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Synergy World Power

Baseload Renewable Energy from Solid Waste in a Sustainable Environment

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and its project companies including
Synergy World Power

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Main Themes

- Environmental Sustainability Through Thermal Conversion of Solid Waste
- Environmental Performance and Reliability as Priorities in Systems Design
- Renewable Power Generation with Fuel or Cement as a Revenue Stream

Technology

- Gasification Processes Chemistry
- Gasification vs. Incineration
- Gasifiers in Distributed Generation
- Rotary Kiln Gasification
  - Rugged, Reliable, Readily Scaled
  - Flue Gas Recirculation
  - LoNOx Burner
  - Sintered Bottom Ash
  - Mid-Kiln Oxidant Insertion
  - Thermal Camera Control
- Highly Scalable and Adaptable
- Specialty Applications

- HTL Conversion of Waste Plastics to Ultra Low Sulfur Liquid Fuels

Environmental and Economic Advantages

- Diversion of Waste from Landfill
- Clean: Low Air Emissions and GHGe Reduction
- Conversion of Ash to Beneficial Materials
- Adaptable for ESG Carbon Footprint Reduction
- Conversion of Plastics to Clean Liquid Fuels

Application Examples

- Conventional Waste to Thermal/Electrical Energy
- Combined Heat and Power
- Conversion of Mixed Wet Waste to Fuel Gas
- Conversion of Waste Ash to Cement Additive
- Recovery of Aluminum from Recycle Waste

Conclusions

Main Chemical Reactions Involved in Combustion vs Gasification

Reactions shown below illustrate the differences between incineration and gasification and indicate the flexibility of the latter

Main chemical reactions involved in ordinary combustion of MSW

1. $C + O_2 \Rightarrow CO_2$	Oxidation of Carbon
2. $1/2\ O_2 + H_2 \Rightarrow H_2O$	Oxidation of Hydrogen
3. $N + O_2 \Rightarrow NO_2$ (NO_x)	Oxidation of Nitrogen
4. $S + O_2 \Rightarrow SO_2$ (SO_x)	Oxidation of Sulfur

Examples of reactions that dominate under gasification conditions

1. $C + CO_2 \Rightarrow 2CO$	Gasification with Carbon
2. $C + H_2O\ (g) \Rightarrow CO + H_2$	Gasification with Steam
3. $C + 2H_2O\ (g) \Rightarrow CO_2 + 2H_2$	Gasification with Steam
4. $C + 2H_2 \Rightarrow CH_4$	Gasification with Hydrogen
5. $CO + H_2O\ (g) \Rightarrow CO_2 + H_2$	Water Gas Shift Reaction
6. $C + 1/2\ O_2 \Rightarrow CO$	Gasification with Oxygen
7. $CO + 3H_2 \Rightarrow CH_4 + H_2O\ (g)$	Methanation Reaction
8. $S + H_2 \Rightarrow H_2S$	Gasification with Hydrogen
9. $C + O_2 \Rightarrow CO_2$	Gasification with Oxygen

Chemical Composition of Syngas and Producer Gas

Combustible components of **Syngas** (oxygen blown system) and **Producer Gas** (air blown system) are much the same. Producer contains inert nitrogen.

Producer Gas (Fuel Gas): CO, H_2, CO_2, H_2O, CH_4, N_2

Syngas: CO, H_2, CO_2, CH_4 + Trace gasses.

Examples of reactions using ammonia for NOx abatement

Injection of ammonia (NH_3) to convert NO_x to inert nitrogen gas and water

$$4NO + 4NH_3 + O_2 \rightarrow 4N_2 + 6H_2O$$

$$2NO_2 + 4NH_3 + O_2 \rightarrow 3N_2 + 6H_2O$$

$$NO + NO_2 + 2NH_3 \rightarrow 2N_2 + 3H_2O$$

Rotary Kiln Gasification Compared to Incineration

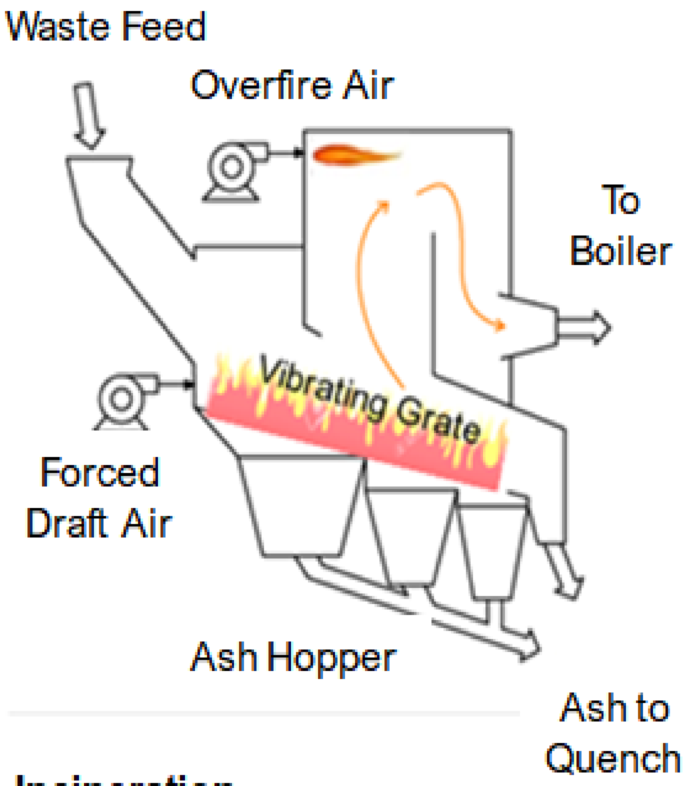
Rotary kiln gasifiers can be designed with emphasis on reliability and environmental performance.

Waste to energy plants are paid to process the feedstock they use.

Therefore, thermal efficiency considerations can take a back seat to reliability and environmental performance.

As described below, the LoNOx sintering kiln design achieves outstanding environmental performance compared to alternatives.

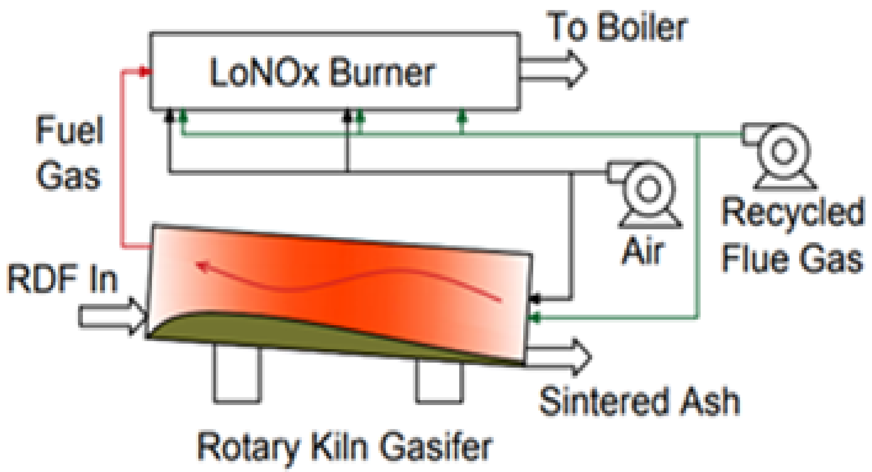
Rotary kilns can also be used as in other roles in converting waste to energy for other beneficial use.



