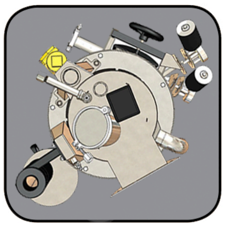
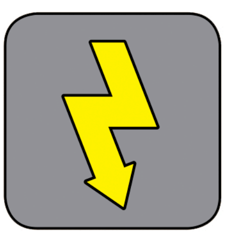
ALL POWER LABS

Power Pallet Technician's Handbook





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ALL Power Labs
personal scale power

Section 1
Introduction to the Power Pallet

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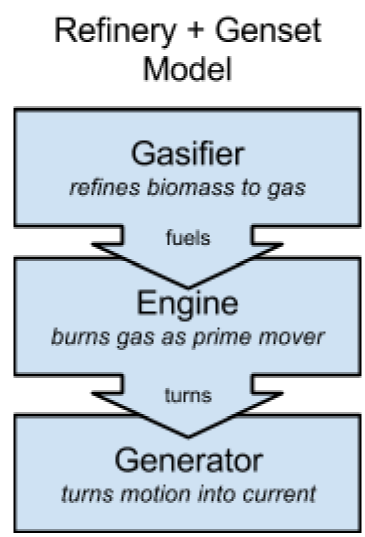
1. Overview

1.1 Conceptual overview



The Power Pallet system is comprised of the GEK TOTTI series gasifier integrated with automation system and an engine coupled to a generator. The purpose of the gasifier is to refine biomass feedstocks into a clean-burning gaseous fuel (producer gas) 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% H_2 and 20% CO, which are both gaseous fuels that the internal combustion engine burns to generate power.

1.2 Sequence of Processes

The major processes of gasification are as follows:

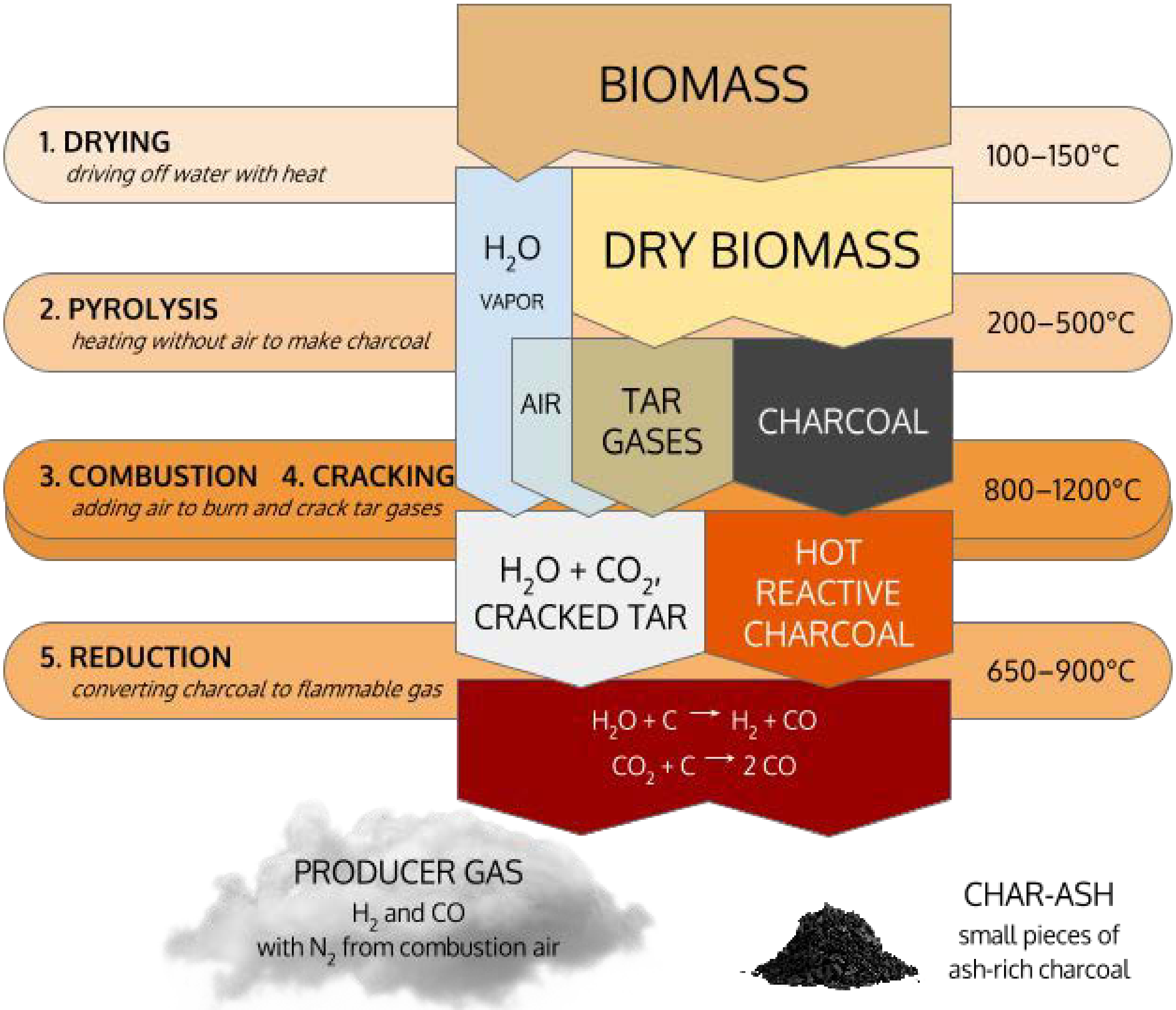
- ***Drying*** — removal of moisture from the feedstock
- ***Pyrolysis*** — thermal breakdown the feedstock into tar gases and charcoal
- ***Combustion and tar cracking*** — burning of charcoal and tar gases to provide heat for the rest of the processes and the thermal cracking of a portion of the tar gases into CO and H_2 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.

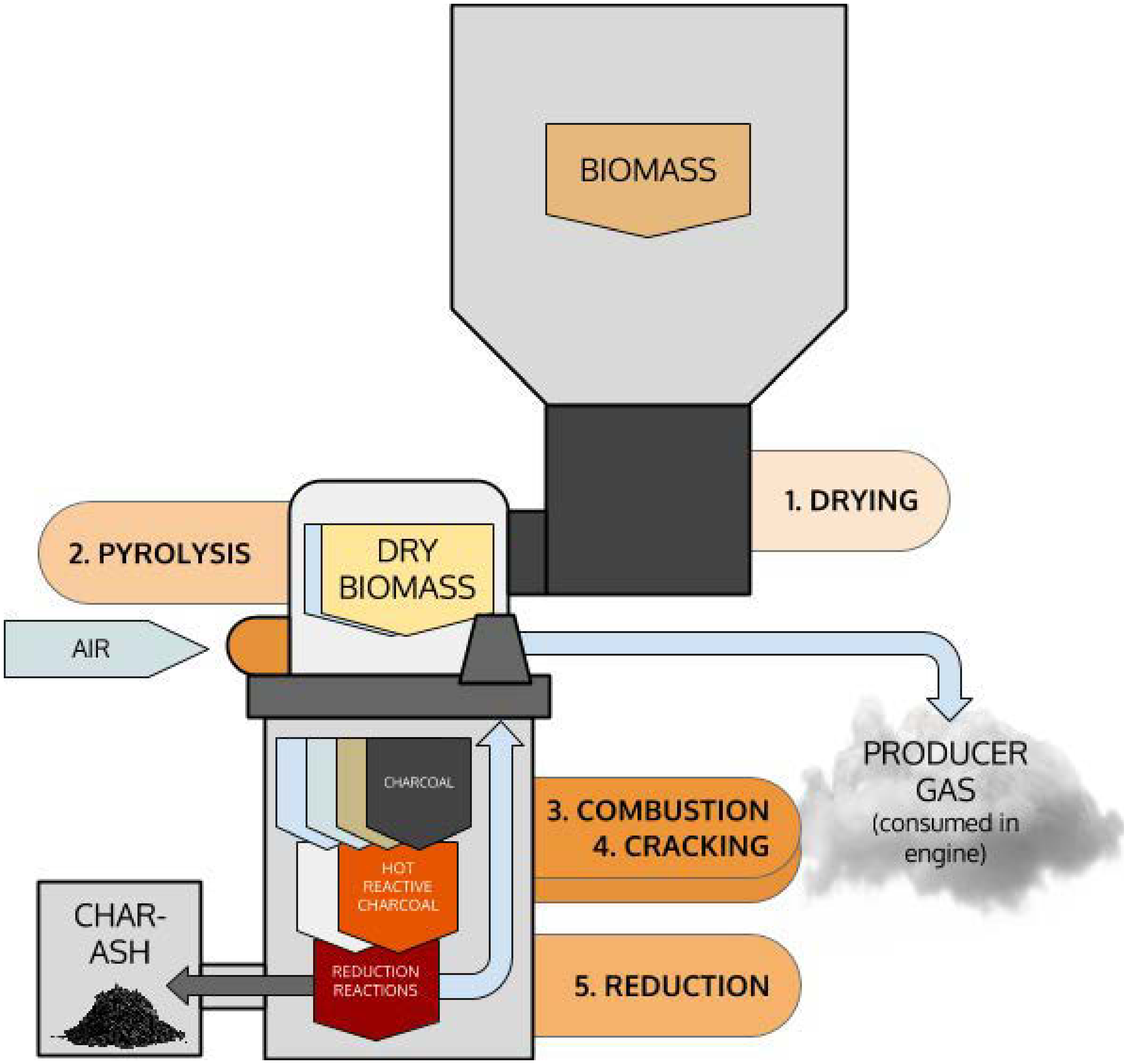
Graphic A: The Five Processes of Gasification



The processes of gasification converts biomass into a clean burning gas which can fuel an internal combustion engine. Gasification involves subjecting biomass to the processes of drying, pyrolysis, combustion, cracking, and reduction. Tar cracking breaks down tar gases into carbon monoxide, hydrogen, and other light gases by exposure to high temperatures, and reduction converts charcoal into carbon monoxide and hydrogen by percolating the carbon dioxide and water vapor produced during combustion through hot charcoal. The resulting combustible mixture of combustible gases and atmospheric nitrogen is known as producer gas.

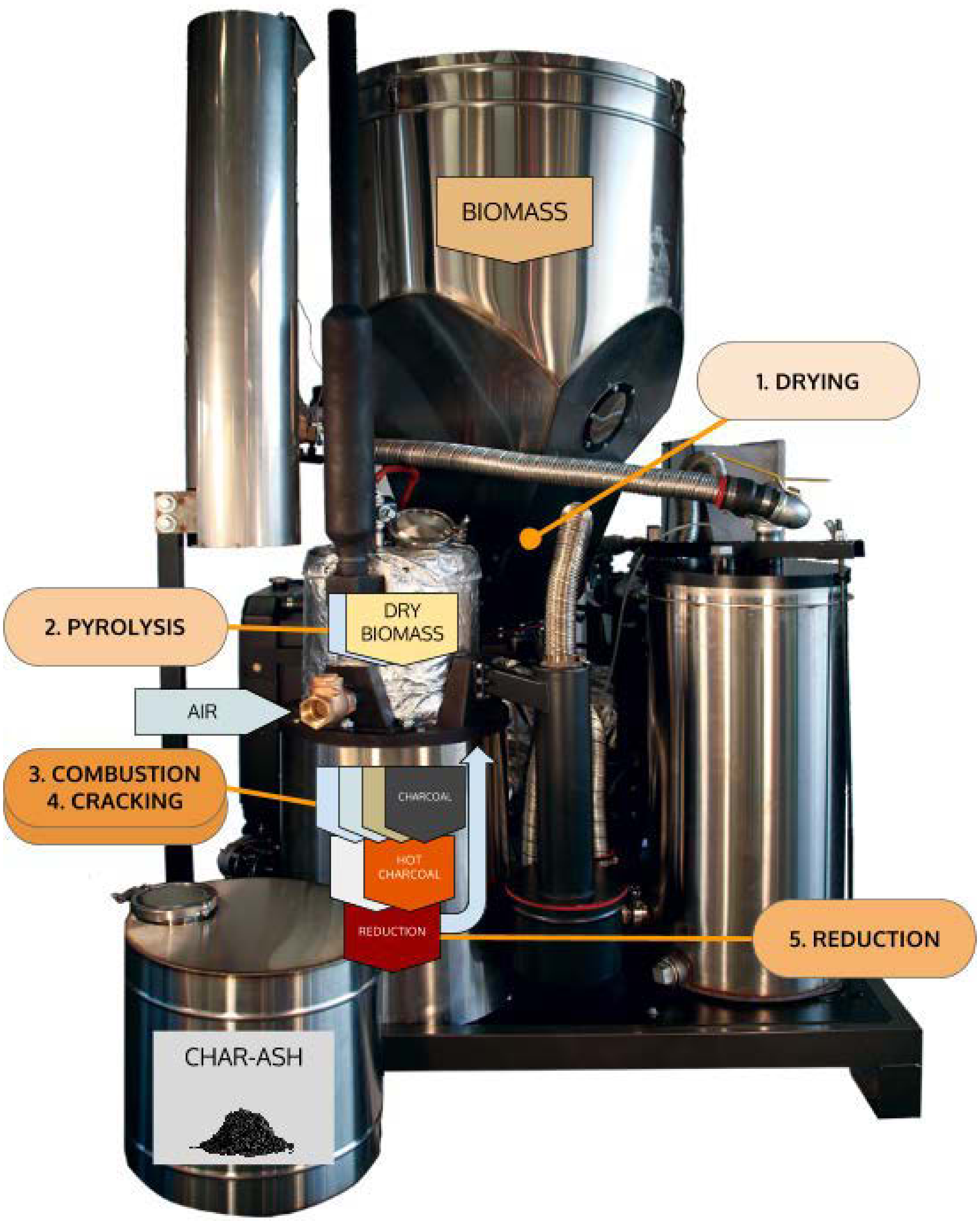
Graphic B: The Five Processes and the GEK TOTTI

Schematic of the GEK TOTTI gasifier system



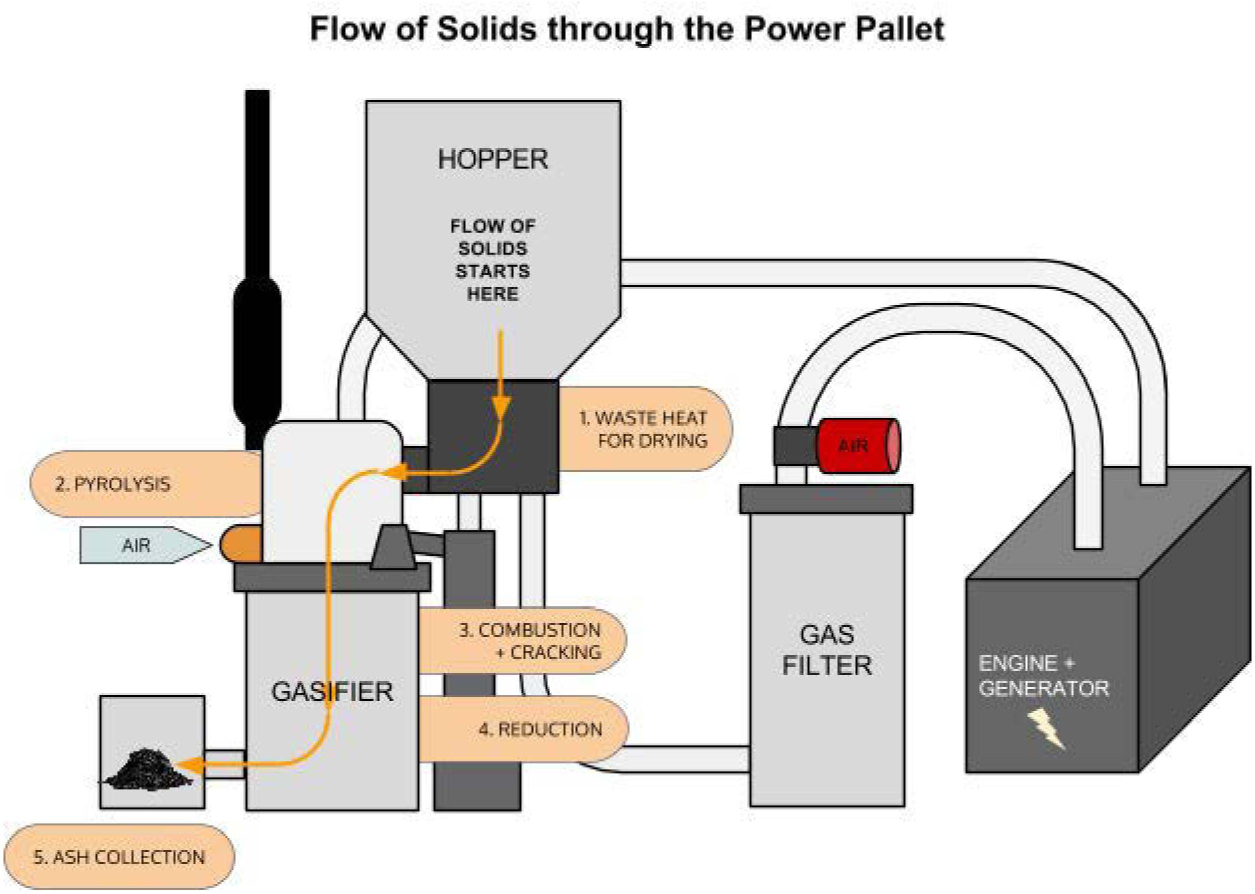
Graphic C:
The Five Processes and the GEK TOTTI–photo overlay

Overlay of the processes on a photo of the GEK TOTTI system



2. 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.



2.1 Drying

$$\textit{biomass}_{wet} + \textit{heat} \rightarrow \textit{biomass}_{dry} + H_2O\ (g)$$

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%.

2.2 Pyrolysis

$$\textit{biomass}_{dry} + \textit{heat} \rightarrow C_{charcoal} + \textit{tar gases}$$

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 Section 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.

2.3 Combustion and tar cracking

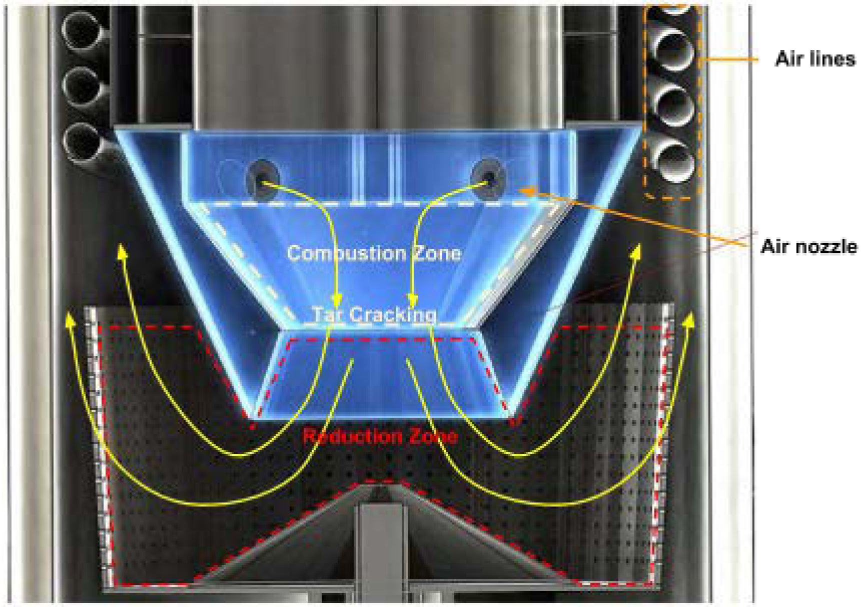
$$C_{charcoal}, \textit{tar gases} + O_2 \rightarrow CO_2\ (g) + H_2O\ (g) + \textit{heat}$$

$$\textit{tar gases} + \textit{heat} \rightarrow CO + H_2$$

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 H_2 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 H_2 are produced from the charcoal and tars. Producer gas diffuses out the top and throughout the grate basket perimeter.

2.4 Reduction

$$CO_2 + C_{charcoal} + \textit{heat} \rightarrow 2\ CO$$

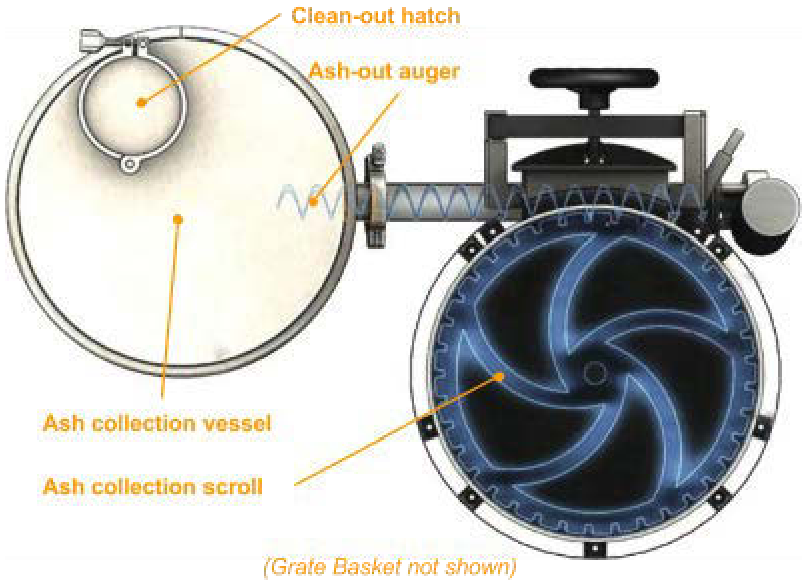
$$H_2O + C_{charcoal} + \text{heat} \rightarrow CO + H_2$$

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 H_2, CO, and some CH_4, 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.

2.5 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.

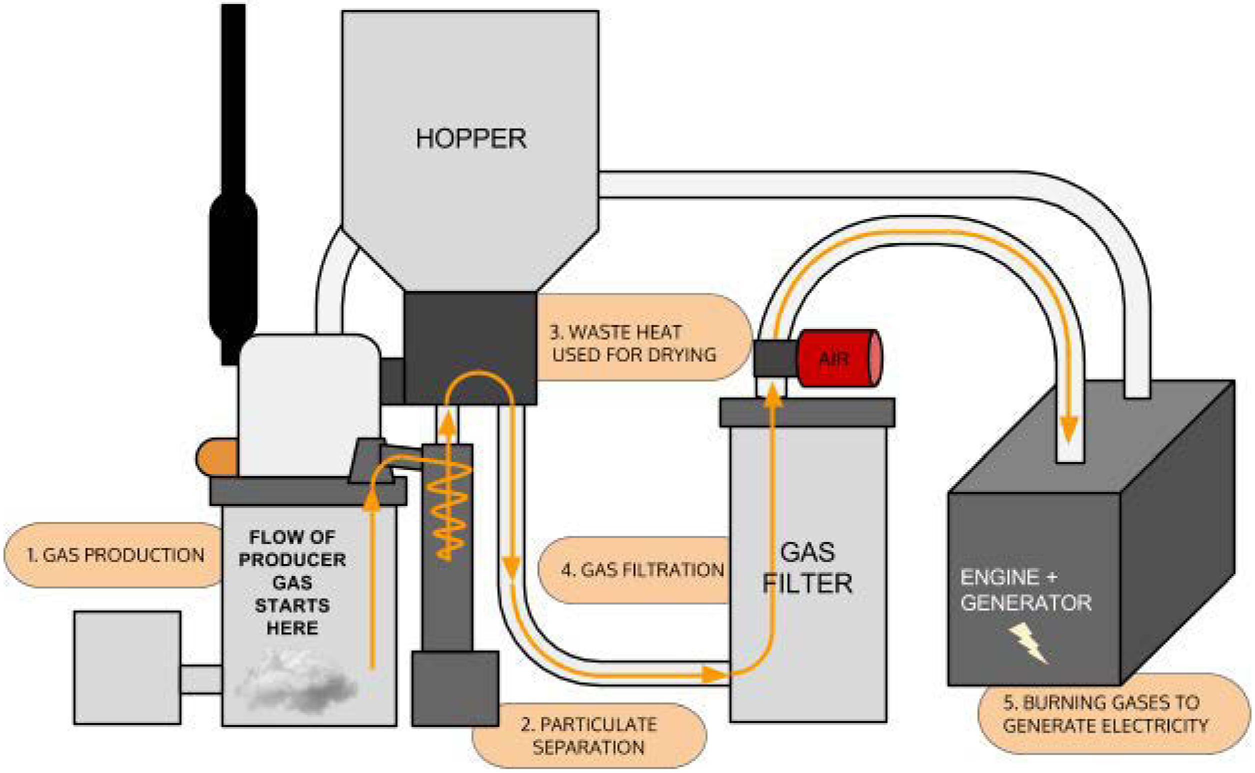


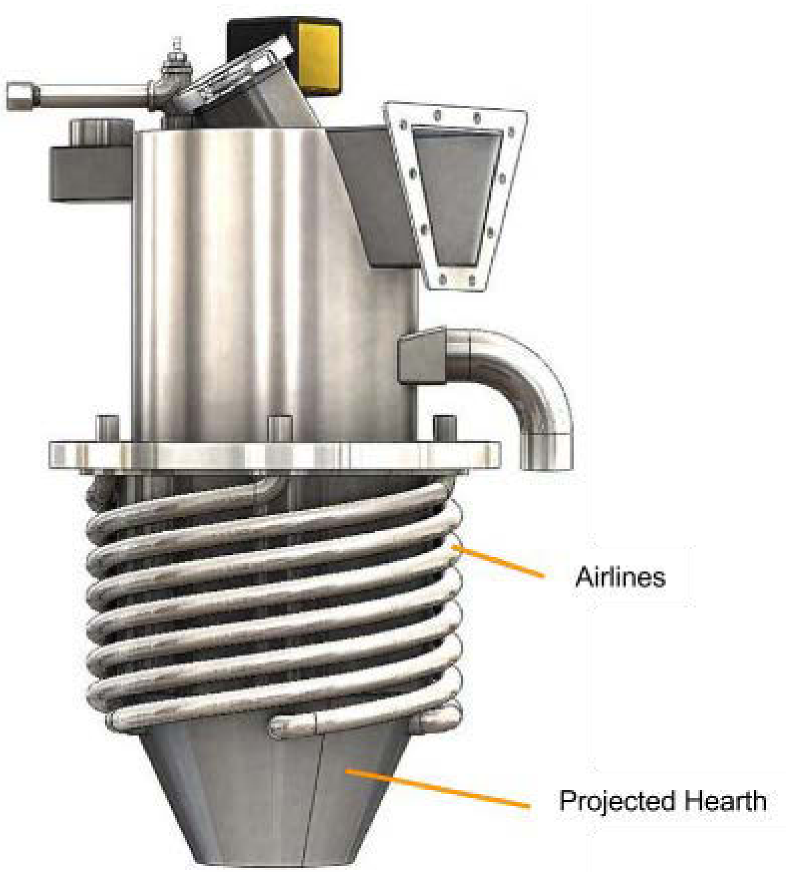
3. Flow of Gases

3.1 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.

Flow of Producer Gas through the Power Pallet





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

3.2 Removing particulates: Cyclonic dust separation

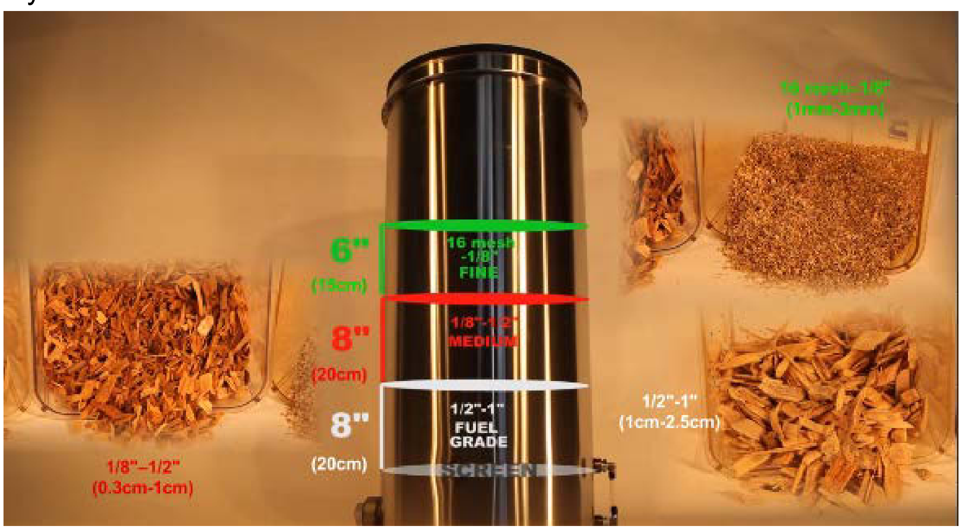
Producer gas entrains charcoal dust and ash as it passes through the reduction zone. This suspended dust must be separated so that it does not foul the parts of the Power Pallet downstream. Particulate removal is achieved by the *cyclone*, in which the gas spins in a descending vortex, causing the suspended 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*.

3.3 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.

3.4 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.



See section on gas filtration in Section 3.

Note: gas temperature at the base of the filter

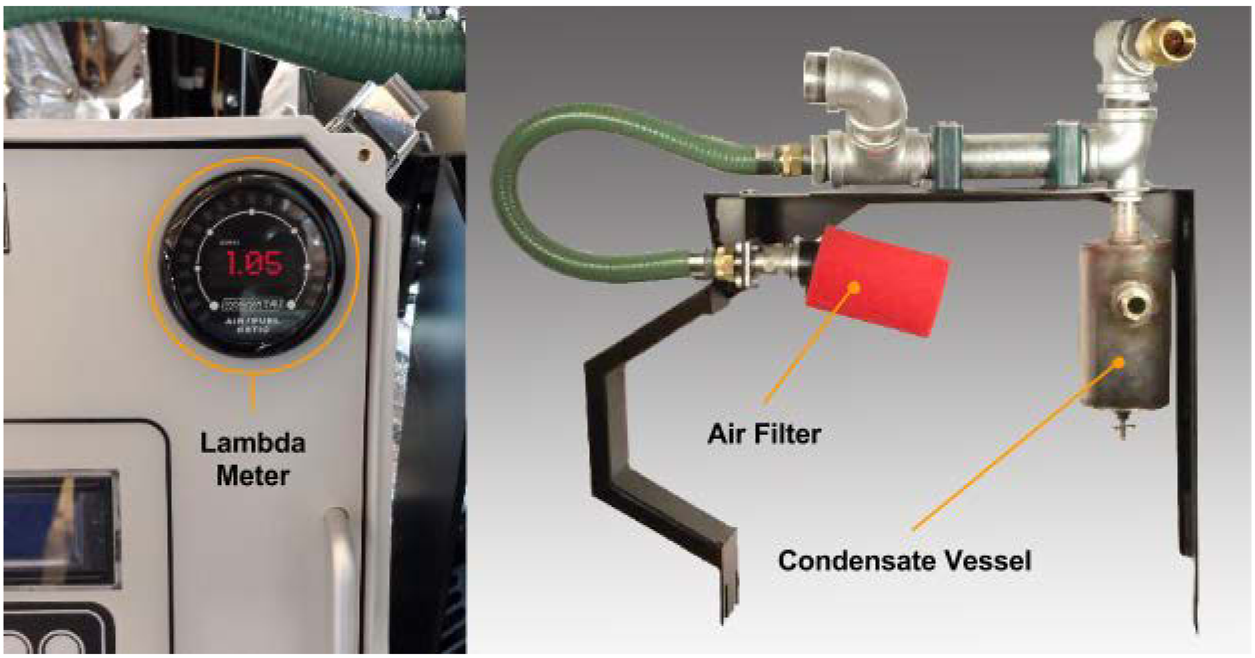
Because the gas filter uses biomass as filter media, the maximum temperature of the gas entering the filter must not approach pyrolysis temperatures. If the gas temperatures exceed 180˚ C, the gas is at risk of pyrolyzing the filter media, which indicates that there is probably something wrong with the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

3.5 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.

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

$\lambda = 1$ indicates a stoichiometric mixture
$\lambda > 1$ indicates a lean mixture
$\lambda < 1$ indicates a rich mixture



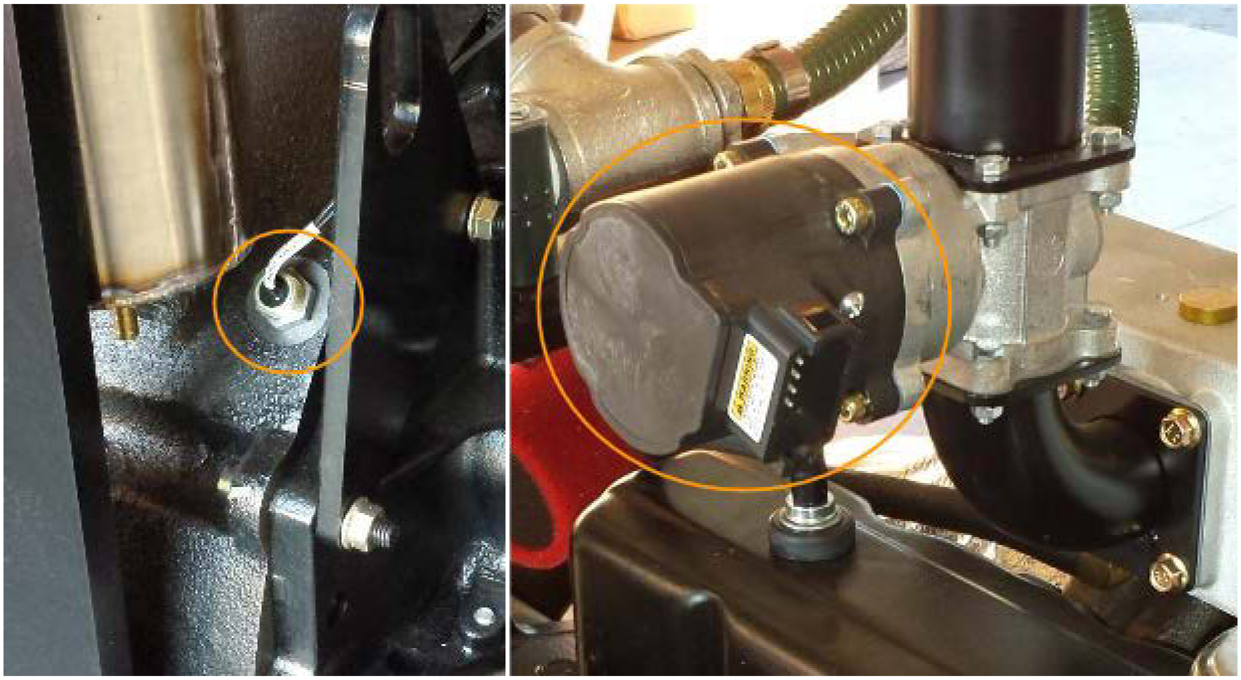
The lambda meter and air mixing sub-assembly are shown above. The air mixer intakes air at the red foam filter, introduces producer gas, and drops out condensate at the condensate vessel. The air and fuel mixture then proceeds to the engine.

3.6 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.

3.6.1 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.

3.6.2 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 H_2, 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.

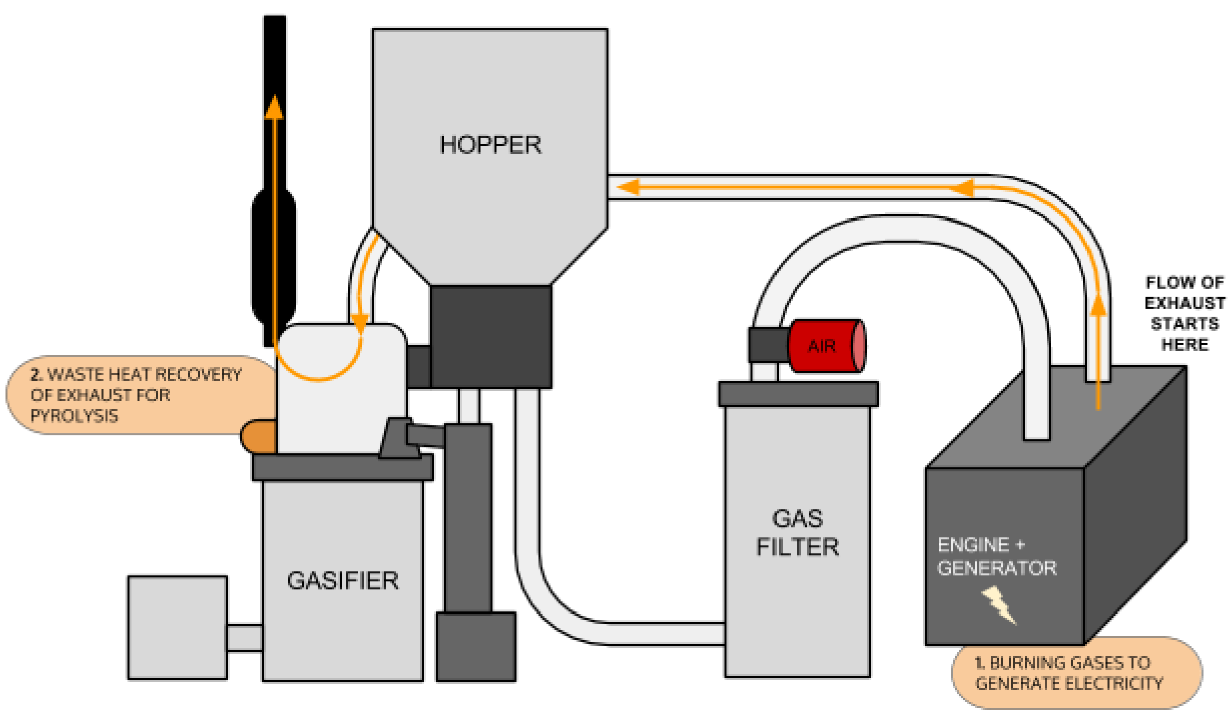
4. Flow of Exhaust

4.1 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) 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.

