PG&E GAS R&D AND INNOVATION

Pyrolysis Technical Analysis

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1 What is Pyrolysis

Pyrolysis is the thermal decomposition of organic compounds in the absence of air/oxygen, starting at temperatures between 350-550°C up to 700-800°C. The long hydrocarbon chains in the biomass break down into smaller molecules in the form of gases, condensable vapors (tars and oils) and solid charcoal.
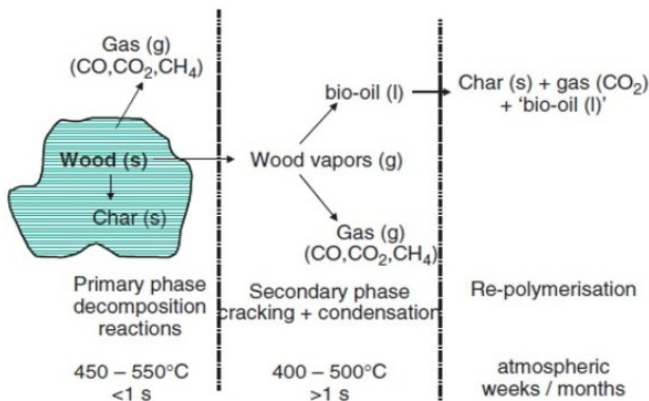
Figure 1 Representation of reaction paths for wood pyrolysis (Jahirul, Rasul, Chowdhury, & Ashwath, 2012)
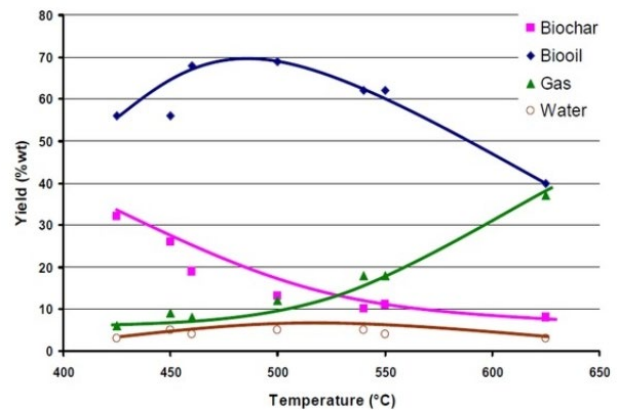
Figure 2 Relative proportions of end products in pyrolysis of biomass (Jahirul, Rasul, Chowdhury, & Ashwath, 2012)

Slow Pyrolysis

Slow pyrolysis has been around the longest to enhance char production at low temperatures and heating rates. The vapor residence time is high (5 min to 30 min) and components in the vapor phase react with each other to produce solid char and other liquids (Jahirul, Rasul, Chowdhury, & Ashwath, 2012). The technology has limitations, since cracking occurs due to high residence time and may negatively affect bio-oil yield and quality; and it typically requires more energy input.

Fast Pyrolysis

The distinguishing characteristics of fast pyrolysis are high heat transfer and heating rate, very short vapor residence time, rapid cooling of vapors and aerosol for high bio-oil yield and good control of reaction temperature. The technology can have fairly low investment costs and high energy efficiencies on a small scale. Some advantages include: low cost and neutral CO2 balance; utilization of second generation of bio-oil feedstocks and waste materials (forest residue, municipal and industrial waste, etc.); high energy density compared to atmospheric biomass gasification fuel gases; and primary separation of sugar and lignin fractions in biomass with subsequent further upgrading.
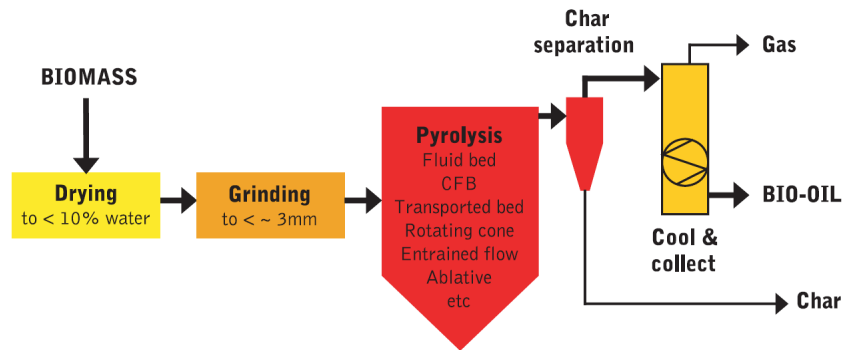
Figure 3 Conceptual fast pyrolysis process (Delgass, Ribeiro, & Agrawal)

Flash pyrolysis

Rapid devolatilization in an inert atmosphere, high heating rate, high reaction temperatures between 450-1000℃ and short gas residence time (less than 1 s) (Jahirul, Rasul, Chowdhury, & Ashwath, 2012). The technology has limitations, including: poor thermal stability and corrosiveness of the oil; solids in the oil; increase of viscosity over time by catalytic action of char; alkali concentrated in the char dissolves in the oil; and production of pyrolytic water.

