the Energy to Lead

Gasification Options for Bioenergy Projects

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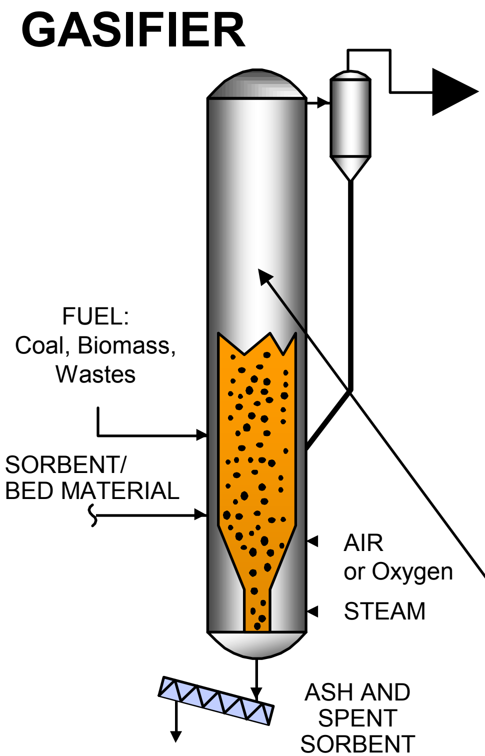
Topics

- Gasification basics and general traits of various biomass gasifier technologies
- Application-specific features that affect performance and economics of gasification-based processes
- Building confidence in gasification solutions
- Leveraging existing infrastructure to optimize the energy value in the biomass

What is Gasification?



Products (syngas):

CO (carbon monoxide)

H_2 (hydrogen)

CH_4 (methane)

By-products:

H_2S (hydrogen sulfide)

CO_2 (carbon dioxide)

Solids (minerals from fuel)

Gas Cleanup **Before** Product Use

Process Conditions:

Pressure = 1 to 30 atm or more

Temperature =1600 – 2600 F

Reactions Important in Gasification

Feed Devolatilization = CH_4 + CO + CO_2 + Oils + Tars + C (Char)

$C + O_2 = CO_2$	(exothermic –rapid)
$C + \frac{1}{2}O_2 = CO$	(exothermic –rapid)
$C + H_2O = CO + H_2$	(endothermic –slower than oxidation)
$C + CO_2 = 2CO$	(endothermic –slower than oxidation)

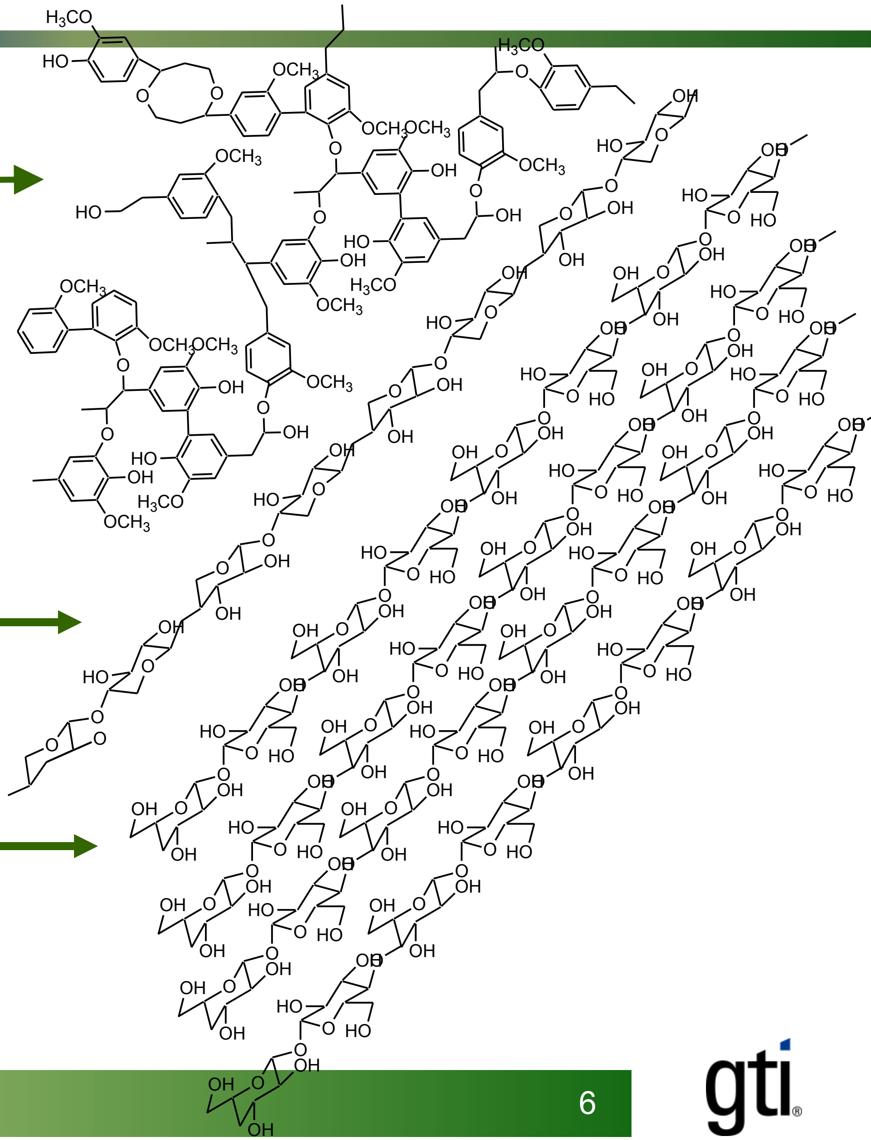
$CO + H_2O = CO_2 + H_2$	Shift Reaction (slightly exothermic–rapid)
$CO + 3H_2 = CH_4 + H_2O$	Methanation (exothermic)
$C + 2H_2 = CH_4$	Direct Methanation (exothermic)

Selecting Reactions to Optimize in Example Cases

fuel gas:	relatively high methane content is good, higher hydrocarbons are not necessarily bad, nitrogen and CO_2 dilution is tolerable
liquid fuels*:	maximize CO and H_2, minimize methane content, no higher hydrocarbons, proper H_2:CO ratio for synthesis, no dilution
SNG:	maximize methane, no higher hydrocarbons, proper H_2:CO ratio for synthesis, no dilution

