# $E^3$ BENEFITS IN VARIOUS APPLICATIONS

## $E^3$: ALL-ENCOMPASSING ENGINE AND EMISSIONS CONTROL

ENHANCED EMISSIONS CONTROL IN LEAN BURN AND RICH BURN GAS ENGINES FUELED BY NATURAL AND RENEWABLE GAS

WOODWARD

Whether driving generators, compressors, or pumps, gas engines fueled by natural and renewable gas are economically attractive and environmentally responsible energy sources. The availability, reliability, and performance of gas engines are well known. And, now Woodward helps keep these engines performing optimally while maintaining compliance with existing exhaust emissions regulations. Woodward's E³ engine and emissions control systems are fitted to either rich burn or lean burn gas engines. The product line is comprised of proven technologies for rich burn trim, lean burn trim, lean burn full authority and lean burn fuel blending engine control systems.

# OVERVIEW
# E³ RICH BURN TRIM

***This is the same strategy successfully used for decades in the automotive industry***

Woodward's E³ Rich Burn Trim Control System overcomes the major drawbacks of rich burn natural gas engines—the inability to meet engine exhaust emissions compliance standards over their operating range and as operating conditions change. This shortcoming results from the traditional methods of air/fuel ratio (AFR) control that require frequent recalibration, costing time and money. Unlike first-generation AFR controls, the E³ Rich Burn Trim effectively analyzes, controls, and optimizes engine and catalyst functions without continuous readjustment. Using the StableSense™ oxygen sensor designed specifically for natural gas engines, the E³ Rich Burn Trim enables engines to meet even the most stringent emissions standards over their operating range without recalibration, keeping them in compliance for years at a time.

## How Woodward's E³ Rich Burn Trim Works

Most rich burn natural gas engines use a three-way catalytic converter to convert toxic exhaust emissions into more environmentally acceptable gases. Our E³ Rich Burn Trim controls the engine's AFR to alternate the exhaust composition between rich (excess fuel) and lean (excess oxygen). We do this by adjusting the amount of fuel going into the combustion chamber through the AFR controlling device, (like a carburetor), improving that device's accuracy. In turn, the AFR's improved performance sends a cycling exhaust gas composition—one that varies between rich (oxygen scarce) and lean (excess oxygen)—to the engine's three-way catalyst. The three-way catalytic converter performs three simultaneous tasks:

- Reduction of nitrogen oxides to nitrogen
- Oxidation of carbon monoxide to carbon dioxide
- Oxidation of hydrocarbons (HC) and volatile organic compounds (VOC) to water and carbon dioxide

The catalyst, working with the cycling exhaust composition delivered by the E³ system, can now operate at its optimum performance in eliminating all three harmful emissions and preventing the damaging effects to the catalyst of poisoning or excessive heat. This keeps the engine in emissions compliance over very long periods of time without recalibrating—even when operating conditions change or oxygen sensors are replaced.

This is the same strategy successfully used for decades in the automotive industry. Woodward's E³ system advances this strategy over traditional setpoint AFR controllers that impair the three-way catalytic converter's performance by delivering the exhaust composition as either oxygen scarce or oxygen excess. Now, Woodward's StableSense oxygen sensor makes it a viable emissions control solution for natural gas engines. The StableSense sensor is designed specifically for natural gas engines, as opposed to the commonly used automotive gasoline type oxygen sen-

sor. And, since the sensor is easily replaced without the need for recalibrating the control, maintenance is much easier and faster—and less costly.

