4Q/57-6Q
Performance projections @ 1490°F (810°C) exit temperature

	SOR	Year 4	Year 5	Year 6	Year 7
Inlet temperature, °F (°C)			1025 (552)		
Inlet S:C			3.15		
Outlet pressure, psig (barg)			310 (21.4)		
ATE, °F (°C)	5 (3)	12 (7)	14 (8)	17 (9)	22 (12)
Pressure drop, psig (barg)	40 (2.8)	47 (3.2)	49 (3.4)	51 (3.5)	53 (3.7)
Outlet composition (mol%, dry)					
Hydrogen	71.0	70.8	70.7	70.6	70.4
Methane	7.0	7.3	7.5	7.6	7.8
Peak TWT, °F (°C)	1553 (845)	1556 (847)	1557 (847)	1559 (848)	1577 (858)
Carbon formation	Unlikely	Unlikely	Unlikely	Unlikely	Potential

JM

Turnaround planning

Analysis performed to see what increasing temperature would do

KATALCO 25-4Q/57-6Q

Performance projections @ 1530°F (832°C) exit temperature

	SOR	Year 4	Year 5	Year 6
Inlet temperature, °F (°C)	1025 (552)			
Inlet S:C	3.15			
Outlet pressure, psig (barg)	310 (21.4)			
ATE, °F (°C)	5 (3)	12 (7)	15 (8)	19 (11)
Pressure drop, psig (barg)	41 (2.8)	48 (3.3)	50 (3.4)	52 (3.6)
Outlet composition (mol%, dry)				
Hydrogen	72.1	71.9	71.8	71.7
Methane	5.4	5.7	5.8	5.9
Peak TWT, °F (°C)	1599 (871)	1600 (871)	1600 (871)	1601 (872)
Carbon formation	Unlikely	Unlikely	Unlikely	Potential

Turnaround planning

KATALCO 25-4Q/57-6Q
Performance projections @ 1490°F exit temperature

	SOR	Year 4
Inlet temperature, °F (°C)	1025 (552)	
Inlet S:C	3.15	
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Carbon formation	Unlikely	Unlikely

KATALCO 25-4Q/57-6Q
Performance projections @ 1530°F exit temperature

	SOR	Year 4
Inlet temperature, °F (°C)	1025 (552)	
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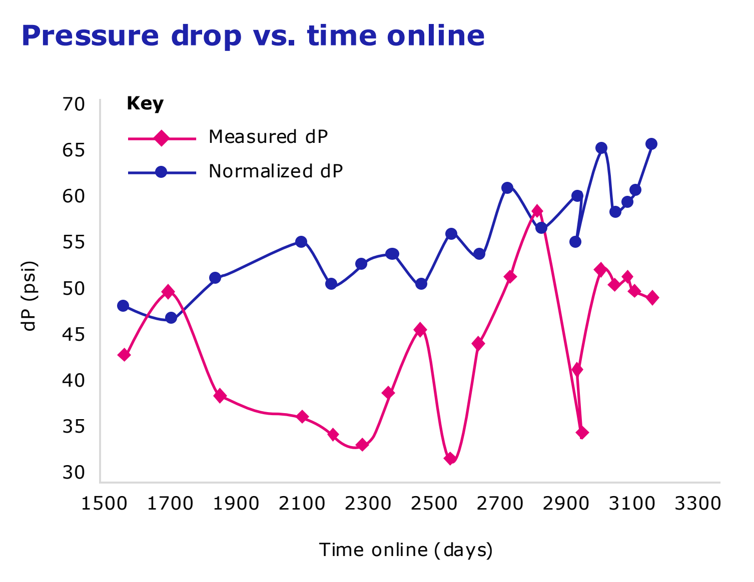
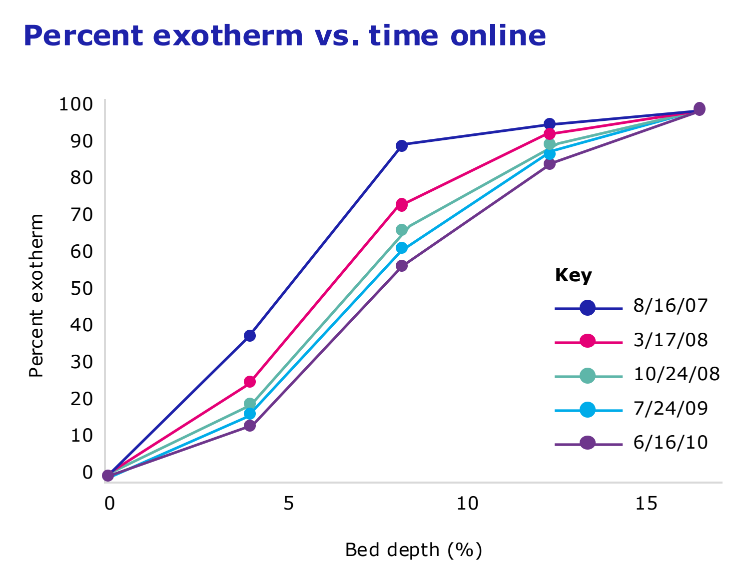
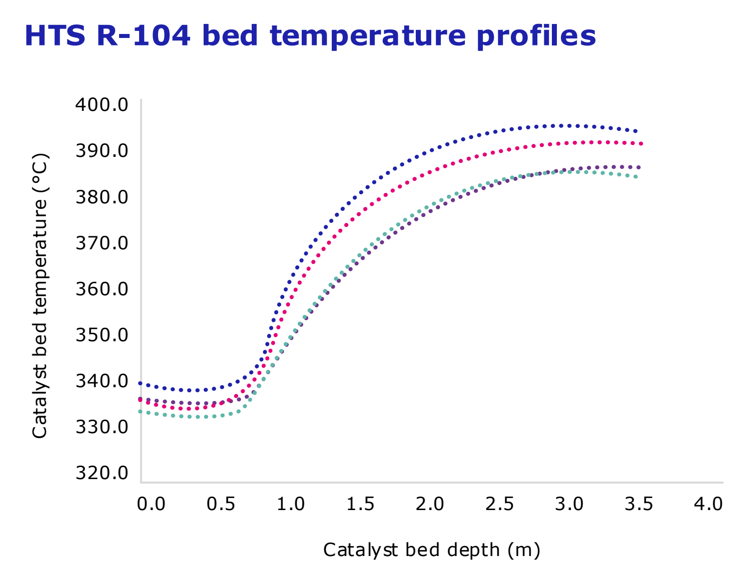
Carbon formation	Unlikely	Unlikely