Incineration

- Operates with excess air
- Generates more PM, NOx and VOCs
- Equipment larger and more expensive
- Ash is often special or hazardous waste

Complete combustion requires a 6.25:1 air to fuel ratio.



Gasification

- Operates sub-stoichiometrically with much lower gas flow through the main reactor.
- Lower mass flow means less particulate carryover
- Generates less PM, NOx and VOCs and no ozone.
- Gasification systems are less expensive
- Ash residue is clean and can be used for construction fill

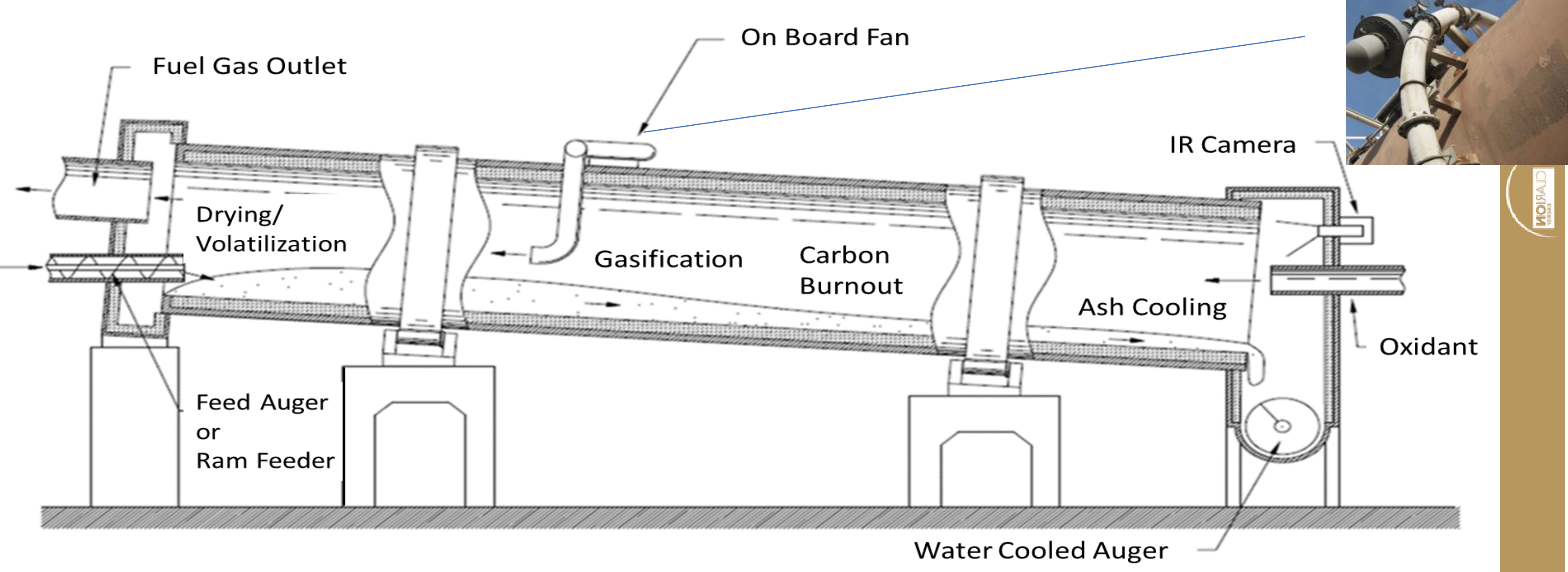
Rotary Kiln Temperature Profile

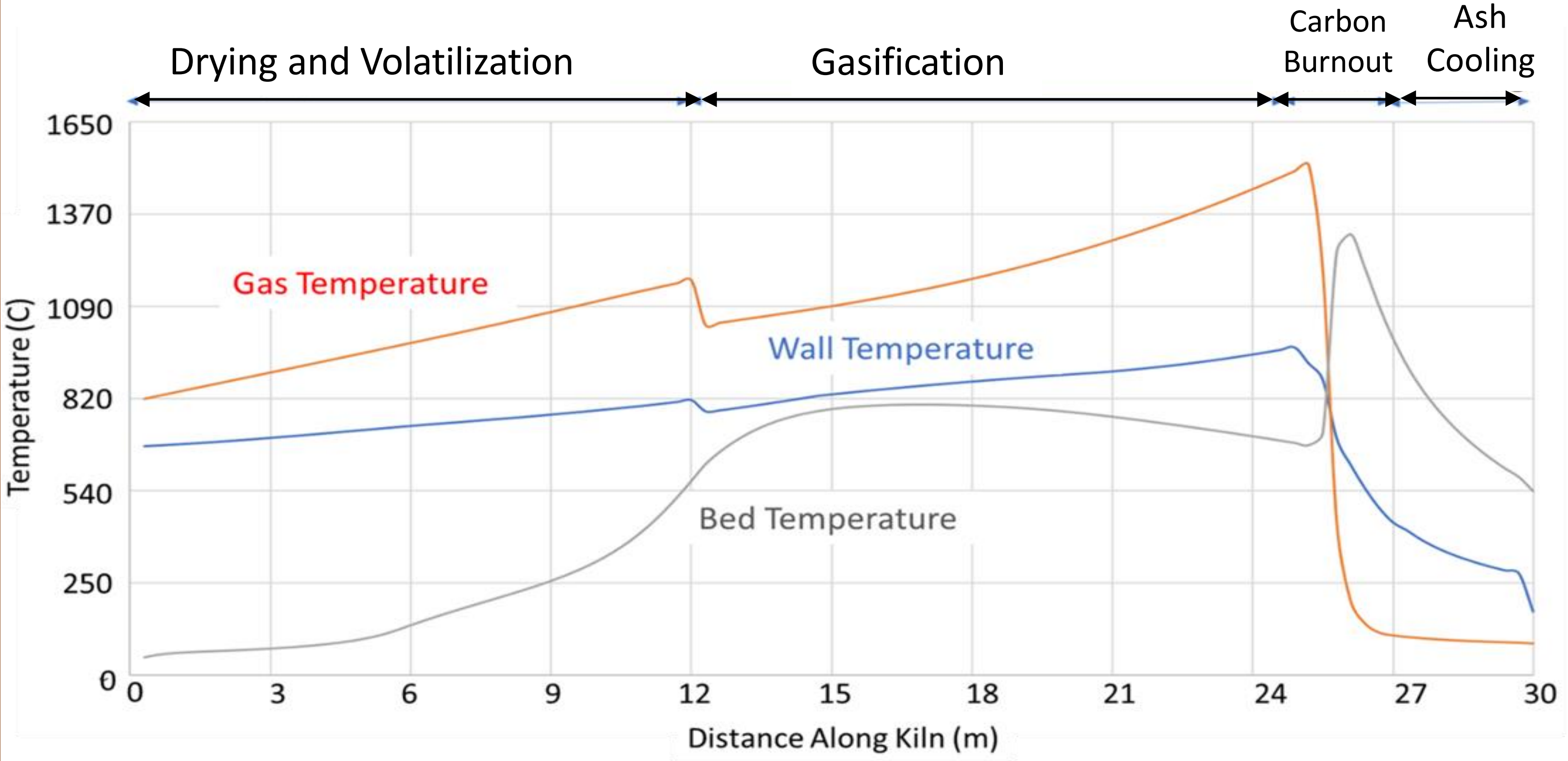
- **Top Right**: Four reaction zones in the rotary kiln. A ram feeder can be used instead of an auger.