1.1 REACTORS

Table 1 Comparison of reactor types (Jahirul, Rasul, Chowdhury, & Ashwath, 2012)

Reactor Type	Description
Fixed bed	Solids flow down a vertical shaft and contact a counter-current upward moving product gas stream. Made of firebricks, steel or concrete with a fuel feeding unit, ash removal unit and gas exit. Operating parameters include high carbon conversion, long solid residence time, low gas velocity and low ash carry over. **Benefits:** Simple & reliable technology for fuels uniform in size with low content of fines. For small scale heat and power applications **Limitations:** Tar removal

Bubbling fluidized bed	Heated sand is used as the bed material. **Benefits:** Simple to construct and operate. Provide better temperature control, solids-to-gas contact, heat transfer and storage capacity due to high solids bed density. Bio-oil yield is between 70-75% weight of biomass on a dry basis. Char doesn't accumulate. **Limitations:** Very small biomass particle size (< 2-3 mm) is needed	
Circulating fluidized bed	Similar features as bubbling fluidized beds. **Benefits:** For large throughputs, despite more complex hydrodynamics. **Limitations:** Shorter residence times for chars and vapors, resulting in higher gas velocity and char content in bio-oil.	
Ablative	Mechanical pressure presses biomass against the heated reactor wall, causing the material to "melt", allowing the residual oil to evaporate away as a vapor. **Benefits:** Feed material doesn't require excessive grinding. Larger biomass particle sizes (< 20 mm) are accepted. **Limitations:** More complex configuration. Scaling is a linear feature of the heat transfer (surface area controlled system) – lacking economies of scale.	
Ablative Vortex	Biomass particles are entrained in a hot (625°C) gas (steam or nitrogen) flow and are injected to the reactor tangentially. High centrifugal forces cause biomass particles to be pressed to the reactor wall, causing them to melt and leave a liquid film of bio-oil.	

	Unconverted particles are recycled. Vapors are swept away using carrier gases. Bio-oil yield is up to 65%.
Ablative rotating disk	Biomass are forced to slide on a hot rotating disk, causing them to soften and vaporize. No inert gas medium is required, resulting in smaller equipment. But, the process is dependent on surface area – lacking economies of scale.
Vacuum pyrolysis	A moving metal belt conveys biomass into the high temperature vacuum chamber. On the belt, the biomass is occasionally stirred by a mechanical agitator. **Benefits:** Able to process larger sized biomass particles (< 2-5 cm) **Limitations:** Lower heat transfer rates yielding bio-oil between 35-50%. Pyrolysis is complicated mechanically and requires high investment and maintenance costs. Special solids feeding and discharging devices are needed to maintain the vacuum seal.
Rotating cone	Biomass and sand are injected at the bottom of the cone and the centrifugal force from spinning moves it upwards. Solids spill over the lip of the cone, and the vapors move on to a condenser. The char and sand go to a combustor where the sand is reheated before being recycled back. **Benefits:** High bio-oil yield. **Limitations:** Design is complex.
PyRos	A cyclonic reactor is used with an integrated hot gas filter (rotational particle separator) to produce particle free bio-oil. The biomass and inert heat carrier are injected as particles into the cyclone, and the solids are transported by recycled vapors. Centrifugal forces cause the particles to flow down to the periphery of the cyclone. Evolved vapors move to the center of the cyclone and leave by the rotating filter. The remaining gases and char can be used to heat the heat carrier and transportation gas. The reactor is compact and low cost, with 70-75% bio-oil yield.

Auger	Oxygen free cylindrical heated tubes move biomass. Char is produced and gases are condensed as bio-oil, with non-condensable vapor collected as biogas.
Plasma	Cylindrical quartz tube surrounded by two copper electrodes. Biomass is fed into the middle of the tube using a variable-speed screw feeder at the top of the tube. Electrodes are coupled with electrical power sources to produce thermal energy to gas flows through the tube. Inert gas removes oxygen from the reactor and is used to produce plasma. The vapors are evacuated by a variable speed vacuum pump. **Benefits:** Tar formation is eliminated due to the cracking effects from plasma with electron, ion, atom and activated molecule species. **Limitations:** Consumes high electrical power – high operating costs. Large amount of heat from thermal plasma is released to the environment via radiation and conduction.
Microwave	A microwave-heated bed is used to transfer energy. The microwave cavity, powered by electricity, is used for the drying and pyrolysis processes. Inert gas is the carrier gas and flows through the reactor to create an oxygen free atmosphere. Microwave reactors provide efficient heat transfer, exponential control of the heating process and enhanced chemical reactivity that reduces the formation of undesirable species.
Solar	Quartz tube with opaque external walls exposed to concentrated solar radiation. A parabolic solar concentrator is attached with the reactor to concentrate the solar radiation (>700°C). Feedstock available for pyrolysis is maximized, since it doesn't need to be used to generate process heat. In addition, there are faster start up and shut down periods.

