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Analytical Solutions for Oil & Gas
Blue Hydrogen Clean Energy Projects

AGENDA

Topic Highlights:

- Clean Energy trends that are driving blue hydrogen in the Oil & Gas market
- Types of processes to generate blue hydrogen
- Critical measurements within each process

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O&G Decarbonizes Via Efficiency, Emission Capture, & H2 Fuel

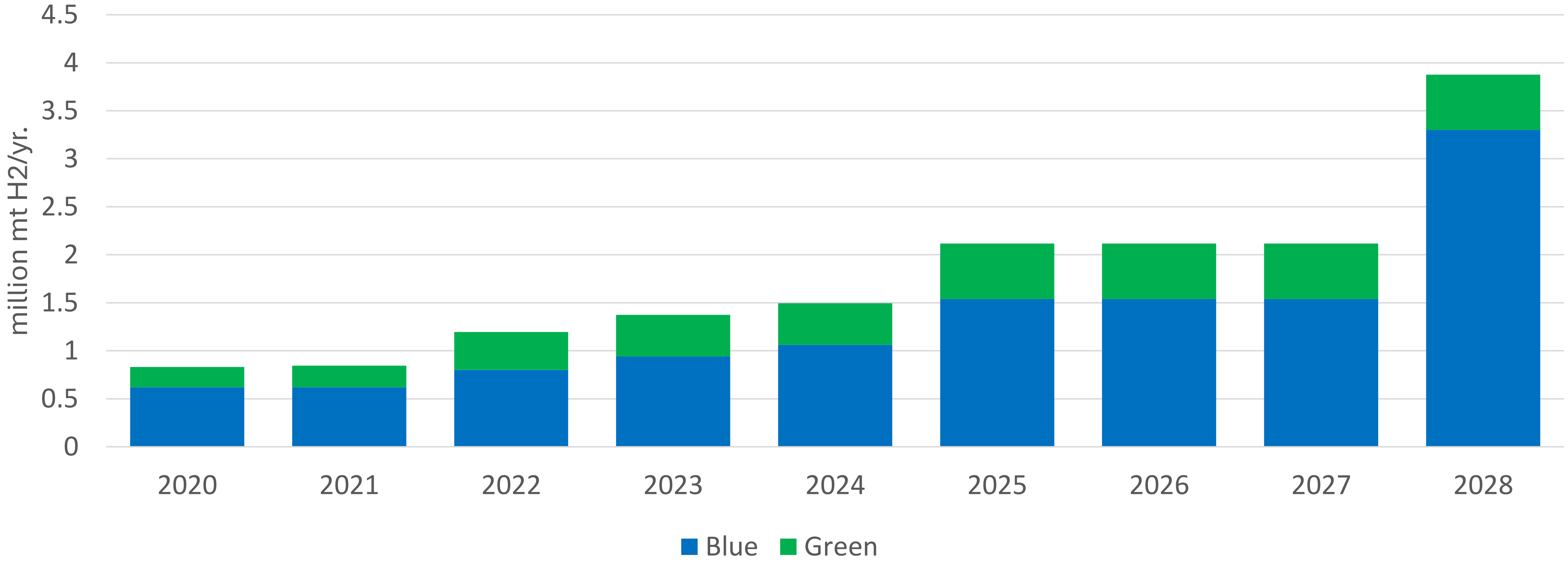
- The market is built on mature technology & focused on efficiency & flexibility
  - End users are **lowering O_2** level to reduce fuel/emissions (risking safety margin)
  - **Reduced flaring** means plants are redirecting these wastes to fuel gas headers
  - **Carbon capture** is the long-term emission primary strategy for O&G majors
  - Efficiency gains reduce near-term emissions on **existing assets**, later by **CCUS**

- Energy transition is focused on migrating to hydrogen fuels (and production)
  - Hydrogen is positioned as the zero-carbon fuel of the future, **now spiked in NG**
  - Most/all major O&G players have a stake in **blue H_2 production (some green)**
  - Cross-country & cross-company **partnerships** drive down costs of hydrogen / CC

ExxonMobil Valero Phillips 66 Marathon HollyFrontier PEMEX Petrobras Sabic Dow Shell lyondellbasell bp Linde

Blue H2 Will Drive Near-term Clean Energy Mega-projects

- Significant spending to **expand** production capacity in **Blue** Hydrogen
- Both green & blue H_2 production driven by **Europe, N. America,** then APAC



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"Clean" Hydrogen Depends On Its Original Source Vs. Emissions

Blue Hydrogen (requires CCUS) | Biomass Gasification | Green Hydrogen

Three (3) Key Technologies For Producing Blue Hydrogen

SMR

- Large reference base, but requires post-combustion CO_2 capture for >90% capture

ATR

- Feed pretreatment
- Steam for reaction
- Fired heater

SGP / POX

- No or minimal feed pretreatment
- Steam production using waste heat
- No direct CO_2 emissions from process