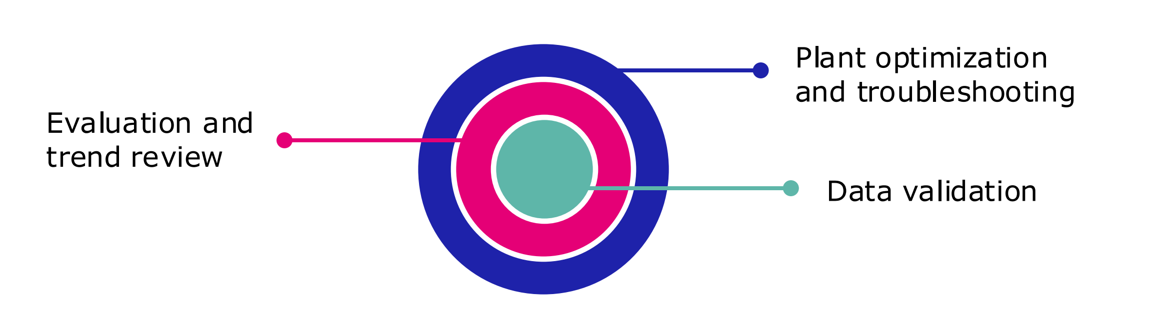
Catalyst evaluations







HTS optimization time (years)	Inlet T (°C)	Exit CO (mol% dry)	H_2 production (Nm^3/hr)
Current operation	338.7	1.71	46,250
+1yr @ fixed inlet T	338.7	1.74	46,231
+2yr @ fixed inlet T	338.7	1.77	46,213
Current optimized	329.0	1.65	46,283
+1yr @ opt inlet T	332.8	1.72	46,244
+2yr @ opt inlet T	335.5	1.76	46,216



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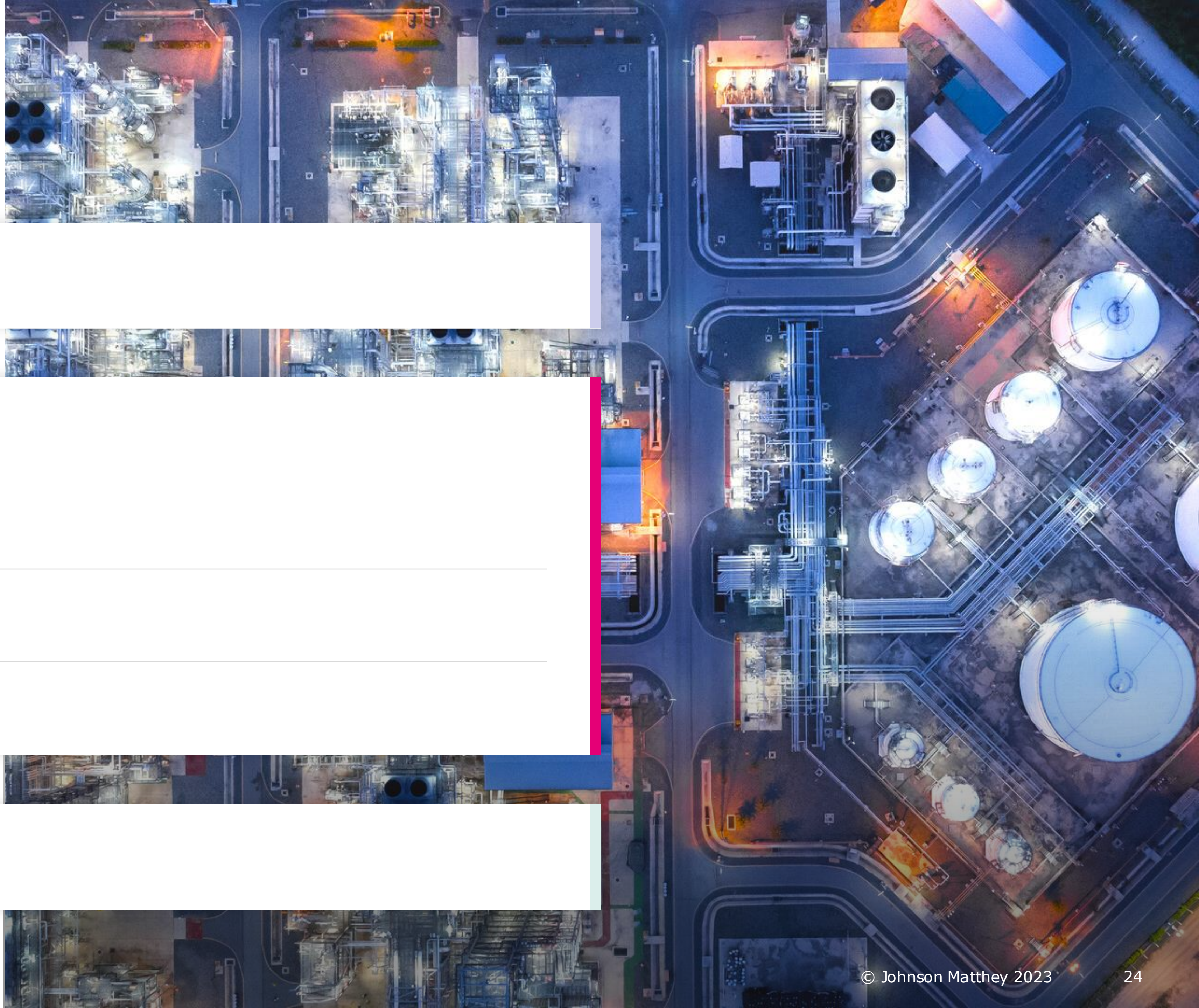


Equipment for reformer surveys

LAND / AMETEK®

Optical pyrometer measurements

Thermal imager measurements of radiant box

Gold cup TWT measurements

What is a reformer survey?

