# Comparison of synthesis gas generation concepts for capacity enlargement of ammonia plants

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# Capacity enlargement of ammonia plants

**Contents:**

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- **Introduction**
- Basics of capacity enlargements
- Compared process concepts
- Energy consumption evaluation
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# Introduction (1)

## Basic situation

- Advantages of capacity enlargements compared to the erection of a new plant
  - – better adjustment to market growth
  - – lower overall investment
  - – faster implementation
  - ⇨ much smaller risk
- The success of a revamp is not independent of
  - > the chosen revamp concept
  - > the amount of additional capacity
- It is therefore of prime importance
  - ⇨ to select the best overall revamp concept and
  - ⇨ to determine the most economical extra capacity

# Introduction (2)

## Scope of the presentation

- **Presentation reports the results of a detailed comparison of three different expansion concepts**
- **Investigation**
  - was based on an existing older ammonia plant
    (reference plant capacity at the time of the investigation ~1665 mtpd)
  - envisaged a 30% expansion ( ~ 500 mtpd)
  - mainly focused on the synthesis gas generation section
  - covered the entire process plant and the steam system
- **Compared synthesis gas generation expansion concepts**
  I. Upgrading of existing steam reformer / secondary reformer
  II. Secondary reformer operation with enriched air
  III. Stand-alone autothermal reformer (ATR) parallel to existing syngas generation

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# Basics of capacity enlargements (1)

## Economical requirements

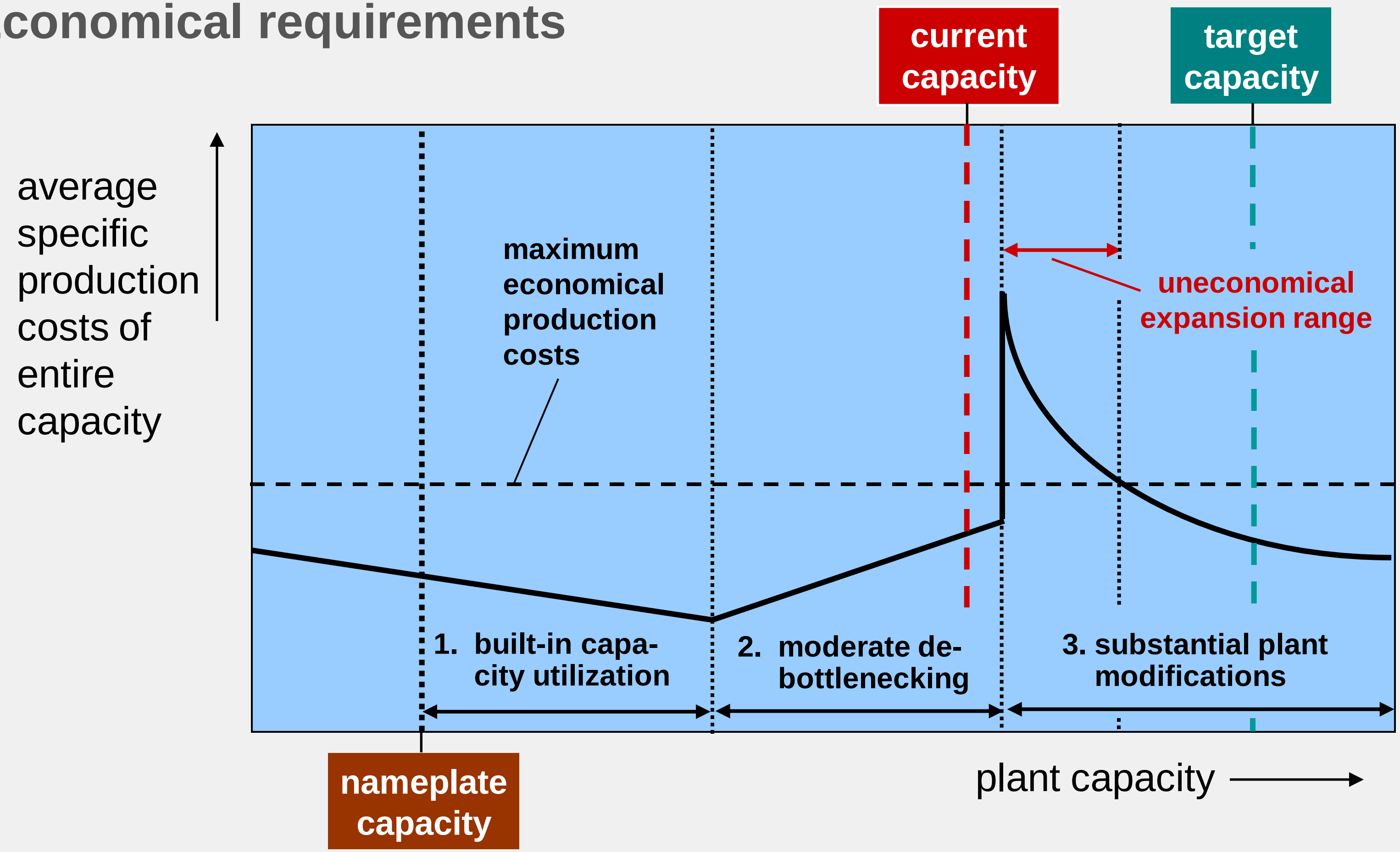
- ➢ **Capacity expansions can usually be assigned to 3 distinct ranges**
  1. **utilization of built-in capacity reserves**
  2. **debottlenecking of limited numbers of process units / equipment items**
  3. **substantial plant modifications**

