Coal and Combined Feedstock Gasification to Fuels, Chemicals, and H_2

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Gasification Technology Status and Pathways for Net-Zero Carbon Economy Workshop

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Introduction

Gasification Usage and Benefits

Gasification: Versatile, feedstock- and product-flexible technology

- Syngas ($CO + H_2$) from any carbon-containing feedstock.
- Enables advantageous (low-volume) and cheaper pre-combustion CO_2 capture.
- Clean syngas: versatile feedstock.
  - Power.
  - Transportation fuels.
  - Methanol.
  - Hydrogen.
  - Other higher-value chemicals.

Commercialized primarily for large-scale coal gasification

- Coal: energy-dense fuel, established infrastructure, widely available in large quantities.
- Co-gasification with biomass and wastes coupled with pre-combustion CO_2 capture.
  - Enable net-zero or even negative CO_2 emissions.
  - Synergism of waste utilization for value-added products plus diversion of wastes from landfill.

Gasification Process Steps

Gasification reactions

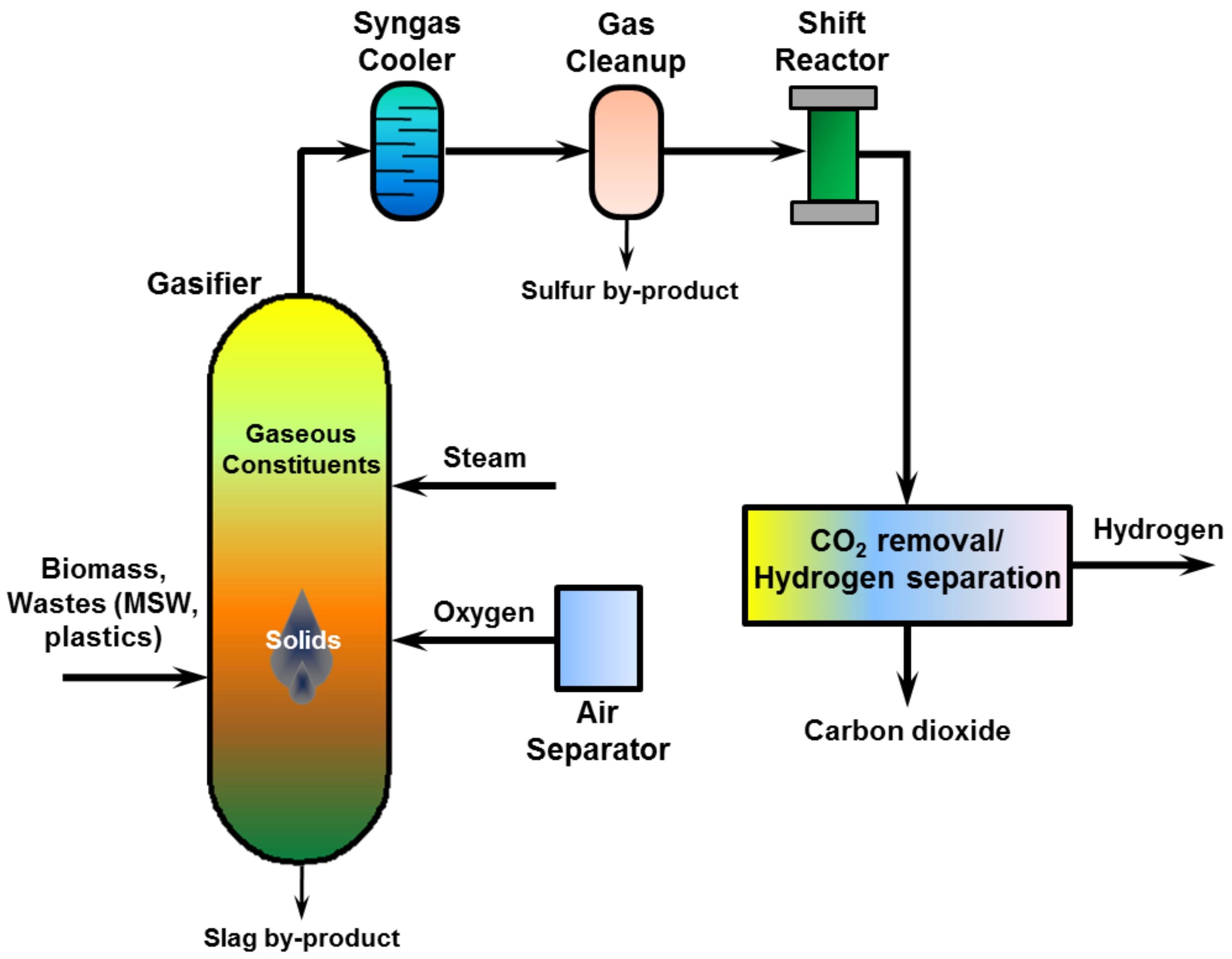
- Drying and devolatilization.
- Pyrolysis.
- Partial combustion.
- Char gasification.