## True System Approach to Engine Control

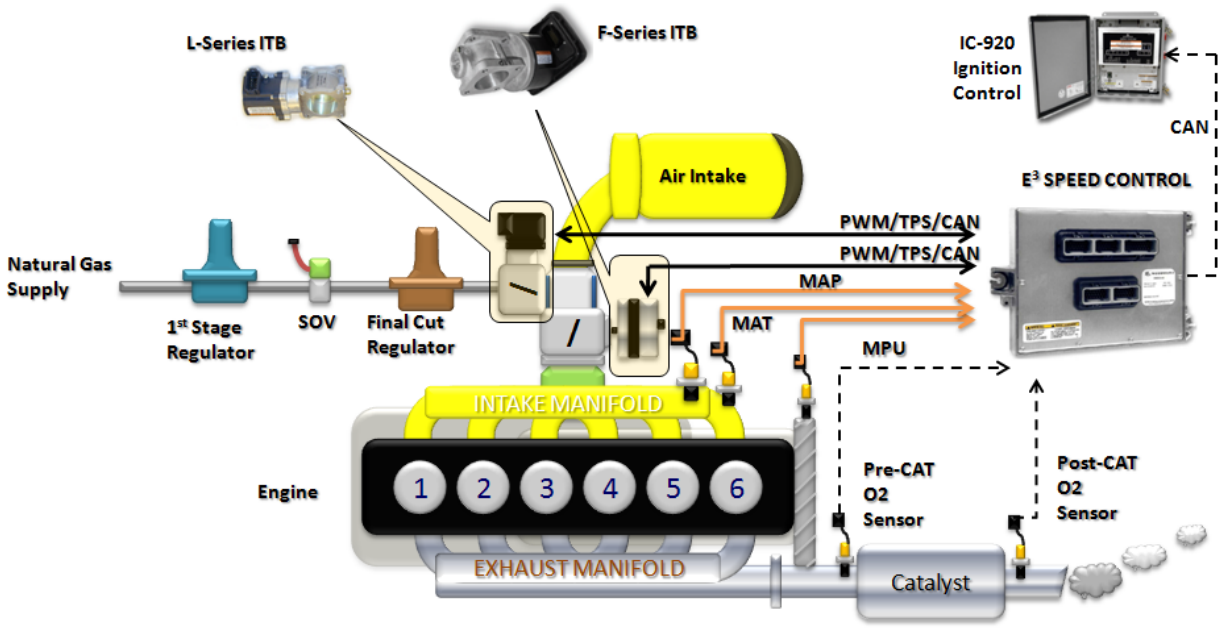
In addition to controlling AFR to keep the engine in emissions compliance for very long periods of time, Woodward's E³ Rich Burn Trim uses a true system approach to engine control.

The addition of an actuator and sensors on the engine provides complete engine speed control (and load control in the case of generator applications) as well as ignition timing control for optimum engine performance. The information supplied by these engine sensors serves as a window into the operation of the engine that enhances diagnostic capabilities. Operators can immediately identify and respond to potentially catastrophic misfire damage, as well as to critical pressure and temperature fault conditions. The E³ Rich Burn Trim also enables power balancing the cylinders on dual bank engines to help the entire engine even out bank loading and meet the required emissions requirements.

The system also includes a start fuel limiter that eliminates over fueling during engine starting, increasing its availability by making it easier to start. All these functions now reside in one small control module. In addition, the control software knows when and where a problem occurs and annunciates it in a timely manner so the problem can be addressed before it becomes catastrophic. This integrated approach eliminates the problems that come from mounting multiple control boxes on the engine or its skid and the communications issues that arise from trying to get multiple sub-systems working together in concert.

Woodward's system approach to engine control is of particular benefit in isolated water pumping installations where maintaining emissions compliance and performance over a range of ambient conditions can be challenging.

E³ Rich Burn Trim engine control system



# FIELD CASES
# $E^3$ RICH BURN TRIM

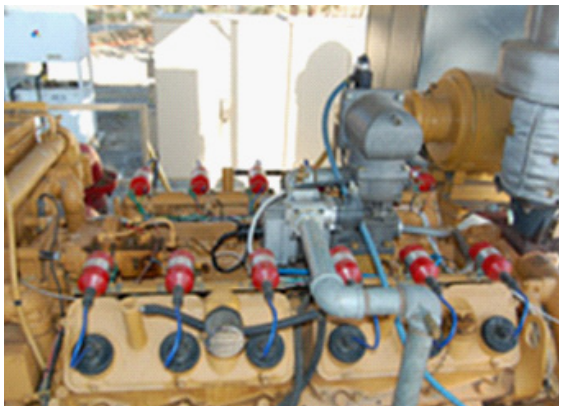
The following field cases show how Woodward's $E^3$ Rich Burn Trim Control System solved emissions control issues for a California water utility and a Wyoming gas pipeline.

## California Water Utility

The company was spending an excessive amount of time keeping their engines in emissions compliance. They were required to perform weekly emissions tests on their Caterpillar 3412 engine to determine if it was staying in compliance and recalibrating it to pull it back into emissions compliance.