- Accurate assessment of reformer performance 1
- Measurement and correction of tube temperatures 2
- Inspection of reformer 3
- Plant data collection and reconciliation CATPER 4
- Detailed simulation PRIMARY 5

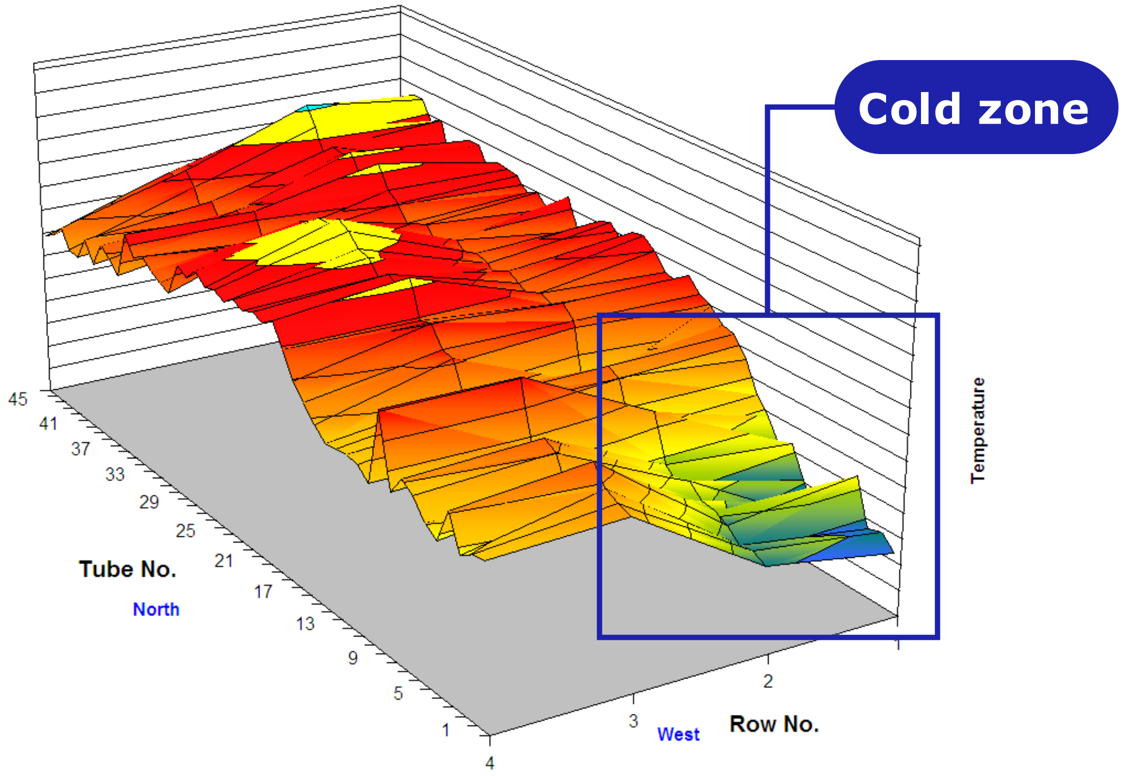
Reformer surveys

Typical output from a reformer survey includes:

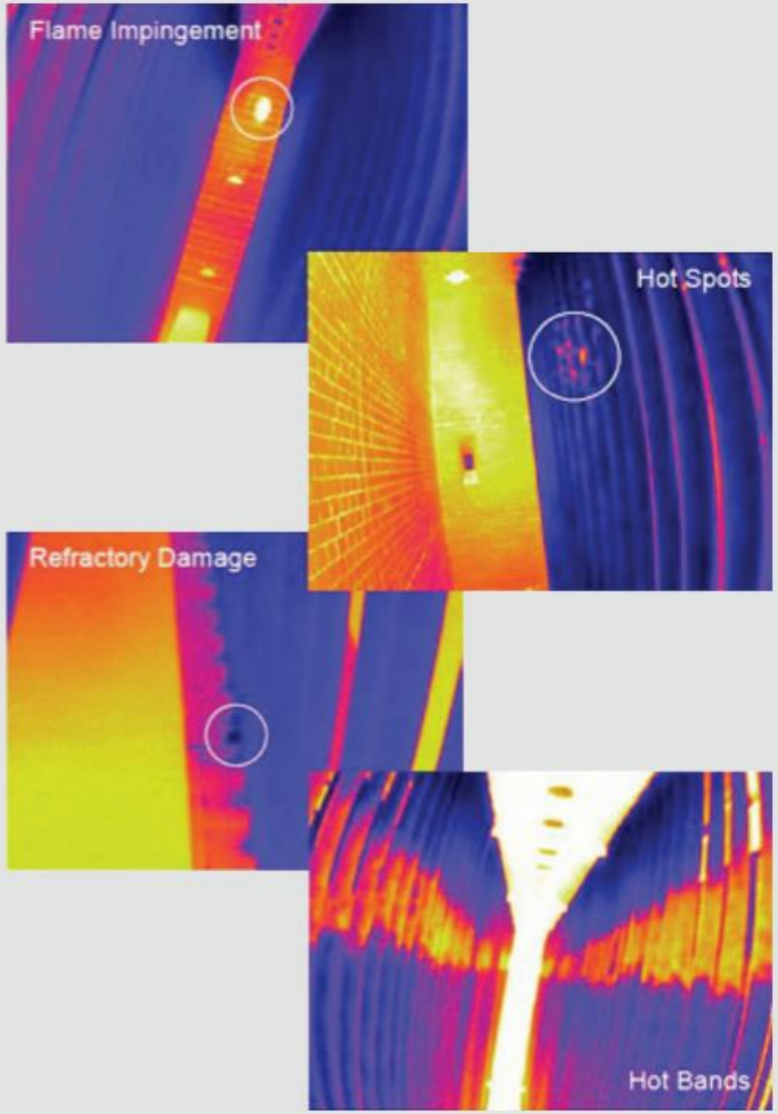
- Catalyst performance
- Efficiency gains
- Real tube skin temperatures
- Reformer balance
- Benchmarking