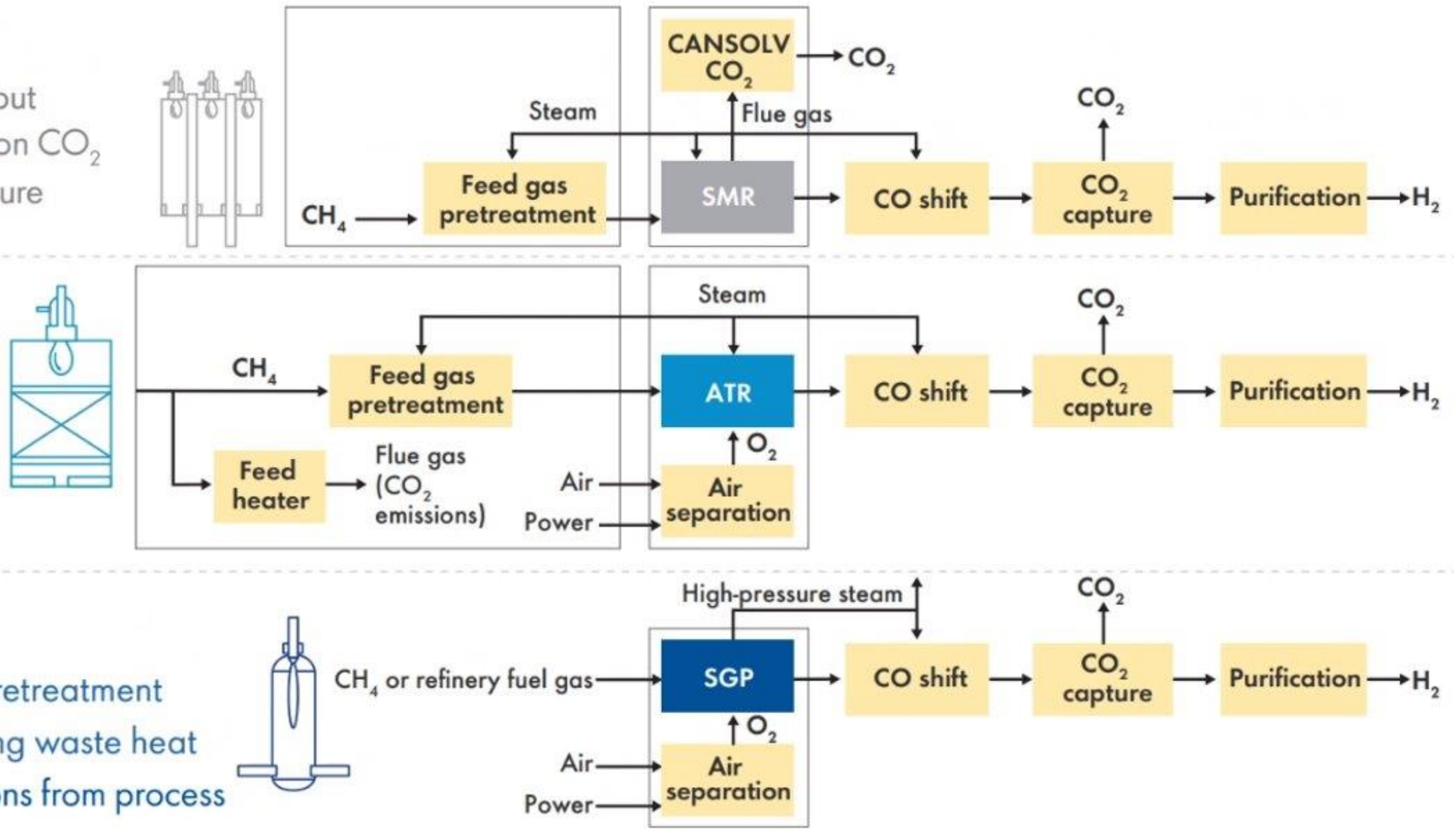
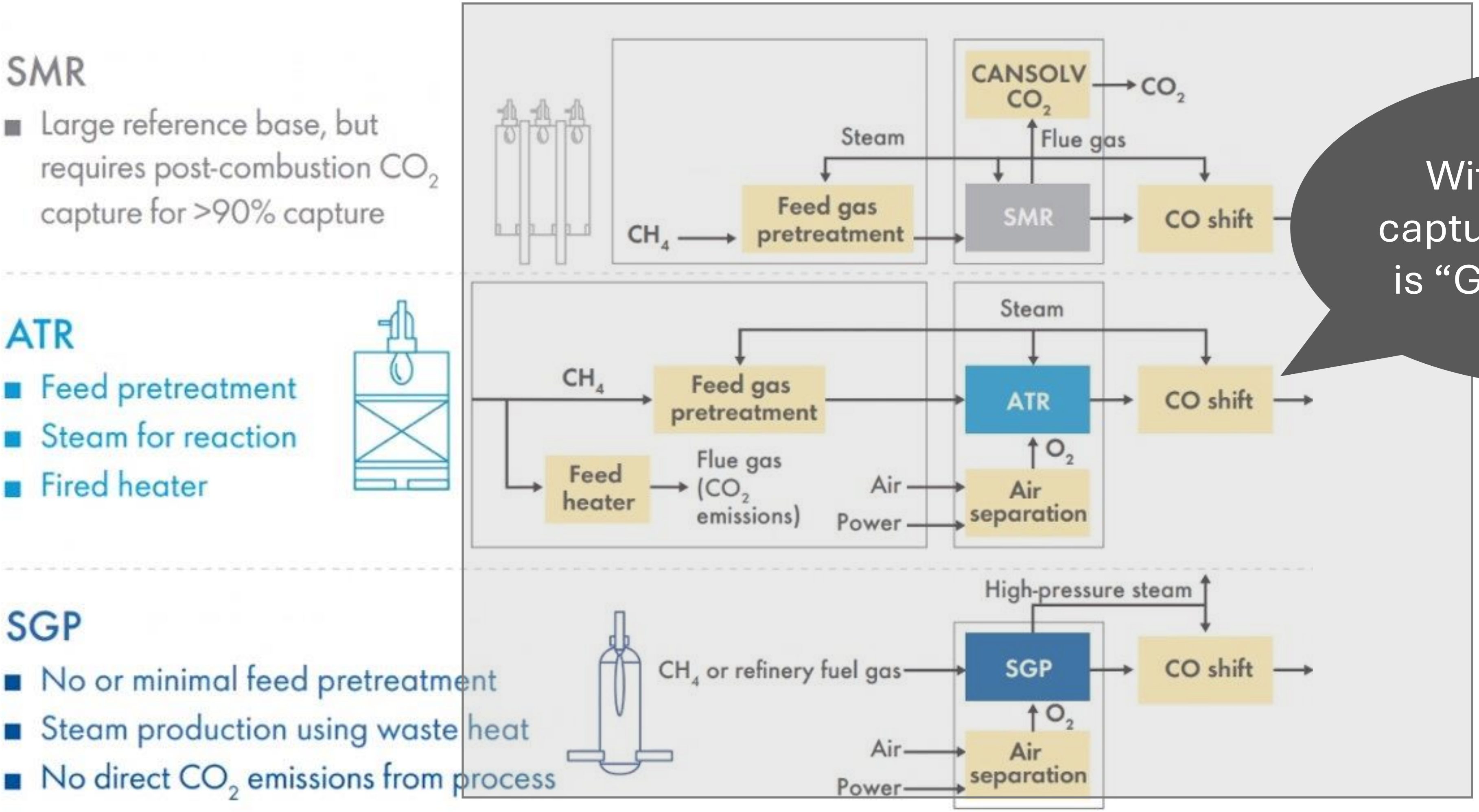