Only after proving that the engine had remained in compliance for four consecutive weeks could the inspection period be extended to once monthly. In addition to performing the actual emissions testing at site, which required sending a technician to the site, testing all the associated measurement and recording them, readjusting the air-fuel ratio control, and returning to their home base, there were data recording and management costs charged, as well as the time involved reporting their finding to the local air management board.

The total amount of time expended was about 90 hours per month per engine. At an average hourly cost of $50/hour, the average annual cost per engine for out-of-compliance operating conditions was approximately $54,000. (Installed and commissioned by Woodward RER – Drake Controls – West, LLC)

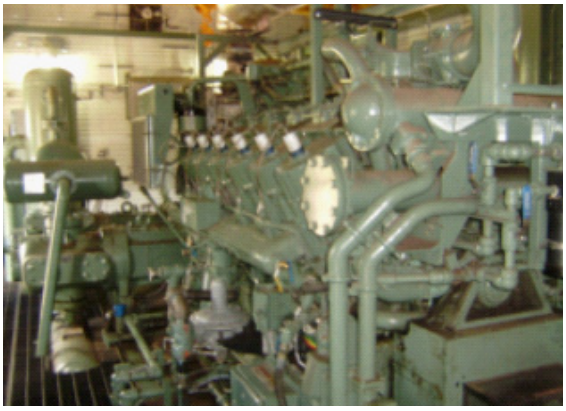


*Caterpillar 3412 engine driving a water pump*

**Wyoming Gas Pipeline**

In this application, a Waukesha 7044 engine is driving a gas compressor.

The engine operator employs six full-time mechanics working 60 to 70 hours a week to keep their 400 natural gas engines functioning within an annual compliance testing cycle. At this pace, technicians could only react to current emergencies. With the state of Wyoming considering changing the testing cycle from annually to quarterly, labor costs were expected to increase significantly. Woodward's $E^3$ Rich Burn Trim ensured that an evaluation engine remained in compliance, eliminating the time and expense previously required to bring it back into compliance. (Installed and commissioned by Woodward RER – Winn-Marion Barber, LLC)



*Waukesha 7044 engine driving a gas compressor*

# OVERVIEW
# $E^3$ LEAN BURN TRIM

Lean burn natural gas engines, by their very nature, run lean with excess air and don't use three-way catalysts. However, they still require AFR control to stay in emissions compliance. Because the lean mixture is just that, lean, it usually takes a higher energy spark to ignite the mixture in the engine's cylinders. This makes it more difficult to start lean burn engines and they often experience misfire events.

Lean burn engines are also extensively used in biogas applications. Although biogas is very similar to natural gas, its energy content fluctuates, again making it more difficult to start an engine on biogas and control its AFR as its energy content changes.

Woodward's lean burn engine control systems are available as three distinct configurations: lean burn trim, lean burn full authority, and lean burn fuel blending. All control the engine's AFR to keep the engine in emissions compliance while enabling reliable starting and misfire detection. All offer a system approach to controlling critical engine parameters.

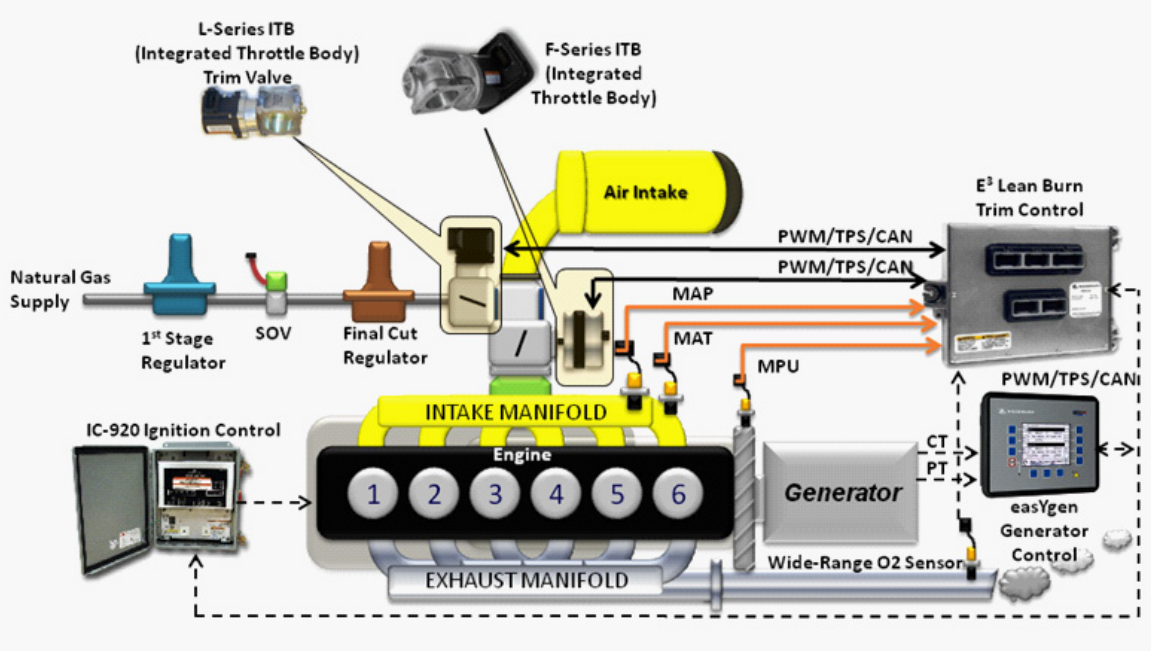
The lean burn trim control system is used on engines where the carburetor is functioning properly and the changes in fuel quality don't cause engine starting problems. The full authority system is used on engines running on biogas, and the fuel blending system is for engines powered by both natural gas and biogas.

