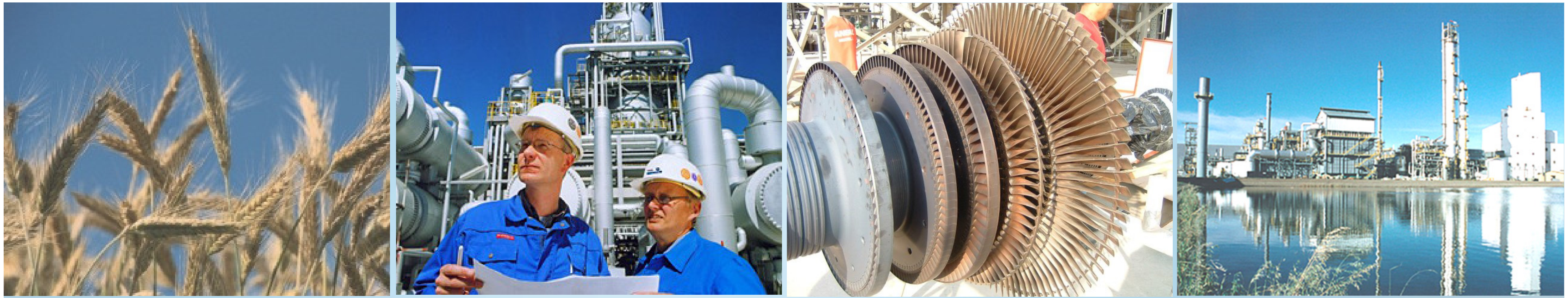

Ammonia Plant Capacity Increase by Autothermal Reforming and Dual Pressure Synthesis

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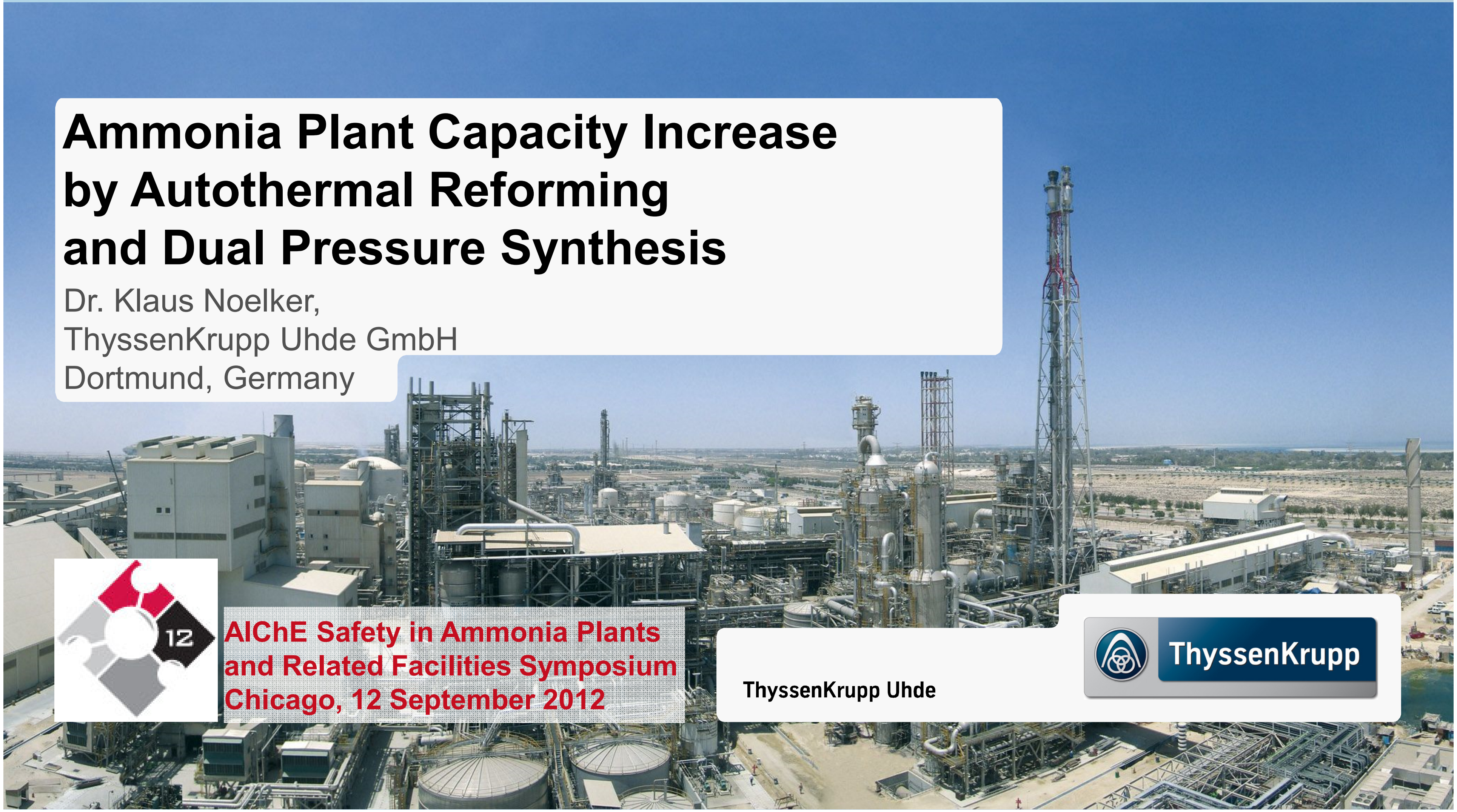
Dortmund, Germany



AIChE Safety in Ammonia Plants
and Related Facilities Symposium
Chicago, 12 September 2012

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Introduction
Ammmonia Plant Capacity Increase

- **Advantages of capacity increase compared to the erection of a new plant:**
  - better adjustment to market growth and feedstock availability
  - lower overall investment
  - faster implementation