- Kiln design is optimized for improved operational control using an onboard fan and infra red camera to control zone length, temperature, and the position of the flame front.

- Bottom Right: graphic shows typical gas temperature, bed temperature and wall temperature profiles along the length of the kiln.

- The significant increase in bed temperature in the carbon burn out zone results in a carbon-free, inert, sintered bottom ash that can be used as for construction fill.





LoNOx Power Plant Block Diagram Showing Fuel Prep, Thermal Island and Power Island

SRF= Solid Recovered Fuel

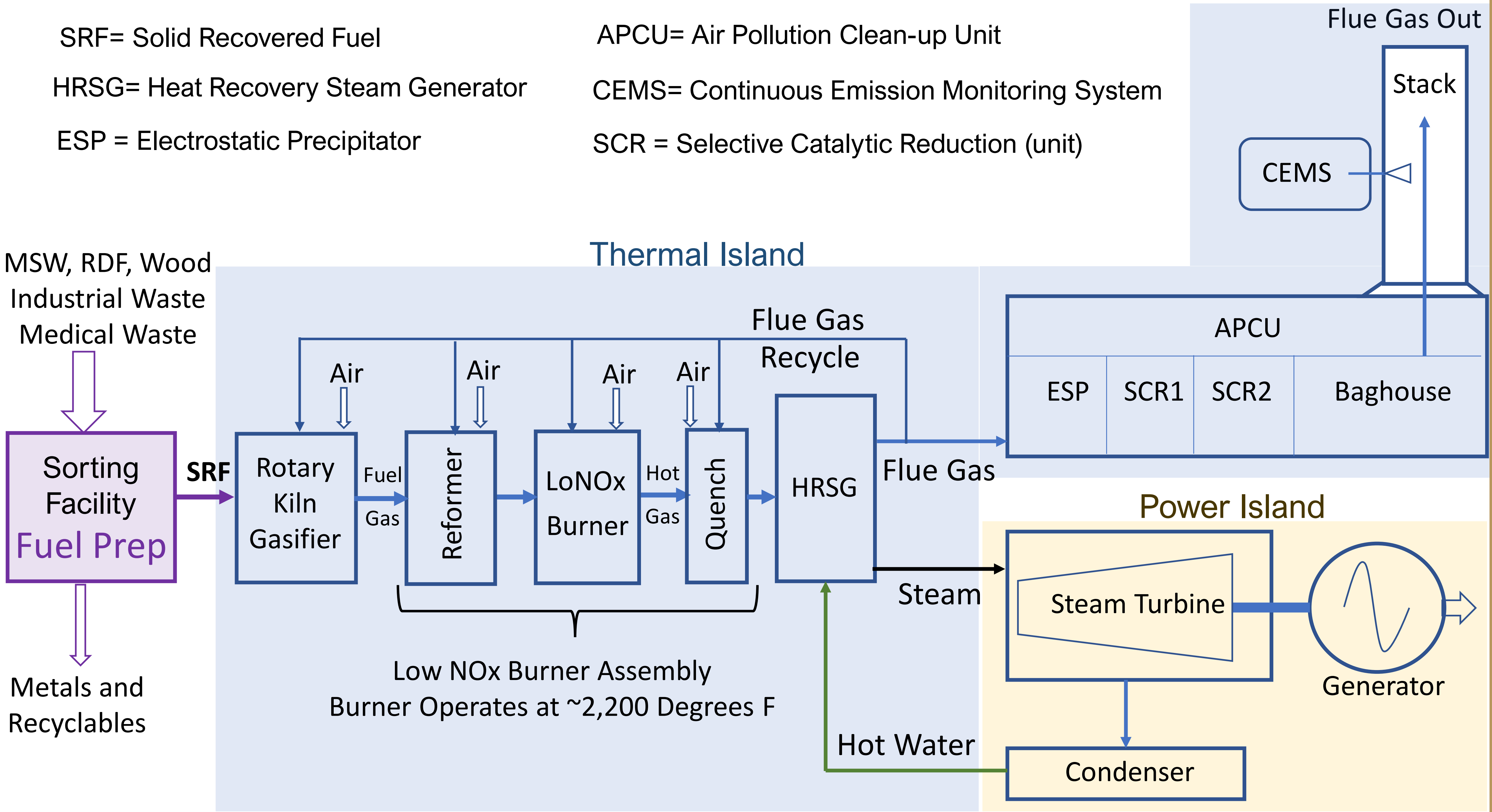
HRSG= Heat Recovery Steam Generator

ESP = Electrostatic Precipitator

APCU= Air Pollution Clean-up Unit

CEMS= Continuous Emission Monitoring System

SCR = Selective Catalytic Reduction (unit)