* Liquids production by catalytic processes

Biomass Constituents



Lignin: 15-25%

- Complex network of aromatic compounds
- High energy content

Hemicellulose: 23-32%

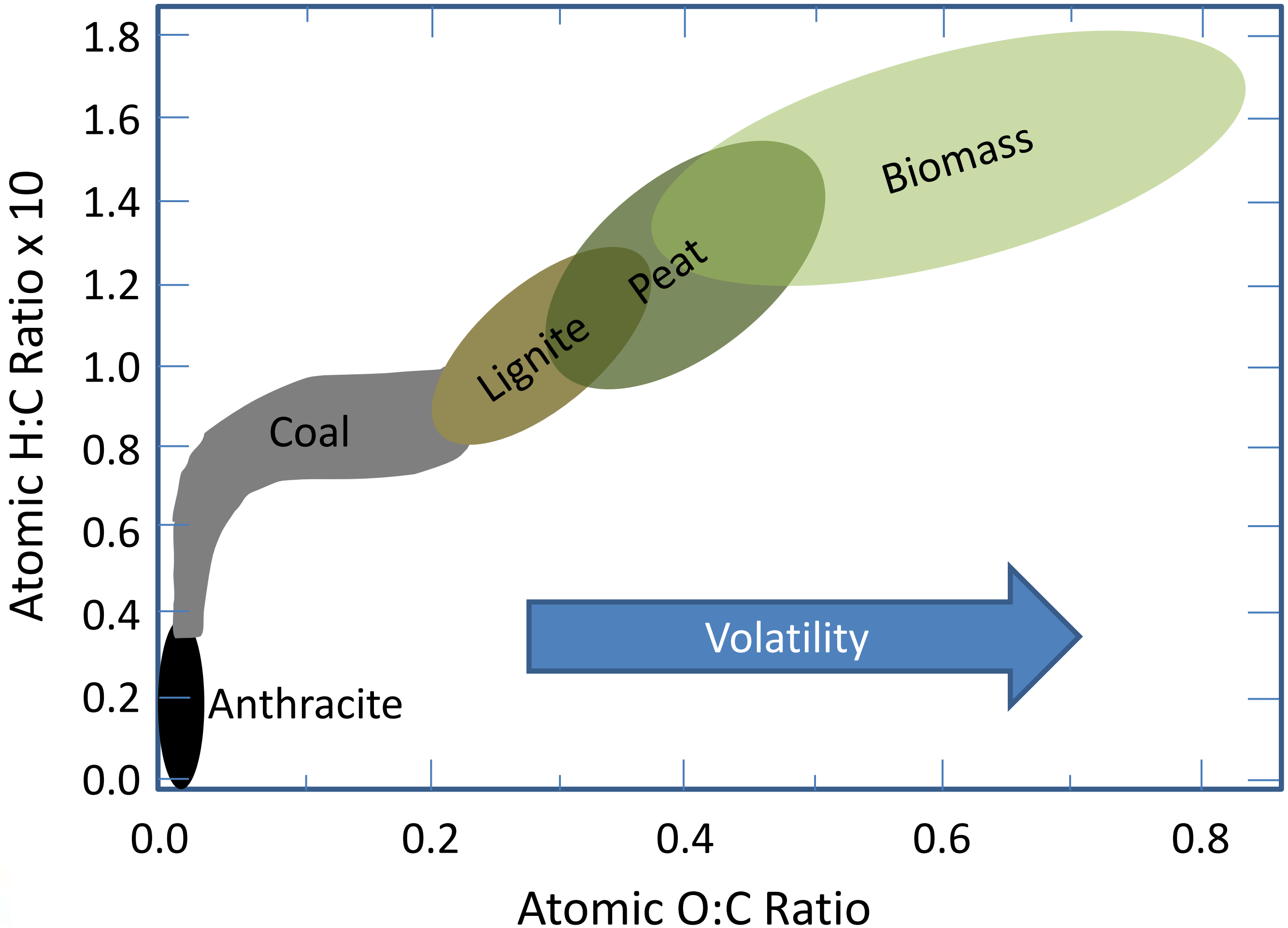
- Polymer of 5 & 6 carbon sugar

Cellulose: 38-50%

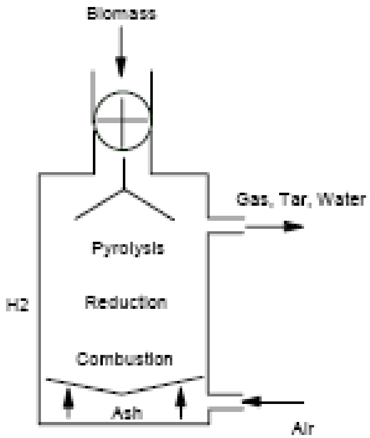
- Polymer of glucose

Ranking of Fuel Volatility

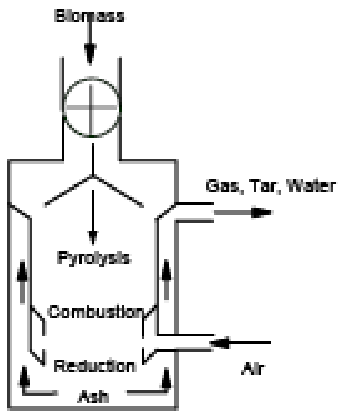
(Van Krevelen Diagram)