⇨ **Specific production costs of the additional capacity show significantly different characteristics in these 3 ranges**

- ➢ **Maximum economical capacity depends on the**
  - → **reserves originally built into the individual process units**
  - → **plant location (feedstock cost and availability)**
  - → **market situation**

# Basics of capacity enlargements (2)

## Economical requirements




⇨ **In general, a detailed investigation is required to determine the situation of a plant and the most suitable expansion capacity**

# Basics of capacity enlargements (3)

## Technical requirements

| Requirements | Countermeasures |
|---|---|
| Increase flowrates through process flowpath | - compressor / driver improvement<br>- larger cross sectional areas |
| Transfer larger amounts of heat | - larger heat transfer surfaces<br>- better heat transfer coefficients<br>- increased temperature differences |
| Maintain reaction conversions | - elevated reaction temperatures & press.<br>- larger catalyst volumes |
| Sustain separation of species | - improved internals of separation units<br>- better solvents (solubility / selectivity) |

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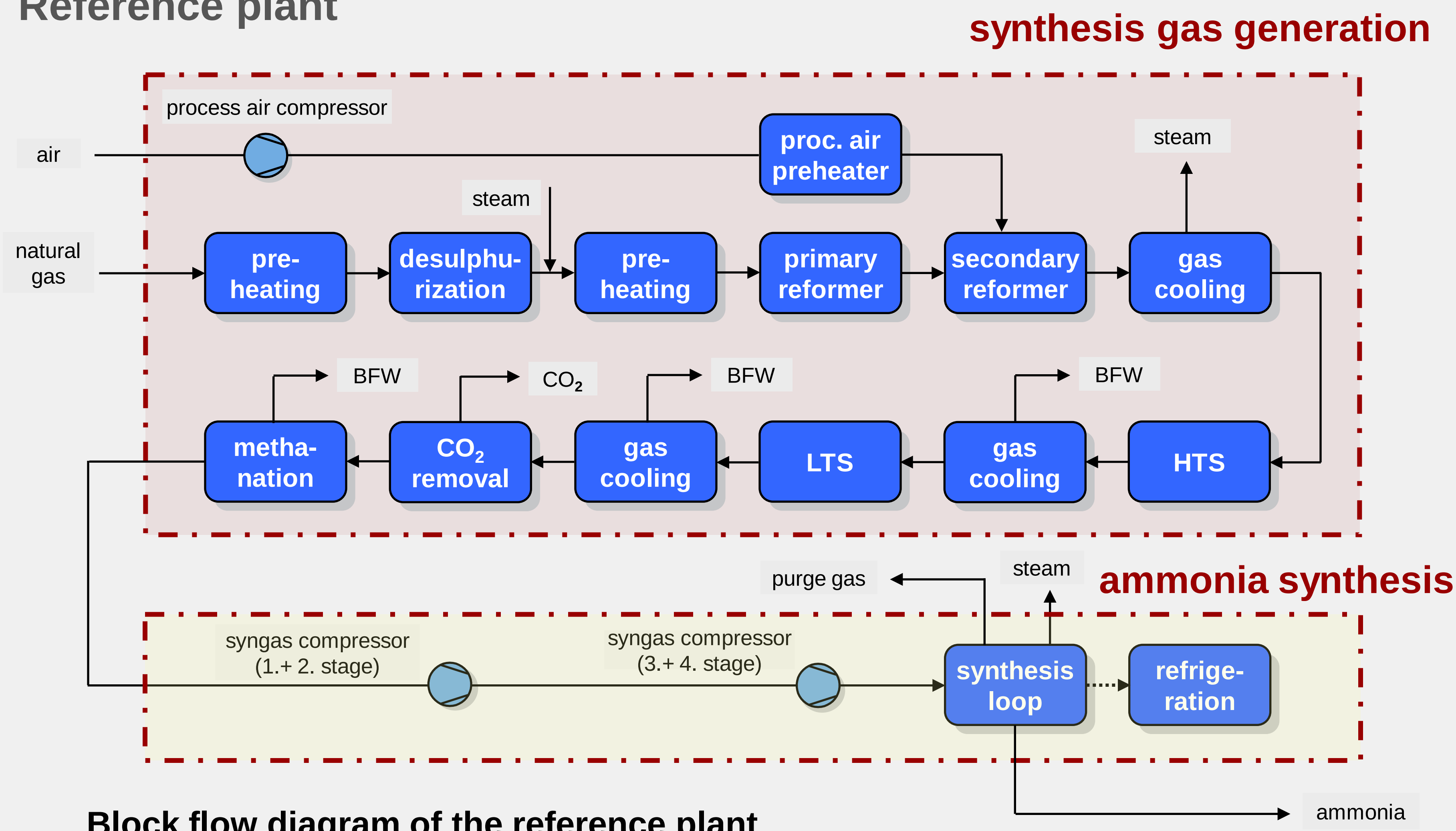
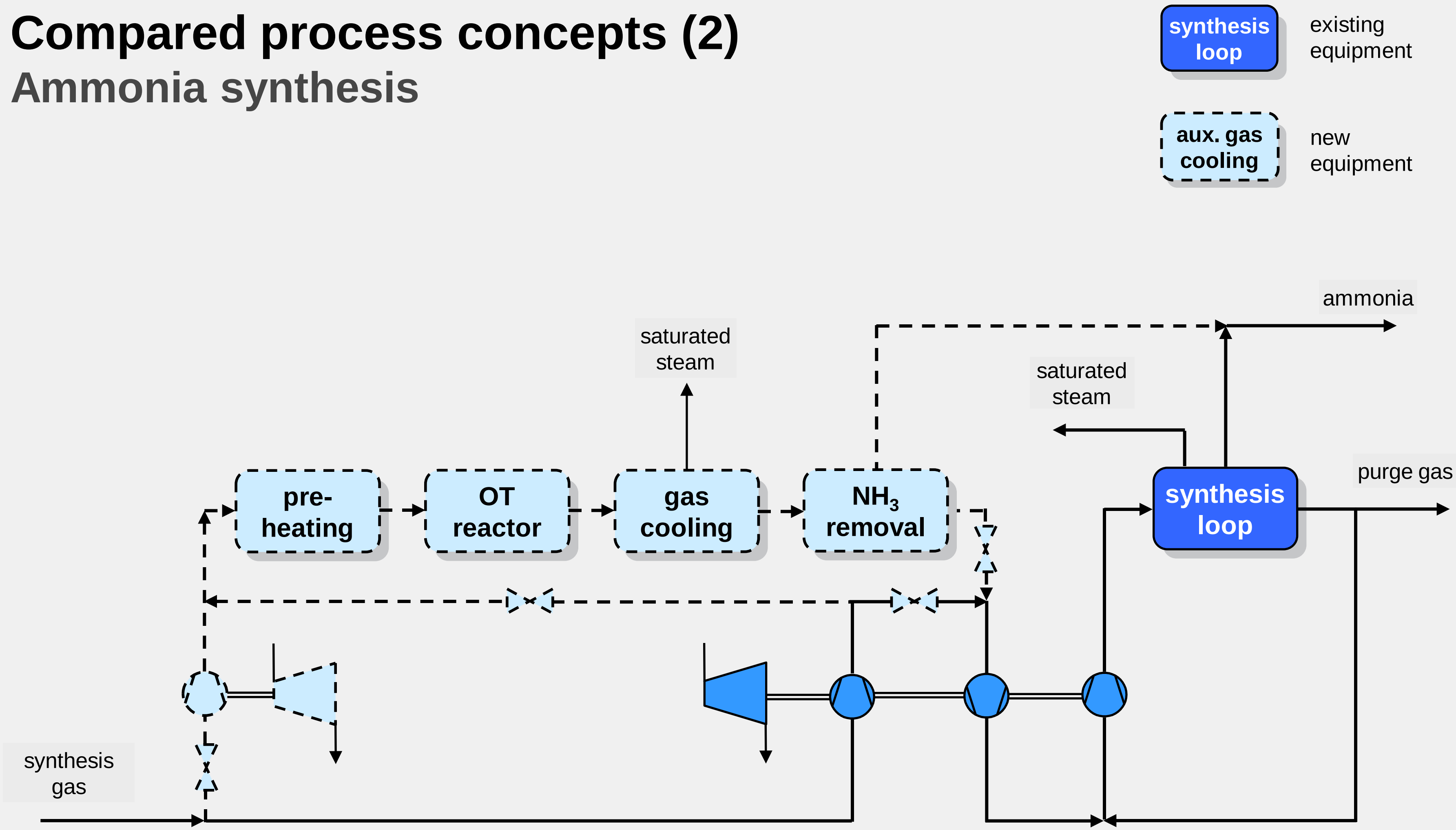
# Compared process concepts (1)