  ⇒ much smaller risk

- **Important aspects:**
  - determine the most economical extra capacity
  - select the best revamp concept

Introduction
Scope of the Presentation

- **Investigation**:
  - based on existing old ammonia plant (capacity at the time of the investigation: 1665 mtpd)
  - envisaged a 30 % expansion (500 mtpd)
  - covered areas:
    - entire process plant
    - steam system
    - focus on the synthesis gas generation section
- **Detailed comparison of three different expansion concepts:**

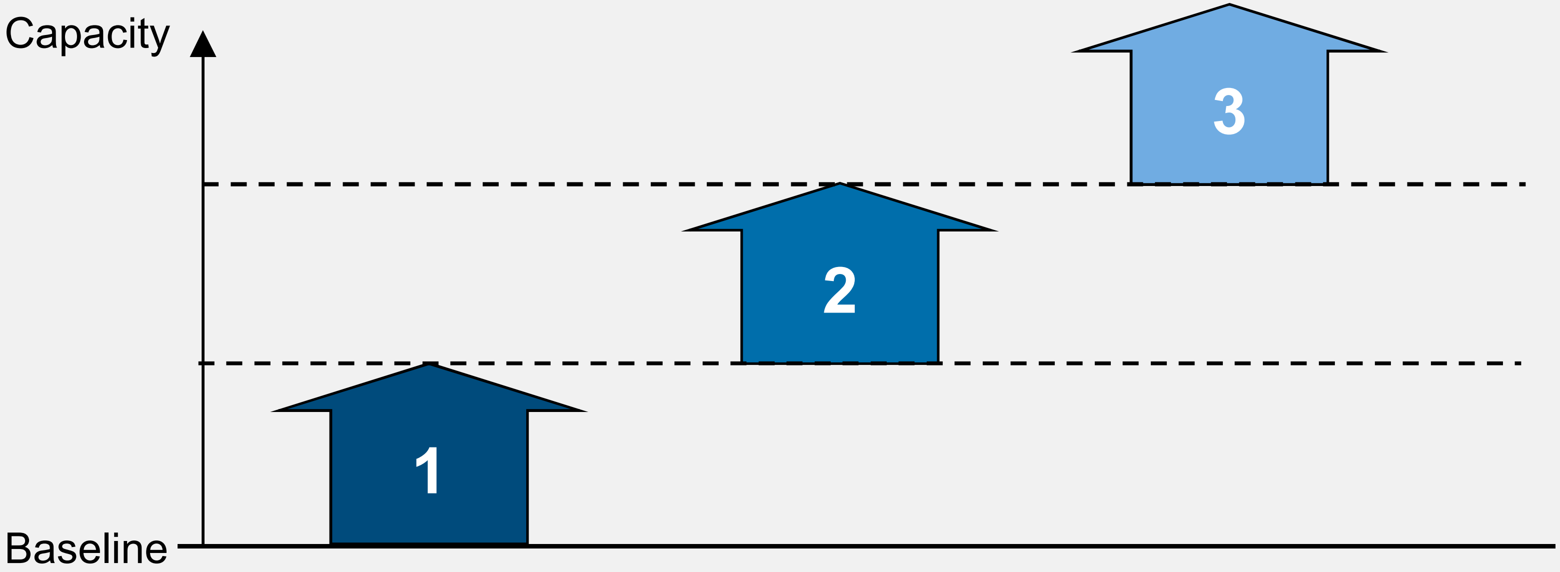
  I. Upgrading of existing steam reformer / secondary reformer

  II. Secondary reformer operation with enriched air

  III. Autothermal reformer (ATR) parallel to existing syngas generation

Basics of Capacity Increase
Economical Requirements

Three distinct ranges of capacity expansion:



utilization of built-in capacity reserves
⇒ no investment

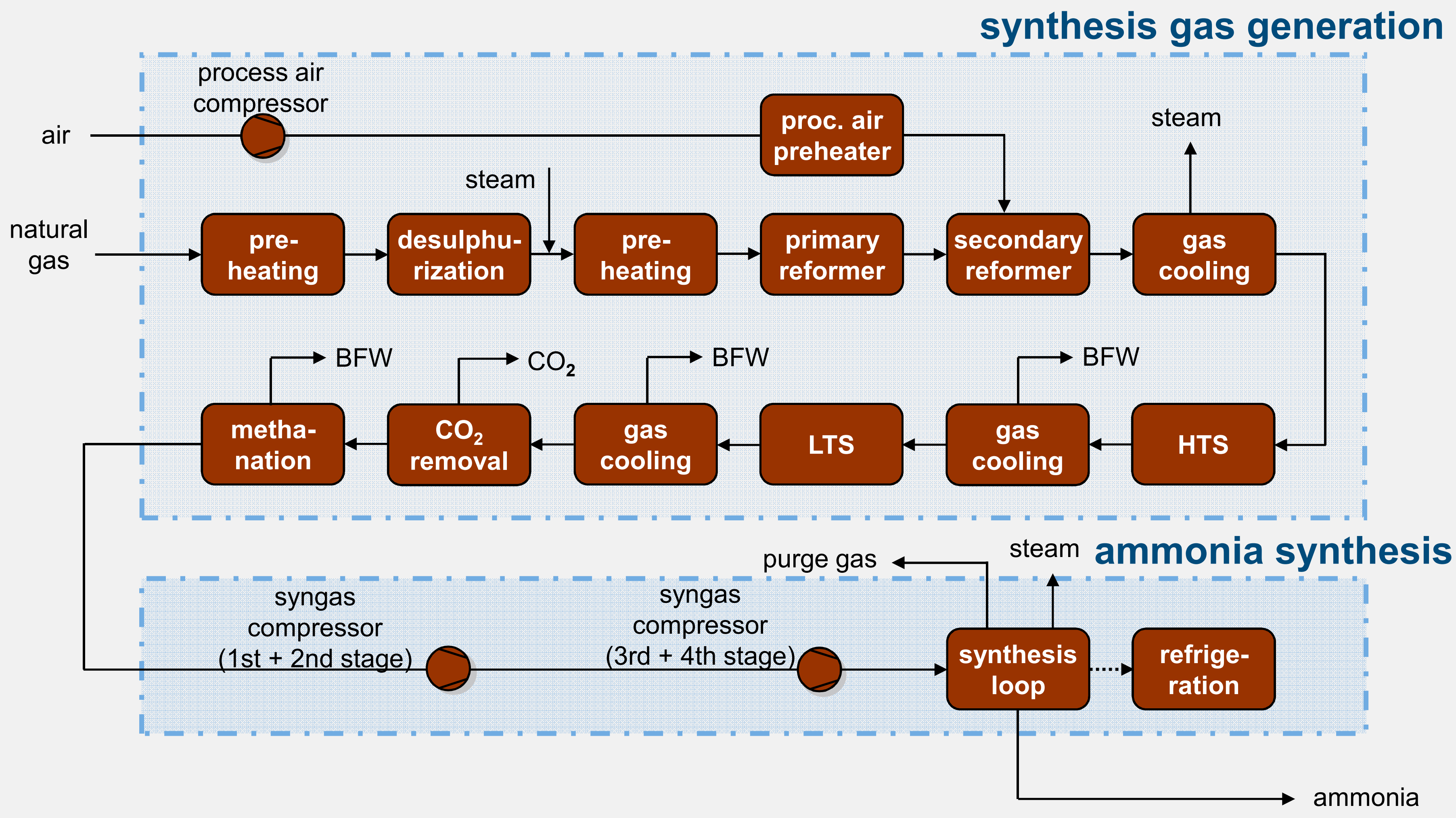
debottlenecking of few units / items
⇒ low investment