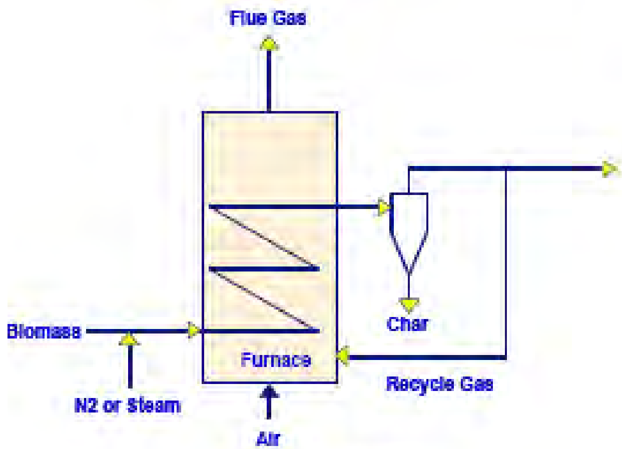
Basic Biomass Gasifier Types



Updraft Gasifier

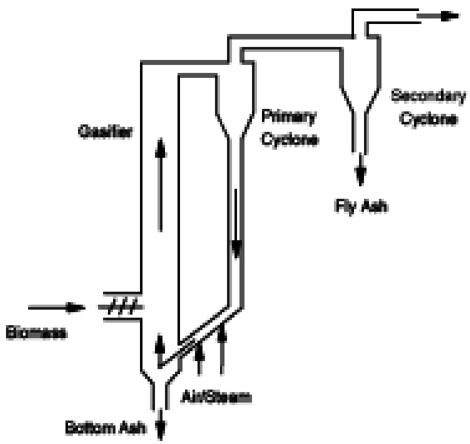


Downdraft Gasifier



Entrained Flow Gasifier

“indirect” 2-stage reactor design typical



Fluid-Bed Gasifier

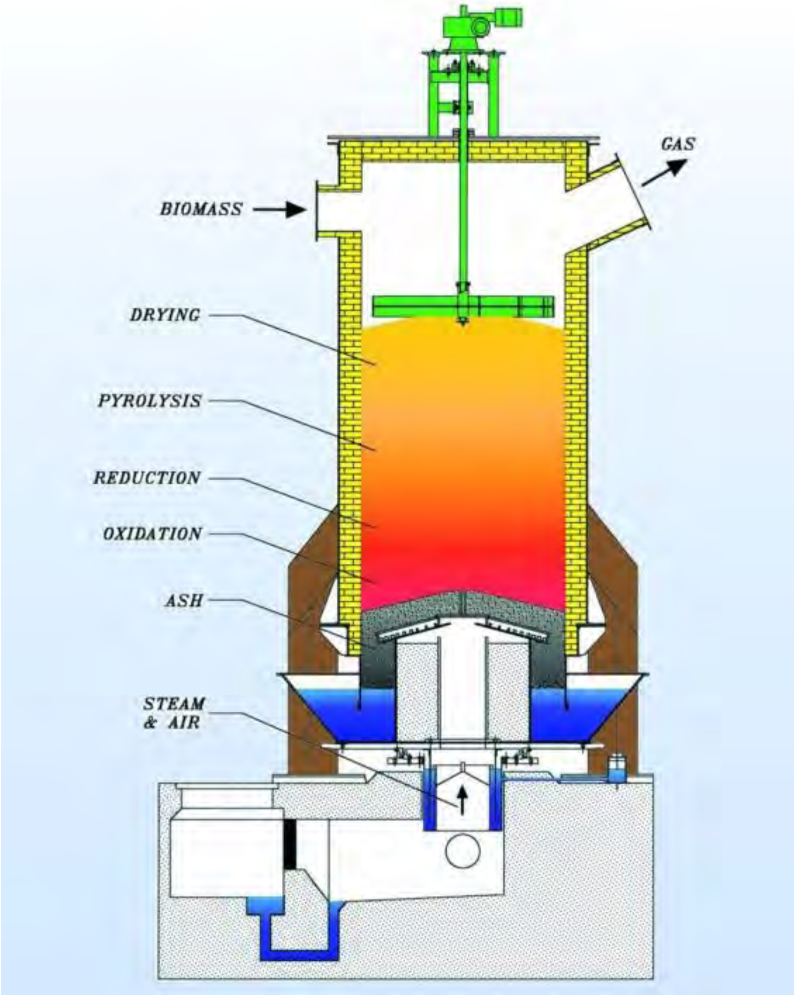
Can operate at high pressure

Tar Production

Fuel Capacity

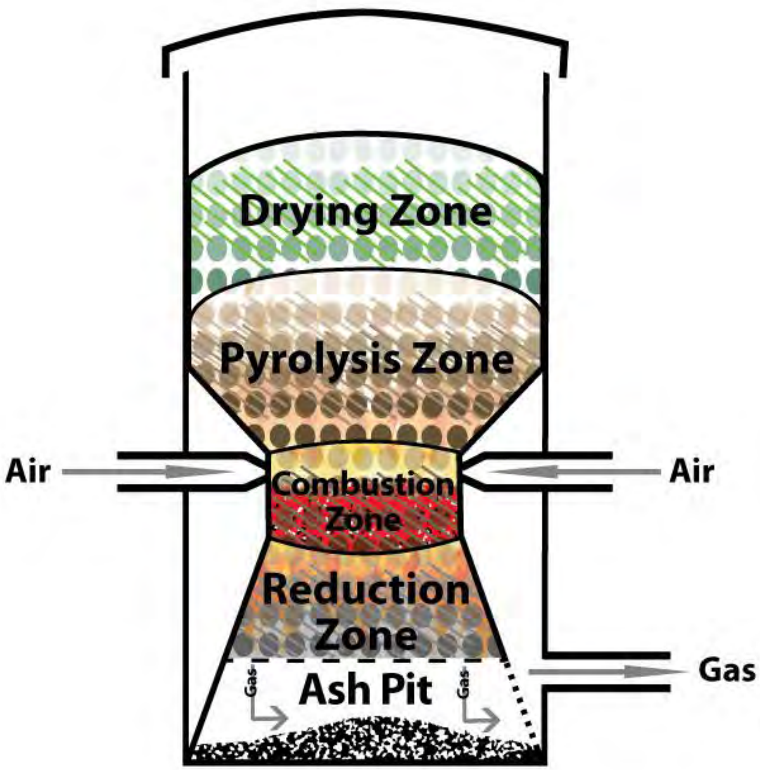
Updraft Gasifier

Nexterra, Babcock Vølund, Condens Oy Novel, and many others



Downdraft Gasifier

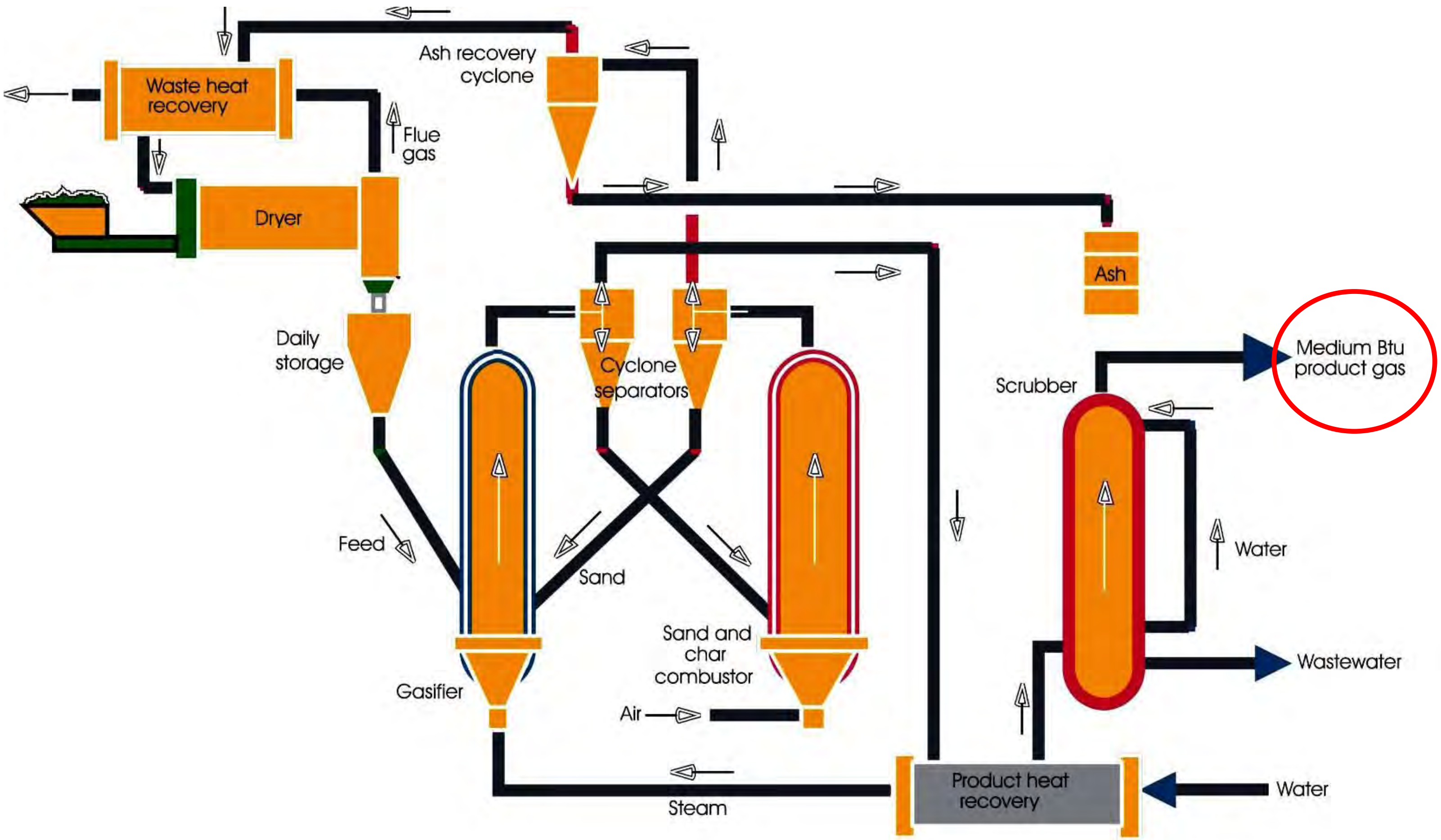
Many suppliers from Ankur to Xylowatt



Ankur Scientific Gasifier
energy from wood, Gujarat,India

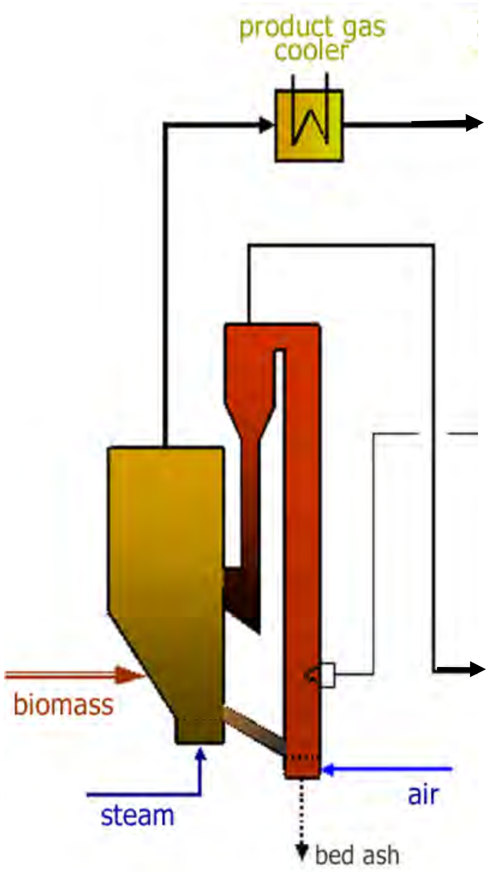
Indirect Gasifier

(Battelle / FERCO / SilvaGas (Rentech))

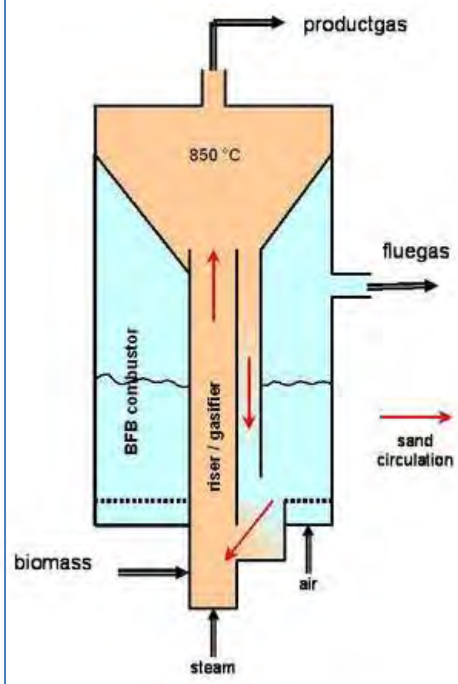


Other Indirect Gasifiers

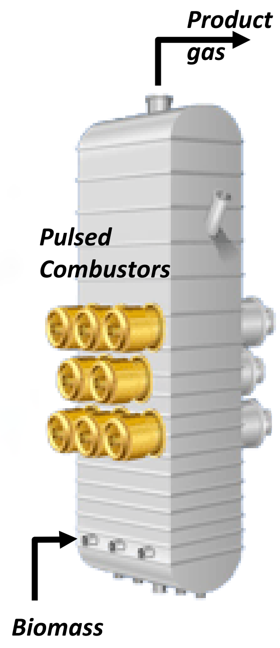
TUV/Repotec FICFB, ECN Milena, TRI, Agnion



