Best Available Techniques for ‘Blue’ Hydrogen Production with Carbon Capture and Storage

Jane Durling

Senior Advisor – Energy Team

Radioactive Substances and Industry Regulation

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Best Available Techniques for ‘Blue’ Hydrogen Production with Carbon Capture and Storage

- What are BAT – best available techniques?
- BAT guidance
  - When is BAT guidance needed?
  - Criteria for determining BAT
  - Development process
- Summary of Process Inputs/Outputs
- Key points for guidance
  - Configuration Choice
  - Performance
- Next Steps
- Published Guidance
- BAT and the Hydrogen Strategy
- Future guidance
- Questions?

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What are BAT?

- ‘Best Available Techniques’ *
  - economically and technically viable techniques
  - best for preventing or minimising emissions and impacts on the environment as a whole

* Directive 2010/75/EU of the European Parliament and of the Council of 24 November 2010 on industrial emissions (integrated pollution prevention and control) (europa.eu)

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BAT Guidance

When is BAT guidance needed?

- Where no relevant BAT reference document (BRef)
- Regulator must set permit conditions following Art.14(6)
- Must consider criteria for determining BAT in Annex III
- Permit conditions must protect the environment
  - basic obligations of the operator (Art 11)
  - environmental quality standards (Art.18)
- Encourage emerging techniques (Art. 27)

BAT Guidance

Criteria for determining best available techniques (IED Annex III)

- Available to be implemented – economically/technically viable at scale
- Emissions to air/water/land including heat,vibrations,noise – effects/quantity
- Low waste - maximise recovery/recycling
- Less hazardous substances
- Energy efficiency
- Raw material/water usage
- Prevent/reduce overall impact
- Prevent/minimise consequences of accidents
- Take account of published information – international

BAT Guidance

Development Process

- BAT review informs BAT guidance
- Summarises the evidence for available process options
- Identifies key environmental issues to address & best practice
- In consultation with industry & agreed by UK regulators
- Assists applicants & regulators in the permit process
- Does not set BAT standards or limits
- Permit conditions – generate evidence for future BAT standards

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‘Blue’ Hydrogen Production Technologies Identified

- Steam Methane Reforming (SMR)

- Autothermal Reforming (ATR)

- Gas Heated Reforming (GHR)

e.g. GHR+ATR or GHR+SMR combined

- Partial Oxidation (POX)

* All will need Carbon Capture and Storage (CCS)

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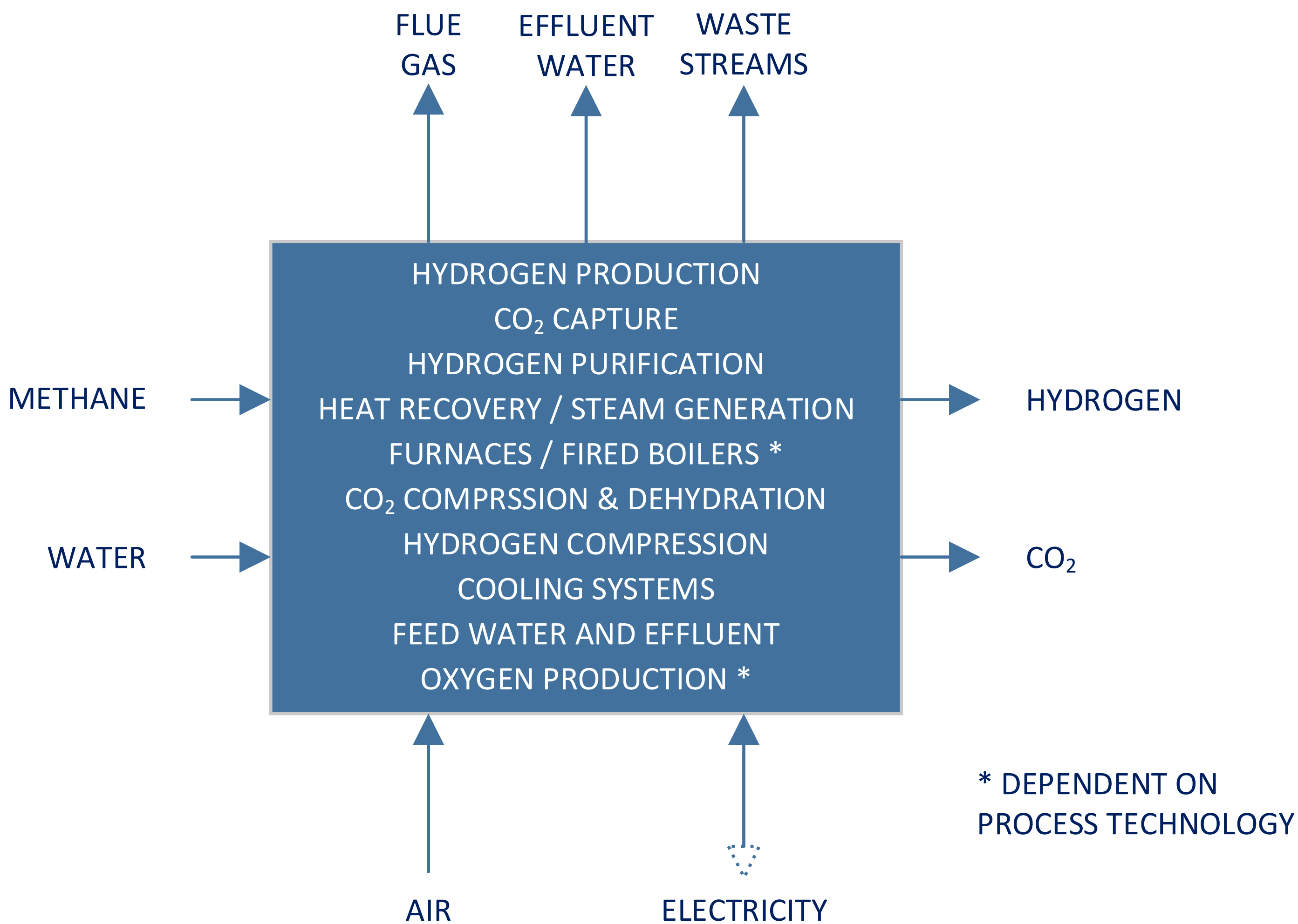
Summary of Process inputs/outputs



