Coal System Studies: Effects of Methane Content and High-Efficiency Catalytic Gasification

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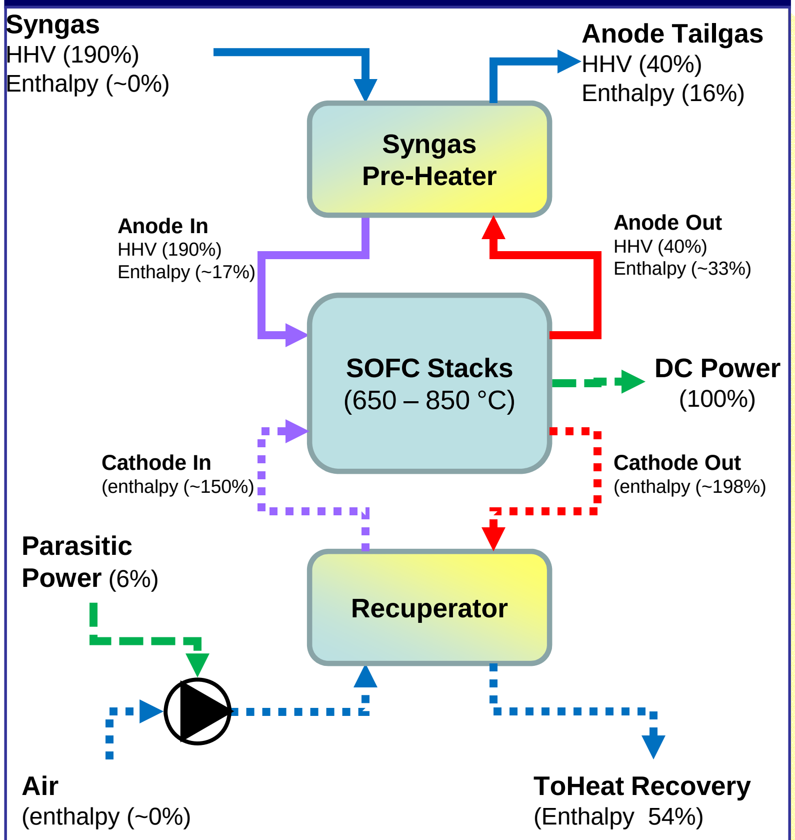
Gasifier choice, some operating conditions and performance affect IGFC efficiency differently than they affect IGCC.

- IGFC can improve efficiency by 15-25% points over IGCC[1]
- For a variety of reasons, almost all commercial IGCC designs have evolved toward the use of high-pressure, oxygen-blown, entrained-flow gasifiers[2]:
  - High conversion, low tar production (and low methane content; it is difficult to capture carbon in methane in IGCC)
  - Cold gas efficiency (CGE) is key to cycle efficiency but use of enthalpy in hot syngas in a HP steam cycle can boost system efficiency appreciably
- For IGFC, some other factors play an important role in determining system efficiency so the choice of gasifier, operating conditions, may be different[3]:
  - Power from fuel cell depends on the reducing power[4] of the syngas, rather than its CGE
  - Methane in syngas is a benefit for IGFC, as it reduces SOFC cooling load parasitics
- This paper presents a high-level overview of some of how syngas methane content and gasifier choice driving IGFC efficiency[5]
  - Overview of IGFC energy balances & efficiency considerations
  - Impact of syngas methane content
  - Impact of gasifier choice

1. Both considered with carbon sequestration
2. For more detailed review of considerations, see Appendix A
3. Cost, reliability drivers may have different impact depending on the specific fuel cell, gasifier used, see Appendix B
4. i.e. how many moles of oxygen can be reduced with the syngas, not how much heat is produced
5. Impact of other factors, such as gas clean-up conditions, fuel cell operating pressure, are discussed in Appendix C