Typical lean burn engines fitted with aftermarket AFR controls are usually sufficient to hold the engine's

exhaust emissions within compliance limits over a narrow operating range but not over the entire operating range of the engine. A stand-alone AFR control is only part of engine control and it requires separate speed and ignition controls. Also, it does nothing to improve engine starting or misfire detection. This piecemeal approach often introduces additional complications when trying to get the various subsystems to communicate effectively and act in concert.

Woodward's E³ Lean Burn Trim Control System addresses all the above issues by incorporating the engine's control functions into one small module. The Lean Burn Trim system offers many of the same functions as its rich burn counterpart, such as controlling AFR over the total operating range of the engine, misfire detection and annunciation, improved engine starting, engine speed and load control, balancing engine cylinder banks, ignition timing control, and knowing when and where system problems exist. All subsystems shown below operate together seamlessly.

*E³ Lean Burn Trim engine control system*



# FIELD CASES
# $E^3$ LEAN BURN TRIM

The following field cases show how Woodward's $E^3$ Lean Burn Trim Control System solved emissions control issues for a New Jersey production facility.

## New Jersey Production Facility

Woodward's $E^3$ Lean Burn Trim Control System was applied to a Caterpillar 3412 driving an air compressor in New Jersey. Its previous AFR control required continual monitoring and adjustment to keep the engine in emissions compliance—especially after ambient air temperature changes. In addition to keeping the engine in emissions compliance, the Lean Burn Trim system also alerted the operators of an ignition failure that was causing misfires and protected the engine and catalytic converter from damage. (Installed and commissioned by Woodward RER – Peaker Services, Inc.)

*Woodward $E^3$ control module*

*Caterpillar 3412 engine driving an air compressor*

# OVERVIEW
# E³ FULL AUTHORITY (BIOGAS FUEL)

***The Full Authority system has all the attributes of the fuel trim system***

A lean burn engine without electronic controls will go out of emissions compliance and be difficult to start if fuel quality fluctuates more than +/- 5%. Applications using only pipeline quality gas are well served with an E³ Lean Burn Trim AFR system while engines running on biogas benefit from the E³ Full Authority system. This type system ensures a consistent energy flow to the engine when using biogas. By compensating for fluctuations in the biogas fuel's energy content and adjusting the engine's AFR the system keeps the engine within emissions compliance.

