



ALL Power Labs
personal scale power

Chapter 1

Introduction to the Power Pallet

PP20 v1.08



(PP20 Grid-Tie model displayed)

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Specifications

	PP20
Electrical output capacity	50 Hz, 1500 RPM: 4–15 kW 60 Hz, 1800 RPM: 4–17 kW
Gasifier flow rate	11-52 m ³ /hr
Gas thermal output at maximum	330,000 BTU/hr 97 kW
Biomass consumption rate	50 Hz: 4.8–19.2 kg/hr 60 Hz: 4.8–20.4 kg/hr
System Footprint (l×w×h)	54" × 70"× 86" (136 cm × 178 cm × 219 cm) Footprint includes ash collection vessel beside the pallet. The pallet itself is a 54" (136cm) square.
System weight	2350 lbs 1066 kg This is the shipping weight, which includes packaging, but does not include the weight of feedstock.

(Electrical output capacity varies with feedstock quality and moisture content; drier fuel supports higher power output.)

Overview

Conceptual overview

The Power Pallet system is comprised of the ALL Power Labs' GEK TOTTI¹ series gasifier integrated with automation system and an engine coupled to a generator to produce electricity. The purpose of the gasifier is to refine locally available waste biomass feedstocks into a clean-burning gaseous fuel (producer gas²) that is compatible with internal combustion engines. The gasifier converts cellulosic biomass feedstock into producer gas using the processes of gasification. Producer gas is made up of about 20% H₂ and 20% CO, which are both gaseous fuels that the internal combustion engine burns to generate power.

Sequence of Processes

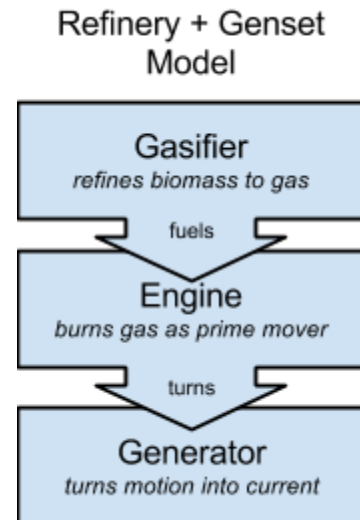
The major processes of gasification are as follows:

- **Drying** — removal of moisture from the feedstock
- **Pyrolysis** — thermal breakdown the feedstock into tar gases and charcoal
- **Combustion and tar cracking** — burning of charcoal and tar gases to provide heat for the rest of the processes and the thermal cracking of a portion of the tar gases into CO and H₂ gas.
- **Reduction** — reaction of combustion products and charcoal to produce gaseous fuel

In the process of producing electricity, there is a sequence of flows from the hopper to the exhaust pipe:

1. **the flow of solids** — Biomass feedstock starts in the hopper, flows through the drying bucket and the *PyroReactor*, and ends in the ash collection vessel.
2. **the flow of gases** — Gaseous fuel is produced towards the bottom of the reactor, flows through two heat-recovery stages, and is consumed in the engine.
3. **the flow of exhaust** — The engine exhaust is directed through a heat-recovery stage before being released to the atmosphere.

Extensive recovery of waste heat is one of the features that sets the Power Pallet apart, resulting in cleaner gas output as well as higher efficiency.

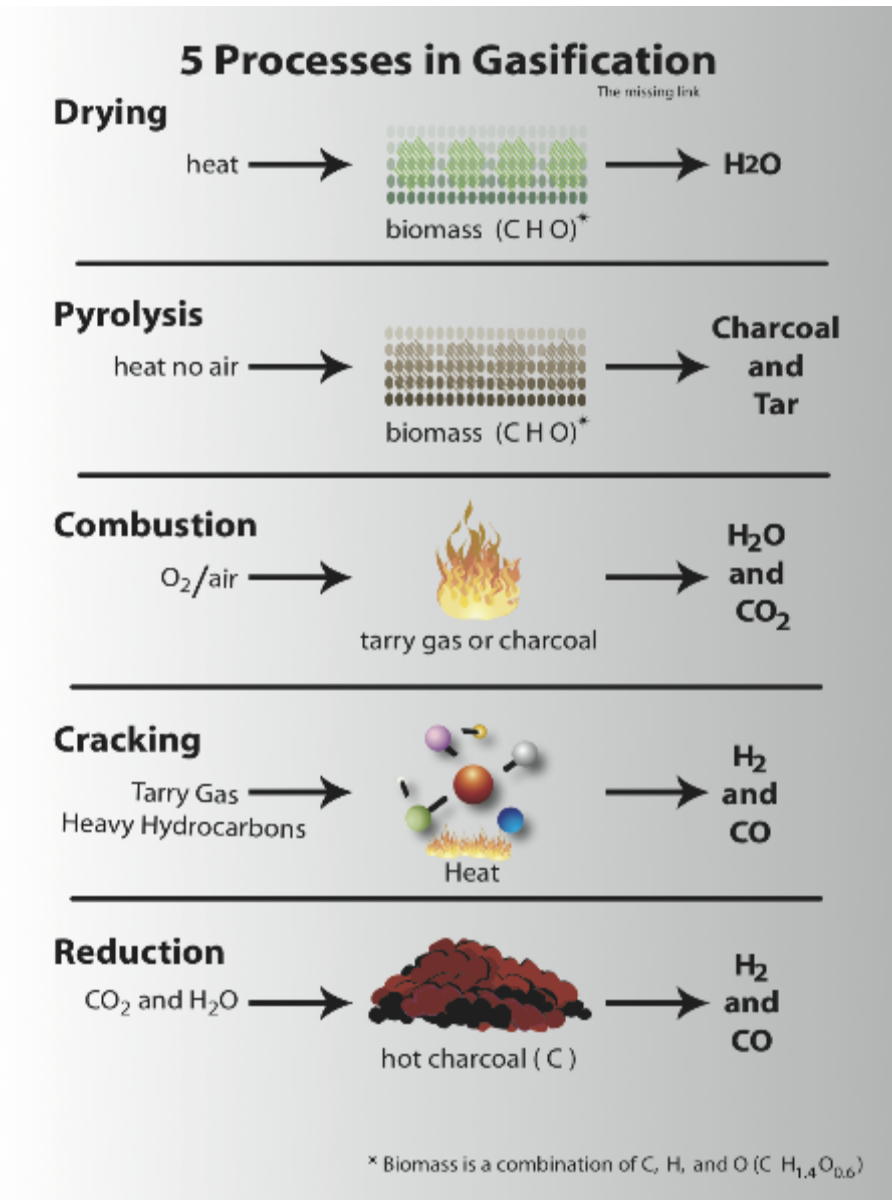


¹ GEK TOTTI is an acronym for Gasifier Experimenter's Kit, Tower of Total Thermal Integration.