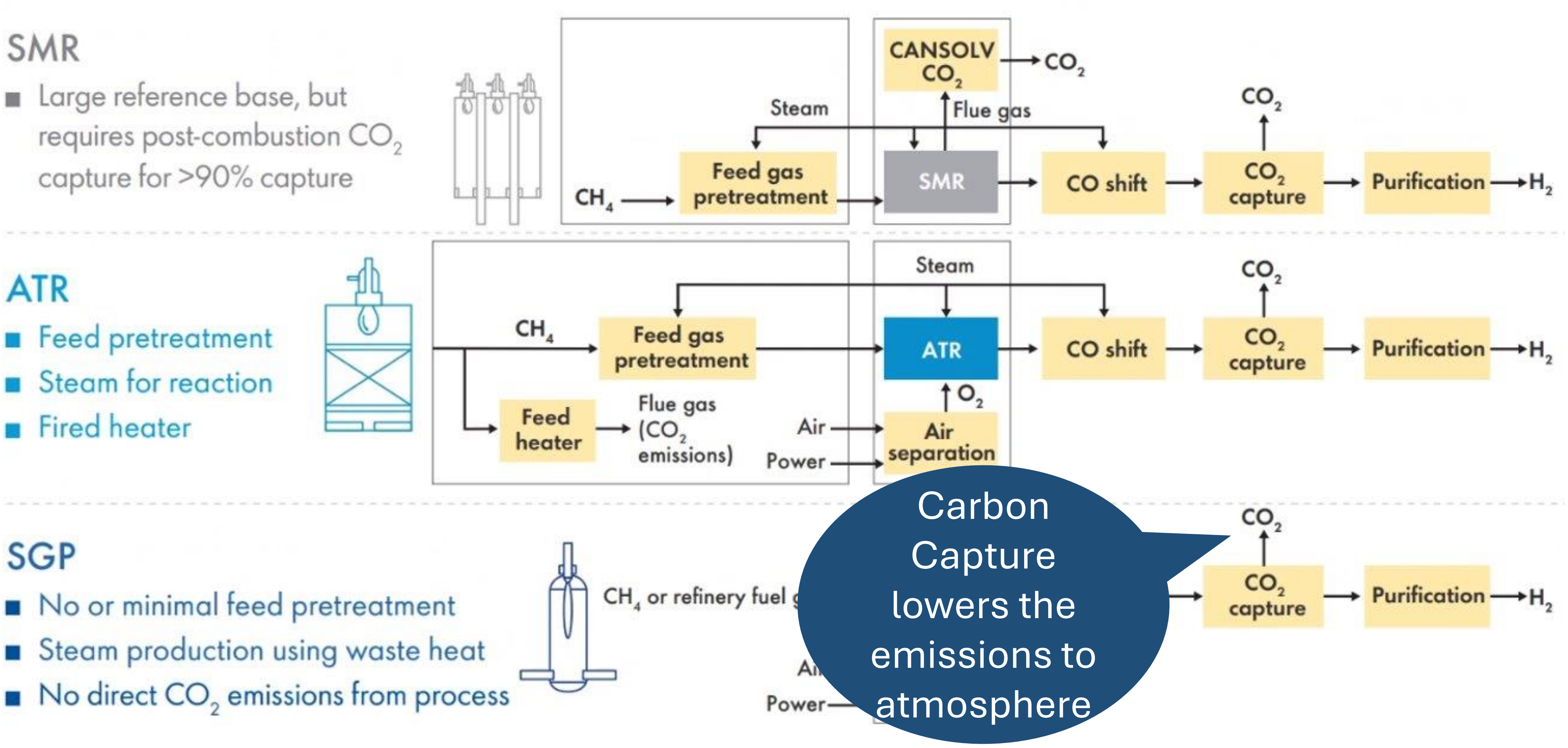
Photo Source: Shell

The Front End Of Blue H2 Generates “Grey” Hydrogen

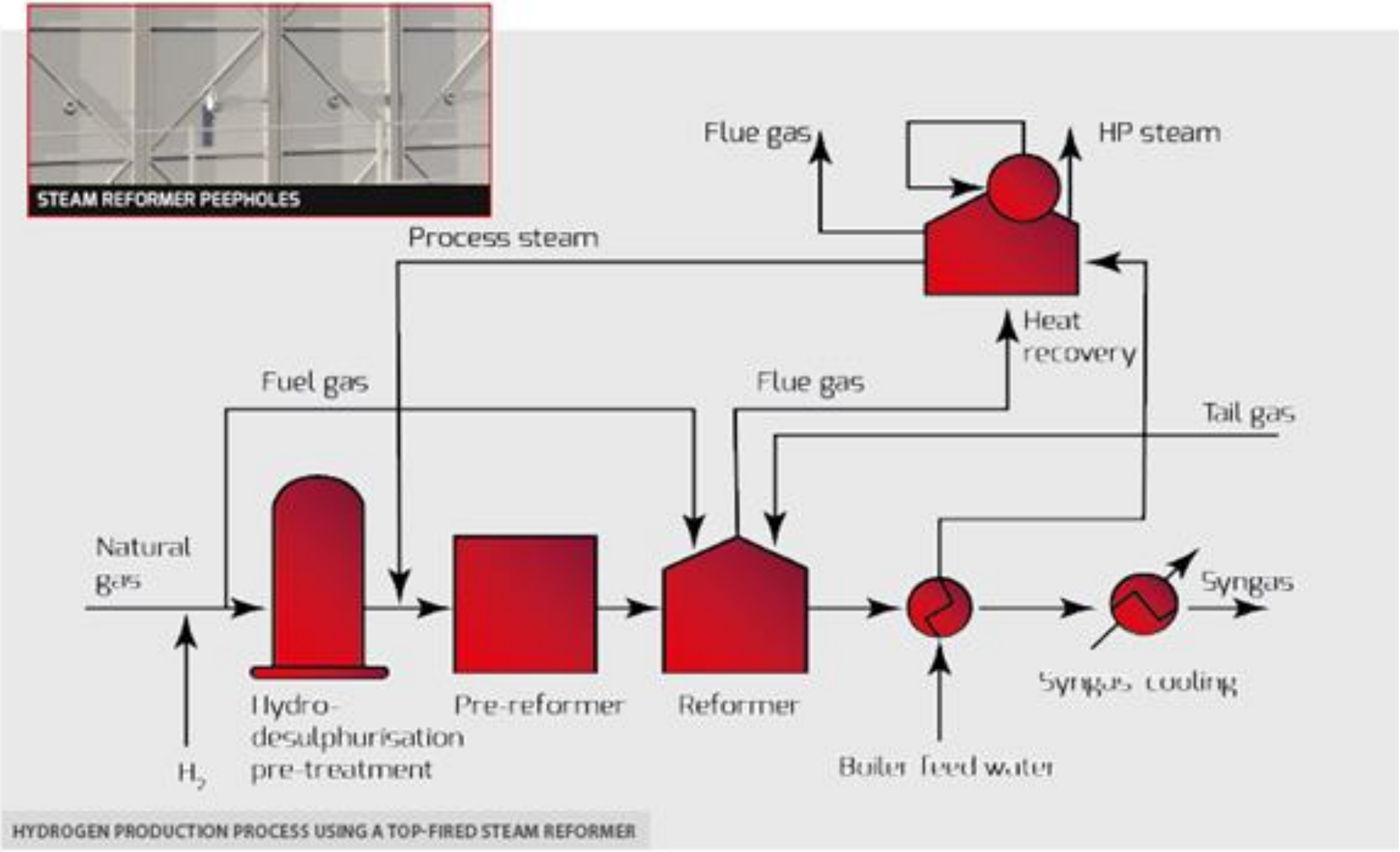


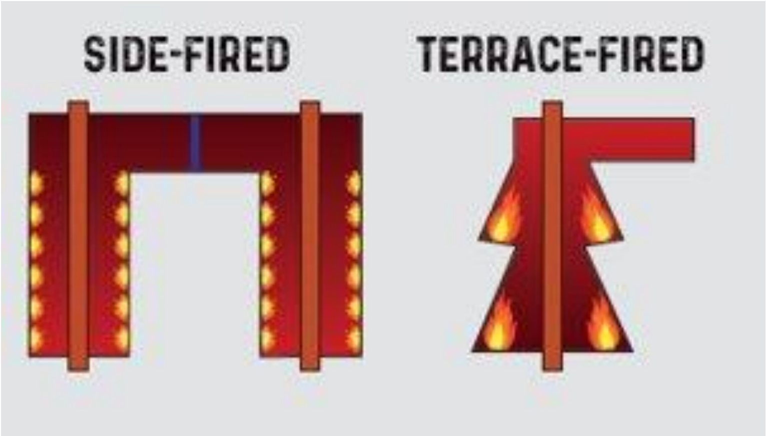
Without carbon capture, the process is “Grey Hydrogen”

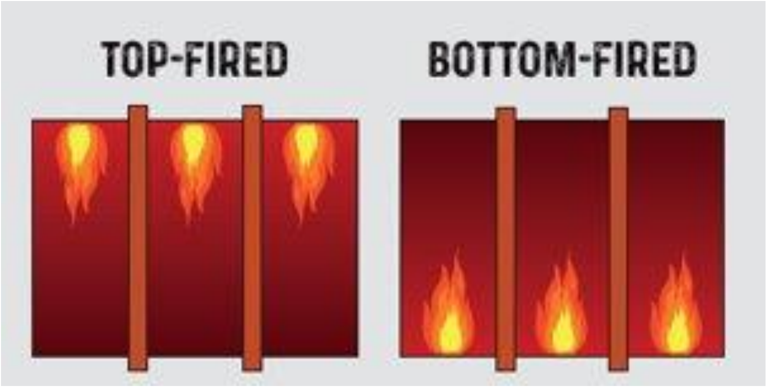
The Back End Of Blue H2 Is Carbon Capture, Making It "Blue"