substantial plant modification
⇒ high investment

Basics of Capacity Increase
Technical Requirements

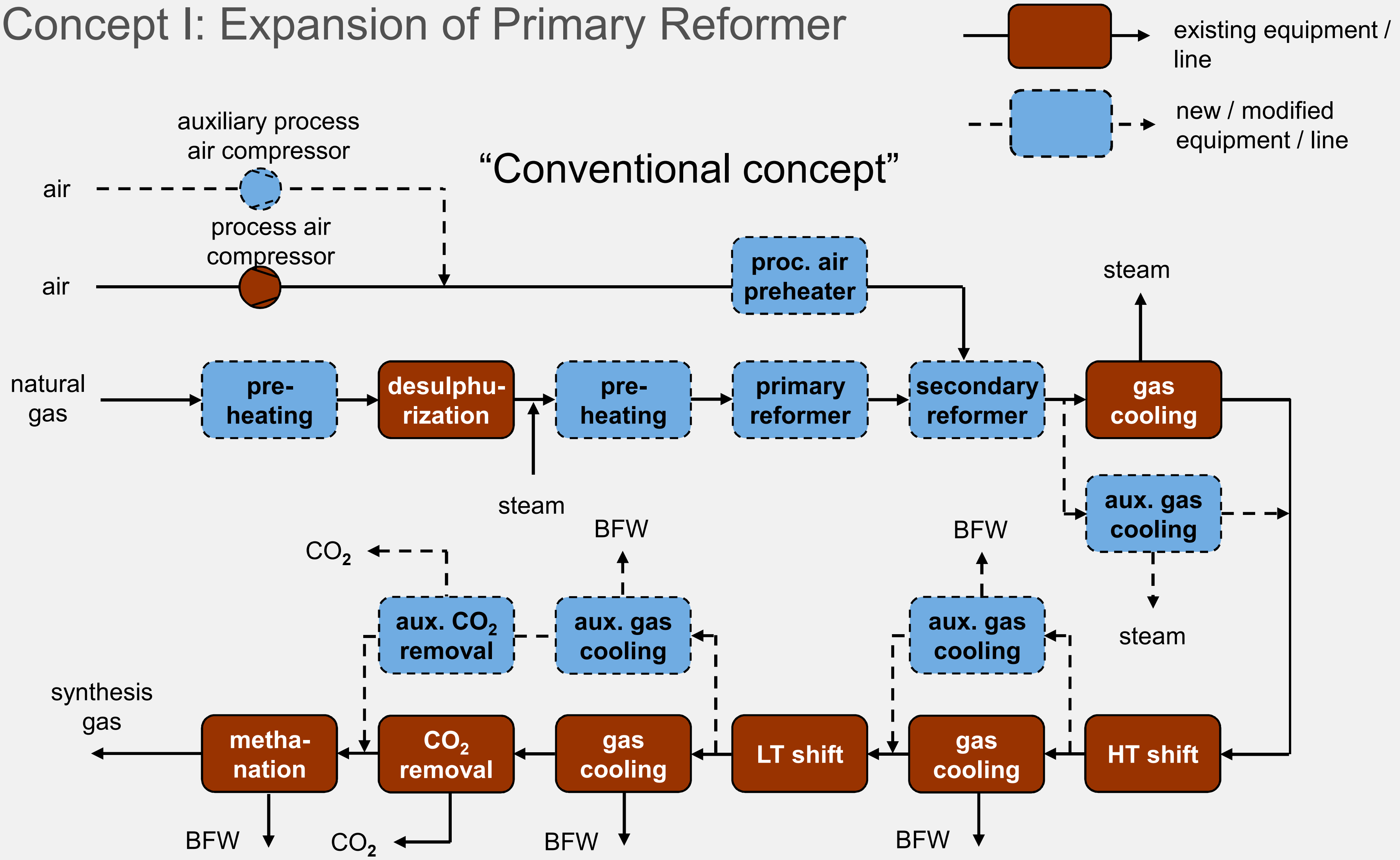
Requirement	Action
Increased flowrates	- compressor / driver improvement - larger cross sectional areas
Transfer larger amounts of heat	- larger heat transfer surfaces - better heat transfer coefficients - increased temperature differences
Maintain reaction conversions	- larger catalyst volumes - modified reaction temp. & press.
Sustain separation of species	- improved internals of separation units - better solvents (solubility / selectivity)