² The term "producer gas", "syngas" and "wood gas" are commonly used as synonyms. In this document, we are using the term "producer gas" to avoid confusion with the additional implications of the term "syngas" as used in industry.

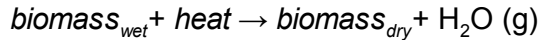
Flow of Solids

Within the gasifier the solids flow downward by gravity, while the gases are pulled through the system by the vacuum produced by either the engine or the gas blowers of the flare system during start-up. The following section describes the major processes of gasification to produce producer gas from biomass feedstock.



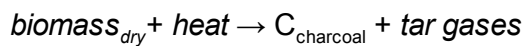
The processes of gasification. Charcoal is consumed converting the combustion gases CO₂ and H₂O into CO and H₂ gas, which burn hot and clean.

Drying



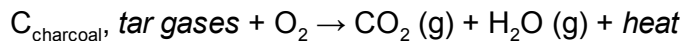
The feedstock flows from the *hopper* into the *drying bucket*. The drying bucket is a double-walled heat exchanger that assists in the drying of the feedstock at 100°-200°C using heat reclaimed from the producer gas. This enables the Power Pallet to gasify feedstocks with a dry-basis moisture content as high as 30%.

Pyrolysis



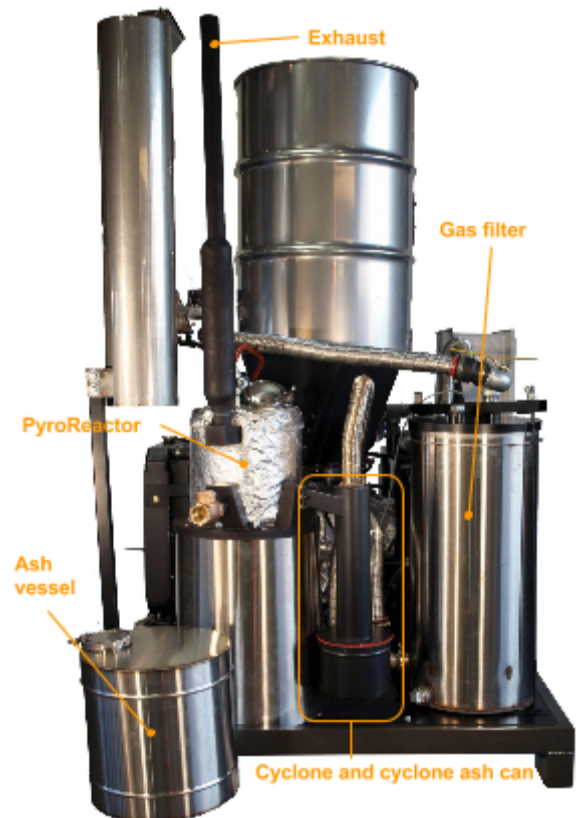
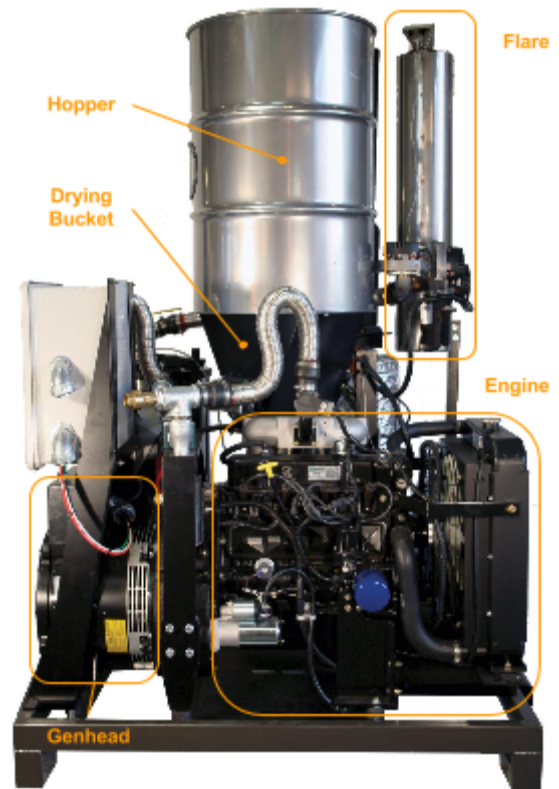
Pyrolysis is the charring process by which the feedstock is converted into charcoal and large quantities of flammable tar gases. The dry feedstock is pushed from the drying bucket into the pyrolysis zone of the PyroReactor by the auger until the reactor is full, as regulated by the fuel switch. (See Exhibit D at the end of this chapter for the location of this switch.) The PyroReactor consists of two heat exchange stages; the first is a double-walled waste-heat-assisted pyrolysis zone which exposes the feedstock to optimal pyrolysis temperatures in the range of 400-600°C using heat reclaimed from the engine's exhaust, and the second is a series of corrugated air lines that preheat incoming air for combustion.