Steam Methane Reforming (SMR)

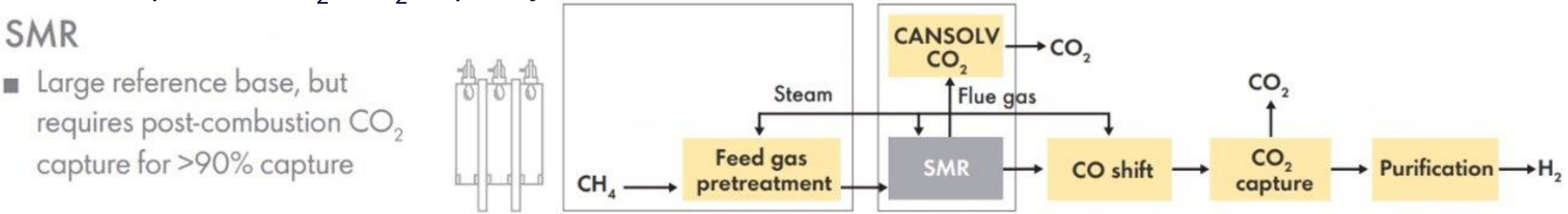






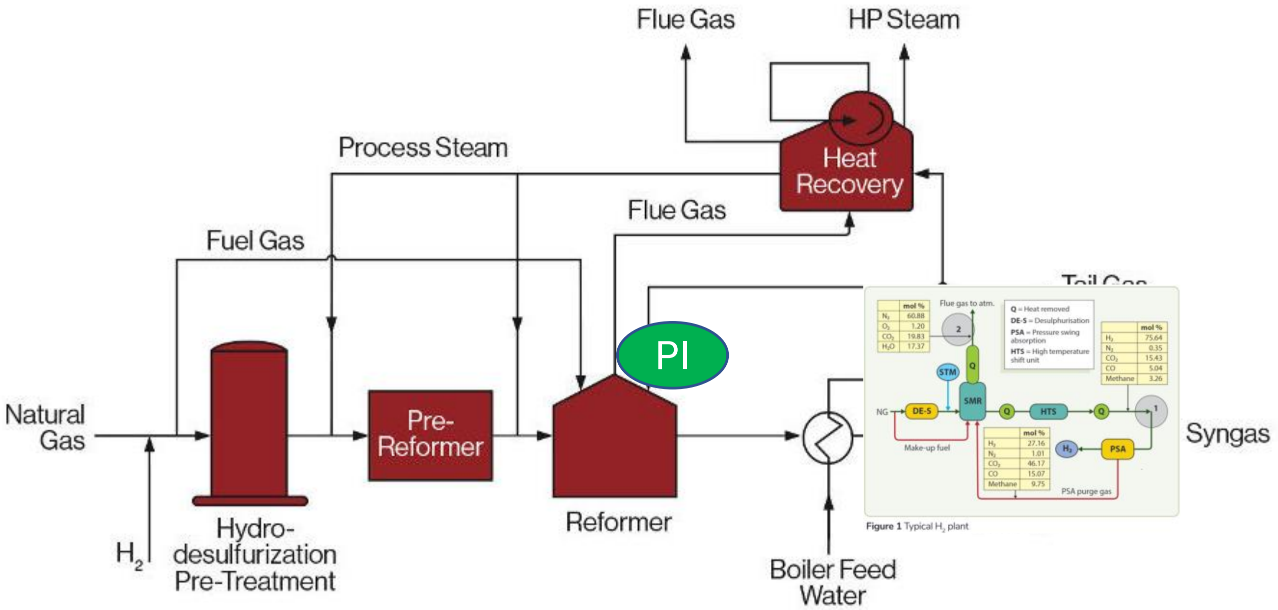
Large Installed Base Of Smrs For Grey H2, Requiring CCUS

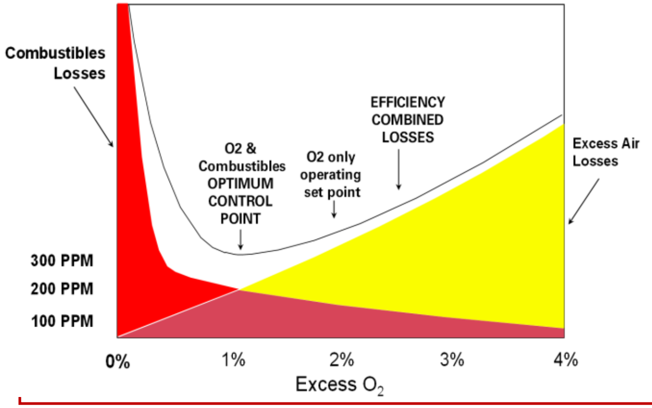
- Highlights:
  - Proven catalytic technology for existing grey H_2 production w/ wide installed base
  - Primary developments are around efficiency: burners, tube alloys, refractory, instr.
  - Process mixes with steam, uses catalyst, & has many tubes with external firing
  - More common for plants re-using their H_2 production internally (not for sale)
- Measurements:
  - Flue gas measurements (O_2, Combustibles, CH_4) to control flame in reformer
  - Syngas purity after steam reformer
  - Captured CO_2 & H_2 impurity measurements



Combustion Optimization Of The Steam Methane Reformer

- Combustion Control
  - Technology: Zirconium Oxide
  - Measure: O_2, Comb., CH_4+
- Low Emission Monitoring
  - Technology: TDLAS
  - Measure: CO_2, CO/CH_4





Combustion Optimization: (for energy efficiency)

- Lower Oxygen concentrations to reduce fuel & emissions
- Fast & safe monitoring via close-coupled design & SIL-2
- Flexibility to monitor for burner & tube leaks, including $_2$
- Supports the greater SMR (grey H_2) installed base

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Analytical Measurements Of SMR Syngas & Carbon Capture