Key Points for Guidance – CO_2 Capture Efficiency

- Overall CO_2 Capture Efficiency >95%
    - Feed gas energy conversion
        – Impact on total CO_2 to be captured from process
    - Capture rate
        – Near complete for process CO_2 capture
        – Post combustion capture >95%
    - CH_4, CO and CO_2 left in hydrogen purification tail gas used as fuel
        – Conversion of methane in reforming
        – Conversion of CO in shift reaction
        – Capture of CO_2 from process

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Key Points for Guidance – Energy/Process Efficiency

- Energy Efficiency
  - Electrical power requirement
  - Excess HP steam – for power/drives/LP steam
  - Oxygen – additional power demand
- Water
  - availability/quality
  - raw material and cooling
- Feed gas
  - S and higher HC content
- Hydrogen product
  - Inerts
- Carbon dioxide
  - Specification for pipeline/storage
  - Delivery pressure

Key points for Guidance
– Processes with post-combustion capture

- Solvent selection, reflect the balance between CO_2 capture performance, associated energy requirements and potential atmospheric emissions, such as:
  - Energy requirements
  - Reclaiming potential
  - Potential for reaction with contaminants in flue gas, e.g. NO_x removal.
  - Potential atmospheric emissions of solvent and associated degradation products such as nitrosamines and nitramines.
  - Proven performance through operational experience, or test programmes under realistic operating conditions.
- Atmospheric emissions, considering:
  - Emissions of solvent components.
  - Emission of additional substances formed in the CO_2 capture system such as nitrosamines, nitramines and ammonia.
  - Emission of ammonia present in flue gas though slippage from upstream NOx removal.
  - Formation of further additional substances in the atmosphere from those emissions.

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Key Points for Guidance- Emissions to Air

Continuous

- Fired heater / steam boiler flue gas
    - Hydrogen rich / low carbon fuel
    - NOx formation – potential need for abatement
- Steam vents – e.g. deaerator

During start-up, abnormal conditions

- Flare combustion products
- CO_2 vent from amine regeneration tower

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Key Points for Guidance- Emissions to Water

Continuous effluent treatment discharges

- Process condensate
  - Containing e.g. methanol, ammonia, CO_2
  - Downstream of CO shift
  - From CO_2 compression / dehydration regeneration
- From air dehydration in oxygen production
- Boiler blowdown
- Cooling tower blowdown (where appropriate)
- Water purge from amine system
  - From regeneration reflux, containing e.g. methanol
  - From water wash
- Potential for water treatment for reuse