Combustion and tar cracking



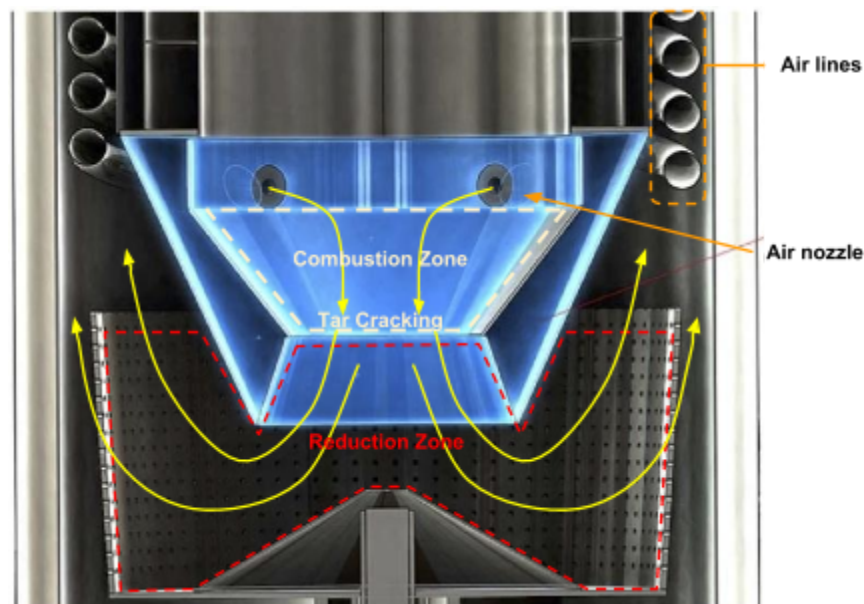
Following pyrolysis, the tar gases descend through the combustion zone, which burns a portion of the tar gases and the charcoal to provide heat for the rest of the processes. Tar cracking, which is the thermal decomposition of the remaining tar gases into CO and H₂ gas, happens concurrently with combustion in the void spaces between the pieces of charcoal.

The combustion zone of the PyroReactor is the region between the air nozzles and the restriction in



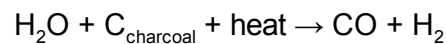
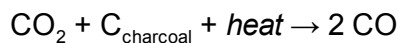
the *hearth* (see illustrations below), which is the structure projecting out of the bottom of the PyroReactor. A few inches above the constriction, five air nozzles provide jets of preheated air to the combustion zone. The air is preheated to a temperature of about 600°C using heat recovered from the producer gas by being drawn through corrugated air lines. The high temperature of preheating increases the efficiency of combustion, enabling the combustion zone to achieve temperatures ranging from 1000-1300°C in front of the air jets. The constriction causes the temperature to homogenize across the opening, forming a 800-900°C tar cracking hot spot through which unburned tar gases must flow, resulting in cleaner producer gas.

Combustion is the main exothermic (heat releasing) reaction in the gasification process. Drying, pyrolysis, reduction, and tar cracking are all endothermic (heat consuming). The Power Pallet's use of recovered heat from the exiting hot producer gas and engine exhaust improves the heat balance of the overall process thus increasing conversion efficiency.



The hearth, in cross-section. Orange arrows represent gas flow paths. The quantity of gas increases as CO and H₂ are produced from the charcoal and tars. Producer gas diffuses out the top and throughout the grate basket perimeter.

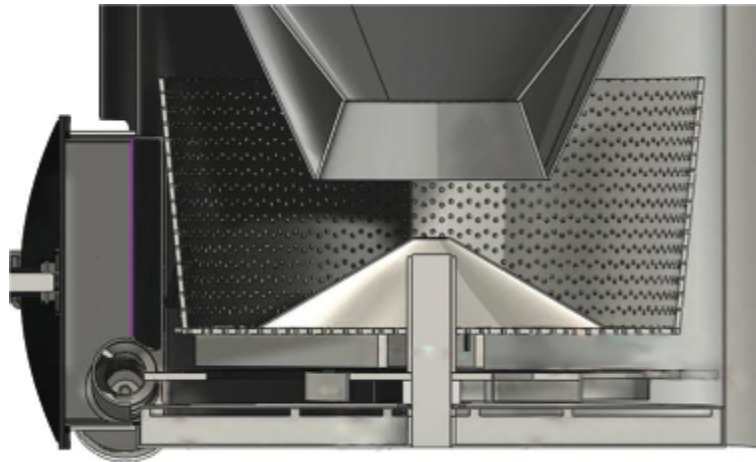
Reduction



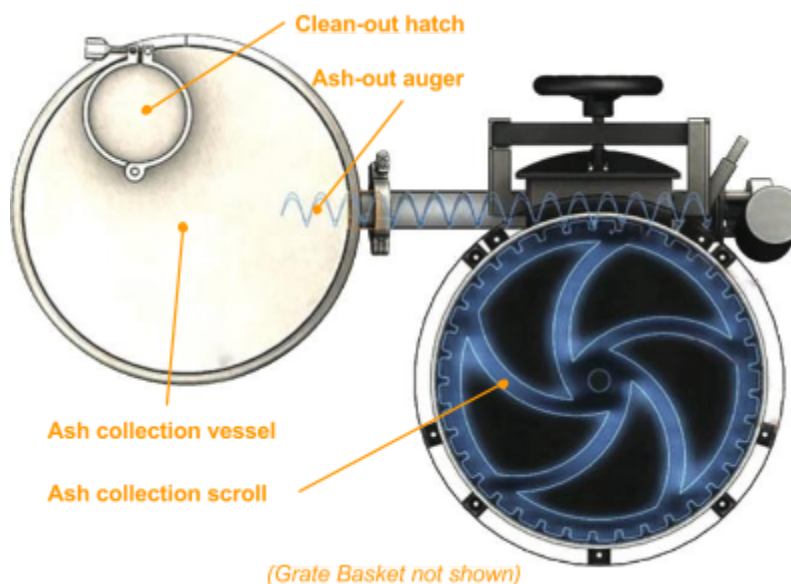
The water vapor and carbon dioxide produced during combustion react with the hot charcoal in the reduction zone. The reduction zone begins under the constriction and extends throughout all the charcoal in the grate basket. Due to the high reactivity of carbon above temperatures of 600°C, carbon dioxide and water vapor are *reduced* (having an oxygen atom removed) to H₂, CO, and some CH₄, which are clean burning gaseous fuels. This conversion of the energy-rich solid feedstock into clean-burning flammable wood gas is the ultimate objective of gasification.

