Today's Waste – Tomorrow's Resource

3rd December 2019

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Agenda

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Wood - Global Footprint

55,000
People

60+
Countries

400+
Offices

- We're accelerating and expanding in new sectors and geographies
- Unlocking our technology across an incredible sector spread

Wood - Global Footprint

Clean Energy

Chemical

Refining

Environment and Infrastructure

Manufacturing

Marine and Defence

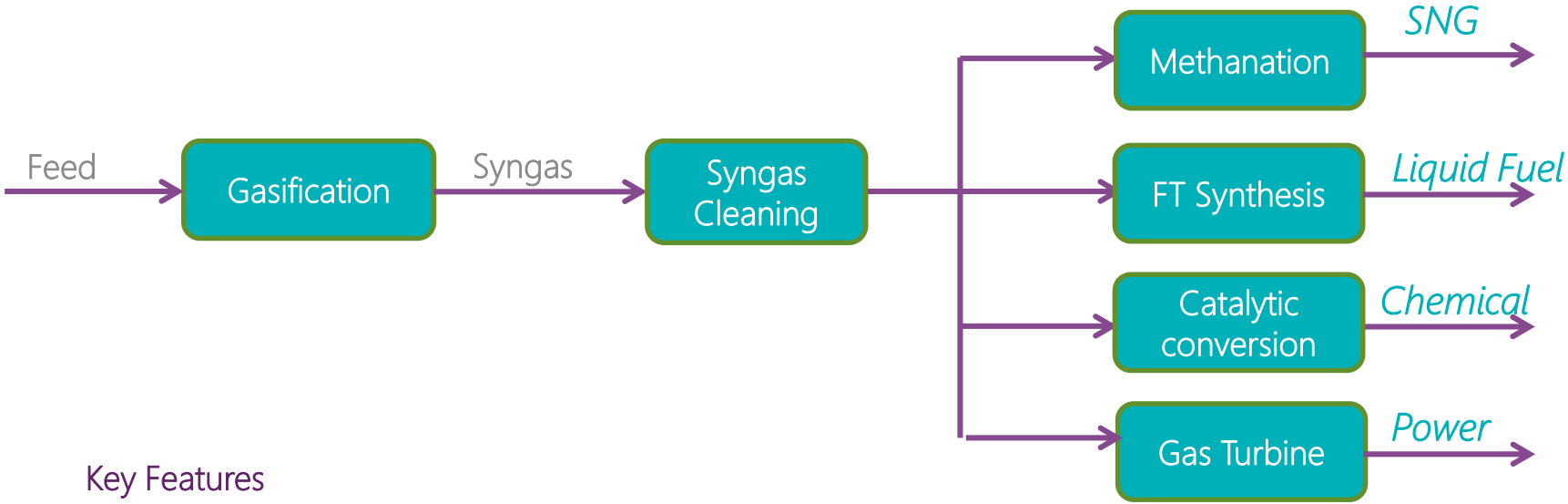
Mining and Minerals

Nuclear, Power and Process

Oil & Gas

Waste to Product

Waste Gasification to Product Scheme



Key Features

- Waste material – Biomass (Wood chips, Wood pellet, Torrified Wood etc), Municipal Solid Waste (MSW), Refused Derived Fuel (MSW)
- Waste gasification using sub-stoichiometric O_2 into H_2 & CO ("Syngas")
- Higher value products generated

Biomass/Waste to SNG Demonstration Plant

Advanced Biofuel Solution, UK

Biomass-to-SNG Demonstration Plant

Advanced Biofuel Solution, UK

Biomass to SNG project is funded by Department of Transport, UK as part of a programme to develop and commercialise technologies required to decarbonise the transport sector. It is also Supported by Cadent.

4.5 MWth demonstration plant will convert 8,000 tonnes of waste per annum into 22GWh of compressed SNG; enough to power 75 heavy goods vehicles.