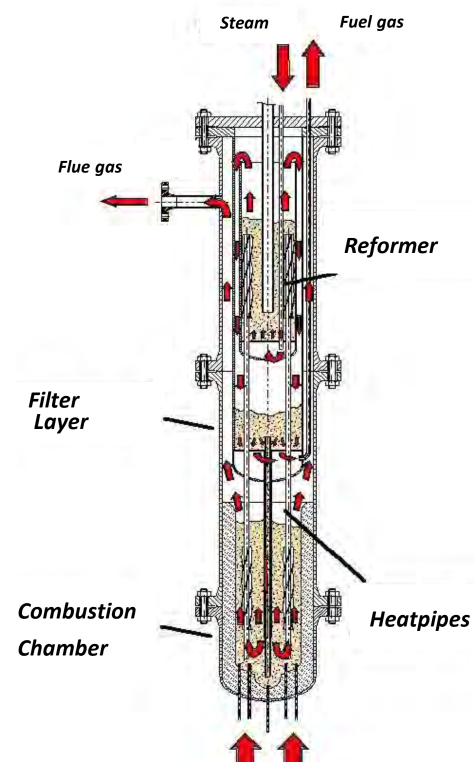
TUV Fast Internally Circulating Fluidized Bed



Milena



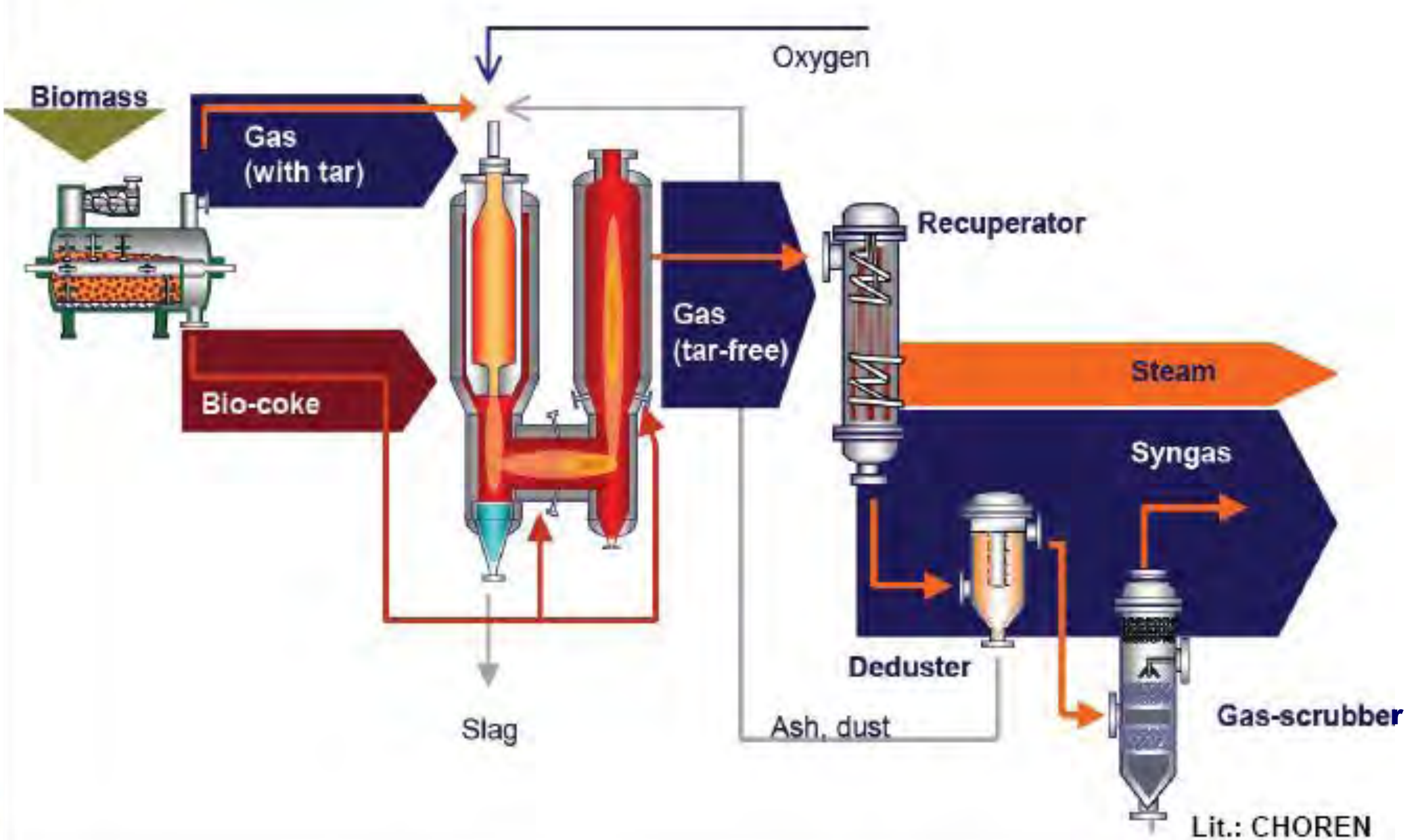
TRI



Agnion

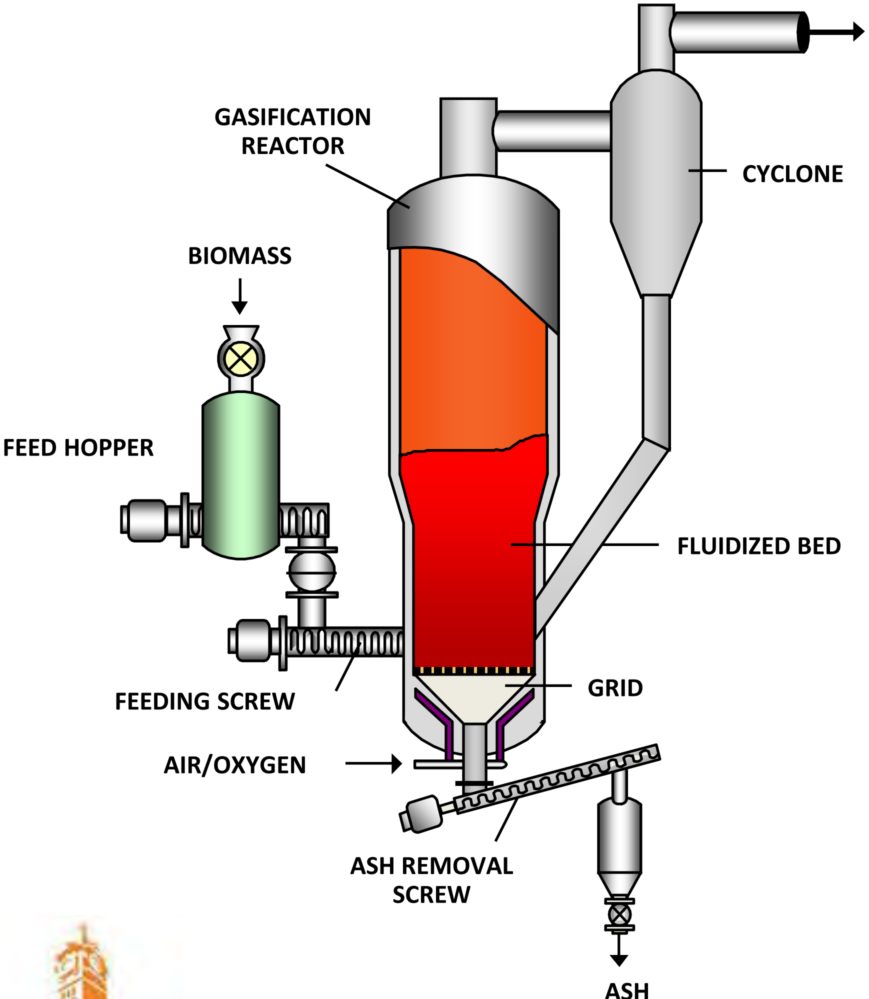
Multi-Stage Gasifier

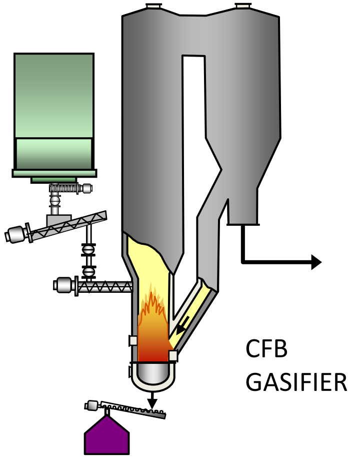
Choren Carbo-V, Cortus, Klepper,



Fluidized Bed Gasifier

GTI, Andritz/Carbona, Foster Wheeler, Metso





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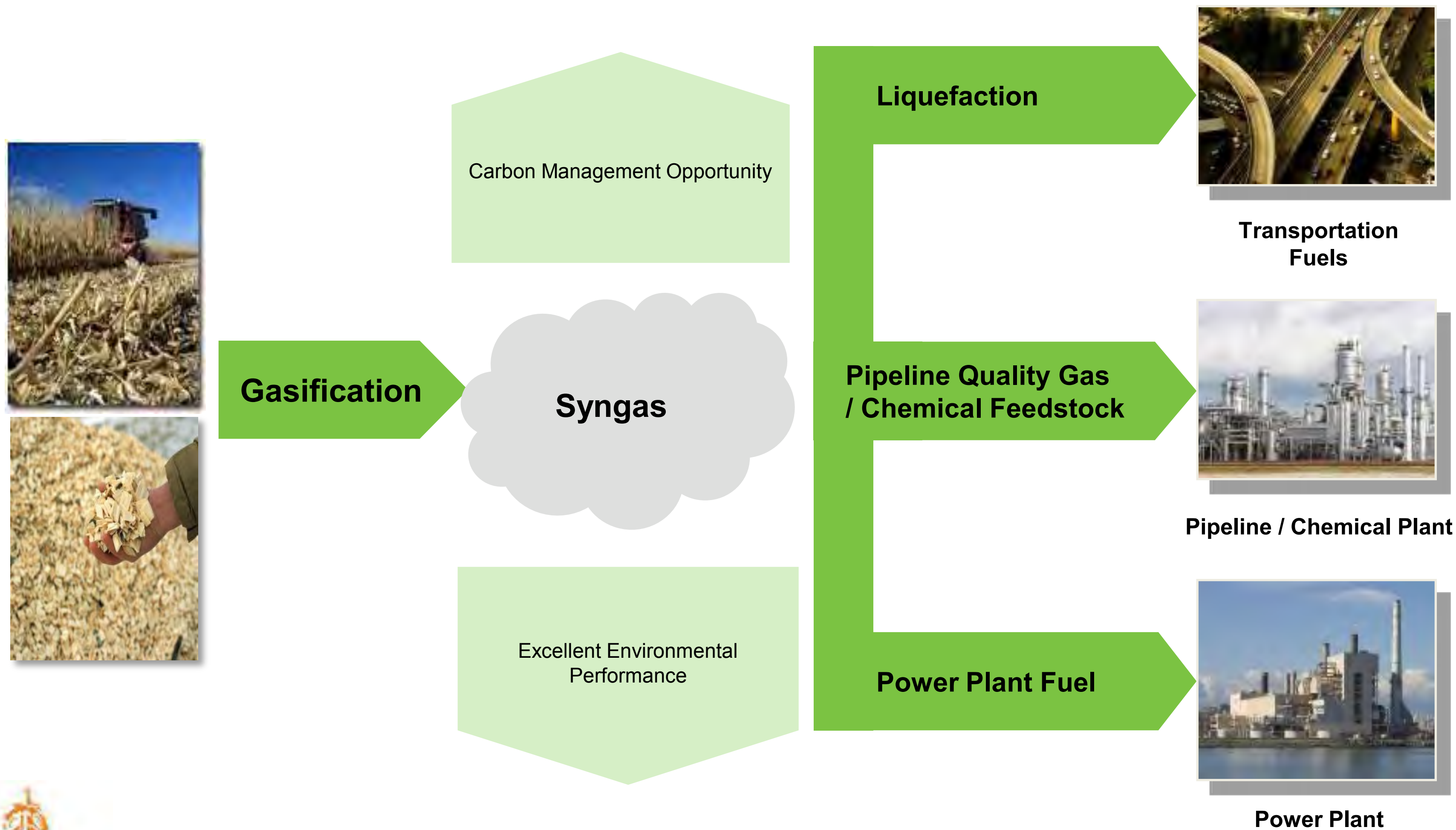
Typical Properties of Biomass Gasifiers

PROPERTY	Updraft	Downdraft	Indirect	Fluid Bed	Multi-Stage
Feed size, mm	5-100	20-100	300-500	>40	>40
Gas exit temp, C	300	700	850	850	900
Tar content	Very high	High	High	Low	Very low
Pressure, atm	1	1	1 to 5	1 to 30+	1 to 5
Gasifying agent	Air	Air	Steam	Air or O_2 + steam	Steam, O_2
Gas heating value	Low	Low	Medium	Low or medium	Medium
Max Scale	100's kW	100's kW	10's MW	100's MW	160 MW

This list is illustrative only. It is not a comprehensive list of important properties.

Gasification – A Means to Convert Biomass into Useful, Clean Energy Products



What are the strengths of biomass gasification?