## Reference plant




**Block flow diagram of the reference plant**

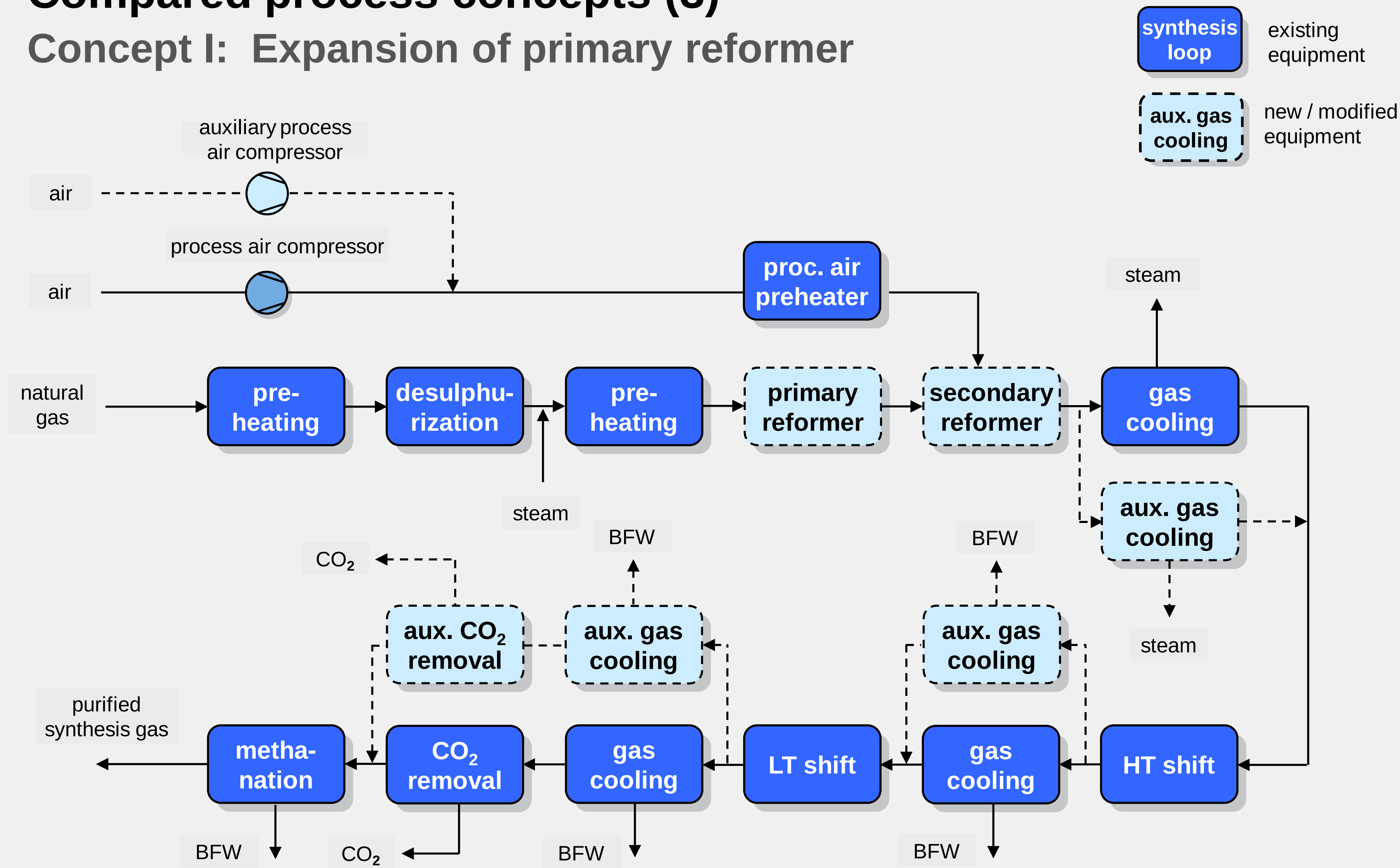
# Compared process concepts (2)
## Ammonia synthesis