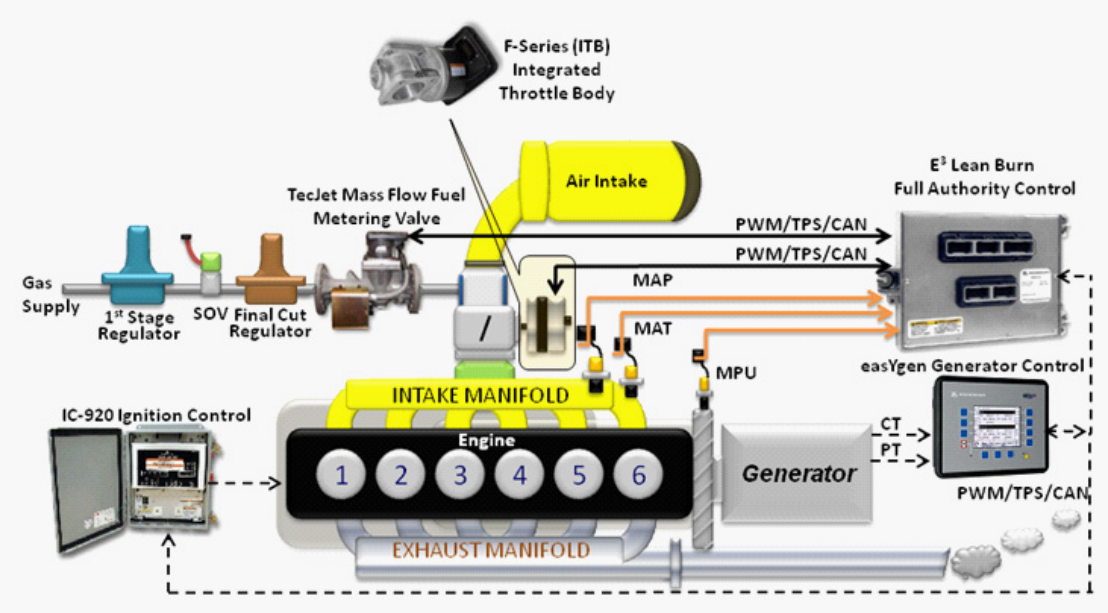
Woodward defines full authority AFR control as metering the fuel flow going to the engine to directly control the AFR. This action keeps the engine's exhaust emissions in compliance without the need for recalibration of the AFR system—even if the composition of the fuel changes. As shown in the diagram below, a Woodward TecJet™ fuel metering valve regulates the gas flow being admitted to the engine.

The Woodward E³ Full Authority system has all the attributes of the fuel trim systems, which include an integrated approach with speed control and ignition control, misfire detection and reaction, cylinder bank balancing, improved starting, and system diagnostics. Plus, the operation of the TecJet gas valve provides the additional feature of fuel flow metering.

## How Woodward's E³ Full Authority Works

The Full Authority control system tells the TecJet valve how much gas at the specific density the engine needs for a particular level of power. The TecJet meters the flow of the gas going to the engine, thus controlling the amount of energy going to the engine instead of just commanding a throttle position. In this

*E³ Full Authority engine control system*



manner, the system delivers the commanded amount of power while keeping the engine in emissions compliance.

The Woodward E³ Full Authority Control System operates under the Gas Quality Closed Loop™ control algorithm. This algorithm uses a known gas density and calculates the amount of power that fuel should be able to develop in the engine. The actual power being developed is then compared to the calculated power based on the assumed gas density. As the gas quality changes, the control recognizes the difference between the calculated power and the actual power and adjusts the fuel flow directly to achieve the power

In most cases, the engine is driving an electrical power generator. Since the Full Authority is an integrated control system, it uses the generator's kilowatt signal from a Woodward easYgen controller or kW sensor to compensate for the fluctuations in the energy content of the fuel. If the energy content of the fuel decreases, the power generated will decrease and the TecJet valve will open further to increase gas flow to maintain the engine's power output. The Full Authority system learns this new requirement and modifies the AFR to compensate accordingly, keeping the engine in emissions compliance.

Sometimes an engine situation outside the control's influence (such as repeated misfires) causes changes in the gas quality that push the reasonable operating limits set in the control. If that happens, the Full Authority system will maintain control at that limit but will trigger an alarm to inform the operator of an abnormal operating condition. The system will maintain the alarm condition until the operating point moves off the limit and resumes normal operating conditions.

# FIELD CASES
# E³ FULL AUTHORITY

The following field cases show how Woodward's E³ Full Authority Control System solved emissions control issues for a Wisconsin dairy farm, a California landfill, and a Wisconsin landfill.

### Wisconsin Dairy Farm

A dairy farm in Wisconsin operates a Caterpillar 3412C-LE engine driving a 450KW electric generator. The engine's fuel comes from the dairy's anaerobic gas process. The engine's previous AFR control system used a stepper motor driven mixing system which could not compensate for changes in gas quality or ambient conditions. This situation caused the engine to be down over 60% of the time. Woodward's E³ Full Authority Control System was installed and dramatically improved engine downtime. With the Woodward TecJet gas valve instantaneously adjusting for changes in the fuel gas quality and ambient conditions, engine downtime was reduced to less than 20%. (Installed and commissioned by Woodward RER – Peaker Services, Inc.)