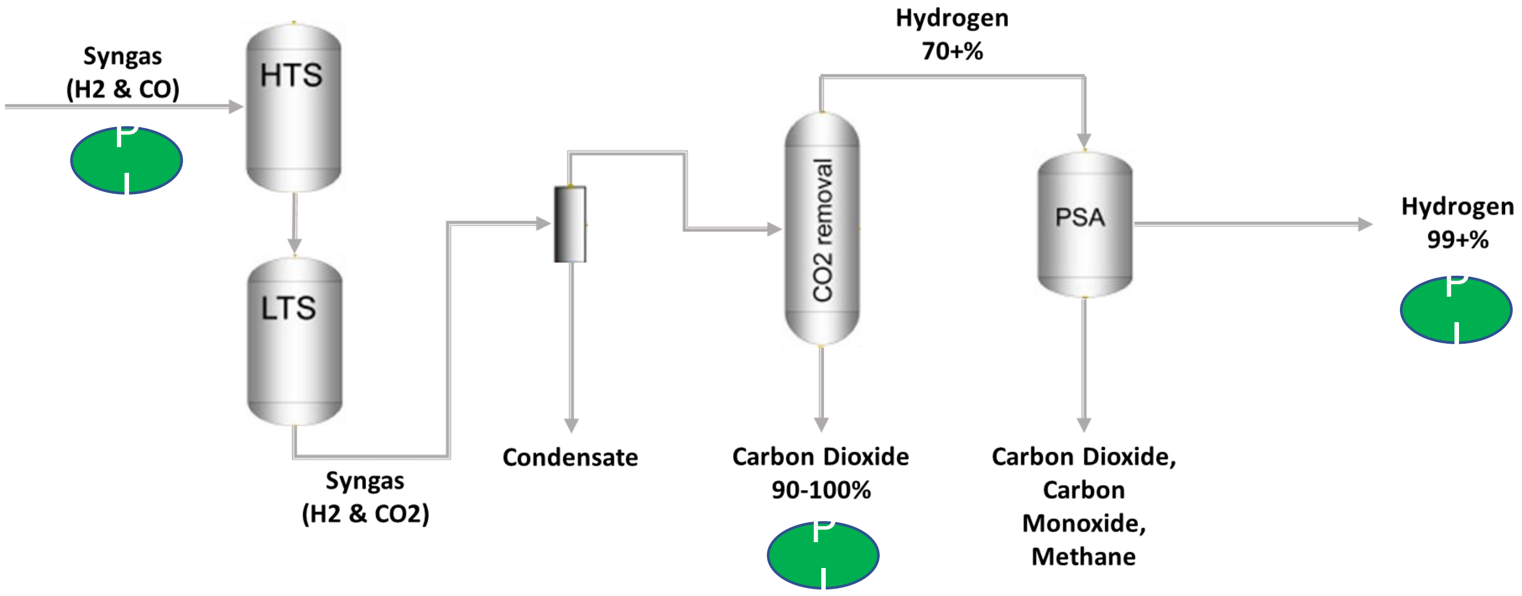
- SMR Syngas Analysis
  - *Technology: TDLAS/UV*
  - *Measure: CO,CH_4, H_2S*
- Captured CO_2 measurements
  - *Technology: TDLAS*
  - *Measure: H_2O, CO, CO_2, CH_4, H_2S*
- Captured H_2 measurements
  - *Technology: TDLAS*
  - *Measure: H_2O, CO_2, CH_4, H_2S*

Steam-methane reforming reaction

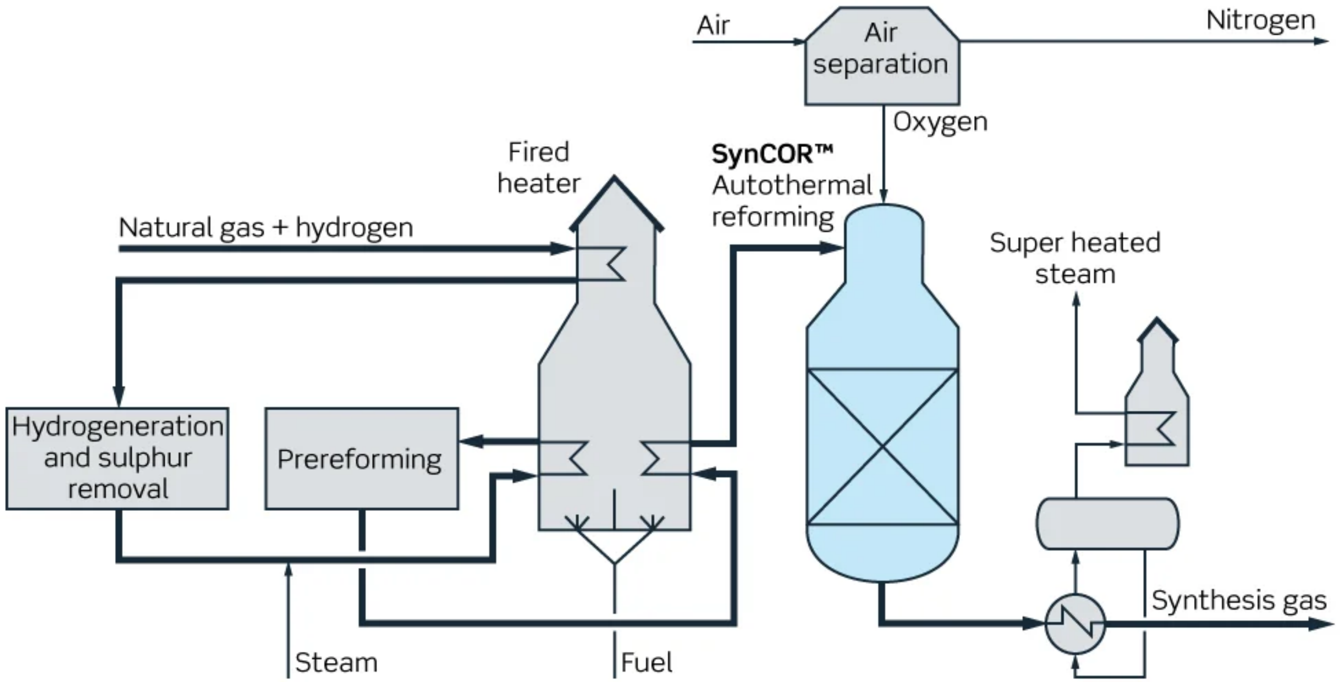
$CH_4 + H_2O + Heat \rightarrow CO + 3H_2$

Water-gas shift reaction

$CO + H_2O \rightarrow CO_2 + H_2 + heat$



AUTOTHERMAL REFORMING (ATR)



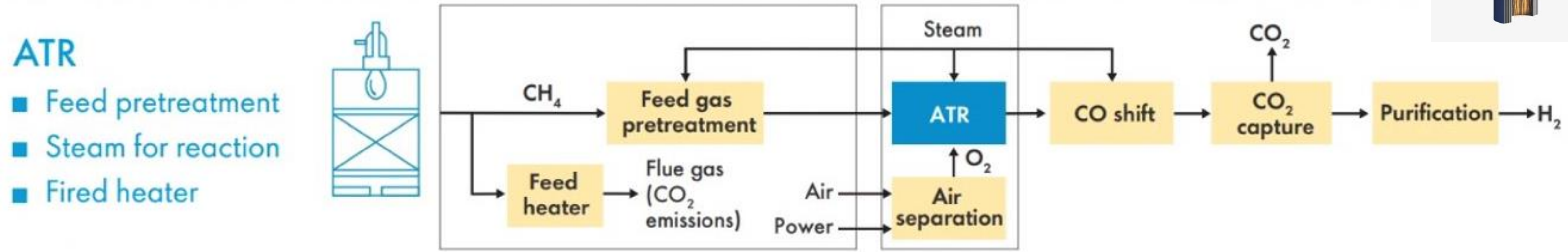
Autothermal Reforming (ATR)

Overview:

- Mature technology as O_2-based, catalytic alternative to SMR… low market share
- Touted as more cost-effective vs. SMR for blue hydrogen (single nozzle)
- Process mixes O_2 with steam, direct firing (no tubes), single catalyst bed
- Expected to be more common when end users are planning to sell / export H_2

Measurements

- Flue gas measurements (O_2, Comb., CH_4) to control flame in fired heater zone
- Syngas purity following autothermal reforming
- Captured CO_2 & H_2 measurements