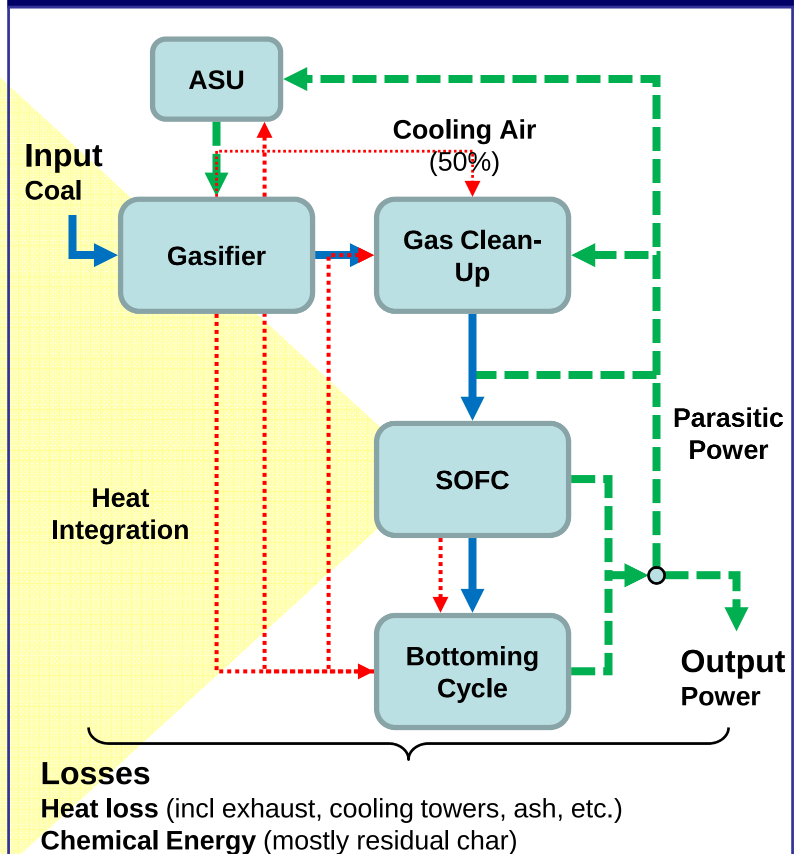
Operating requirement of the SOFC drive its thermal management as well as the overall system thermal integration.

Typical Energy Balance in SOFC[1]



1 Typical values assuming cell operating voltage of 0.8V, single-pass fuel utilization 80%, near-atmospheric SOFC; percentages are % of stack DC output

Main Energy Flows in Typical IGFC System[1]



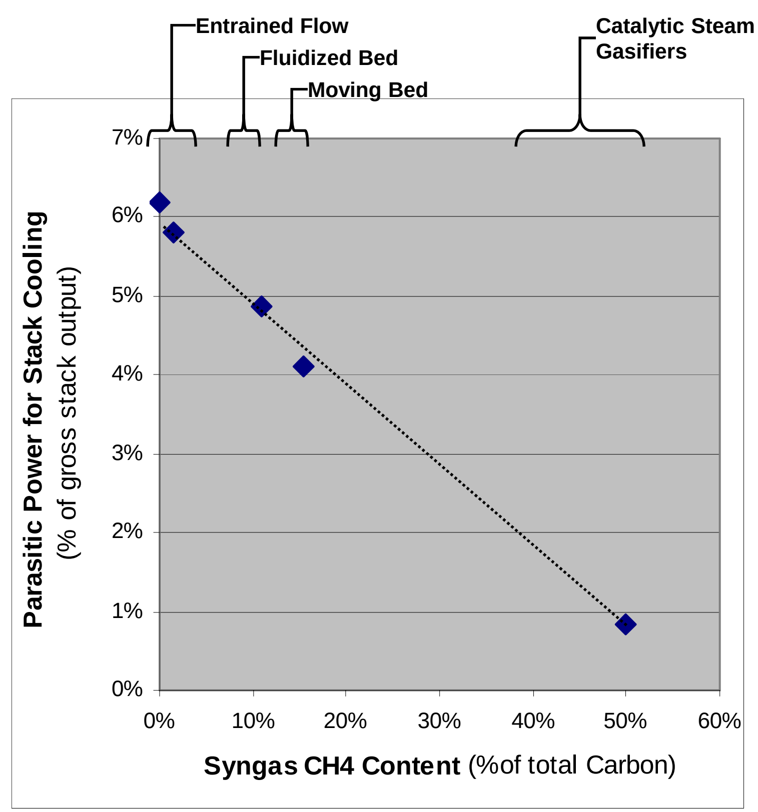
1 With an oxygen-blown gasifier

High methane content in the raw syngas provides a benefit in IGFC systems, unlike in IGCC systems.