Flow of Exhaust through the Power Pallet



5. 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 *Section 4: Automation Assembly* for details.

6. Identifying Power Pallet components

Exhibit A: Front view

Label	Description	Label	Description
1	Hopper	**6**	Operation panel
2	Valves to flare and engine	**7**	Generator
3	PCU panel	**8**	Wiring configuration box
4	Ash collection vessel	**9**	Grid tie controler
5	Gas filter		

Exhibit B: reactor side view

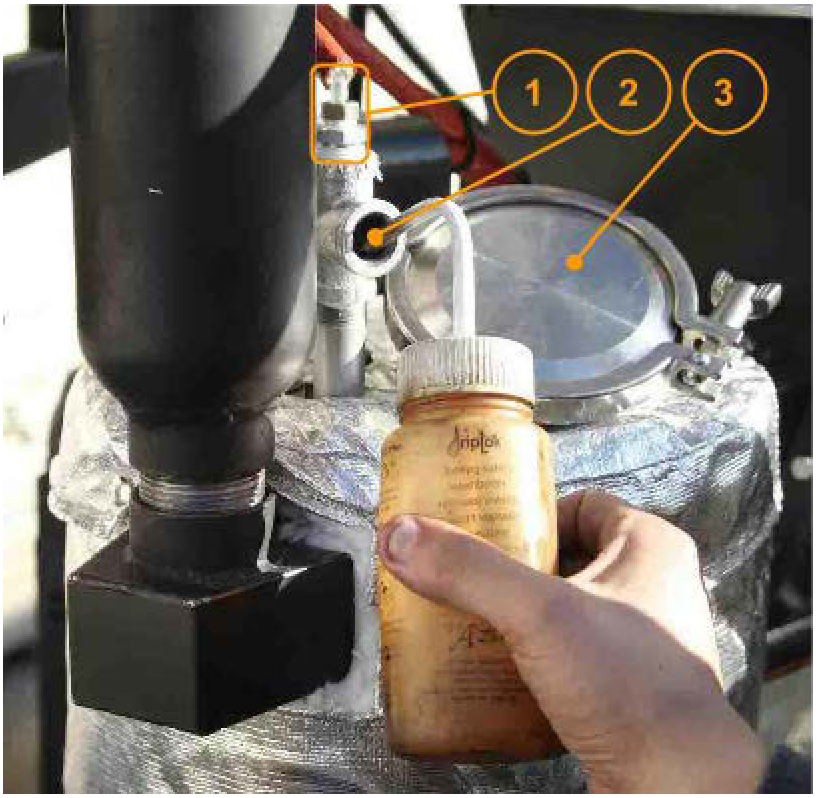
Label	Description	Label	Description
1	Flare	**6**	Cyclone
2	Exhaust stack	**7**	Filter condensate drain bung
3	PyroReactor access port	**8**	Filter lid locking lever
4	Gasifier	**9**	Drying bucket
5	Air inlet check valve		

Exhibit C: Engine corner view

Label	Description	Label	Description
1	Back-pressure relief valve	**6**	Reactor access door and ash system motor
2	Engine governor	**7**	Central wiring conduit
3	Condensate vessel	**8**	Air blower

4	Engine starter	**9**	Gas blowers
5	Oil filter	**10**	Flare igniter

Exhibit D: Detailed Views



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)

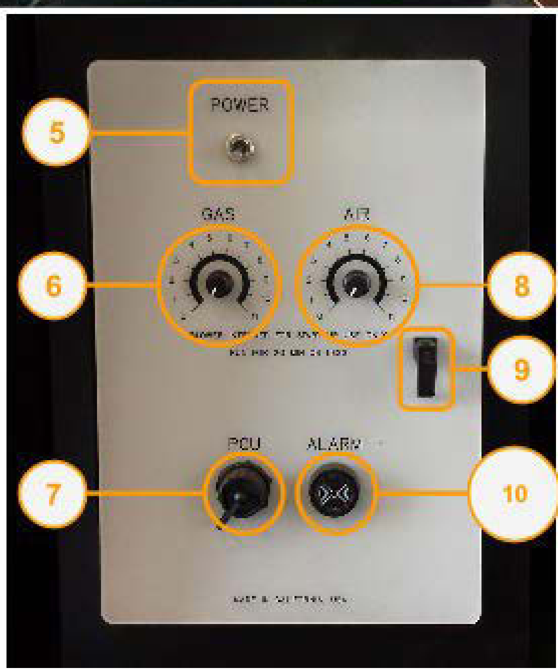
Oxygen Sensor

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 *lambda*, 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.

Exhibit E: PCU and control panel

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

Note: The control panel shown below is for a grid-tied system. The grid-tied systems do not have a keyed engine start.



Label	Description
1	Hour meter
2	Lambda meter
3	PCU display
4	PCU input buttons
5	Power switch
6	Gas blower knob
7	PCU USB port
8	Air blower knob
9	Operation panel door latch
10	Alarm

Section 2
Biomass Feedstock Requirements

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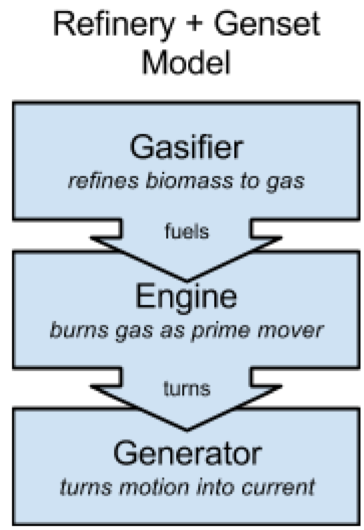
1. Feedstock related terms

1.1 Feedstock, Fuel



The GEK TOTTI Gasifier onboard the Power Pallet is a refinery that takes crude biomass in the hopper and refines it into a clean-burning gaseous fuel for the engine, while producing char-ash as a waste product. In engineering parlance, material fed into a refinery to drive a chemical process would be called *feedstock*, and the refined product going into the engine would be called *fuel*. However, from the perspective of the user of the Power Pallet, the machine is fueled by biomass. Because of this, you may find the terms *feedstock* and *fuel* used interchangeably. For example, the paddle switch on top of the PyroReactor that regulates the feeding of biomass into the PyroReactor is called the *fuel level switch* (see Annotated Figure A in Section 3), but in most of our literature, the biomass is referred to as feedstock.

1.2 Oversized, Undersized, and Fines

In the course of feedstock pre-processing, the operator may need to chip and sift material into various size grades—*oversized*, *undersized*, and *fines*. Each Power Pallet comes with hardware cloth screens for the user to sift their feedstocks with. (See the graphics on p. 14.)

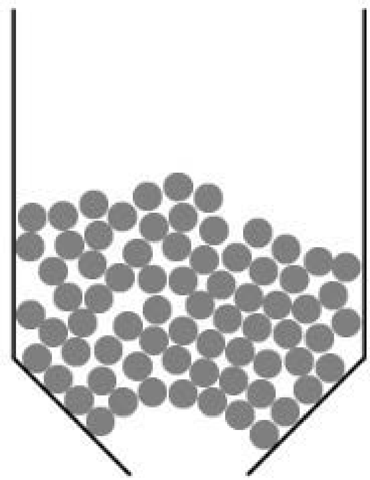
- Oversized feedstock ("*overs*" for short) is material that fails to fall through the 1" mesh
- Undersized feedstock ("*unders*" for short) is material that falls through the ½" mesh, but remains above the ⅛" mesh.
- Fines are all of the remaining material small enough to pass through the ⅛" mesh but too coarse to pass through the window screen mesh.

All material that passes through the window screen mesh is effectively sawdust, and is neither suitable as feedstock nor as gas filter media.

1.3 Fuel Jams: Bridging, Rat-holing, Binding

Many of the difficulties that arise when working with solid feedstocks come from difficulties with bulk material handling. Three of the most common forms of fuel jams are *bridging*, *rat-holing*, and *binding*.

Bridging refers to when the feedstock forms an arch or a dome held together by friction, compression, or entanglement, and does not flow as the material below it is emptied away; surface friction and bad feedstock geometry are the primary culprits behind this phenomenon. Bridging is most likely to happen where the hopper narrows down as the material is wedged together by the walls of the hopper.



An illustrated cross-section example of feedstock bridging.

Rat-holing refers to the problem of feedstock flowing only along a narrow column or tunnel while the material around the tunnel resists flowing due to friction, compression, or entanglement. Rat-holing can sometimes enable flame to back-propagate from the combustion zone through the tunnel in the feedstock all the way into the volume of combustible gases that have mixed with air in the hopper, causing a *puff event.*, Puff events are relieved by the pressure relief valve on the hopper.

An exampe of rat-holing in feedstock.

Binding refers to the problem of feedstocks forming compression resistant piles or stacks rather than freely flowing or falling when pushed by the auger or by the weight of material above it. When such a formation occurs, transport of the feedstock from the hopper to the reactor halts.

Any of the above problems may require operator intervention to resolve; if severe, these may even disqualify a feedstock as impractical for gasification.

2. Feedstock Qualifications

The GEK TOTTI gasifier system is a fuel refinery that takes cellulosic biomass as its crude fuel input and refines it into clean burning producer gas for an internal combustion engine. In order to facilitate this process, the feedstock must be both **physically compatible** with the auger and the gasifier to minimize the risk of fuel jams and bridging, as well as **chemically compatible**, to facilitate the necessary chemical reactions and to minimize the risk of fouling by clinkers and mineral deposits from the ash.

At the present time, the GEK TOTTI gasifier system is only known to be compatible with feedstocks composed of pieces of *lignocellulosic biomass*—in layman's terms, dry woody biomass such as wood chips, nut shells, and canes and prunings of similar composition.

2.1 Physical compatibility

The physical compatibility of a feedstock is determined by the following qualifications:

2.1.1 Upper size limit

The feedstock should not have pieces with a maximum dimension larger than 1.5 inches (about 4 cm). Feedstock with sizes exceeding these limits are at risk of jamming the auger or may fail to engage the auger at all, since the flights of the auger are about 1.5 inches apart. Long pieces also tend to have difficulty flowing and are prone to bridging.

2.1.2 Lower size limit

The lower size limit that the operator should use during sifting is ½" (about 1.25 cm). No more than 10% of the feedstock should be smaller than ½"; Feedstock with an excess of small particles is at risk of imparting too much gas flow resistance to support the rate of reaction needed to sustain an engine. Undersized and fine pieces also increase the risk of bridging in the hopper.

2.1.3 Correct shape

Due to the great diversity of feedstocks available, and the limited control most users have over processing methods, there is not so much a correct shape as there are incorrect shapes that should be avoided. Good shapes have sufficient surface area to support reduction reactions as well as enough voidspace in the bulk material to support a high rate of gas percolation. (Void spaces are discussed in detail later on.) The feedstock must ***not*** have shapes that are conducive to stacking or tangling. For example, cubic and domino shaped pieces are not compatible even if they are of the right size because these shapes tend to cause binding and cause severe jams in the drying bucket and at the interface of the auger and the PyroReactor. Also, long stringy particles must be separated from the feedstock; materials such as corn stover, vines, grain stalks, or leaf matter will entangle the feedstock or even the auger and cause constant fuel jams.

2.1.4 Correct surface texture

The ideal surface texture for feedstock is smooth, such as found on some nut shells and wood chips produced by a chipper with sharp blades. Extremely rough feedstocks are at risk of fuel jams simply because the pieces tend to lock together to form bridges rather than flowing. For example, pinecone pieces and coarse chunks of bark tend to interlock and jam in the hopper. Wood chips are also at risk if they are excessively rough and exhibit a lot of internal friction as a bulk material. It has been observed that wood chips tends to have smoother surfaces if they are chipped while moist rather than chipped when very dry; dry wood tends to splinter and shatter rather than be cut by the blades of a chipper, and the resulting surfaces tend to be rough.

2.1.5 Friability

Friability is the ease with which a solid material breaks into smaller pieces by physical contact. In layman's terms, friability means the ability to crumble. Friable feedstocks are not compatible with the GEK TOTTI gasifier system on the Power Pallet. The physical transportation of the feedstock by the auger may crush friable feedstocks into crumbs, which would likely be smaller than the lower size limit and choke the flow of gases.

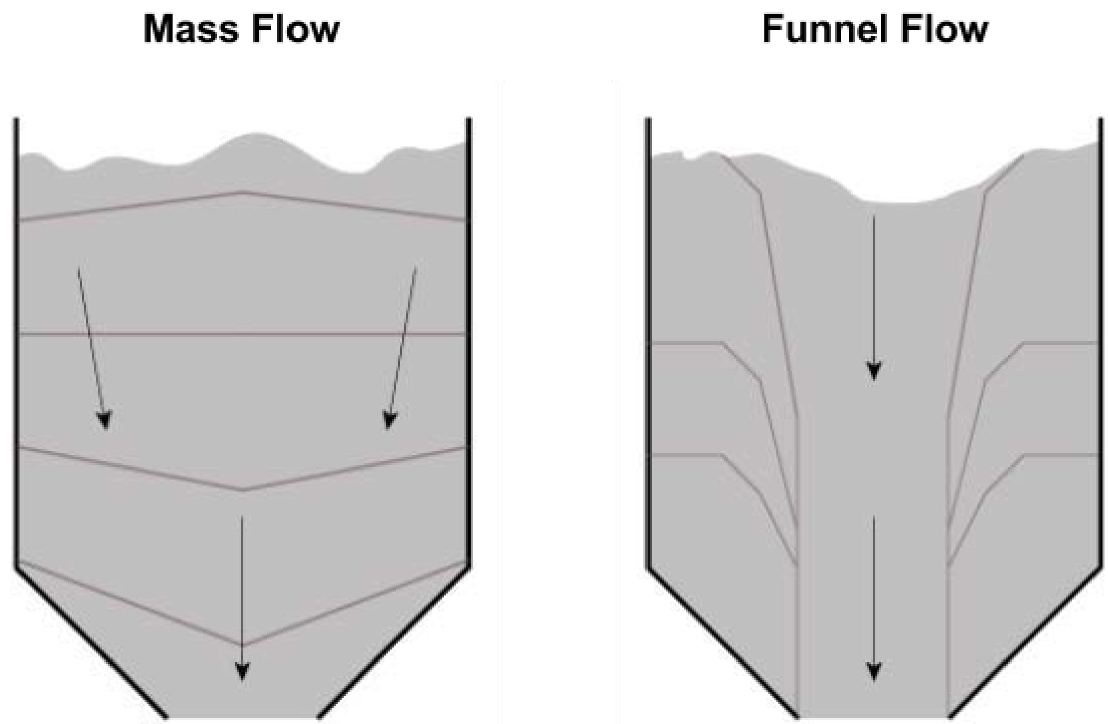
2.1.6 Resistance to Steamed Disintegration

Densified lignocellulosic feedstocks such as pellets and briquettes have a tendency to swell and disintegrate when exposed to high humidity. For this reason, even correctly sized pellets and briquettes can be impractical feedstocks; moisture driven off of the feedstock in the drying stage steams the feedstock in the hopper, and steaming causes pellets and briquettes to disintegrate into sawdust and to swell and compress into a single mass. Pellets or briquettes that disintegrate and swell from humidity in the reactor after shut-down can form a large packed plug of material that is very hard to clean out of the reactor.

With sufficient expertise in managing steam exposure, densified fuels can be used, particularly if the operator manually manages the shut-down process to prevent the build-up of steam in the reactor and hopper. Torrefaction (low temperature pyrolysis in the range of 200˚-350˚C, akin to toasting) of pellets and briquettes may potentially be usable because torrefaction stabilizes densified fuels against steamed disintegration.

2.1.7 Flow Characteristics

The flow characteristics of a feedstock are a function of their shape, size, and texture, and have a major impact on how practical a feedstock will be. The two characterizations of how solid materials flow are *funnel flow* and *mass flow*. Most feedstocks will have flow characteristics somewhere between these two.



Mass flow is preferable to funnel flow; feedstocks that strongly exhibit funnel flow are prone to rat-holing and bridging. ***Both rat-holing and bridging fuel jams leave feedstock deceptively visible through the viewport on the hopper***; if the low fuel alarm is sounding, but the hopper viewport shows feedstock, there is probably a fuel jam of some sort in the hopper.

2.1.8 Angle of repose

The *angle of repose* of the feedstock correlates with the flow characteristic of the feedstock. The angle repose is the angle at which the a large heap of the feedstock will settle to when pulled by nothing but gravity. Even small samples will give you a pretty good sense of the angle of repose of your feedstock. In the following illustration, cylinders of feedstock were inverted onto a flat surface, and gently lifted off, permitting the feedstock to settle into a heap. As you can see, wood chips, which are rough, exhibit a greater angle of repose compared to smooth round macadamia nut shells. The larger the angle of repose, the greater the risk of bridging and rat-holing.

A comparison of the angle of repose of wood chips and of macadamia nut shells. The greater angle of repose of the wood chips correlates a greater risk of bridging and rat-holing.

2.1.9 Blending feedstocks to compensate for shape and texture

The texture of a feedstock may be compensated for by blending a rough feedstock with a smooth and easily flowing feedstock. For example, wood chips that are prone to jamming due to texture or shape may benefit from being blended with smoother feedstocks, such as hazelnut or macadamia nut shells. Because there is so much variation in feedstock availability, the optimal blend must be determined by experimentation on a case by case basis.

2.1.10 Void spaces and physical compatibility

The aspect that the size and shape qualifications are trying to control is the *average void-space size* in the feedstock—the average size of the spaces between the pieces of feedstock. Gasification is critically dependent on the following processes which depend on a balance between adequate void space and surface area:

- **Combustion and tar cracking**— combustion of tars happens in the gaseous phase, and can only occur when there are large enough spaces between the pieces of charred feedstock to support the mixing of oxygen and tar gases for combustion, and to prevent the endothermic reduction reactions at the surface of the char from suppressing the high combustion temperatures. With correctly sized feedstock, a portion of the tar gases is combusted, and the remaining tar gases are cracked into H_2 and CO gases by the high temperatures.
- **Gas flow through solids**— the void spaces in the charred feedstock also support gas flow through the char bed. As the combustion products flow through the char bed, reduction reactions convert H_2O and CO_2 into H_2 and CO gases while consuming the char. The feedstock must have enough void space to support a rate of flow through the char bed that matches the gas consumption rate of the engine.

Feedstock that is too fine or that has too large a proportion of fine pieces will inhibit combustion and choke the flow of gas; feedstock that is too coarse may not have enough surface area in contact with the percolating gases to support the surface reactions that yield high energy gas.

2.1.11Feedstock particle size and char-ash byproduct percentage

Fine feedstocks and feedstocks with a higher proportion of fines will produce more char ash per amount of feedstock compared to coarser feedstocks. As the pieces of charcoal shrink, they eventually inhibit gas flow and are eventually purged by the grate shaker to restore the rate of gas flow. Finer feedstocks reach this condition more quickly and more often than coarser feedstocks, and result in a larger proportion of their volume purged.

2.2 Chemical compatibility

Chemical compatibility refers to how well the chemical composition of a feedstock supports the chemical reactions in the gasifier. Poor chemical compatibility will result in weak gas, dirty gas, or excessive clinkers fouling the grate basket of the reactor. The four major aspects of chemical compatibility are:

2.2.1 Fixed carbon content

The fixed carbon content describes how much of the carbon in the feedstock remains as charcoal after pyrolysis. If the feedstock does not have sufficient fixed carbon (generally around 20% or more by weight), it will not form a good charcoal, without which the feedstock will not be able to support the reduction reactions that produce most of the combustible gas.

2.2.2 Volatile content

The rest of the carbon content of lignocellulosic biomass is contained in the volatile chemicals that contain hydrogen, oxygen, and other elements; these volatiles come off of the feedstock during pyrolysis as tar gases (wood smoke) during pyrolysis. The reactor combusts a portion of these gases to provide heat to drive the rest of the reactions, and cracks the rest of these tar gases into CO and H_2 gas by exposing them to temperatures in excess of 800˚C.

2.2.3 Fixed carbon to volatile ratio

Typical biomass volatile to fixed carbon ratios are in the range of 75/25 to 80/20; try to pick feedstocks with comparable ratios for best results. The fixed to volatile carbon ratio influences the temperature at which the reactor operates. The volatile content of biomass contributes to two endothermic processes: pyrolysis, and tar cracking. Feedstocks that are too high in fixed carbon while having insufficient volatile matter tend to burn too hot. For this reason, feedstocks such as coal and pure charcoal are not suitable. Feedstocks that have too large a proportion of volatiles compared to fixed carbon tend to burn too cool to support efficient tar cracking.

2.2.4 Ash content

The ash content of a feedstock consists of minerals that form solid oxides. These mineral oxides do not contribute to the gas production of the feedstock; they are purged along with small pieces of char in the form of black *char-ash* by the shaking of the grate basket, and secondarily through the cyclone, which captures any char dust and ash material that become entrained in the gas stream. If the ash content of a feedstock is in excess of 5%, the feedstock is at risk of forming slag and clinkers, and may fouling the ash handling system. Such feedstocks are not suitable for gasification.

2.2.5 Alkali Index, slagging, and clinker formation

The temperature at which a feedstock's ash fuses into slag and clinkers (ash rocks) is an important factor in determining whether the feedstock is suitable for gasification. The temperatures in front of the air nozzles, where the combustion is most intense, can be as high as 1200˚C; the temperatures in the reduction zone can be in the range of 800˚-1000˚C. If the feedstock ash is at risk of fusing in these temperature ranges, the feedstock may not be suitable.

The *alkali index* has been proposed as another method to help determine how prone biomass is to slagging. Alkali indices above 0.17 kg/GJ clinker and ash fouling is probable, and above 0.34 kg/GJ fouling is virtually certain to occur. This is because sodium and potassium are fluxing agents that decrease the fusion temperatures of other mineral oxides.

Alkali Index is calculated as follows

$$\frac{1{,}000{,}000}{HHV} \times \frac{Ash}{100} \times \frac{K_2O + Na_2O}{100}$$

where:

HHV is fuel High Heating Value [GJ/kg]
Ash is fuel ash [% dry weight]
K_2O is potassium oxide [% ash weight]
Na_2O is sodium oxide [% ash weight]

Feedstock	HHV [MJ/kg]	Alkali Index [kg/GJ]
Hybrid Poplar wood	18.95	0.29
Switchgrass	18.08	0.60
Rice Straw	18.91	1.31
Rice Husks	15.84	0.50
Almond Hulls	18.90	1.74
Sugarcane Bagasse	18.99	0.01
Sunflower Shells	18.64	0.80

Alkali index of example feedstocks

Alkali index is only one of several factors that determine the likelihood of slagging and clinker formation. Silica content is another major indicator of slagging risk. Feedstocks rich in silica, such as rice husks, are too prone to fouling to be usable as feedstocks, even when they are physically compatible.

An example of one of the clinkers that fouled a reactor running a test on almond husks.

The ECN Phyllis2 biomass database is a great resource for finding data on fixed carbon, volatiles, and ash content. Using data from this database, you can usually pre-qualify or disqualify a prospective feedstock based on chemical compatibility.

ECN Phyllis2
https://www.ecn.nl/phyllis2/

3. Feedstock Preparation

3.1 Chipping

When processing feedstock such as tree limbs, logs, and canes, it will be necessary to chip the material. There are three major styles of chippers, two of which operate on the same principle:

- **Disc and drum chippers**— these chippers have a heavy disc or drum with a bladed slot as the cutting device. The cutting device is spun at a high speed, and wood is struck with a great deal of momentum by the blade, which removes a thin layer of chips with each revolution. In models with adjustable blade offsets, the size of the chips can be regulated by adding or removing shims under the blade.
- **Screw auger chippers**— these chippers have a conical bladed auger that rotates with a great deal of torque. The auger pulls the wood against a bearing surface and cuts it into layers it while pulling each layer apart. This kind of chipper does not have an adjustable chip size; the only way to change the chip size is to swap out the bladed auger for another auger designed to produce a different sized chip.

An example of the chipping mechanisms of a disc chipper compared to a screw auger chipper.

Disc and drum chippers are more common and more affordable, but produce a much larger distribution of chip sizes which require sorting, whereas bladed auger chippers produce a very consistent chip size, but are expensive and are only available from a few brands. When determining chip size, adjust blade offsets and auger sizes according to the size recommendations described under the physical compatibility section above.

3.2 Chunking

Feedstocks such as vine canes, thin tree limbs, and saplings may be better processed by chunking rather than chipping. Chunkers have a highly leveraged blade and a depth stop that will cut long canes into chunks. If properly calibrated, chunkers will process raw feedstock into very consistently sized and shaped pieces.

3.3 Pelletizing and Briquetting

Feedstocks that have incompatibly small particle sizes (such as saw dust) can potentially be made usable by being pressed into briquettes or pellets, especially if they are subsequently torrefied. Pellet mills compress the raw feedstock through a plate under extremely high pressure, often resulting in enough heat to fuse the lignin content of wood. Briquetting systems compress the raw feedstock or a feedstock slurry into a mold, often with a binder mixed in; the feedstock material then binds together to form larger pieces.

The biggest risk of pelletizing and briquetting are friability and steam disintegration, which torrefaction may mitigate. These are discussed in the prior section on physical compatibility.

3.4 Sorting

Each Power Pallet ships with several hardware cloth mesh screens on the crate: 1 inch, ½ inch ⅛ inch, and window screen. These meshes are intended for sorting feedstock and filter media. The recommended method for sorting the feedstock using the mesh screens is as follows:

Sifting with the 1” screen to remove over-sized pieces.
Over-sized pieces remain above the screen.

Lean the screen against a wall, and use a large shovel such as a snow shovel, and toss some feedstock on the top of the screen. As the feedstock tumbles down the incline, pieces which are too large to pass through the mesh will remain above, and pieces which are small enough will pass through. The material may need several passes for thorough sorting. If the material needs some agitation to help it along, spread it around with the shovel.

Sifting with the ½" screen to remove undersized pieces and fines. These fall through the screen.

For feedstock, you want to isolate the pieces which are smaller than 1" and larger than ½" for the bulk of your feedstock, and then blend in fines as needed.

3.5 Blending undersized pieces and used filter media with feedstock

The current generation of the GEK TOTTI gasifier (V5) can tolerate up to 10% of its feedstock as undersized pieces and fines. To maximize the utilization of your biomass, you may blend some of the fines back into your feedstock.

The gas filter uses biomass as its filter media in layers, starting with fuel grade biomass at the bottom, medium sized fines smaller than ½" (about 1cm) in the middle, and very small pieces smaller than ⅛" (about 3mm) at the top. (See the filtration section in Section 3.) In the course of filtration, the filter media acts as a condensation surface to remove residual tar from the producer gas. The tar content is still energy rich, and the used filter media should be dried and mixed with the feedstock to recover this energy content.

When blending fines and used filter media into freshly sorted feedstock, please limit these to 10% or less by volume, and make sure the used filter media is adequately dried and evenly blended into the feedstock.

3.6 Recovery of tars from condensate

The condensate liquid that collects in the condensate vessel and in the bottom of the gas filter is rich in tars; this liquid is smelly, and not generally safe to dispose of into streams or soil because of its toxicity, which is akin to the toxicity of cigarette tars. This energy content of these tars can be recovered by disposing of the condensate by pouring or spraying the condensate evenly over feedstock and letting it dry to appropriate levels; the tars will eventually be consumed in the gasifier.

3.7 Drying feedstock to correct moisture levels

The GEK TOTTI gasifier system onboard the Power Pallet operates best with feedstocks that have a moisture content no higher than 30%, and no lower than 10%, as measured on a dry weight basis. The gasifier will tolerate increasing levels of moisture (up to 30%) with increasing load, since higher loads afford the gasifier more waste heat with which to dry feedstock, and higher temperatures in the combustion zone with which to drive reduction reactions which consume water vapor. At moisture levels above 30%, the water vapor within the system interferes with the gasifier’s ability to maintain the temperatures required for producing clean gas. Moisture levels under 10% risk excessively high temperatures at the hearth and the formation of clinkers from the fusion of ash.

To ensure a quick start up of the GEK systems, use feedstock with <15% moisture content in the pyrolysis column and the drying bucket at first, since during the first start the drying bucket and pyrolysis column are cold. When the flare is sustained, the system will be able to take up 25% moisture content. Moisture levels above this will make it difficult to light the gasifier and will burden the system with a higher amount of tar.

The recommended method of drying wood for feedstocks is to chip your wood first, and then dry it by spreading it out on a tarp or on hardware cloth and leave it exposed to the sun. This is because dried wood tends to splinter and form rough pieces when chipped, and rough feedstock tends to cause bridging and fuel jams. Also, drying chipped wood is much faster and more efficient than drying whole wood due to the increased surface area exposed to the air.

3.8 Moisture Testing

To determine the moisture content of your feedstocks, we recommend the following two methods:

3.8.1 Moisture Meter

The Power Pallet user kit comes with a battery powered moisture meter that can detect moisture levels up to 40%. To obtain an estimate of the moisture content of the wood:

1. Pick out a few random samples of feedstock. Be sure to sample from within your pile of feedstock; samples from the surface may be drier than average and may give you misleading test results.
2. Test each piece of feedstock: turn on the moisture meter and stab the two prongs into a single piece of feedstock. The display will give a fairly reliable estimate of the moisture content.
3. Average the moisture levels of each of the pieces you tested.

3.8.2 Microwave Method

This method is recommended for materials that cannot be tested using the moisture meter, such as nut shells.

1. Select a random sample of your biomass.
2. Weigh the sample (m_{wet}) and record.
3. Place the sample in a microwave and microwave for 15-60 seconds.
4. Record the new weight of the sample.
5. Repeat steps 3-4 until measured weights stabilize.
6. Average the last three (stabilized) measurements (m_{dry}).
7. Report the percentage moisture content on a dry basis:
   $100 \cdot (m_{wet} - m_{dry}) / m_{\text{dry}}$

Note: you can also use an oven, but be sure not to burn the sample.

4. Table of Feedstocks

The following table of feedstocks shows the most common feedstocks that are known to work, and what feedstocks are known to be problematic.

4.1 Suitability Key

Dark Green	Known to work with minimal operations and maintenance effort
Green	Known to work with increased operations and maintenance effort
Yellow	Maintenance intensive. Will work with increased operations and maintenance effort, may have increased slagging and other downtime impacts.
Red	Not tested or known to not work.
Dark Red	Known fundamental incompatibilities.

4.2 General Requirements For All Feedstocks

- Particle size: 0.5”–1.5” (1 cm–4 cm)
- Moisture content (% by dry weight): <30%
- Ash content <5%

Feedstock	Notes	Processing
Walnut Shells	Shell halves and large pieces work; finely crushed shells do not.	Sifting, drying.
Coconut Shells	See general requirements. Caution: Large pieces may cause auger binding or bridging.	Crushing, sifting, drying.
Hardwood Chips - Oak, Beech	See general requirements. Caution: Thick chips may cause auger binding.	Chipping, sifting, drying.
Softwood Chips - Douglas Fir, Pine	See general requirements.	Chipping, sifting, drying.
Corn Cobs	Must not contain husks. Caution: Increased chance of slagging.	Needs to be chopped to correct size.

Palm Kernel Shells	Caution: Risk of high temperatures	May work if blended with feedstocks that burn cooler
Wood Pellets	Larger pellets have better void spaces Caution: Pellets crumble due to humidity on shutdown.	
Saw Dust	Caution: Too fine, not physically compatible.	
Manure - Cow, Pig, Chicken, etc	Caution: High slag, low energy density.	
Coffee Grounds	Pellets of grounds prone to disintegration.	
Macadamia Nut Shells	Not enough testing to validate performance; excellent physical compatibility when sifted.	
Bamboo	Processing into chips difficult.	
Grassses - Switchgrass, Miscanthus, etc.	High silica and low bulk density.	
Paper Waste	Not physically compatible in paper form; same risks as pellets when pelletized. High ash content.	
Sugarcane Bagasse	Stringy material - not physically compatible; certain fuel jams.	
Corn stover	High ash content; silica content leads to slag.	
Oil Palm Pressings		
Rice Husk	High silica content leads to slagging.	
Coconut Husk	Not physically compatible	

Municipal Solid Waste / Trash	Slag risk; heavy metals; plastic content not suitable, especially PVC.	
Coal	Burns too hot; processes not designed to handle sulfur and other contaminants.	
Plastics	Melts and fouls auger/reactor; does not have good fixed carbon content. May contain or create toxic compounds	
Tires	Not chemically compatible.	

5. Biomass Consumption Table

The biomass consumption rate of the Power Pallet is approximately 1.2 kg of feedstock per 1 kWh of electrical energy. The actual consumption rate varies with load, moisture and quality of the feedstock.

Adjust the consumption rate according to your experience with the feedstocks that you have access to.

Power [kW]	Estimated feedstock consumption rate [kg/hr]
2	2.4
4	4.8
6	7.2
8	9.6
10	12.0
12	14.4
14	16.8

16	19.2
18	21.6
20	24.0
22	26.4
24	28.8

Section 3
GEK TOTTI Gasifier System

Version 5.x series

Table of Contents

1. Overview

The GEK TOTTI (*Gasifier Experimenter's Kit, Tower of Total Thermal Integration*) is the gasifier system at the heart of the Power Pallet. This document will introduce the major subsystems of the v5.x series GEK TOTTI gasifier in the sequence that starts from the feedstock hopper, proceeding through the drying bucket and reactor, and ends with the gas filter.

1.1 Notes about nomenclature and terms

The following are some terms you may come across in our product literature, videos, and in the course of speaking with our sales and support personnel which should be clarified to preclude confusion.

1.1.1 Feedstock, Fuel

The GEK TOTTI Gasifier onboard the Power Pallet is a refinery that takes crude biomass in the hopper and refines it into a clean-burning gaseous fuel for the engine, while producing char-ash as a waste product. In engineering parlance, material fed into a refinery to drive a chemical process would be called *feedstock*, and the refined product going into the engine would be called *fuel*. However, from the perspective of the user of the Power Pallet, the machine is fueled by biomass. Because of this, you may find the terms *feedstock* and *fuel* used interchangeably. For example, the paddle switch on top of the Pyroreactor that regulates the feeding of biomass into the Pyroreactor is called the *fuel level switch* (see Annotated Figure A), but in most of our literature, the biomass is referred to as feedstock.

1.1.2 Syngas, Wood gas, Producer gas

The terms *syngas* (short for *synthesis gas*), *wood gas*, *town gas* and *producer gas* can be found in various literature on gasification. Each term has a few implications that differentiate it from the others:

- **syngas** (synthesis gas) refers to a gas mixture of CO (carbon monoxide) and H_2 (hydrogen) produced by reduction reactions where carbon is the reducing agent. Syngas is often used as a chemical precursor for the synthesis of other organic chemicals. Because of its use as a precursor for chemical synthesis in industry, this term usually implies a level of purity and concentration not seen in gas produced by air-aspirated biomass gasifiers.

- **wood gas** refers to gas produced by the gasification of wood. Wood gas is also rich in CO and H_2, but may also contain tar gases, and may be diluted with nitrogen gas if the gasifier was aspirated with atmospheric air. However, since the Power Pallet does not necessarily gasify wood, and can be used to gasify various other feedstocks such as palm kernel shells, nut shells, and other biomass, we do not use this term in order to avoid implying the need for wood.
- **producer gas** is a term generic enough to encompass wood gas, syngas, and other produced gasses.

We will be using the term *producer gas* throughout our documentation because it most accurately describes the product from our gasifier.

1.1.3 TOTTI, Pyrocoil, Pyroreactor

The terms *TOTTI*, *Pyrocoil*, and *Pyroreactor* refer to parts of the engine exhaust waste heat recovery system. Some of these terms are legacy terms not relevant to the present machine, but still show up in discussions and literature, and bear clarification.

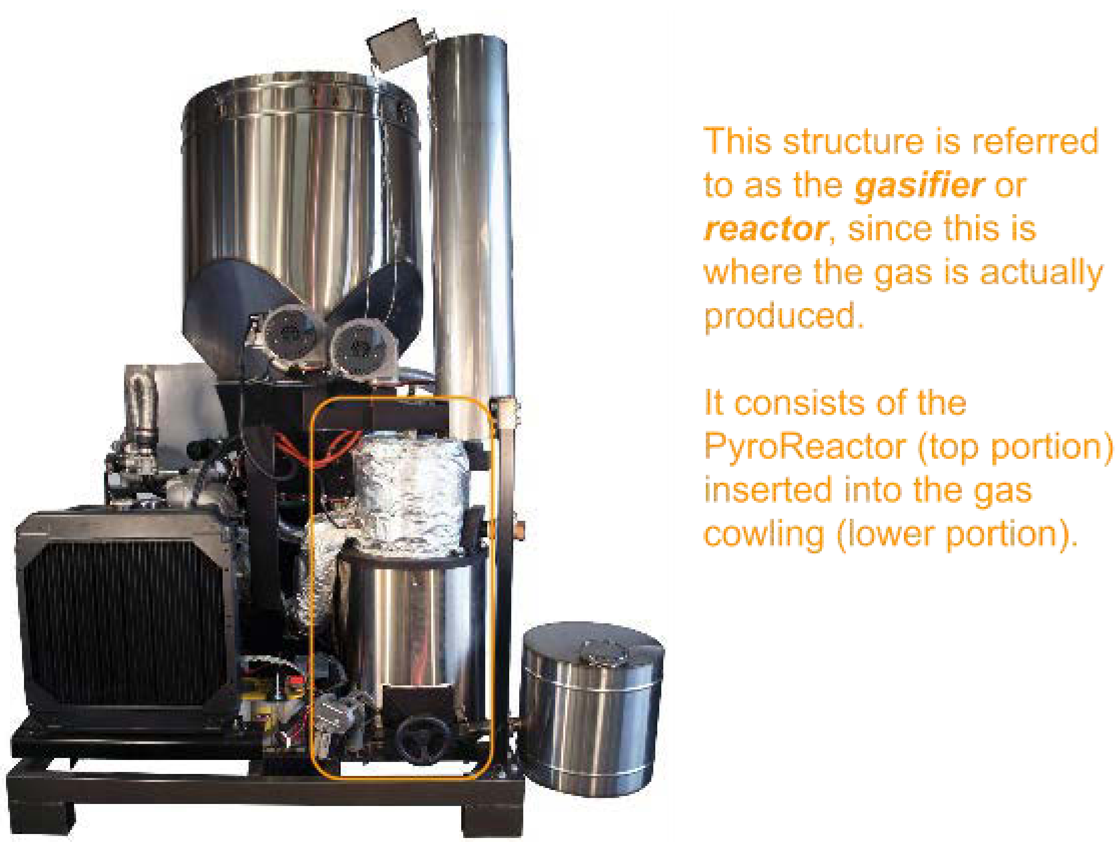
The term TOTTI in GEK TOTTI stands for "*Tower Of Total Thermal Integration*." The original GEK gasifier only incorporated one stage of waste heat recovery— recovering heat from producer gas to preheat incoming air. Later on, an addition to the gas circuit which we deemed the "Hot TOTTI" was developed to recover the heat from engine exhaust for pyrolysis and to enhance feedstock drying with more heat recovered from the producer gas. The combined GEK gasifier with the TOTTI heat recovery system was called the GEK TOTTI.