1.2 PROCESS DETAILS

1.2.1 Stages

Stage 1: Feed Preparation

High moisture content can decrease the resulting bio-oil's calorific value. Pyrolysis needs a moisture content in the biomass between 5-15% (weight basis). Drying of the biomass is needed to decrease the amount of water and acids. Then, it is ground to 2-6 mm particle size to allow for fast reaction in the reactor. (Jahirul, Rasul, Chowdhury, & Ashwath, 2012)

Note: A study showed that an increase in drying temperature influenced the yield of pyrolysis products, but an increase in drying time had no effect. High temperature may produce thermal-oxidative reactions, causing a cross-linked condensed system of components and a higher thermal stability of the biomass complex.
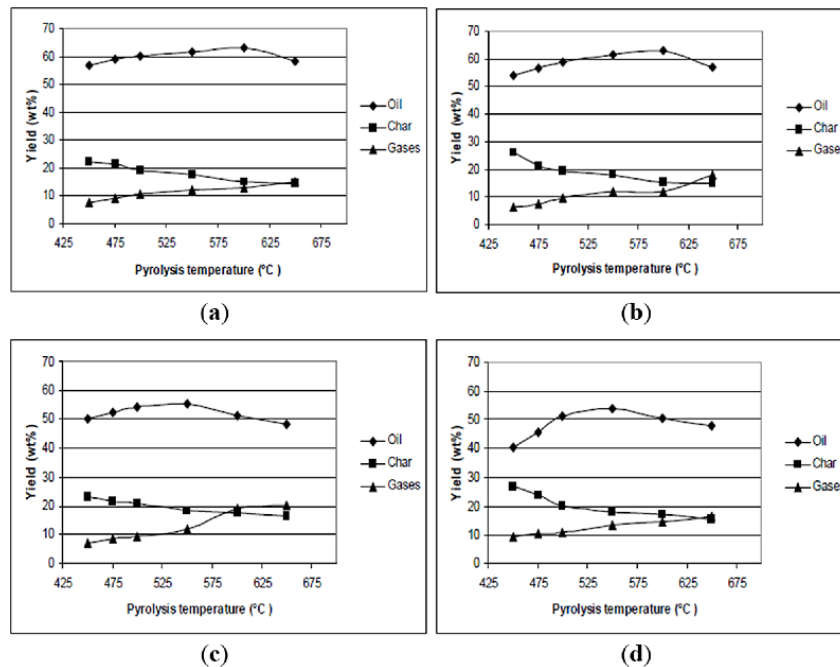

Figure 4 *Change in yield of oil, char and gases versus pyrolysis temperature of wood at drying parameters of (a) 200oC, 45 min; (b) 200oC, 90 min; (c) 240oC, 45 min; (d) 240oC, 90 min (Jahirul, Rasul, Chowdhury, & Ashwath, 2012)*

Stage 2: Biomass Heating

Heat transfer in the reactor is a high concern: (1) heat transfer to the reactor heat transfer medium (e.g. solid and gas in a fluid bed reactor or reactor wall in ablative reactor) and (2) from the heat transfer medium to pyrolysis biomass.

Heating methods (e.g. convection, conduction, and radiation) used are specific to the reactor type. Biomass particles need to be very small to allow for rapid heating, since the thermal conductivity is very low and the heat transfer is largely gas-solid based.
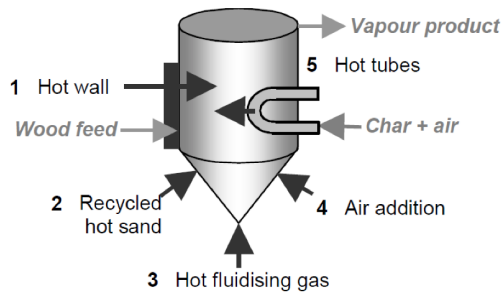
Figure 5 *Methods of heat transfer to a reactor* (Jahirul, Rasul, Chowdhury, & Ashwath, 2012)