- Methane in the raw syngas generally provides a benefit to SOFC parasitics in IGFC systems[1]:
  - In SOFC, methane is internally reformed, reducing heat release by ~20% compared with CO and H_2
  - This reduces cooling duty and associated parasitics by up to ~5% of stack output[2]
  - Fluidized and moving bed gasifiers offer a modest advantage over entrained flow gasifiers typical in IGCC
- Typically, higher methane content syngas:
  - Correlates with lower O_2 use and higher efficiency[2]
  - Must be balanced against:
    - Lower coal conversion
    - Higher tar production
    - Lower gasifier exit temperature (lower quality sensible heat)
  - If air is mixed with the syngas in the fuel cell high methane limits carbon capture level achievable
  - Finding optimum gasifier choice and methane level will require detailed engineering and modeling

1. CO has the opposite effect
2. Only if CH4 is formed in the gasifier, subsequent methanation reduces efficiency as it converts chemical energy to low-level heat

Typical Impact of Methane on SOFC Heat Balance[1]



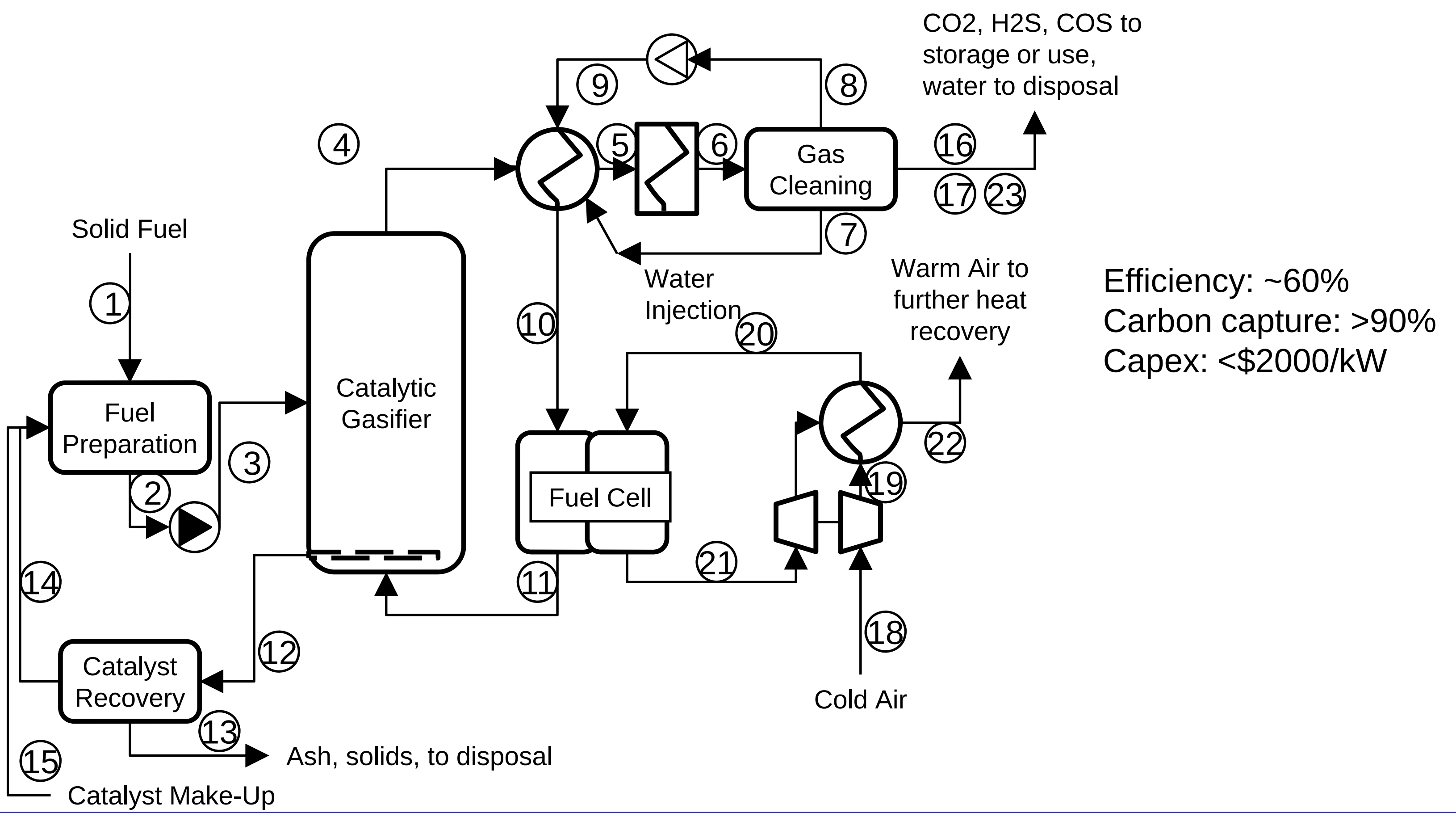
1 Assuming cell operating voltage of 0.8V, single-pass fuel utilization 80%, near-atmospheric SOFC