Purging char ash

In the course of the reduction reactions, the charcoal pieces are consumed to produce CO gas and shrink and break apart until they pack densely and are rich in ash and minerals, inhibiting the flow of gases through the hearth. These small pieces must be purged to restore gas flow. The Power Pallet's pressure sensors detect this condition, and automatically actuate the *grate shaker* to shake the grate basket until the smallest pieces of char-ash fall onto the bottom of the gas cowling, which is cleared by the *scroll plate*. The purging of these small char pieces restores the flow of gases. The ash collection scroll then pushes the char-ash to the ash-out auger, which pushes it into an external collection vessel that extends off the skid and resides alongside the Power Pallet. The grate basket is the boundary of the flow of gas and the flow of solids in the gasifier; the remaining char-ash solids are conveyed to the ash collection vessel.



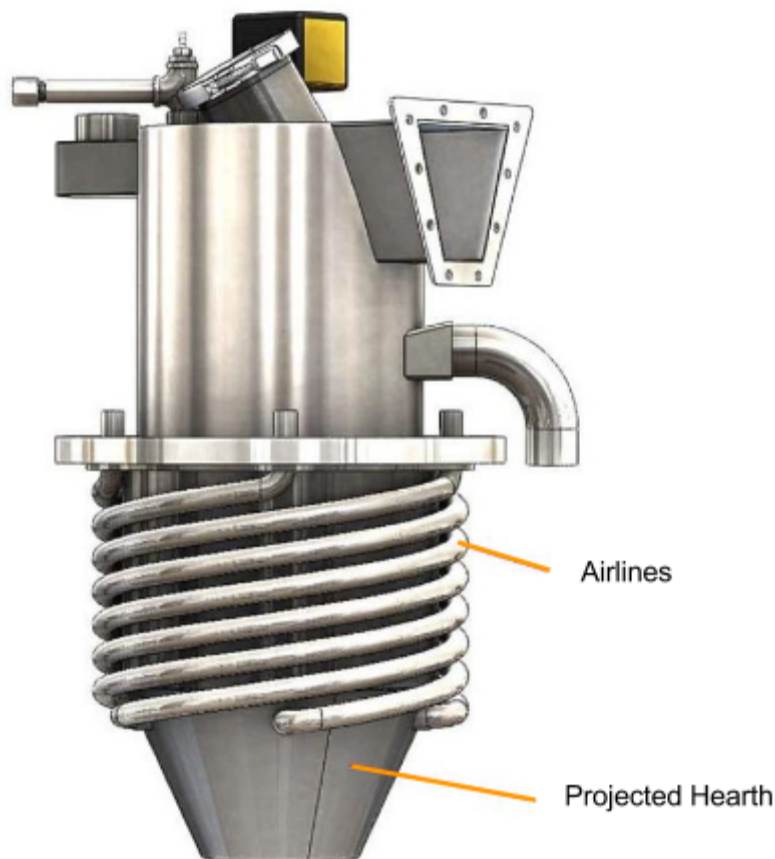
The grate basket holds the charcoal chips, which react into CO gas. The basket is shaken to purge char-ash, which inhibit gas flow as it accumulates. The pieces that shake through the grate are moved to the ash collection vessel by the scroll and the ash-out auger.



Flow of Gases

First stage of waste heat recovery: Preheating intake air

At the end of the reduction reaction, the producer gas is at a very high temperature and contains a lot of recoverable heat. Many historic gasifiers pass the hot producer gas through a radiator to dissipate excessive residual heat into the environment, but the Power Pallet recovers as much of this heat as possible to increase its operating efficiency and the quality of the producer gas. The hot producer gas (700°–800+°C) ascends through a space surrounding the PyroReactor after percolating through the charcoal in the grate basket, exchanging heat with the *air lines*—corrugated tubes through which air flows from its intake to the air nozzles in the combustion zone. (These tubes can be seen in the cross section on the prior page. Also, see the illustration bellow.) This process preheats the intake air flowing towards the combustion zone to about 600°C and cools the producer gas significantly. The preheated air resulting from this process enables the combustion zone to achieve the high temperatures with the least amount of air used for combustion, which minimizes the amount of dilution in the producer gas. The high combustion temperatures achieved by preheating also enhance the efficiency of tar cracking. Together, these two benefits of this design improve the energy density of the producer gas.



A view of the internal parts of the reactor. The air lines that pre-heat intake air using heat recovered from fresh producer gas.

Removing particulates: Cyclonic dust separation

Producer gas entrains charcoal dust and ash as it passes through the reduction zone. This suspended dust must be separated so that it does not foul the parts of the Power Pallet downstream. Particulate removal is achieved by the *cyclone*, in which the gas spins in a descending vortex, causing the suspended dust and ash to separate due to centrifugal force. The producer gas then ascends out of the cyclone through a central passage as the particulates fall into the *cyclone ash can*³.



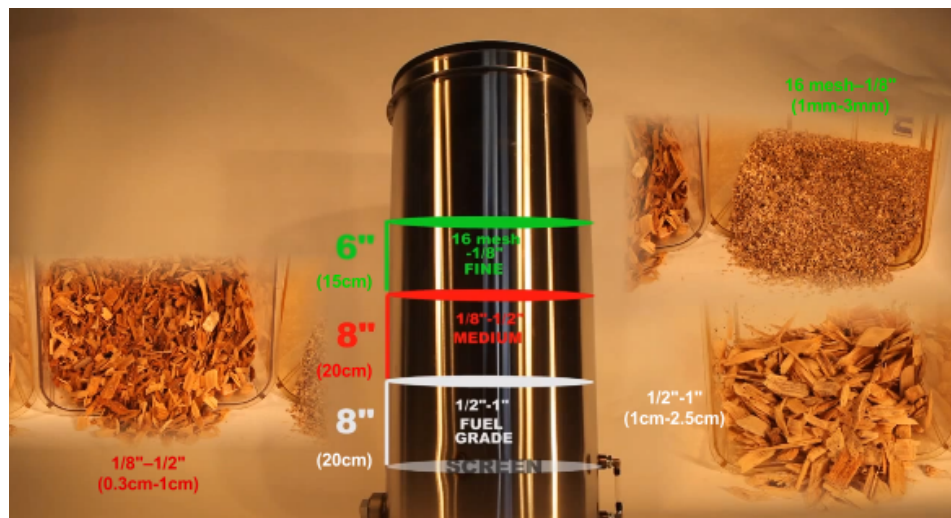
Second stage of waste heat recovery: Drying the feedstock