1. All sorts of biomass can be converted, as well as peat, coal, pet coke, and wastes. (an answer to feed vs. food vs. fiber vs. fuel debate)
2. All the carbon in the feed is available for conversion. Gasification takes carbon from all the plant material to make product.
3. The reactions can be optimized for different applications. (This means technology choices are important and meaningful.)
4. The produced gas can be manipulated to remove contaminants, separate products, change relative concentrations (shift) – all to the specific level required to make the product and meet regulations.
5. All sorts of product options exist, and co-product options exist. The choice of application is constrained by market values and competitive economics, not the gasification process.

What matters for process performance and economics? Everything.

Product(s)

- Value
- Market
  - Size
  - Acceptance
  - Access
  - Volatility
- Drivers

Feedstock

- Energy content
- Composition
  - Volatility
  - Moisture
  - Minerals
- Handling
- Abundance
- Sustainability

Technology

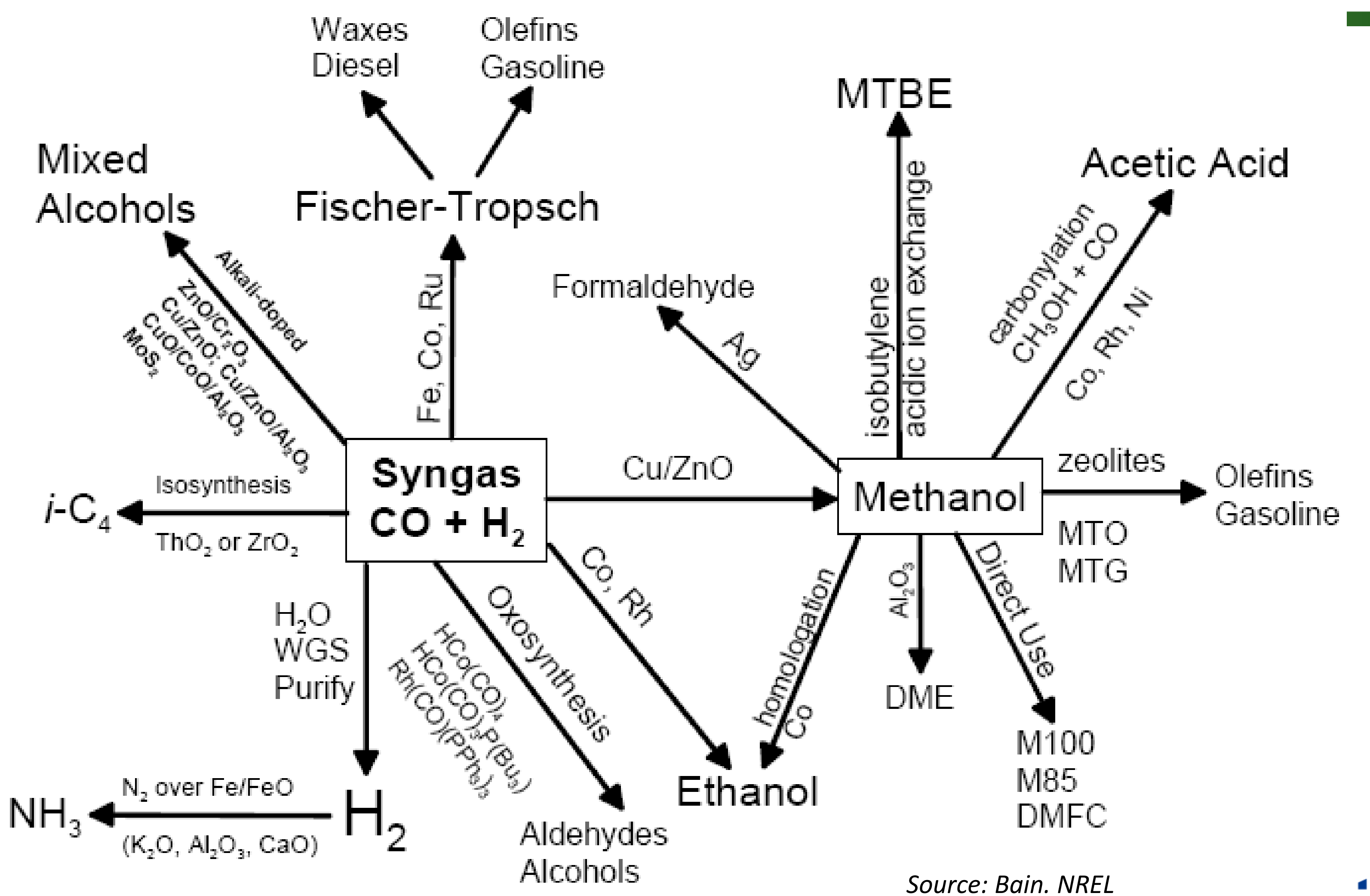
- Efficiency
- Scalability
- Operability
- Reliability