**Ammonia synthesis expansion with Uhde dual-pressure concept**

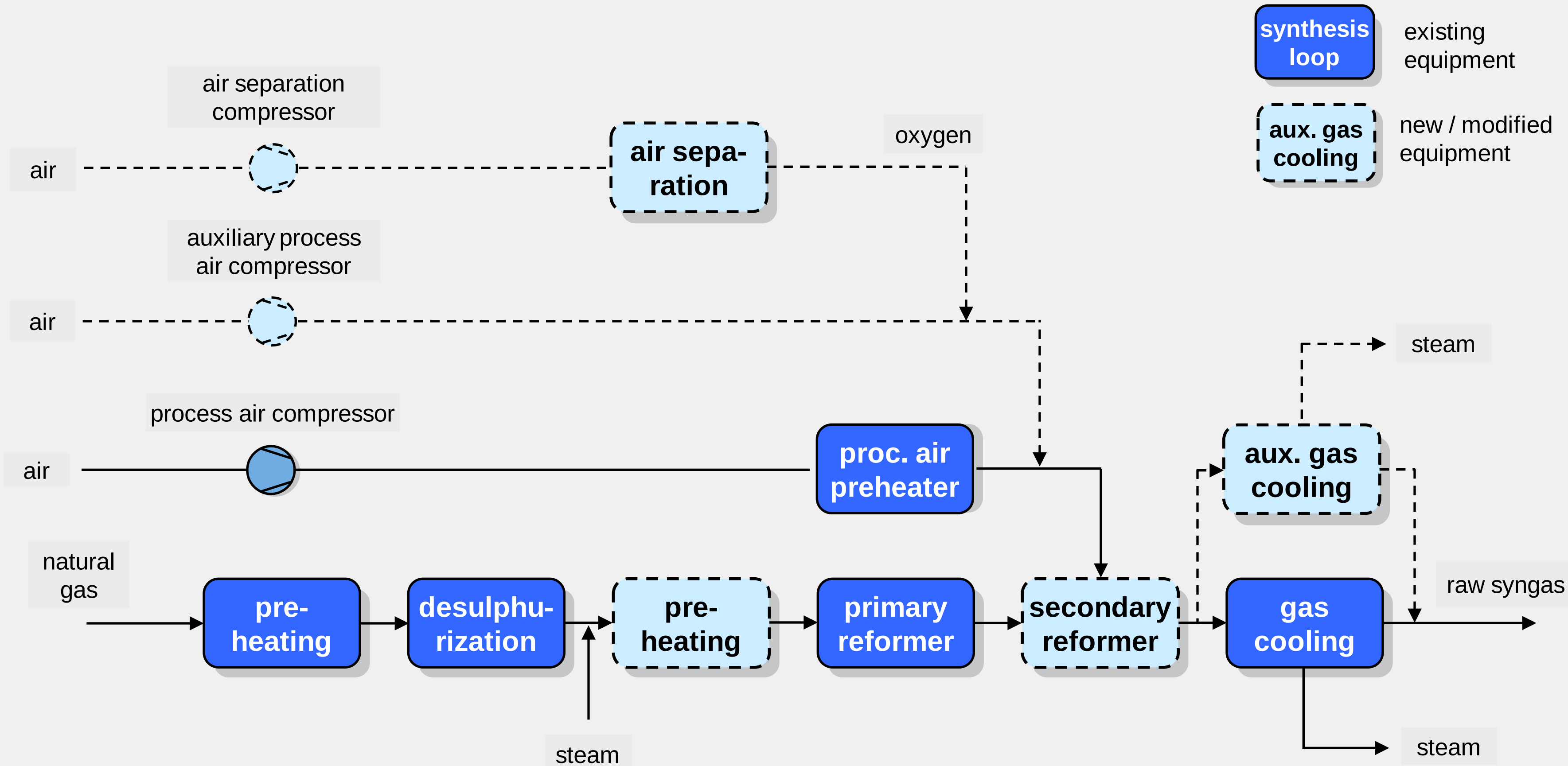
# Compared process concepts (3)