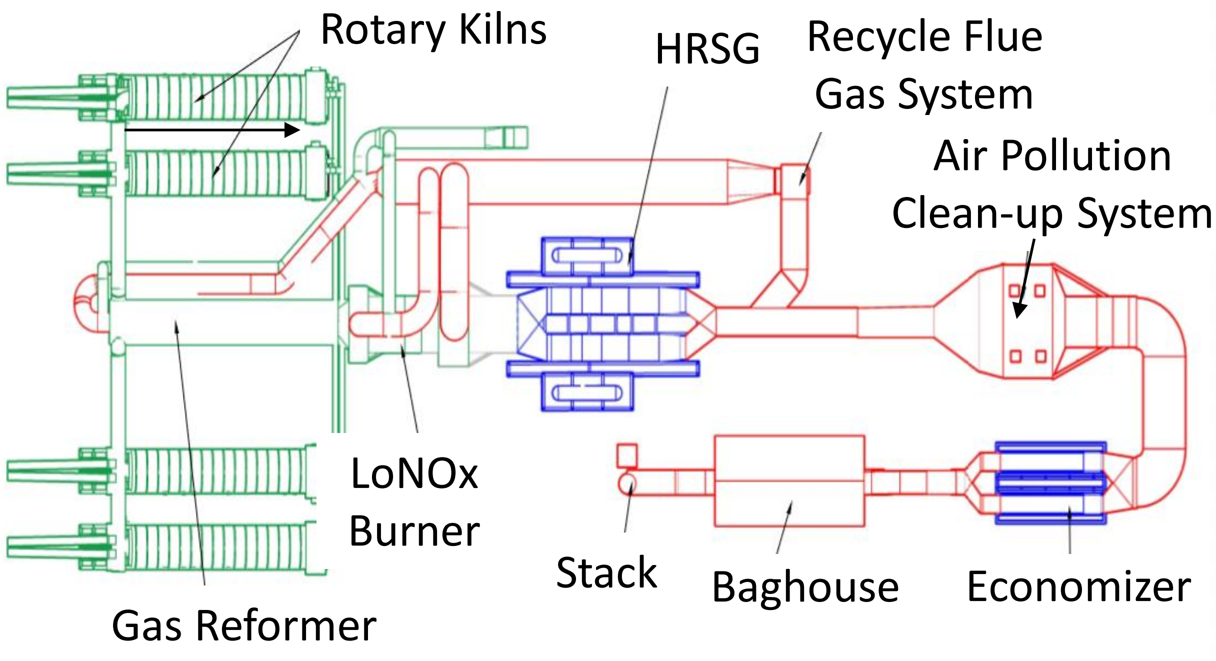


Rotary Kiln Gasification Power Plant with Emission Reduction Components

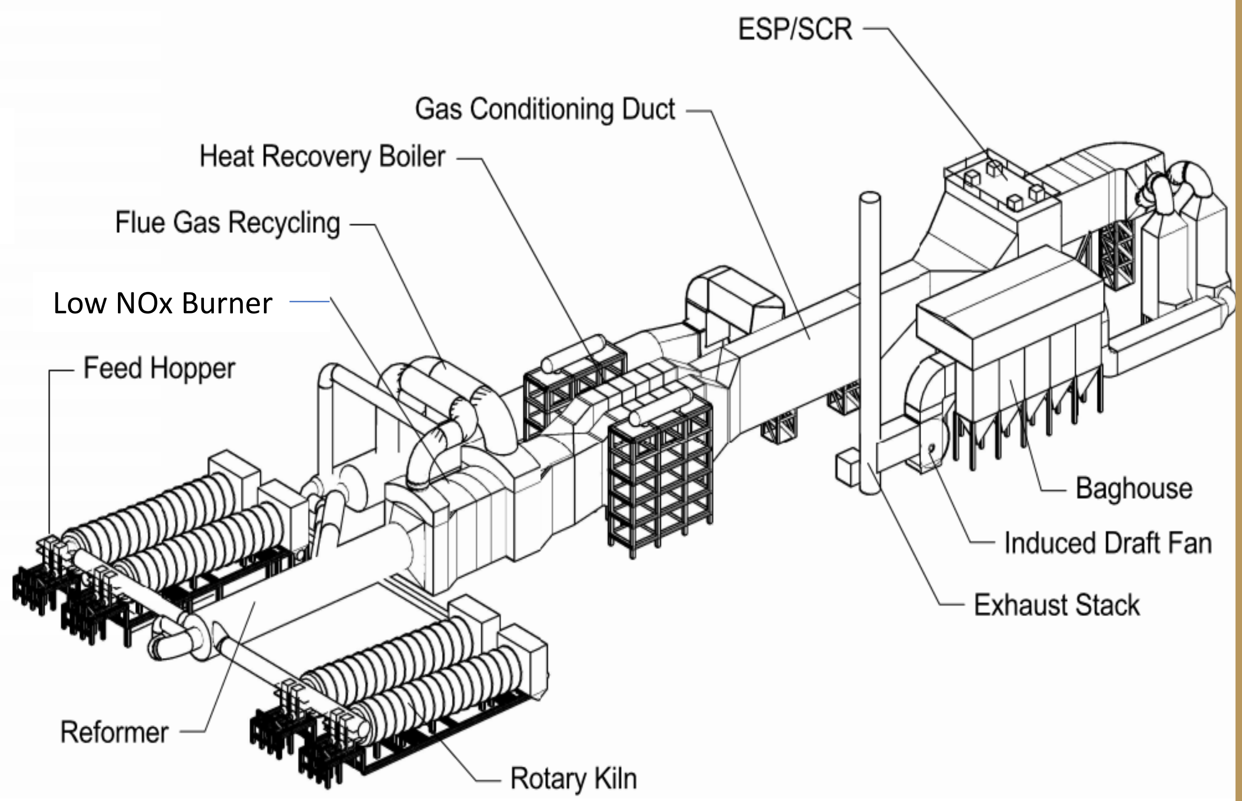
Plan view of a rotary kiln gasifier thermal island showing the components involved in gasification and reforming, steam generation, and flue gas clean-up.

Unit	Target Pollutant	Capture
LoNOx Burner	NOx	~90%*
Dry Sorbent Injection	SOx, HCl, HF	90%, 95%
ESP	PM, Heavy Metals	90%
SCR	NOx, CO	90%, 70%
AC Injection	Heavy Metals, VOC	85%
Baghouse	PM	99%

Line drawing of low- profile gasification thermal island showing the configuration of the rotary kilns, reformer, LoNOx burner, flue gas recycle, APCU components, and baghouse.



Green: Gasification Components, Blue: Steam Generation (Boiler & Economizer), Red: Flue Gas Clean-up