Some Biomass Gasification Product Options

- Biomass-to-power in boiler
  - Simple process design; low efficiency (20-30%); limited co-firing range; boiler and site modifications required; commercial
- Biomass-to-power with engines or gas turbine
  - kW to MW scale; varying efficiency (28-50%) without waste heat integration; high efficiency possible in CHP application requiring consistent heat load; commercial
- Syngas fermentation for alcohols
  - Route to cellulosic ethanol; medium efficiency (50%); limited distribution system; high water demand; technology still in R&D
- Biomass-to-Liquid transportation fuels via catalytic synthesis
  - Moderate efficiency (35-45%); can be improved with significant heat/steam integration; ultra-clean gas required; direct gasoline synthesis available, whereas F-T product needs further refining; commercial technology available
- Substitute Natural Gas (SNG)
  - High efficiency (65-70%); increased efficiency with waste heat integration; pipeline infrastructure-ready, storable product; ultra-clean gas required; commercial technology available

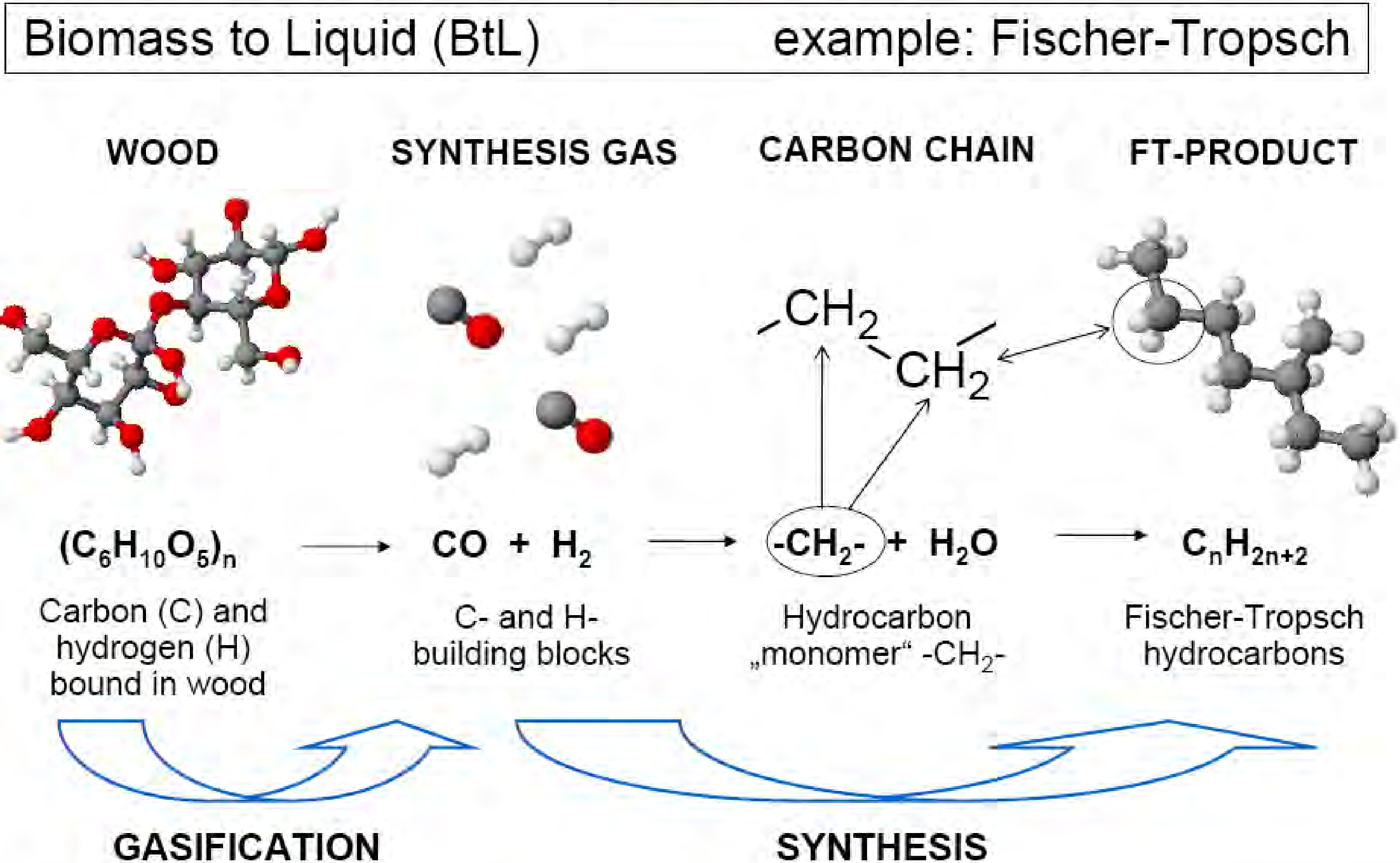
(efficiency on HHV basis)