Despite the heat recycled into the air lines and the heat dissipated in the cyclone, the producer gas retains enough useful heat such that this heat can be recovered by routing the gas into the space between the double walls of the drying bucket. This second heat-exchange process cools the gas sufficiently to be safely filtered, while also enabling the gasifier to tolerate feedstock with a higher moisture content.

Gas filtration

Filtration is the last stage of the flow of producer gas before it is mixed with air in preparation for combustion in the engine. Residual tar gases condense on the filter media (which consists of sifted biomass), protecting the engine from tar build-up. The filter uses wood chips as the filter media. A pair of oiled foam filter discs filter the fine particulates and prevent the filter media from being entrained into the gas stream. When the filter media is being changed, the dirty fuel-grade-sized filter media can be dried and added back into the feedstock at less than 10% for recycling back into the system which minimizes tarry waste streams that are seen in other gasification systems.

³ The cyclone will remove most of the fine particles entrained in the gas stream, but the finest particles (suspended soot) will still remain in suspension.



See section on gas filtration in Chapter 3.

Note: gas temperature at the base of the filter

Because the gas filter uses biomass as filter media, the maximum temperature of the gas entering the filter must not approach pyrolysis temperatures. If the gas temperatures exceed 180° C, the gas is at risk of pyrolyzing the filter media, which indicates that there is probably something wrong with the cooling process in the gas circuit, such as char ash dust fouling the drying bucket and inhibiting heat exchange.

Air mixing

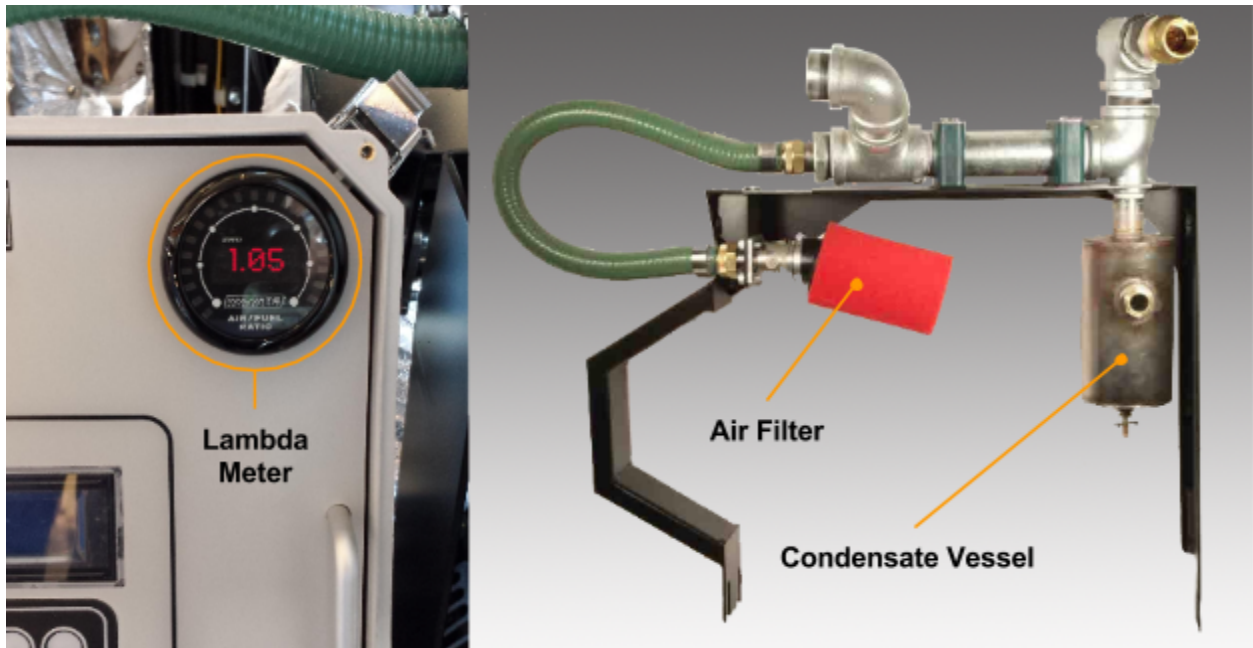
After filtration, the producer gas is mixed with air and fed to the engine for combustion. The intake of air is regulated by an air servo controlled by a PID (proportional integral derivative) loop run from the PCU based on input from the oxygen sensor reading the oxygen concentration in the exhaust. This method of regulation tunes the air/fuel ratio that is optimal for producer gas. The circular meter located on the upper right of the PCU front panel indicates the λ (*lambda*) reading; lambda is the quotient of the detected air:fuel ratio and the stoichiometric air:fuel ratio. The control loop tries to maintain a lambda of 1.05, which we have found to result in the best combination of power and clean emissions.

$$\lambda = \frac{\text{measured air-fuel ratio}}{\text{stoichiometric air-fuel ratio}}$$