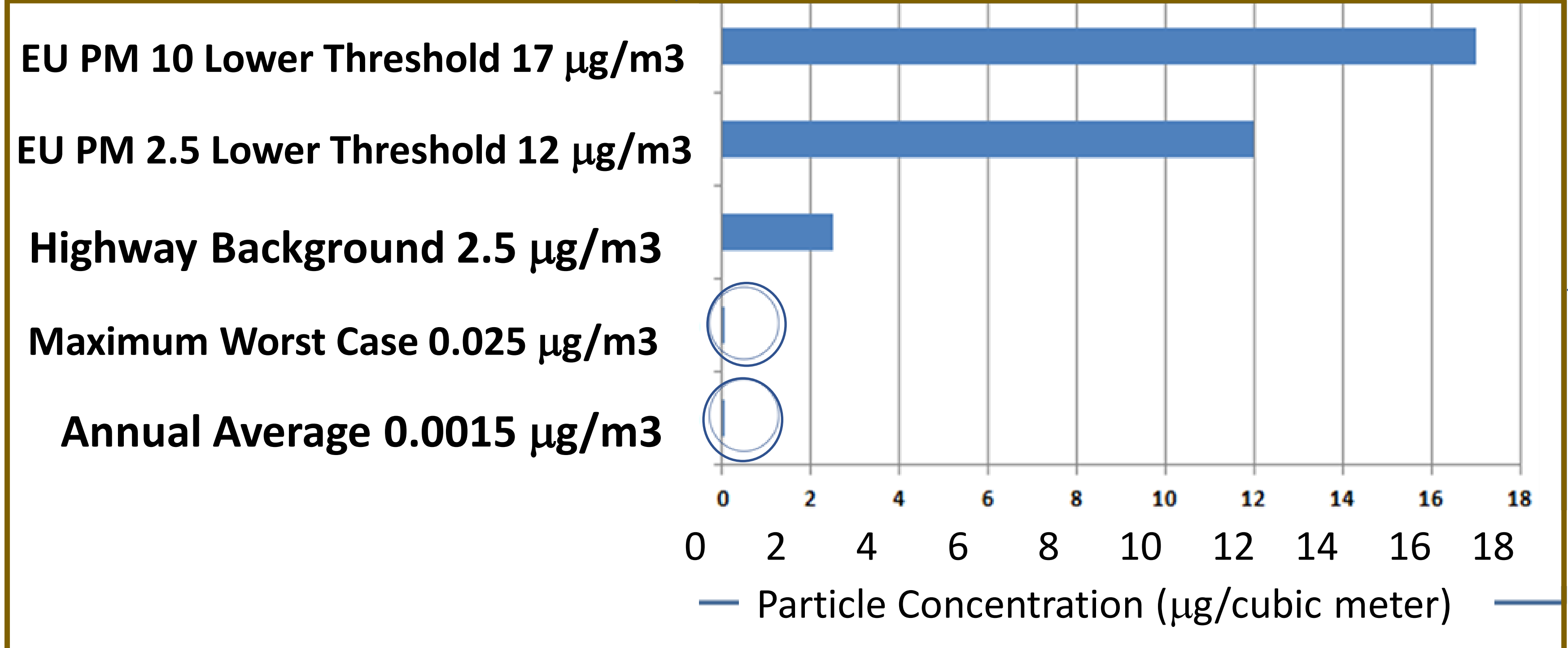


Air Emissions Compared to USEPA and EU Standards

Stack emissions from a 1,000 t/d LoNOx gasification power plant compared to USEPA 40 CFR 60 Subpart Eb large boiler standard.

Constituent	Stack Concentration (mg/m^3)	Adjusted Stack Concentration (mg/m^3)	"Eb" Standards (mg/m^3)	% of Actual To Standards
CO	10.9	8.5	58.2	15%
NOx	11.6	9.0	286.9	3%
SOx	14.4	11.2	79.9	14%
PM	2.8	2.2	20	11%
VOC	1.2	0.9	20	5%
HCl	5.7	4.4	37.9	12%
Total	60.7	47.1		

Ground level concentrations of particulate matter from 1,000 t/d LoNOx gasification power plant at 500 meters from the stack compared to EU air quality standards.



Both stack concentrations of criterial pollutants, and ground level ambient air concentrations of particulate matter, from EPR rotary kiln gasification plants are well below applicable USEPA and Republic of Ireland (EU) air quality standards.

Rotary Kilns Process Feedstocks Containing Inerts and Metal Components

No shredding is required for run of the dump waste.

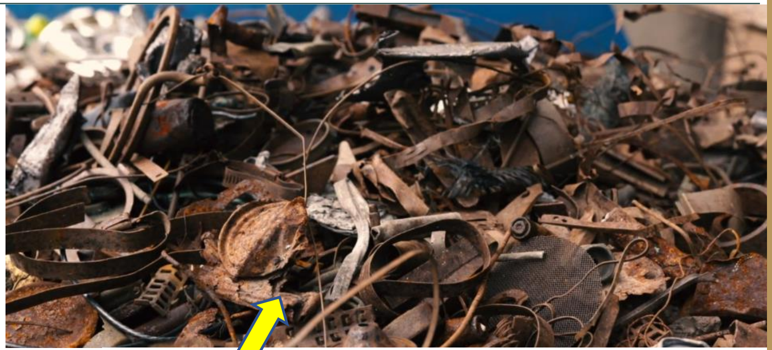
Rotary kiln operating on run of the dump waste.

Typical piping for cool gas

- The rotary kiln gasification power plant in these images has been operating on 440 tons per day of run of the dump MSW since 2011.

- This ram fed rotary kiln will accept solid objects sized up to approximately 30 inches, or more, and can process partially combustible materials such as waste tires, converting the combustible components to fuel gas and leaving the metals to be collected and recycled.

- Ferrous metals and aluminum in the waste can be readily recovered from the bottom ash and recycled.



Steel scrap recovered from unsorted waste after gasification

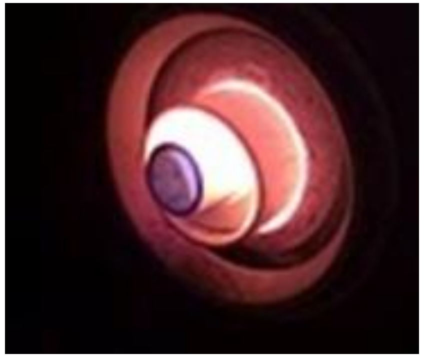
Wire from processing waste tires

Ferrous metals and aluminum can be recovered after combustible components are gasified

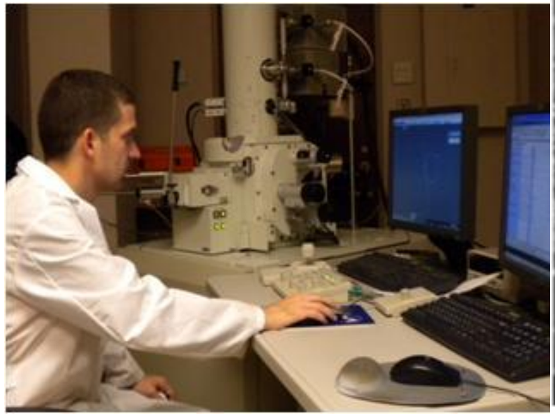
LoNOx Rotary Kiln Gasifiers were Designed from the Ground up for the Environment

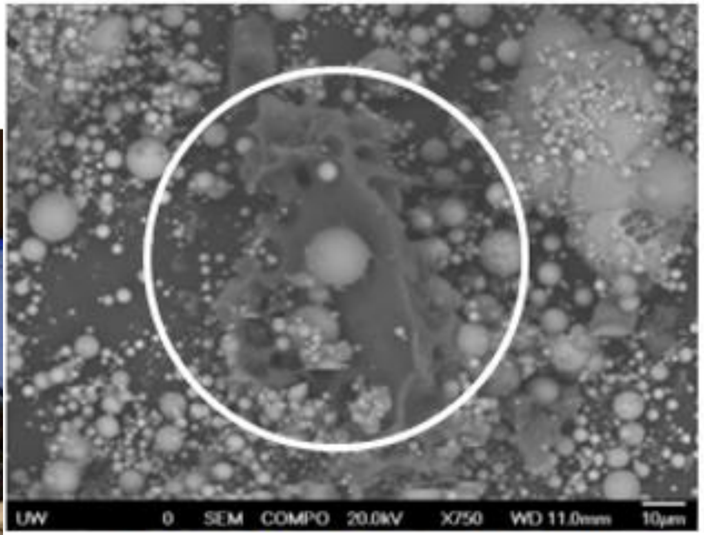
LoNOx rotary kiln gasifiers were developed through partnerships with scientists and engineers at the University of Washington, the University of Utah, and Metso.