The TOTTI structure consisted of two major components, both of which recovered waste heat: the *Pyrocoil*, and the *drying bucket*. The Pyrocoil recovered heat from engine exhaust to create conditions for lower pyrolytic temperatures (400˚-600˚) that result in primary tars, which are easier to crack. The drying bucket was a waste-heat-assisted drying vessel which enabled the gasifier to tolerate feedstock with higher moisture content. The Pyrocoil was inserted into the reactor of the GEK, and received feedstock pushed in by the auger at the bottom of the drying bucket via an inlet on its side.

In the current version of the GEK TOTTI, the Pyrocoil has been integrated into the reactor to form a new and improved structure we call the *Pyroreactor*. Because the Pyrocoil is no longer a distinct component, the TOTTI is no longer a distinct part of the gasifier. The name GEK TOTTI is now used as a brand.

1.1.4 Gasifier, Reactor

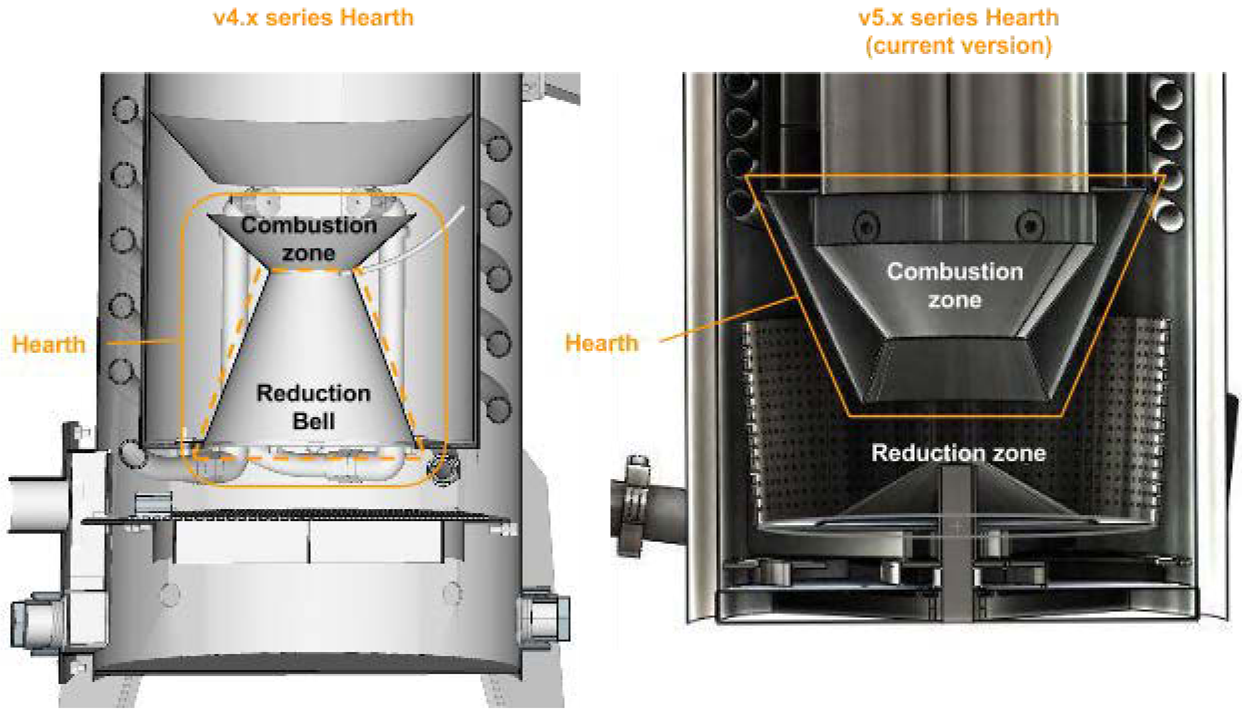
The *reactor* is the component of the gasifier that actually produces gas. When speaking of the structure circled in the image of the Power Pallet below, the terms *gasifier* and *reactor* are sometimes used interchangeably in our literature. In its entirety, the GEK TOTTI gasifier system includes the feedstock hopper, the drying bucket, the Pyroreactor, the gas cowling, the cyclone, the gas filter, and the flare system. The portion circled in the following graphic shows the Pyroreactor installed into the gas cowling; these together form the structure that is referred to as the gasifier or reactor when speaking of components of the Power Pallet.



Behind the gasifier access panel on the PP20-GTE

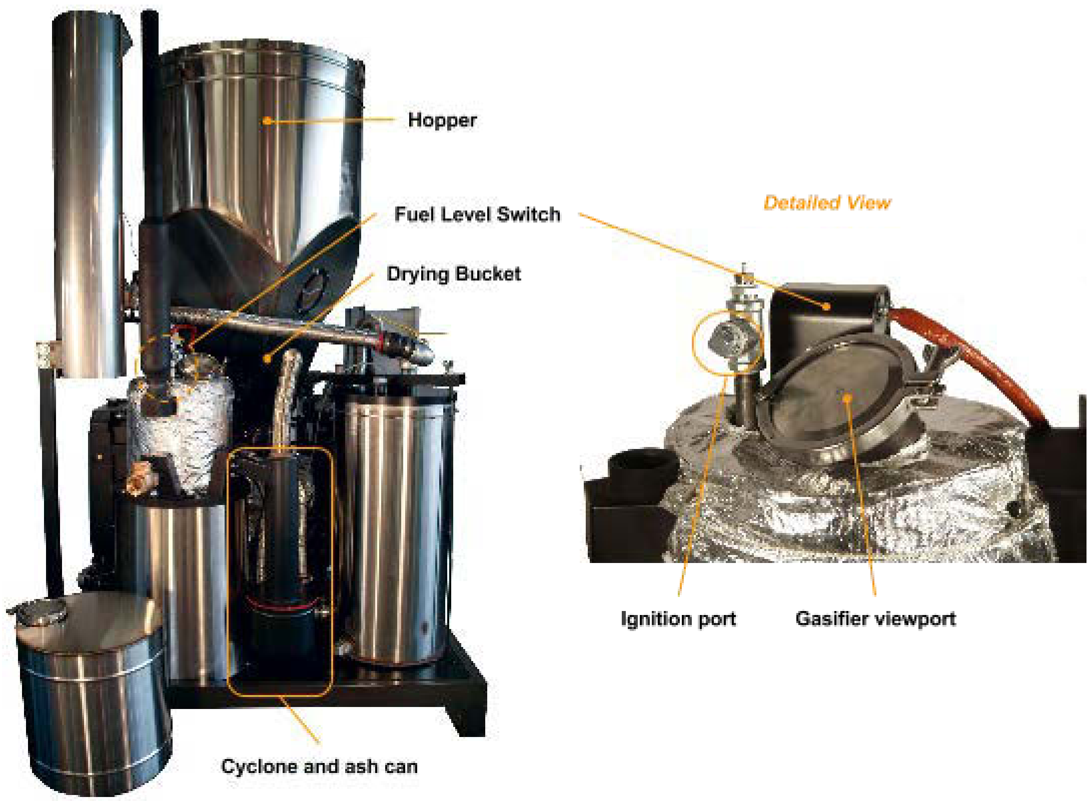
1.1.5 Hearth, Reduction Bell

The term *reduction bell* may appear in our literature or in postings on our online forums. This term is a legacy term and does not apply to the current generation of the GEK TOTTI gasifier. In the original GEK gasifier, reduction reactions were primarily contained in a truncated cone-shaped device called the *reduction bell*. In subsequent revisions of the design, the reduction bell became integrated with another truncated cone that contained the combustion zone. This combined combustion/reduction structure was known as the *hearth*, which was used interchangeably with the term reduction bell. The old hearth is shown below, next to the new hearth. The new hearth carries out reduction throughout the grate basket, and does not have a reduction bell; as such, the term *reduction bell* is now obsolete.



A comparison of the version 4 series hearth and the version 5 series hearth currently in use. The version 5 hearth is a projected hearth which is supported only from above, and does not have a reduction bell; reduction reactions become the dominant process starting under the combustion zone, and continue throughout the grate basket.

2. Feedstock Feed System



2.1 Hopper

The Power Pallet comes with a hopper barrel for holding feedstock. The hopper is attached to the top of the drying bucket with a silicone gasket and bolts. The hopper barrel lid is sealed at the top with a lever lock. A *puff bung* (a pressure relief valve) is threaded in the hopper barrel lid to release the pressure from puff events in the rare case where flame back-propagates and ignites combustible gases that may have diffused back into the hopper.

2.2 Cyclone and Drying Bucket

The producer gas exits the reactor between 250˚-400˚C and enters the *cyclone* for dust removal. The cyclone behaves like those used for dust separation in vacuum cleaners: gases spin in a descending vortex, then ascend through a central tube while the heavier suspended particles separate out by centrifugal force and descend into the cyclone ash can. After the cyclone, the gas flows through a passage between the double walls of the *drying bucket*; this heat exchange stage recovers waste heat to dry the feedstock while simultaneously cooling the producer gas to temperatures suitable for the filter and engine. This specialized drying stage enables the Power Pallet to tolerate feedstocks with moisture contents as high as 30% when powering a high load. The gas does not come in contact with the drying feedstock; only heat is exchanged between the gas and the feedstock. In addition to improving heat exchange, the baffles between the walls of the drying bucket also help any suspended dust settle out of the gas stream.

The GEK TOTTI is intentionally designed with a structural separation between the drying zone from the pyrolysis zone. This results in more efficient tar cracking and cleaner producer gas by allowing the drying and pyrolyisis to occur at different and more optimal temperatures.

2.3 Auger and Fuel Level Switch

The auger assembly, located toward the bottom of the drying bucket, includes a 12VDC motor that is powered by the 12 starter battery (not included) on the Power Pallet, and a flexible steel auger helix. The flexible auger is able to deal with some inconsistencies in feedstock and affords a greater margin of safety in the case of fuel jams. Feedstock outside of the recommended size range of ½” to 1 ½” size are difficult for the auger system to handle. The auger may not be able to handle longer slivers, easily entangled pieces, or cube-shaped feedstock. Any feedstock outside of the specified parameters may cause jams, bridging or other problems downstream of the auger regardless of how well the auger itself moves the feedstock.

The auger spiral is installed at a slight angle (about 5˚) downward so that it meets the bottom floor of the drying bucket as it enters into the reactor. Because of friction from this contact, the auger may cause a screeching noise against the drying bucket if the drying bucket is empty.

The auger motor is controlled by the *fuel level switch* (See Annotated Figure A)*;* this switch leaves the auger motor on until feedstock pushes up against the stainless steel paddle of the switch, which turns the auger motor off. The sensitivity of the fuel level switch is adjusted through calibration.

The PCU detects the auger state and current to make determinations about auger performance. The logic can detect possible bridging, low fuel states, or jamming conditions. The auger circuit has two relays, one for controlling forward motion and one for reverse (used to help dislodge jams), each protected by 15A fuses located adjacent to the relays on the relay board under the PCU. (See *Section 4: Automation Assembly* for details.)

2.3.1 Calibrating the Fuel Switch

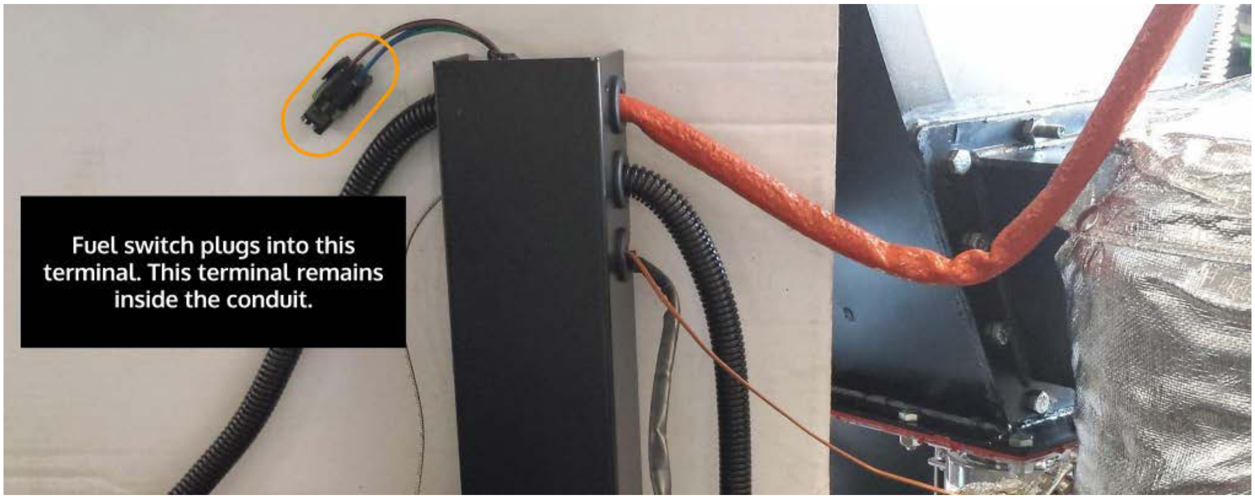
Calibration is done prior to assembly and installation on Power Pallet.

1. If switch rod and magnet are not concentric with switch body, bend corrugations by hand until switch rod rests at center.
2. After the switch rod is centered, drop Limiter Tube into switch body over the switch rod so that it sits inside corrugations. It should easily slide in and then slide out when the switch is inverted.

3. Bolt on Top Flange.
4. Screw in Reed Switch Assembly until the brass stud gently contacts the top of the magnet rod.
5. Unscrew the reed switch assembly 1/2 turn and tighten the stainless jam nut to prevent further movement.
6. Check the functionality of the assembled switch with a multimeter by testing continuity through the reed switch assembly leads. While connected to the multimeter, push gently on the paddle while keeping the flex switch body stationary and in the vertical upright position. The circuit should open when the paddle is pushed to about 3/4 of it's total range of motion in the direction of fuel flow (90 degrees perpendicular to the face of the paddle).

2.3.2 Installing the Fuel Switch

Thread the switch into the top of the reactor fuel switch bung until hand tight. Use a pipe wrench to further tighten the switch until the indicator notch on switch bottom flange is directly opposite of the side of the drying bucket. This ensures the switch paddle face is in a normal position relative to the direction of fuel flow from the drying bucket. Be very careful not to twist Reed Switch wire while installing. Once installed, thread the wire through the third grommet from the top on the left side (gasifier side) of the central conduit, and plug it into the fuel switch terminal.



3. Annotated Figures

Exhibit A: GEK TOTTI Gasifier with ash collection vessel

Label	Description	Label	Description
1	Fuel Level Switch	**5**	Ash removal system motor
2	Inlet from drying bucket	**6**	Reactor access door
3	Exhaust inlet to Pyroreactor	**7**	Air inlet with check valve
4	Grate basket shaker motor	**8**	Ash collection vessel

Exhibit B: GEK TOTTI Gasifier with ash collection vessel, cont.

Label	Description	Label	Description
1	Ignition port (shown with extension)	4	Pyroreactor viewport
2	Outlet to exhaust stack	5	Cyclone
3	Ash removal port	6	Cyclone ash can

Exhibit C: Gas Cowling and Pyroreactor

The Pyroreactor fits into the gas cowling in the assembled gasifier.

Label	Description	Label	Description
1	Gas cowling (inner vessel)	**5**	Inlet from drying bucket
2	Gas cowling insulation shroud	**6**	Air lines
3	Ash-out auger	**7**	Projected hearth

4	Grate basket shaker motor		

Exhibit D: Gasifier cross section

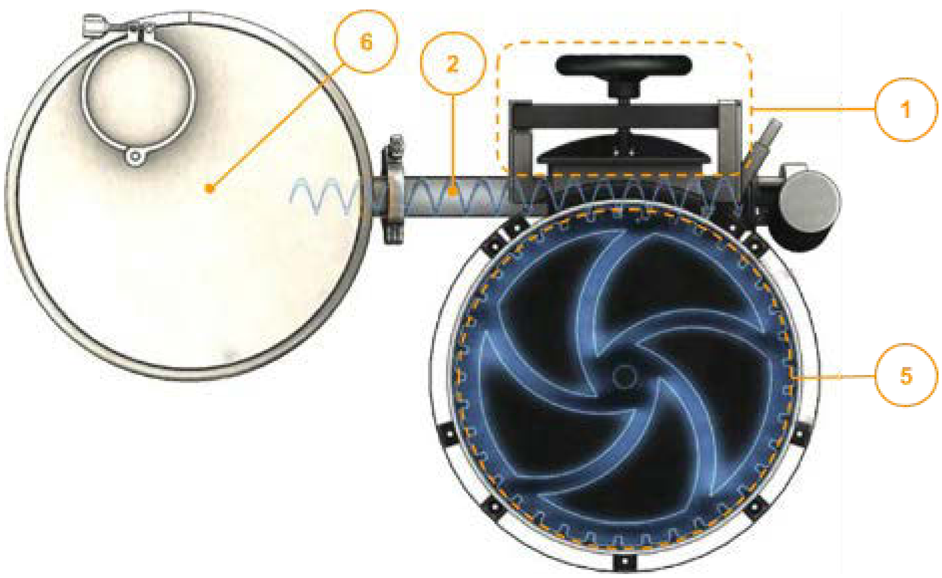
Label	Description	Label	Description
1	*Pcomb* pressure barb	6	Air lines
2	Lighting tube	7	Projected hearth
3	Pyrolysis column	8	Grate basket
4	Air nozzles	9	Ash scroll

5	Exhaust inlet to Pyroreactor		

Exhibit E: Detail of Hearth and Grate Basket

Cross-section detailed view of grate basket and ash handling system

Transparent top view of ash handling system



Label	Description	Label	Description

1	Reactor access door	**4**	Activator cone
2	Ash-out auger	**5**	Scroll plate
3	Grate basket	**6**	Ash collection vessel

4. GEK Gasifier Reactor components

Please refer to the annotated figures on the prior pages for images of the parts described below.

4.1 Air inlet

(See Annotated Figure A)

The air inlet is a check valve allows air to enter the system when the gasifier is operating and under suction, but does not allow expanding hot producer gas to escape out through the inlet during shutdown.

4.2 Air Lines

(See Annotated Figures C and D)

After entering the air inlet, the air is divided among the five corrugated air lines that spiral around the outside of the reactor. The air lines are the first stage of waste heat recovery; they preheat the incoming air while cooling the producer gas. The recovered heat increases the temperature of incoming air to about 600˚C, which contributes to hotter combustion and improved tar cracking.

4.3 Air Nozzles

(See Annotated Figure D)

The air nozzles experience the hottest temperatures in the reactor as they introduce the air into the combustion zone; temperatures in the range of 1200˚C are often found directly in front of the nozzles. The air nozzles are oriented directly at the center of the column, right above the projected hearth.

4.4 Lighting Port

(See Annotated Figure B)

This port allows the operator to light the feedstock in the reactor with a small propane torch during start-up. This port is to be closed when the temperature indicated for the display variable **Trst** (*Temperature at the restriction*) on the PCU display is 100˚C or above.

4.5 Projected Hearth

(See Annotated Figure D)

The projected hearth is the heart of the version 5 of the GEK TOTTI gasifier, which is used on the Power Pallet version 1.08. This structure begins at the bottom of the pyrolysis column and projects into the grate basket. Its shape regulates the flow of solids and gasses for the key chemical processes of gasification— *combustion, tar cracking* and *reduction*.

Combustion occurs in the area above the restriction in the projected hearth; a portion of the tar gases and charcoal are combusted by the introduction of preheated air. The restriction in the hearth funnels all of the combustion gases and unburned tar gases together to homogenize the temperature while causing the tar gases to flow through a concentrated hot spot of about 800˚-900˚C, resulting in efficient *tar cracking*—the thermal decomposition of these tars into CO and H_2 gas. Tar cracking is necessary for reducing the tar content of the gas and to make the gas compatible with internal combustion engines; even though tar gases are combustible, they can badly foul an engine by condensing into a thick sticky substance, and must either be burned, cracked, or filtered out to protect the engine from fouling.

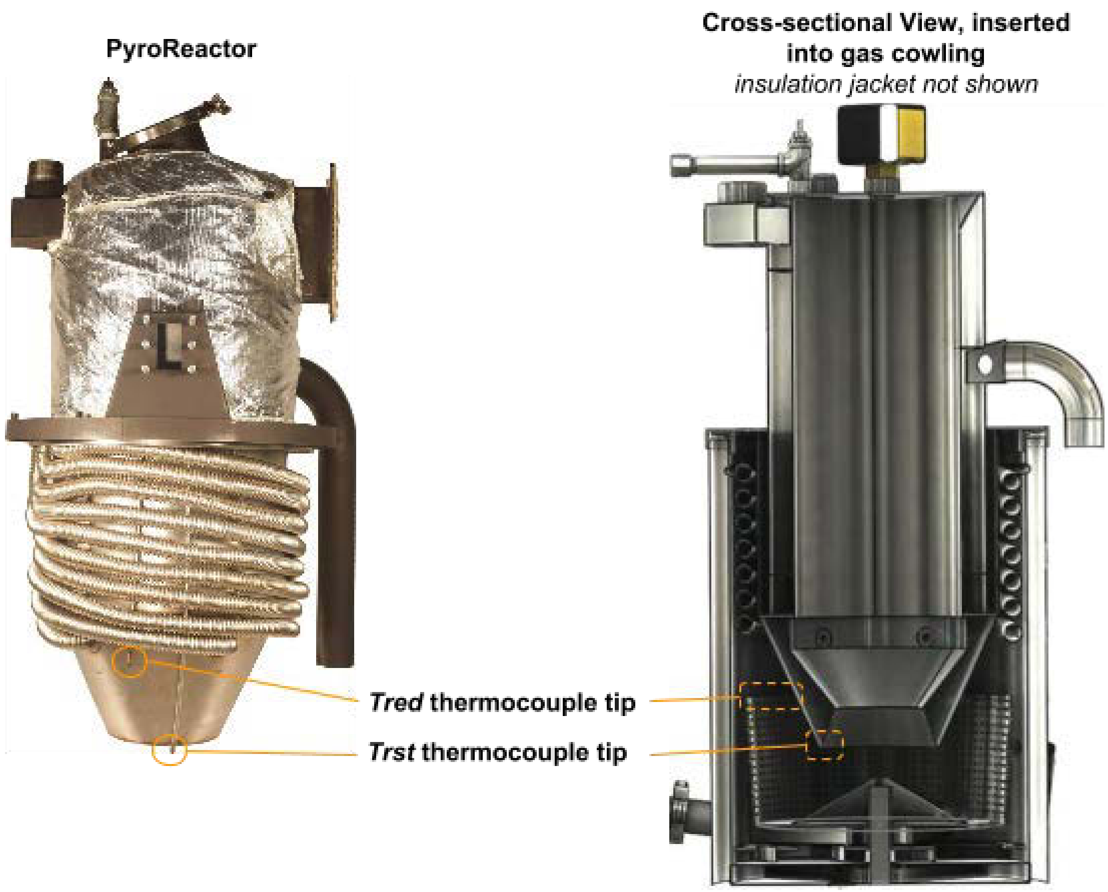
Reduction is an endothermic process that converts the CO_2 and H_2O, produced during the combustion of tar gasses and charcoal produced during pyrolysis, into clean burning gases that are suitable for use in the engine. The carbon from the hot charcoal in the reduction zone has a very high oxygen affinity, and will react with CO_2 and H_2O according to the following reactions:

$$CO_2 + C + \textit{heat} \rightarrow 2CO$$

$$H_2O + C + \textit{heat} \rightarrow CO + H_2$$

The CO and H_2 (and some methane, CH_4) are the combustible gases that make up approximately 40-50% of the volume of the producer gas; the rest of the volume consists of non-flammable N_2 from the air aspirating the gasifier, and any unreduced CO_2 and H_2O.

4.6 Thermocouples of the Power Pallet



The Power Pallet comes with three ungrounded type K thermocouples to monitor the reactor and engine coolant temperature. The following table indicates the location, temperature ranges during normal operation, and other technical specifications.

4.7 Table of Thermocouples

Display Variable:	Trst	Tred	Tcoolant
Abbreviation of:	**T**emperature at the **rest**riction	**T**emperature of **red**uction	**T**emperature of **coolant**
Specific Location	Inside a steel sleeve; measures under the restriction of the hearth	Inside a steel sleeve; measures at the top of the grate basket	Top of engine coolant circuit, before coolant enters radiator.
Steady-state operating temp.	800˚–1000˚C	700˚–800˚C	<100˚C
PCU Port	T0	T1	T2
Thermocouple Specs	K-type, 1/16" dia. x 24" L	K-type, 1/16" dia. x 24" L	K-type Pipe Plug Probe

			¼" dia

See the troubleshooting guide at the end of the Section for instructions on how to test the thermocouples.

5. Grate Basket Shaker and P_{ratio}

Onboard the Power Pallet, the only direct influence the PCU exerts on the gasifier is the timing and triggering of the grate basket shaker. A reciprocating mechanism driven by the grate basket shaker motor causes the basket to rapidly rotate back and forth about 15˚ on its vertical axis, and is programmed to shake the grate for a period of three seconds once every five minutes. The shaking of the grate basket serves two purposes:

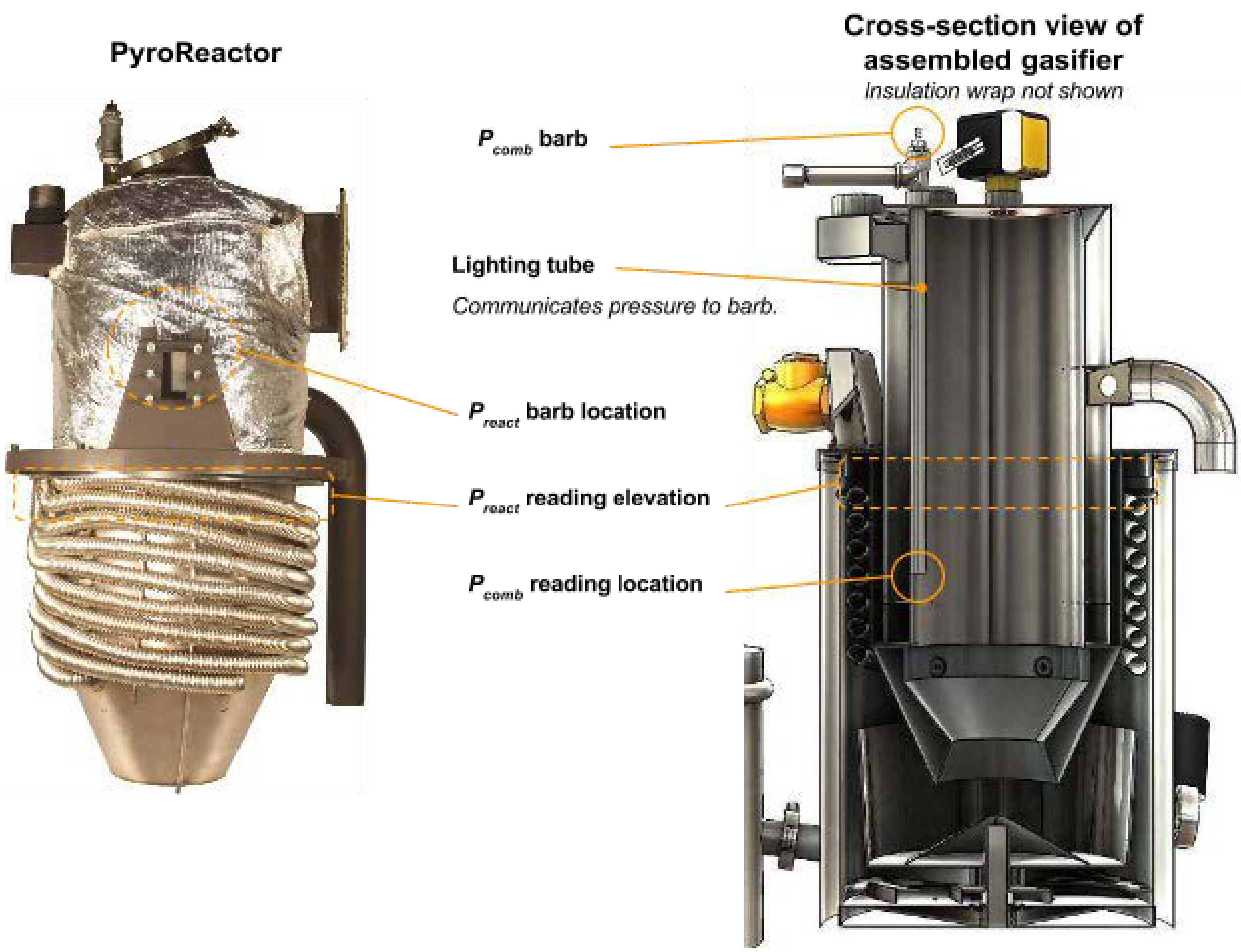
1. the periodic shaking cause the column of char bearing down on the activator cone (seeFigure E, item 4) to settle and descend down and radially outwards into the grate basket as the char is consumed by reduction reactions. The settling of char into the basket moves char through the combustion zone, preventing any char from residing in the hottest zone for too long. The agitation of the char pieces and the shorter residence time in the hot zone reduces the risk of ash fusion and clinker formation.
2. the reciprocating motion causes ash and small particles of char to migrate down toward the bottom of the basket, where the smallest pieces fall through the holes to be removed as char-ash.

Besides the periodic shaking, which is timed, the PCU also determines whether small char pieces are choking the flow of gas through the char basket by calculating P_{ratio} (Pressure ratio, displayed as **Pratio** on the PCU screen), which is a parameter that indicates how much of flow restriction is being imparted on the gas by the char bed.

P_{ratio} is calculated as the following:

$$P_{ratio} = \frac{P_{comb}}{P_{react}} \times 100$$

where P_{comb} stands for the pressure above the combustion zone, and P_{react} stands for the pressure in the reactor after the gas has passed through the grate basket. They are displayed as **Pcomb** and **Preact** on the PCU screen. The following graphic indicates where these two pressure readings are taken from.



When P_{ratio} is too low, it indicates flow restriction due to small char pieces; to correct for this flow restriction, the programming accelerates the countdown timer to trigger grate shaking sooner in order to purge the small pieces of char. When P_{ratio} is too high, it indicates that bridging is occurring inside the reactor, and is preventing char from filling the grate basket.

The variables from which regulate the countdown timer for the grate shaker and how to adjust them are explained in *Section 5: Software*.

The pressure readings on the Power Pallet are as follows:

Display variable:	**Pcomb**	**Preact**	**Pfilt**
Abbreviation of:	**P**ressure at the **comb**ustion zone	**P**ressure of the **react**or	**P**ressure at the **filt**er
Specific Location	Reading taken at the top of ignition tube, which leads to the top of the	Reading taken at the gas outlet from the reactor right before it enters the	Reading taken at the top of the filter.

	combustion zone. See Annotated Figure D.	cyclone.	
PCU barb	P2	P0	P1

5.1 Reading pressure values on the PCU

The numbers the PCU uses to represent the magnitude of vacuum for its pressure readings stand for measurements in a rather unusual unit: tenths of an inch of water column. The use of this unit of vacuum pressure comes from the legacy of the manually operated GEK gasifiers, which had water filled manometer tubes indicating the level of vacuum, as measured off of a scale marked off in inches. These units happen to be very conveniently scaled for the purpose of operating our gasifiers, since most of the pressures encountered in our gasifier fall between 1 and 12 inches of water column.

The following table shows the various ranges that the pressure measurements can fall under, and the interpretation of what these various values of P_{ratio}.

5.2 Pressure Ratio Ranges and Conditions for Grate Shaker Control

Pressure Ratio (Pratio)	Condition
<30	**Lower boundary**: gas flow when Pratio is <30 is likely to be restricted due to fine char accumulating in the grate basket. This condition may also be caused by clinkers.
30-60	**good:** ideal operating conditions
>60	**Upper boundary**: reduction bell is empty, or feedstock is too coarse; possibly out of feedstock, or feedstock is bridging in reactor

The design of the version 5 GEK TOTTI reactor has largely eliminated low **Pratio** problems. However, if you encounter bad **Pratio**s while operating your Power Pallet, please see the troubleshooting section at the end of this Section for how to address problems indicated by **Pratio**. Low **Pratio**s usually indicate that small char pieces are accumulating in the grate basket, whereas high **Pratios** usually indicate that bridging somewhere in the column is preventing char from descending into the grate basket.

It is possible to manually turn the grate shaker on and off via the buttons and user interface of the PCU. See the Section on Automation for this procedure.

6. Ash Handling

The ash handling system of the v5 GEK TOTTI consists of the scroll plate, the ash-out auger and its motor, and the ash collection vessel. (See Annotated Figure E for the top/ghosted view of what the ash handling system looks like. All of the items in this section refer to this annotated figure.) As the grate basket is shaken, char ash accumulates on the floor of the reactor under the basket. Once there, the following sequence removes the char-ash:

- the scroll plate periodically rotates and pushes the char-ash out towards the walls of the gas cowling
- the scroll plate also pushes char-ash that is already against the walls of the gas cowling along the walls until it falls into the opening on the side of the auger tube. (This opening resides behind the reactor access door facing the inside of the reactor.)

- the auger pushes the char up the tube toward the ash collection vessel, where it accumulates.

The ash collection vessel has enough capacity to store the char ash from approximately 24 hours of Power Pallet operation, with variation due to load and feedstock qualities.

6.1 Ash-out Auger Motor, and clearing jams

Both the ash-out auger and the scroll plate are driven by the ash-out auger motor. The motor turns the auger, and the auger turns the scroll plate by pushing against the teeth along the edge of the scroll plate. In the case of an obstruction jamming the moving parts, a current sensing circuitry detects the resistance against the motor and the PCU cycles the motor back and forth to clear the blockage. If the blockage cannot be cleared by cycling, the machine will sound an alarm and indicate this blockage on the PCU. Such blockages may need to be cleared manually.

Before manually clearing an obstruction in the ash handling system, the operator should ensure good ventilation in the work area; clearing jams in the ash handling system involves opening the reactor, which may expose the operator to carbon monoxide if there is insufficient ventilation. First turn off the Power Pallet and let it fully cool down, then open the reactor access door. Let any gases in the reactor vent out and away, then scoop out any char near the access door. The operator should be able to find any obstructions by reaching around the auger tube and feeling along the edge of the opening, where hard material may have become pinched between the auger and the edge of the opening in the tube. Visual inspection may reveal obstructions preventing the scroll plate from turning. Ensure an air-tight seal when replacing reactor access door; air leaks are hazardous to the machine.

7. Gas filtration system

The gas that emerges from the reactor will contain fine particulates, some uncracked tar gases, and water vapor. To mitigate these contaminants, the v5.x GEK TOTTI gasifier has a much improved reactor design that optimizes tar cracking and offers maximal area for gas percolation through the char, lessening high speed flow near the char bed that is more likely to entrain fine particles. However, on the occasions where the gasifier may not be operating in its ideal temperature range for tar cracking, and to capture any residual dust that does become entrained in the gas stream, the system must still protect the engine from these contaminants. It does so by removing dust using the cyclone, filtering out tar with the packed-bed filter, and collecting condensation from the cooling producer gas using a *condensate vessel*.

7.1 Cyclone

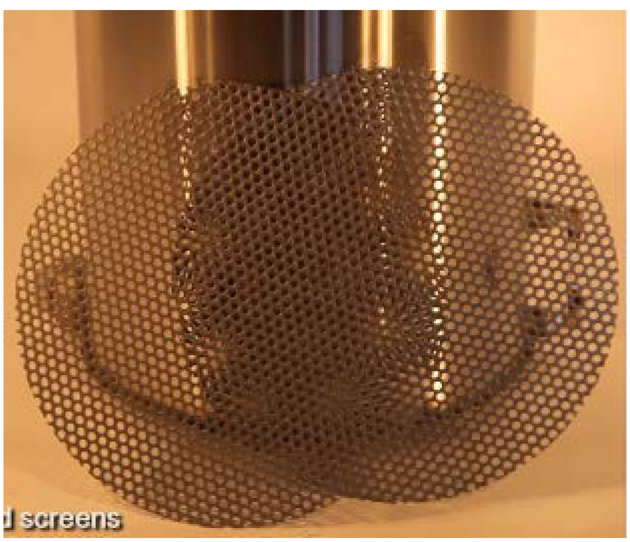
After the producer gas leaves the gasifier, it is directed into the cyclone, where it cools and spins to separate out particles of charcoal dust and condensation from the temperature drop. The condensate and particulates descend and accumulate in the cyclone ash can at the bottom. (See Annotated Figure B) The can, which has enough capacity to support 24 hours of operation, should be emptied each time before starting the Power Pallet. When reattaching the cyclone ash can, it is important to establish an airtight seal, since air leaks are hazardous to the gasifier.