$\lambda = 1$ indicates a stoichiometric mixture

$\lambda > 1$ indicates a lean mixture

$\lambda < 1$ indicates a rich mixture



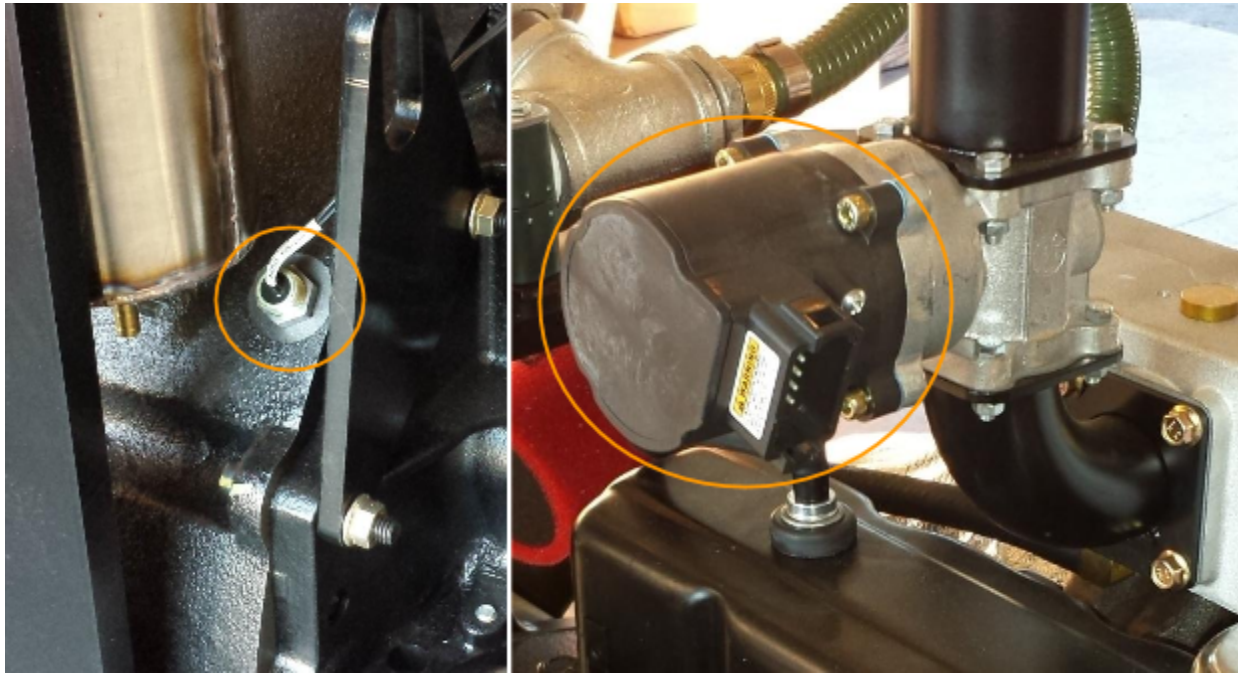
The lambda meter and air mixing sub-assembly are shown above. The air mixer intakes air at the red foam filter, introduces producer gas, and drops out condensate at the condensate vessel. The air and fuel mixture then proceeds to the engine.

Combustion of producer gas in the engine

After mixing with air, the air-fuel mixture is drawn into the engine to be combusted for the production of power. The entry and combustion of the producer gas into the engine is the end of the flow of gases, and the beginning of the flow of exhaust.

Engine output regulated by the MPU

The Power Pallet has a direct connection between the engine's drive shaft and the onboard AC generator. In order for the generator to output electricity with a constant AC frequency, the engine must be held at a specified and constant RPM, while varying the power output to match the load on the generator. The Power Pallet achieves this stable RPM via an engine governor which reads the RPM of the engine with a Magnetic Pick-Up (MPU) that senses the teeth on the outer perimeter of the engine's flywheel. The governor then adjusts the engine's throttle to counter any change in the RPM in response to the load thereby holding the RPM constant. This control programming is resident in the governor and operates independently of the PCU.



The MPU is shown on the left; the engine governor is shown on the right.

Note: unique combustion characteristics of producer gas

Because producer gas burns much more slowly than gasoline and natural gas, the flame front progresses much more slowly. The engine onboard the Power Pallet has its spark timing adjusted to be optimal for producer gas, making it risky if not incompatible for use with gasoline and natural gas. Because the Power Pallet's spark timing is advanced too far to be operated with gasoline, propane or natural gas without risk of engine knocking, ALL Power Labs does not currently support multi-fuel use.

Producer gas has significantly lower energy density compared to petroleum-based fuels; because the gasifier is aspirated with atmospheric air, which is 80% nitrogen (which is non combustible), the resulting producer gas is diluted to a concentration of about 50-60% nitrogen before it is even mixed with air for combustion. Secondly, the combustible molecular species in the producer gas, CO and H₂, have a significantly lower energy density than the combustible molecular species in natural gas (methane and ethane). As a result, the energy density of producer gas is typically about one eighth the energy density of natural gas, and engines using this gas have a de-rated power output compared to their ratings for petroleum-based fuels.

Flow of Exhaust

Third stage of waste heat recovery: Exhaust-heat assisted pyrolysis

The engine's exhaust gases are in the range of 400°-600°C, which is ideal for driving pyrolysis while not being so high as to cause the formation of refractory tars that are difficult to crack. Rather than let this energy go to waste, the Power Pallet routes the exhaust between the double walls of the PyroReactor so that this exhaust heat can be used to pyrolyze the feedstock at the

desired temperatures. It is important to note that the exhaust does not mix with the feedstock; it simply exchanges heat through the inside walls of the PyroReactor. After the exhaust has given up its useful heat, it is released into the atmosphere via the exhaust pipe.

When woody biomass is exposed to lower pyrolytic temperatures (400°–600°C)⁴ for an extended period of time, the resulting pyrolysis produces primary tars, which are more susceptible to thermal cracking, resulting in cleaner gas. The PyroReactor of the v5.0 GEK gasifier used on the Power Pallet has a significantly extended pyrolysis zone, achieving complete pyrolysis in the ideal temperature range, enhancing the energy density and quality of the gas.