Research to improve high temperature processes as well as the capability for analysis and performance testing of raw materials, process intermediates, and by-products, for example, are essential to determining the optimum process configuration for each plant.

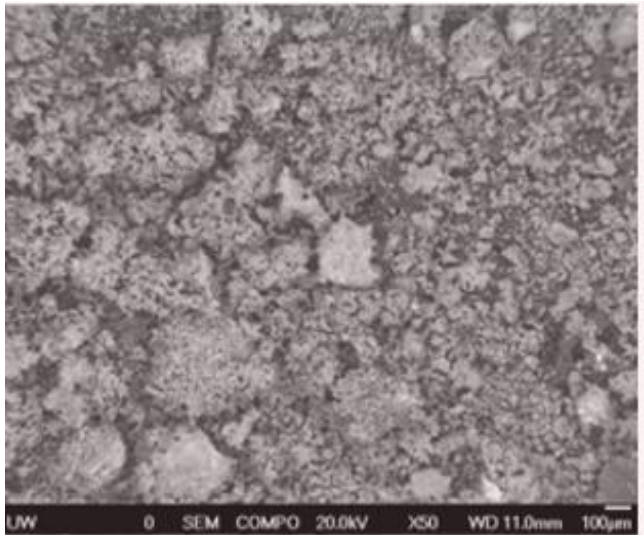


Shown below are the before and after electron micrographs of a high carbon coal fly ash to which other minerals were added before autothermal conversion in a rotary kiln to a high-quality supplemental cementitious material (SCM).

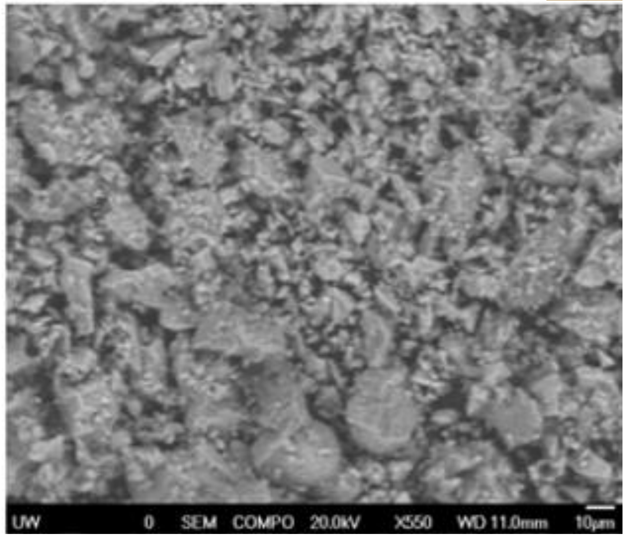




Carbon Particle in ALF Fly Ash



SCM from ALF Fly Ash

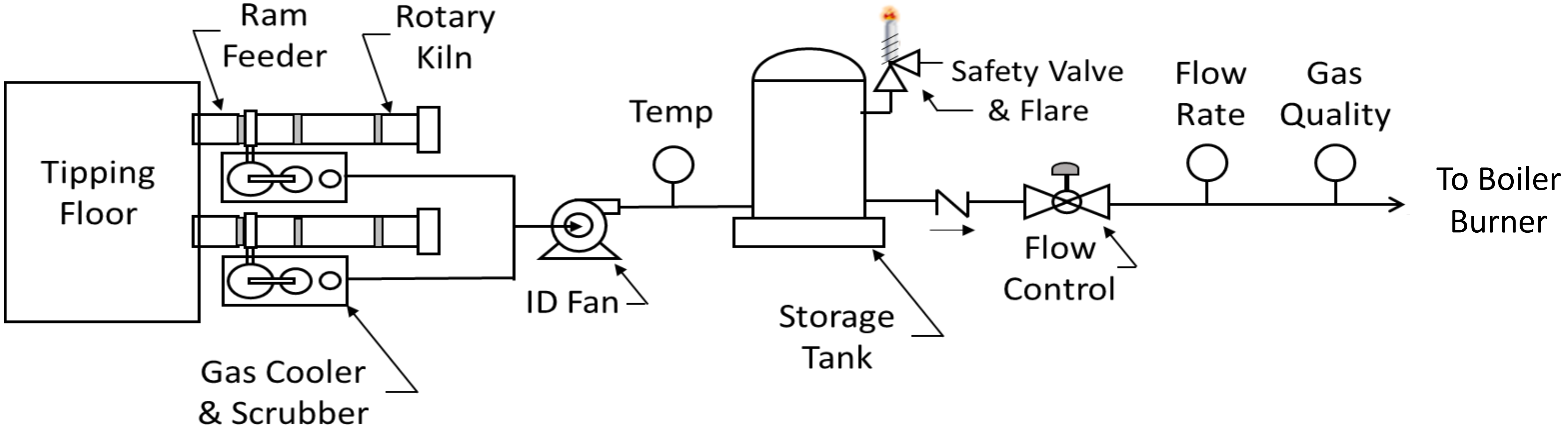


Portland Cement

Example of industrial waste best processed with rotary kiln gasifiers

Cardboard recycle pulping "wrag" waste and tailings consisting of fiber and plastic with up to 55% moisture as well as steel wire, glass, dirt, etc. This material can be gasified onsite to produce sustainable **fuel gas** for firing or co-firing boilers for process steam or steam turbine power generation. The latter process qualifies for RECs.

Because of the steel wire content, this material must be fed with a ram feeder and guillotine to limit wire length with the steel wire being recovered from the bottom ash with magnets and by screening.



More examples of industrial waste best processed with rotary kiln gasifiers

Aluminum Recycling Shredding Outfall

This waste material is up to 40% unrecoverable aluminum by weight in small shreds mixed with plastic and paper. It is normally landfilled. Rotary kiln gasification was designed and demonstrated to recover the aluminum while converting the paper and plastic into fuel gas for use in de-coater kilns.