Raw syngas cleanup

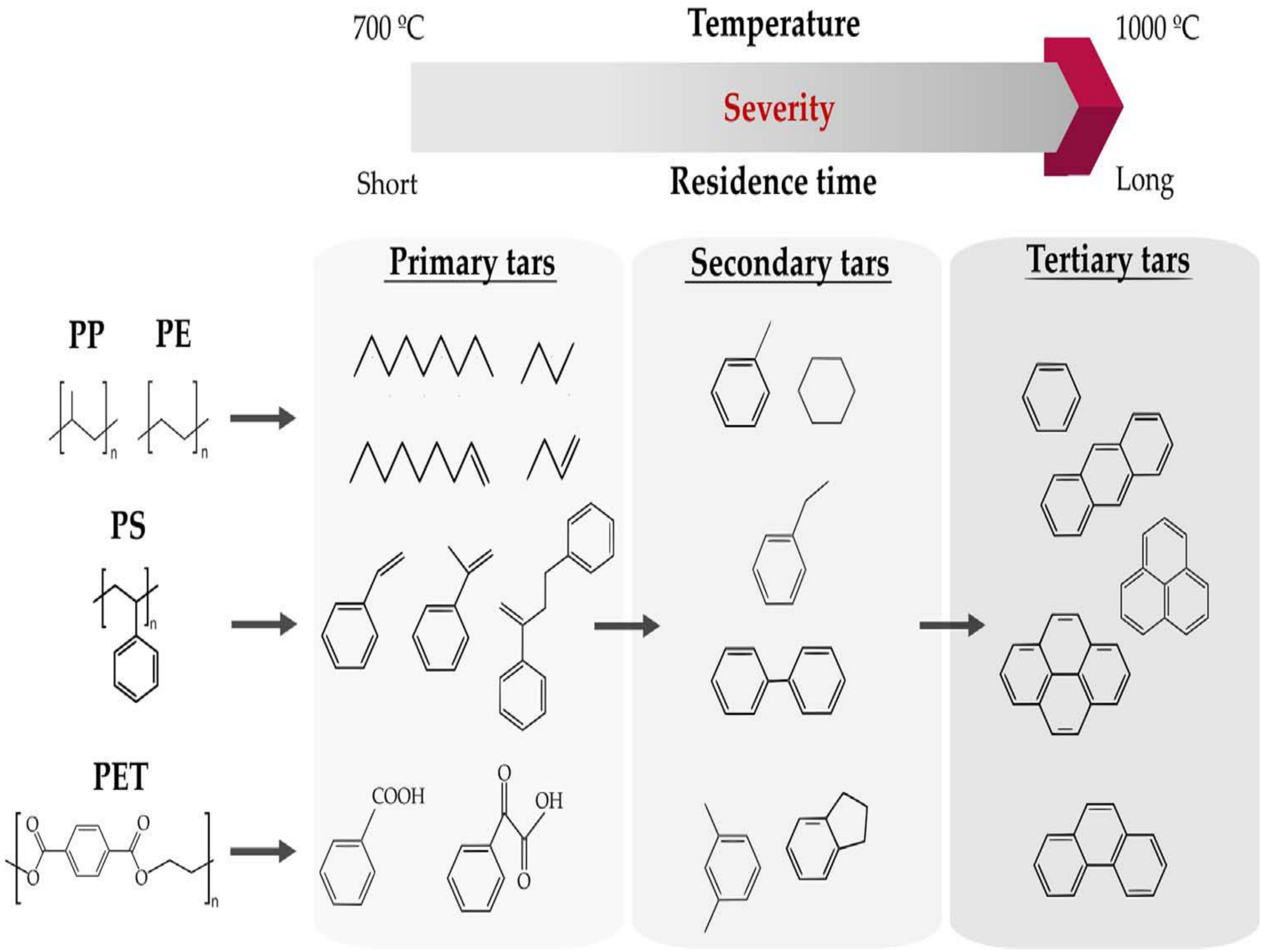
- Particulate/trace contaminants.
- Sulfur gases (H_2S, COS).
- Tar—particularly important with combined feed.

Water gas shift to adjust H_2/CO ratio or produce H_2

- Transportation fuels and methanol—2:1.
- Hydrogen—maximum shift.
- Power—shift for decarbonization.



Tar Formation From Plastics Gasification*

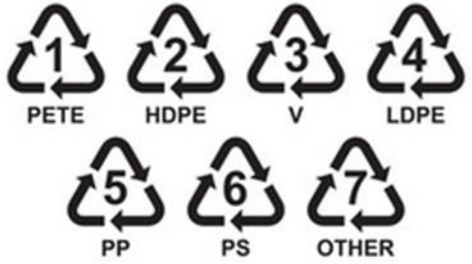


* Lopez, G. et al. (2018) Renewable and Sustainable Energy Reviews, 82 (1), 576-586

Gasification of Combined Feed

Special Considerations

- Mixed feedstock feeding issues.
- Feed compatibility with type of gasifier.
- Melting/softening of plastics over a wide temperature range (100–270 °C).
  - Stickiness and tendency to agglomerate.
  - Propensity to form highly problematic tar during pyrolysis.
  - >95% volatile matter significantly reduces importance of char gasification.
- Both biomass and plastics gasify at lower temperatures and tend to produce more tar than coal.
  - >1250 °C and >0.5 second residence time required to destroy tar.
- Feed variability: different plastics types in the waste mix pyrolyze differently.
- Contamination with other municipal or industrial solid waste.