Table 2 *Typical heating methods used in different reactors* (Jahirul, Rasul, Chowdhury, & Ashwath, 2012)

Heating Method	Reactor Type
Heated recycle gas	Bubbling fluidized bed
Wall and sand heating	Circulating fluidized bed
Gasification of char to heat sand	Rotating cone
Direct contact with hot surface	Vacuum
Wall heating	Ablative
Fire tube	Auger
Radio-frequency	Plasma
Electromagnetic	Microwave reactor
Solar	Fluidized bed/Quartz

Stage 3: Char Separation

Char is a solid residue byproduct formed during the pyrolysis process. Separation of the char is needed to prevent the char from contributing to the formation of polycyclic aromatic hydrocarbons (PAHs), especially at low temperatures.

Chars are typically separated using a cyclone method. However, fine particles end up in the liquid product where they accelerate aging and create instability issues. Another approach is to use in-bed vapor filtration and rotatory particle separation. But, the char and pyrolytic liquid react to form a gel-like phase that blocks the filter. Solvents (e.g. methanol or ethanol) may be used to modify the liquid micro-structure, but lead to the dilution of the liquid product and increases the process costs.

Stage 4: Liquids Collection

Vapor and non-condensable gases need to be rapidly cooled, and aerosols need to be coalesced / agglomerated to prevent secondary reactions. Cooling is typically done with a heat exchanger, quenching in product oil or in an immiscible hydrocarbon solvent or use of orthodox aerosol capture devices (e.g. demisters, electrostatic precipitators).

1.1.2 Pyrolysis Products

Table 3 Pyrolysis reactions at different temperatures (Jahirul, Rasul, Chowdhury, & Ashwath, 2012)

Condition	Processes	Products
Below 350°C	Free radical formation, water elimination and depolymerization	Formation of carbonyl and carboxyl, evolution of CO and CO2, and mainly a charred residue
Between 350°C and 450°C	Breaking of glycosidic linkages of polysaccharide by substitution	Mixture of levoglucosan, anhydrides and obligosaccharides in the form of a tar fraction
Above 450°C	Dehydration, rearrangement and fission of sugar units	Formation of carbonyl compounds such as acetaldehyde, glyoxal and acrolein
Above 500°C	A mixture of all above processes	A mixture of all above products
Condensation	Unsaturated products condense and cleave to the char	A highly reactive char residue containing trapped free radicals

Bio-Oil

This is a liquid produced from the condensation of vapor of a pyrolysis reaction. It has a heating value of 40-50% of that of hydrocarbon fuels (Jahirul, Rasul, Chowdhury, & Ashwath, 2012). It is a mixture of oxygenated compounds, with the functional groups of carbonyl, carboxyl, and phenolics. It has issues with fuel quality, phase separation, stability, and fouling on thermal processing.

Bio-Char

This is a rigid amorphous carbon matrix produced from the thermal breakdown of lignin and hemicellulose whereby volatiles are lost. 10-35% bio-char can be produced from pyrolysis (Jahirul, Rasul, Chowdhury, & Ashwath, 2012). It consists of carbon, hydrogen and various inorganic species in two structures: stacked crystalline graphene sheets and randomly ordered amorphous aromatic structures.
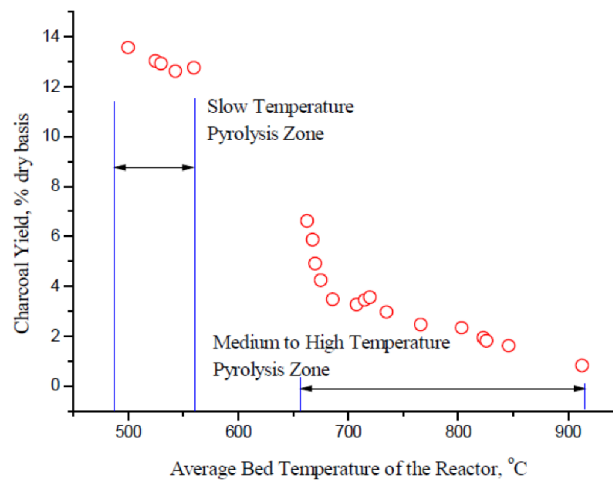
Figure 6 Bio-char yields variation versus average temperature in a fluidized bed (Jahirul, Rasul, Chowdhury, & Ashwath, 2012)

Syngas

It mostly consists of hydrogen and carbon monoxide, with small amounts of carbon dioxide, water, nitrogen, methane, ethane, tar, ash, etc. Hydrogen is produced from the cracking of hydrocarbons at higher temperatures. Carbon monoxide and carbon dioxide indicate the presence of oxygen in the biomass, resulting oxygenation. Its yield is heavily influenced by pyrolysis temperature. High temperatures favor tar decomposition and thermal cracking of tar to increase syngas production, and decreased oil and char content. High moisture content promotes extraction of water-soluble components from the gaseous phase, decreasing syngas production. The light hydrocarbons (e.g. methane, ethane) are a result from tar reforming.