*Woodward TecJet gas valve*

## California Landfill

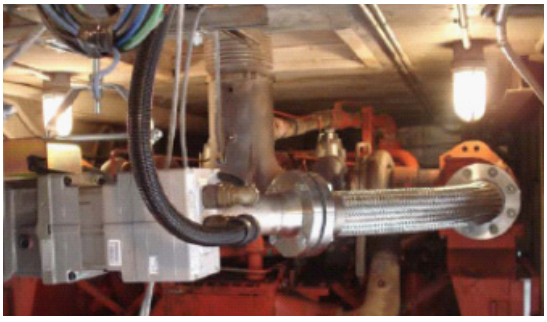
At a landfill in California, a Caterpillar G3516-LE engine, operating only on landfill gas, was retrofit with the E³ Full Authority Control System, operating with Woodward's TecJet gas valve and ProAct integrated throttle body (ProAct ITB). The previous AFR system used a fuel trim and throttle valves operated by a single actuator through a complex set of linkage. The multiple linkage points required continual maintenance to correct for engine instability. The Woodward gas valve and throttle system eliminated the need for the old linkage, reducing maintenance time and the problems associated with misadjusted or worn linkage components. Downtime due to mechanical failure was reduced by more than 52%. (Installed and commissioned by Woodward RER – Peaker Services, Inc.)

*Woodward ProAct ITB Throttle*

## Wisconsin Landfill

At a landfill in Wisconsin, a Waukesha 5794 engine driving an electrical generator running only on landfill gas was retrofit with the Woodward E³ Full Authority Control System. The system included Woodward's TecJet gas valve, ProAct integrated throttle body, and easYgen 3200 generator controller. The engine's previous AFR control system used a stepper motor to control fuel volume, but above 300 Kw of generator load the engine's AFR would shift rich or lean, causing misfire.

The full authority system precisely meters the fuel based on engine/generator load and maintains AFR across all operating loads. Plus, the directly coupled Woodward ProAct throttle actuator eliminated the previous actuator's linkage with multiple pivot points and reduced maintenance and system complexity. (Installed and commissioned by Woodward RER – Peaker Services, Inc.)



*Woodward ProAct ITB throttle*

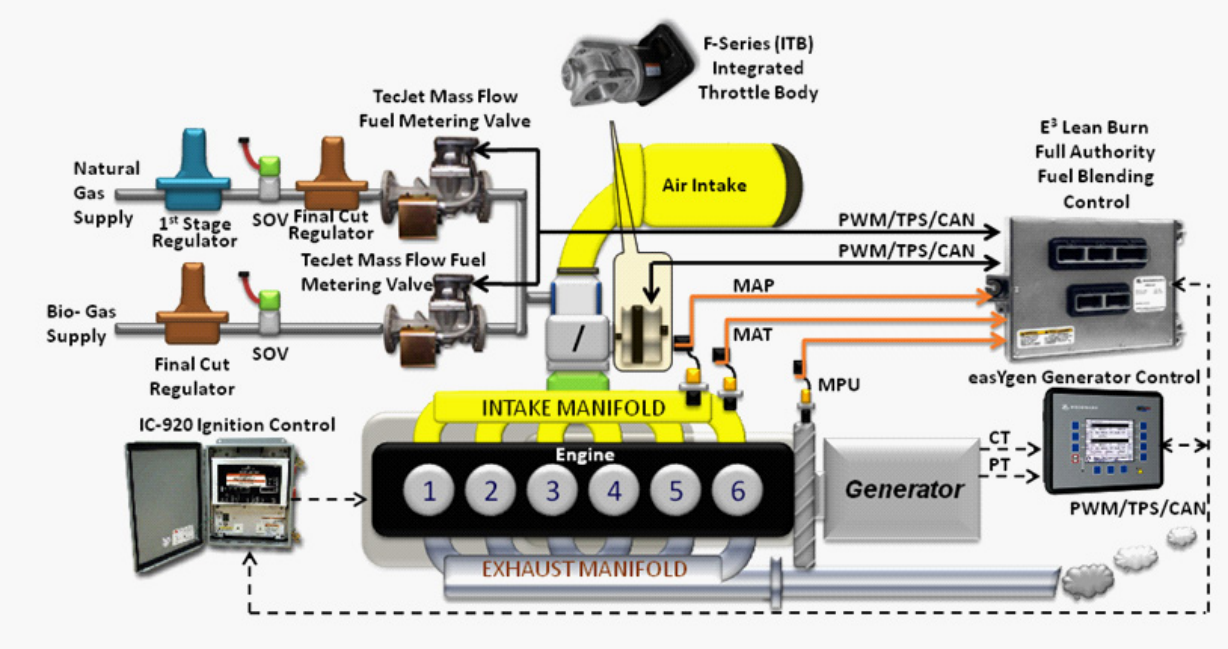
# OVERVIEW
# E³ FUEL BLENDING (NATURAL GAS & BIOGAS)