Key Points for Guidance - Waste Streams

- **Liquids**
  - Demineralised water production reject stream
  - Amine solvent – e.g. from bleed / feed, replacement
  - Dehydration solvent – e.g. in case of tri-ethylene glycol dehydration
  - Amine reclaimer residue

- **Solids**
  - Depleted catalyst material
    - Hydrogenation, reforming, CO shift
  - Spent adsorbent materials
    - Gas treatment, dehydration, hydrogen purification
  - Solids from amine filtration
  - Soot (POX process)

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Key Points for Guidance - Monitoring

- Emissions to Air – NO_x, CO, SO_2, NH_3, amines/degradation products
- Emissions to Water – NH_3, amines, methanol
- CO_2 capture performance
- Process performance – energy efficiency, solvent performance

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Next Steps

- BAT review complete.
- BAT guidance subject to final regulatory confirmation
- Guidance to be published on .gov.uk
- BAT review will be referenced
- BAT review available on request

Published BAT Guidance and BAT Review for Post Combustion CCS

- Summary of BAT Guidance for New-Build and Retrofit Post-Combustion Carbon Dioxide Capture Using Amine-Based Technologies for Power and CHP Plants Fuelled by Gas and Biomass as an Emerging Technology under the IED for the UK
- https://www.gov.uk/guidance/post-combustion-carbon-dioxide-capture-best-available-techniques-bat

- BAT Review for New-Build and Retrofit Post-Combustion Carbon Dioxide Capture Using Amine-Based Technologies for Power and CHP Plants Fuelled by Gas and Biomass as an Emerging Technology under the IED for the UK
- https://ukccsrc.ac.uk/best-available-techniques-bat-information-for-ccs/

- IChemE Webinars – BAT for post combustion CCS – John Henderson, EA
    - BAT for 'Blue' Hydrogen Production with CCS – Jane Durling, EA
- ESIG Webinar archive - IChemE

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Future BAT Guidance

- BAT guidance for Hydrogen Production by Electrolysis
- Ongoing work to support post-combustion CCS
  - Improved modelling of atmospheric chemistry of amine releases
  - Certified monitoring methods
  - Develop more EALs for amine solvents & degradation products
  - Decarbonisation clusters and multiple sources of amines
- Other BAT guides to support Net Zero delivery
- Other BAT guidance needed?

How does BAT fit with the UK's Hydrogen Strategy?

- Advising as part of the HAC Standards and Regulations WG
- Identify any interactions with current environmental regulations
  - e.g. CO_2 equivalent accounting method
- UK hydrogen strategy - GOV.UK (www.gov.uk)
- Designing a UK low carbon hydrogen standard - GOV.UK (www.gov.uk)
  - Consultation on standard now closed

Thank you

Any Questions?

Email: jane.durling@environment-agency.gov.uk

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Appendices for Reference

Recent US paper on carbon intensity of 'blue' hydrogen production

	Howarth & Jacobson	UK: domestic gas	UK: US LNG	
Leakage rate from production and delivery	3.5%	0.5%	3.5%	
Upstream CH4 emissions	1.11	0.1	1.11	$gCH_4/MJ\ H_2$
Global warming potential (GWP)	86	28	28	
Upstream emissions	102	3	31	$gCO_2e/MJ\ H_2$
SMR plant efficiency with CCS	56%	79%*	79%*	$MJ\ H_2/MJ\ CH_4$
CO2 capture rate	62%	95%*	95%*	
CO2 released from the SMR to the atmosphere	33	3	3	$gCO_2/MJ\ H_2$
Total emissions	**135**	**7**	**34**	$\mathbf{gCO_2e/MJ\ H_2}$
Emissions from the UK residential sector				
Residential natural gas use		58	88	$MtCO_2e$
If blue hydrogen replaced all natural gas		7	36	$MtCO_2e$

* JM **LCH**[TM] process

* UK TIMES energy system model

Data on slide courtesy of Paul Dodds, UCL

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Equilibrium reactions (BAT review)

Table 15 – Steam Methane Reforming and Shift Chemical Reactions

Chemical Reactions		
Steam Methane Reforming	$CH_4 + H_2O_{(g)} \rightleftharpoons CO + 3\ H_2$	ΔH_{298} = 206 kJ/mol
Water Gas Shift	$CO + H_2O_{(g)} \rightleftharpoons H_2 + CO_2$	ΔH_{298} = - 41 kJ/mol
Overall Reaction *	$CH_4 + 2\ H_2O_{(g)} \rightleftharpoons CO_2 + 4\ H_2$	ΔH_{298} = 165 kJ/mol