7.2 Packed Bed Filter

The packed bed filter is a 25 gal (94 liters) canister that is to be filled with sifted biomass or charcoal as its filter media. The filter separates out any particulates, tar that survived tar cracking, or condensate that failed to be captured through the cyclone; as the producer gas ascends through the filter, it cools further and condenses residual tars onto the sifted biomass.

The filter comes with two perforated disc screens; one to hold the filter media off the bottom of the filter canister, and one to hold down the two oiled foam discs that come with the filter, which rest on top of the filter media to trap dust particles. The top perf disc is especially important because it holds the foam discs down against the suction of the engine. Without this disc, the vacuum from the engine will pull the foam into the gas outlet, causing a serious bottleneck for the gas to travel through that will ultimately choke the engine.

Note: *The images shown below are for the PP20 and PP25. The PP25 has a square filter, but the instructions are the same.*

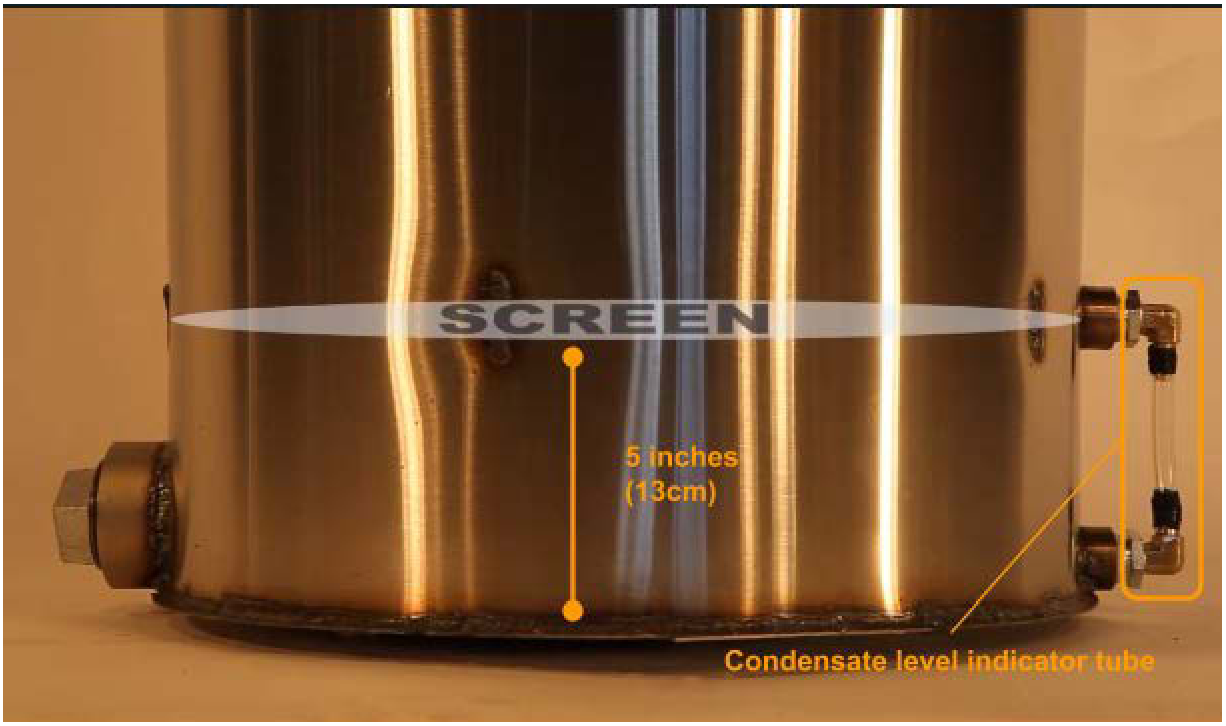


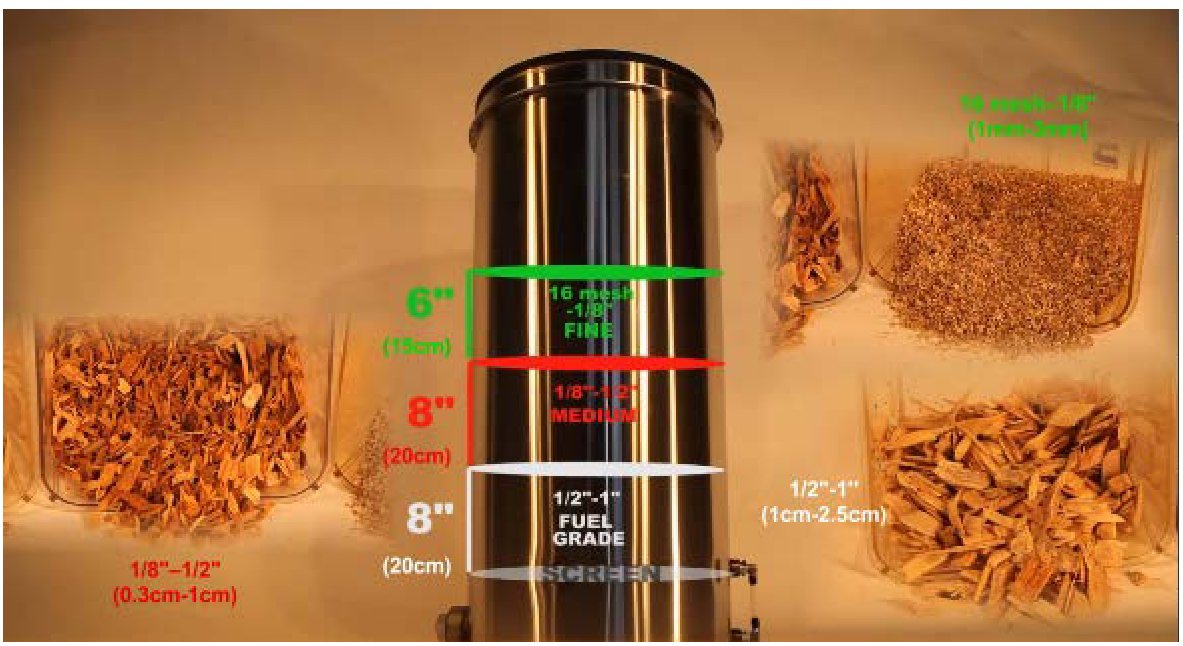
Perforated discs and foam filters that come with the gas filter.

7.2.1 Packing the gas filter

1. Set one of the screens on the tabs that are about 5 inches (13 cm) above the bottom. This 5 inch space below the filter media bottom grate is reserved for collecting condensate in the filter. The level of condensate can be checked through the condensate level indicator tube.

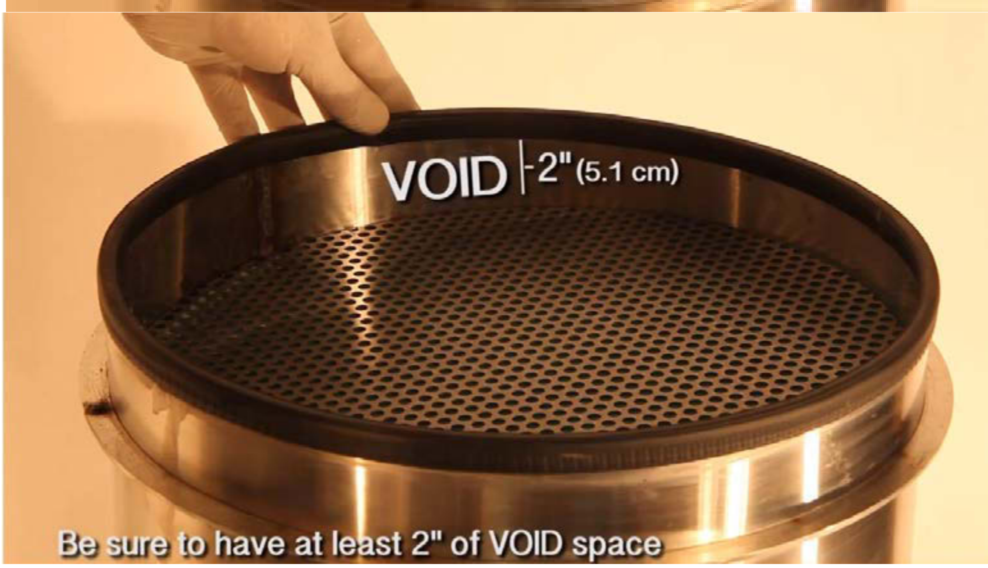
Condensate may be drained through the gas inlet at the bottom of the filter.





2. Add the layers of sifted biomass as shown in the image above.

3. Insert the black (coarse, 45 dpi) foam disc, then the green (fine, 65 dpi) foam disc, and then gently insert the perforated steel screen on top. Be careful to not damage the gasket around the upper lip of the filter drum when inserting and removing the screen.
4. Be sure not to overfill the filter. There should be a 2 inch (5cm) space at the top of the filter.



The filter is only designed for filtering gas produced from cellulosic biomass. The filter is not sufficient for filtering the gas products of coal, peat, plastics, or municipal solid waste (MSW); none of these feedstocks are suitable for use in the GEK TOTTI.

Warning:
do not operate with filter drum empty

Do not attempt to operate the Power Pallet with an empty gas filter drum. Running the system with an empty gas filter could be hazardous to the user and the machine; air inside the empty filter drum will mix with gas entering the drum, and any stray spark or static could violently ignite the mixture.

7.2.2 Changing the filter media

The filter media gradually accumulates tar and needs to be checked and changed as necessary. The filter media should be checked weekly; since most of the fouling of the filter occurs during startup, check your filter media more often if you start your machine often. Long operating sessions foul the filter much less than frequent starts.

When changing the filter media, the spent filter media should be dried and blended into fresh feedstock to no more than 10% of the total mixture. The tar that condenses on the filter media is energy dense, and is not problematic for the gasifier as long as it is blended with plenty of fresh feedstock.

8. Flare

The gases produced during the startup process are too rich in tar to be burned in an engine, so they are cleanly burned off in the flare until the reactor is hot enough to produce clean gas. The flare is designed to burn the tar gases with sufficient heat and oxygen such that the flare exhaust is clean and smoke-free.

8.1 Blowers

The reactions in the gasifier are driven by suction; during normal operation, the engine provides the suction, but during startup, the suction is provided by a pair of blowers connected in a series. This pair of blowers are identified as the *gas blowers*, and can be seen mounted on the flare assembly. The rate of suction of the gas blowers is controlled by the knob on the control panel labeled ‘**GAS**’. The gas blowers are connected in a series in order to achieve enough suction and high enough a flow rate to bring the reactor up to operating temperatures while being powered solely by the 12V DC car battery onboard the Power Pallet. A third blower, also mounted to the flare assembly, provides air to the flare so that the tar-rich gases produced during the startup process can be burned cleanly. This blower is identified as the *air blower*, and is controlled by the knob on the control panel labeled ‘**AIR**’.

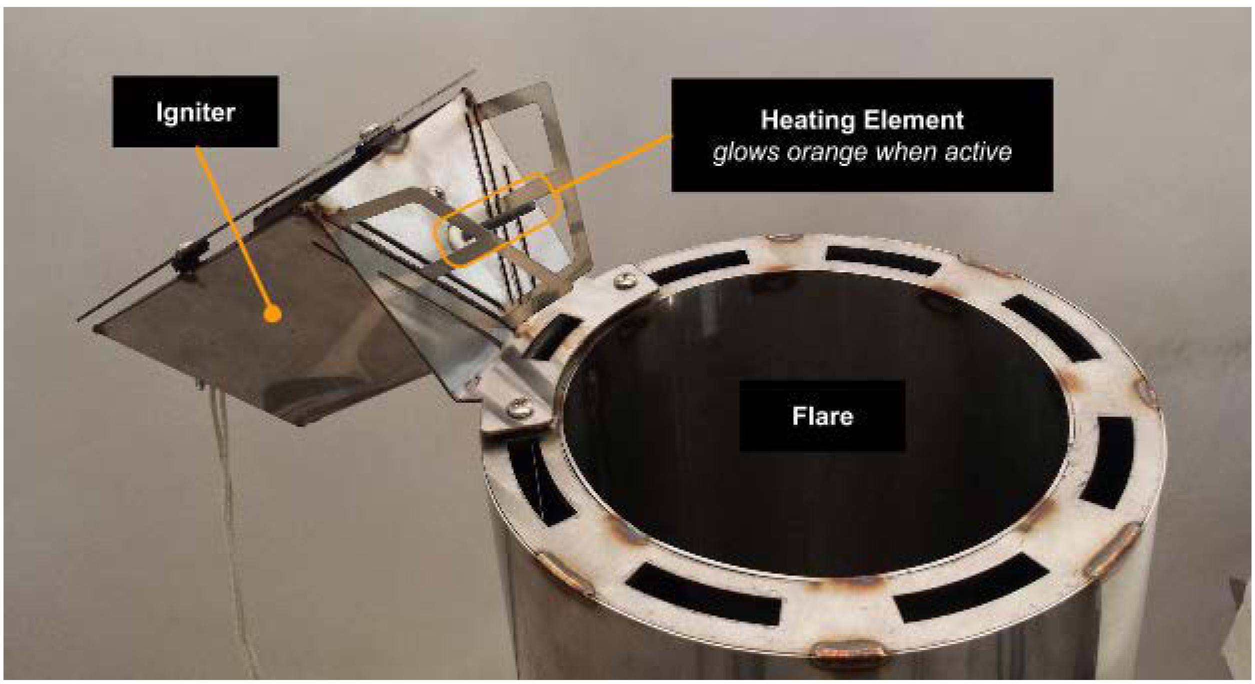
Operation Panel

Note: Grid-tied model lacks keyed ignition switch

During startup, water vapor and some smoke will initially emit from the top of the flare until the igniter lights it. Once the smoke starts burning, the user should adjust the **AIR** setting so that the combustion descends into the flare. The combustion has descended into the flare if the flare makes a deep-toned roaring sound. If flame is visible above the flare, this indicates that the flame is starved of oxygen. Adjusting the air blower knob such that the air setting is somewhat higher than the gas setting provides enough oxygen to pull the flame it into the flare stack for more efficient combustion.

8.2 Igniter

At the top of the flare, there is a triangular device that has a peg-shaped hot surface that glows orange during the startup process. This structure is the igniter:



The igniter automatically turns on when **Preact** is greater than 5 and the engine is not running. When these conditions are true, the igniter relay turns on the igniter at the top of the flare stack, which glows orange with heat, igniting any gases that emit from the top of the flare, including smoke and carbon monoxide.

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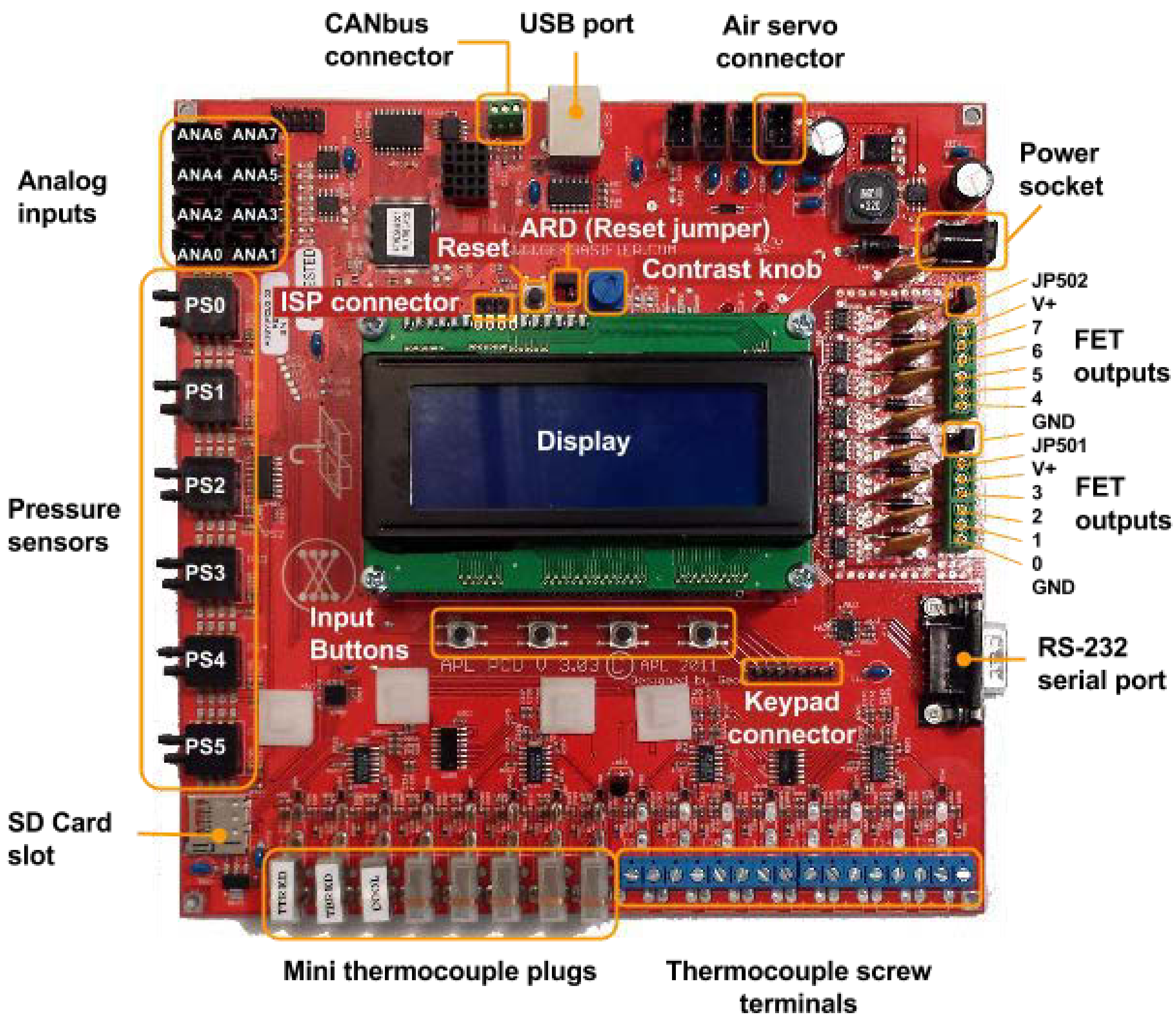
Section 4
Automation Assembly

Table of Contents

1. Process Control Unit (PCU)

1.1 Introduction

The PCU is a printed circuit board (PCB) that serves as the digital control unit that automates and provides data logging for the Power Pallet. The PCU's processor is an *Atmel ATmega1280*, the 8-bit RISC microcontroller of the AVR family. The PCU receives data from sensors mounted on the Power Pallet through its input channels and commands the subsystems through its outputs to the relay board, which is mounted underneath it.



1.2 PCU Power Cable

The PCU converts the 12V DC input power, provided by the on-board battery, to 5V DC and 3.3V DC for most of its components.

1.3 Display and input controls

The PCU displays information on a 4-row, 20-column text screen, which accepts user input from the keypad on the front panel, or through the four input buttons directly below the display on the PCB.

1.4 Analog Inputs

The PCU has 8 analog input (ANA) channels that enable it to sense variable-voltage signals that indicate the state of the Power Pallet's subsystems. Each channel reads a voltage from 0 to 5V, which is then converted to a proportional 10-bit digital value in the range of 0 to 1023. For example, 2.5V, which is halfway between 0 and 5V, would be read as a value of 511, which is halfway between 0 and 1023.

The PCU's analog inputs are ordered as follows:

ANAs *from Relay Board to PCU*			
ANA0	O_2 Sensor Signal (Lambda)	**ANA4**	Auger Current
ANA1	Fuel Switch	**ANA5**	Throttle Position (since 11/2013)
ANA2	Key Switch	**ANA6**	*Coolant (Not Used)*
ANA3	Engine Oil Pressure	**ANA7**	Ash auger motor driver 5V DC power output (to driver PCB) and current sense input (from driver)

1.5 FET Outputs

The 8 Field Effect Transistor (FET) outputs from the PCU are connected open-drain circuits that control electromechanical relays. When on, each FET provides a connection to ground. When off, no connection is made.

The FETs are wired to the Power Pallet's subsystems as follows:

FETs *from PCU to Relay Board*			
FET 0	Fuel auger forward	**FET 4**	Flare ignitor
FET 1	Grate shaker	**FET 5**	O2 sensor reset
FET 2	Engine ignition	**FET 6**	Alarm
FET 3	Engine starter	**FET 7**	Fuel auger reverse

1.6 Thermocouple Connectors

The PCU's T0–T6 thermocouple connections are K-type mini thermocouple plugs, and connections T7–T14 are K-type screw terminal connections. The thermocouple that measures the gas temperature at the reactor's hearth restriction is connected to T0 and displayed as **Trst**, the thermocouple measuring the gas temperature of the end of the reduction zone (at the top of the grate basket) is connected to T1 and is displayed as **Tred**, and the thermocouple measuring the engine's coolant temperature is connected to T2. Additional thermocouple connections are available for user-customized operation and firmware.

1.7 Table of Thermocouples

Display Variable:	Trst	Tred	Tcoolant
Abbreviation of:	**T**emperature at the **rest**riction	**T**emperature of **red**uction	**T**emperature of **coolant**
Specific Location	Inside a steel sleeve; measures under the restriction of the hearth	Inside a steel sleeve; measures at the top of the grate basket	Top of engine coolant circuit, before coolant enters radiator.
PCU Port	T0	T1	T2
Thermocouple Specs	K-type, 1/16" dia. x 24" L	K-type, 1/16" dia. x 24" L	K-type Pipe Plug Probe ¼" dia

1.8 Differential Pressure Sensors

Two ranges of pressure can be measured by the PCU's pressure sensors: P0-P3 can sense +/- 28 inches of water (7 kPa); P4 & P5 can sense +/- 8 inches of water (2 kPa).

Display variable:	Pcomb	Preact	Pfilt
Abbreviation of:	**P**ressure at the **comb**ustion zone	**P**ressure of the **react**or	**P**ressure at the **filt**er
Specific Location	Reading taken at the top of ignition tube, which leads to the top of the combustion zone. See Annotated Figure D.	Reading taken at the gas outlet from the reactor right before it enters the cyclone.	Reading taken at the top of the filter.
PCU barb	P2	P0	P1

Note: Pressure lines should be connected to the top barb of each sensor. The bottom barb must remain open to the atmosphere.

1.9 ARD Jumper Settings

- The **ARD** jumper must be set (both pins connected) in order to communicate with the PCU through the USB serial connection. When the **ARD** jumper is set, any serial connection to the PCU will reset it; therefore, we recommend that the jumper remain unset (connected to one pin only) during normal operation of the Power Pallet. (ARD stands for Arduino, the type of microcontroller used on the PCU.)
- Jumpers **JP501** & **JP502** enable voltage clamping diodes and should be left unset during normal operation.

1.10 Firmware Upload

The Arduino firmware program is installed on the PCU and provides the automated control logic for the Power Pallet. Each Power Pallet is shipped with firmware installed; however, reprogramming may be necessary to update the code to the latest version or if the PCU has been replaced. Instructions to reprogram the PCU are below. Remember, the ARD jumper must be connected to reprogram the Power Pallet.

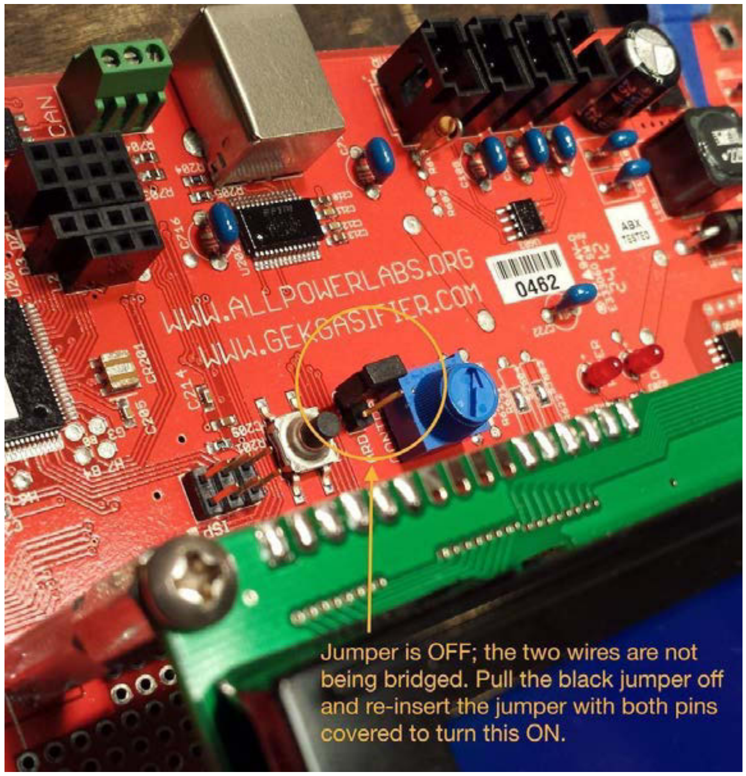
You will need:

- **Computer** (Windows)
- **USB cable** (Power Pallet exterior USB connector has B-type socket; A-B USB cable provided in user kit)
- **FTDI USB Serial Driver** (Driver software is required to communicate with the PCU via USB link. Drivers are available at http://www.ftdichip.com/FTDrivers.htm)
- **Arduino Programming Software (for versions prior to 1.2)** (v0.20 - v0.23) (Arduino software is available from the Arduino website: http://www.arduino.cc/en/Main/software). Please familiarize yourself with the Arduino software before continuing: http://arduino.cc/en/Guide/HomePage
- **KS Library Package (for versions prior to 1.2)** (Download the libraries here: KSlibs - Arduino Support Libraries. (Please see the Arduino instructions for *Manual Installation* of the libraries: http://arduino.cc/en/Guide/Libraries).
- **KS Power Pallet Software Source Code for software versions prior to v1.2:**
    - (The latest stable version of the PCU software can be downloaded at https://github.com/allpowerlabs/KS_PowerPallet). Extract the files to your Arduino sketchbook folder.
- **KS Power Pallet Compiled Binary for software versions v1.2 and later:**
    - For a copy of this file please contact support@allpowerlabs.org.

1.10.1 Uploading the Firmware

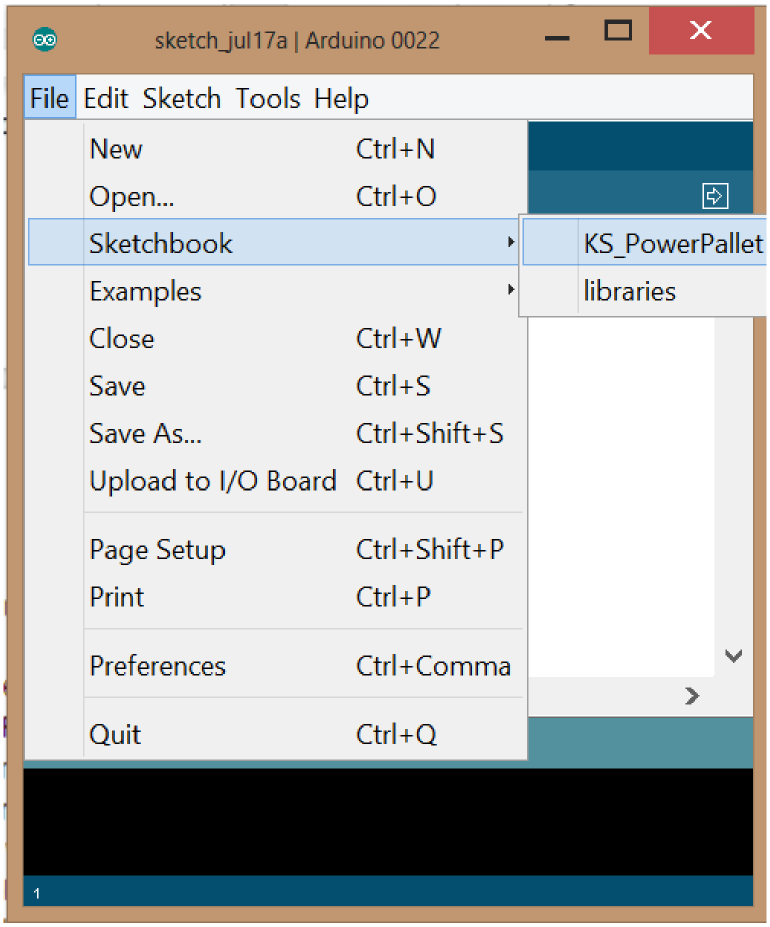
Warning: Ensure the Power Pallet is completely powered off before performing this operation and that the engine key is in the off position (all the way left).

1. Connect the PCU reset jumper (ARD).

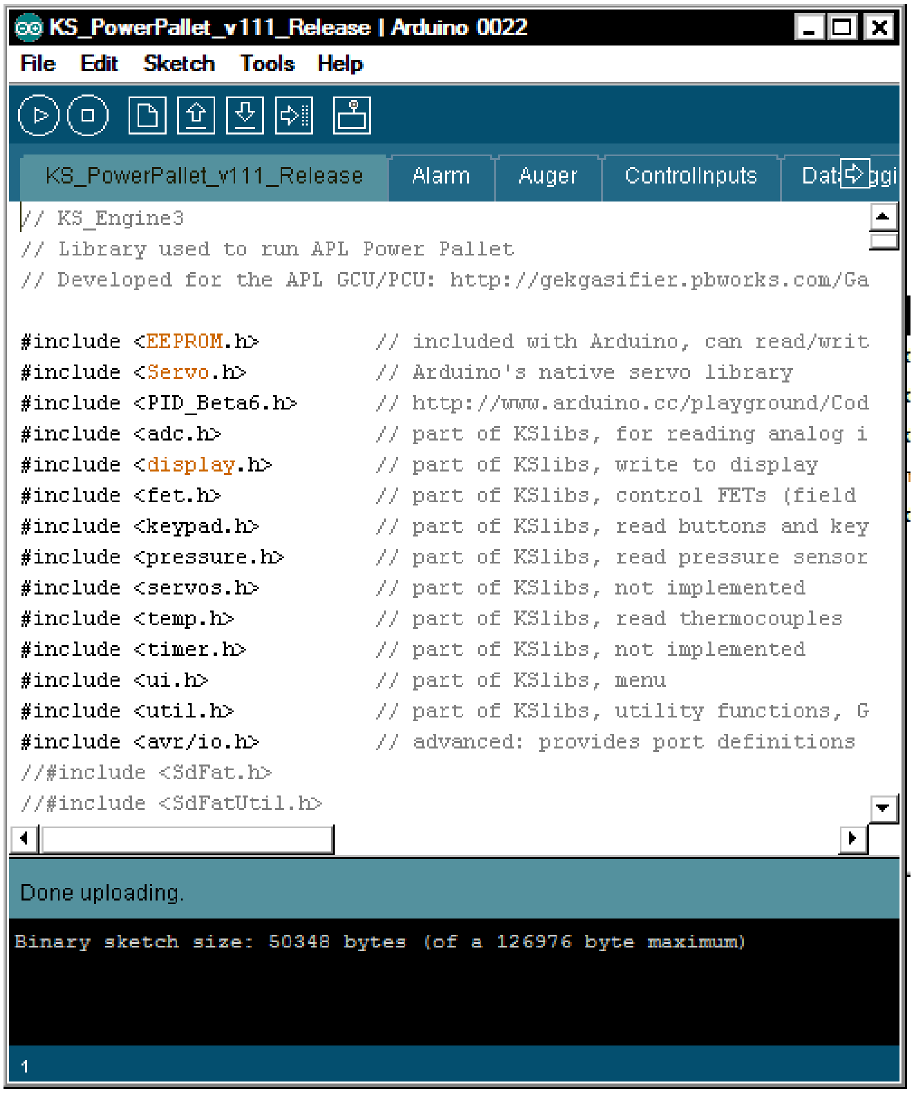


2. Connect computer to programming port on the front control door using USB cable (provided in the user kit).

3. Start the Arduino software and load "KS_PowerPallet.pde" (only for versions prior to 1.2).



4. Turn on the Power Pallet using the power switch on the front control door.
5. Select the correct board type using the menu, "Tools> Board> Arduino Mega (ATmega1280)"
6. Select the correct serial port using the menu, "Tools> Serial Port". The exact name of the port will vary, but it will not appear in this menu before the Power Pallet is powered on. You can also check the COM port assignment in the "Device Manager" on your computer.
7. Press the "Upload" button. Wait for the upload to complete, which should take approximately 1 minute. If you encounter an error at this point, please stop and consult the "Troubleshooting" section below before continuing.
8. Power off the Power Pallet and disconnect the programming jumper.

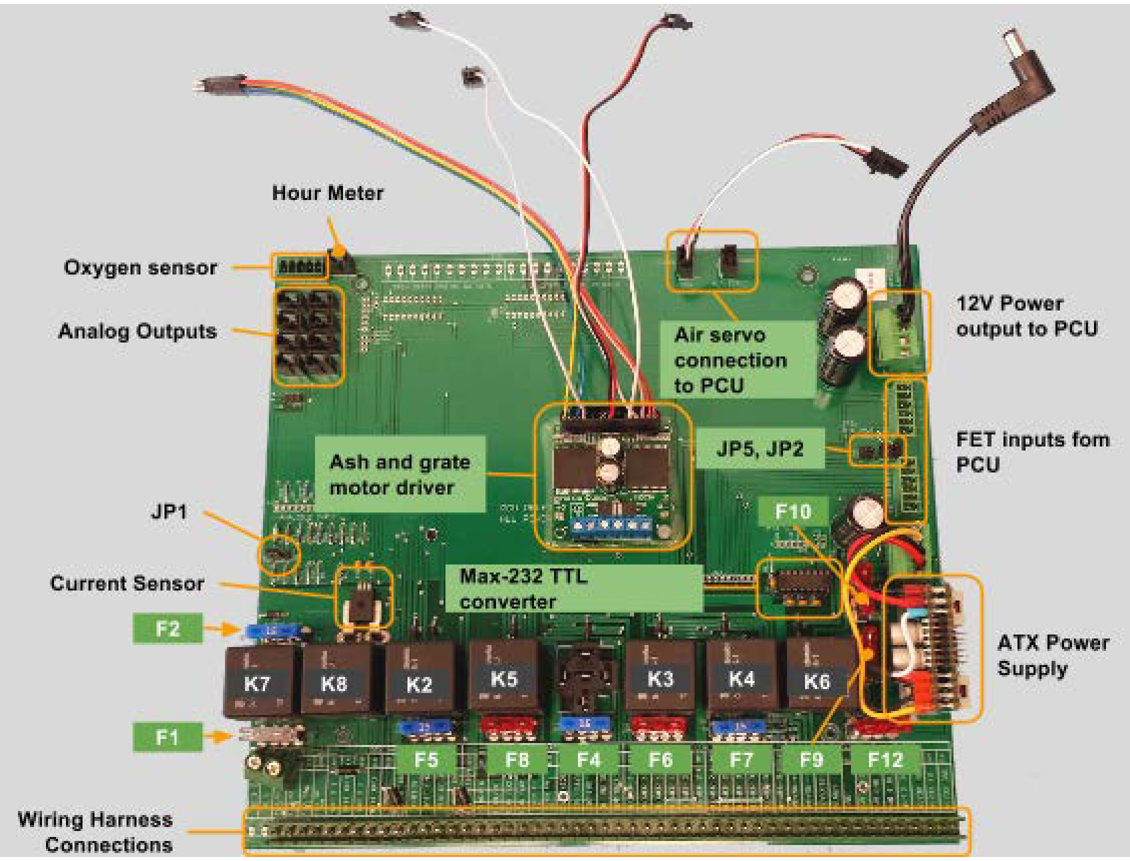


The Arduino interface showing that PCU program KS_PowerPallet is uploaded.

2. Relay Board

2.1 Introduction

The Relay Board receives the power and data through the wiring harnesses, and manages input/output signals to the various subsystems and the PCU. Please refer to this diagram for the descriptive sections on the following pages.



Relays			
K1	*Not used*	K5	Flare ignitor
K2	Grate shaker	K6	*Not Used*
K3	Engine ignition and governor	K7	Fuel auger forward
K4	Engine starter	K8	Fuel auger reverse

Fuses					
F1	25A	Main battery power	**F7**	15A	Engine starter
F2	15A	Fuel auger forward/reverse	**F8**	10A	Flare ignitor
F4	15A	Ash auger (v1.08 or newer) – previously Aux	**F9**	10A	Oxygen sensor reset
F5	15A	Grate shaker	**F10**	10A	ATX power input
F6	10A	Engine ignition, governor, hour meter	**F12**	10A	Blowers

2.2 Power Terminals

12V DC and ground connections power the entire automation system.