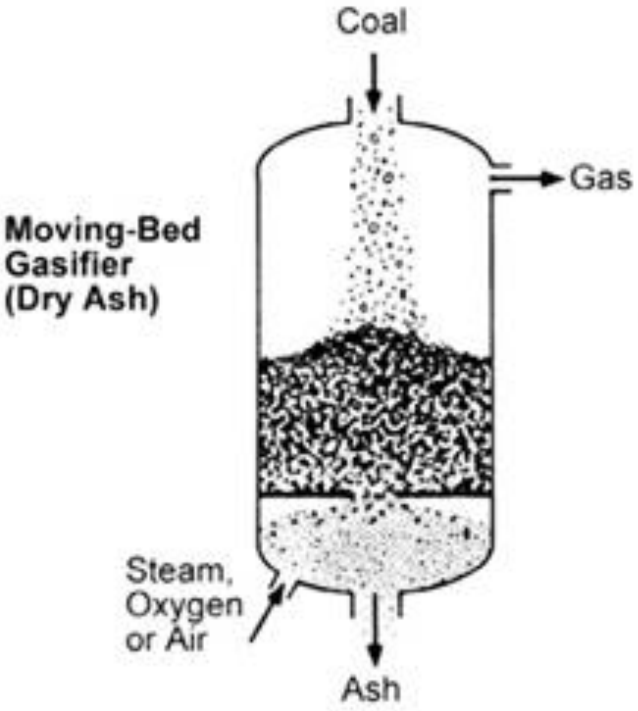


Combined Feed Gasification Reactor Choices (1)

Fixed (Slow Moving)-Bed

Characteristics

- Simplest to design.
    - Updraft.
    - Downdraft.
- Poor choice due to low heat transfer rates.
- Pelletizing biomass and plastics (to alleviate feeding issues) is expensive.



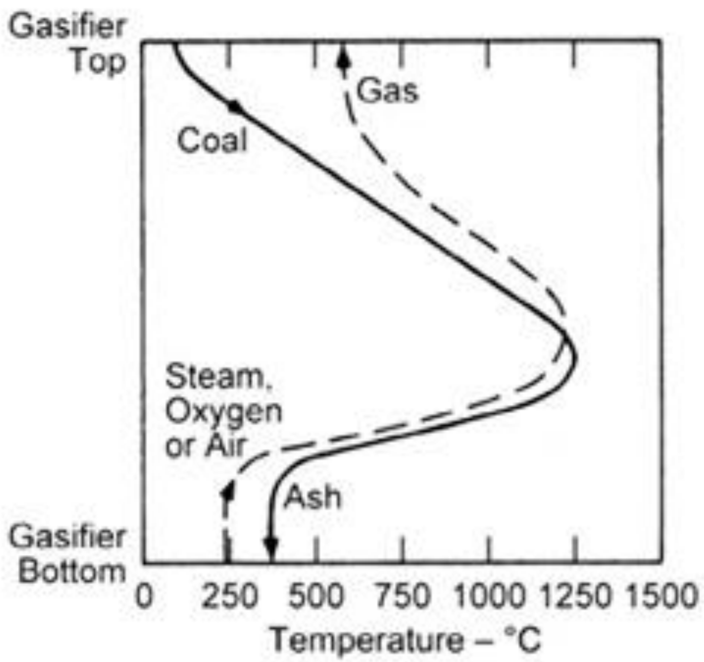


Image source: Electric Power Research Institute

Combined Feed Gasification Reactor Choices (2)

Fluidized-Bed

Characteristics

- Good heat transfer rates and fuel flexibility.
- Documented in the literature for waste plastics.
- Nearly all plastic research-scale gasifiers are bubbling-bed.
    - Catalyst used as bed material to crack tars.
    - Maximum 850–900 °C.
- Unavoidable tar formation.
- Smaller scale than entrained-flow.