Reformer survey output

Statistical and graphical analysis of TWT



Troubleshoot operational issues

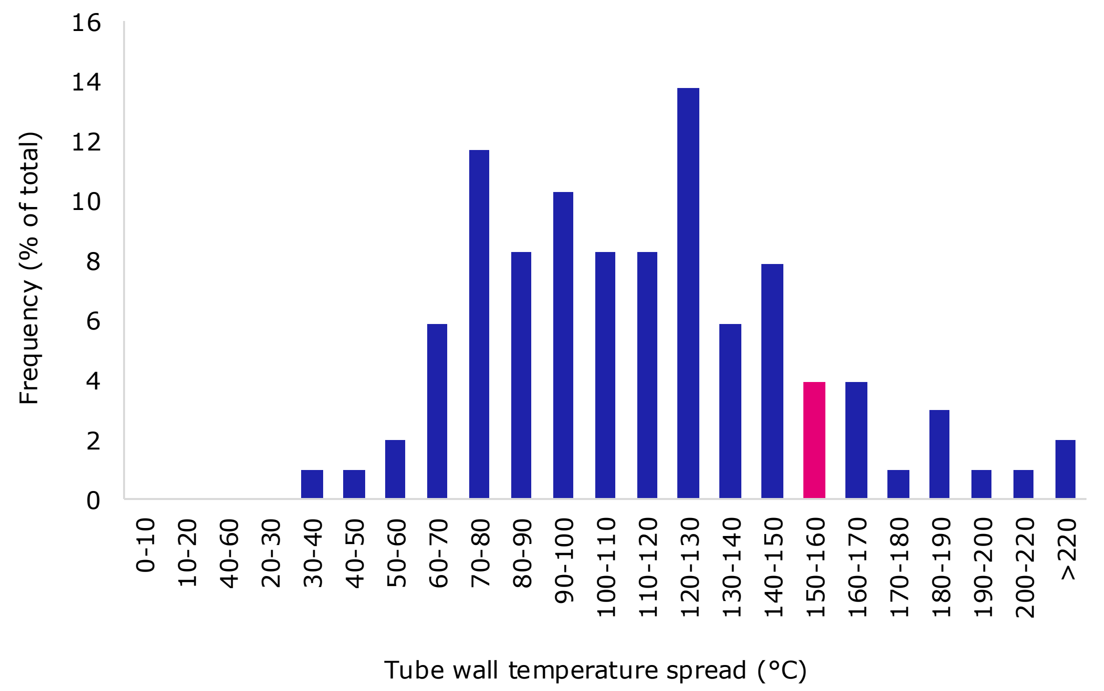


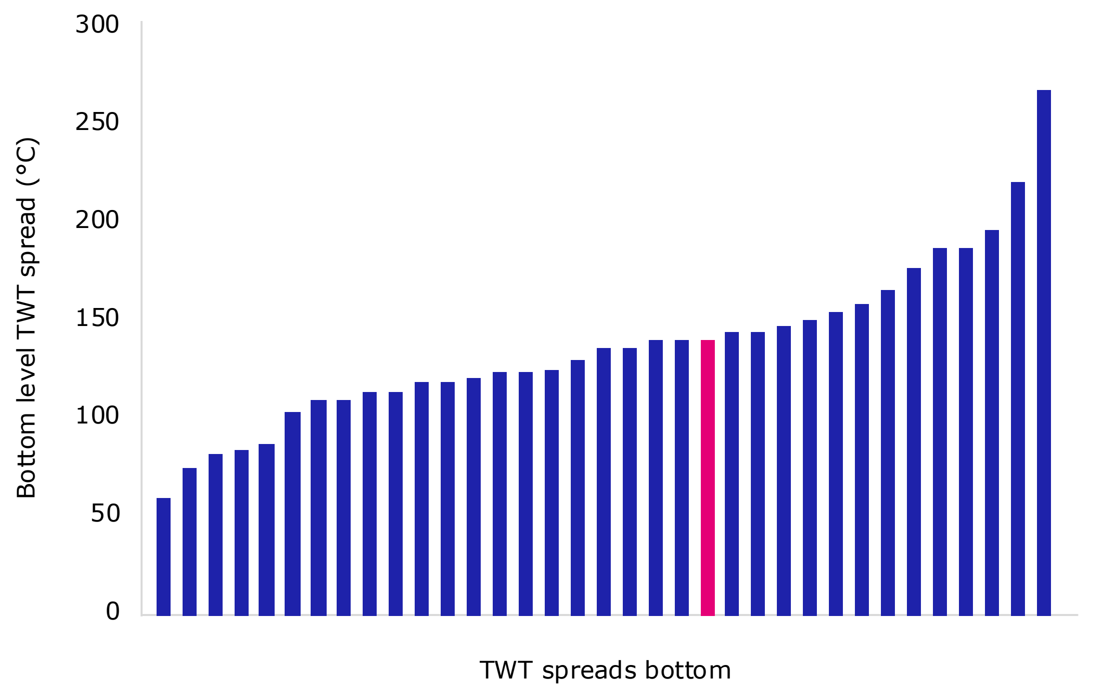
Benchmarking reformer performance

Database **captured results** of reformer surveys

Allows for **benchmarking** of reformer

Compare against similar reformers and peers/other plants