The overall process will use RadGas technology (gasification+plasma conversion) to convert biomass/RDF to syngas followed by Wood's VESTA SNG technology to convert syngas to substitute natural gas (SNG).

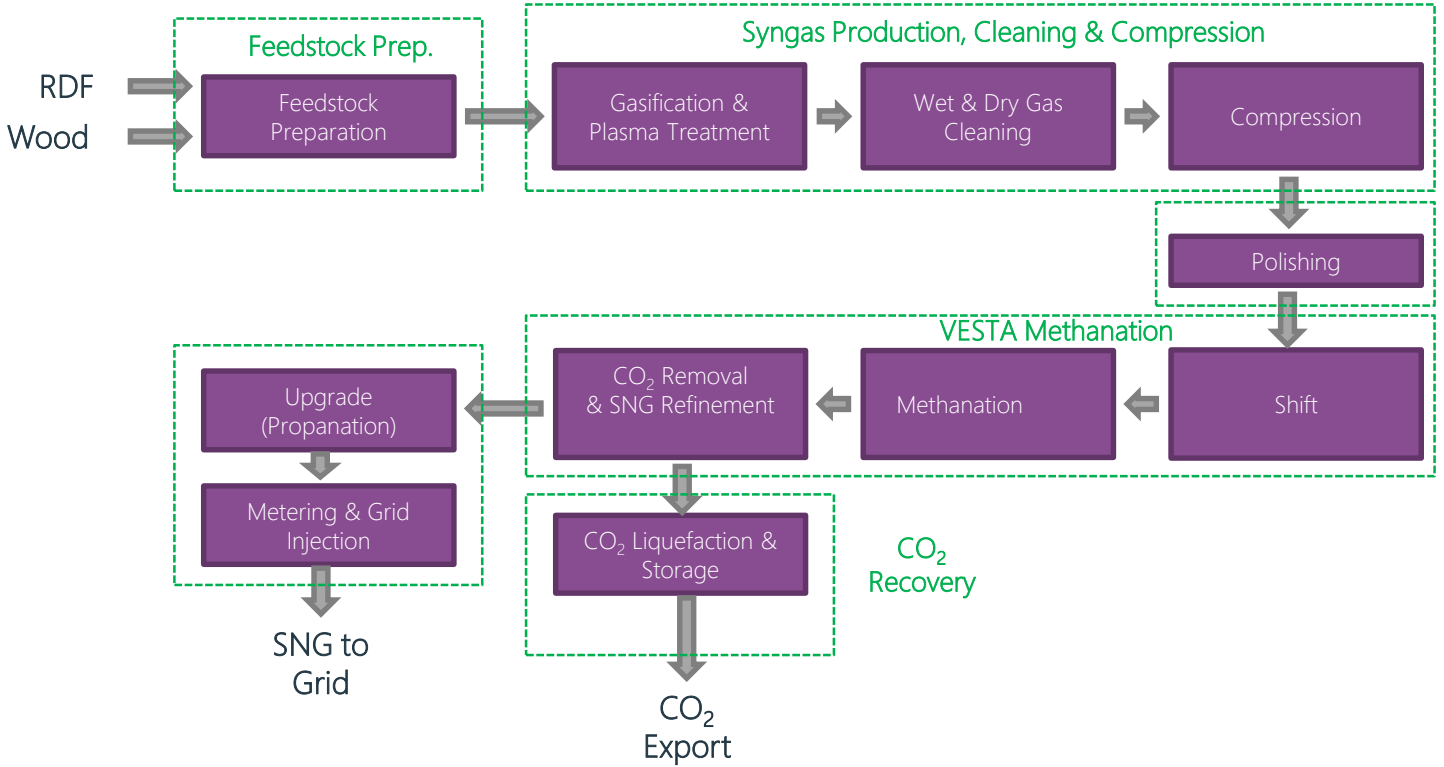
Wood's scope of work: Basic Engineering Design (BED) followed by Engineering Procurement & Fabrication (EPF) of the Wood's VESTA SNG technology which included the followings sections:

- Gas compression stage
- Final gas clean-up (Deep Desulphurization, Dehalogenation)
- Clean syngas methanation & CO_2 removal system
- SNG drying

Demonstration Plant - Advanced Biofuel Solution, UK

- Will be first plant in the world to produce BioSNG from household waste
- Construction restarted in November
- Construction complete April 2020
- Gas to grid expected Q4 2020
- Will operate on a full-time basis in commercial environment
- £28m spent on project to date

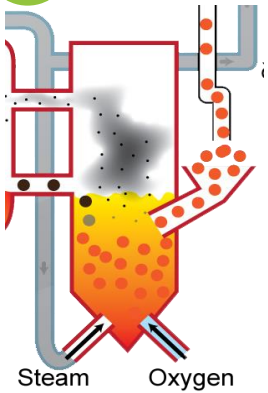
Technology – Typical Process Flow



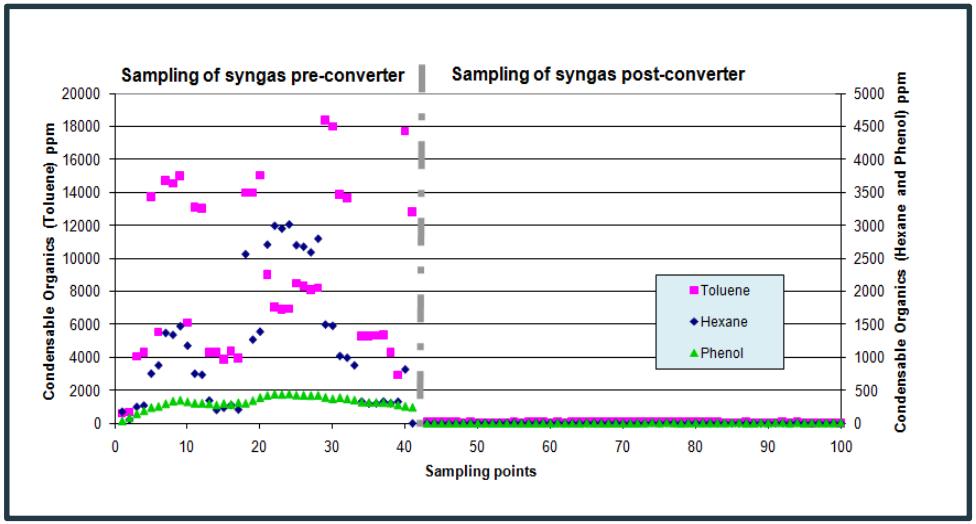
RadGas Technology - Gasification & Plasma Treatment

The process is an innovative combination of two well-established technologies, both of which have decades of proven commercial operation:

1 Gasification



2 Plasma Conversion



Exceptionally Clean Syngas

Syngas Polishing

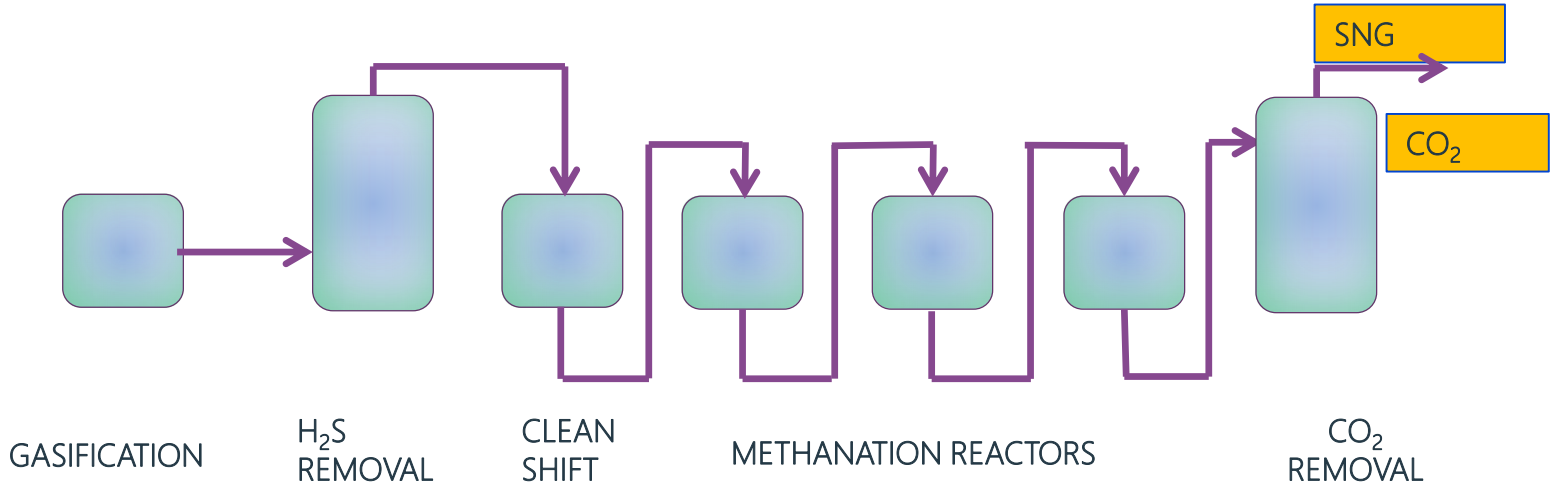
The clean syngas from the gasification island needs further polishing to meet the inlet specification of the downstream catalytic SNG process. The syngas polishing section has been designed using adsorbent / catalytic steps required for specific contaminants.

Following are typical polishing steps required for VESTA SNG catalytic process using municipal solid waste as feedstock:

- Dehalogenation: Using adsorbent which acts as a guard bed for traces of residual HCl and other halogen contaminants in the syngas
- Hydrogenation: Using catalyst which promotes the hydrogenation of residual olefins and sulphur compounds in the syngas
- Desulphurisation: Using adsorbent which acts as a guard bed for H_2S; reducing the total sulphur content to ~10 ppb

Wood's VESTA Methanation Technology

Innovative VESTA methanation technology produces Substitute Natural Gas (SNG) from gasification of fuel such as Coal, Petcoke, Waste, Biomass etc.



VESTA is a simple, safe and reliable process

VESTA Highlights

Catalytic methanation process:

- Methanation reactors filled with proprietary Clariant catalyst - Ni-based catalyst
- The catalyst has a higher conversion rate and wider operating temperature range (230-700°C) than conventional methanation catalysts.
- Long operational history and industrial references of the catalyst
- Once-through operation
- Temperature in the reactor does not exceed 550°C
- No need for expensive recycle compressors or refractory-lined reactors as CO2 and H2O control the exothermic heat of reaction : reducing capital expenditure
- No uncontrolled reaction

VESTA Highlights

Flexibility of syngas composition:

- SNG production is easy to operate and does not require strict control of the hydrogen / carbon ratio
- The product quality is therefore more stable and reliable
- No need for sour gas shift

VESTA Pilot Plant in China

Wood (Amec Foster Wheeler) signed a cooperation agreement with Clariant International AG and Wison Engineering Ltd to build a pilot plant to demonstrate the Wood's Foster Wheeler VESTA technology.

Syngas Conversion - Demonstration Plant

Wood's VESTA Methanation

COMPRESSION

Syngas compressed to high pressure. Demonstration plant use 3 stage reciprocating compressor to take gas to 15 bar.

CATALYTIC CONVERSION

Syngas passed over a series of catalysts to convert it to desired product.
Demonstration plant uses:

- Polishing reactor to reduce contaminants to ppb levels.
- Water gas shift reactor to increase H_2 content.
- Five methanation reactors to convert CO and H_2 into CH_4.