Reference Plant Flowsheet



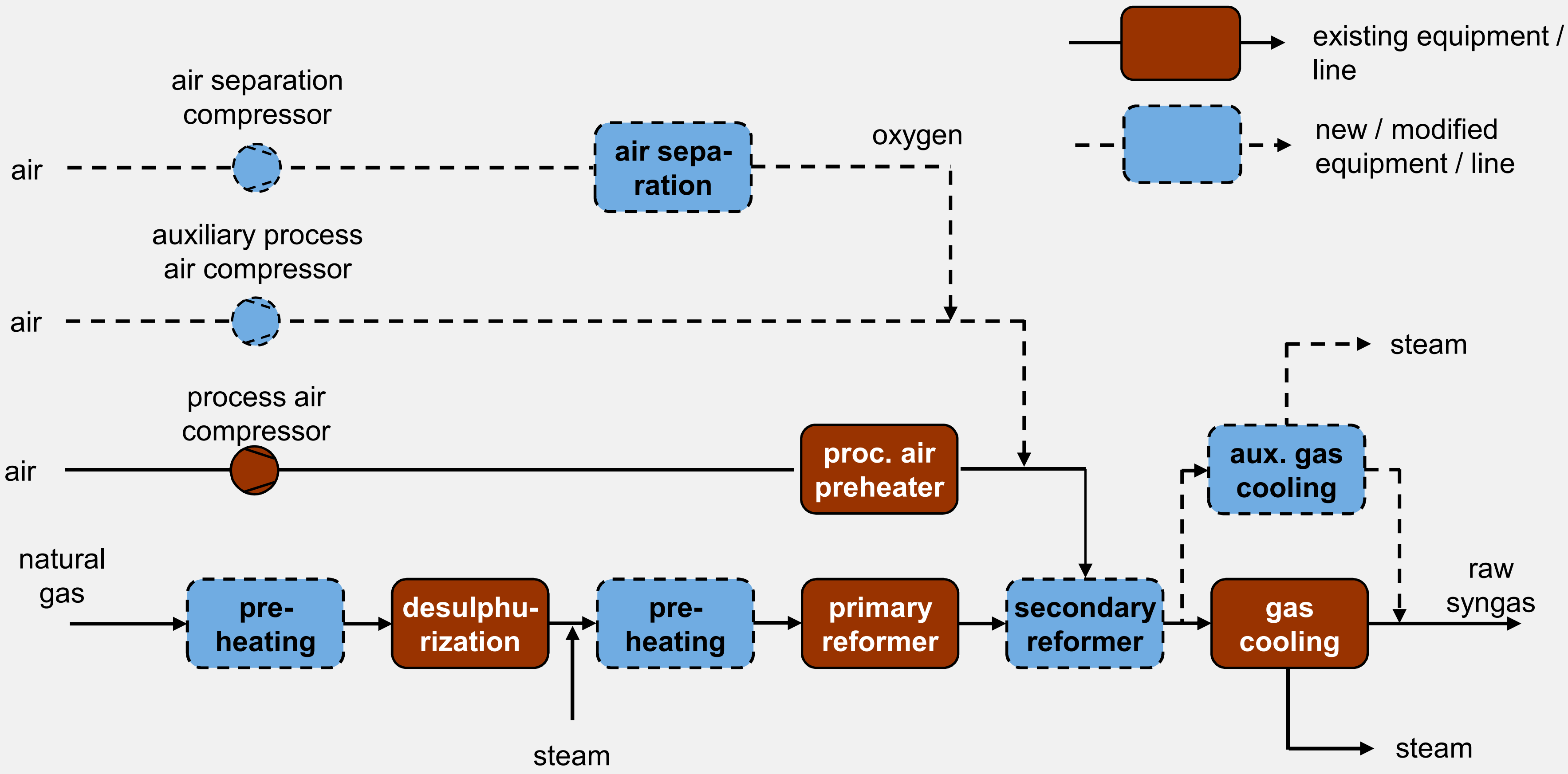
Compared Process Concepts

Concept I: Expansion of Primary Reformer



Compared Process Concepts