Through fuel blending, natural gas is added to biogas to make up for the low volume or fluctuating energy content of the biogas. In applications with commitments to deliver a prescribed amount of electrical power to the power grid or thermal energy to the process, it becomes imperative to augment the biogas with natural gas to avoid steep financial production penalties. Woodward's E³ Fuel Blending Control System facilitates the real time combination of the two fuels while keeping the engine in emissions compliance.

The Fuel Blending system operates in a manner similar to the E³ Full Authority Control System in controlling the engine's AFR. Since the actual volume of each gas going to the engine is known, this system is ideal for Green Credit applications.

One of the major advantages of the Woodward E³ Fuel Blending Control System is that it is mounted on the engine and doesn't require an expensive off-board fuel blending skid. It smoothly and quickly transitions from one fuel to another in any proportion in real time. Critical AFR settings and ignition timing adjustments are made without sacrificing engine electrical or thermal output.

*E³ Lean Burn Fuel Blending engine control system*

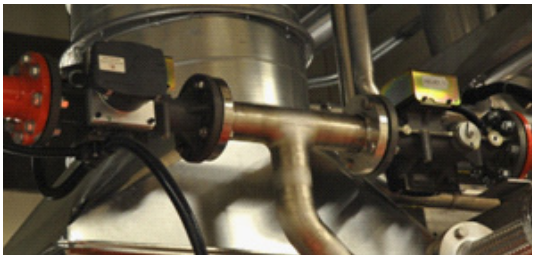


# FIELD CASES
# $E^3$ FUEL BLENDING

The following field cases show how Woodward's $E^3$ Fuel Blending Control System solved emissions control issues for a Colorado brewing facility and a Michigan wastewater treatment plant.

## Colorado Brewery

A major craft brewery in Colorado uses a Guascor SFGL 480 cogeneration genset fueled by biogas derived from the brewing waste along with natural gas to maintain the thermal and electrical energy needed for brewery processes. The E3 Fuel Blending Control System uses two Woodward TecJet gas valves, a Woodward ProAct integrated throttle body, a Woodward easYgen 3200 generator control, and a Woodward IC-920 electronic ignition control system. All the Woodward components communicate across a CAN network, which monitors engine parameters and the operating condition of components. (Installed and commissioned by Woodward RER – Peaker Services, Inc.)



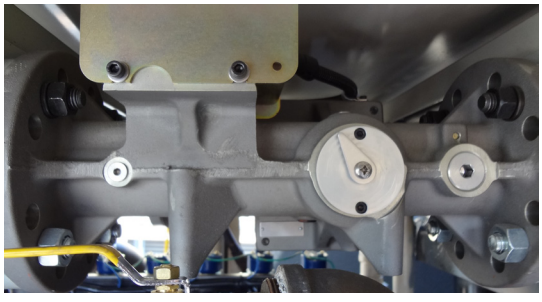
*Woodward TecJet gas valve*

*Woodward ProAct ITB throttle*

## Michigan Wastewater Treatment Plant

At a wastewater treatment plant in Michigan, a Doosan GV222Ti cogeneration genset uses digester gas from the wastewater treatment process to provide thermal and electrical energy for the treatment process. The $E^3$ Fuel Blending Control System uses two Woodward TecJet gas valves, a Woodward F-Series integrated throttle body, Woodward IC-920 electronic ignition control system and a Woodward easYgen 3200 generator control. All the Woodward components communicate across a CAN network, which monitors engine parameters and the operating condition of components. The plant runs isolated from the utility and maintains the site at a constant 60 Hz frequency. (Installed and commissioned by Woodward RER – Peaker Services, Inc.)


*Doosan GV222Ti*



*Woodward TecJet*

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