REFINING

Product separated from by-products ready for sale.
Demonstration plant used K_2CO_3 solution to capture food grade CO_2.
Methane is then injected into grid.

VESTA Module - Demonstration Plant

Waste to SNG Study

MSW to SNG: A case study

Study basis

- ~1700 tpd of raw municipal solid waste (MSW) to the plant boundary
- Location – North East UK
- Feedstock preparation for gasification process: Material Recycling Facility followed by drying to meet feed specification
- ~1000 tpd of processed municipal solid waste (MSW)
- Feedstock drying to meet feed specification for Gasification Process
- Oxy-steam gasification followed by plasma conversion to produce syngas for VESTA methanation
- Plant availability: 85% or 7,446 hours/year
- Project life 25 years

MSW to SNG: A case study

	MSW Gasification to SNG
Dried process MSW to Gasifier	28 TPH
Thermal Input to Oxy-steam Gasifier	120 MW
Clean Syngas from RadGas technology gasification boundary to VESTA	33 TPH
Clean Syngas from RadGas technology gasification boundary to VESTA	102 MW
Gasification Efficiency	85 %
SNG	7700 Nm^3/h
SNG (HHV)	80 MW
Overall Plant Efficiency Waste to SNG (HHV)	62 %

MSW to SNG: A case study

	Waste Gasification to SNG
TIC, MM£	~200
CAPEX Intensity, MM£/MW_{HHV} of SNG	2.5
Assumed £ to $	1.3
CAPEX Intensity, MM$/$MW_{HHV}$ of SNG	3.3

Revenue Stream (2016 Basis)	Waste Gasification to SNG
Average MSW Tipping Fee (UK)	£70 / t
UK Government Incentive (RTFC)	£37 / MWh_{HHV}
SNG selling price (UK)	£15 / MWh_{HHV}

MSW to SNG: A case study

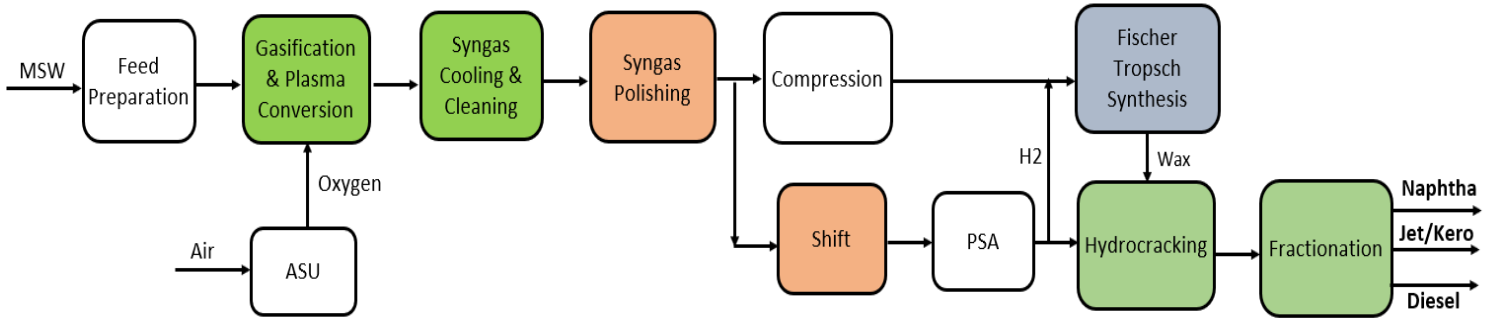
Typical schedule for a Waste Gasification to SNG Fuel project:

Waste to Liquid Fuel

Waste-to-Liquids Feasibility Study

Techno-economic evaluation of a facility converting 1700 TPD MSW plant to liquid transport fuels (aviation kerosene/Jet fuel, diesel and naphtha):