Table 16 – Autothermal Reforming and Shift Chemical Reactions

Chemical Reactions		
Methane Partial Oxidation	$CH_4 + \frac{1}{2} O_2 \rightleftharpoons CO + 2\ H_2$	ΔH_{298} = -36 kJ/mol
Steam Methane Reforming	$CH_4 + H_2O_{(g)} \rightleftharpoons CO + 3\ H_2$	ΔH_{298} = 206 kJ/mol
Combined ATR Reaction *	$CH_4 + \frac{1}{4} O_2 + \frac{1}{2} H_2O_{(g)} \rightleftharpoons CO + \frac{5}{2} H_2$	ΔH_{298} = 85 kJ/mol
Water Gas Shift	$CO + H_2O_{(g)} \rightleftharpoons H_2 + CO_2$	ΔH_{298} = - 41 kJ/mol
Overall Reaction	$CH_4 + \frac{1}{4} O_2 + \frac{3}{2} H_2O_{(g)} \rightleftharpoons CO_2 + \frac{7}{2} H_2$	ΔH_{298} = 44 kJ/mol

Table 17 – Partial Oxidation and Shift Technology Chemical Reactions

Chemical Reactions		
Methane Partial Oxidation	$CH_4 + \frac{1}{2} O_2 \rightleftharpoons CO + 2\ H_2$	ΔH_{298} = -36 kJ/mol
Water Gas Shift	$CO + H_2O_{(g)} \rightleftharpoons CO_2 + H_2$	ΔH_{298} = -41 kJ/mol
Overall Reaction	$CH_4 + \frac{1}{2} O_2 + H_2O_{(g)} \rightleftharpoons CO_2 + 3\ H_2$	ΔH_{298} = -77 kJ/mol