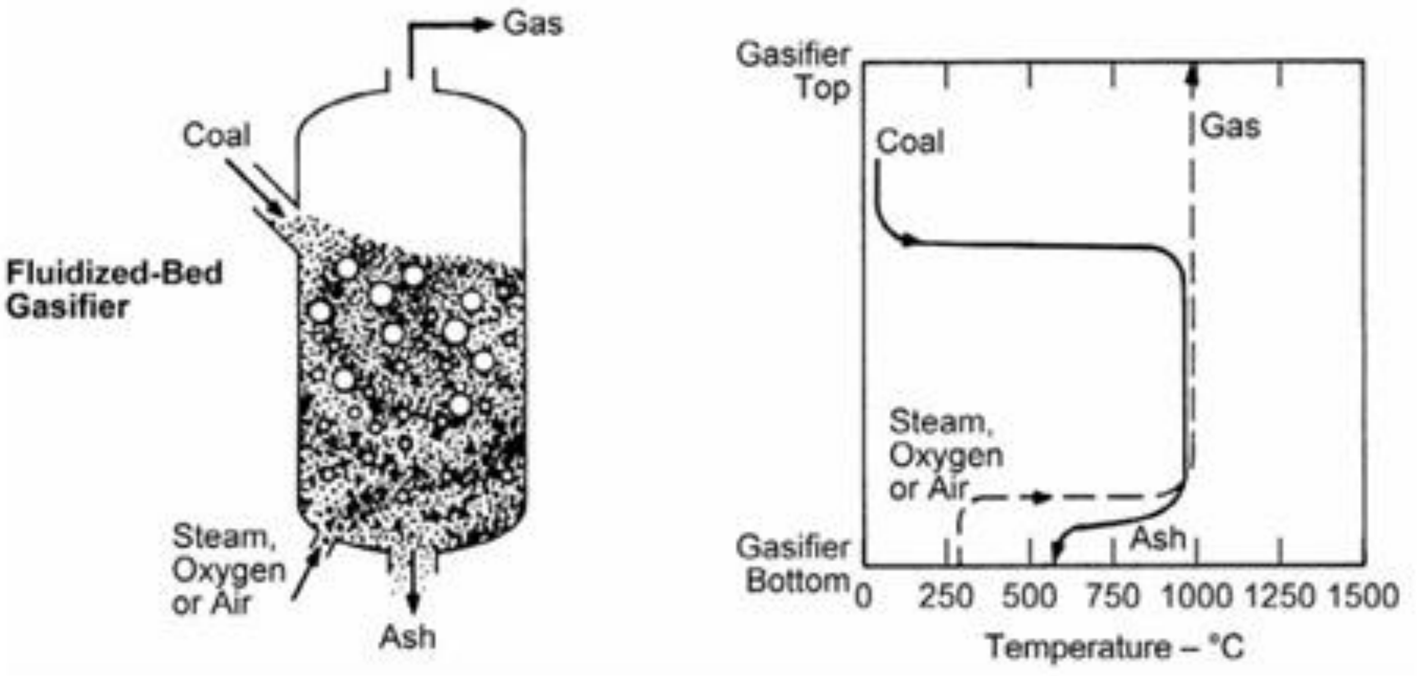


Image source: Electric Power Research Institute

Combined Feed Gasification Reactor Choices (3)

Entrained Flow

Characteristics

- Temperatures of 1350– 1400°C can be achieved to fully crack tars.
- Less fuel flexibility in design compared to fluidized–bed gasifiers.
- Reactors of choice for large-scale pressurized operation.
- 5 tpd waste plastics entrained flow gasifier.*