Concept II: Secondary Reformer Operation with Enriched Air



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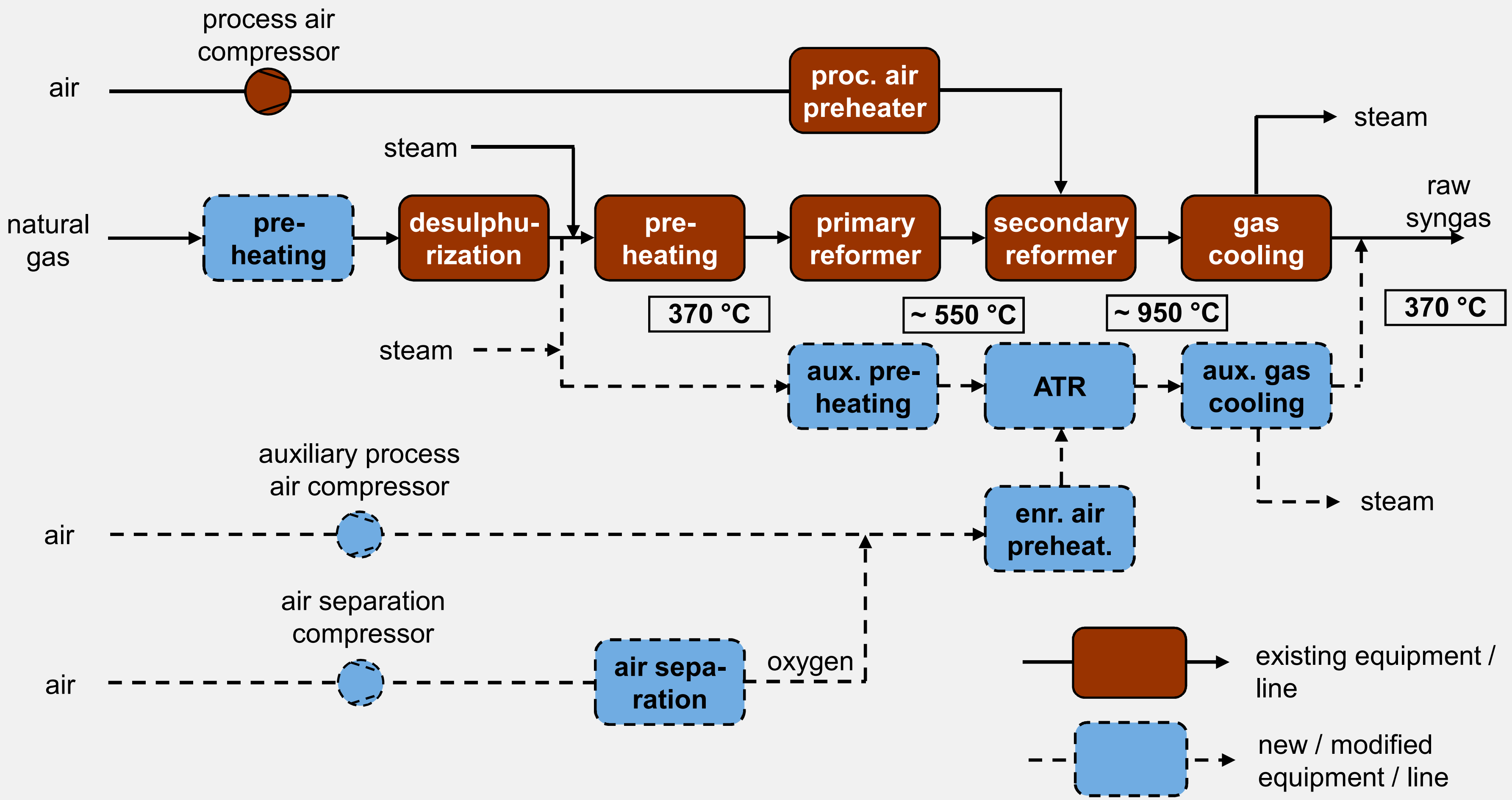
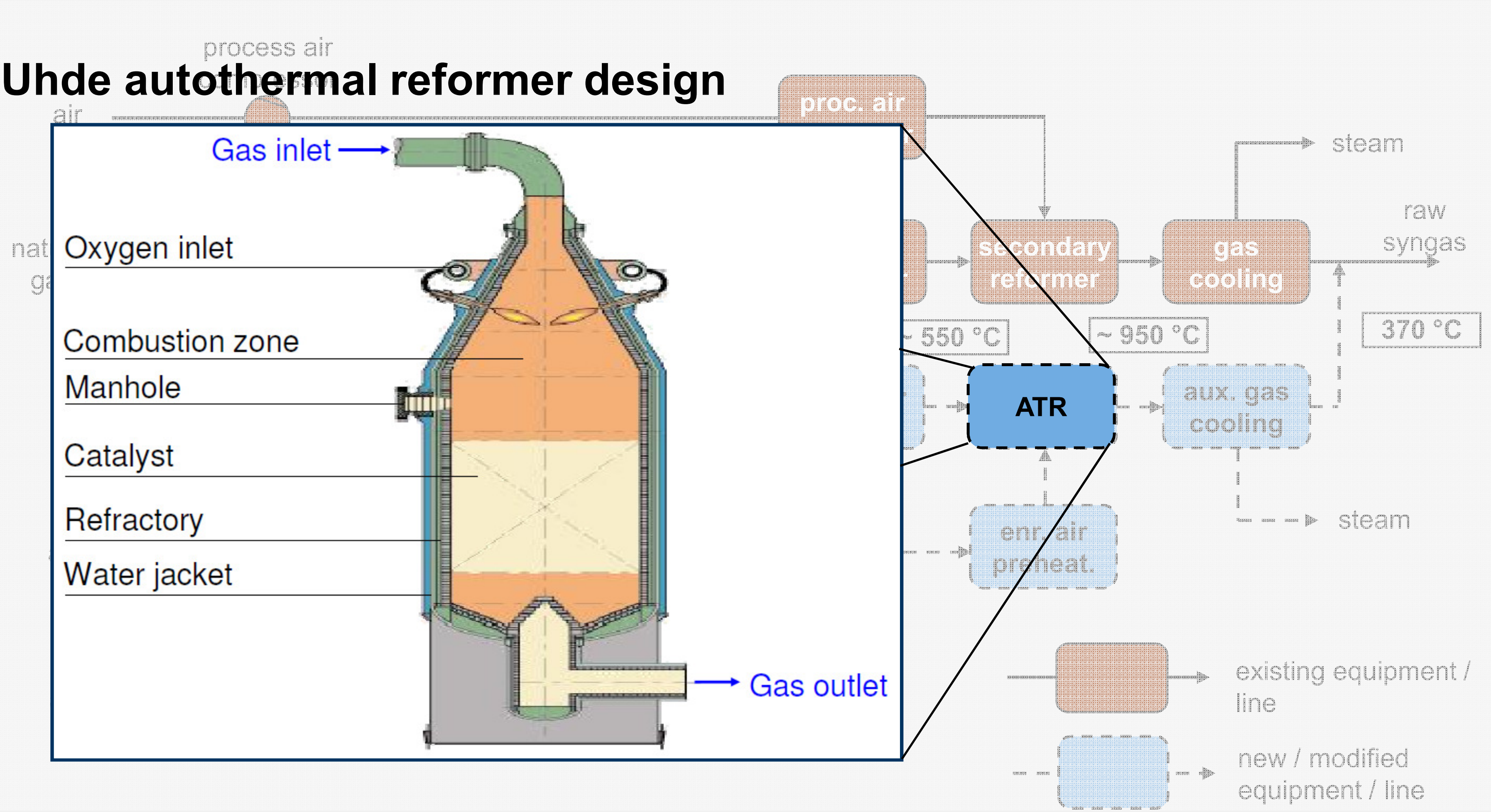
Compared Process Concepts