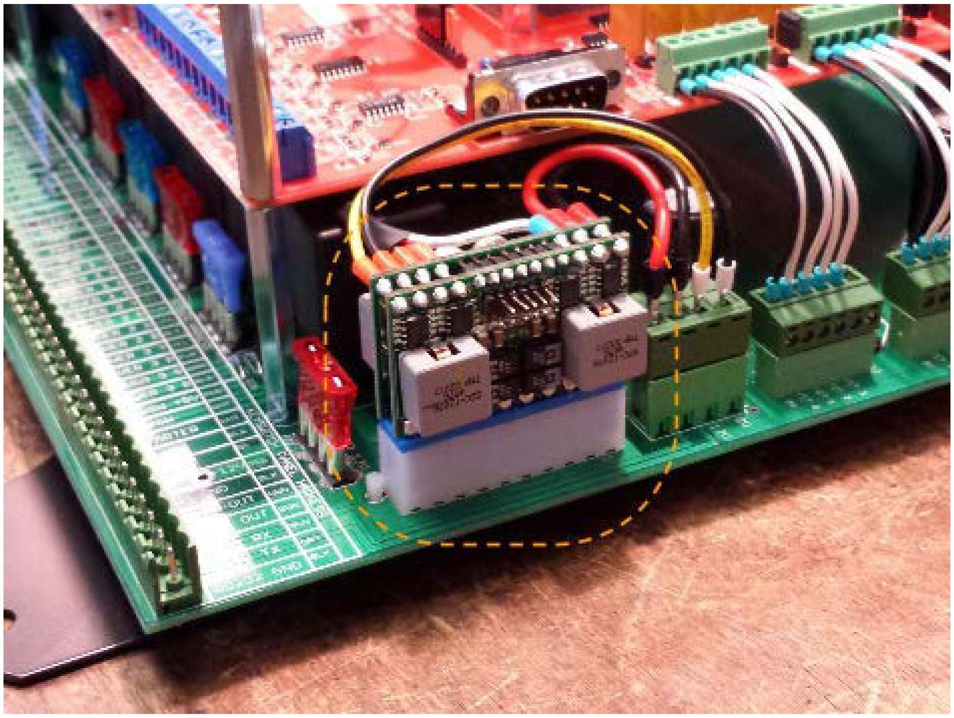
2.3 Current sensor

The relay board includes a Hall-Effect sensor that measures the current flowing through the fuel auger circuit. This enables "smart reversing" of the fuel auger. If there is feedstock jamming the fuel auger, the amount of current that the auger pulls will spike, as it attempts to push through the jam, which the current sensor will pick up and pass the information to the PCU through an analog input (ANA4). Once the current passes a certain threshold, the PCU will know the fuel auger is jammed and reverse its direction. This will generally dislodge the jammed feedstock. If it does not, the PCU will command the fuel auger to cycle backward and forward repeatedly, which will almost always clear the jammed feedstock.

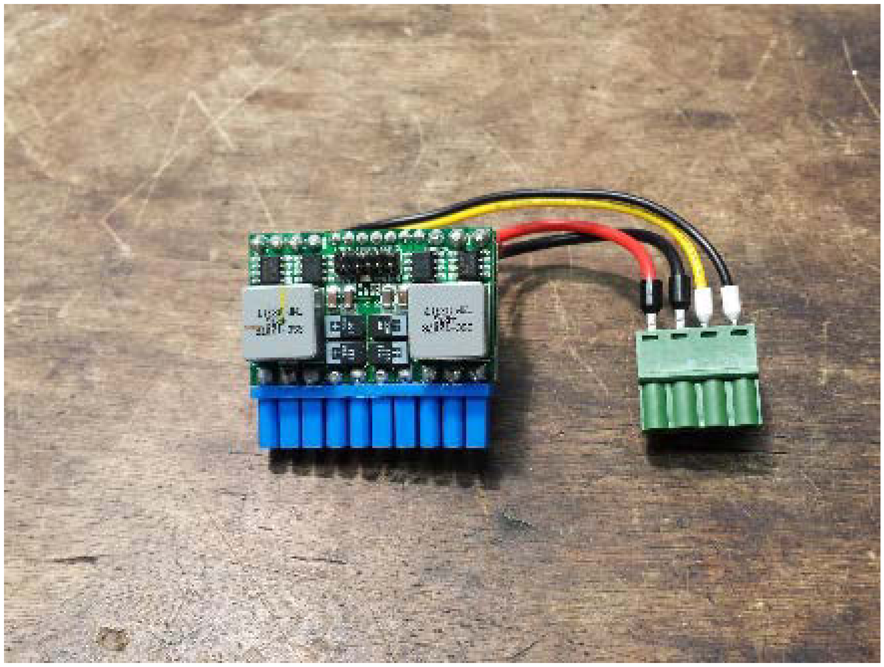
2.3.1 Ash Auger Motor Driver PCB

The *ash auger motor driver PCB* (often called the *ash auger driver* for short), is a standalone PCB that is a functional H-bridge which drives the motor allowing the ash auger to run both forward and backward. The ash auger driver also has an integrated current sensor, the output of which feeds back to the PCU through ANA7, enabling the PCU to automate smart reversing of the ash auger, just like the fuel auger. The ash auger driver uses a fused 12V DC supply from the Auxiliary relay socket to power the motor, while taking the ground from the GEK harness at the bottom of the relay board. 5V DC logic level power is supplied to the motor driver board through ANA7, and the output commands from the PCU originate from the Port D and Port L I/O expansion headers on the PCU. A Pulse Width Modulation (PWM) input to the motor driver PCB from the PCU allows variable control of motor power. Orange and black forward and reverse wires run directly from the motor driver PCB to the ash auger motor.

2.4 ATX Power Supply Module



Most automated subsystems draw current from the on-board 12V DC battery supply, including some motors with large current requirements, which significantly reduce the instantaneous voltage in the system as they come on. To prevent voltage drops from resetting the PCU, or power spikes from damaging the PCU, the ATX power supply unit provides clean 12V DC power to the PCU. The ATX module is a standalone power supply mounted on the relay board with connections in its 20-pin socket and in/out power connections to the relay board in a separate 4-pin screw terminal.



The ATX power supply unit

2.5 Relay Board Configuration Jumpers

JP1: Oil Pressure Sensor/Sender

3 pin jumper

- Jump Pins 1 (leftmost) & 2 (middle) = PP20 configuration (indicated on board)
- Jump Pins 2 (middle) & 3 (rightmost) = PP10 configuration (discontinued)

JP2: Alarm Enable & Relay Selection (O2 reset or Auxiliary)

6 pin jumper

Pin #	Position	Notes
1-2	Leftmost pins	Pins must be jumped to enable the audible alarm. All PP20 systems will have these pins jumped.
3-4	Middle pins	These two pins must be jumped to operate the ash auger **ONLY** on **v1.08** systems with **NO MOTOR DRIVER PCB** installed. [If there is a ribbon cable connected to ANA7 and L0-L2/D0-D2 I/O expansion ports on the PCU, then a motor driver board is installed.] The majority of Relay Boards will not have these pins jumped. These pins will **NOT** be jumped on v1.06 systems.
5-6	Rightmost pins	These two may be jumped to enable the Lambda meter to automatically reset under error conditions. These pins should be jumped on: a) v1.06 Power Pallets, b) v1.08 Power Pallets **WITH** an ash auger motor driver PCB installed. They are **NOT JUMPED** on v1.08 systems without an ash auger driver PCB.

JP5: Currently Unused

4 pin jumper
Jump bottom 2 pins

2.6 Max-232 TTL converter

This integrated circuit provides an electrical buffer for serial communication with the engine governor.

2.7 Analog Connections from Relay Board to PCU

These connectors output various analog signals from the Relay Board to the PCU.

2.8 Oxygen Sensor Controller

This connector powers the oxygen sensor (lambda) meter, which enables proper functioning of the air/fuel mixing system, and relays the analog signal (0.25-5V analog, 51-1023 digital value) to the PCU. Under error conditions the oxygen sensor gauge outputs 0V.

2.9 Hour Meter

This connector provides power to the hour meter when the engine ignition relay is activated.

2.10 Air Servo

These are pass-through connections from the PCU to the air servo. Control signal is passed through from the PCU while power for the servo is provided by the ATX power supply.

2.11 FET Inputs from PCU to relay board

The FET inputs are used to control relays based on signals from the PCU. A relay is activated when the PCU connects the pin on its respective FET connector to ground. For example, connecting the “FET 1” pin on to ground (0V) will turn on relay 1, activating the grate shaker motor.

FETs *From PCU to Relay Board*			
FET 0	Fuel auger forward	**FET 4**	Flare ignitor
FET 1	Grate shaker	**FET 5**	Ash auger
FET 2	Engine ignition	**FET 6**	Alarm
FET 3	Engine starter	**FET 7**	Fuel auger reverse

3. Wiring Harnesses

The GEK, Engine, Blower, and Key Switch harnesses connect to the bottom of the relay board with plug-in screw terminals, through which power and signals are routed to and from the the relay board, PCU, and automated subsystems on the Power Pallet. Please contact support@allpowerlabs.org if you require detailed diagrams and pinouts, as the harnesses are consistently upgraded.

3.1 Main Power Switch

A 30A breaker is used as the main power switch for the Power Pallet’s automation system, providing protection from over-current events. When it is flipped up into the “on” position, it powers the automation assembly with 12V DC from the main battery.

3.2 Engine start key switch

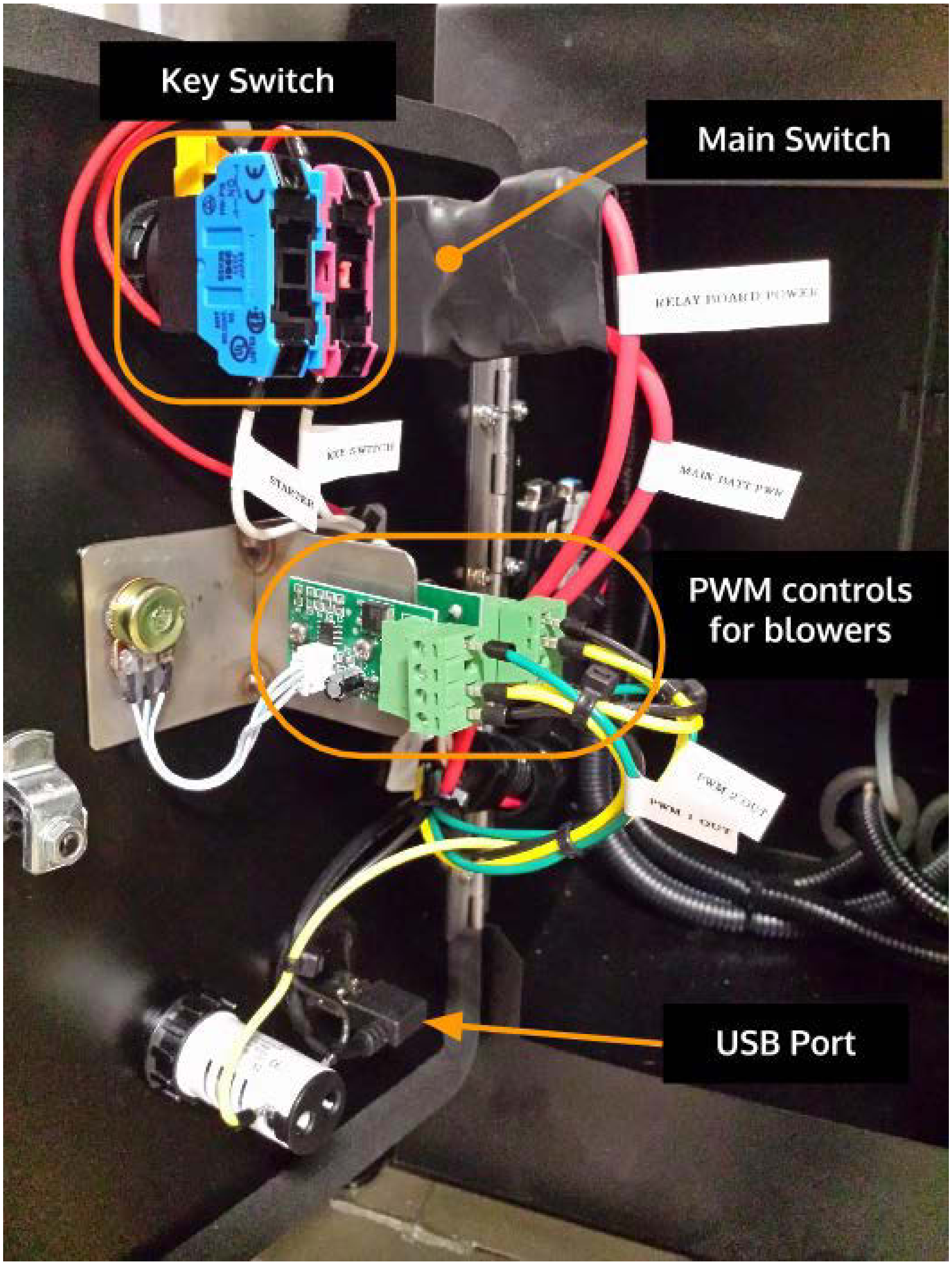
The engine start switch is a three position, spring return (OFF - ON - MOMENTARY) key switch, much like that in a typical car. The leftmost position is off. The switch is an input to the PCU and does not directly control any circuit: its functions are completely software defined. The “on” positions powers on the engine and governor, while the third “momentary” position starts the engine.

3.3 PWM blower controls

The gas and air blowers are controlled by two pulse width modulation (PWM) circuits located on the back of the podium door and operated by dials on the front of the door. The PWMs send out a series of pulses, the duty cycle of which changes with the turning of the dial switches, providing signal on a continuum for smooth increase and decrease of blower speed.

3.4 USB Port

The Universal Serial Bus (USB) port, labeled "PCU", is a serial connection that allows a computer to communicate with the PCU. The operator may use it to upload control code and to download and log run data. The outside port is a B-type female socket, so the operator will need the A-B male-male USB cable from the User Kit in order to connect his or her computer to the Power Pallet. It is important to keep the waterproof cap on the USB port when the connection is not in use in order to protect the connector against the elements and mechanical disturbance.


Key Switch
Main Switch
PWM controls for blowers
USB Port

Section 5
Software v1.3

Table of Contents

1. Component Control Logic

1.1 Notes about Component Control Logic

The PCU control logic monitors the reactor temperature and pressure, oxygen sensor reading, and engine state. It also controls fuel feed, char bed agitation, and ash removal. If any critical issue occurs, the control system will sound an alarm to alert the user to the state of the machine. The user has the ability to change parameter values from the defaults through the PCU menu display.

1.1.1 Filter

The pressure of the media filter is recorded as `Pfilter` and can be used to determine the pressure drop across the filter bed.

1.1.2 Igniter

The igniter is lit if the Reactor pressure (the value of the variable `Preac`) is below -100 pascals (-4 on PCU display) and the engine isn't running.

1.1.3 Feedstock Auger

Fuel is fed into the reactor with a motorized spiral auger controlled by the PCU. The PCU determines fuel level in the reactor by monitoring a mechanical paddle switch. The switch is activated by the force of fuel on the paddle once the fuel has reached a high level in the reactor. The switch is electrically closed when no fuel is present and electrically open when the paddle is depressed. When the switch is in the closed position the PCU activates the auger to feed fuel into the reactor; when the switch is open the PCU stops the feed of fuel. The PCU monitors auger motor current while feeding. The auger motor current level is used to detect mechanical or electrical faults of the fuel feed system.

1.1.4 Grate Shaker

The system attempts to keep the reactor pressure ratio within a desirable zone to optimize gas flow. The ideal zone is determined by the configurations "Pratio Low" and "Pratio High" which are the low and high set points respectively. The grate shaker does not become active until the reactor is above 40°C and under 4 inches of water vacuum (100pa).

There are three configurations used for automated control of the grate shaker:
"Grate Max Inter" for setting the maximum number of seconds the grate should go before shaking, "Grate Min Inter" for setting the minimum time between shakings, and "Grate On Interv" for setting the time which the grate shakes each time a grate shaking event occurs. The main function of the grate shaker is to cause movement in the char-ash in the reduction zone so that small ash particles that would normally restrict flow fall out into the ash tray. The grate only shakes when the reactor is deemed to be on. The system attempts to keep the Pratio within a desirable zone to optimize gas flow, where Pratio is defined as (Pcomb / Preac) x 100. The ideal zone is determined by the configurations "Pratio Low" and "Pratio High" which are the low and

high set points respectively. The time until a grate shake event is like sand in an hourglass. If Pratio drops below the low zone time runs out quicker (the hole in the hourglass is larger and thus sand drains faster) than if the Pratio is in the proper zone. Once all of the time runs out a grate shake event occurs.

Beyond Automated control, the operator can also go to the Manual Control view on the PCU and select OFF and ON to either turn the grate off or on respectively while the operator is in this view.

The system senses the current draw of the auger motor and times the auger state to detect possible errors in feedstock transport. Fuel jams and bridging are the most common conditions.

1.1.5 Mixture Control

The system checks the lambda sensor and then uses a PID loop to adjust the servo that controls the butterfly valve that controls the air into the system. The P and I values are set in the Lambda view along with the Lambda setpoint.

Control State	Engine	Lambda	Servo Position
OFF	STOPPED	N/A	Closed
STARTING	STARTING	N/A	Start (30 degrees)
CLOSED LOOP	RUNNING	In range	PID Controlled
OPEN LOOP	RUNNING	Error	Last position

If there is a loss in signal from the oxygen sensor, the logic will attempt to reset the sensor while maintaining the mixture servo at the last position until signal returns. On engine shutdown, air servo valve is opened to maximum position. After 3.5 seconds, the ignition system is de-energized and the air servo valve is closed. On grid tie systems the air servo valve is closed immediately upon receiving a shutdown signal from the DeepSea controller.

1.1.6 Reactor Conditions

The PCU monitors the temperature and pressure ratio of the reactor. The PCU sounds an alarm for reactor temperatures below the minimum threshold (default 750°C) when the engine is running because temperatures under the threshold result in inefficient tar cracking. The high levels of tar present in the gas stream at low temperatures risk fouling the engine valves and spark plugs.

The pressure ratio between the combustion pressure (`Pcomb`) and the reactor pressure (`Preac`) is indicated as `Pratio` and the grate is shaken at the specified threshold values. A low `Pratio` indicates fines clogging the reduction zone. A high ratio can indicate fuel burn out or bridging. If the grate shaker is unable to purge the grate basket, an error state will be in effect, and manual inspection and cleaning may be needed.

1.1.7 Engine Oil Pressure

Low pressure reading for the first 3 seconds of running (startup) is ignored. For the PP20 Power Pallet, the low-pressure threshold is user configurable.

1.1.8 Automatic Shutdown

When there is an automatic shutdown, the cause remains on display and the system will not resume until reset by the user via the control panel. Shutdown causes are persistent on the display after automatic shutdown for the user to view.

1.2 Displayed Alarms and System Responses

Below is a table of the errors that are displayed and the action taken by the system.

Alarm Message	Alarm Conditions	Time until Alarm	System Shutdown Time	Advice Displayed
Auger on too long	Auger on	4 min	Auto Engine Shutdown at 6 min	Check Fuel
Auger off too long	Auger off	8 min	Auto Engine Shutdown in 10 min	Bridging?
Bad Reactor P_ratio	if P_ratio value is <p_ratio low value and >p_ratio high value (user configurable; default = 30, 60)	Variable	No action	Reactor Fuel Issue
Trst low for engine	< 700°C (default; user adjustable) for trest	3 sec	No action	Increase Load
Tred high for eng.	Engine on and reduction temperatures above 950°C (hystersis between 900-950°C).	Immediate	Engine shutdown at 60 sec	Low Fuel in Reactor?
Check Oil Pressure	Oil pressure less than user setting (default = 6psi)	No alarm	Auto engine shutdown after 0.5 sec. Note: first 3 seconds during engine start up ignored	Check Oil Pressure
No O_2 Sensor Signal	Greater than .25 sec	30 sec	Reset oxygen sensor at 0.25 sec Auto engine shutdown after 60 sec.	No 02 Sensor Signal
Auger Low Current		1 min	Auto engine shutdown after 3 min	Check Fuel
FuelSwitch/ Auger Jam	10 auger fwd/rev cycles	Immediate	Auto engine shutdown at 20 forward/reverse cycles	Check Fuel & Switch

High P_comb	Combustion vacuum > 300 units	No alarm	Immediate	Check Air Intake
High Coolant Temp	Greater than 98°C default (user configurable)	0 sec	Engine shutdown 3 sec	High Coolant Temp
Reduction Temp Low	Engine on and top restriction temperatures below 790°C (hystersis between 790-800°C)	3 sec	Engine shutdown 7 sec	Increase Load
Restriction Temp High	Engine on and Trst > 1050°C (user configurable)	No alarm	Engine shutdown 15 sec	Reduce Load
Reduction Temp High	Engine on and Tred > 975°C (user configurable)	No alarm	Engine shutdown 60 sec	Reduce Load

The display will allow for multiple alarm conditions. If multiple alarm conditions are present, the alarm view shows the alarm count in the upper right corner. The time before shutdown is shown as a countdown on the display. Alarms that do not cause an automatic engine shutdown can be unset by resolving the alarm condition. Silencing of the alarm is allowed and turns off siren. Any new alarm conditions will turn the alarm back on.

2. Description of Operator Views

2.1 Splash Screen

```
     Power Pallet
  www.allpowerlabs.org
   [firmware version]
[PP S/N]        [PCU S/N]
```

Variables	
Firmware Version	Firmware version in the format <*major*>.<*minor*>.<*revision*>, e.g. v1.3.0
PP S/N	Power Pallet serial number, entered during production
PCU S/N	PCU board serial number, entered during production

2.2 Reactor Status

```
Trst    TTT  Pcomb   PPP
Tred    TTT  Preac   PPP
Pratio  RRR  Pfilt   PPP
NEXT  ALARM  T:    00000
```

Variables			
`Trst` *TTT*	Temperature of restriction in ˚C, measured at the hearth restriction	`Pcomb` *PPP*	Pressure at the combustion zone*
`Tred` *TTT*	Temperature of reduction in ˚C, measured at top of grate basket	`Preac` *PPP*	Pressure of reactor, measured as gas enters the cyclone*
`Pratio` *RRR*	Pressure ratio: the quotient `Pcomb/Preac` × 100	`Pfilt` *PPP*	Pressure at the filter*
`NEXT`	Press the button below the `NEXT` label to advance to the next menu.	`ALARM`	*The* `ALARM` label will flash when there is an active alarm. Press the button below to view active alarms.

T:	This area displays the number of seconds the PCU has been powered on and can be used to correlate events with a timestamp in the data log.		

** Pressure in units of 0.1 inches of water column (e.g. a reading of 10 means 1 inch of water column)*

2.3 Lambda

```
LamSet  SSS  Lambda LLL
P       PPP  I      III

NEXT   ADV    +    -
```

Lambda is the quotient of actual air:fuel ratio divided by the stoichiometric air:fuel ratio. It gives you an idea of how the actual ratio compares to the theoretical stoichiometric mixture. Lambda = 1 is an stoichiometric; Lambda > 1 indicates a leaner mixture, Lambda < 1 is a richer mixture.

Values	
SSS	Lambda setpoint (lambda × 100) Default: 1.05
LLL	Current lambda reading (lambda × 100)
PPP	Lambda PID P value (P × 100) Default: 0.13
III	Lambda PID I value (I × 100) (PID D value is 0, so control loop is actually PI) Default: 1.00
	Note: Running the system at different set points can greatly impact emissions and or cause the system to become unstable. Do not adjust from default values without review from a technician.

Keypad			
NEXT	ADV	+	-
Go to next menu	Go to next menu item	Increase item value	Decrease item value

2.4 Manual Control

```
Manual Control
```

```
<Component>: <MODE>

NEXT  ADV         MODE
```

Values	
Component	Grate Shaker, Fuel Auger, or Ash Auger
<Mode>	Grate Shaker ● Auto: Grate shaker will turn on at intervals according to parameters. ● ON: Grate shaker on continuously ● OFF: Grate shaker disabled. Fuel Auger ● AUTO: Fuel auger will turn on when fuel level is low ● OFF: Fuel auger disabled Ash Auger ● AUTO: Ash auger will turn on at intervals according to parameters. ● ON: ● OFF: Ash auger disabled.

2.5 System Information

```
[PP S/N]          [PCU S/N]
          Time:        SSSS
     [SD Card Status]
NEXT  ADV
```

Values	
S/N	Serial Number
SSSS	Time reading

2.6 Testing

```
Test Relay: X
FETX Name
State:[state]
NEXT  ADV   ON    OFF
```

Tests	
0. Fuel Auger Fwd	Turns on/off auger forward relay (FET0)
1. Grate	Turns on/off grate shaker relay (FET1)
2. Engine/Governor	Turns on/off engine ignition relay (FET2)
3. Starter	Turns on/off engine starter relay (FET3)
4. Flare	Turns on/off flare igniter relay (FET4).
5. Ash Auger	Turns on/off Lambda meter reset relay (FET5).
6. Alarm	Turns on/off flare igniter relay (FET6).
7. Fuel Auger Rev	Turns on/off flare igniter relay (FET7).
Note: Menu is not available while engine is running	

Keypad	
NEXT	TEST
Go to next menu	Advance through tests

2.7 Analog Inputs

```
Analog Input: ANAX
FET Name
State: [state]
NEXT  ADV   ON    OFF
```

Analog Input	FET Name
ANA0	ANA_Lambda
ANA1	ANA_Fuel_Switch
ANA2	ANA_Eng_Switch
ANA3	ANA_Oil
ANA4	ANA_Aug_current
ANA5	ANA_Throttle_Pos
ANA6	ANA_Coolant_Temp
ANA7	Unused *(Currently shows ash auger current)*

2.8 Air Servo

```
ServoMin LLL  Max   HHH
Careful of Sides!

NEXT  ADV   +    -
```

Values	
LLL	Servo Minimum (Closed)— minimum servo mixer angle (degrees)
HHH	Servo Maximum (Open)— maximum servo mixer angle (degrees)

Keypad			
NEXT	ADV	+	-
Go to next menu	Go to next menu item	Increase item value	Decrease item value

2.9 Calibrate Pressure Sensors

```
Calibrate Pressure
Sensors to zero?

NEXT      YES
```

Keypad	
NEXT	YES
Go to next menu	Calibrate pressure sensors

Note: This will zero pressure sensors to handle any sensor zero-offset. Only calibrate when the system is fully off and under no vacuum or pressure. This menu is not available while engine is running

2.10 Configuration

```
    Configurations
[Configuration name:Value]
ADV to save choice
NEXT   ADV    HHH   LLL
```

Keypad			
NEXT	ADV	HHH	LLL
Go to next menu	Go to next configuration submenu	Text depends on configuration submenu. See Configuration Menu and Options below.	Text depends on configuration submenu. See Configuration Menu and Options below.

Note: Menu is not available while engine is running

2.11 Configuration Menu and Options

Configuration Setting	Options	Default
Reset Defaults?	NO: does not reset defaults YES: resets factory defaults for all values.	NO
Engine Type	10k 20k	Factory default matches original Power Pallet size.
Relay Board	NO : system DOES NOT have relay board installed YES : system DOES have relay board installed	YES
Auger Rev(.1s)	+ : increase value - : decrease value (Units: 0.1 seconds)	1.0 sec
Auger Low(.1A)	+ : increase value - : decrease value (Units: 0.1 Amps)	3.5 Amps
Auger High(.1A)	+ : increase value - : decrease value	10.0 Amps

	(Units: 0.1 Amps)	
Low Oil(PSI)	+ : increase value - : decrease value (Units: 1 PSI)	6
Datalog SD card	YES: command to datalog to SD card (if present). NO:command to not datalog to SD card	YES
Pratio Accum#	+5 : increase value - 5: decrease value (Units: 5)	50
High Coolant T	+ : increase value - : decrease value (Units: 1˚C)	98
Display Per .1s	Not Used	N/A
Trst low temp?	+5 : increase value -5 : decrease value (Units: 5˚C)	650
Trst High Temp	+5 : increase value -5 : decrease value (Units: 5˚C)	1050
Tred High Temp	+5 : increase value -5 : decrease value (Units: 5˚C)	975
Pfilter Accum#	+ : increase value - : decrease value (Units: 1)	50
Grate Max Inter	+5 : increase value -5 : decrease value (Units: 5)	30
Grate Min Inter	+5 : increase value -5 : decrease value (Units: 5)	60
Grate On Interv	+ : increase value - : decrease value (Units: .1second)	30
Servo Start Pos	+ : increase value - : decrease value (Units: 1)	30
Lambda Rich	+ : increase value - : decrease value (Units: 1)	140
Modbus Enabled?	NO: Disables modbus YES: Enables modbus if in use	NO

Modbus Baud	+ : increase value - : decrease value (Units: 1)	3
Modbus Parity	+ : increase value - : decrease value (Units: 1)	0
Modbus Address	+ : increase value - : decrease value (Units: 1)	1
Grid Tie?	YES: Grid tie configuration (with Deep Sea) NO: Off-Grid configuration.	Factory default matches original Power Pallet configuration.
Praio Low	+ : increase value - : decrease value (Units: 1)	30
Trst Warn Temp	5+ : increase value 5- : decrease value (Units: 5˚C)	750
Pratio High	+ : increase value - : decrease value (Units: 1)	60
Ash Aug Lim (A)	+ : increase value - : decrease value (Units: 1)	10
Ash Aug Hyst(A)	+ : increase value - : decrease value (Units: 1)	1
Ash Aug Period	5+ : increase value 5- : decrease value (Units: 5)	900

2.12 Alarm

```
ALARM  [current]/[total]
[Alarm Name]
[Alarm Advice]
NEXT   ADV   QUIET  RESET
```

Keypad			
NEXT	ADV	QUIET	RESET
Go to next menu	Show next alarm	Silence alarm (will be turn on again if a new alarm occurs)	Reset conditions causing the alarm

Note: If the alarm caused a shutdown of the engine or auger, the alarm MUST be reset or acknowledged for the system to operate correctly

4. Data Logging Outputs

When data logging with the PCU, a table of values is output with the following variable headings and information.

Variable	Value	Units
Time	Time since PCU is powered on	Seconds
T_tred	Temperature at the restriction of the reduction bell (0˚-1250˚C)	˚C
T_bred	Temperature at the bottom of the reduction bell (0˚-1250˚C)	˚C
T_eng_coolant	Temperature of engine coolant	˚C
T_reactor_gas_out	*Temperature of gas coming out of reactor (Not implemented)*	˚C
P_reactor	Pressure of reactor (vacuum pressure)	Pascals
P_filter	Pressure at the top of the gas filter (vacuum pressure)	Pascals
P_comb	Pressure at the combustion zone (vacuum pressure)	Pascals
P_Q_air_rct	*Not implemented*	Pascals
P_Q_gas_eng	*Not implemented*	Pascals
ANA0	Oxygen sensor signal	˚C
ANA1	Fuel switch state	mV
ANA2	Key switch voltage	mV

ANA3	Engine oil pressure	mV
ANA4	Feedstock auger current	mA
ANA5	Throttle position (enabled since 11/2013) 0.75v-4.25v DC, quantized into integer between 0-1023	enumerated
ANA6	*Coolant Temperature, same as T_Eng_coolant (not used)*	˚C
ANA7	*governor auxiliary signal (not used)*	
Grate	Grate shaking state, enumerated (1=ON, 2=OFF)	enumerated
P_ratio_reactor	Pressure ratio (P_comb/P_react × 100)	0-100
P_ratio_state_ reactor	State of P_ratio_reactor (GOOD, BAD) 30 < Pratio < 70 is good	enumerated
Grate_Val	Grate state accumulator value (0 - 320000 for shaking period)	enumerated state
P_ratio_filter	Filter flow ratio (P_react/P_filter × 100)	0-100
P_ratio_filter_ state	State of filter (good, bad)	enumerated
Lambda_In	Air/fuel ratio reading from O_2 sensor	
Lambda_Out	Air/fuel ratio target for air premix	
Lambda_Setpoint	Air/fuel ratio set point	
Lambda_P	Engine air premix/oxygen sensor P value for PID loop	
Lambda_I	Engine air premix/oxygen sensor I value for PID loop	

Lambda_D	Engine air premix/oxygen sensor D value for PID loop	
P_reactorLevel	Reactor State (0= OFF, 1= LOW, 2= MEDIUM, 3= HIGH)	enumerated
T_tredLevel	Temperature state (0=COLD, 1= COOL, 2=WARM, 3=HOT)	enumerated
T_bredLevel	Temperature state (0=COLD, 1= COOL, 2=WARM, 3=HOT)	enumerated
Engine	Engine state (1=ON, 2=OFF)	enumerated
AugerCurrent	Biomass auger current in 0.1 of an amp	
AugerLevel	Auger state: 0= off, 1= starting, 2= forward, 3= forward, high current, 4= reverse, 5= reverse, high current	enumerated

5. Serial Commands

The following commands are available over a serial connection made at 115600 baud:

Symbol	Action
?	Device info
!	Rewrite specified EEPROM space (give number followed by ';')
p	Add 0.02 to p
P	Subtract 0.02 from p
i	Add 0.02 to i
I	Subtract 0.02 from i
d or D	*Reserved for d in PID (not implemented)*
c	Calibrate Pressure Sensors
s	Add 10 to Servo1 calibration
S	Subtract 10 from Servo1 position
l	Add 0.01 to lambda_setpoint
L	Subtract 0.01 from lambda_setpoint
t	Subtract 100 ms from Sample Period (loopPeriod1)
T	Add 100 ms from Sample Period (loopPeriod1)
g	Shake grate
G	Switch Grate Shaker mode (Off/On/Pressure Ratio)
m	Add 5ms to grate shake interval
M	Subtract 5 ms from grate shake interval
e	Engine Governor Tuning mode
h or H	Print Help Text

Section 6
Engine

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1. Engine

The Power Pallet engine is a spark-ignition engine, similar to those found in most automobiles, with some minor differences: a special-purpose mixing system provides the appropriate fuel/air mixture, and spark timing is advanced significantly to compensate for the slow flame propagation of producer gas. On stand-alone systems, the *Process Control Unit* (PCU) monitors and controls the engine. On grid-tie systems, the DeepSea control unit performs all engine control functions.

1.1 Power Pallet Engines

Power Pallet model	Engine Type
PP20, PP25	GM Vortec 3.0L 4cyl gasoline engine

1.2 Engine Specifications

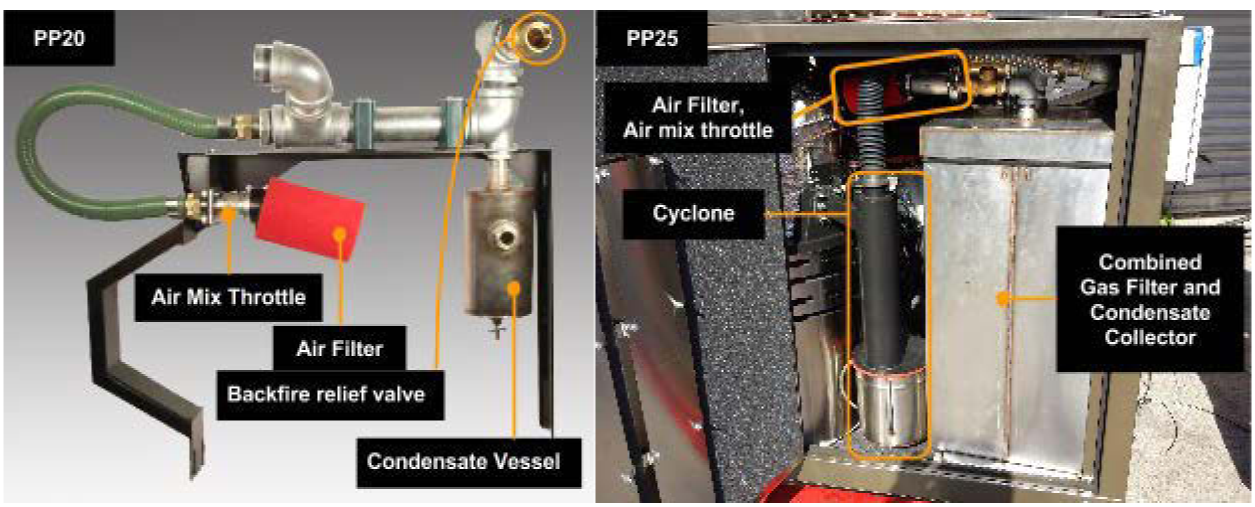
	PP20, PP25 @ 50Hz	PP20, PP25 @ 60Hz
RPM	1500	1800
Spark Advance	38° before top-dead-center	42° before top-dead-center

2. Mixing System

2.1 Overview

The system immediately preceding the engine is the mixing system, which mixes producer gas with air to the correct ratio. 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 dynamically adjusts the air/fuel ratio to a target that is optimal for producer gas. Following the mixing of air and producer gas, condensation that forms in the gas is collected in the condensation vessel. The major components of this system are the condensate vessel, the oxygen sensor, and the air servo, each of which will be covered in detail in the following sections.

The lambda meter and air mixing sub-assembly are shown in the next figure. The air mixer intakes air at the red foam filter, introduces the air stream into the stream of producer gas. The introduction of air causes additional condensation to precipitate out of the gas; in the PP20 Power Pallet, the condensation is collected at the condensation vessel, whereas in the PP25, the condensation drops into the gas filter. A backfire pressure relief valve protects the gas circuit in the occasion of a backfire. The air and fuel mixture then proceeds to the engine.



2.2 Condensate Vessel (PP20 only)

The producer gas, when exiting the filter, is still quite warm and nearly saturated with water vapor. The condensate vessel is a stainless steel jar that collects water that condenses out of the producer gas after it cools from being mixed with air. Excessive condensate may damage the engine if too much of it enters the engine. The condensate vessel captures this liquid, and permits the user to easily drain it.

The condensate vessel has a sight glass that indicates when the condensate should be drained. The condensation vessel should be drained regularly, before there is enough liquid in the vessel to be visible through the sight glass. You should not wait until the sight glass is submerged to drain the vessel; this puts it at risk of being overfilled.

Warning: *Drain the condensate vessel only when the engine is off.*

To drain the vessel, screw the draincock upwards; this opens the internal valve that permits condensate to drain out. Condensate will flow out of the brass tap. Be sure to screw the tap back down when done. It is recommend that a plastic tube be mounted to the brass tap to assist in draining the condensate. (The tube is not included.) See Section 2 for condensate disposal.