Figure 7 Syngas composition of cotton stalks versus pyrolysis temperature (Jahirul, Rasul, Chowdhury, & Ashwath, 2012)

1.2.3 Catalysts

It increases the rate of a chemical reaction without being consumed or changed. It is used to enhance reaction kinetics by cracking higher molecular weight compounds into lighter hydrocarbon products. There are three groups for pyrolysis catalysts: 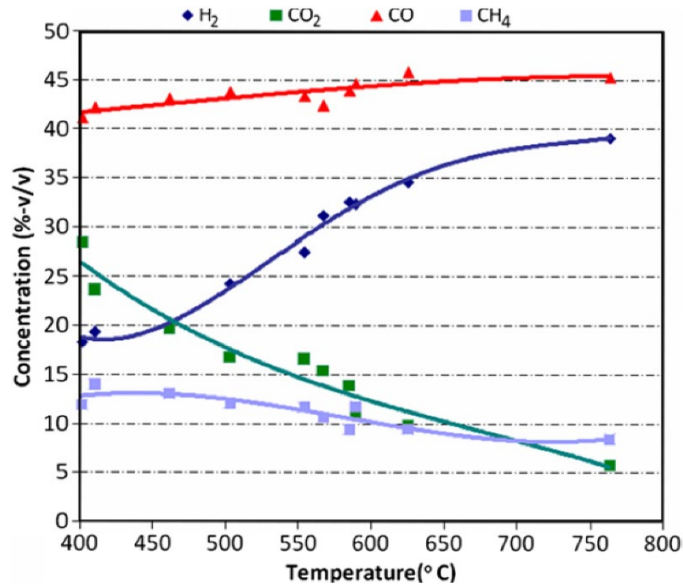(1) added to the biomass before fed to the pyrolysis reactor; (2) added directly to the pyrolysis reactor; (3) added to a secondary reactor located downstream from the pyrolysis reactor. Catalysts include: dolomite, Ni-based, alkali metal and novel metal. For example, calcined dolomite is inexpensive, abundant and reduces tar formation in syngas. However, it has a low melting point making it unstable at high temperatures and it's not effective in heavy tar cracking (< 90% tar conversion). Other catalysts have been studied, including: Ni, CeO_2, Al_2O_3, alumina, sodium feldspar, CeO_2, Rh, SiO_2, Li, Na, K carbonates, Na_2CO_3, K_2CO_3, $ZnCl_2$, Ni/SiO_2-N, zeolite and ZrO_2. The Ni and alkali metal based catalysts are effective in heavy tar elimination (>99% destruction), but inactivated by carbon deposition. (Jahirul, Rasul, Chowdhury, & Ashwath, 2012)

1.3 COMPARISON

Table 4 Typical operating parameters and products for pyrolysis process (Jahirul, Rasul, Chowdhury, & Ashwath, 2012)

	Solid Residence Time (s)	Heating Rate (K/s)		Temp. (K)	Product Yield (%)

Pyrolysis Process			Particle Size (mm)		Oil	Char	Gas
Slow	450-550	0.1-1	5-50	550-950	30	35	35
Fast	0.5-10	10-200	<1	850-1250	50	20	30
Flash	<0.5	>1000	<0.2	1050-1300	75	12	13

2 Pyrolysis Technologies

2.1 G4 INSIGHTS – PYROCATALYTIC HYDROGENATION

2.1.1 Summary of Technology

([Ref 2.1SS](#))

The G4 PyroCatalytic Hydrogenation (PCH) process is a low temperature thermochemical process that produces RNG from lignocellulosic biomass. The PCH process is not gasification and methanation. The technology uses a single catalytic conversion stage without the intermediate production of syngas prior to methanation. It combines fast pyrolysis and catalysts to directly produce methane from biomass.
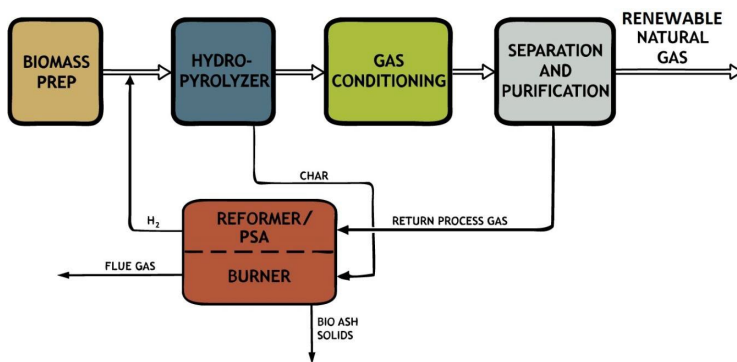
Figure 8 G4 Insights technology flow chart (G4 Insights Inc., 2016)