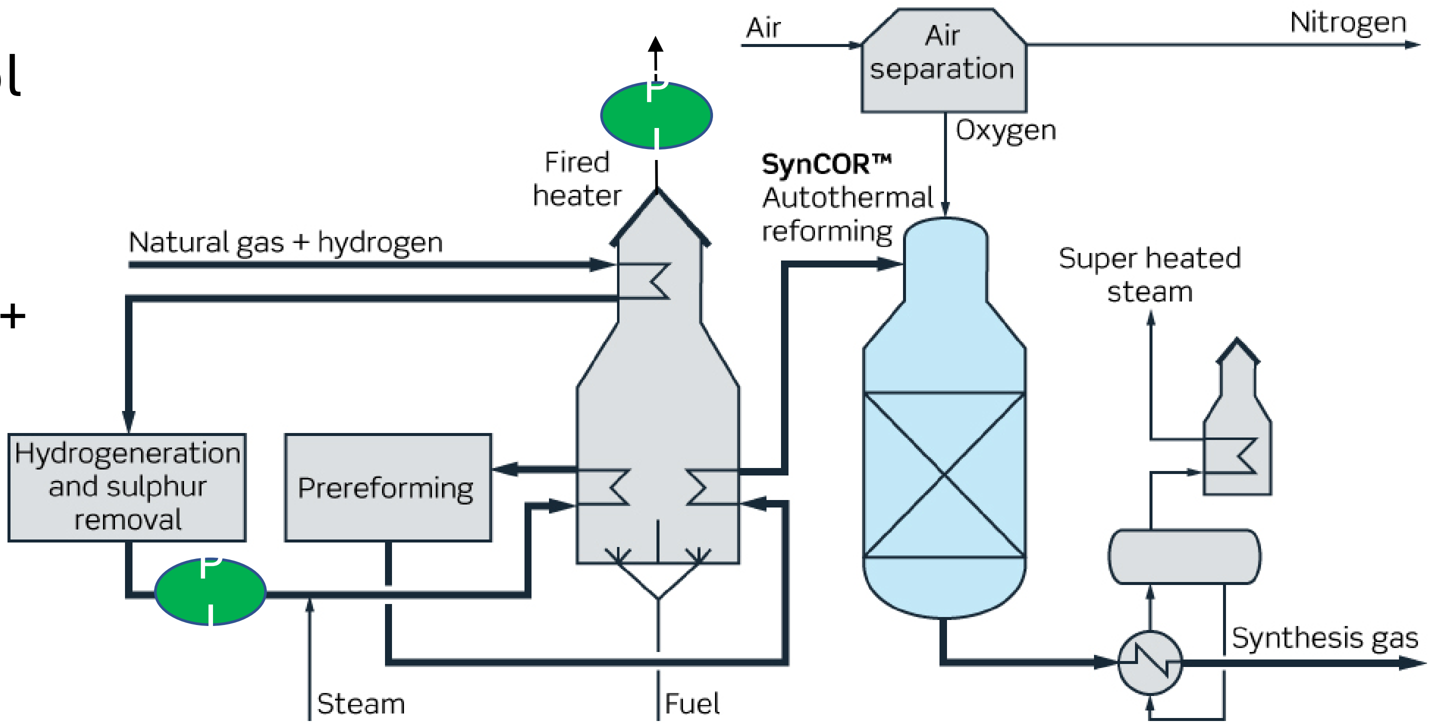
Combustion & Sulfur Measurements For ATR