- Plasma gasification for syngas production followed by Fischer-Tropsch technology
- Licensor data obtained for Syngas Polishing and product hydrocracking sections
- Two important income streams: tipping fees from waste disposal contractors and Renewable Transport Fuels Certificates (RTFC) available for transport fuels generated from non-fossil sources
- Sensitivity analysis performed – H_2 production/availability (Shift/PSA; Over-the-fence or SMR)
- Capital and operating costs, plus Internal Rate of Return developed
- H_2 production via Shift/PSA more economical than other options



Waste-to-Liquids Feasibility Study

Syngas Polishing

- Catalytic FT process has a very stringent inlet impurity specification; hence syngas polishing step is required to ensure removal of trace components to ppb level
- Adsorbent and catalyst based scheme can reduce the majority of the impurities to the level required by the FT catalyst.
- Rectisol (chilled methanol) can be considered as well to remove acid gases and can achieve total sulphur limits of <100 ppb sulphur. The process has been proven on coal based gas in a Fischer Tropsch application at Sasol's Secunda facility in South Africa

Product & Revenue

- ~ 850 BPSD of Naphtha, Jet/Kero and Diesel Blendstock products with ~ 50% Jet/Kero
- The MSW gate fee and Government incentive for biodiesel (RTFC) have a profound impact on the IRR of the project
- ~ 70% Revenue from the tipping fee; ~8% from RTFC and rest from product
- Hence, long-term confidence in government support for renewables is critical for the viability of the project.
- UK Govt announced incentives for renewable jet fuel in 2018 which would be more beneficial for the scheme.

Waste to Renewable Aviation Fuel Project, UK

Aviation accounts for more than 2% of global CO_2 emissions, with around 895m t of CO_2 emitted from domestic and international flights in 2018 according to the International Air Transport Association.

Aviation is extremely difficult to decarbonise and as the industry grows, finding a way to reduce emissions will be critical.

Altalto Project, UK: a collaboration between Velocys, British Airways and Shell

- The proposed plant will take over half a million tonnes per year of MSW and convert it into cleaner burning sustainable aviation fuel
- 20 million gallons / year of jet fuel and naphtha
- The overall scheme enables a net 70% reduction in greenhouse gas emissions for each tonne of sustainable jet fuel that displaces a tonne of conventional fuel.
- The greenhouse gas reductions that will be achieved from the plant's annual output are equivalent to up to 40,000 standard size petrol engine cars.
- The site is near Immingham, close to the Humber Estuary with Target Financial Close Q2 2021

Velocys Technology:

The Fischer-Tropsch (FT) process is a catalytic chemical reaction that turns synthesis gas into fuels (liquid hydrocarbons, such as diesel or jet fuel).

Gas-to-liquids (GTL) Oklahoma demonstration plant: qualified for renewable fuel credits, running for over 5000 hours of cumulative operation across 2 FT reactors.

Waste to Transportation Fuel Project

The Bayou Fuels project, Mississippi USA:

- The process will take waste woody biomass and convert it into transportation fuels, such as diesel for heavy trucks and sustainable aviation fuel, using Velocys' proprietary Fischer Tropsch process.
- The integrated technical solution is suited to carbon capture, usage, and storage (CCUS); the CO_2 is captured before it enters the atmosphere.
- OLCV, a wholly owned subsidiary of Occidental, will take, transport and store CO_2 captured from the Bayou Fuels facility, when it is completed, enabling the production of transportation fuels that have a net negative carbon intensity.

Demonstration facility in Nagoya, Japan:

- Velocys has announce of securing a purchase order and technical service agreements with Toyo Engineering Corporation (Toyo) for the use of Velocys technology in a publicly funded demonstration facility in Nagoya, Japan.
- Toyo has placed an order with Velocys to supply its Fischer-Tropsch (FT) technology, equipment and catalyst for a biomass-to-jet fuel demonstration facility currently under construction by a consortium of Japanese companies.

Waste to Syncrude Project

Fulcrum Bioenergy:

- Fulcrum's process combines gasification technology with a Fischer-Tropsch ("FT") fuel process.
- A prepared MSW enters the gasification process where it is converted to a synthesis gas. This syngas then enters the FT process where it reacts with a proprietary catalyst to form a FT product which is then upgraded to a transportation fuel.