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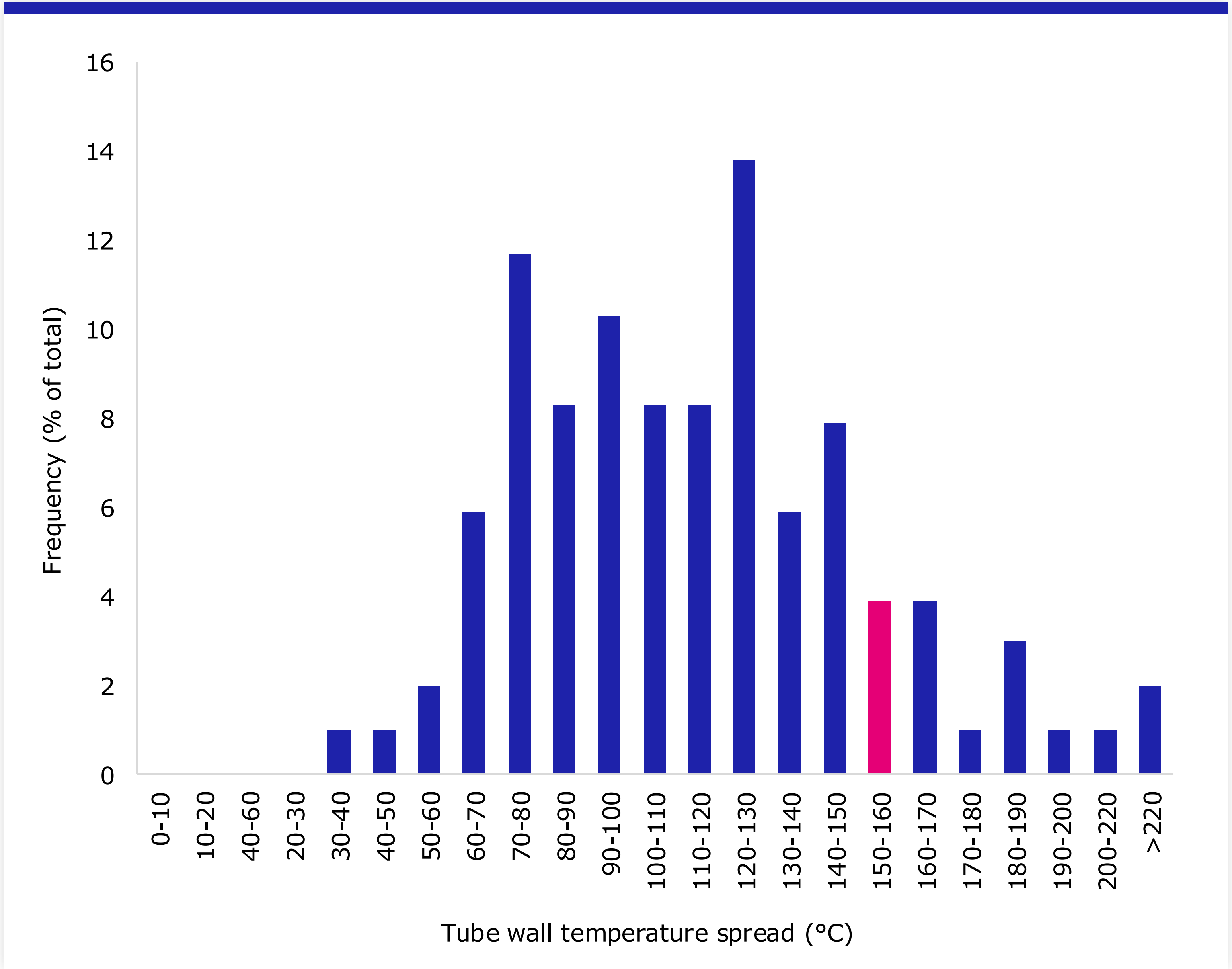
Benchmarking reformer performance

Database **captured results** of reformer surveys

Allows for **benchmarking** of reformer

Compare against similar reformers



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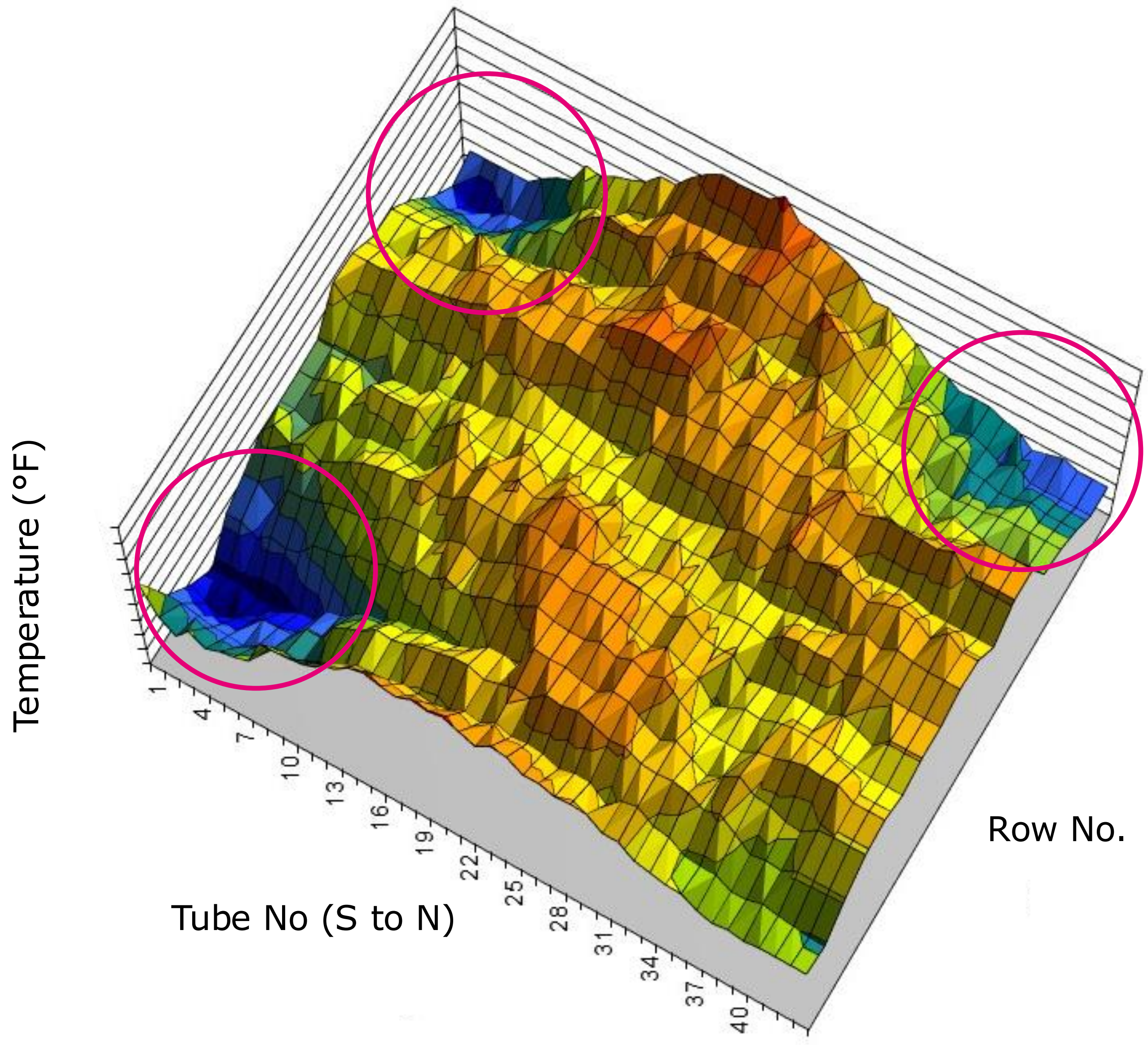
Thermal imager case study (1)