## Concept I: Expansion of primary reformer



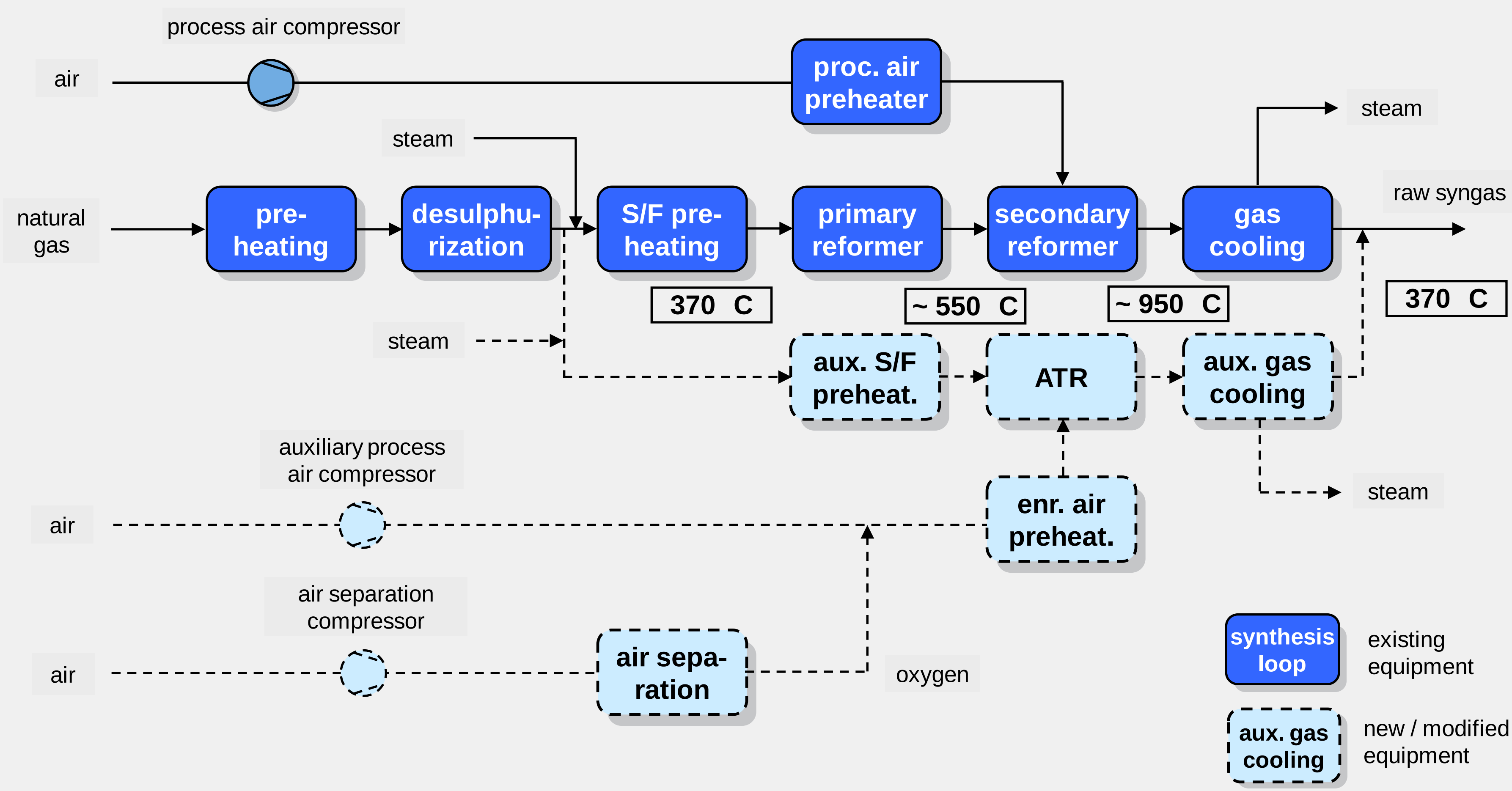
# Compared process concepts (4)

## Concept II: Secondary reformer operation with enriched air



# Compared process concepts (5)

## Concept III: New ATR parallel to existing synthesis gas generation



# Compared process concepts (6)

## Main equipment items in the expansion concepts

| | expansion concept | | |
|---|---|---|---|
| | I | II | III |
| new or modified main equipment item | enlarged SMR | sec. ref. with enriched air | ATR |
| auxiliary air compressor | x | x | x |
| air separation unit | | x | x |
| steam reformer oven box expansion | x | | |
| combustion air fan | x | | |
| flue gas fan | x | | |
| secondary reformer replacement / modification | o | x | |
| autothermal reformer | | | x |
| fired heater | | | x |
| process air preheating | o | o | |
| combustion air preheating | o | o | |
| feed / steam preheating coil | o | o | |
| natural gas preheating coil | o | o | o |
| waste heat boiler & steam drum | x | x | x |
| auxiliary synthesis gas compressor | x | x | x |
| once-through (OT) synthesis | x | x | x |
| $CO_2$ absorber | x | x | x |