*https://www.nipponsteel.com/en/tech/report/nsc/pdf/8604.pdf

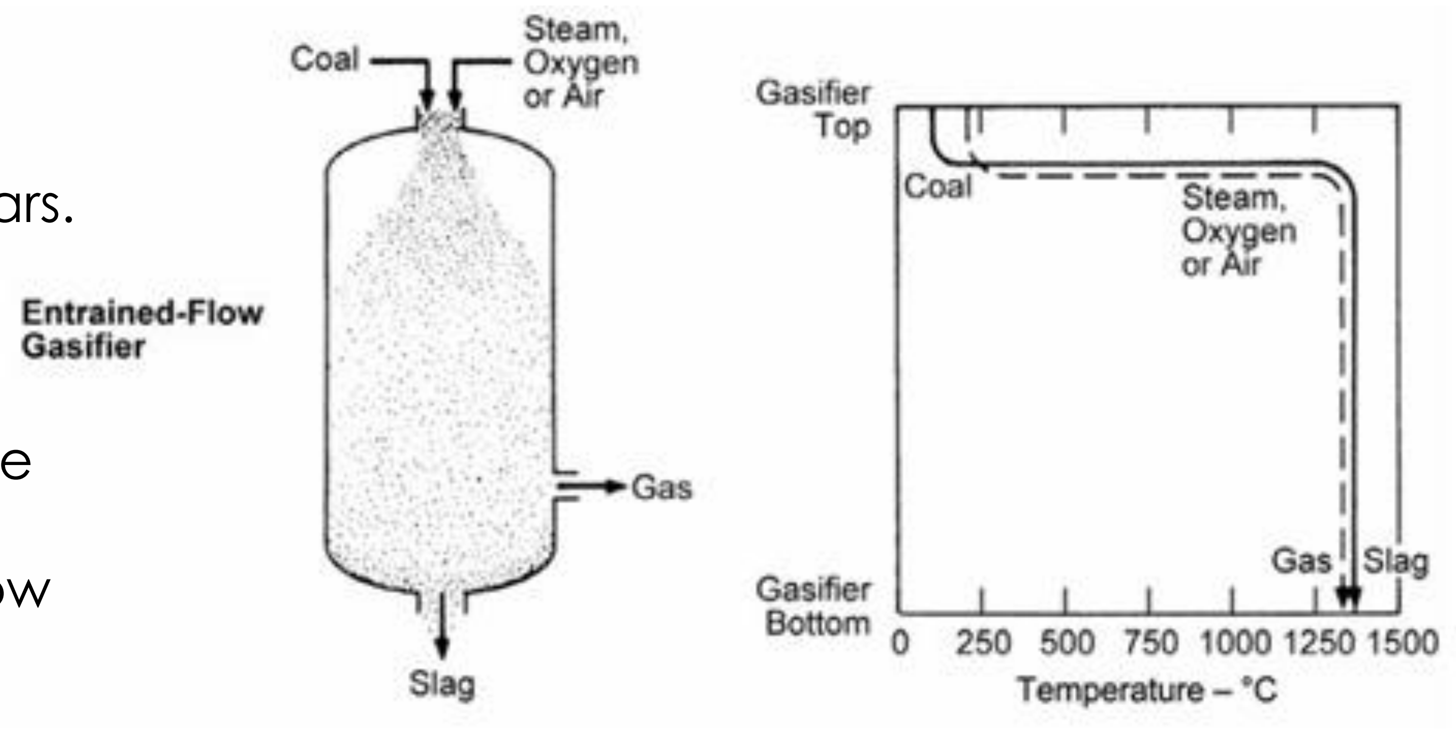


Image source: Electric Power Research Institute

Syngas Cleanup

Typical cleanup steps

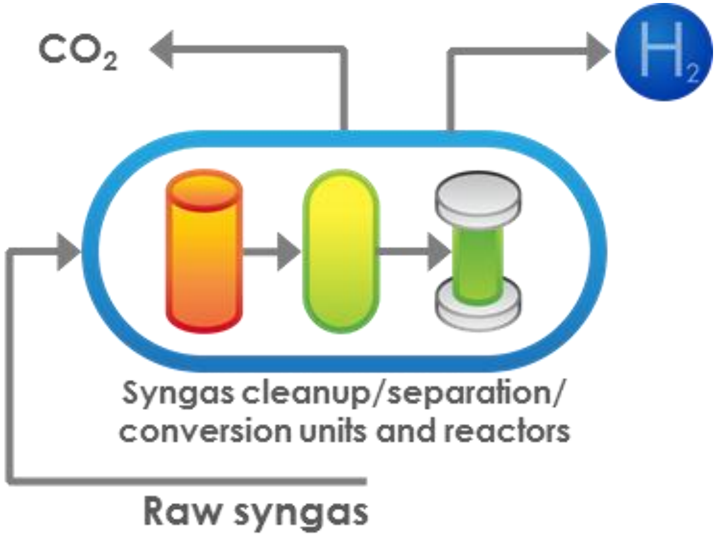
- Particulate and trace contaminant control—quench or filtration at moderate temperatures (200–300 °C).
- Sulfur removal.
- CO_2 capture.

Clean up targets depend on product

- Sulfur levels down to <30 ppb required for fuels or methanol production—commercial Selexol or Rectisol followed by a guard bed.
- Less stringent for combustion turbine use (~50 ppm).

Sour water-gas shift

- Enables process streamlining.
- Hydrogen, fuels, methanol/chemical production.



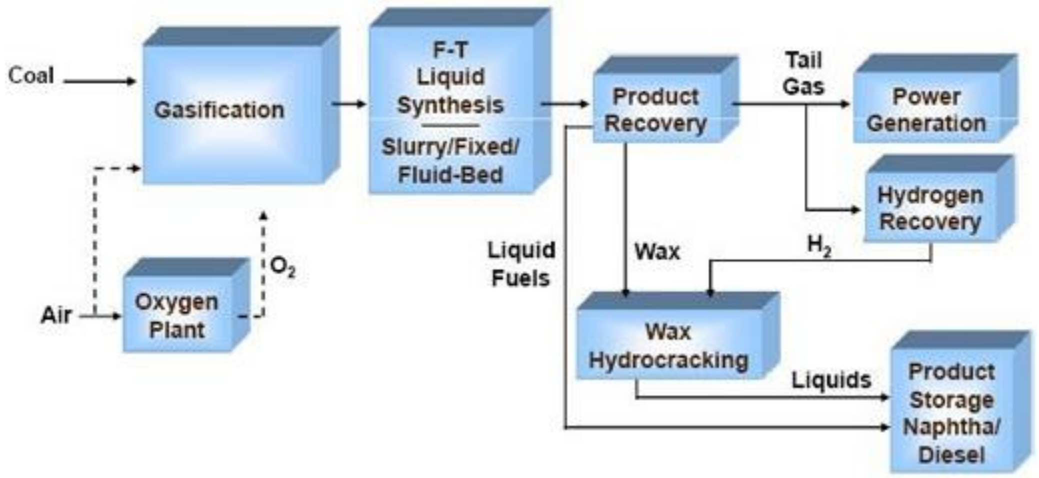
Syngas Conversion

Power

- Decarbonization—deep WGS followed by pre-combustion CO_2 capture
- Pure H_2 turbine status [UiS, GE].