1. Biomass Preparation – Forest biomass is prepared by grinding and drying
2. Hydropyrolysis – Biomass is vaporized at low temperature in a hydrogen atmosphere and byproduct biochar is also produced
3. Gas Conditioning – The bio-vapors are catalytically converted into biomethane
4. Separation and Purification – Biomethane rich gas is separated and purified into RNG
5. Hydrogen Generation – Rejected gas, liquids, and biochar solids are used to

generate hydrogen required for the
hydropyrolyzer

2.1.2 Benefits

(G4 Insights Inc., 2016)

- Hydrogen enhances pyrolysis reactions. It also contributes towards the H_2:CO ratio that is needed for methanation downstream for production of RNG.
  - In contrast to the use of nitrogen, which prevents having to remove it downstream, a complex and expensive process
- The PCH process can be coupled with a power-to-gas application, converting extra renewable wind/solar electricity into hydrogen
- Bio ash solids byproduct can be used as fertilizer enhancement
- Char byproduct is used as fuel for the steam reformer

2.1. 3 Limitations

(G4 Insights Inc., 2016)

- Hydrogen generation may be thermodynamically inefficient, as in it requires electricity with no entropy to produce a product with entropy and low value electricity. It is also expensive.
- Feedstock includes biomass varieties only (no MSW, medical waste, hazardous waste, etc.)

2.1.4 R&D Opportunities

- Power-to-gas demonstration in California using a renewable energy source (e.g. wind, solar) to produce hydrogen which will then feed the G4 PCH process to produce RNG
- Inexpensive and commercial scale production of hydrogen for the PCH process
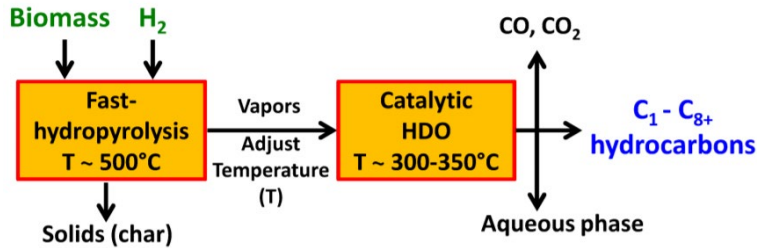
2.2 H2BIOIL

2.2.1 Summary of Technology

Figure 9 Process flow chart of fas-hydropyrolysis followed by catalytic hydrodeoxygenation (Delgass, Ribeiro, & Agrawal)

The process is based on biomass fast-hydropyrolysis (FHP) combined with vapor-phase catalytic hydrodeoxygenation (HDO).

The biomass is rapidly heated in a high pressure (up to 200 bar) hydrogen environment to produce fast-hydropyrolysis vapors, which are sequentially catalytically hydrodeoxygenated to produce hydrocarbons. It's important to upgrade the reactive oxygenate molecules by vapor-phase catalytic hydrodeoxygenation before any undesirable secondary reactions can take place during condensation of the bio-oil mixture. The high pressure of hydrogen is needed for high rates of HDO reaction, similar to hydrotreating processes used in a petroleum refinery, and also aids in avoiding coking on the catalyst.
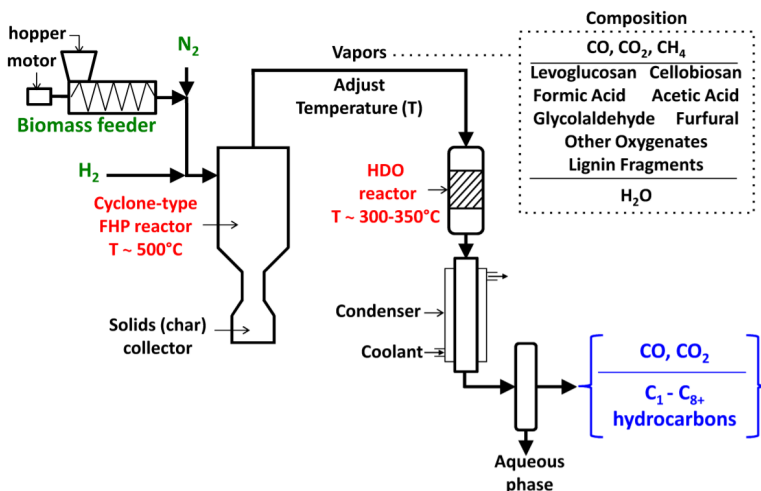