Automation

The Power Pallet's automation system has a series of pressure, temperature, current, and oxygen sensors, and other sensors that are monitored by the *Process Control Unit (PCU)*. The PCU runs on the open-source Arduino software platform. The PCU automatically controls the various physical functions required to keep the system running smoothly. These functions include:

- grate shaking, to maintain the flow of feedstock and to purge small char particles from the gasifier bed
- augering the feedstock into the system as needed
- adjusting the air-fuel mixture for the engine to ensure complete combustion of the producer gas, resulting in high efficiencies and clean emissions
- triggering an alarm if any events of concern arise

The PCU also allows for data-logging, additional input/output capability as well as the ability to modify the open-source code for research, development and customizations. This automation system is what makes the GEK gasifier system practical for use with a generator, managing the various parameters which would otherwise need continuous operator intervention. See *Chapter 4: Automation Assembly* for details.

⁴ Based on *Biomass Gasifier "Tars": Their Nature, Formation, and Conversion* by Milne, et al. In Figure 2.4, the bulk of primary formation happens around 400-600°C.

Exhibit A: Identifying Power Pallet components (Front view)



1. Feedstock Hopper
2. Flare
3. Exhaust stack
4. Gas valves to flare and engine
5. Ash collection vessel—
This vessel has enough capacity to handle 12-24 hours of runtime.
6. Gas Filter (packed bed filter)
7. PCU (Process Control Unit) user interface
8. Operation Panel
9. Grid-tie control box (only available on Grid Tie models)
10. Electrical configuration box
11. Generator

Exhibit B: Identifying Power Pallet components (Reactor side view)



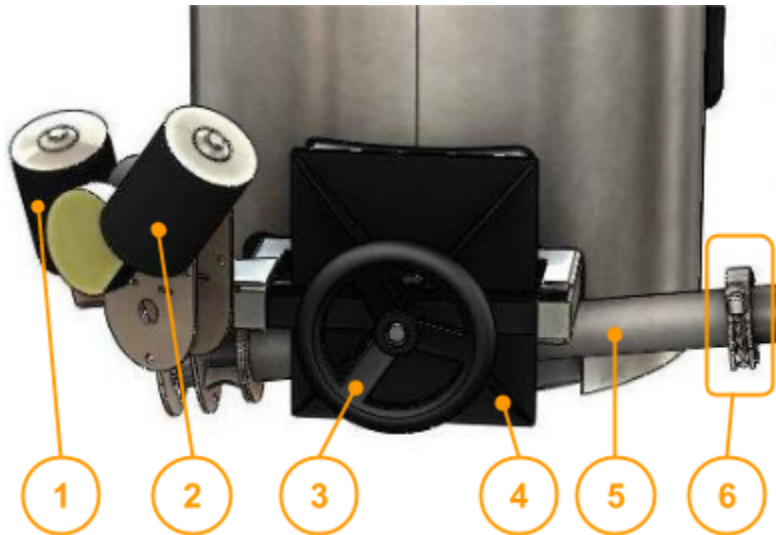
1. Drying bucket
2. Gas filter lid locking lever
3. PyroReactor view port
4. Gasifier—Includes
PyroReactor and gas cowling.
5. Air inlet check valve
6. Cyclone and cyclone ash can
7. Gas filter drain bung

Exhibit C: Identifying Power Pallet components (Engine corner view)

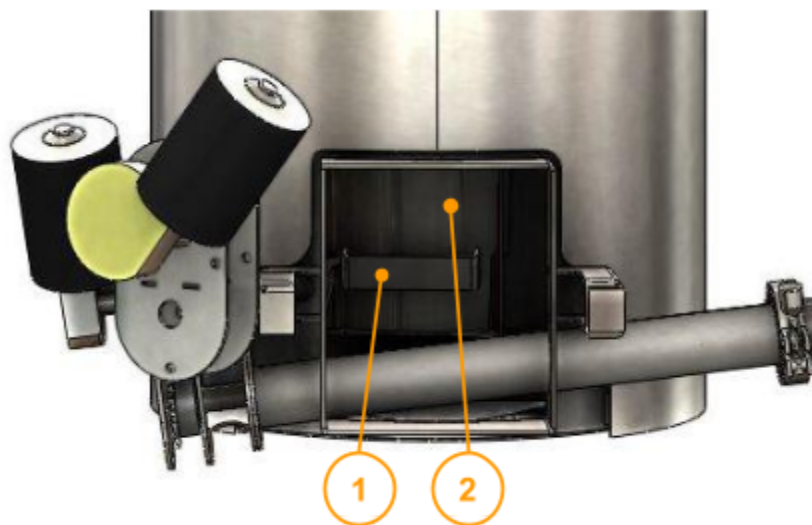


1. Flare Igniter
2. Blowers
(Double blowers blow gas to the flare during startup; single blower blows air)
3. Central wiring conduit
4. Engine governor
5. Back-pressure relief valve
6. Condensate vessel
7. Engine oil filter
8. Grate basket shaker motor
9. Reactor access door

Exhibit D: Identifying Power Pallet Components (Detailed Views)