Liquid Fuels

- Fischer-Tropsch synthesis.
  - High a, Co or Fe catalyst, 210–250 °C.
  - $CO + 2H_2 \rightarrow$ -CH2- $+ H_2O$
  - $CO + H_2O \rightarrow CO_2 + H_2$ [Fe catalyst].



Methanol

- Cu-Zn catalyst; 200–210 °C.
- $CO + 2H_2 \rightarrow CH_3OH$

Hydrogen

- Sulfided Co-Mo catalyst (250–300°C).
- $CO + H_2O \rightarrow CO_2 + H_2$

Conversion reactions are exothermic requiring reactor designs for good heat management to prevent catalyst sintering and maintain selectivity to desired product.

Syngas Conversion Reactor Design Considerations

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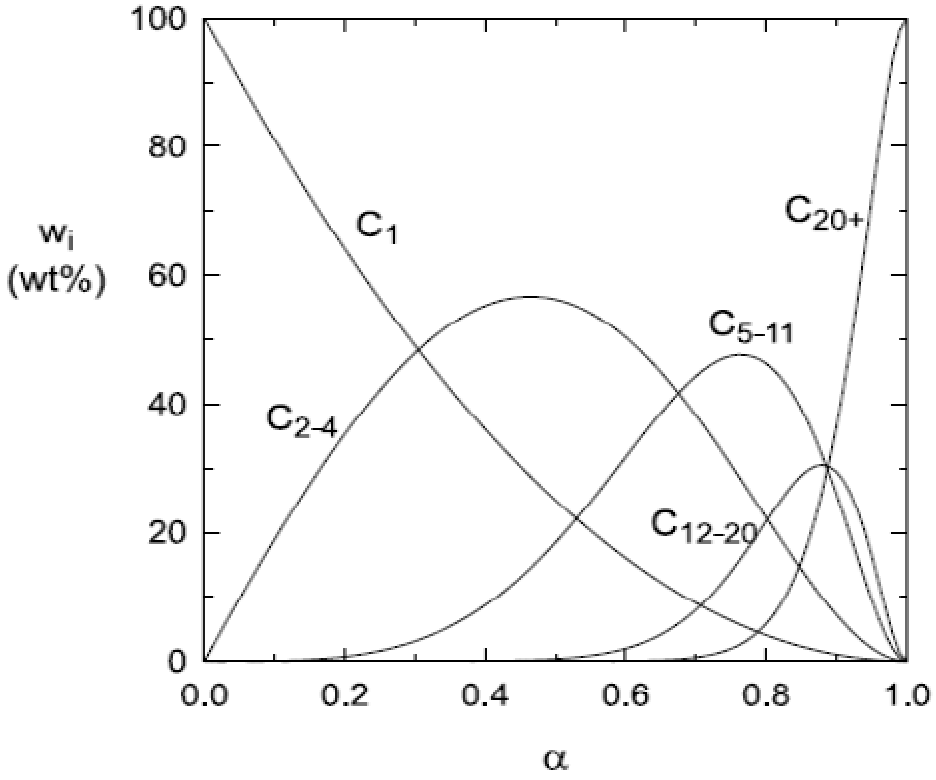
Hydrocarbon Selectivity as a Function of Chain Growth Probability Factor, a