Syngas-to-Liquids Options



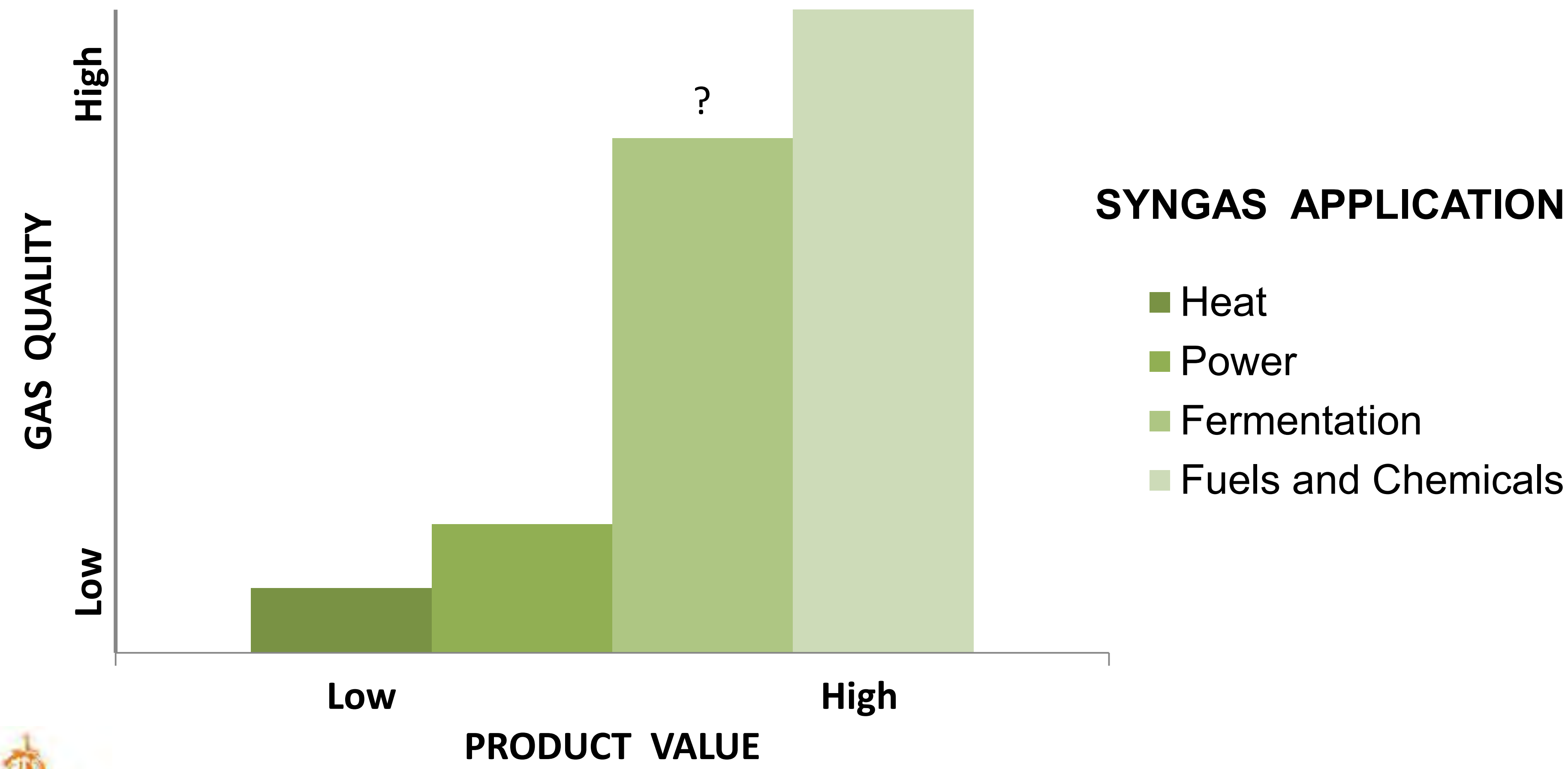
Source: Bain. NREL

Example of Product Synthesis

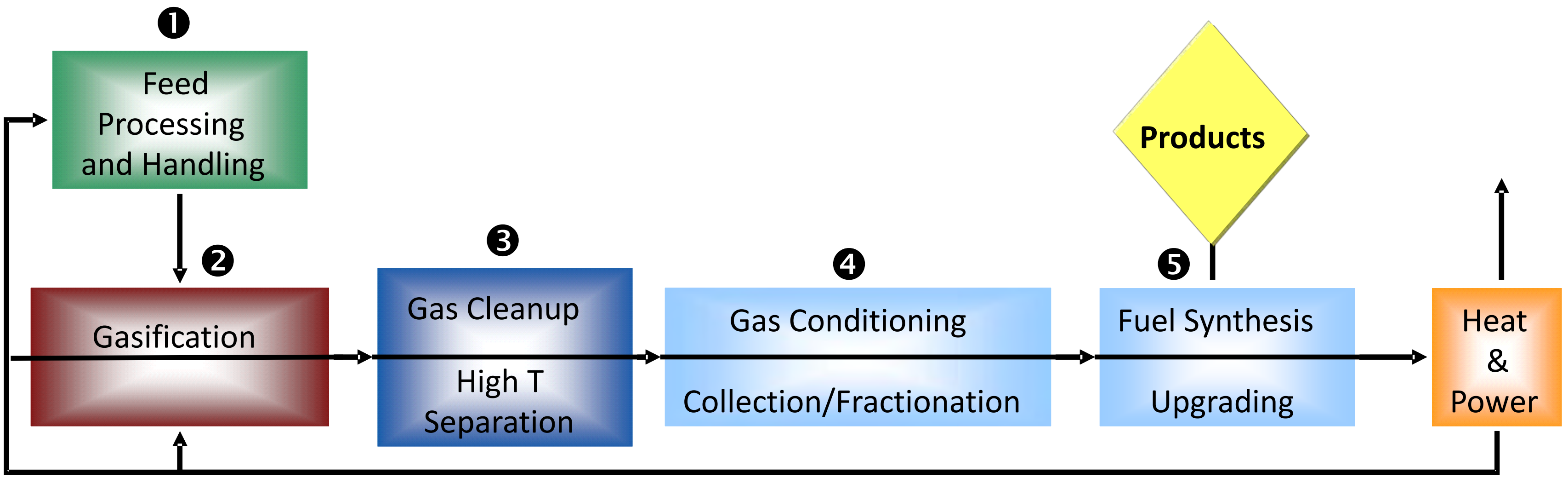


Graphic Source: reNet: Renewable Energy Network Austria

Application Dictates Process Design



Thermochemical Process Conceptual Design

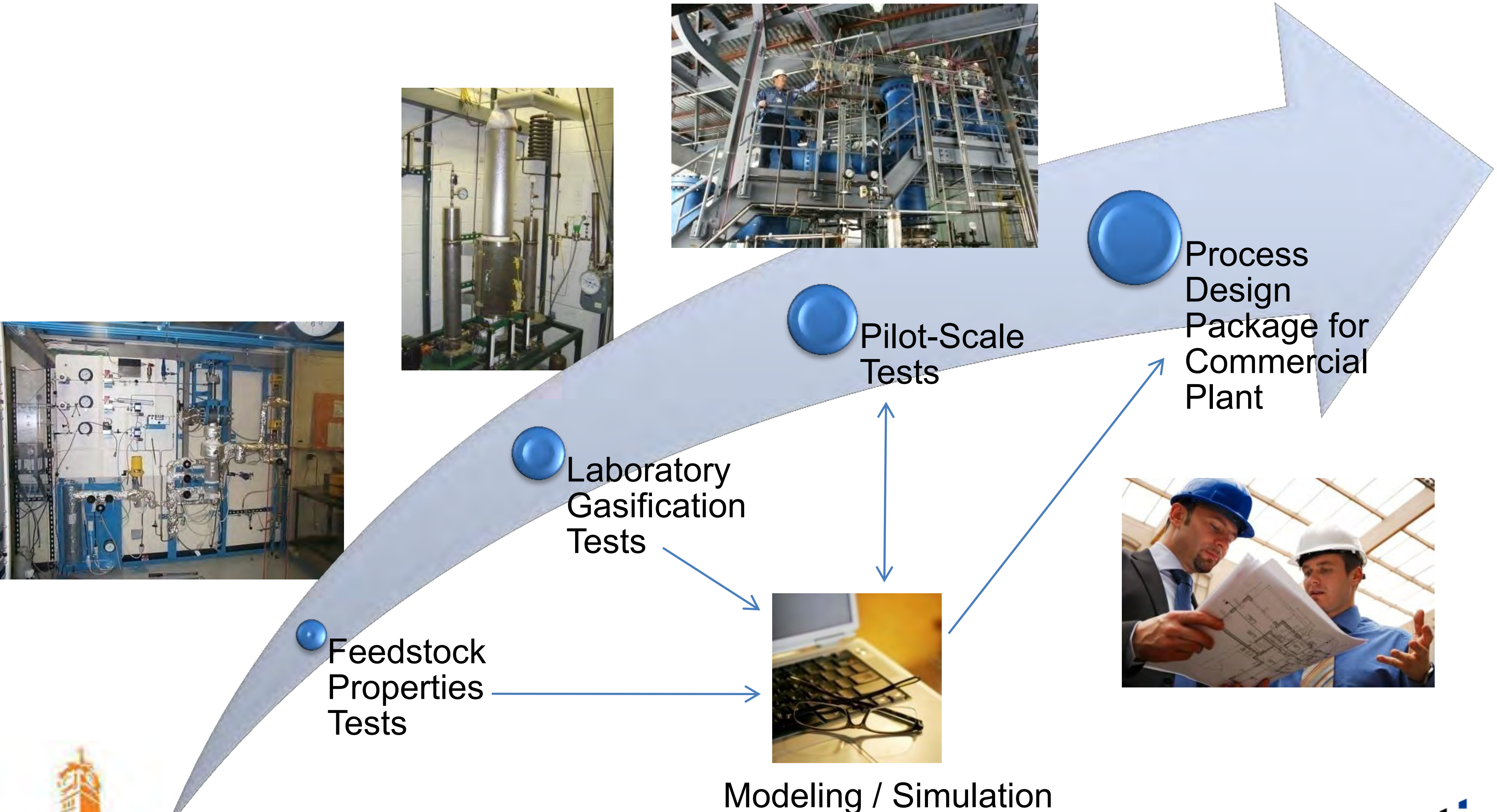


Based on: Phillips, S.; Aden, A.; Jechura, J.; Dayton, D.; Eggeman, T. [*(2007). Thermochemical Ethanol via Indirect Gasification and Mixed Alcohol Synthesis of Lignocellulosic Biomass*.](#) 132 pp.; NREL Report No. TP-510-41168.

What are the challenges for biomass gasification applications?

- Variable biomass composition imposes design inefficiencies and makes it harder to manage produced gas quality to meet application needs.
- There are so many choices and claims for technology, and yet so few successful reference plants. What are false economies and what are prudent choices?
- Higher value products requires higher capital expense which favors large-scale production.
- Immature technology options cause uncertainty in process selection. Scaling up with confidence takes time.