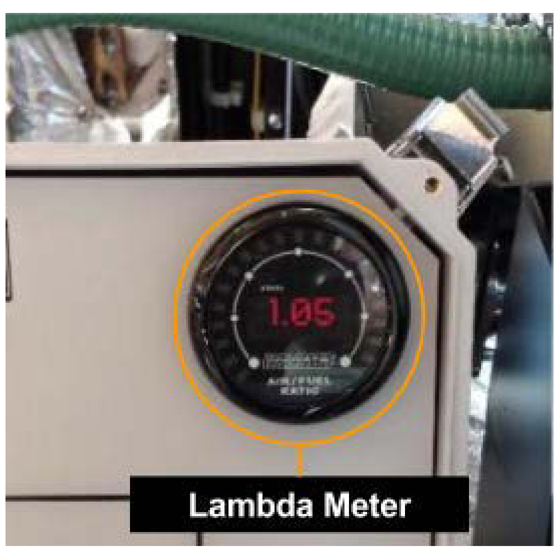
2.3 Oxygen Sensor and Lambda Meter

The Power Pallet uses a wideband oxygen sensor (model MTX-L) and digital lambda meter manufactured by Innovate Motorsports to monitor the oxygen content of the exhaust. The oxygen sensor is located in the engine exhaust stream and detects the amount of free oxygen (O_2) in the exhaust to determine if the fuel mixture is lean (proportion of oxygen exceeds the stoichiometric ratio) or rich (proportion of combustibles exceed the stoichiometric ratio). The sensor is monitored by the lambda meter and an analog output signal is sent to the Process Control Unit (PCU). This signal is used in a feedback control loop to maintain proper air/fuel ratio for desired combustion qualities in the engine. The air/fuel ratio is regulated by targeting a specific *lambda* (λ) value. Lambda is determined by the following equation:

Lambda indicates how the detected air/fuel ratio compares to the stoichiometric ratio; λ=1 indicates an exact match, λ<1 indicates a rich mixture, and λ>1 indicates a lean mixture. The target lambda value set point is 1.05, and is programmed into the code of the PCU board. This value is slightly lean in comparison to a perfectly stoichiometric mixture. This is done intentionally to produce cleaner exhaust emissions.

The software control loop is a proportional-integral-derivative (PID) type. The PID control values are stored in the internal memory of the PCU. If new firmware is to be flashed onto the PCU, be sure to save the PID values, as tuning them can be difficult and is not normally recommended without training. Default PID values may be set in the configurations menu. See Section 5 (Software) for more details on PID configurations.

When the automation system is first powered on, the lambda meter goes into a standby mode while the oxygen sensor begins preheating to reach operating temperature. Once the sensor has reached operating temperature, the lambda value is shown on the meter on the upper right corner of the automation front panel.



The lambda meter receives power from the ATX power supply located on the relay board to prevent signal dropout from larger current loads (e.g. engine start) on the 12 VDC battery. The PCU considers voltages below 0.25V to indicate an error or no signal condition from the lambda meter.

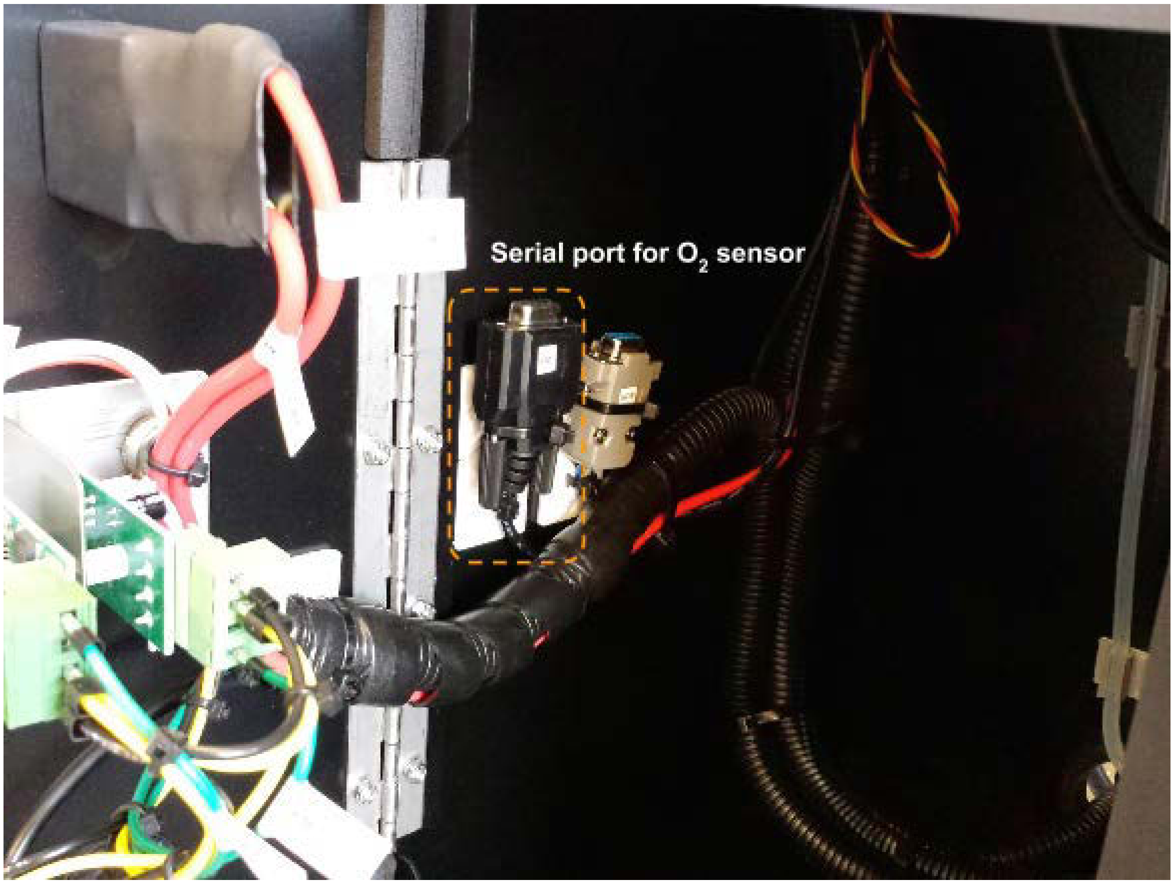
The MTX oxygen sensor comes with Logworks software, a program for updating the firmware, data logging signal values, and for changing the output characteristics of the analog outputs and the display values. The RS232 connector is located behind the automation front panel. It is not typically recommended to make changes to the oxygen sensor values as the control values have been tuned with the sensors stock signal characteristics.

2.4 Programming the Lambda Meter

Note: this section requires the use of the *Bosch Oxygen Sensor LogWorks Program*, or *LM Programmer*, found on the USB drive that comes with the user kit

Every lambda meter must be programmed before the first use. ALL Power Labs performs this programming on every Power Pallet before shipping. The following directions outline this process of re-programming the lambda meter in the field.

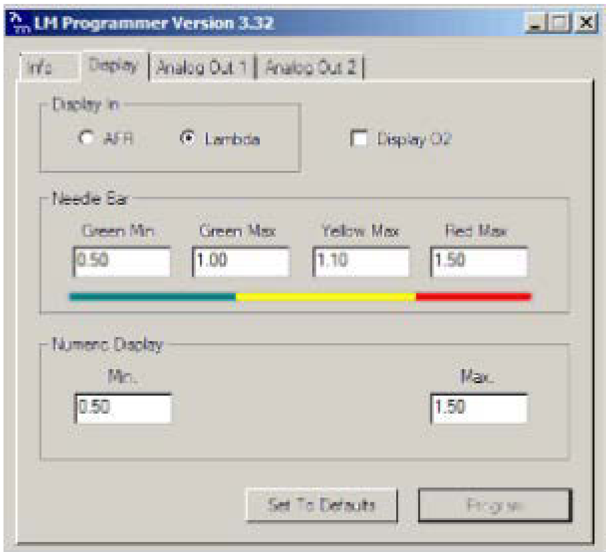
1. Make sure Power Pallet is turned on.
2. Use a serial programming cable to connect your computer to the lambda meter's black serial cable on the left wall inside the podium.

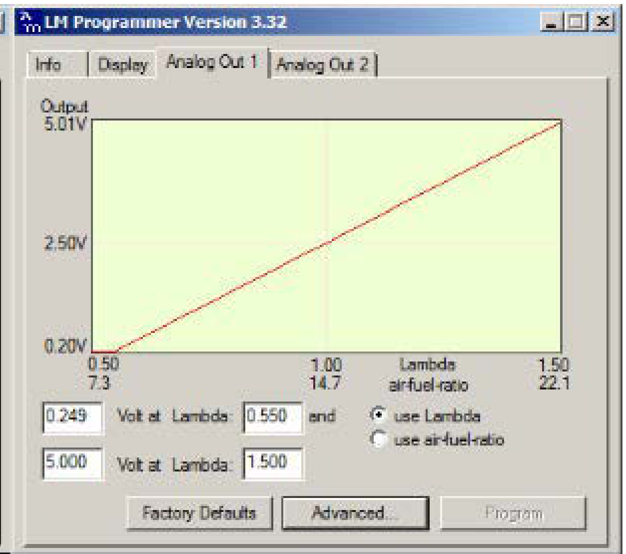


Lambda Meter serial cable, inside the podium on the left wall.

3. Launch **LM Programmer**
4. Select the “Display” tab and set the values below.

Setting	Value	Setting	Value
Green Min	0.5	Red Max	1.5
Green Max	1	Numeric Min	0.5
Yellow Max	1.1	Numeric Max	1.5
Display in	Lambda		

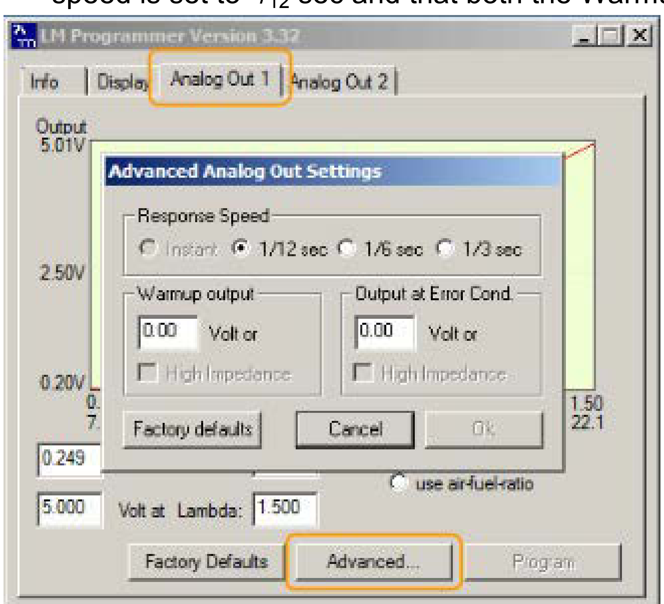




5. Set the same options for the "Analog Out 1" tab using table below:

Volts	Lambda
0.25	0.55
5	1.5

6. Enter the “Advanced” dialog box on the “Analog Out 1” tab and make sure that the response speed is set to $^{1}/_{12}$ sec and that both the Warmup Output and Error Outputs are set to 0.00V:



7. Repeat steps 5 and 6 for “Analog Out 2.”
8. Click “Program” to set these parameters.

2.5 Air Servo

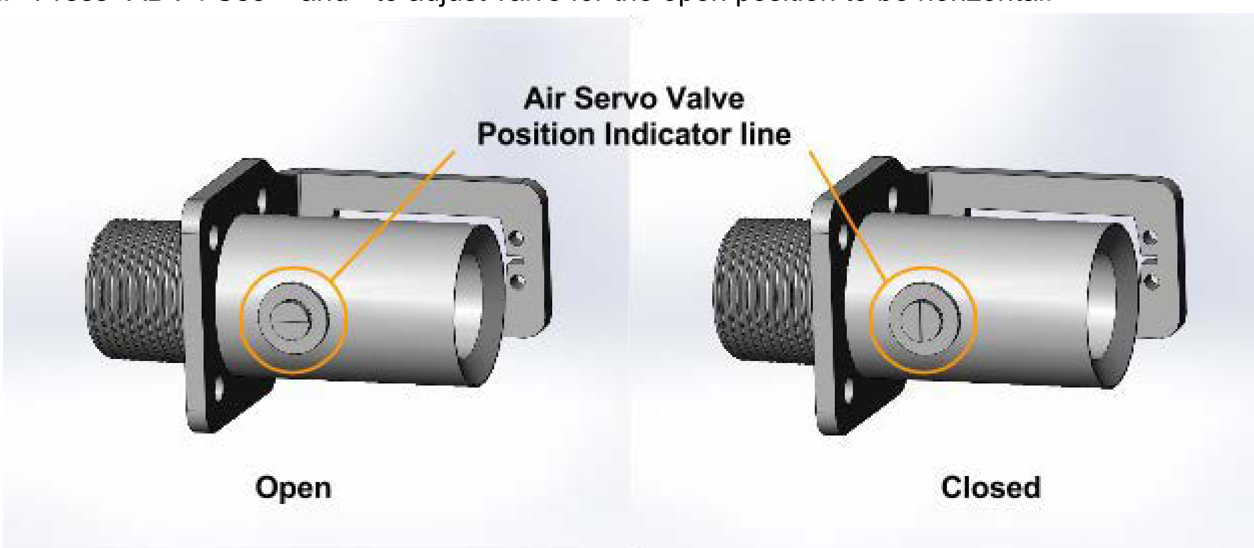
The air mixture servo valve has a small indicator line on the end of the shaft so one can visually see the valve positioning. Attached to the inlet of the air mixture servo valve is an oiled air filter.

2.5.1 Calibration

The air mixture servo is calibrated to the valve at assembly time, but in a few rare cases, it may be necessary for the user to adjust the stored values of the minimum and maximum positions.

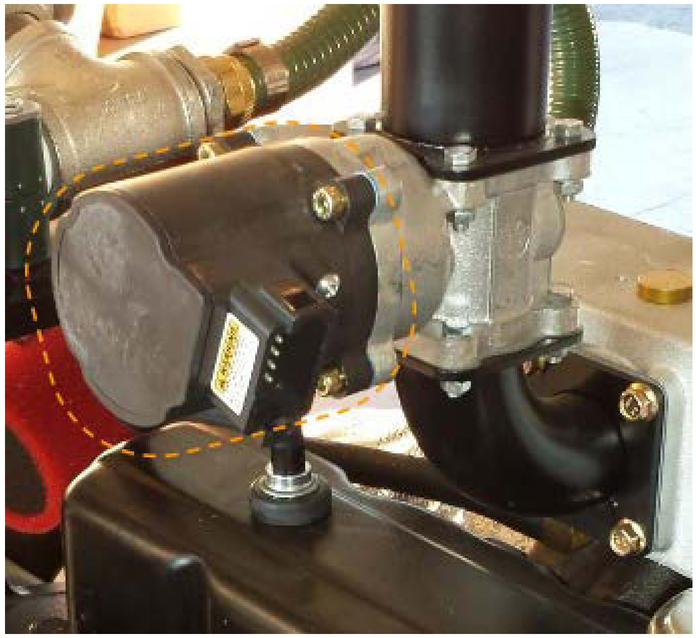
Use the leftmost PCU button to advance to air servo calibration menu. Cursor position indicates the value being adjusted. For “Min” this is for the closed position.

1. Use + and - to adjust valve so that it is closed completely in the vertical position.
2. Press "ADV". Use + and - to adjust valve for the open position to be horizontal.



Observe that the indicator line on the end of the valve shaft. This indicates the valve position.

3. Engine Governor



Note: this section requires the use of the Woodward Governor *L Series Configuration Tool*, found on the USB drive that comes with the user kit

The Woodward L-series 36mm ITB throttle assembly is an engine governor; it maintains a steady engine speed by monitoring the frequency of the electronic signal produced by the MPU (Magnetic Pick-Up), which indicates the flywheel speed, and adjusts the throttle butterfly valve to counteract any acceleration or deceleration of the flywheel. The engine speed must remain steady for the Power Pallet to produce a stable AC electrical output frequency. The governor's operating parameters are programmed using a computer with special software from the manufacturer. Within this program, the settings and control dynamics can be changed. (Default configurations are available.) It is not recommended to change these values outside of the available configurations unless the operator is fully knowledgeable about the system.

Before the governor can be used for the first time it must be programmed and calibrated. The engine governors are calibrated by ALL Power Labs prior to commissioning. In the rare condition that the governor must be entirely reprogrammed and calibrated, the following instructions outline these procedures.

3.1 Programming the Electronic Governor

The governor must be powered on before it can be programmed. The governor power is on the same circuit as the engine ignition. Depending on the Power Pallet model and build date the exact method required for powering on the governor may differ.

3.1.1 Standalone Systems

These instructions are for Power Pallets with a relay board running v1.11 software.

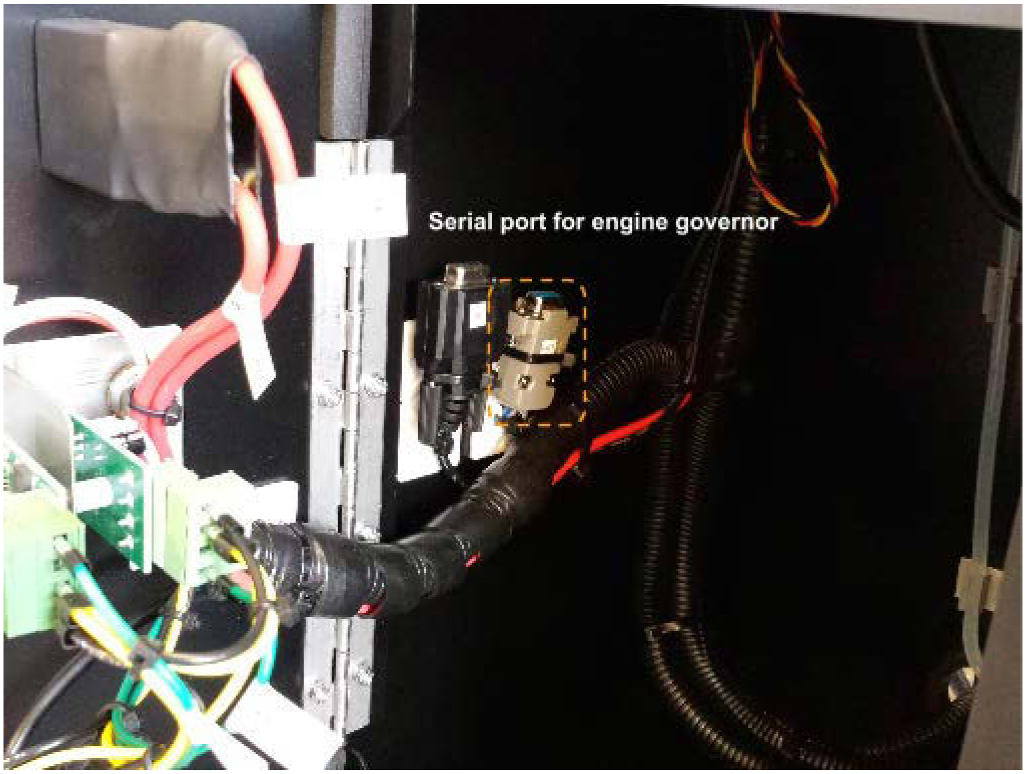
Turn on the Power Pallet. The PCU will boot and show the system status screen. Press the left-most button under the display until the **Testing** screen appears. Press the button labeled **TEST** until the **ENGINE** test mode is activated. The governor should now be powered on, and should emit a soft electronic humming noise.

3.1.2 Grid-Tie Systems

Grid-tie capable systems manage the engine and generator with a dedicated genset controller. On these systems the governor power is connected to the system power and is always on when the system is on.

3.1.3 Connecting To The Governor

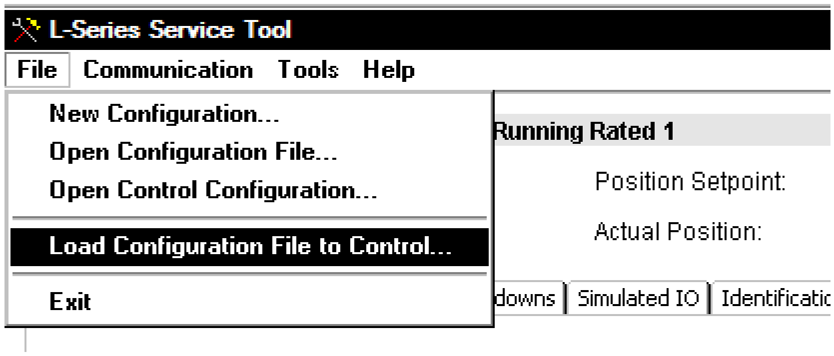
1. Connect computer serial cable to the "**GOV**" RS-232 connector on the left wall inside the automation cabinet.



2. Open the Woodward **L-Series Configuration Tool**, select the appropriate serial port. (The exact port name may vary.) Once connected the configuration diagram will pop up. If screen is blank or lines turn grey, the signal with the governor was lost and will need to be reconnected.

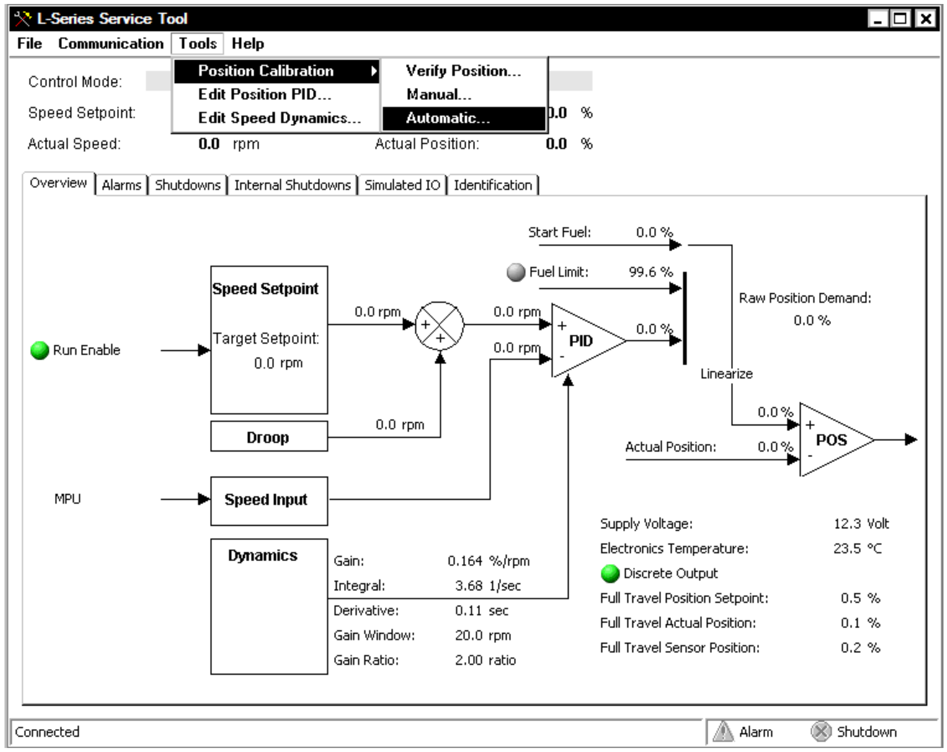
3.1.4 Loading a Configuration File

1. In the L-series Tool select:
   File → Load Configuration File to Control...

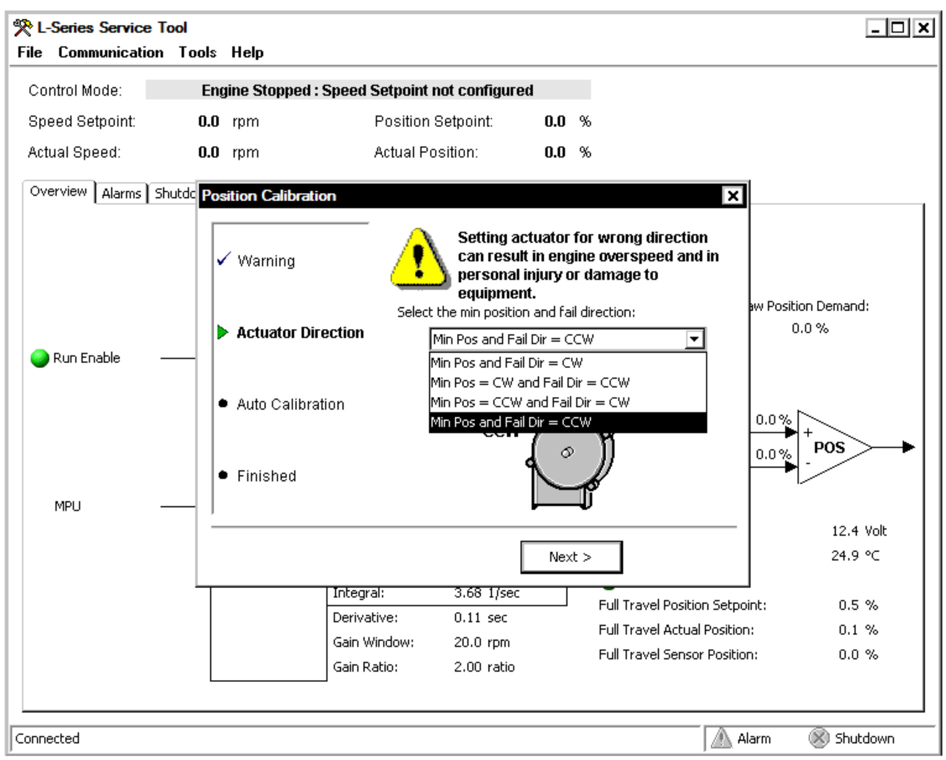


Select the configuration file that corresponds with the specification of the Power Pallet.

3.1.5 Calibrating the Electronic Governor

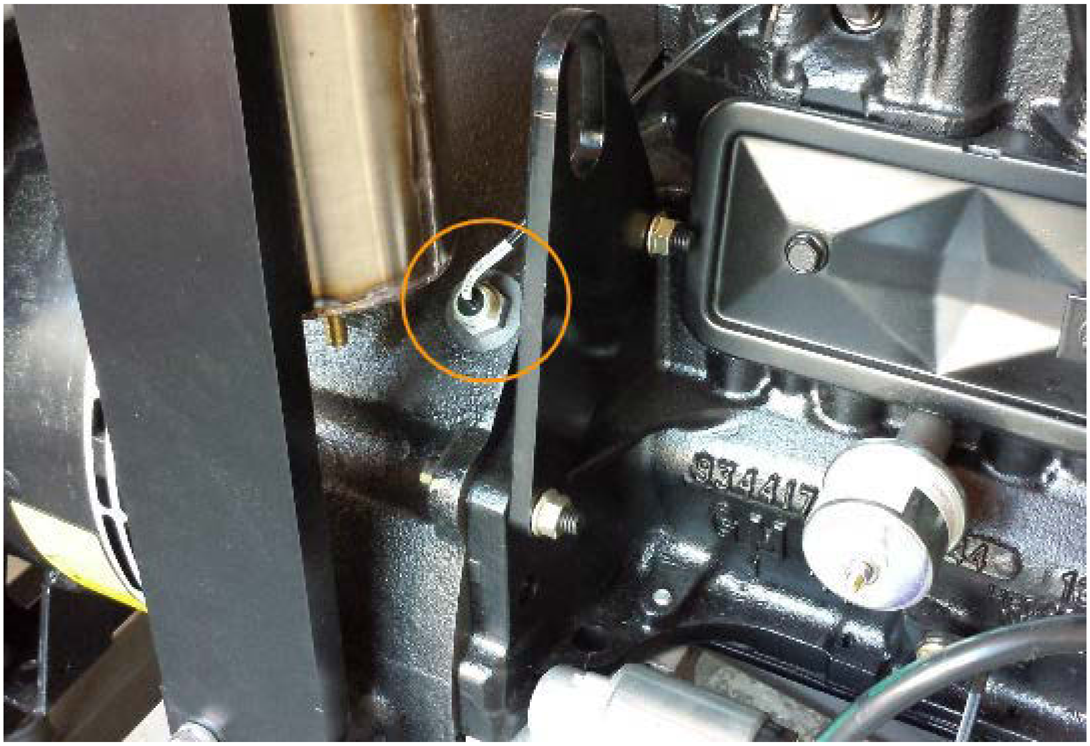


1. To calibrate the governor position use the menu: **Tools →Position Calibration → Automatic**
2. Click the box for “The preceding has been followed” to continue.
3. Follow the on-screen instructions. All settings can be left at their defaults. **Note:** In the “Actuator Direction Screen” make sure counter clockwise (CCW) is selected.
4. Click “Finished”.
5. Power off the Power Pallet



4. MPU

The MPU (magnetic pick-up) is a sensor installed in the engine flywheel housing which outputs a 3V pulsed signal as the teeth on the flywheel pass near it. The frequency of these pulses are used by the engine governor to determine the rotation speed of the engine.



The MPU is circled above. In the rare case where you must make adjustments, you may need to detach the condensate vessel for ease of tool access to the MPU.

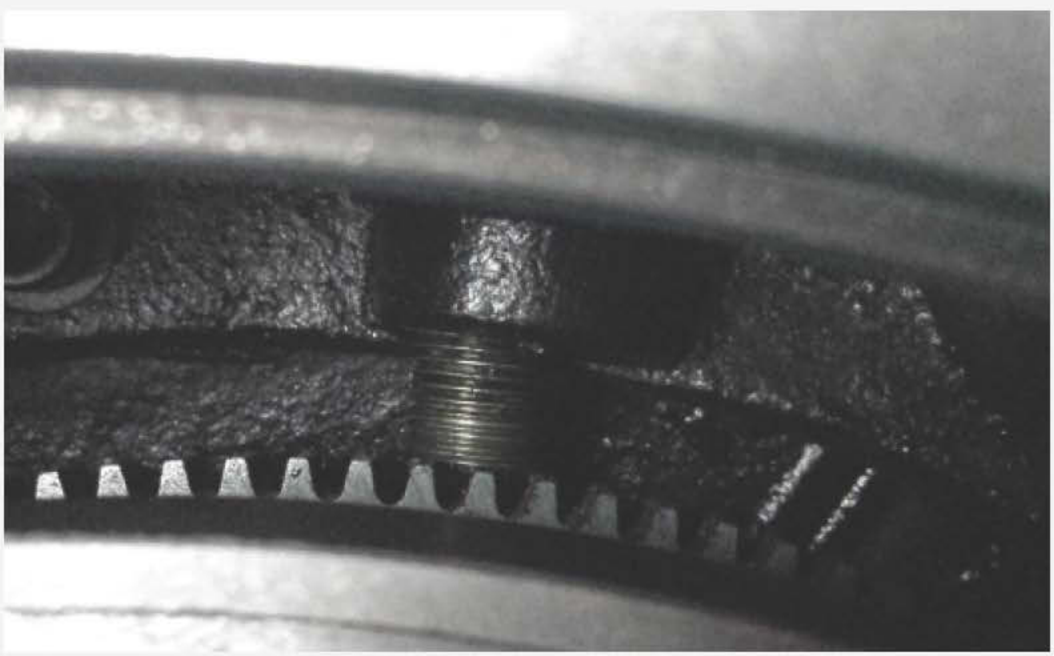
Installation and tuning of the MPU is performed at the factory and should not normally require adjustment. In the case that the MPU is disturbed, fails to produce a strong enough signal or requires replacement, it must be re-adjusted.

4.1 Adjusting the MPU

Warning: MPU adjustment risks

Extreme care must be taken when adjusting the MPU to avoid contact with the flywheel teeth. Contact with the flywheel teeth can result in destruction of the MPU.

This MPU was destroyed by contact with the flywheel teeth while the engine was running.



Internal view of the MPU. It is only separated a few thousandths of an inch from the flywheel.

The MPU is essentially as close as possible without actually touching the teeth; the separation is only a few thousandths of an inch. This close positioning enables the MPU to produce a 3V signal for the governor by induction from the teeth of the flywheel.

To adjust the MPU:

1. Make sure the engine is off.
2. Loosen the lock nut until the sensor can turn freely.
3. Thread the MPU in until it just contacts the teeth of the flywheel. Do this by hand if possible; if using a tool, be careful to stop turning just as the MPU contacts the flywheel.
4. Turn the MPU back ¼ a turn.
5. Use a wrench to hold the MPU steady and lock the MPU's position in place with the lock nut.
6. Turn the engine with the starter while measuring the voltage on the sensor terminals using a meter in the AC mode. Adjust the sensor until the voltage reads in the range of 2-3V. If you must make adjustments, do so only with the engine off. Each adjustment should be about ⅛ of a turn or less; be very careful not to have the sensor touch the flywheel to avoid a collision. If contact is made, back the sensor out by a ¼ turn, and try again.
7. When the voltage is around 3V, hold the sensor steady and lock its position with the lock nut.

Section 7
Generator

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Disclaimer

All electrical output connections are the responsibility of, and are at the discretion of, the end user. When making terminal connections, all cable and terminal lugs should meet the relevant standards of the country of final destination. It is recommended that power conditioning be used for the operation of sensitive equipment. ALL Power Labs is not responsible for any damages due to inappropriate wiring or output connections, variations in voltage, or otherwise. This document is to be used only as a general guide for technicians who have read and understand the installers manuals of the Mecc Alte generators. All configuration changes and connections to the generator should be performed by a qualified electrician in conformance with local electrical code. Please refer to the generator configuration documentation provided for specific wiring information.

1. Generators

The electric generator unit of the Power Pallet is a 6-winding alternator (AC generator). The generator can be wired in several configurations to produce 3-phase or split single phase current. The frequency of the alternating current produced by the generator is a function of engine speed.

	20PP/50Hz	**20PP/60Hz**
Model	MeccAlte NPE32 E/4 12-wire 4-Pole Generator	MeccAlte NPE32 E/4 12-wire 4-Pole Generator
Poles	4	4
Engine RPM	1500	1800

Note: The frequency stated on the generator nameplate may be different from the actual operating frequency. This is because the generators come with a standard stator unit that can operate at either 50Hz or 60Hz, even if the generator nameplate is indicated as 60Hz. Operating frequency is determined by governor setting.

1.1 Frequency

Two common frequencies of alternating current are used through most of the world are 50Hz and 60Hz. Because a significant amount of equipment is designed to use only one frequency or the other it is vital that the Power Pallet produce current at the correct frequency for the equipment that it will power.

The generator is driven synchronously with the engine, meaning the generator turns at the same rate as the engine, and the frequency of the alternating current (AC) produced by the generator is a multiple of the engine speed. A 2-pole generator unit will produce current frequency that is the same as the engine speed; a 4-pole unit will produce current at twice the frequency of the engine speed. For example, a 2-pole generator driven by an engine at 1800 rotations per minute (RPM) is the same as a frequency of 30 Hertz

$$\frac{\text{1800 rotations}}{\text{1 minute}} \times \frac{\text{1 minute}}{\text{60 seconds}} \times \text{1 pair of poles} =$$

$$\frac{\text{30 rotations}}{\text{1 seconds}} \times \text{1 pair of poles} = \text{30Hz AC current}$$

A 2-pole generator driven at 1800 RPM produces a 30hz AC current.

When a 4-pole generator is attached the AC frequency will be 60HZ:

$$\frac{\text{1800 rotations}}{\text{1 minute}} \times \frac{\text{1 minute}}{\text{60 seconds}} \times \text{2 pair of poles} =$$

$$\frac{\text{30 rotations}}{\text{1 seconds}} \times \text{2 pair of poles} = \text{60Hz AC current}$$

A 4-pole generator driven at 1800 RPM produces a 60hz AC current.

The operating frequency of the Power Pallet is configured during production. The model PP20 Power Pallet can be converted between 50hz and 60hz by re-programming the electronic governor unit and adjusting the engine spark timing. See the engine section for details on performing these tasks.

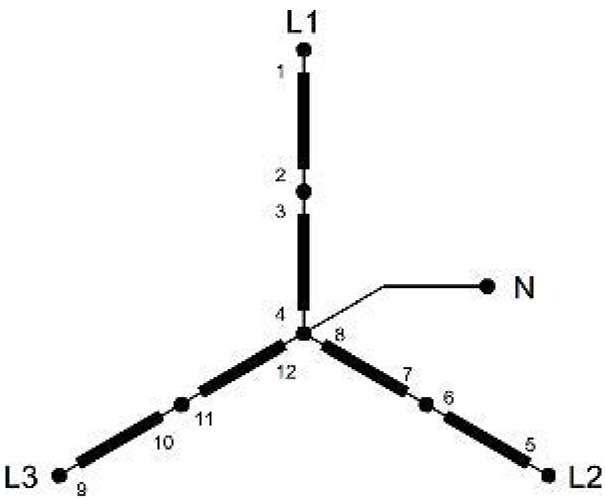
2. Wiring Configurations

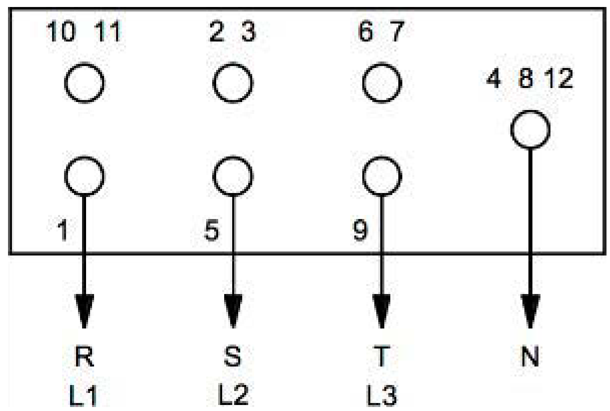
The generator's stator unit contains six independent windings. Each winding is wired to a numbered ring terminal at either end. To change the configuration of the generator, the terminals must be connected the appropriate studs on the terminal block inside the housing on the top of the generator. The Figures 1 (for 50Hz) and 2 (for 60Hz) below shows terminal connections for several common configurations. The tables following each figure list the voltages.