Fired Heater Combustion Control

- *Technology: Zirconium Oxide / TDLAS*
- *Measure: O2, Combustibles, CH_4+*

Sulfur Removal Outlet

- *Technology: UV/TDLAS*
- *Measurements: ppm H_2S*



Analytical Measurements Of ATR Syngas & Carbon Capture

ATR Syngas Analysis

- *Technology: TDLAS/UV*
- *Measure: CO,CH_4, H_2S*

Captured CO_2 measurements

- *Technology: TDLAS*
- *Measure: H_2O, CO, CO_2, CH_4, H_2S*

Captured H_2 measurements

- *Technology: TDLAS*
- *Measure: H_2O, CO_2, CH_4, H_2S*

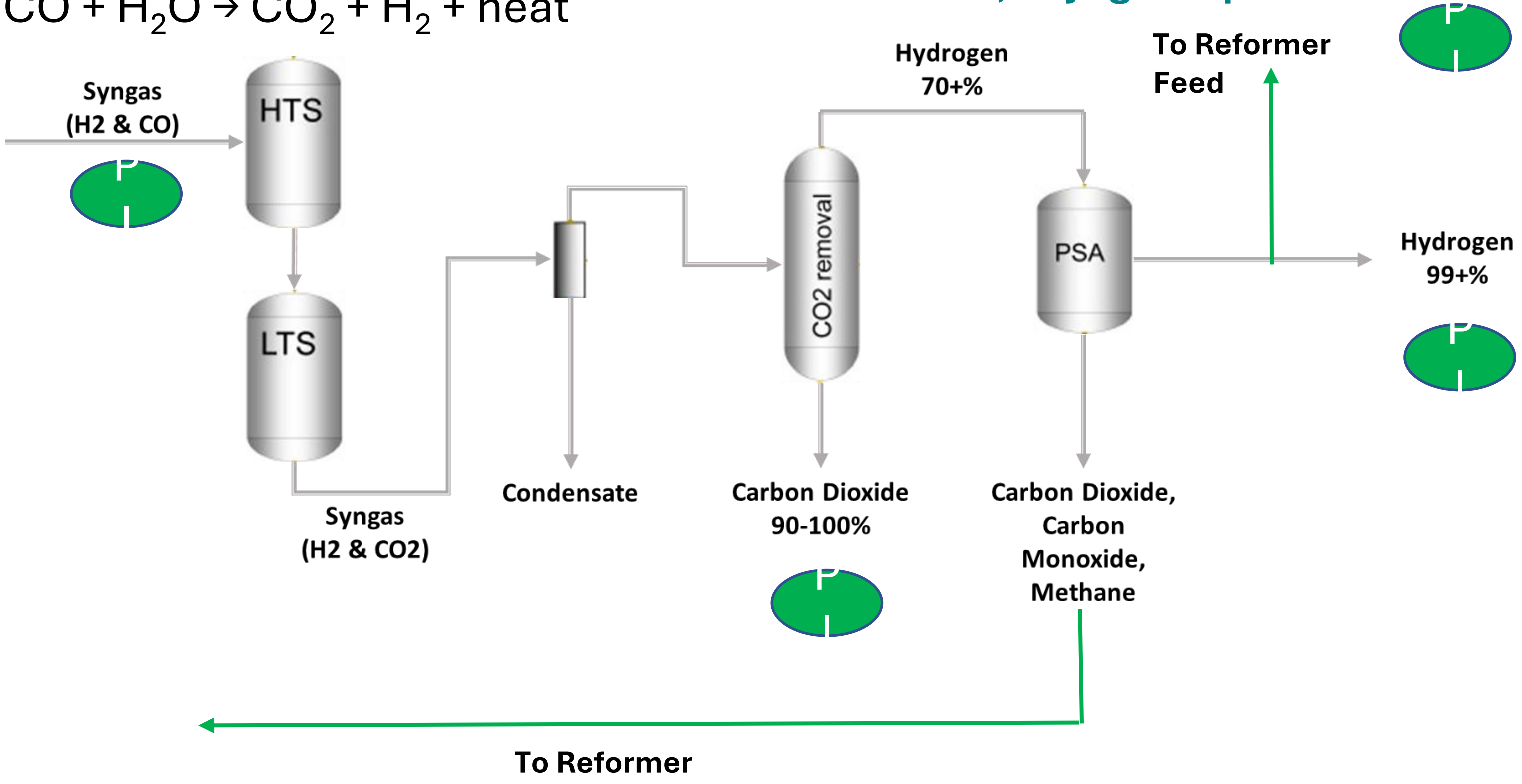
ATR reforming reaction

2CH4+O2+CO2⟶3H2+3CO+H2O

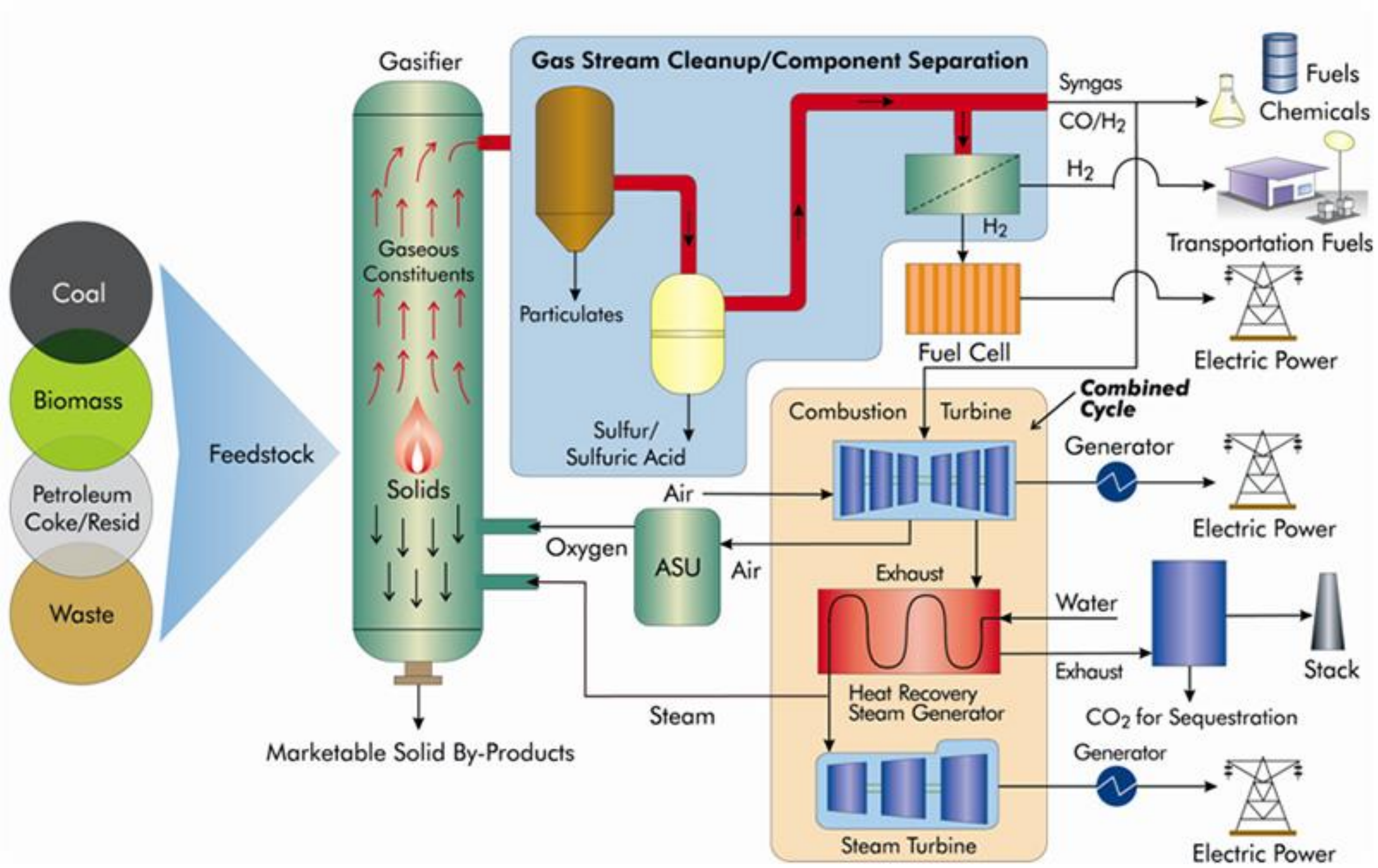
Water-gas shift reaction

$CO + H_2O \rightarrow CO_2 + H_2 + heat$

*** Alternate technologies and layout**
- VPSA
- Compressor
- Membranes, Cryogenic processes



PARTIAL OXIDATION (POX) & SHELL GASIFICATION PROCESS (SGP)



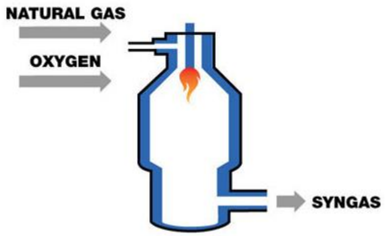
Partial Oxidation (POX) & Shell Gasification Process (SGP)

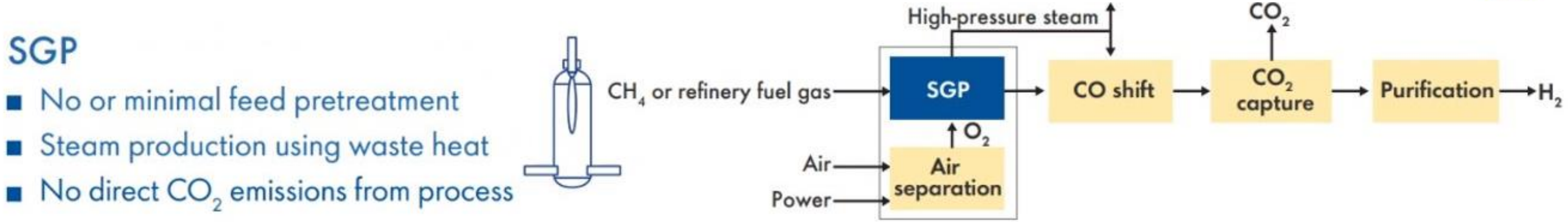
Overview:

- Process is an O_2-based system with a direct firing reactor, and noncatalytic
- Does not consume steam (rather generates it) and has no direct CO_2 emissions
- Leverages a simpler/smaller design to reduce cost of H_2 by 22% (vs. ATR)
- Wide flexibility of feedstocks

Measurements:

- No combustion measurements
- Syngas purity
- Captured CO_2 and H_2 purity





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Analytical Measurements Of POX Syngas & Carbon Capture