Figure 10 Schematic of the fast-hydropyrolysis (FHP) and catalytic hydrodeoxygenation (HDO) (Delgass, Ribeiro, & Agrawal)

2.2.2 Benefits

(Delgass, Ribeiro, & Agrawal)

- The reactive oxygenate molecules are upgraded quickly by vapor-phase catalytic hydrodeoxygenation before any undesirable secondary reactions can take place during condensation of the bio-oil mixture

- The downstream vapor-phase catalytic hydrodeoxygenation, recently referred to as 'ex situ', allows for independent control of the hydropyrolysis and catalysis at their respective optimum conditions (reaction temperatures, pressures and catalysts) for tailoring the yields and selectivities of the hydrocarbon products.
- H2Bioil process is envisioned to be deployed as mobile biofuel processing unit close to the biomass sources, which would aid the process economics by reducing biomass transportation costs

2.2.3 Limitations

(Delgass, Ribeiro, & Agrawal)

- Hydrogen generation may be thermodynamically inefficient, as in it requires electricity with no entropy to produce a product with entropy and low value electricity. It is also expensive.
- Feedstock includes biomass varieties only (no MSW, medical waste, hazardous waste, etc.)
- Catalyst is sensitive to sulphur compounds

2.2.4 R&D Opportunities

Note: We are not interested in pursuing this technology, but R&D opportunities are listed for reference

(Delgass, Ribeiro, & Agrawal)

- Data on the effects of process conditions, such as hydrogen partial pressure and types of biomass on the hydrocarbon yields and distributions from the H2Bioil process
- Testing to find a catalyst that can achieve complete HDO of a mixture of oxygenated molecules with different functional groups to produce a hydrocarbon stream

2.3 KORE INFRASTRUCTURE
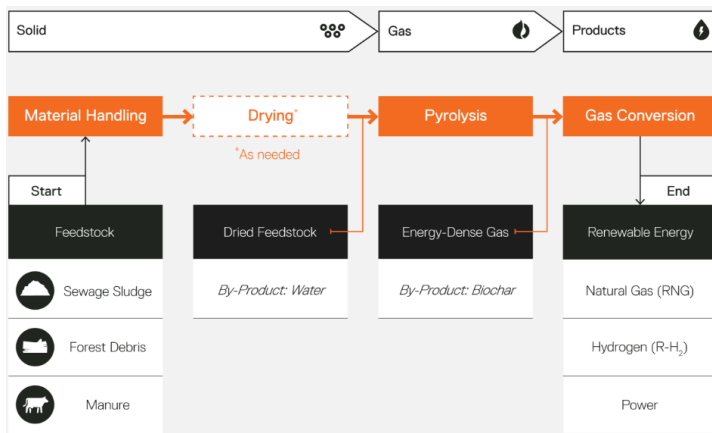
2.3.1 Summary of Technology

Figure 11 Kore's process flow chart (Kore Infrastructure, 2017)

Feedstock is dried through a paddle dryer, which takes the moisture and reuses the water, while preserving the BTU value of the dry feedstock. The material handling equipment is kept under vacuum with offgas odors removed via aqueous scrubbers and carbon filters to remove odors effectively. (Gildea, 2018)

Dry feedstock enters the reactor through a series of airlocks where they are pyrolyzed at high temperature (above 500°C) under vacuum conditions to generate an energy-dense pyrogas and biochar (Kore Infrastructure, 2017). The resulting pyrogas, is scrubbed, cooled, and further conditioned to remove all hydrogen sulfide and other contaminants in order to prepare it for conversion to liquids or for heat and power generation.

2.3.2 Benefits

- Equipment is modular and compact to allow for multiple configurations, and ease siting requirements (Kore Infrastructure, 2017)
- Feedstock includes sewage sludge (biosolids), in addition to traditional forest debris (woody biomass) and manure (Kore Infrastructure, 2017)

- Operates at temperatures above 500°C to avoid the production of pryo-oil (which could be turned into biocrude to substitute fossil crude oil) that is traditionally produced within the process (Kore Infrastructure, 2017)

2.3.3 Limitations

- Unable to handle MSW, medical waste, hazardous waste, etc. as feedstock
- Not enough data available