The terminal block and AVR (Automatic Voltage Regulator) are in the box above the generator.

In the photo of the terminal block shown above, observe that each of the terminals has a blue collar with numbers printed in white. The numbers indicate the number of each terminal, corresponding to the numbers in the diagrams on the following pages. The rear row has two terminals per bolt. The *shorting bars* (also known as *bridges* or *link bars*) are stored on the right-most pair of bolts. These may be used to configure the generator output according to any of the configurations on the following pages by shorting between the terminals as indicated on the terminal block diagrams.

2.1 Series Star	**50Hz**: 400 VOLT (L-L), 3 PHASE **60Hz**: 480 VOLT (L-L), 3 PHASE

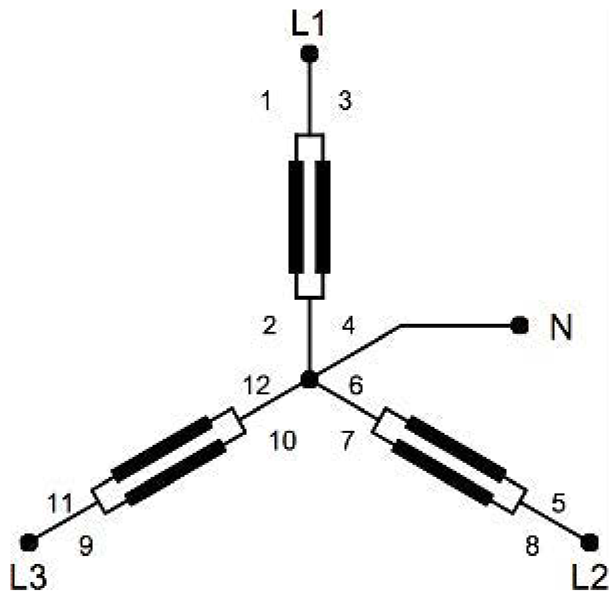


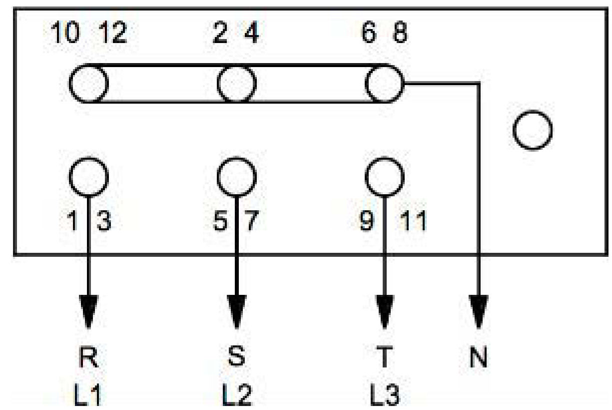


Legs		Voltages			
L1-L2-L3	**50hz** **60hz**	380 3Φ 415 3Φ	400 3Φ 440 3Φ	415 3Φ 460 3Φ	440 3Φ 480 3Φ
L-L	**50hz** **60hz**	380 415	400 440	415 460	440 480
N-L	**50hz** **60hz**	220 240	230 254	240 266	254 277

2.2 Parallel Star

50Hz: 200 VOLT, 3 PHASE; 115 VOLT, 1 PHASE
60Hz: 208 VOLT, 3 PHASE; 120 VOLT, 1 PHASE

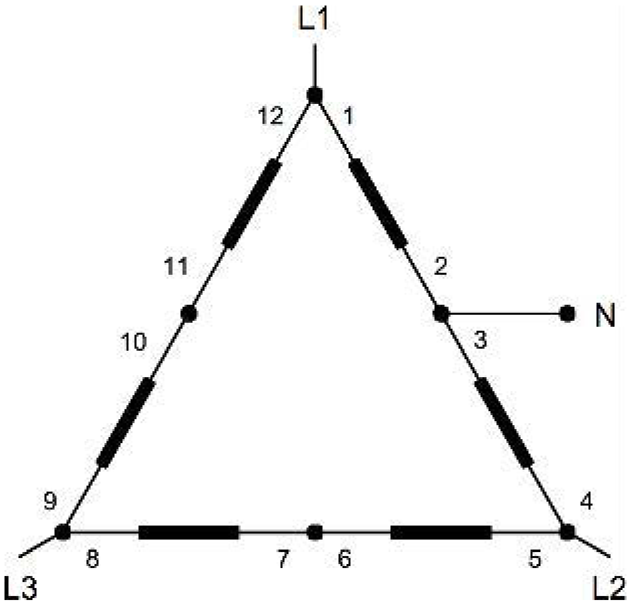


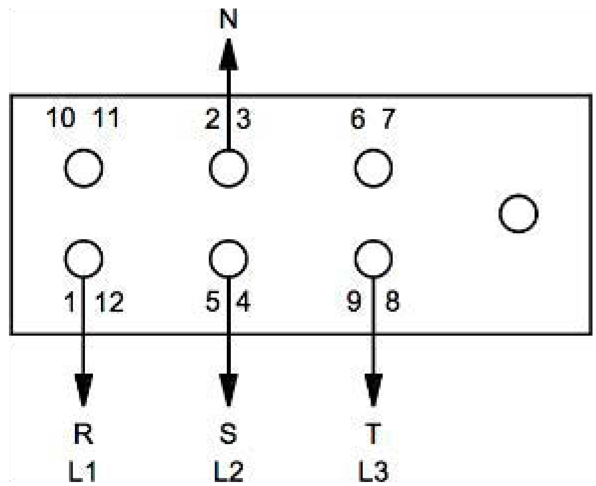


Legs		Voltages			
L1-L2-L3	**50hz**	190 3Φ	200 3Φ	208 3Φ	220 3Φ
	60hz	208 3Φ	220 3Φ	230 3Φ	240 3Φ
L-L	**50hz**	190	200	208	220
	60hz	208	220	230	240
N-L	**50hz**	110	115	120	127
	60hz	120	127	133	139

2.3 Series Delta

50Hz: 230 VOLT, 3 PHASE; 115/230 VOLT 1 PHASE
60Hz: 240 VOLT, 3 PHASE; 120/240 VOLT 1 PHASE

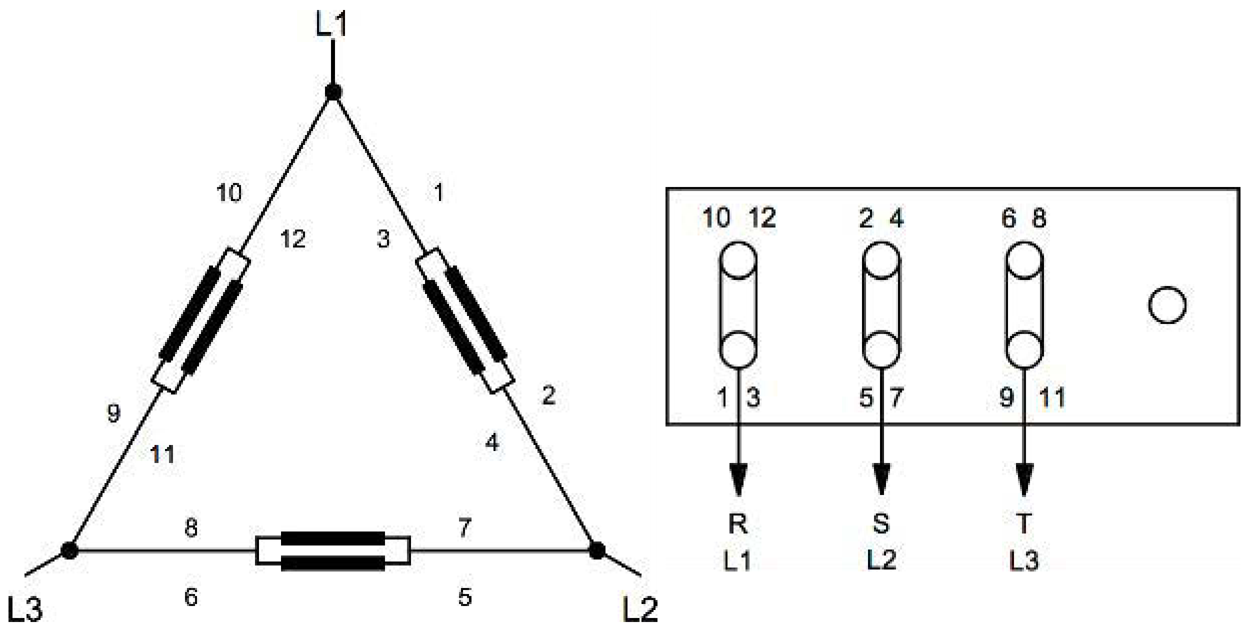




Legs		Voltages			
L1-L2-L3	**50hz** **60hz**	220 3Φ 240 3Φ	230 3Φ 254 3Φ	240 3Φ 266 3Φ	254 3Φ 277 3Φ
L-L	**50hz** **60hz**	220 240	230 254	240 266	254 277
N-L	**50hz** **60hz**	110 120	115 127	120 133	127 139

2.4 Parallel Delta

50Hz: 115 VOLT, 3 PHASE; 115 VOLT, 1 PHASE (L1-L2)
60Hz: 120 VOLT, 3 PHASE; 120 VOLT, 1 PHASE (L1-L2)

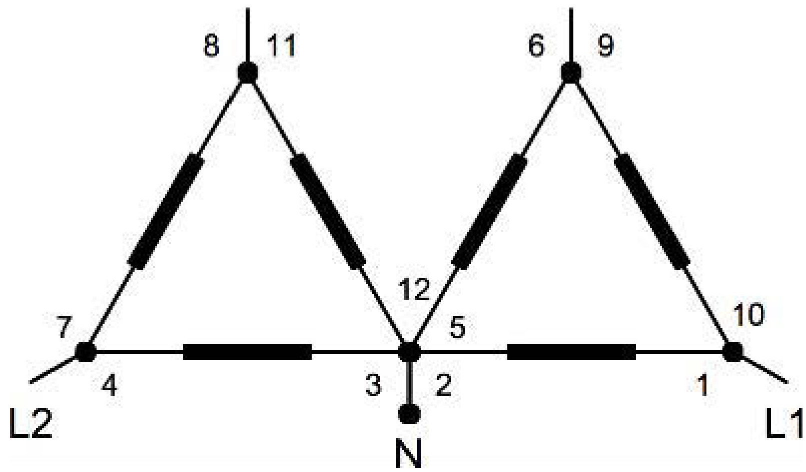


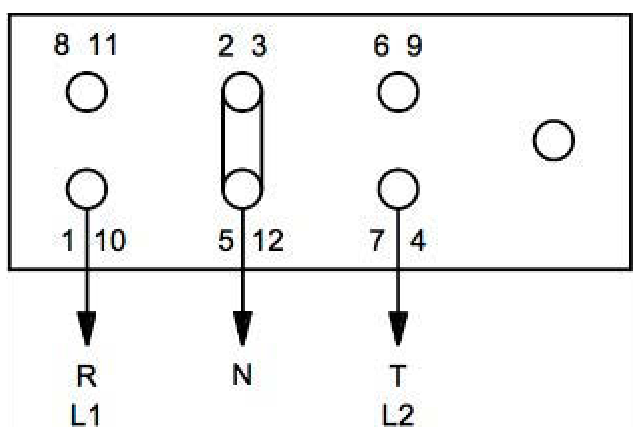
Legs		Voltages			
L1-L2-L3	**50hz** **60hz**	110 3Φ 120 3Φ	115 3Φ 127 3Φ	120 3Φ 133 3Φ	127 3Φ 139 3Φ
L-L	**50hz** **60hz**	110 120	115 127	120 133	127 139

2.5 Double Delta

50Hz: 115/230 VOLT, 1 PHASE
60Hz: 120/240 VOLT, 1 PHASE

Note: purely 1 phase configurations are not compatible with the grid-tie system



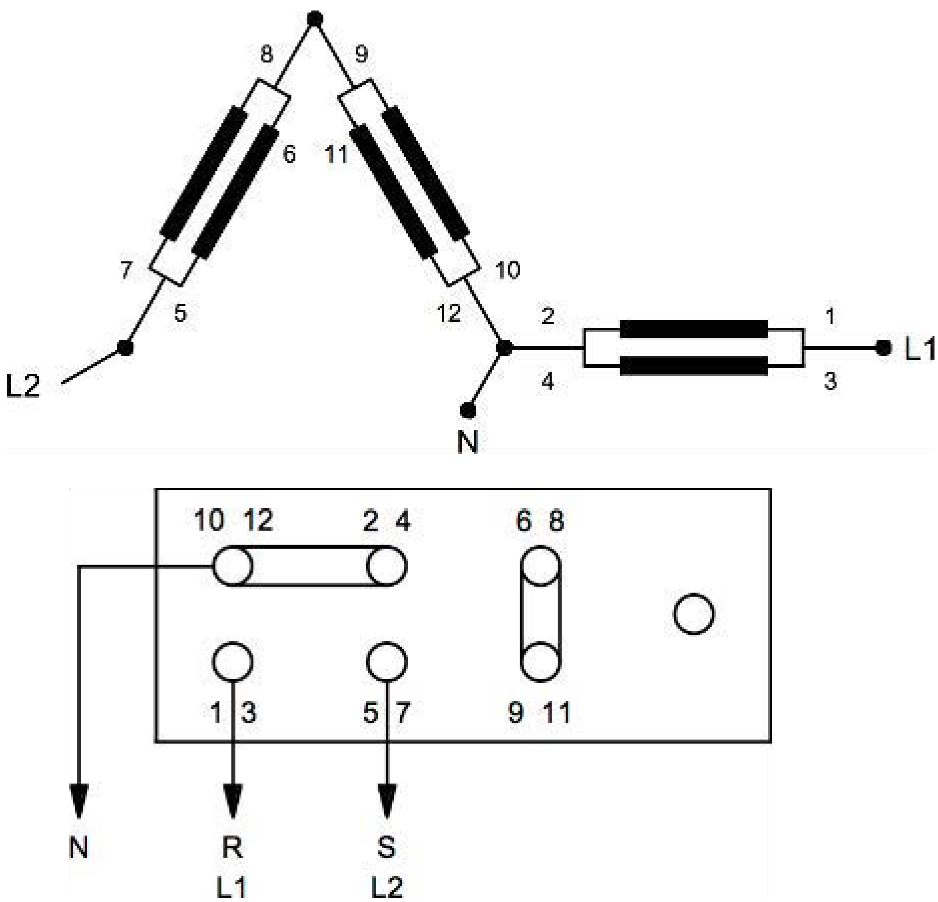


Legs		**Voltages**			
L-L	**50hz**	220	230	240	254
	60hz	240	254	266	277
N-L	**50hz**	110	115	120	127
	60hz	120	127	133	139

2.6 1 Phase Zig-Zag

50Hz: 115/230 VOLT, 1 PHASE
60Hz: 120/240 VOLT, 1 PHASE

Note: purely 1 phase configurations are not compatible with the grid-tie system



Legs		Voltages			
L-L	**50hz**	220	230	240	254
	60hz	240	254	266	277
N-L	**50hz**	110	115	120	127
	60hz	120	127	133	139

2.7 Load Imbalance

While the maximum load imbalance for three-phase loads is not specifically stated in the relevant literature, it is generally accepted that three-phase motor loads are not tolerant of voltage imbalance of more than 2% between phases. Therefore, it is advisable to ensure that, when single-phase loads attached to a generator wired for three-phase current, the loads should be evenly distributed among each phase.

3. Automatic Voltage Regulator (AVR)

AVR Type DSR.

The Automatic Voltage Regulator (AVR) moderates the generator AC voltage and provides various protection mechanisms. Output voltage is adjusted by a potentiometer on the AVR board.

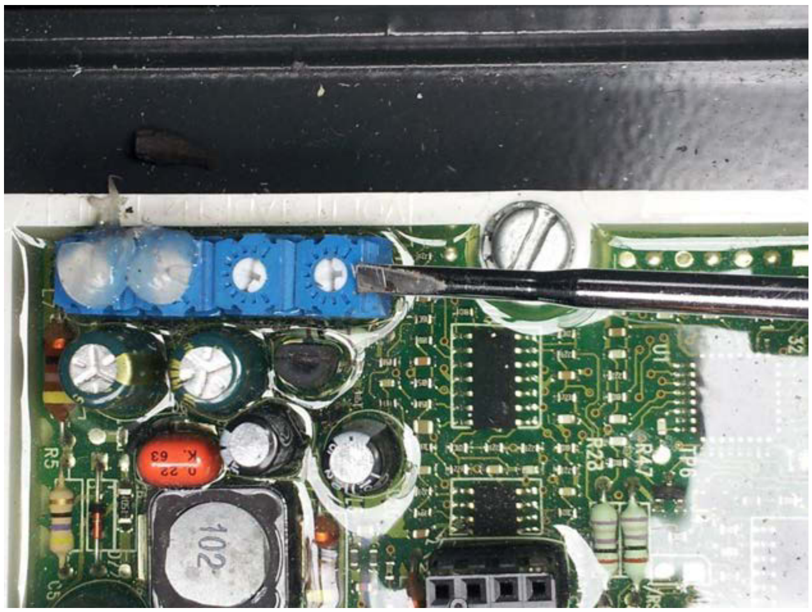
Note: The AVR senses voltage only on one leg. Please refer to the Mecc Alte Installers manual for further information

The manuals for the AVR are provided for the DSR model (Manuale_DSR_EN_rev05.pdf) and the SR7 model. Only the DSR type is currently used.

3.1 AVR Adjustment

This procedure should be performed if changing the stator wiring or if the voltage is outside of the desired range. In order to measure and adjust the voltage, the generator must be running at the target operating frequency and any load must be disconnected.

WARNING: *This procedure involves working near a high-voltage power source and should only be performed by a qualified technician.*



Location of the VOLT potentiometer

Measure the voltage from L1 to L2. Refer to the wiring chart to determine the proper terminals. Adjust the VOLT potentiometer on the AVR until the measured voltage is as desired.

Section 8
Technician Level Maintenance

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1. Warning: Maintenance Hazards

The gas circuit is under vacuum pressure and at high temperatures during operation; doing any of the above while the machine is hot will introduce air into the gas circuit where it can mix with hot combustible gases, cause internal fires and explosions, and/or release enough carbon monoxide to seriously harm the user.
While the gasifier is hot (whether in operation or stopped), ***do not***

- remove the ash collection vessel
- open the ash inspection view port
- open the reactor access door
- remove the cyclone ash can

These operations must not be done until the exposed parts of the gas circuit, such as the cyclone, are cooled to the point of being safe to the touch. Cooling may take half an hour or more, depending on ambient temperatures.

1.1 Carbon Monoxide

The gas left in the gas circuit after the machine has cooled down will still be rich in carbon monoxide, which is a poisonous gas as well as a fire hazard. Carbon monoxide exposure is also a risk when refilling the hopper. Always have adequate ventilation and do not do Power Pallet maintenance in the presence of open flames and sparks. When opening the reactor or any portion of the gas circuit, be sure to have the blowers turned on to a low setting to draw the gases away from the work area. Be sure to have the carbon monoxide detector near by when maintaining the machine to alert you to dangerous concentrations of carbon monoxide.

Operations that may involve a Carbon Monoxide hazard will be indicated with the following sign:

1.2 Re-establishing air-tight seals

Everything that can be unsealed and opened by the Power Pallet operator in the course of maintenance must be re-sealed with an air-tight seal because air leaks are hazardous to the machine. Examples of such seals include

- the hopper lid,
- the cyclone ash can,
- the gas filter lid
- the hose connections to the filter and its lid
- the reactor access door
- the ash collection vessel connection and ash removal port
- the gasifier viewport

Air leaks can cause internal fires that cause irreversible damage to the machine.

1.3 Scope of this Section

Please see the *Power Pallet Operation Manual* for the schedule of maintenance and all operator level maintenance procedures. The following are maintenance instructions that should be conducted by trained technicians only.

2. Gasifier

2.1 Overhaul Gasifier

At the suggested interval, the reactor will need to be taken out of the gas cowling and purged of any accumulation around the air lines. The gasifier and the major components attached to it must be disassembled, and everything in the way of removing the gasifier must be disconnected and removed from the skid.

Some of these steps may involve securing the item you are detaching with straps to an overhead support as you unbolt them.

- Unplug the fuel auger.
- Empty the gasifier of all feedstock and charcoal.
- Empty the hopper; secure the hopper to an overhead support and unbolt the hopper from drying bucket; set the hopper aside, and keep the nuts and bolts.
- Unbolt the drying bucket bottom plate; detach hoses.
- Secure the drying bucket to an overhead support; unbolt the drying bucket from the gasifier; set the drying bucket aside, and keep the nuts and bolts.
- Unplug all of the electric cables, pressure tubes, and thermocouples attached to the gasifier and to the ash handling system.
- Detach the ash collection vessel.
- Detach exhaust conduit from gasifier.
- Secure the gasifier to an overhead support; unbolt the gasifier from the skid, and lift it off the skid; remove the grate basket door and set this aside to be used with the new reactor.
- Detach the gas filter and all supporting gas lines for ease of access to the central electronics conduit.

Then after the gasifier is free from connections to other components, unbolt it from the gas cowling and lift it upwards. Be careful to not damage the airlines. Use a wire brush to brush off accumulation on the airlines and the inside of the gas cowling.

2.2 Overhaul Hopper

The plexiglass viewport can show some deterioration over time and may need replacing. Remove the old plexiglass view port and use the clear silicone to adhere it back onto the hopper. Reassemble the flanges and tighten evenly. Wipe off any excess silicone. Wait until it is fully dry before operating the Power Pallet.

2.3 Replace Gasifier

Remove the gasifier as described in *2.1 Overhaul Gasifier* section above. Insert the new gasifier. Assembly is the reverse of disassembly.

3. Engine

3.1 Governor Deep Clean Procedure

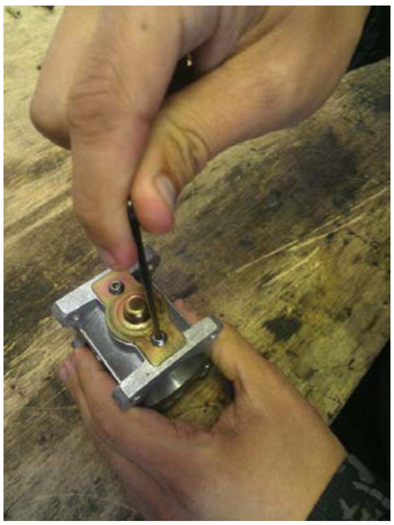
The daily servicing of the governor is explained in the *Power Pallet Operation Manual*. These instructions for the deep cleaning of the governor are provided in the case that disassembly may be required.

> **Warning:** The following procedure should only be done by a trained professional. It is possible to break the internal parts which will require a replacement of the entire governor. We do not sell individual subparts to the governor.

Tools needed

- 8MM combination wrench (x2)
- 4MM Hex key
- 3MM Hex key
- 2.5MM Hex key
- Alcohol
- Mallet

Disassembly

		
Remove governor and throttle body from intake runner.	Disconnect the governor from the throttle body.	Remove the two screws that hold on the throttle plate.
		
Remove the end cap.	Remove the retaining screw.	Note the orientation of the spring.
		
Use a drift and mallet to remove the shaft and	Carefully note the order in which the components are	The outside bearing is held in place with a pressed-

bearings.	installed.	in retaining ring. The ring should be installed with the chamfered edge oriented inward.

Cleaning

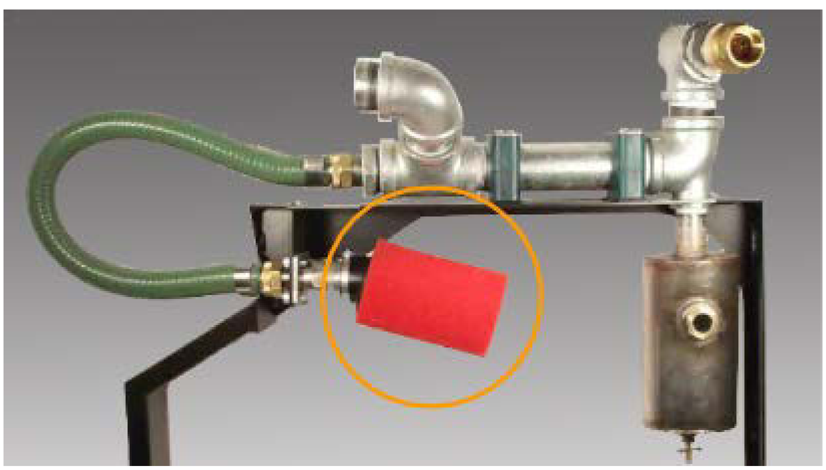
Clean all metal components in denatured or isopropyl alcohol. Tough deposits may require soaking components overnight. A wire brush may aid in faster cleaning. Bearings should turn smoothly.

Reassembly

Generally speaking, reassembly is the reverse of removal. All moving parts should be lubricated with light bearing grease. Bearings should be pressed in carefully by hand. Use light-duty thread locking compound on all screws. Verify the throttle plate is clear of the bore and does not bind anywhere in its movement.

3.2 Cleaning the Air Filter

The red foam air filter immediately preceding the air mixing system on the lid of the gas filter should be cleaned with soapy water to remove accumulated dust and lightly re-oiled with a light oil such as mineral oil or filter foam oil.



3.4 Spark Plug Inspection

The spark plugs of the Power Pallet may gradually accumulate mineral fouling when mineral rich feedstocks are used:

Examples of fouled spark plugs that caused malfunction.

At the recommended engine tune-up interval, be sure to inspect the spark plugs, and either clean the with a wire brush or replace them.

To remove the spark plug, pull the spark plug boot off and use a spark plug socket wrench to unscrew the plug.

3.5 Overhaul Engine

Overhauling the engine includes the following: flushing the radiator, replacing the starter motor, thermostat, alternator, water pump and adjusting the engine valves. Please refer to the *PSI 3.0L INDUSTRIAL ENGINE SERVICE MANUAL* for replacement instructions.

3.6 Turbo

3.6.1 Turbo Maintenance

The turbo will need to be disassembled and cleaned according to the maintenance schedule. Use isopropyl alcohol to soak the parts and use a toothbrush to clean off any accumulation. There is an O-ring located inside the turbo that may also need to be replaced.

3.6.1 Replace Turbo

To replace the turbo, disconnect all gas, exhaust and coolant line connections. Installation is reverse of removal.

3.7 Replace Oxygen sensor

To remove the oxygen sensor, use a flat head screwdriver to separate it at the connector near the sensor. Then gently unthread the sensor from the exhaust and replace with a new one. You will need to also calibrate the sensor in free air before running. These instructions are in the *Power Pallet Operation Manual.*

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Chapter 9 Troubleshooting

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1. Most Common Problems

The most common problems that cause failures to start are:

- **Starter not turning over: Insufficient battery charge**— during the flaring process, the air and gas blowers, igniter, grate shaker, and all of the electronics are being powered by the battery. If the battery is insufficiently charged, the flaring period can deplete the battery to the point of being insufficiently charged to start the engine. Charging the battery or replacing it with a fresh battery should fix this problem
- **Engine governor and ignition not working: blown fuse**— if the hour meter does not come on and the engine governor does not produce a soft electronic whine when you turn on the Power Pallet, the circuit they share may not be receiving electricity. Check fuse F6 on the relay board to see if this fuse was blown. See Chapter 4 of the Technician’s Handbook for an annotated image of the relay board identifying fuse F6.
- **Engine turns over but won’t start: gas path obstruction**— if the engine starter is clearly operational, but the engine still won’t start, the gas path may be obstructed. Make sure the the valve leading to the engine is open and the valve leading to the flare is closed; also check the throttle valve to make sure it is not obstructed with tar residues.

2. Gasifier Troubleshooting

2.1 Testing the fuel level switch

2.1.1 Paddle Switch

To test the fuel level switch, access the testing mode screen on the PCU. In the fuel level switch test mode, it should give the following values:

- Numbers less than 600 means the switch is depressed by feedstock.
- Numbers near 900 means the switch is untouched, and feedstock level is low .
- 0 means there's no signal and the circuit should be checked for loose connections.

2.1.2 Flex Reed Switch Troubleshooting

1. The switch remains closed at the limit of the the paddles' travel. (Auger remains on when paddle is depressed)
    a. Loosen jam nut and back off the reed switch assembly 1/8 turn. Retighten jam nut and repeat test.
2. The switch remains open in the rest position. (Auger stays off when reactor is empty)
    a. Check to make sure the Switch Rod is concentric with switch body. If not, complete Flex Switch Calibration procedure.
    b. If the Switch Rod is concentric, loosen jam nut and screw in the reed switch assembly 1/8 turn. Be sure there is enough clearance between the switch rod and the reed switch by moving the paddle by hand. Retighten jam nut and repeat test.
3. If scenarios 1 and 2 cannot be resolved, remove the reed switch assembly and test by checking continuity through the switch. The reed switch should show no continuity in the absence of a magnet, and SHOULD show continuity when a magnet is held against the distal end of the threaded stud. The switch should NOT have continuity through any one of the leads and the body of the switch.

2.2 Testing the Thermocouples

The thermocouples may need to be tested to check to see if they are giving correct readings. To test a thermocouple on the Power Pallet, turn on the Power Pallet, unscrew and extract the thermocouple while leaving it plugged in, then apply a small flame such as a flame from a lighter to the tip of the thermocouple and watch for the temperature reading on the PCU to rise. If the thermocouple reading does not rise when heat is applied to the thermocouple, the thermocouple itself is probably damaged, and should be replaced.

2.3 Testing for leaks

Air leaks constitute an entire class of problems that can arise anywhere there is a joint or interface or even a faulty hose. Because the entire gas circuit is under vacuum pressure when the machine is operating if there is a leak, air will leak into the gas circuit rather gas leaking out. Because of this, testing for leaks is not always easy. The most common ways to detect a leak are:

- **Observing the emission of smoke when the machine is shut down**—
  Immediately after the Power Pallet is shut down, the system will no longer be under vacuum pressure. There will be enough residual heat in the system to continue pyrolysis, so the biomass in the pyrolysis column will continue to smoke. The smoke will eventually migrate throughout the system. If you observe smoke leaking from any point, the location where the smoke is exiting the gas circuit is usually the location of the leak.
- **Observing excessive heat anywhere on the gas circuit during operation**—
  if there is a leak, and air is being introduced into the gas circuit while the machine is operating, it is not unusual for internal fires to ignite around the leak. Rapid heating surrounding a likely leak point indicates that an internal fire is burning near an air leak. Undetected air leaks can cause a jet of flame to burn right through whatever structure is in front of the leak. The machine should be stopped as soon as possible if this is the case to avoid irreversible damage.

An example of localized overheating due to an internal fire caused by an air leak from a poorly re-sealed interface.

- **Scanning for leaks with a mechanic's stethoscope, or other detection methods—** The most reliable way to detect leaks is to use one of the detection methods listed below to detect air rushing out of a leak as a little bit of positive pressure is applied to the gas circuit while the machine is fully cooled down. To apply positive pressure, shut both of the valves leading out of the gas filter and to apply a low level of positive pressure to the gas circuit (as little as ½ psi, no more than 2 psi) using an adapter and a restricting valve with a pressure dial connected to a source of compressed air. Alternatively, you can connect some other source of blown air, such as shop vacuum cleaner's air outlet. To detect leaks, the following methods all work quite well: (**WARNING**: Be sure to totally purge the gas circuit with the gas blowers before you attempt any positive pressure leak tests; if there is a leak, carbon monoxide left in the gas circuit can leak out and asphyxiate the technician testing the machine.)
    - **Spray soapy water over likely leak points.** If there is a leak, you will see bubbles form around the leak. Be sure to wipe away the soapy water when you finish testing for leaks.
    - **Slowly move a smoking incense stick past potential leak points** while the machine is under positive pressure. If there is a leak, you will see the stream of air disturb the smoke from the incense. **WARNING**: the All residual gases must be purged before this test. If combustible gases leak out, the smoldering tip of the incense stick may ignite the gases and cause a fire.
    - **Slowly move a downy feather past potential leak points.** The principle of this test is the same as above; you should be able to see any leak disturb the feather as you move it by.

If you find a leak, the appropriate remedy depends on what is leaking. Any seals you can tighten should be tightened; if a leak is occurring on a hose or other component, it may be patched as a temporary fix while a replacement is ordered. Often times, leaks near gaskets between imperfect mating surfaces can be remedied by the application of RTV silicone sealant.

2.4 Tables of Symptoms

2.4.1 Hopper

Symptom	Possible root cause	Solution
Air leaks around hopper	1) Damaged lid gasket	Align or replace lid gasket
	2) Misaligned bolts or flange gasket	Align or replace drying bucket flange gasket. If leaking seen through bolt holes, apply silicone RTV around bolt hole and reinsert bolt.

2.4.2 Auger

Symptom	Possible root cause	Solution
Auger jamming	1) Feedstock is too difficult for auger	Remove any material that is over 1.5" in length. Avoid feedstock that has a natural tendency to entangle or other natural transport difficulties.
	2) Auger is bent.	Disconnect the auger assembly from the drying bucket. Gently bend the auger spiral to be straight in alignment with the auger motor shaft.
	3) Auger is catching on inner wall of drying bucket.	portion of the drying bucket right above the base of the auger may need to be trimmed or bent forward.
	4) Fuel level switch needs adjustment.	The fuel level switch may not be actuating properly to turn the auger off in time allowing the auger to compact the fuel into the reactor. Double check that the switch works and adjust the tension spring on the fuel level switch.
	5) Tar build-up around fuel switch obstructs motion	Unscrew the entire fuel switch fixture and clean out all tar with solvents.
Auger not turning on	1) Fuse needs replacement.	Check the two forward and reverse fuses for the auger on the relay board.
	2) Relay needs replacement.	Replace relay on the relay board.

	3) Fuel level switch is damaged.	Replace.
	4) Tar build-up holds switch in off-position.	Unscrew the entire fuel switch fixture and clean out all tar with solvents.
Low current state for auger	1) Bridging in the hopper or drying bucket.	Check the two forward and reverse fuses for the auger on the relay board.
	2) Low/No feedstock	Fill the hopper up with feedstock.
PCU is not indicating the correct auger state.	1) Current sensing not working properly	Make sure current sensor is wired correctly or current sensor may need replacing.

2.4.3 Cyclone

Symptom	Possible root cause	Solution
Ignition of gas inside the cyclone indicated by excessive heat, blistering paint, etc.	Cyclone ash can does not have an air tight seal	Take the can off of the cyclone and clean the components. Make sure the gasket is seated properly; replace gasket if damaged.
No condensate or ash accumulates in the cyclone ash can after running for a while.	Blockage in the inside the cyclone	Use a wire brush and a stick to check for and clear out blockages in the cyclone.

2.4.4 Gas filter

Symptom	Possible root cause	Solution
Pfilt is less than **Preactor** by a difference greater than 30 (3 inches WC)	Filter media is saturated with tar, or was packed with too many fines.	Change the filter media.

2.4.5 Flare

Symptom	Possible root cause	Solution
Too much air allowed into flare stack at low flows	Air blower gasket stuck in housing.	Adjust the gasket so that it seats properly in the gasket housing.
Flame seen above the flare stack	Flare does not have enough air; flame starved of oxygen.	Increase air blower output using the knob on the control panel.
Flare is not lighting.	1) White smoke seen as steam actually seen during start up of the reactor.	Reactor is not lit yet. White smoke is actually steam coming off of moisture in the system.
	2) Improper air to fuel ratio in flare stack.	Try increasing or decreasing the air blower to achieve the right air to fuel mixture in the flare stack.
	3) Igniter not working properly.	Test igniter using testing screen on the PCU. Check fuse on the relay board. Replace igniter tip if damaged.
Gas blowers are not able to achieve over 5 WC.	1) Charcoal is packing densely the grate basket	Clean out the reactor and char basket, then use correctly sized charcoal and feedstock for the second start.
	2) Gas blower malfunctioning.	Check to see if both fans are operational and the fan blades are intact or fouled with tar; clean with alcohol if fouled.
	3) Low battery	Recharge the 12V DC battery.

2.4.6 Air inlet

Symptom	Possible root cause	Solution
Smoke seen passing through air inlet check valve when machine is off.	1) Gasifier is on an incline, causing check valve flap to fail to seal.	Level the Power Pallet.
	2) Check valve flap physically obstructed or stuck open by tar.	Tap on the flap and it should fall back into place. Remove check valve and remove tar residue with alcohol.

2.4.7 Difficulty starting and operational problems

Symptom	Possible root cause	Solution
Ignition port melted from heat	Torch being applied to ignition port for too long by operator trying to light the reactor.	Lighting the reactor should take no longer than 10 minutes. If feedstock does not seem to light, see the row below.
Reactor temperatures not increasing after extended application of torch to the ignition port	Bridging, non-combustible debris, or other problems may be hindering ignition.	Open the PyroReactor viewport and break the bridging with a stick. If bridging is a common occurrence, feedstock might need to be sifted or processed differently.
Melted or damaged components, or discoloration from local over-heating	Air leak in somewhere in the gas circuit causing a fire in the wrong place	Find and replace the part with the air leak. If it is a welded piece of the pyroreactor, the whole pyroreactor will need to be replaced. Ensure that there are no leaks in the reactor around the bungs, flanges, gaskets, and joints before running the system.
Difficulty starting reactor	Clinker formation around the air nozzles; high temperatures around nozzles may be causing ash fusion	Clean out the reactor, chip away clinkers. Perhaps use a lower mineral feedstock.