x new equipment

o modified equipment

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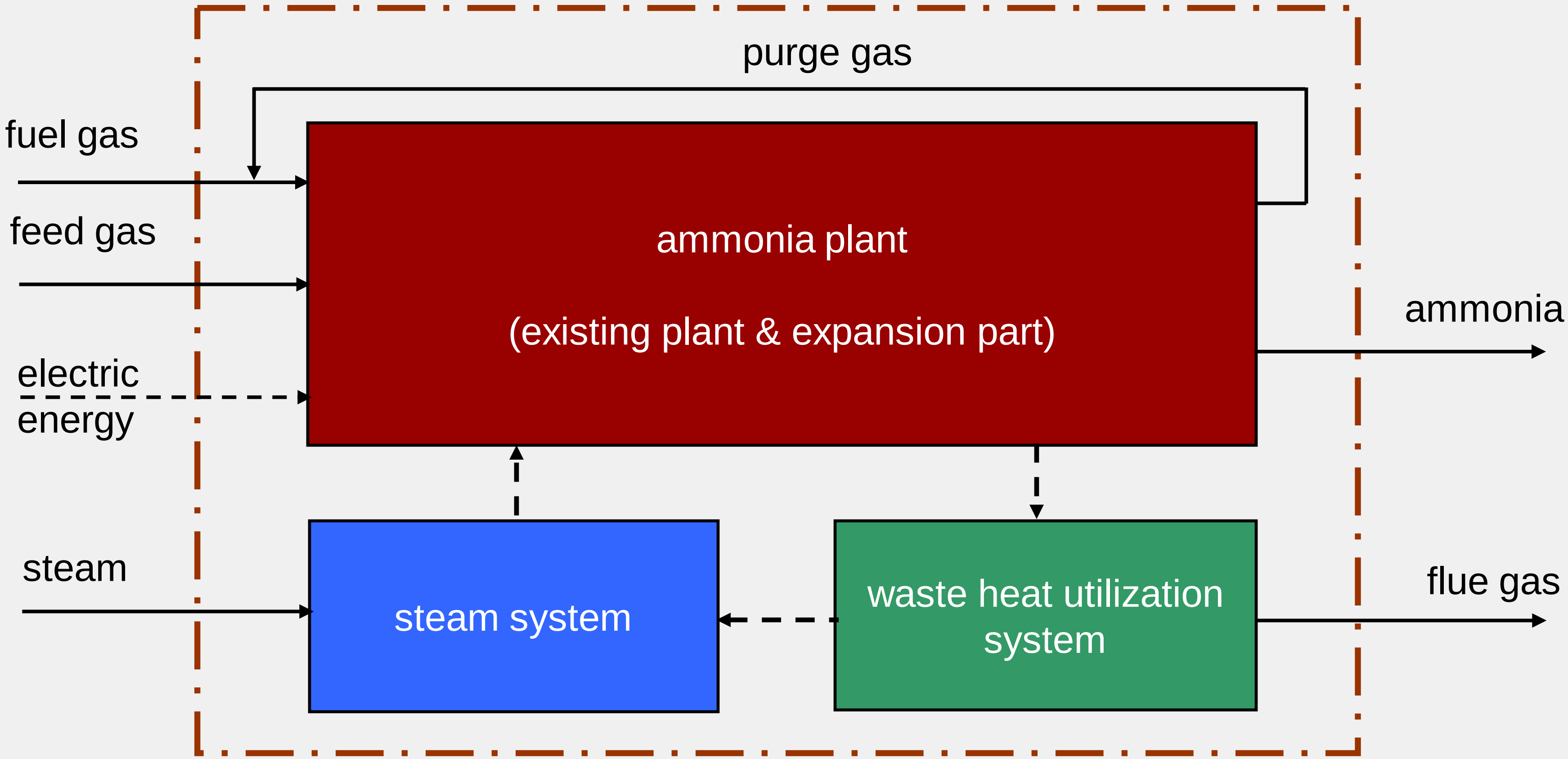
# Energy consumption evaluation (1)

## Methodology




Relevant utilities and balanced plant sections

# Energy consumption evaluation (2)

## Methodology

- Calculation of individual utilities consumptions via Aspen Plus-based material and heat balances
- Calculations contained entire process plants and steam systems
- Equipment characteristics included in the process models
  - pressure losses := f (flowrate)
  - compressor heads / eff. := f (flowrate; speed)
  - heat transfer := f (mean log. temperatur difference)

**Transformation of utilities consumptions into equivalent energy consumptions:**

- ➢ feed and fuel gas ⇔ lower heating values (LHV)
- ➢ steam ⇔ specific enthalpy
- ➢ electric power ⇔ 30% overall eff. from nat. gas to el. power
- ➢ purge gas ammonia synthesis ⇔ lower heating value

# Energy consumption evaluation (3)

## Results

<u>Individual energy consumption figures of the expansion concepts</u>

| | | revamp concept | | |
|---|---|---|---|---|
| | | I | II | III |
| **utility** | **unit** | **enlarged SMR** | **sec. ref. with enriched air** | **ATR** |
| feed gas | Gcal / $t_{NH3}$ | 5,45 | 5,80 | 5,77 |
| fuel gas | Gcal / $t_{NH3}$ | 2,76 | 2,42 | 2,39 |
| imported MP steam | Gcal / $t_{NH3}$ | 0,50 | 0,41 | 0,38 |
| electrical power | Gcal / $t_{NH3}$ | 0,23 | 0,28 | 0,27 |
| **overall spec. cons.** | **Gcal / $t_{NH3}$** | **8,94** | **8,91** | **8,81** |

**Result:** ATR-based concept shows lowest overall energy consumption

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# Investment cost evaluation (1)

## Calculation of capital cost for each expansion concept

- **Scaling of individual equipment cost via**

$$\frac{C_{rc,i}}{C_{bc,i}} = \left( \frac{V_{rc,i}}{V_{bc,i}} \right)^{\alpha}$$

| | |
|---|---|
| C | capital cost of equipment "i" |
| V | volume flowrate |
| rc | revamp concept component |
| bc | base / reference component |
| $\alpha$ | cost escalation exponent |