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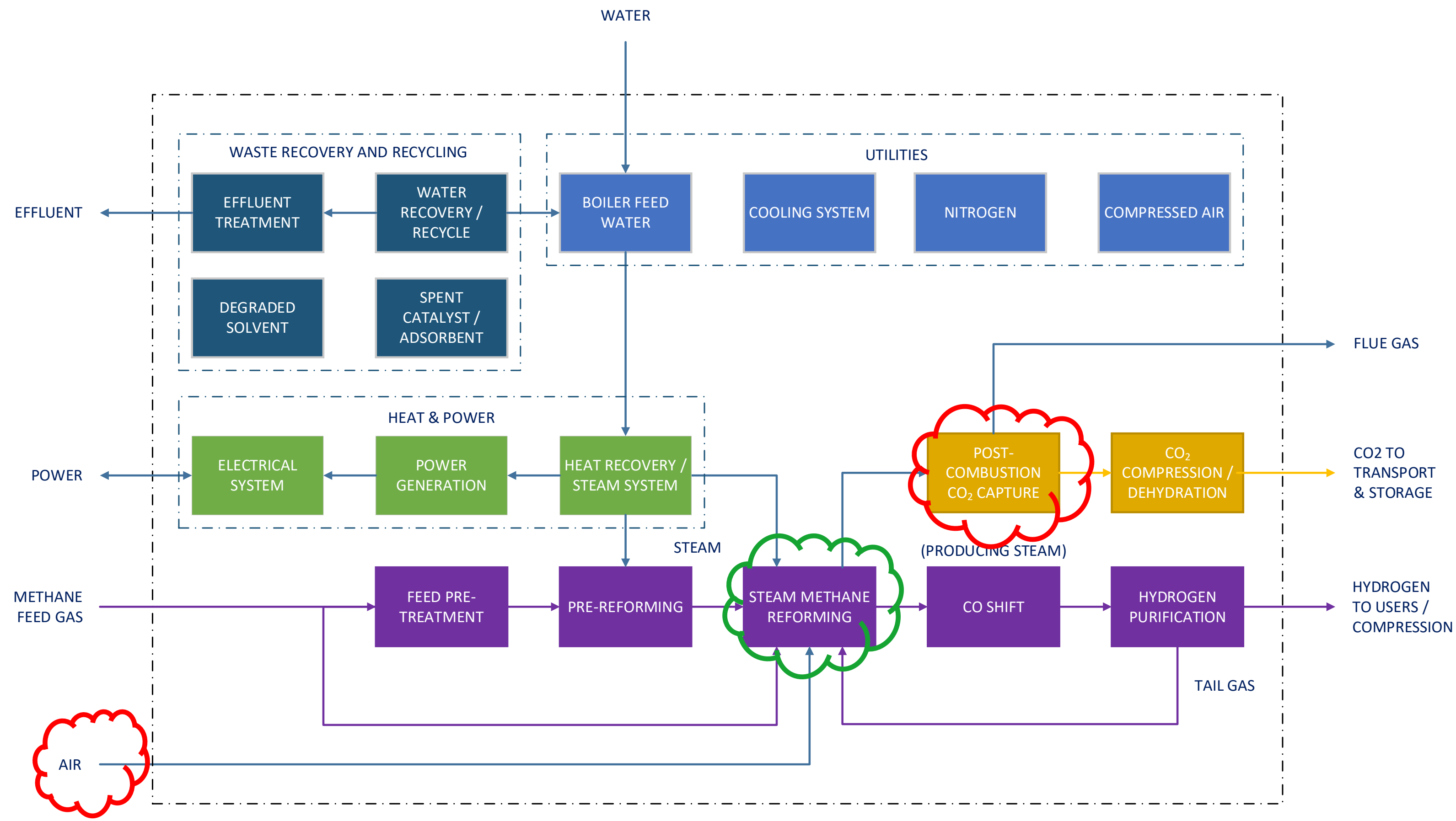
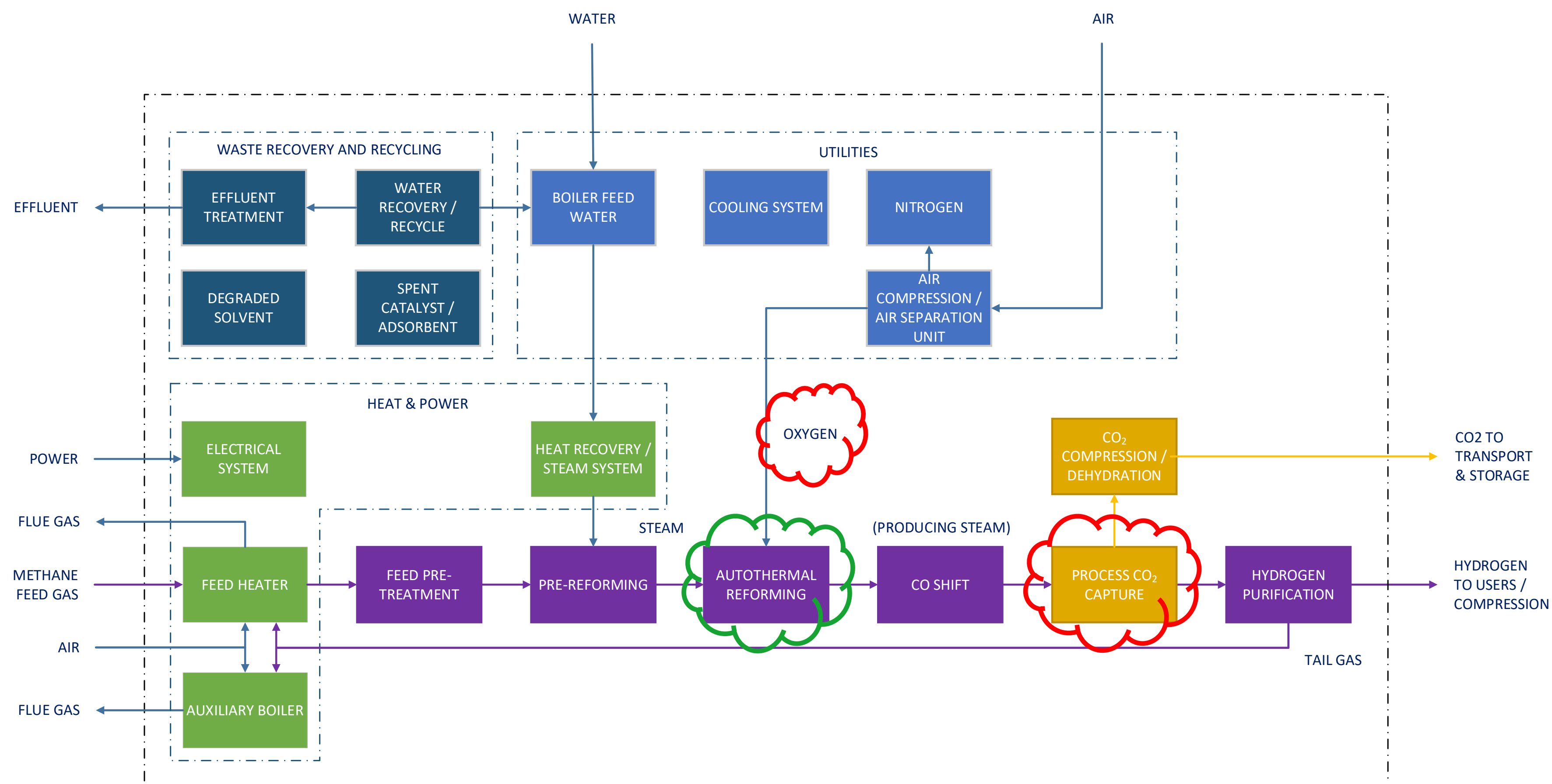
Steam Methane Reforming Process