North American Plant

Cold zones found in initial imager study



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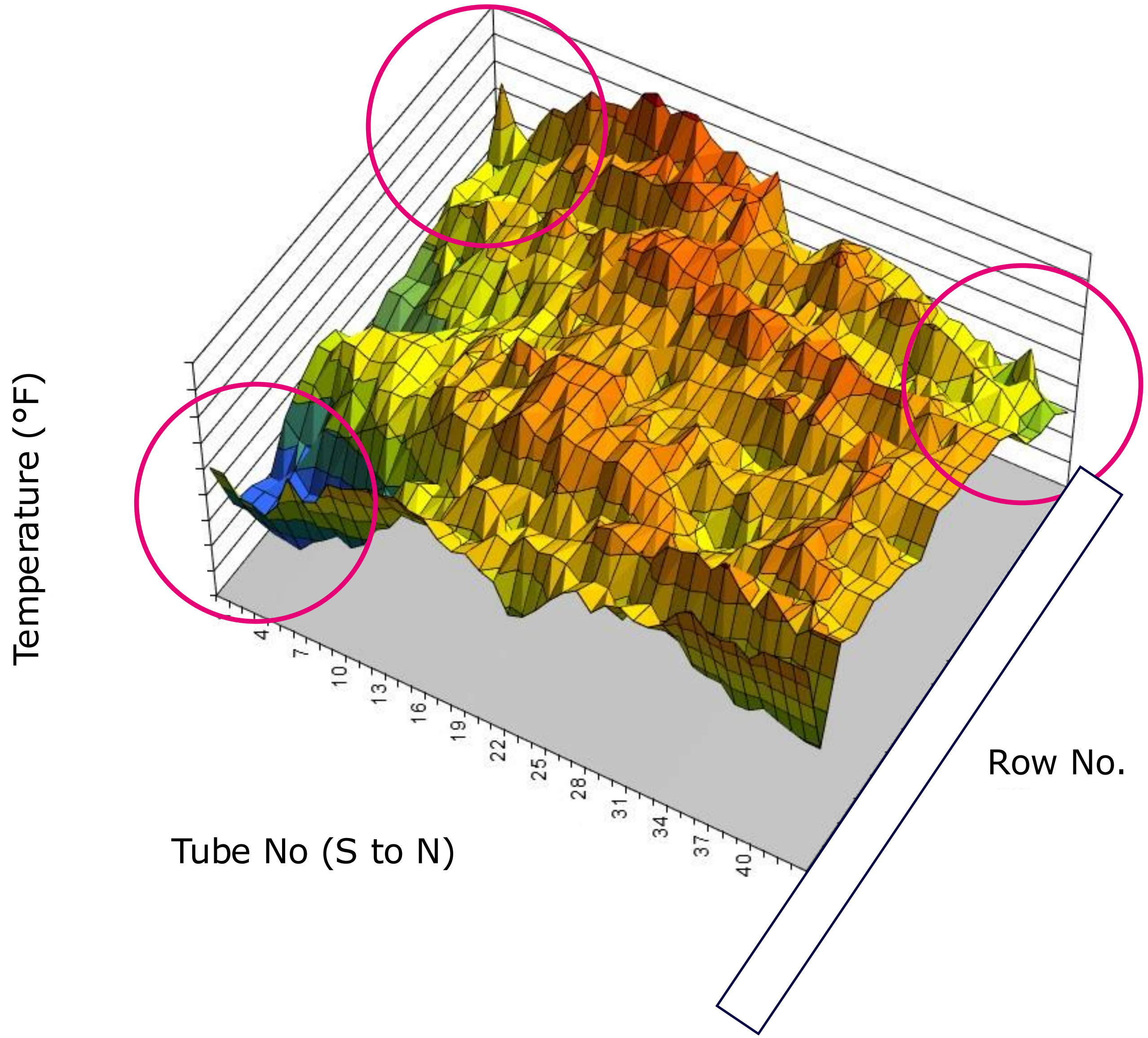
Thermal imager case study (1)

Three days later

Improved balance

Methane slip decreased 0.25% at same firing

Increased hydrogen production



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Thermal imager case study (2)

North American Hydrogen Plant

Inspection team limiting firing due to high TWT

Visual appearance of tubes showed no signs of hot spots

Thermal imager study performed

Study found an approximately 50°F (28°C) difference between JM measurement and refinery measurement

JM showed lower temperatures

Lower temperature was confirmed by third party

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Thermal imager case study (2)

Economics for H_2 production

	Low1	Low2	Base	High
H_2 price (US$/MT)	725	1,500	2,400	–
Gas price (US$/MMBTU)	–	–	2.14	3.5