- **Cost for engineering, piping, instrumentation etc. accounted for through cost escalation factors to individual equipment cost**
- **Entire erection costs for each expansion concept derived as sum of adjusted equipment cost**

# Capital cost evaluation (3)

## Importance of tie-in time

Expansion concepts are associated with significantly different tie-in time spans

→ **considerable differences in lost production revenues**

| | | expansion concept | | |
|---|---|---|---|---|
| | | I | II | III |
| **subject** | **unit** | **enlarged SMR** | **sec. ref. with enriched air** | **ATR** |
| tie-in situation | --- | reconstruction of steam reformer | replacement / modific. of sec. reformer | only non-critical tie-ins |
| add. downtime beyond regular maintenance shutdown | days | 28 | 7 | 0 |
| **add. lost production revenue*)** | **Mio. USD** | **16,8** | **4,2** | **0,0** |

*) lost prod. revenue of 0,6 Mio USD/d assumed (400 USD/$mt_{NH3}$, 3,0 USD/MMBTU)

# Capital cost evaluation (4)

## Results

Capital cost of the expansion concepts in Mio. USD

| | expansion concept | | |
|---|---|---|---|
| | I | II | III |
| **plant section / cost component** | **enlarged SMR** | **sec. ref. with enriched air** | **ATR** |
| synthesis gas generation | 80,40 | 98,40 | 93,70 |
| OT synthesis | 71,20 | 71,60 | 69,10 |
| steam system | 2,10 | 2,20 | 2,10 |
| reformer waste heat section | 3,90 | 2,90 | 3,10 |
| basic erection cost | 157,60 | 175,10 | 168,00 |
| lost production revenue | 16,80 | 4,20 | 0,00 |
| **total capital cost** | **174,40** | **179,30** | **168,00** |

**Result:** ATR-based concept shows lowest overall investment costs

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# Overall CAPEX / OPEX comparison (1)

## Methodology

**General**

- All expansion concepts have the same annual turnover
  - ⇒ specific production costs reflect the economic ranking

- Individual specific production costs are calculated according to

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

# Overall CAPEX / OPEX comparison (2)

## Methodology

**Operating expenditure (OPEX)**

- Costs / credits included in the OPEX calculation for
  - feed and fuel gas
  - steam
  - electrical energy
  - purge gas ammonia synthesis
- All other costs contributing to OPEX e.g. for
  > staff
  > maintenance
  > tax

  assumed to be the same for all expansion concepts and therefore excluded.

# Overall CAPEX / OPEX comparison (3)

## Methodology

**Capital Expenditure (CAPEX)**

- Calculation of annual capital costs (annuity) via

$$\text{annual CAPEX} = \frac{\text{plant capital cost} + \Sigma \text{ interest (entire payback period)}}{\text{required capital payback period}}$$

- Equal interest rates for equity and loans
- Scenarios considered to illustrate the influence of capital and energy costs
  - Annual interest rates: 5 / 15 %
  - Capital payback period: 5 / 15 yrs.
  - Specific energy cost: 0,75 / 3,00 USD/MMBTU

# Overall CAPEX / OPEX comparison (4)

## Results

Specific production costs of the expansion concepts in USD / $t_{NH3}$

| | | | expansion concept | | |
|---|---|---|---|---|---|
| | | | I | II | III |
| **spec. energy cost (USD/MMBTU)** | **annual interest rate [%]** | **capital payback period [yrs.]** | **enlarged SMR** | **sec. ref. with enriched air** | **ATR** |
| 0,75 | 5 | 15 | 128 | 130 | 123 |
| | 15 | 5 | 329 | 336 | 316 |
| 3 | 5 | 15 | 212 | 210 | 203 |
| | 15 | 5 | 412 | 416 | 395 |

- ATR-based concept shows lowest production costs in all cases, irrespective of energy cost, requested capital payback time and annual interest rate.
- Significant margins in all scenarios to cover costs not accounted for in this comparison.

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# Summary

- **Presentation reported the results of an investigation concerned with the economics of ammonia plant production expansion**
- **Main focus on the synthesis gas generation**
  - → **Same $NH_3$ synthesis expansion concept applied for all revamp concepts**
- **Investigation established an economic ranking between the expansion concepts via a CAPEX + OPEX comparison**
- **<u>Conclusion</u>:**

  **A stand–alone ATR parallel to the existing syngas generation**

  - ⇨ **is a very competitive alternative in general**
  - ⇨ **requires minimum interference with the existing plant**
  - ⇨ **is the superior solution if full implementation costs and associated risks are taken into consideration**

# Thanks for your attention

Questions

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Comments

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Suggestions

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