Concept III: New ATR parallel to Existing Syngas Generation

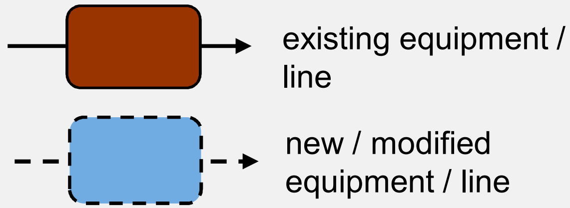


Compared Process Concepts

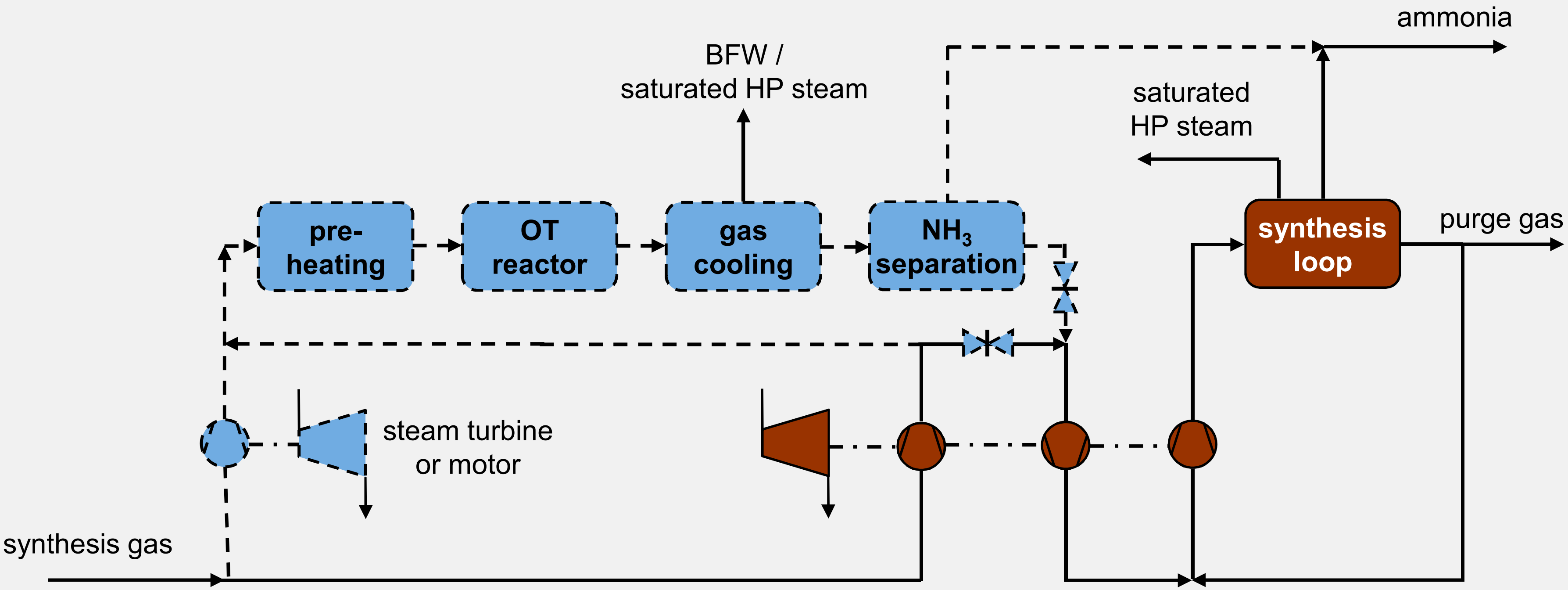
Concept III: New ATR parallel to Existing Syngas Generation