Value of addition H_2 produced at higher temperatures

Economics evaluated at different H_2 values as well as natural gas cost

Gas price / H_2 price	Low1	Low2	Base
Base	$11M	$20M	$31M
High	$13M	$22M	$32M

Higher natural gas cost results in more heat recovery savings

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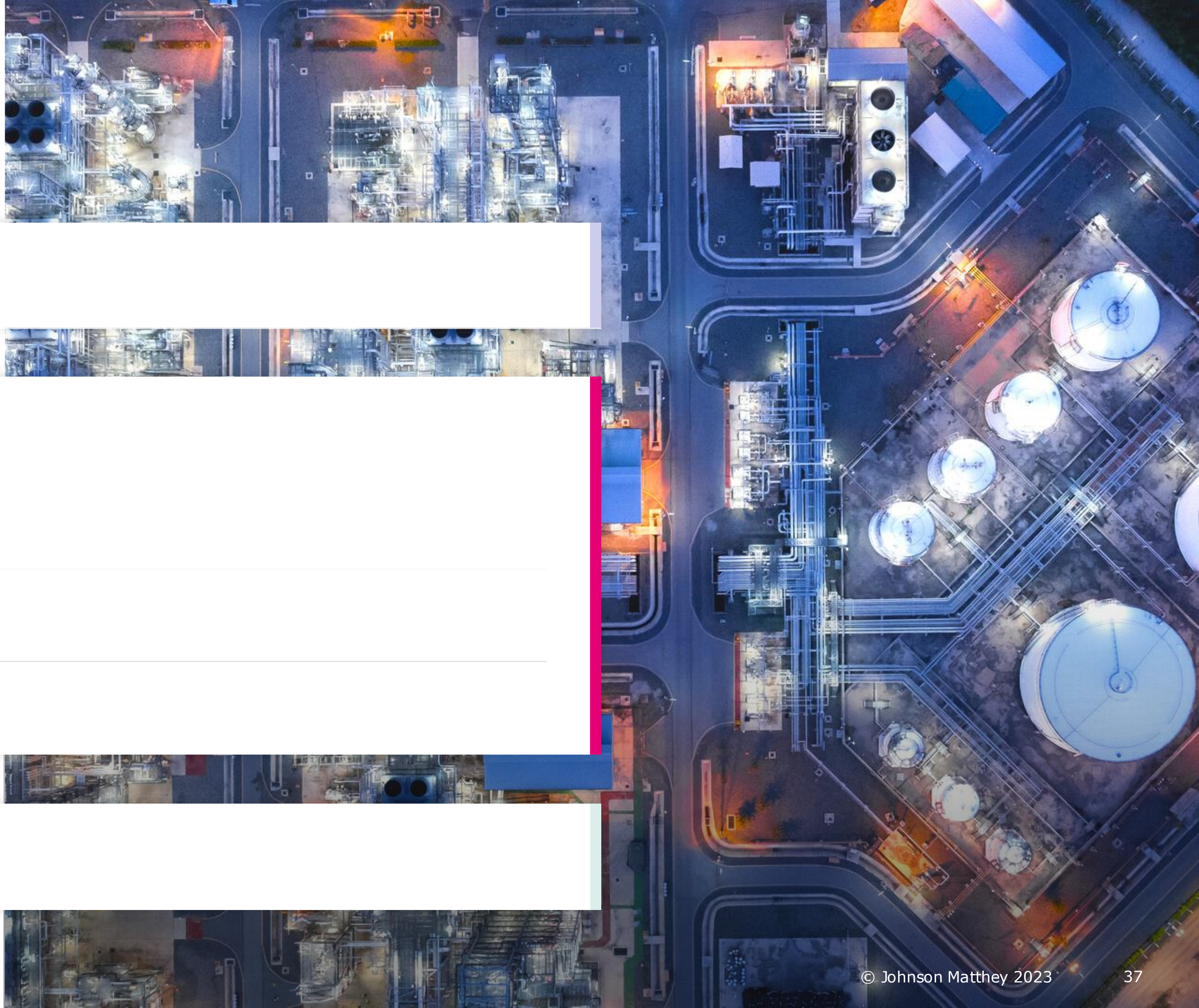

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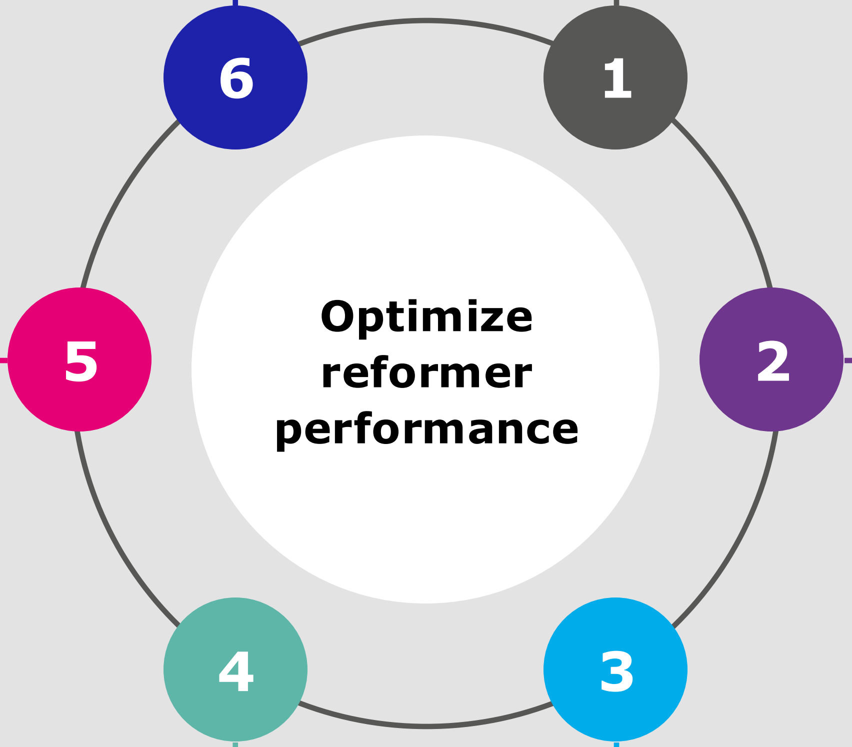

1 Reformer balancing

Minimize tube wall temperature spread

2 Increase tube life

Reduce the likelihood of tube failure

3 Efficiency gains

Increase in methane conversion and fuel efficiency

4 Catalyst performance

Increase in reforming catalyst life

5 TWT analysis

Identify current and potential issues in the reformer

6 Benchmarking

Identify opportunities for further improvement

Optimization studies (1)

North American Hydrogen Plant

Plant runs to set methane slip

Wanted to understand how changing methane slip would effect reformer

	5.00 mol% Methane slip	4.00 mol% Methane slip	3.00 mol% Methane slip
Natural gas feed flow rate (MMSCFD)		10.5	
Exit pressure (psig)		280	
Catalyst exit temperature (°F)	1516	1546	1582
Estimated peak TWT (°F)	1554	1584	1620
Process heat load (MMBtu/hr)	118.2	124.0	130.5
Natural gas fuel flow rate (MSCFH)	61.4	75.4	91.7
ATE (°F)	5	5	5
Pressure drop (psi)	21	21	21
Exit composition (mol%, dry)			
Hydrogen	73.0	73.6	74.3
Nitrogen	0.4	0.4	0.4
Carbon Monoxide	12.4	13.1	13.9
Carbon Dioxide	9.2	8.8	8.4
Methane	5.0	4.0	3.0
Outlet dry gas flow rate (MMSCFD)	39.8	40.8	41.8
Carbon formation	Unlikely	Possible	Possible
Increased hydrogen production	Base	3.45%	7.02%