To take advantage of high methane content, future IGFC could combine a catalytic gasifier with a high-pressure SOFC.

- Pressurized catalytic gasifier (Exxon or GPE):
  - Catalyst allows steam / CO2 gasification at modest temperature (600 – 700 °C)
  - Normally high temperature steam and balancing of syngas ratio is needed to achieve thermal balance (i.e. the gasifier operates in an adiabatic mode)
  - SOFC integrates well with gasifier, substituting anode recycle for steam:
    - Critical to completely reform methane (either in the SOFC or in separate reformer)
    - This requires high steam / syngas ratio in the fuel cell
    - High temperature anode exhaust (850 or 900 °C) helps thermally balance reactor (operates at nominal 600 – 700 °C)
  - Must operate at a minum pressure of about 30-35 bar
- Pressurized SOFC:
  - 0.8 -0.82 V/cell
  - 75% single-pass utilization (utilization is adjusted to help thermally balance gasifier)
  - 10% purge from CO2 free syngas to tailgas burner to control inert concentrations
- 1-step HP CO2 removal (e.g. Selexol with ~95% removal, low-power)
- Syngas and tailgas waste heat use:
  - Fuel and air preheat
  - AGR
  - 2-part HRSG & ST

Such a system could meet all the DOE's targets, but would require the development of a 35 bar SOFC with separate flows.

Flow Schematic for HP IGFC with Catalytic Gasifier



Efficiency: ~60%
Carbon capture: >90%
Capex: <$2000/kW

Gasifiers that produce high-methane syngas, such as catalytic steam gasifiers can lead to higher system efficiencies in IGFC.

- High methane content syngas provides several advantages in SOFC:
  - Reduces cooling requirements in the SOFC, and hence parasitic losses
  - Can be produced more efficiently (less coal is oxidized completely)
- Catalytic steam gasifiers appear to provide an even better match with SOFC:
  - Can utilize recycled anode gas in the gasifier to balance gasifier thermally, avoid separate coal-fired boiler, and improve overall fuel utilization in fuel cell (eliminating the parasitic load on the gasifier)
  - Produces high methane gas minimizing SOFC airflow requirement and parasitics
  - But catalytic steam gasifiers are not yet commercially available and may require additional development:
    - Development by Exxon through demonstration stage for SNG production in 1980s
    - Greatpoint Energy is currently pursuing technology for SNG application
    - Full benefit may be contingent on a pressurized SOFC with separate anode and cathode (additional risk in SOFC development)

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