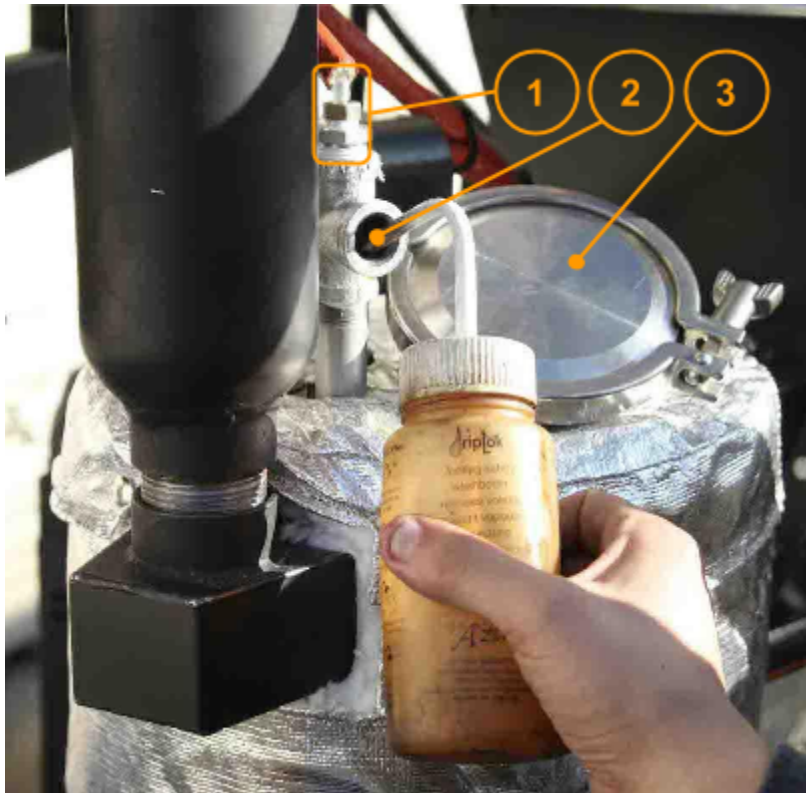


1. Ash Removal System Motor (Ash-out Auger Motor)
2. Grate Shaker Motor
3. Reactor Access Door Hand Wheel
4. Reactor Access Door
5. Ash Auger Pipe
6. Sanitary Clamp



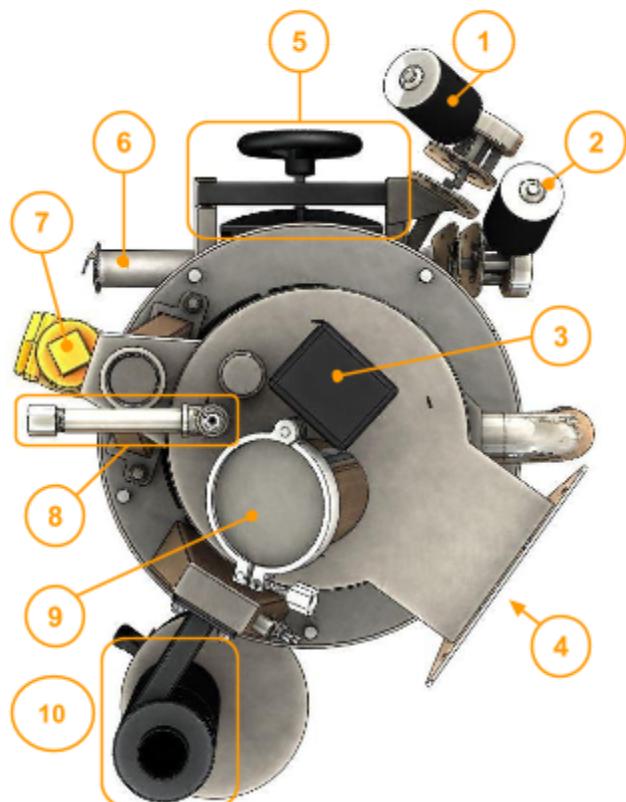
1. Ash Grate Door Handle
2. Ash Grate Door Panel

Identifying Power Pallet components (continued)



1. Pcomb pressure tube barb
2. Ignition port
(ignition fluid may be added as shown to assist in starting the reactor)
3. PyroReactor viewport
(may be opened to break fuel jams in the reactor)

Top View of Gasifier (Insulation not shown)

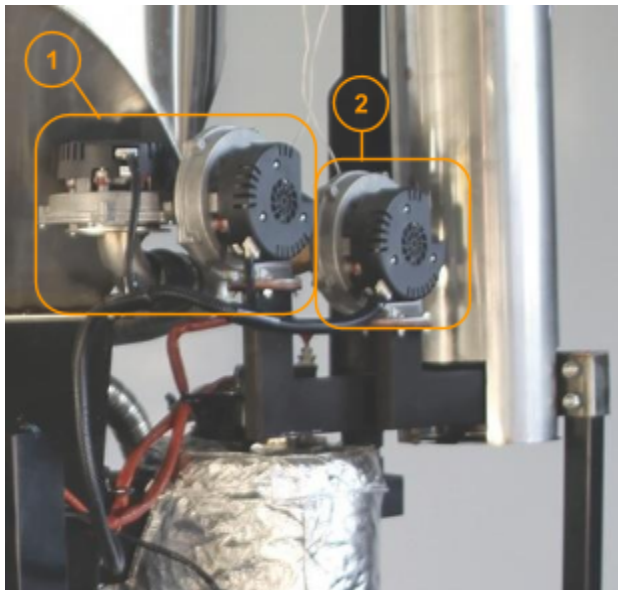


1. Grate shaker motor
2. Ash-out auger motor
3. Fuel switch—
turns off the feedstock auger when the PyroReactor is full.
4. Feedstock inlet from drying bucket
5. Reactor access door
6. Ash-out auger tube—
connects with ash collection vessel
7. Air inlet check valve
8. Ignition port (shown with extension tube)
9. PyroReactor viewport
10. Cyclone



Oxygen Sensor

The oxygen sensor reads the oxygen concentration in the engine exhaust as it is fed into the PyroReactor for heat recovery. The oxygen concentration reading is then used to calculate λ , a parameter that indicates how the air-fuel ratio compares to the stoichiometric ratio. This is used to regulate the air mixing subsystem to ensure clean exhaust.



1. Gas blowers—
Two blowers mounted in a series to provide strong enough suction to draw the gas through the entire gasifier and the filter during startup. The gas is blown into the flare for combustion.
2. Air blower—
Provides enough air to the flare for complete combustion of tar gases produced during startup. The air blower is necessary to maintain clean emissions during flaring.

Exhibit E: Identifying Power Pallet components (Control Panel)

The following is the interface to the automation system of the Power Pallet. Please see Chapter 4 for more information on the automation system.



1. Engine Hour meter (not used on Grid-Tie models)
2. Lambda meter (displays the output of oxygen sensor)
3. PCU display and input buttons
4. Main power switch
5. Engine key switch (not present on Grid-tie models)
6. Gas blower control knob
7. Air blower control knob
8. USB connection port for the PCU (A-type)
9. Warning alarm buzzer