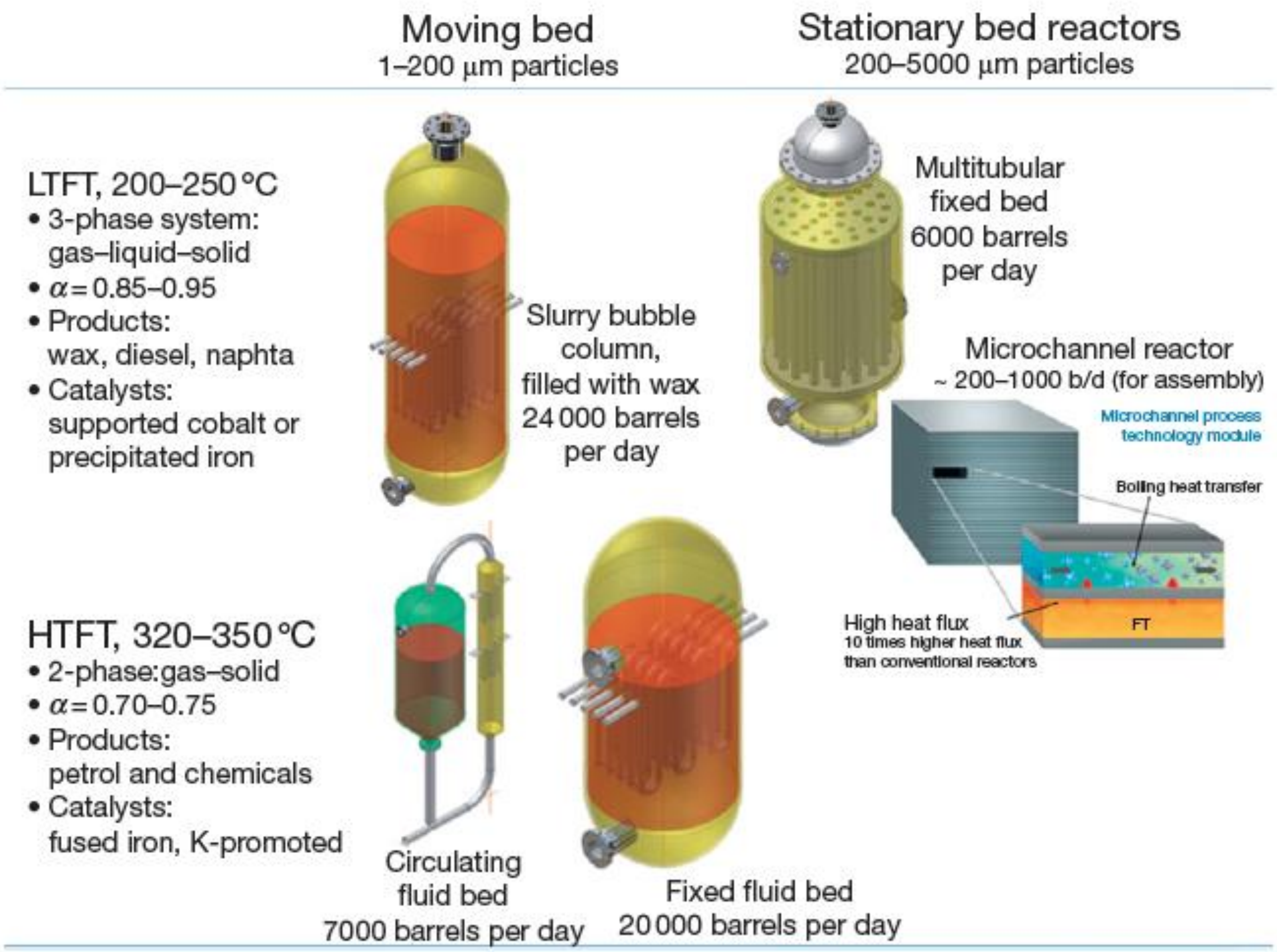
Typical Commercial Reactor Designs for Hydrogen Production and Methanol Synthesis

- Series adiabatic reactors with intercooling.
- Series adiabatic reactors with recycle in the first reactor and with heat exchangers between reactors.
- Quench reactors that mix cold unreacted gas with hot gas from one reactor and distribute it across the next reactor.
- Shell and tube reactor with syngas recycle and with catalyst either in the tubes or on the shell side.



van der Laan, G.P. et al. (1999)"Kinetics and Selectivity of the Fischer-Tropsch Synthesis", Catal. Rev. Sci. Eng., 41, 3-4, 255-318

FT Reactors*



*van der Loosdrecht et al. (2013), "Fischer-Tropsch Synthesis: Catalysts and Chemistry", in Comprehensive Inorganic Chemistry II. From Elements to Applications, 7, 525-557.

Newer Trends in Syngas Conversion

Small-scale modular systems

- Microchannel reactor.
- Larger diameter heat exchange reactor.
- Small methanol plants.

Selective and/or bifunctional catalyst

- Direct conversion to C2–C4 olefins (e.g., ethylene, propylene, butene).
- High selectivity to diesel and/or jet fuel range hydrocarbons.