2.3.4 R&D Opportunities

- SoCal Gas is collaborating with Kore Infrastructure (April 2017 – July 2018) to de-risk Kore's pyrolyzer unit to increase financing viability for a full scale commercial biosolids-to-RNG project (throughput: 144 TPD | RNG production: 14800, CFD) (Kent, 2018)
    - Build commercial-scale facility to take biosolids and produce RNG for pipeline injection (Nastri, 2017)
    - Within the process, the treatment of sulphur products, such as H2S/siloxanes need to be addressed

2.4 TAIL-GAS REACTIVE PYROLYSIS (TGRP)

2.4.1 Summary of Technology

(Dorado, Mullen, & Boateng, 2015)

Pyrolysis of mixtures of agricultural plastic waste in the form of polyethylene hay bale covers (PE) (4−37%) and switchgrass were investigated using the US Department of Agriculture's tail gas reactive pyrolysis (TGRP) process at different temperatures (400−570 °C). TGRP of switchgrass and plastic mixtures significantly reduced the formation of waxy solids that are produced during regular pyrolysis. Under an atmosphere of approximately 70% recycled tail gas, mostly noncondensable gases were produced along with highly deoxygenated and aromaticized pyrolysis oil. When the atmosphere was diluted further to a recycled tail gas concentration of about 55%, higher yields of liquid product were achieved but with less deoxygenation. TGRP of low plastic mixtures (4−8%) produced oils with increased carbon and reduced oxygen content compared to the fast pyrolysis of switchgrass alone. Noncondensable gas fractions containing high concentrations of H2, CO, ethylene, and other light hydrocarbons remained a significant portion of the product mixture at temperatures above 500 °C. It was

found that pyrolysis oils with properties similar to those produced from the catalytic pyrolysis of switchgrass could be produced using tail-gas reactive pyrolysis (TGRP) TGRP is a patent-pending USDA-ARS process that relies on performing fluidized bed pyrolysis at carefully controlled reaction conditions under a non-inert atmosphere partially comprised of gas recycled from the tail stream.

The goal of the study was to explore the plastic utilization in quantities that complement the TGRP process and establish the optimum coprocessing conditions in terms of ease of operation along with pyrolysis oil yield and quality.

2.4.2 Benefits

- TGRP of switchgrass and plastic mixtures significantly reduced the formation of waxy solids that are produced during regular pyrolysis (Dorado, Mullen, & Boateng, 2015)
- Feedstock includes switchgrass and plastic mixtures from agriculture plastic waste (Dorado, Mullen, & Boateng, 2015)
- The quality of TGRP deoxygenated liquids is equal to or better than the bio-oil produced by catalytic pyrolysis (AgResearch Magazine, 2016)
- Not enough data available

2.4.3 Limitations

- Unable to handle MSW, medical waste, hazardous waste, etc. as feedstock
- The achievable carbon yield is still limited by the low H/C ratio (Dorado, Mullen, & Boateng, 2015)
- Not enough data available

2.4.4 R&D Opportunities

Note: We are not interested in pursuing this technology, but R&D opportunities are listed for reference

- Scaling of TGRP process
    - Conduct further laboratories studies to fine tune operating conditions
    - Conduct a pilot demonstration, should the laboratory studies prove successful

3 COMPARISON OF PYROLYSIS TECHNOLOGIES

3.1 Metrics

Technology	Reactor Type	Feedstock Accepted	Moisture Content	Other Inputs	Temperature	Pressure	Byproducts	Energy (Thermal) Efficiency	Scale Achieved
G4 Insights[1] (Ref 2.1SS)	Coupled reactors: (1) fast pyrolysis (2) catalyst bed in H_2 rich atmosphere	Woody biomass	30%	H_2	<1202°F	< 20 bar	Flue gas, bio ash solids, bio char	70%	100 kg biomass/day = 1 GJ RNG/day
H2Bioil[2]	Continuous-flow cyclone-type fast-hydropyrolysis (FHP) reactor system with on-stream vapor-phase catalytic hydrodeoxygenation (HDO)	Cellulose, poplar	Data not available	H_2	< 930°F	< 27 bar	C_1-C_8 hydrocarbons, char, aqueous phase products	75%	Lab scale proof of concept

[1] (Church, 2018)

[2] (Delgass, Ribeiro, & Agrawal)

Kore Infrastructure[3]	Data not available	Sewage sludge, forest debris, manure	25%	Data not available	> 930°F	Data not available	Bio char	Data not available	14800 CFD RNG production
TGRP[4]	Bubbling fluidized bed	Agricultural plastic waste (e.g. PE hay bale covers) with switchgrass	Data not available	N_2	750-1060°F	Data not available	Bio char	Data not available	Lab scale study

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[3] (Kore Infrastructure, 2017), (Kore Infrastructure, 2017), (Zuback, 2017)

[4] (Dorado, Mullen, & Boateng, 2015)

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