Sierra Biorefinery, Nevada, USA:

- The facility will take MSW feedstock produced at the fuel preparation facility and convert it into a low-carbon synthetic crude oil, or "syncrude".
- The syncrude product will then be transported to a Marathon Petroleum refinery to be further processed into transportation fuel.
- The Biorefinery, currently under construction, is expected to begin operations in 2020.
- Once completed, Sierra is expected to process approximately 175,000 tons of MSW feedstock annually, creating 11 million gallons per year of renewable synthetic crude oil

Waste to Chemical

Waste to Chemical project

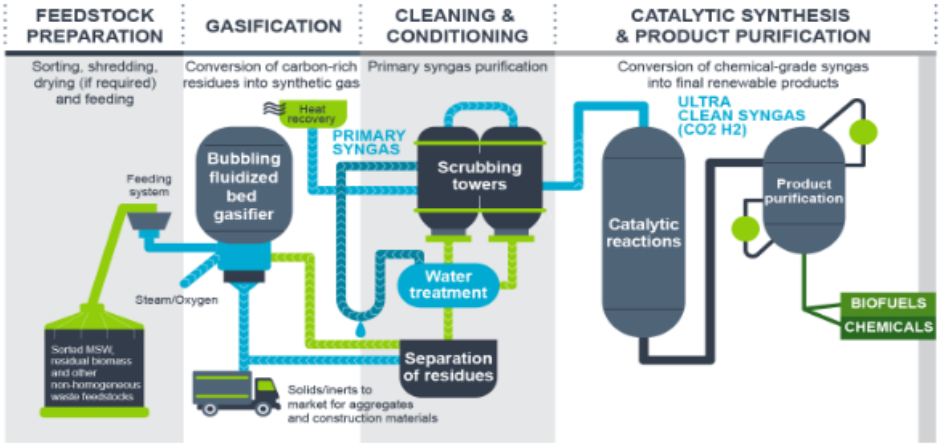
Enerkem Alberta Biofuels Project: Edmonton, Canada

A thermochemical process to converts household waste into green chemicals, such as ethanol and methanol. The facility is reducing the volume of waste sent to landfills by over 100,000 tonnes per year.

Type: Single-line methanol-ethanol production commercial facility
Status: Initiated production of methanol in 2015 and ethanol in 2017
Feedstock: MSW (after recycling and composting)
Products: Methanol, Ethanol
Capacity: 38 million litres / 10 million gallons per year

Enerkem's 4-step thermochemical process:

- feedstock preparation
- gasification
- cleaning and conditioning of syngas
- catalytic synthesis



Waste to Power

Biomass power plant – Teesside UK

MGT Teesside Ltd:

- World's largest biomass power plant (circulating fluidised bed (CFB) technology) under construction on Teesside situated on the River Tees, North East England.
- The plant would burn ~1.2 million tons of wood pellets per year, imported from Europe and America.
- This would generate ~300 megawatts of electricity, enough to power 600,000 homes
- It is expected to save 1.2 million tonnes of CO_2 per year, accounting for 5.5% of the UK's renewables target

Drax Power Plant:

- Drax power station is a large biomass and coal-fired power station in North Yorkshire, England, capable of co-firing.
- It has a ~2.6 GW capacity for biomass and ~1.3 GW capacity for coal.
- Drax has switched to fourth biomass generating unit in 2018.
- Drax planning to switch other two coal fired unit to CCGT
- In May 2018, Drax announced Carbon Capture and Storage pilot scheme that it would undertake in conjunction with the Leeds-based firm, C-Capture.
- The focus of this pilot will be on capturing carbon post combustion from the biomass burners.
- This would yield about 1tonne of CO_2 per day from the process, which could be sold on for use in the drinks industry.

Agenda

Questions Please?

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