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Optimization studies (2)

North American Hydrogen Plant

Want to introduce a ROG feed stream

How much feed be could used

What operational changes were needed

S:C ratio	3.0	3.5	4.0	4.5	5.0
SOR feed flow rate (%)	53	64	72	76	78
SOR carbon margin	Unlikely	Unlikely	Unlikely	Unlikely	Unlikely
Three-year feed flow rate (%)	28	34	36	37	37
Three-year carbon margin	Unlikely	Unlikely	Unlikely	Unlikely	Unlikely
EOR feed flow rate (%)	11	12	11	10	9
EOR carbon margin	Likely	Likely	Likely	Likely	Likely

*EOR = 6 years

Optimization studies (3)

North American Hydrogen Plant

Wanted to increase temperature

Needed more H_2

Inexpensive NG

Historical issues made it difficult to increase temperatures

Operators like to run where they felt comfortable

Management didn’t understand what benefit increasing temperature would do

Ran models at various temperatures to show incremental H_2 increase

Optimization studies (3)

KATALCO 25-4Q/23-4GQ
Performance projections

	1496°F current temperature	1506°F exit temperature	1526°F exit temperature
Inlet temperature (°F)		1054	
Inlet S:C		2.85	
Outlet pressure (psig)		315	
Catalyst exit temperature (°F)	1515	1525	1545
Indicated exit temperature (°F)	1496	1506	1526
ATE (°F)	3	4	4
Pressure drop (psi)	30	30	30
Outlet composition (mol%, dry)			
Hydrogen	71.0	71.3	71.9
Nitrogen	0.3	0.3	0.3
Carbon monoxide	12.8	13.1	13.6
Carbon dioxide	8.8	8.6	8.3
Methane	7.1	6.6	5.8
Exit steam-to-dry gas	0.51	0.50	0.49
Exit dry gas flow (MSCFH)	2397	2422	2469
Heat load (MMBtu/hr)	156.5	159.7	166.0
Peak TWT (°F)	1579	1590	1613
Carbon formation	Unlikely	Unlikely	Unlikely
Increase in H_2 Production (%)	Base	1.5	4.2

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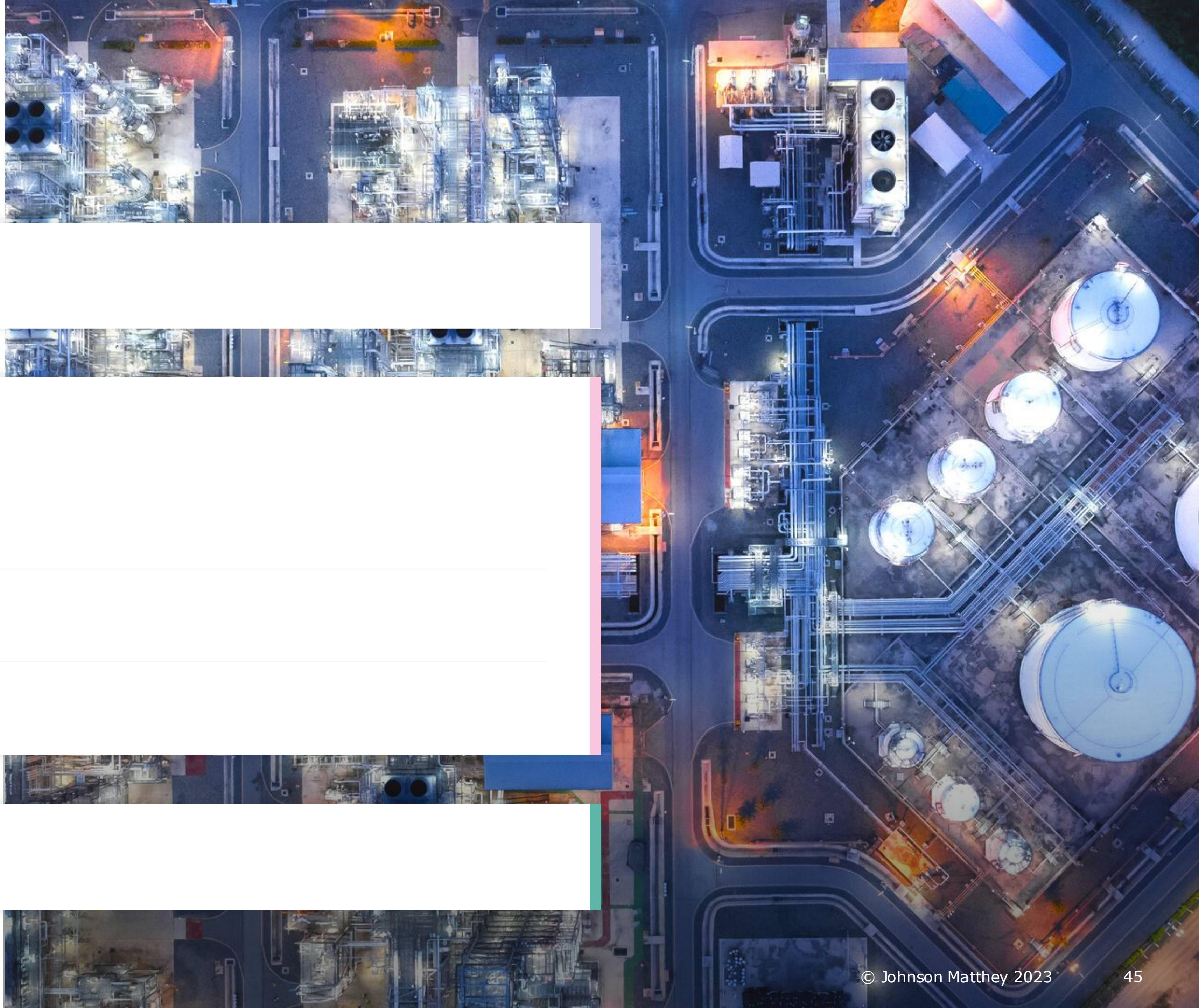

Summary

Many different ways to optimize the reformer

- Catalyst evaluations
- Reformer surveys
- Case studies

Optimization can improve the economics of the hydrogen plant

- Run more efficiently
- Overcome bottlenecks

Johnson Matthey has all the tools to help you optimize your reformer


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Inspiring science, enhancing life