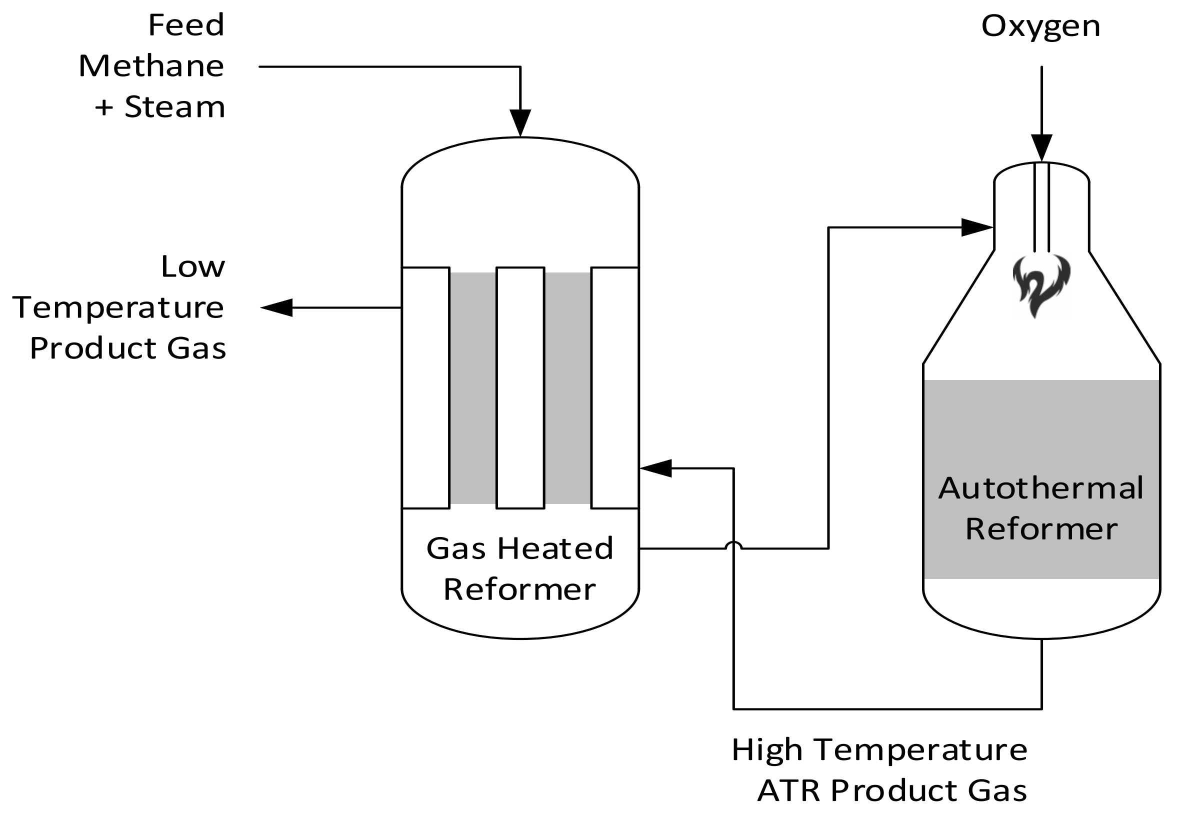
Block Flow Diagram of SMR Technology with Carbon Capture
(Typical – Other Configurations are Possible)