Gasifier Application Development: Reducing Risk & Building Confidence



GTI's Pilot Gasification Test Facility

1. Advanced Gasification Test Facility
   - -1a Haldor Topsøe TIGAS Process
   - -1b PWR Gasification System
   - -1c Biomass Syngas Conditioning Systems

2. Flex-Fuel Test Facility
   - -U-GAS and RENUGAS Gasification Systems

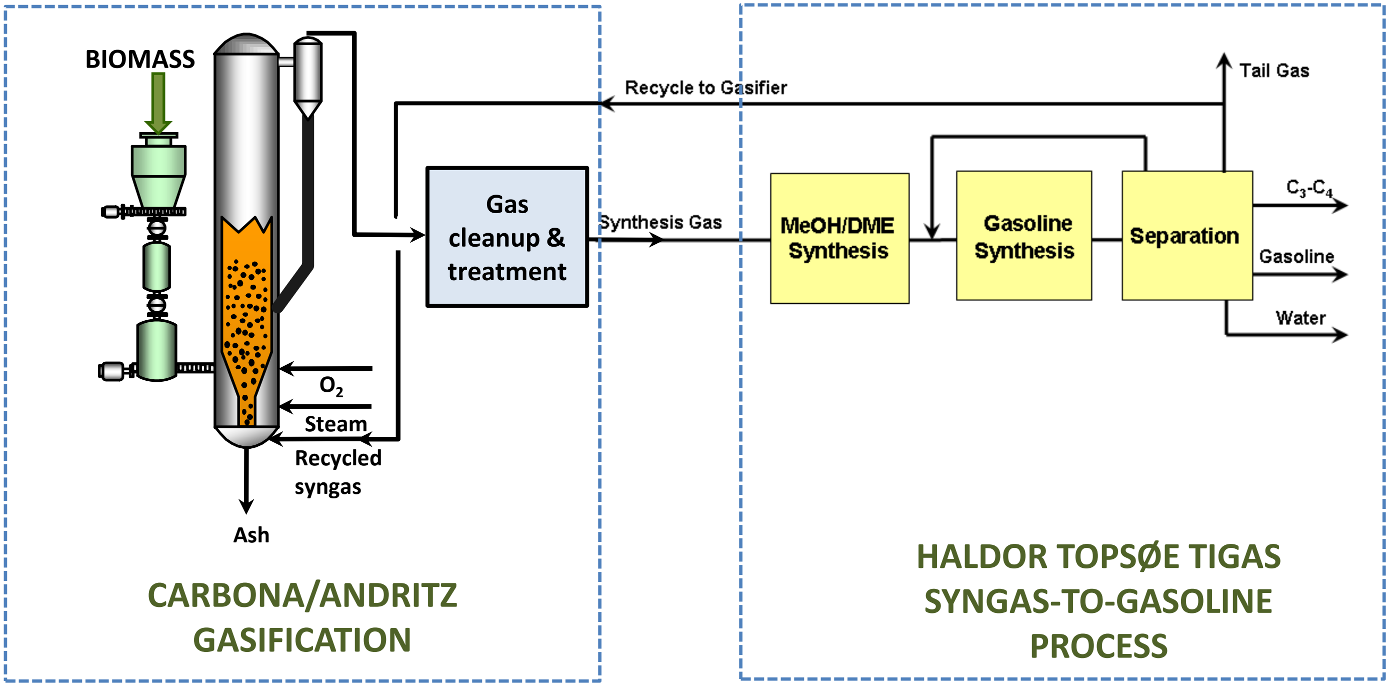
3. Morphysorb®
   - -Gas/Liquid Contactor for CO_2 & H_2S Removal

4. SulfaTreat®
   - -Sorbent-based Sulfur Scavenger

5. High Pressure Oxygen and Nitrogen Supply

Pilot Tests for the Application Green Gasoline From Wood Using Fluidized Bed Gasification and Haldor Topsøe TIGAS Processes

- Demonstrate a technology for thermochemical conversion of **woody biomass** to **gasoline**



- 20- and 30-day tests of fully integrated process.

Example of Using Existing Infrastructure to Optimize the Energy Value of Biomass

Issue

- Capital-intensive projects improve economics by increasing scale.
- Biomass has a low energy density and is disperse.
- Need to aggregate large amounts of biomass sustainably.

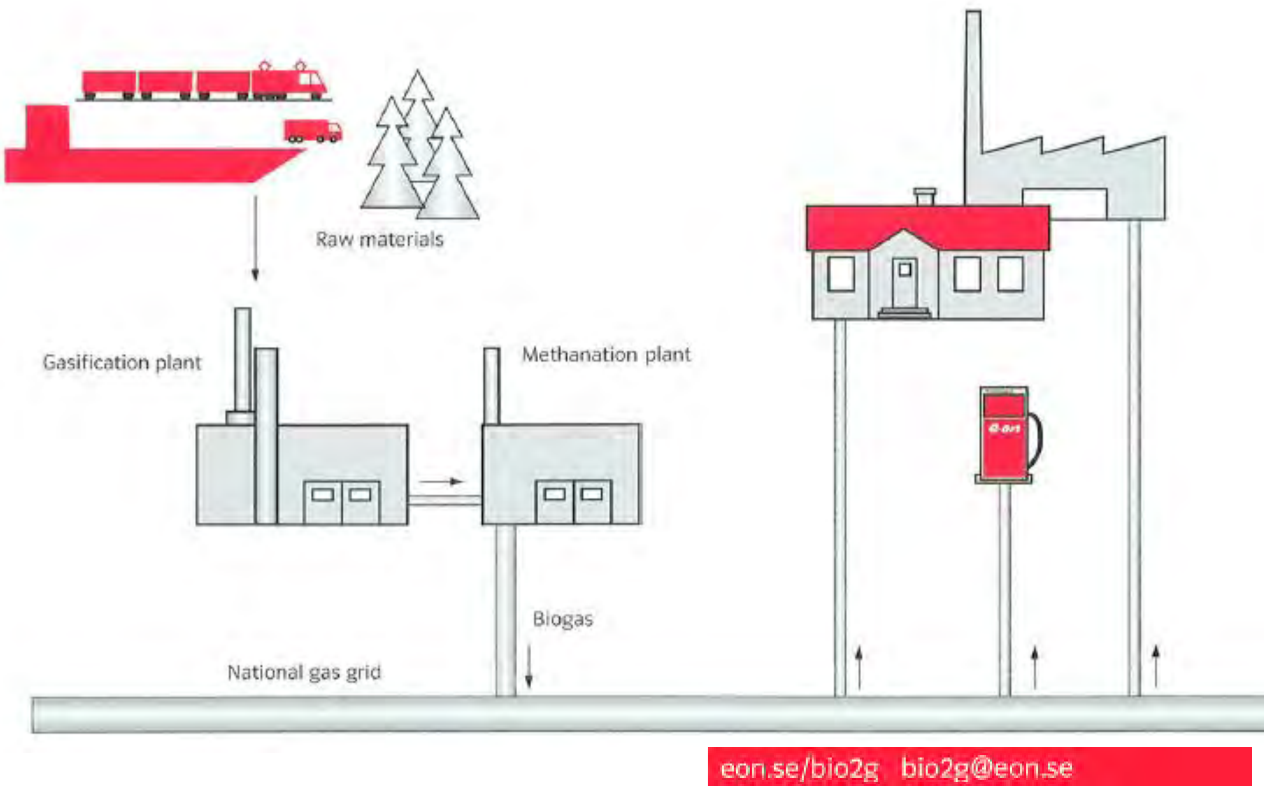
Option

- Piggy-back – go to the biomass (forest industry).
- Use the biomass at maximum conversion efficiency.
- Make a fungible product for a vast market.
- Use existing infrastructure to get the product into the economy.

Fischer-Tropsch Products from Gasification of Forest Biomass

- > Sponsored by UPM-Kymmene (CY 2008 - CY 2011)
- > Pilot gasification and gas processing at GTI: 15 tpd biomass gasification, catalytic reforming
- > Forest residues: tops, bark, hog fuel, stumps
- > Andritz Carbona partner
- > Commercial sites for 300 MWth scale in Finland and France selected

Bio2G: Forest to Renewable Natural Gas



- Sustainably managed forests
- Existing supply infrastructure
- High conversion efficiency
- Existing distribution infrastructure
- Decarbonize all sectors of economy
- Highest potential end use efficiency

Successful Biomass Gasification Projects are no Accident

IT ALL MATTERS:

- **The product**
- **The feedstock**
- **The technology**

Quantify Risks - Verify Performance - Optimize Design

Questions or Discussion?