Compared Process Concepts
Ammonia Synthesis



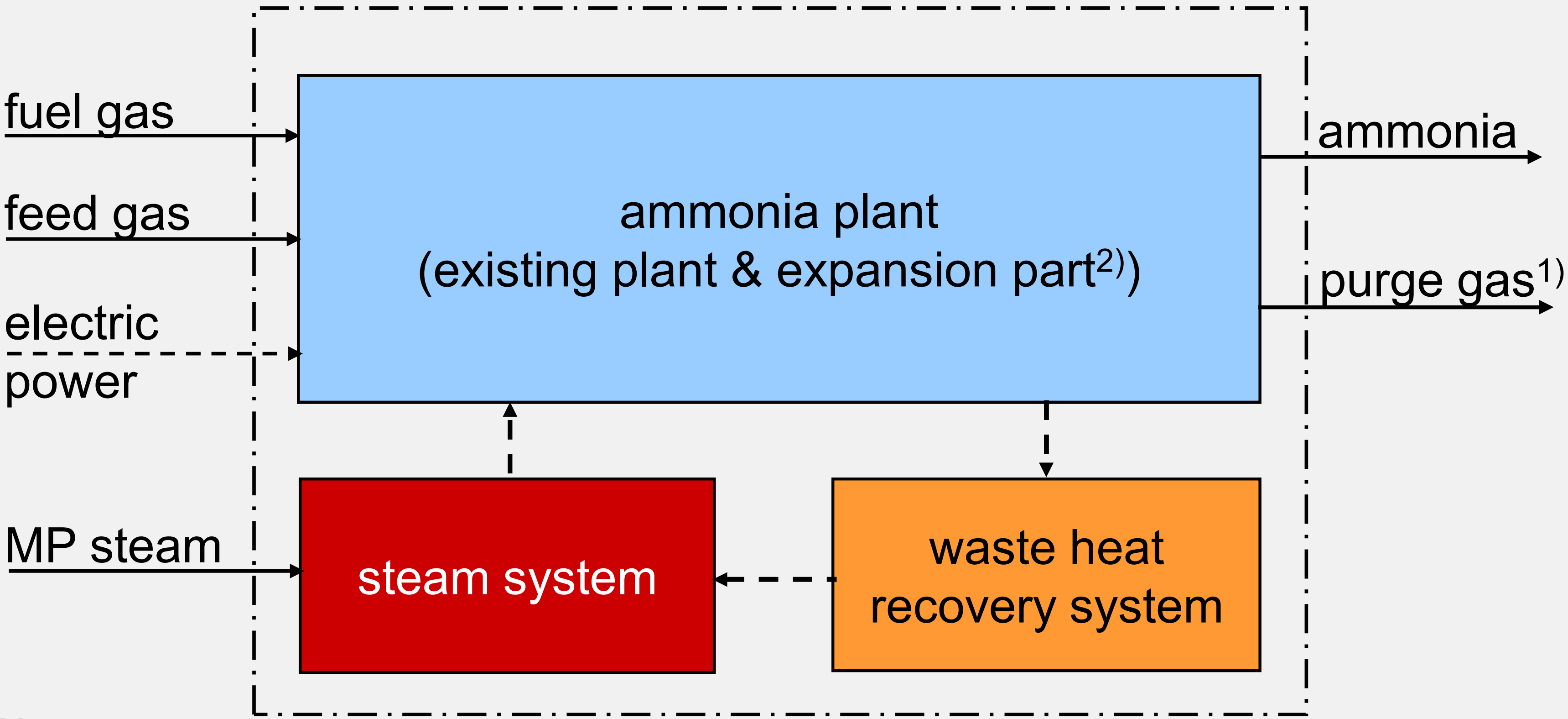
Ammonia synthesis expansion with Uhde dual-pressure concept:



Energy Consumption Evaluation
Methods

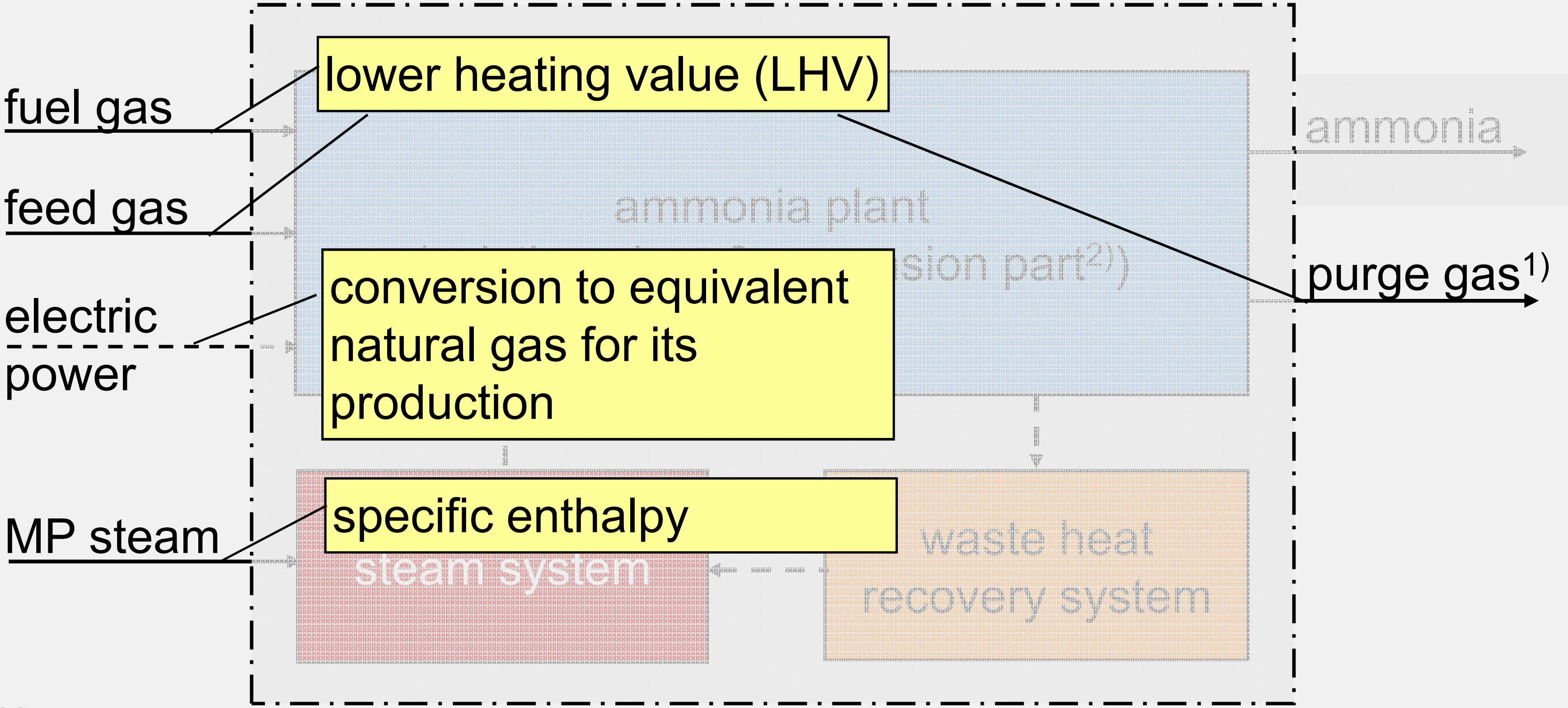
- Mass and energy balances in Aspen Plus
- For process plant and steam system
- Equipment characteristics included in the process models:
  - pressure losses: function of flowrate
  - compressor heads / eff.: function of flowrate, speed
  - heat transfer: function of mean log. temperature diff.