- Syngas Analysis
  - *Technology: TDLAS/UV*
  - *Measure: CO,CH_4, H_2S*

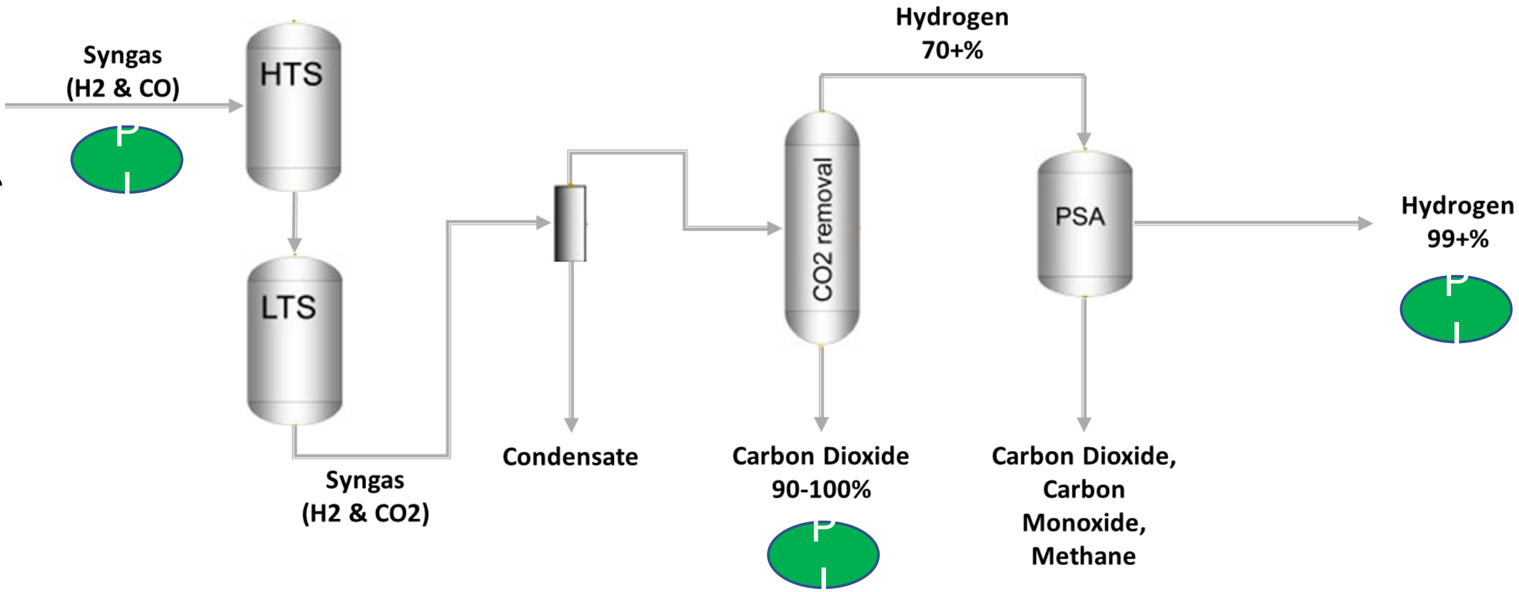
Partial oxidation of methane reaction

$CH_4 + ½O_2 \rightarrow CO + 2H_2 + Heat$

Water-gas shift reaction

$CO + H_2O \rightarrow CO_2 + H_2 + Heat$

- Captured CO_2 measurements
  - *Technology: TDLAS*
  - *Measure: H_2O, CO, CO_2, CH_4, H_2S*
- Captured H_2 measurements
  - *Technology: TDLAS*
  - *Measure: H_2O, CO_2, CH_4, H_2S*



Overall, Strong Opportunity In Blue Hydrogen

- Combustion Control
  - *Technology: Zirconium Oxide, TDLAS*
  - *Measure: O_2, Comb., CH_4+*
- SMR Syngas Analysis
  - *Technology: TDLAS/UV*
  - *Measure: CO, CH_4, H_2S*
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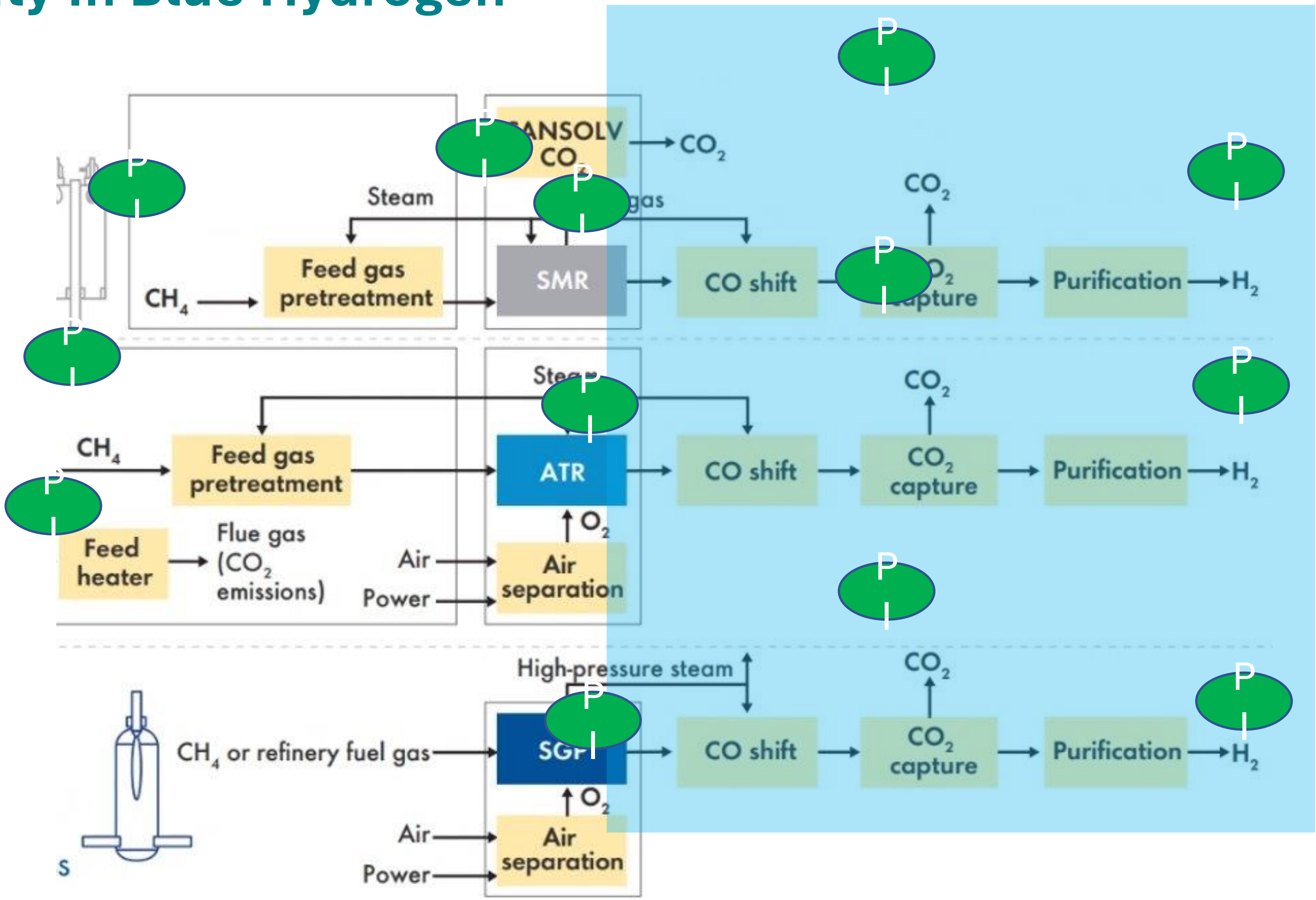

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Takeaways

- Market Takeaways
  - **Blue hydrogen** poses a large opportunity across end users, for new & expansion projects
  - Much of the installed base is SMR technology (requiring CCUS) and **focusing on efficiency**
  - New blue H_2 plants will likely consider **ATR** or partial oxidation to reduce H_2 production costs
- Measurement Takeaways & Considerations
  - **Flue gas measurements:** Required for SMR & ATR, but will likely face pressure to meet lower O_2 levels, faster responses, and greater measurement points for greater control
  - **Analytical measurements:** TDLAS offers measurements for syngas, captured CO_2, and H_2 generation, and we have provided these solutions for *years*.

Imagine. Ideate. Innovate.

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