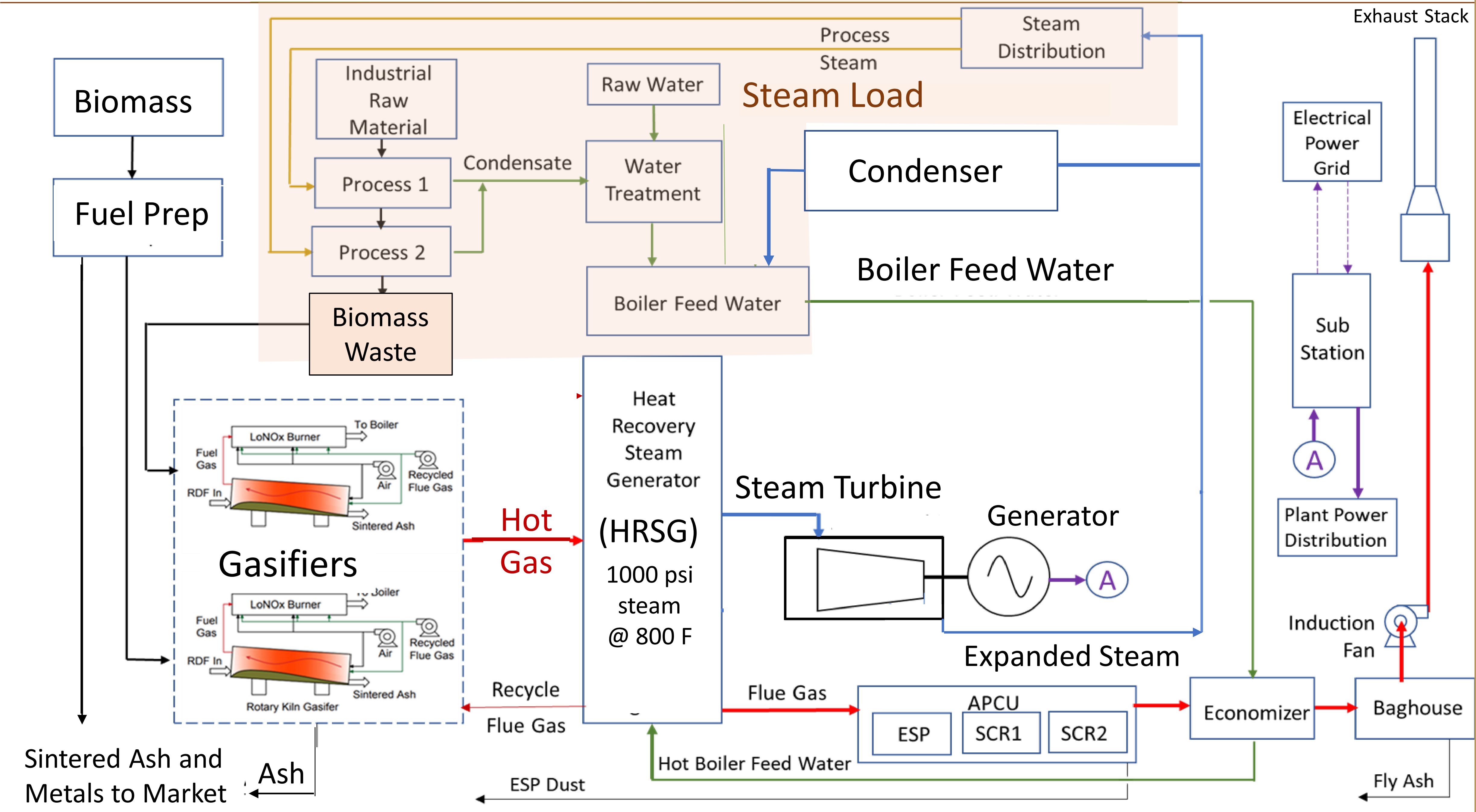
Spent Wood from Chemical Extraction

A rotary kiln gasification combined heat power plant was designed to use spent wood material along with combustible construction and demolition waste in a combined heat and power plant. Process steam and renewable electrical power will be generated for the host facility.