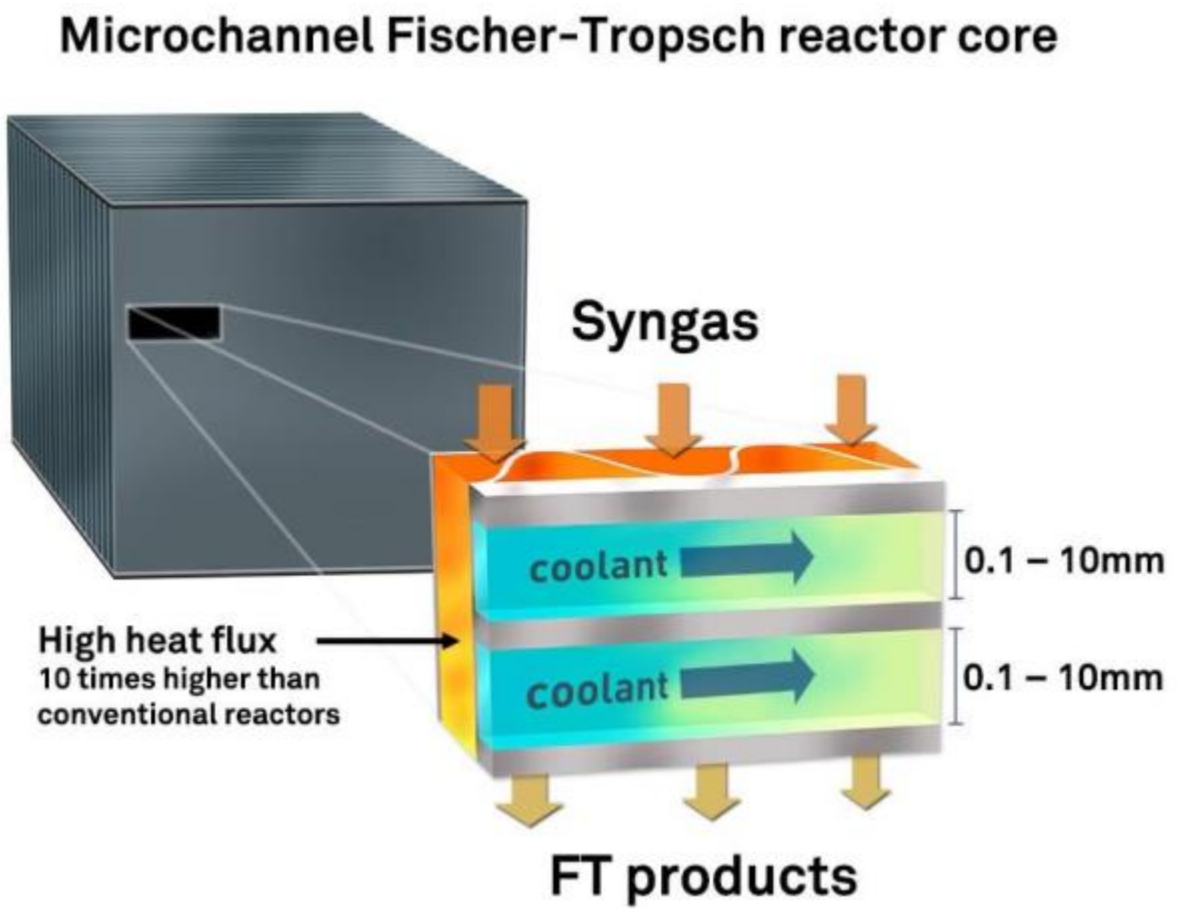


Image from LeViness, S., Deshmukh, S.R., Richard, L.A. et al. Velocys Fischer–Tropsch Synthesis Technology—New Advances on State-of-the-Art. Top Catal 57, 518–525 (2014). https://doi.org/10.1007/s11244-013-0208-x

Desired Gasification Technology Evolution

Large-scale coal gasification plants (power, hydrogen, transportation fuels, methanol)

- Commercialized.
- But in current market, new plants not cost-effective.
- Questionable in deep decarbonization scenarios.

Requirements for gasification plants of the future

- Highly efficient, flexible, reliable—leverage gasification process advantages.
- Environmentally responsible—leverage syngas cleanup advantage and emerging advances in pre-combustion capture.
- Cost effective—pursue any and all cost reduction possibilities.
- Enable cycling and handling multiple fuels (coal, biomass and waste plastics) for strategic gasifier plant siting to market opportunities and role in attaining net-zero carbon emission goals.

RD&D Path Forward: Modularity

Smaller-scale modular gasification-based systems

- Address market needs for maximum flexibility at minimized cost.
- Multiple product application (power/hydrogen/fuel/chemicals) accessing niche markets.
- Modular air separation, gasification reactor, syngas cleanup, and conversion reactor unit ops.
- Site specific system integration to local feedstock availability and labor
- Capital reduction inherent to modular/smaller units.

Co-gasification of waste plastics and biomass with wastes and waste coal

- Co-located wastes and biomass opportunity
- Co-gasification's operational/logistical advantages and GHG reduction potential
- Significant advances in gasification of blended and variable feed stocks needed

Conclusions/Summary

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Gasification attributes/current status

- Feedstock and product flexible technology.
- Inherent efficiency and environmental performance advantages.
- Commercially demonstrated at several scales (large-scale coal gasification-based processes).
- Traditional large plants not competitive in current market.

Smaller-scale modular systems

- More flexible for co-gasification of biomass with plastic, waste coal (high calorific value feedstocks).
- Couple with capture and sequestration to enable net zero or negative carbon emissions.
- Modular integrated sub-systems and distributed gasification plants: potential for maximum flexibility and minimized cost; application to niche markets and ready availability of local feedstock and labor.

Gasifier designs

- Entrained flow gasifier—most suitable for gasification(excellent tar destruction).
- Fluidized bed gasifiers—greater flexibility to handle variable/mixed feeds.

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