2.4.8 P_{ratio} problems

Symptom	Possible root cause	Solution
Pratio too low	1) **Pratio** reads lower than 10 during start up and does not increase due to leaking upstream of the reactor.	Make sure there is no leaking in the reactor lid, reactor port cover, hopper and drying bucket connection, or hopper lid.
.	2) **Pratio** is 15-20 due to packing in the reduction bell	This can happen when using feedstocks that produce very fine particles of charcoal, such as pelletized feedstocks.
	3) Charcoal used for starting gasifier has too many small pieces or made from pelletized charcoal dust.	Turn up the gas blower or increase the load on the engine or repack the reactor with coarser charcoal, sifted to remove dust.
	4) Grate basket may be	Clean out grate basket, perhaps blend

	fouled with clinkers	clinker-prone feedstock with lower-mineral feedstock.
	5) **Pratio** is below 15 for most all of the run	If the gasifier operates well in spite of the low **Pratio**, this is not a problem, and alarm threshold needs to be adjusted.
Pratio too high	1) Reactor is out of feedstock.	If the hopper, drying bucket and the reactor are completely empty of feedstock the system should turn off. If it does not shut down automatically, turn the system off immediately and wait until the system cools before filling with feedstock. Operating without sufficient feedstock is an explosion hazard.
	2) Bridging in the hopper, reactor or the drying bucket.	Open the reactor lid port, and check to see if there is bridging; use a rod to break apart any bridges. Be careful as air allowed through the port may cause flame to rise.
	3) Jammed auger.	Check auger to see if it is working properly; a broken auger may fail to push material into the reactor, leading to **Pratio** problems.

2.4.9 Temperature related problems

Symptom	Possible root cause	Solution
Trst too low or not increasing	1) Wet feedstock or charcoal.	Replace with appropriate feedstock and charcoal.
	2) **Pratio** values are too low/resistance is too high in the reactor to support proper reaction rates	Feedstock particles are too fine in reactor, pelletized feedstocks may have fallen apart and caused packing in the reactor.
.	3) Gas flows too low in reactor	Increase flows by turning up the gas blower or increase the load on the engine/generator.
	4) Thermocouples installed incorrectly	Make sure thermocouples are properly connected and installed to the right depth.
	5) Faulty thermocouple or grounded thermocouple	Test the thermocouple, replace if needed.

	6) Fault connection on the PCU board.	Switch **Trst** and **Tred** to see if each connector gives the same reading, replace if needed.
Temperatures are too high (above 1020˚C)	1) Insufficient feedstock in pyrolysis zone (pyrolysis and tar cracking are endothermic, and help regulate top temperatures.)	Turn off the system by closing the gas or engine valve. Fill the hopper up with feed stock when the system is cool.
	2) Fuel burns too hot; coal, and some nut shells burn extremely hot	Do not use coal in gasifier; if nut shells are giving excessive temperatures, blend with some wood chips, or use some fuel with higher moisture content.
	3) Localized combustion due to leaks inside the system	Shut down the system, locate leak and repair.
Thermocouple reading does not exceed 2	Faulty extension cable.	Replace extension cable.

3. Engine Troubleshooting

3.1.1 Engine

Symptom	Possible Cause	Corrections/Solutions
Engine cranks but does not start.	1) If first starting the system up, there will be air in the gas filter and the lines leading to the engine.	Cranking the engine will purge the air until wood gas and the correct air mixture reaches the engine. This can normally take longer than a typical engine start approx 20 sec). **Do not operate the starter continuously for more than 30 seconds.** Be sure to allow the starter motor to rest for 30 seconds between start attempts. If the engine does not start after 3 attempts allow the starter to cool for 10 minutes before attempting to start again.
	2) Gas quality may be poor.	Switch over to the flare and make sure that the reactor is producing good gas and the reactor temperatures are ideal. If the flare will not ignite please refer to the troubleshooting section in Chapter 3.
	3) Gas filter may be clogged.	Check the filter media to see if it needs to be changed. Tars may cool from previous run and typically condense around the bottom grate. Reactor vacuum (`Preact`) should be less than 3 inches of water (30 units) above reactor vacuum. Change the filter media if needed. Refer to the gas filter documentation for further information.
	4) Throttle valve may need maintenance	Check throttle valve operation, clean if necessary.

	5) Air mixture servo not opening properly	Check lambda meter for error code. Use air servo adjustment menu to verify operation of the air servo.
	6) Grid Tie Systems: “Engine On” signal from DeepSea to PCU disconnected.	Mixture on grid-tie systems is controlled by the PCU. A single wire from the DeepSea controller to the tells the PCU to enable mixture control. If this connection has been severed, the PCU will not control mixture and the engine will not start.
Engine starts then abruptly shuts off after a few seconds.	1) This can be due to the governor automatic shutdown thresholds.	Refer to the governor and throttle documentation.
	2) Air mixture servo not opening properly.	Possibly due to oxygen sensor malfunction. See oxygen sensor documentation.
Engine shuts down. PCU display shows oil pressure alarm.	1) Engine oil level low	Check oil level with dipstick. Add oil if necessary.
	2) Configuration wrong in the configuration screen of the PCU	Check the configuration screen on the PCU and make sure it matches the configuration of the Power Pallet.
	3) Jumper configuration wrong on the relay board	Check relay board documentation and make sure that the jumper is configured properly.
Engine backfires	1) Air/Fuel mixing in the line before engine.	Check for air leaks upstream of the engine. Check the gas lines and gas filter and other components upstream for air

		leaks.
	2) Poor gas quality	Switch to flare. See troubleshooting section in Chapter 3.
	3) Wrong spark timing	Confirm spark plugs are wired for correct engine firing order.
Engine pre-ignition when starting	Poor spark plug wire seating	Confirm wires are well seated.
Engine speed unstable	Sticky valve on engine governor	Open up throttle and clean valve using alcohol or other solvent.

3.1.2 Troubleshooting for the Air Servo

Symptom	Possible Cause	Solution
Servo does not move when adjusted	1) Servo not connected to PCU	Check all wiring connections from servo to PCU
	2) Adjustment outside of servo range	Make sure adjustment is between 0 and 180.
	3) Servo faulty	Replace servo
Servo having difficulty rotating all the way	Air filter could be obstructing the servo.	Pull air filter away from servo linkage. Check air servo for internal binding. This will be indicated by vibration felt on the plastic servo body
Min or max position outside of servo range		Remove servo from valve and adjust or flip the valve around. Set servo to lowest position using adjustment menu (See Air Servo section above), disassemble, and re-align with splines on butterfly shaft.

3.1.3 Troubleshooting for the Governor

Issue	Possible Cause	Solution
Service tool does not	1) Governor not powered on	Ensure PCU is in engine test

connect to governor		mode, listen for governor "whine"
	2) Serial cable not connected	Verify all cable connections, ensure use of correct port on automation assembly.
	3) Harness connections mis-wired	Verify governor and key switch harness RS-232 connections at relay board. Wire colors are marked on the board.
	4) Relay board serial buffer IC is faulty	Perform serial loop-back test. Replace buffer IC if necessary
	5) Governor is faulty	Replace governor
Engine shuts down abruptly after starting.	The engine may have exceeded the underspeed threshold of the governor and the governor may have gone into automatic shutdown mode.	Start the engine under a lighter load and ramp more slowly to the desired load.
Engine can crank for more than 90 seconds but fails to start.	Throttle sticking and unable to open or actuate properly.	Throttle valve in need of maintenance. Follow maintenance instructions above.

3.1.4 Troubleshooting for the Oxygen Sensor and Lambda Meter

Symptom	Possible Cause	Solution
"Please connect the device to a serial port and switch it on" when launching LM Programmer	1) Serial cable not connected	Verify serial cable connection
	2) Wrong communications port on lambda meter	Ensure cable is connected to "OUT" port on lambda meter
	3) Faulty lambda meter	Replace meter
"No serial port available" when launching LM Programmer	1) USB serial adapter not connected	Verify USB connections
	2) Required device drivers not installed	Install appropriate drivers

	3) No serial port	Obtain USB serial adapter or use computer with serial port
Lambda meter display unintelligible after programming		Power cycle lambda meter. Replace if issue continues.
"E2" error on lambda meter display	Oxygen sensor not connected	Check all oxygen sensor cable connections and ensure plugs are fully engaged to their sockets
E8 error shown on oxygen sensor dial, “No O2 sensor Signal” shown on PCU.*	Signal error caused by either low battery or poor connection to sensor	Check continuity between the oxygen sensor module and the sensor wire on the Relay Board.
E9 error shown on oxygen sensor dial. Or oxygen sensor resetting over and over. *	Low battery voltage	Charge the 12VDC battery.
Air mix servo not responding.	1) O_2 sensor issue.	Refer to O_2 sensor troubleshooting above.
	2) Air mix servo wire connection loose or misconnected.	The air mix servo connector should be securely connected to SRV0 on the PCU board
While running the flare, O_2 sensor reads very rich , starts at 1.5 then decreases while engine is not on.	Leak in the Pyrocoil	Replace Pyrocoil.

4. Generator Troubleshooting

Symptom	Possible Root Cause	Solution
Heavy load step causes frequency drop	High instant torque on engine	Adjust STAB pot (this will cause voltages to dip, but allow larger loads to be placed on the engine with minimized frequency impact). See Meccalte “regulators.pdf” for tuning method.
Low frequency while engine throttle is wide open	The load is above what engine/gasifier can support under current conditions	Improve gas quality. Reduce load.
Voltage is greater than +/- 5% from expected voltage.	VOLT needs adjustment	Take off the front panel of the generator to access the VOLT adjustment pot. Adjust accordingly, measuring voltage on legs with a volt meter.

**Please see the Mecc Alte Installers Manual for more troubleshooting.*

5. Automation Assembly Troubleshooting

5.1 Troubleshooting FETs

To test operation of a FET output, use a voltmeter on the low-resistance or diode-check setting. The meter should read a low resistance to ground when the FET is switched, on and infinite resistance when it is switched off.

5.2 Firmware Upload Troubleshooting

Symptom	Possible Cause	Solution
PCU serial port does not appear in menu / “Serial port not found” error when uploading	FTDI USB serial driver not installed	Install USB serial driver on computer
Unable to find COM port	USB cable not connected	Verify USB connection at top of PCU, back of podium front door, and front of podium front door.
Unable to find COM port	No power to PCU	Turn on Power Pallet using power switch on podium front door
Error "avrdude: stk500_getsync(): not in sync: resp=0x00" when uploading	Programming jumper not set	Ensure programming jumper (ARD) is set.

5.3 Relay Board Troubleshooting

Symptom	Possible Cause	Solution
Subsystem not functioning	1) Fuse may have blown	Check fuse and replace if needed (wire connection in center of fuse is broken and plastic housing is discolored/darkened).
	2) Wires disconnected	Check all connections in screw terminals on harnesses (at bottom of relay board) and on FET screw terminals at relay board. Check that all connectors on the other

		ends of the harnesses are fully plugged into their mates. Use visual inspection and continuity test with volt-meter
	3) Circuit boards, harnesses, or subsystems incorrectly wired	Check all connections in terminals inside the enclosure and at subsystems against Wiring Harness Documents (found in appendices to Technician’s Handbook). Use visual inspection and continuity test with volt-meter.
	4) Faulty connection to PCU	Check that PCU FET outputs and analog inputs have a solid electrical connection.
	5) Faulty relay	Replace relay with spare
	6) Faulty subsystem component	Check voltage at subsystem when PCU commands it on. Replace if necessary.
	7) Faulty component on PCU	Check voltages on PCU. Replace PCU f necessary. (see section on FET output troubleshooting)
Fuse blows more than once.	Shorted wiring connection	Check for shorted connections on relay board or swapped wires in harnesses and subsystem (refer to Wiring Harness Documents found in appendices).

5.4 Troubleshooting the PCU

Symptom	Possible Cause	Solution
Unable to read LCD screen/ nothing on LCD screen	1) Contrast non-ideal for lighting conditions.	Adjust the blue contrast knob or cover the LCD screen to shade from direct sun.
	2) Display connection not secure.	Check and secure connections.
	3) Display malfunction.	Replace display.
	4) ATX power supply may be faulty	Check that the green ATX LED on the right side of the relay board comes on. If not, replace ATX.
White blocks across the screen	1) Contrast not ideal	Adjust contrast knob
	2) Firmware corrupt	Re-upload firmware
LCD screen stuck on splash screen	Program timing glitch due to key switch being on when automation is turned on	Turn key switch to the OFF position and power cycle system.
Incorrectly proportioned pressure values	1) Pressure lines incorrectly connected	Connect pressure lines to correct ports on PCU
	2) Sensor offset calibration incorrect	Remove lines, calibrate sensors (see page 6 of this chapter for details)
Incorrect temperature readings	1) Thermocouple extension disconnected or connected to incorrect socket	Verify thermocouple extension connections at PCU and at connection to thermocouple
	2) Thermocouple faulty	See section on operational troubleshooting
PCU resets when USB cable connected or disconnected	ARD jumper set	Disable ARD jumper

ALL Power Labs
personal scale power

Chapter 10
Grid Tie Module

Featuring the DSE 8610 Grid Tie Auto-start Load Share Control Module

Table of Contents

Brief Explanation of the Grid Tie System

The Power Pallet Grid Tie module uses a Deep Sea 8610 controller to synchronize the Power Pallet with and export power to the grid. It is configurable through the *Deep Sea Configuration Suite Software* with many settings also accessible through the controller interface. ALL Power Labs ships the Power Pallet Grid Tie systems already configured. The settings should not be changed unless done so by a trained professional.

1. Warnings/Hazards

NOTE: Observe local regulations. Local codes may supersede these recommendations. Plan your system with your utility company and an electrical engineer before connecting to the grid. Be sure to read the DSE manuals and the manuals for the generator before attempting a grid tie installation.

- Improperly connecting the Power Pallet to an electrical system can cause electrical current from the generator to backfeed into the utility grid or microgrid when it should be shut down. This backfed power could unexpectedly electrocute utility workers or other individuals who come into contact with wires or electrical equipment, or cause the generator to explode or catch fire. It is imperative that you consult the utility company or a qualified electrician in order to determine the additional equipment that will be required to safely interconnect to the utility grid or microgrid.
- Disconnect the electrical system from the grid before carrying out maintenance or repairs on the grid tie system.
- There is risk of danger to equipment if the equipment is in mains paralleling mode and ‘stand-alone mode’ is enabled. In this case, the system will close to dead bus and thus will energize the grid causing risk danger to equipment and operator or linemen.
- Improper connections to an electrical system can allow electrical current from the generator to backfeed into the utility lines. Such backfeed may electrocute utility company workers or others who contact the lines during a power outage, and the generator may explode, burn, or cause fires when utility power is restored. Consult the utility company or a qualified electrician.
- Always disconnect system from the grid before servicing. Do not work on equipment when powered.

III. Reference Materials

Deep Sea Electronics has a full listing of manuals and quick start guides available in several languages on their website available for download. Please visit:
http://www.deepseaplc.com/support/product-software/dse-genset/synchronising-load-sharing-controllers/dse8610.
This document may occasionally refer you to one of the following technical manuals.

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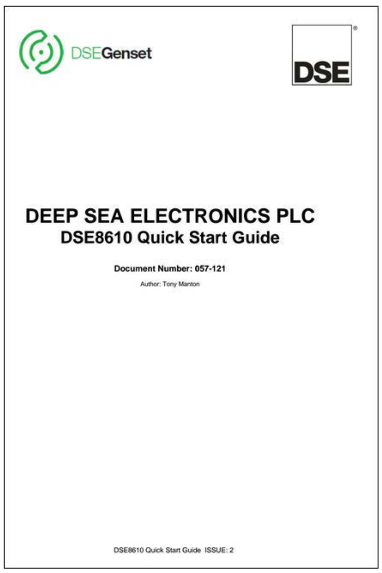
<td>
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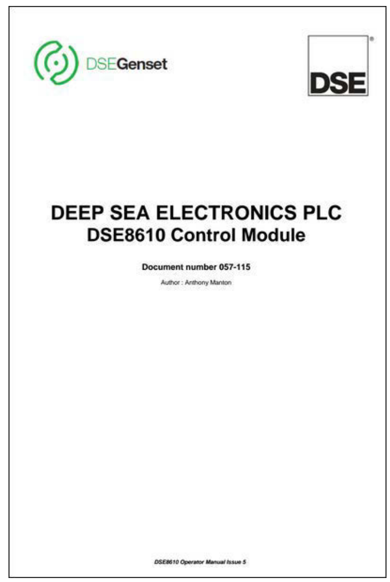
<td>
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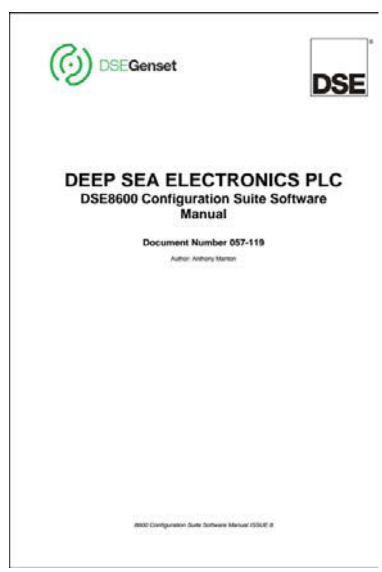
<td>
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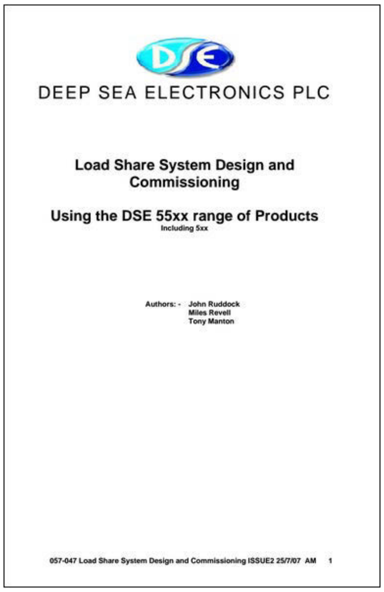
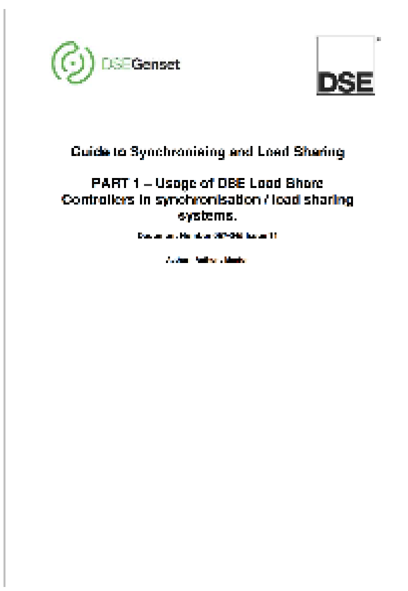
 DEEP SEA ELECTRONICS PLC Load Share System Design and Commissioning Using the DSE 55xx range of Products Including 5xx Authors: - John Ruddock Miles Revell Tony Manton 057-047 Load Share System Design and Commissioning ISSUE2 25/7/07 AM 1	
Load Share System Design and Commissioning	

 DSEGenset DSE Guide to Synchronising and Load Sharing PART 1 – Usage of DSE Load Share Controllers in synchronisation / load sharing systems.	
Guide to Synchronising and Load Sharing Part 1	**Guide to Synchronising and Load Sharing Part 2**

IV. Use Cases

A. Use Cases and Available Features

The following features sets are available:

Feature	Mains Paralleling	Part of a Microgrid	Stand Alone Operation
Fixed export control	Yes	Yes	No
No Break transfer	N/A	No	N/A
Islanding	No	No	No
Load sharing	No	No	No
Close to dead bus	No	No	Yes
Earth fault detection	No	No	No
Mains decoupling	Yes*	No	N/A
Vector Shift	Yes	No	N/A

*Does not meet IEEE 1547, CEI not met (Mains Decoupling triggers)

a. Connection to a Utility for Mains Paralleling

In this case, a single Power Pallet is connected to a utility grid with fixed power export—i.e. a constant power level that does not vary with load. If multiple Power Pallets are onsite, each is independently tied to the grid with no load sharing between the units.

b. Part of a Microgrid

A microgrid is an independent electrical grid, typically small- or distributed-scale, that may connect to a larger utility grid, but can meet its power and control requirements within the microgrid system.. Because a grid-tied Power Pallet is configured for fixed export, the generator will not respond to match the load demand as a standalone Power Pallet will. Therefore, ensure that the microgrid includes another power source or storage ability. If the Power Pallet is exporting more power than there is load on the microgrid, excess power will be generated with no sink, leading to unstable operation, high reactive power, and potentially overcurrent electrical trips and shutdowns.

If there is more load on the microgrid than the Power Pallet is exporting and there is no other power source that can support excess load, the Power Pallet's generator will bog down and an underfrequency or under-voltage electrical trip alarm is likely to occur.
An example of this is a diesel generator and Power Pallet supplying load to the microgrid.

c. Stand-Alone Operation

Note: ALL Power Labs does not support stand-alone operation of the Power Pallet Grid-Tied models. However, instructions are provided for troubleshooting purposes only that are only to be done by an APL certified technician.

In order to enable this feature connect battery ground on main negative bus inside enclosure to digital input D (DSE pin 63). Contact APL support before carrying out any changes related to standalone operation.

V. Commissioning Procedure

Please note that the Grid Tie Power Pallets are already configured when shipped. The commissioning procedure listed here is offered for reference only.

1. PCU Configuration

Enable ‘Grid Tie’ mode on the PCU. Navigate to the view for this configuration setting by using the buttons on the control panel.

2. Deep Sea Configurations

The APL Grid Tie Configuration Worksheet is available in the Documentation and Resources package on the USB key that is sent with each system as a resource to calculate the configurations needed for site specific needs. Please contact support@allpowerlabs.com for this if needed.

APL Configuration Worksheet inputs:

1. Configuration (generator)
    a. frequency
    b. generator wiring
2. Nominal voltage
3. Upper and Lower mains disconnect values (if different than IEEE 1547 defaults)
    a. frequency
    b. voltage

Once the input values have been entered into the worksheet, use the output values in the lowest section of the spreadsheet to configure your DSE controller. To do this, the “Deep Sea Configuration Suite PC Software” must be installed on your computer, which you can download from the Deep Sea Electronics website after creating a free user account (http://www.deepseaplc.com/home/). You should enter the worksheet’s output values into the **base file*** (which is provided by APL and includes other base configurations for the Power Pallet) using the DSE Configuration Suite software. Upload the modified config file to DSE from the DSE configuration program over a USB connection. Please consult the DSE 8600 Configuration Suite Software Manual for upload instructions. Note: if the DSE 8610 module firmware version is different than the DSE base configuration file version, you must reconcile the two by upgrading or downgrading the configuration file or the module firmware.
If the configuration of the system is changed from its original configuration when shipped, APL customer service representative must be notified to ensure future service and warranty coverage.
If you are re-configuring your Power Pallet or grid tie system, you should download the original DSE configuration file from the Deep Sea module and save it on your computer, in addition to saving a version of the new DSE configuration file.
**Please contact APL Customer Service for the base file.*

3. AVR Tuning

a. Disconnect the two (orange and black) bias wires on the generator’s AVR (automatic voltage regulator). See wiring diagram.
b. Make sure that the tiny arrow on the AVR VOLT potentiometer is centered within the tick marks.
c. The arrow on the STAB potentiometer should be set two marks clockwise from the, fully-counterclockwise position.
d. Start the engine. Wait until “Generator Available” appears on the DSE controller screen.
e. Adjust the VOLT potentiometer to change the phase to phase (Ph-Ph) voltage to the desired nominal voltage, as displayed on the DSE controller screen.

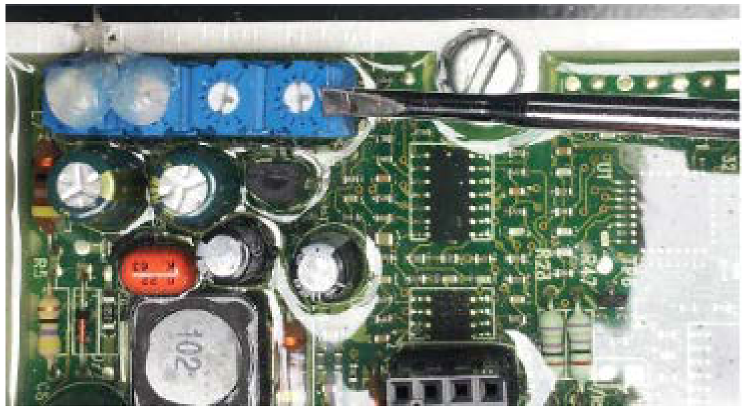


Figure x. Location of VOLT and STAB potentiometer on generator AVR.

4. Configure DSE SCADA Settings

The following procedure is designed to confirm that the DSE is able to accurately control genset output voltage (through the AVR) and the frequency (controlled by the governor) via the DSE program's supervisory control and data acquisition (SCADA) interface. To set the SCADA settings most easily, connect your computer to the USB port on the DSE controller and connect to the module using the Deep Sea 8600-series Configuration Suite. For further reading, please see page 15 in the *Deep Sea Commissioning Load Share System Design Manual.*

IMPORTANT: The SCADA settings must be set independently after the configuration file is uploaded to the DSE module because they are not stored as a part of the module configuration file. This feature also permits the DSE controller to carry out real-time monitoring and control through SCADA, without the need to re-upload configuration files. The Clone Module feature transfers both the configuration AND the settings of the Multiset, Governor/ AVR interface and the Sync page. For more information see DSE 8600 Config SW Manual.

The DSE module controls the governor and AVR on the genset through bias voltages, which command them to increase or decrease the output frequency and voltage, respectively. The bias voltages are configured through setting the bias "center" voltage (SW1), and range (SW2).

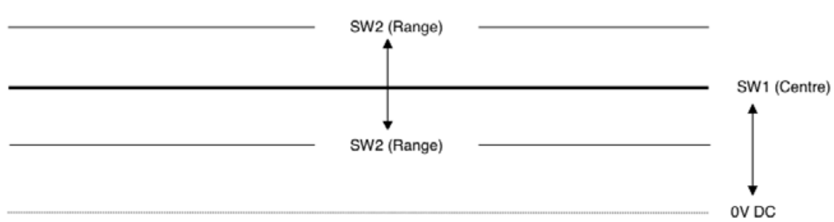


Figure 1. Illustration of the center and range of the bias voltages for the AVR and governor.

The following procedures confirm that the Deep Sea has control of the genset voltage and frequency.

A. AVR Bias Tuning Procedure

CAUTION: For bias voltages exceeding 2.5V, the AVR's default behavior is to reject the bias input. This can lead to unexpected behavior of the generator. For more information, consult the AVR manual.

CAUTION: Bias voltages outside the range of -5V to +5V may damage the AVR. The Deep Sea can output voltages from 0-10V.

- Initial AVR SW1 = See Value In Configurations Table
- Initial AVR SW2 = See Value In Configurations Table
- Record initial SW1 value (SW1i)
- With genset running - Adjust SW1 to raise the output frequency 15% over nominal voltage.
    - For example: 230V Ph-Ph * 115% = 265V (230V + 35V) (see Table 1)
- The generator should be kept running without load
- Record the value of SW1 (SW1f)
- Set SW2 to the difference between SW1f - SW1i
- Set SW1 to the initial value (SW1i)

Table 1. Nominal and Upper phase-to-phase voltage examples

Nom. V Ph-Ph	Upper V Span (115% of Nom.)
190	219
200	230
208	239
220	253
230	265
240	276
254	292
266	306
277	319
380	437
400	460
415	477
440	506
460	529
480	552

B. Governor Bias Tuning Procedure

- Disconnect governor bias wires from back of DSE controller
- Initial Governor SW1 = See Value In Configurations Table
- Initial Governor SW2 = See Value In Configurations Table
- The generator should be kept running without load
- Record initial SW1 value (SW1i)
- With genset running - Adjust SW1 to raise the output frequency by 2.5Hz (SW1f)
- Record the final value of SW1 (SW1f)
- Set SW2 to the difference between SW1f-SW1i
- Set SW1 to the initial value (SW1i)

Editing Parameters:

All settings can be configured using the Configuration Suite software. Do not alter these settings unless recommended by a trained APL certified technician. Most settings can also be configured through the DSE control panel: Press and hold the (√) button for basic settings. For advanced settings press and hold (√) and (STOP) buttons.
For more information see: ***DSE8610 Control & Instrumentation System Operators Manual - 9. FRONT PANEL CONFIGURATION***

VI. Dynamic Tuning for Grid Tie Operation

Each utility grid or microgrid has unique dynamics and the Power Pallet's generator must be "tuned" to properly synchronize and maintain stable power export.
The figure below shows the hardware configuration of the Deep Sea Module and the Power Pallet:

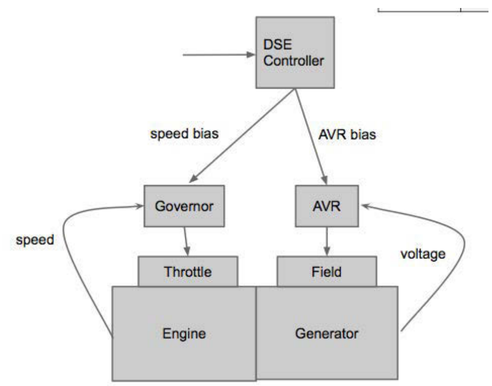


Figure x. Control Scheme of the Power Pallet and Deep Sea Module

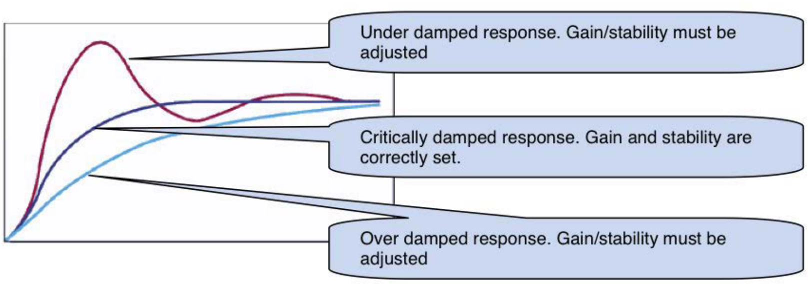


Figure x. Control dynamic response in relation to gain and stability values

Figure 3. Dynamic system responses according to gain/stability parameters.

State	Available	Sync	On Grid
Governor	No Bias	Frequency Match	Load Share Control
Generator Field	No Bias	Voltage Match	Reactive Power Control

The Deep Sea control module has SCADA settings that determine how the AVR and governor bias control loops react dynamically to fluctuations in the grid in an effort to maintain a stable, synchronized connection between the Power Pallet and the grid. These settings are called gain and stability and, during synchronization, the frequency synchronizer and voltage matcher are controlled by their gain, while, when the Power Pallet is exporting power, gain and stability control load share and reactive power control.

Gain
The gain determines how rapidly the control module bias can respond to instantaneous changes in the grid or generator's dynamics. In general, a lower gain setting results in a slow frequency or voltage matching process, but too high a setting may cause instability (hunting).

Stability
The stability determines how the control module bias responds to the longer-term relationship between the nominal and actual voltage. In general, a higher stability setting will cause the actual frequency or voltage to come very close to the nominal values, but may reduce the control module's ability to respond quickly when there is a disturbance in the grid or generator.

Note: The pre-set gain and stability settings will be acceptable in some, but not all, use cases. Please contact APL customer support if it is necessary to adjust these values to tune your Power Pallet to the grid. Changing these values without an APL-certified technician may void the warranty.

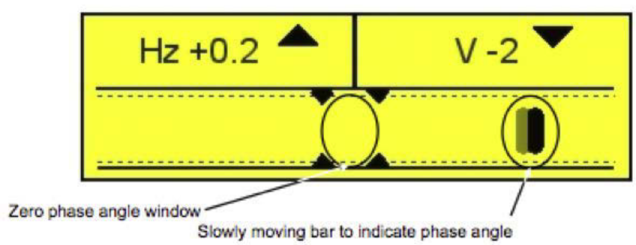


Figure 4. Deep Sea synchronizer screen

1. *Frequency Synchronizer*

The frequency synchronizer adjusts governor bias to bring the generator's frequency into sync with the grid during the synchronization process. This is displayed on the upper left side of the synchronization screen as a +/-Hz reading when out of synchronization range, or with a check mark if the voltage is within bounds.

- **Slip Frequency**

The difference between the Power Pallet's generator frequency and the bus/mains frequency of the grid. For example, with a slip frequency of 0.2 Hz, the two power sources will be in phase (zero phase angle) once every five seconds. With stable generator frequency, the bar will consistently move to the right across the screen, while frequency variation will show as inconsistent movement back and forth across the screen.

2. Voltage Matcher

During the synchronization process,the voltage matcher adjusts the AVR bias in order to synchronize the generator's voltage to that of the grid. This is displayed on the upper right side of the synchronization screen as a +/-V reading when out of synchronization range, or with a check mark if the voltage is within bounds.

When both the frequency and voltage of the Power Pallet's generator are synchronized with those of the grid, the bar will move into the zero phase angle window and be bounded by vertical bars. At this time, you should hear a loud click, which is the contactor closing the circuit and creating a connection between the generator and the grid.

3. Load Share

When the Power Pallet is connected to the grid, the load share control adjusts the governor bias. Because the generator is locked in synchronization with the grid when the contactor is closed, the speed change request effectively is a request to open or close the governor throttle. Thus, the load share effectively controls the amount of real power export from the system based on the configurable target power setpoint.

4. Reactive Load Control

When the Power Pallet is connected to the grid,the reactive load control controls the AVR bias . Since the generator voltage is locked in synchronization with the grid when the contactor is closed, the voltage change request effectively is a request to increase or decrease the generator field, adjusting the ratio between reactive power for the amount of real power.

Note: Reactive load control is typically unstable under 5 kW of real power.

VII. Configuration Screens

[image of configuration screen]

The DSE control module has a series of monitoring and configuration screens. In order to switch between different information topics in the monitoring screens, use the left and right arrow buttons. In order to see different status screens within each topic area, use the up and down arrow buttons. The "Status" screen is important, as it displays the status of the generator, such as "Generator at Rest", "Generator Available", and "On Load". Once the Power Pallet is on load, the most useful monitoring screens are under the "Generator" heading. Simply press up once to see the targets for various critical variables, such as load level, reactive power, power factor, and biases displayed as percentages and up once more to see their absolute values.

- ***Target Power***

The Power Pallet target power output for fixed export can be adjusted through the SCADA settings in the DSE Configuration Suite software, under Multiset ->Load Levels ->Maximum.
It can also be adjusted on the Deep Sea control module interface by adjusting “Load Parallel Power” - see “editing parameters”

(Note: Minimum load level is the point at which the contactor will open when ramping off load. We recommend maintaining the preset value in order to prevent contactor arcing)

Other important values, such as the power factor, can also be adjusted in the Configuration Suite under Multiset within SCADA settings or through the DSE control module interface. For complete instructions, please see________(manuals).

VIII. Diagnostics

A. CT Polarity Diagnostics

See 8610 User Manual sections 3.5.2 and 3.5.3 for more information on the CT Polarity Diagnostics method.

B. Load Acceptance Test

- Load acceptance test - load system to 50% of power rating and confirm stable operation.
- During this load test, confirm current transformers are reading correct power [kW] and PF (e.g. ~1 for resistive loads)
- Engine should accept and shed load with stable recovery to nominal speed and voltage (e.g. within a maximum of 10 seconds)

C. Test PCU Shutdown Command

- Enter PCU Test menu
- Scroll to FET3 Starter
- Turn on
- The DSE control module should raise an alarm that says “PCU Commanded Shutdown”

IX. Troubleshooting

The troubleshooting provided in this table is only for a trained APL technician only or if directed by a trained APL technician or APL support team. Please do not conduct any troubleshooting below before contacting APL support.

Symptom	Possible Root Cause	Solution
System Does not Parallel to Bus/Grid	Miswiring or loose wiring.	Check that the DSE Input/Output pins and the enclosure's internal wiring are correct
PCU shutdown alarm not shutting down Deep Sea	DSE Input/Output pins may not be properly configured	Test PCU Shutdown Command. Check that wiring from PCU, inside enclosure, and at DSE controller is correct and connected.
Synchronizing system does not export power and causes "Reverse Power" alarm	Mains Paralleling mode may not be enabled.	Check that Mains Paralleling mode is enabled. Shipped configuration: Input D is left "open" = Mains Paralleling active
AVR bias rapidly fluctuating while on grid	Incorrect reactive power control tunings	Adjust reactive power control after consulting APL support
Symptom?	AVR bias out of range	Adjust AVR SW1/2
Fluctuating amperage or power factor despite stable governor	Poor reactive power control	Adjust reactive power control settings
Unstable power export	Poor load share control	Adjust load share settings
"Fail to sync" alarm	Unstable frequency	Check gas quality, governor stability, clean governor
Contactor not operating correctly	Possible miswire of solenoid voltage wiring	Check wiring
Negative power values reported.	CT(s) reversed polarity	Flip CTs to correct polarity

Over-voltage	Incorrect DSE wire-topology settings	Incorrect AVR potentiometer setting or bias
Under-voltage	Incorrect DSE wire-topology settings	
“E-stop alarm”	Ignition circuit fuse blown	Replace fuse (#3?)
“E-stop alarm”	Bad wiring	Confirm wiring
Unexpected engine shutdown	Outside pre-set parameters	Operate with in pre-set parameters or change parameters.
Unexpected engine shutdown	E-stop pressed	Reset E-stop button
Unexpected engine shutdown	PCU commanded shutdown	Check PCU alarm and refer to Automation Assembly section of APL Technician’s Handbook

*See provided DSE 8610 User Manual Section 11 and the DSE 8600 Series Configuration Suite Software Manual Section 4.5.3 for expanded troubleshooting