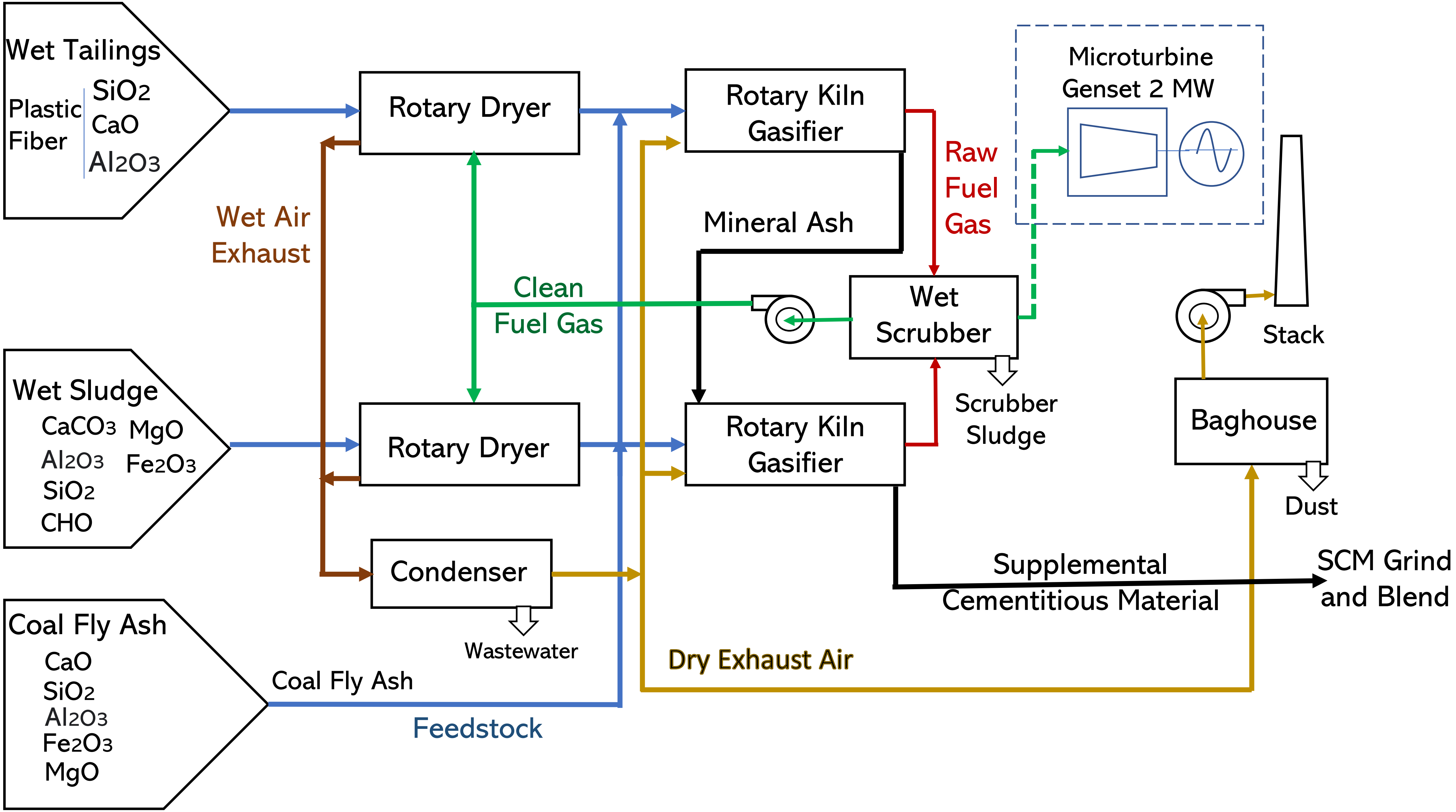
Paper Mill Sludge

Using fuel from gasification of wet pulper tailings, a series of rotary dryers, calciners, and cement kilns can convert wet paper mill sludge into a green supplemental cementitious materials (SCM)- a beneficial additive for Portland cement. Several types of coal fly ash can also be used in this process. Coal fly ash in SCM can increase concrete compressive strength.

Gasification Combined Heat and Power Plant Process Flow Diagram



Rotary Kiln Conversion of Paper Mill Waste to Green Cement Additive



Environmental Benefits of LoNOx Rotary Kiln MSW Gasification Plants

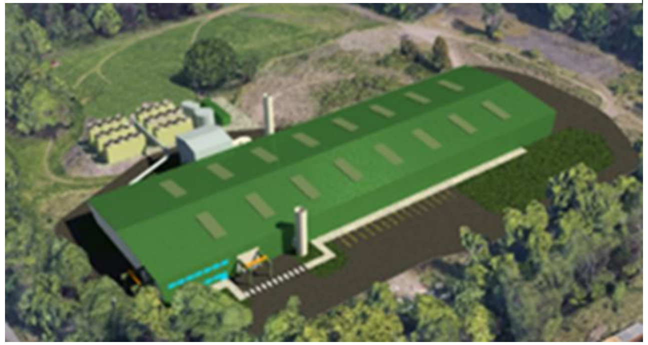
Compared to placement in a landfill or conventional incineration, gasification for energy generation from solid waste offers several advantages including:

- Reduced air emissions compared to generation of electrical power by incineration,
- Elimination of incineration ash as hazardous or special waste,
- Substantial reduction in material, especially food waste, placed into landfill,
- Reduced emission of greenhouse gas equivalents compared to landfill,
- Elimination of odors and fugitive materials associated with landfill placement.

Gasification waste to energy projects help achieve sustainability goals by:

- Reducing the amount of solid waste shipped out of state, eliminating a large portion of the air pollution and traffic congestion caused by more than 10,000 diesel truck trips to out of state landfills annually.
- Reducing the amount of solid waste going to landfill.
- Providing the option for using HTL to convert most plastic waste into ultra-low sulfur distillate fuels at a fraction of the energy for making them from crude oil.
- Providing a clean and efficient means of generating electrical power from solid waste as compared to incineration.

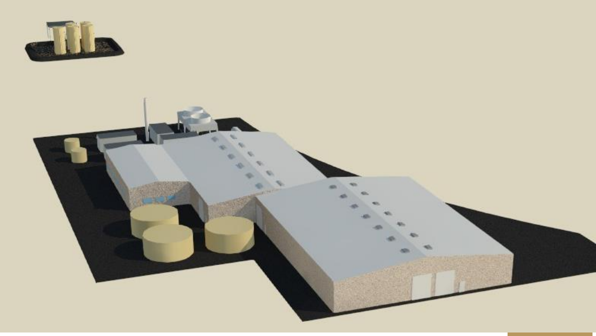
440 t/d rotary kiln MSW gasifier



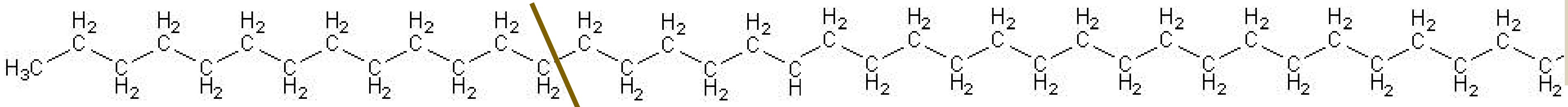
900 t/d rotary kiln RDF gasifier

1,300 t/d rotary kiln gasifier with HTL

Hydrothermal Liquefaction (HTL) of Waste Plastics to Make Diesel Fuel

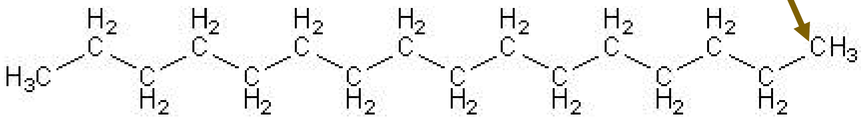


HDPE Plastic: ~10,000 carbon atoms in each molecule



Thermal Cracking + 

Cetane



Typical component of diesel fuel: ~16 carbon atoms in each molecule

Most plastics waste can be converted directly to diesel fuel. This is done by cleaving the polymer carbon backbone at high temperatures.

To make diesel from plastics, we are developing technology that uses superheated, high-pressure water in a proprietary process (that may include gasification) and can convert a variety of wastes to liquid fuels.

HTL system designs that can be tailored to the available waste feedstock and product fuel requirements.

Advantages of using HTL to make diesel from plastics include*:

- **Dramatically less energy is required to** make a liter of ultra low sulfur diesel from plastic, as compared to refining it from crude oil.

- **Reduction in greenhouse gas emission** is achieved with HTL compared to conventional diesel production

* Life-Cycle Analysis of Fuels from Post-use Non-recycled Plastics," was published in the April 14, 2017, edition of the journal **Fuel.**

Conclusions

- LoNOx Rotary Kiln gasification is a valuable tool in sustainable distributed generation of baseload renewable power, sustainably helping to stabilize local power grids.
- LoNOx Rotary Kiln gasification can meet the most stringent air emission limits in the EU and in US jurisdictions such as California and New Jersey.
- Versatility and scalability make LoNOx gasification adaptable to a variety of applications.
- While RECs and Offsets are available for project greenhouse gas reduction, properly designed gasification waste to energy projects can be profitable without government subsidies and thus make attractive long-term investments.
- Helping corporations achieve Environmental, Social and Governance (ESG) goals has created an opportunity for BOT or BOOT installations of custom designed LoNOx plants.

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