Autothermal Reforming Process

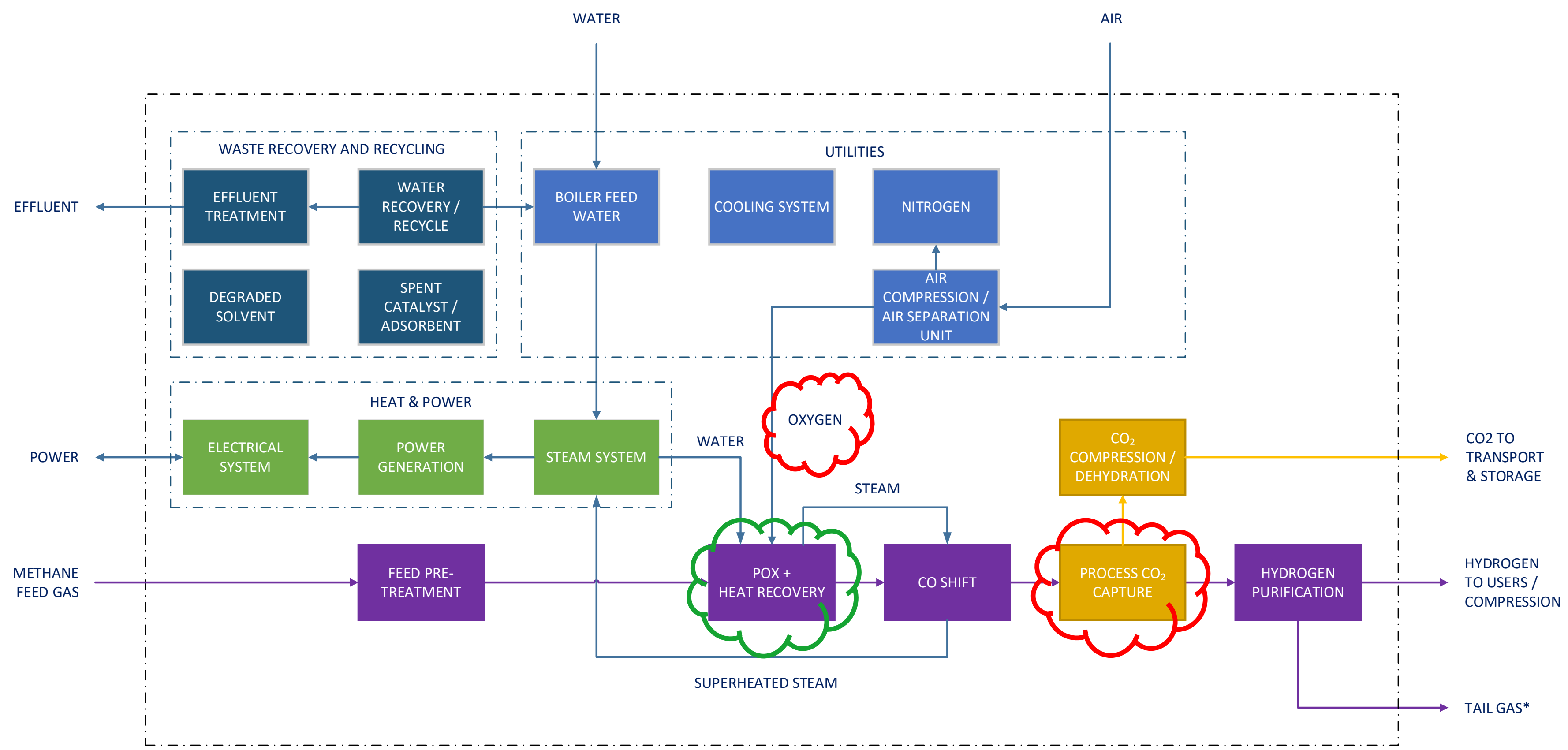


Block Flow Diagram of ATR Technology with Carbon Capture (Typical – Other Configurations Possible, e.g. with Addition of Gas Heated Reformer)

Gas Heated Reforming Process e.g. GHR+ATR in series



Gas POX (Partial Oxidation) Process



* DEPENDENT ON HYDROGEN PURIFICATION TECHNOLOGY - METHANATION FOR EXAMPLE PRODUCES NO TAIL GAS.

Block Flow Diagram of POX Technology with Carbon Capture (Typical – Other Configurations are Possible)

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