Energy Consumption Evaluation
Method



Notes:
1) purge gas export is desired in this study because it is used in another plant
2) also including air separation unit where applicable

Energy Consumption Evaluation
Method



Notes:
1) purge gas export is desired in this study because it is used in another plant
2) also including air separation unit where applicable

Energy Consumption Evaluation
Results

Item	Unit	Process Concept		
		I	II	III
		Enlarged SMR	SR with enriched air	Parallel ATR
Feed gas	GJ/t NH_3	22.83	24.28	24.15
Fuel gas	GJ/t NH_3	13.28	11.94	11.78
MP steam	GJ/t NH_3	2.07	1.72	1.58
Electricity (converted)	GJ/t NH_3	0.98	1.16	1.15
Purge gas export	GJ/t NH_3	-1.73	-1.79	-1.74
Overall	GJ/t NH_3	37.43	37.31	36.91

Result: ATR-based concept shows lowest overall energy consumption

Investment Cost Evaluation

Calculation of Capital Cost for Expansion Concepts

- Cost estimation for individual equipment items by scaling from reference data:

$$\text{actual cost} = \text{reference cost} \left(\frac{\text{actual capacity}}{\text{reference capacity}} \right)^{\text{exponent}}$$

- Factors applied for cost for engineering, piping, instrumentation etc.
- Entire erection cost for each expansion concept:
  sum of adjusted equipment cost
- Production loss caused by **shutdown time for tie-ins**:
  - Concept III: tie-ins only in cold piping
  - Concept II: new secondary reformer ⇒ need one week more
  - Concept I: difficult work at reformer box ⇒ need four weeks more

Investment Cost Evaluation
Results – Importance of Shutdown Time

Item	Unit	Process Concept		
		I	II	III
		Enlarged SMR	SR with enriched air	Parallel ATR
Erection cost (process and steam sys.)	million USD	157.5	175.1	168.0
Lost profit[1)] by add'l shutdown time	million USD	15.7 (4 weeks)	3.9 (1 week)	0.0
Overall capital cost	million USD	173.3	179.1	168.0

+ 3 %   + 7 %

Note: 1) example: 400 USD/t sales price,
4 USD/MMBTU gas cost

Result: ATR-based concept is most attractive

Overall CAPEX / OPEX Comparison
Method

General aspects:

- All expansion concepts have the same annual production
  $\Rightarrow$ specific production costs represent the economic ranking

$$\text{specific production cost} = \frac{\text{annual CAPEX} + \text{annual OPEX}}{\text{annual production}}$$

- Scenarios for cost evaluation:
  - annual interest rate: 4 or 10 %
  - required payback period: 5 or 15 years
  - specific energy cost: 1.0 or 4.00 USD/MMBTU (LHV)
  - operating days per year: 350

Overall CAPEX / OPEX Comparison
Method

OPEX Considerations:

- Costs / credits included in the OPEX calculation for all streams across B.L.:
  - gas
  - steam
  - electric power

  (same as for calculation of consumption figure)
- All other costs contributing to OPEX, e.g:
  - staff
  - maintenance
  - tax

  assumed to be same for all concepts $\Rightarrow$ therefore excluded

Overall CAPEX / OPEX Comparison

Resuling Specific Production Cost, based on CAPEX and OPEX

Economic scenario			Production cost for process concept		
Energy cost	Annual interest rate	Payback period	I	II	III
			Enlarged SMR	SR with enriched air	Parallel ATR
USD/MMBTU	%	years	USD/t	USD/t	USD/t
1.0	4	15	128	129	122
	10	5	307	309	289
4.0	4	15	231	234	226
	10	5	404	412	394

Result: ATR-based concept shows lowest overall production cost, irrespective of energy cost, interest rate and payback period

CO_2 Production
Comparison

CO_2 emission:

- CO_2 containing streams emitted by the ammonia plant and its utilities:
  - flue gas from reformer stack (ISBL)
  - flue gas from boiler stack (OSBL)
  - vent from CO_2 removal unit

approx. 10 % CO_2, ambient pressure

approx. 99.5 % CO_2, 1.3 – 1.7 bar abs.: easily available for urea production

CO_2 and Urea Production

Comparison

CO_2 and urea production after revamp at 2,180 t/d ammonia production:

Stream	Unit	Process Concept		
		I	II	III
		Enlarged SMR	SR with enriched air	Parallel ATR
Total CO_2 generation	$t\ CO_2 / t\ NH_3$	2.10	2.09	2.06
CO_2 available for urea	$t\ CO_2 / t\ NH_3$	1.16	1.23	1.20
Max. urea production	t/d	3,449	3,667	3,650

+ 6.1 % + 5.8 %

Result: Concepts II and III offer more CO_2 to be used for urea, less CO_2 emission

Summary

- Investigation on economics of ammonia plant production increase
- Focus on synthesis gas generation – three options compared
- NH_3 synthesis: same concept for applied to all cases
- Result: economic ranking between the concepts, based on CAPEX and OPEX data
- Conclusion:
  A stand-alone ATR parallel to the existing syngas generation:
  - is a very competitive alternative
  - requires minimum interference with the existing plant
  - is the superior solution if full implementation costs (shutdown time, risks) are taken into consideration
  - makes more CO_2 available for urea production compared to conventional concept

Thank you
for your attention!

Questions?

Comments?

Suggestions?

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