Ensuring compliance with the

Retrofit options for reciprocating gas engines.

By **Douglas Bird**

In March 2023, the U.S. Environmental Protection Agency (EPA) finalized a rule (as part of its 'Good Neighbor' plan) that will impose enforceable emissions standards for seven non-electric generating industries in 20 states, including the natural gas transmission and storage industry.

The rule, which will take effect in May 2026, applies to any facilities with stationary, natural gas-fired, spark-ignited reciprocating internal combustion engines that have a maximum rated capacity of 1,000 horsepower (hp) or greater. It requires applicable engines to be retrofitted with pollution controls to meet new NOx limits or replaced with a drive that is not subject to the new provision, such as a gas turbine or electric motor.

LEC retrofit options

For compressor stations where a driver swap is not viable either due to CAPEX or downtime, Siemens Energy offers several Low Emission Combustion (LEC) NOx reduction conversion hardware packages for most Dresser-Rand, Clark, Ingersoll-Rand, and Worthington legacy engines. Since 1980, the company's Painted Post and Fort Collins facilities have installed LEC systems on 100 production engines and performed an additional 425 field conversions.

This article provides additional details on available LEC retrofit options and discusses important steps operators can take to ensure compliance with the Good Neighbor Rule (GNR).

Understanding NOx emissions

Most of the NOx formation in integral gas engines occurs inside the engine's combustion chamber. During combustion, high temperatures initiate a chemical reaction between nitrogen and oxygen in the air, resulting in the formation of nitrogen monoxide (NO). Subsequent reactions can lead to the creation of nitrogen dioxide (NO_2). Collectively, these are referred to as NOx.

Research shows that majority of NOx emissions generated in the combustion chamber occur in the region after the combustion process, known as the post-flame zone. Several factors contribute to the generation of NOx emissions -- notably the combustion temperature, the fuel composition, and the air-fuel ratio.

Lean-burn gas engines operate with a higher proportion of air to fuel relative to



THE AUTHOR



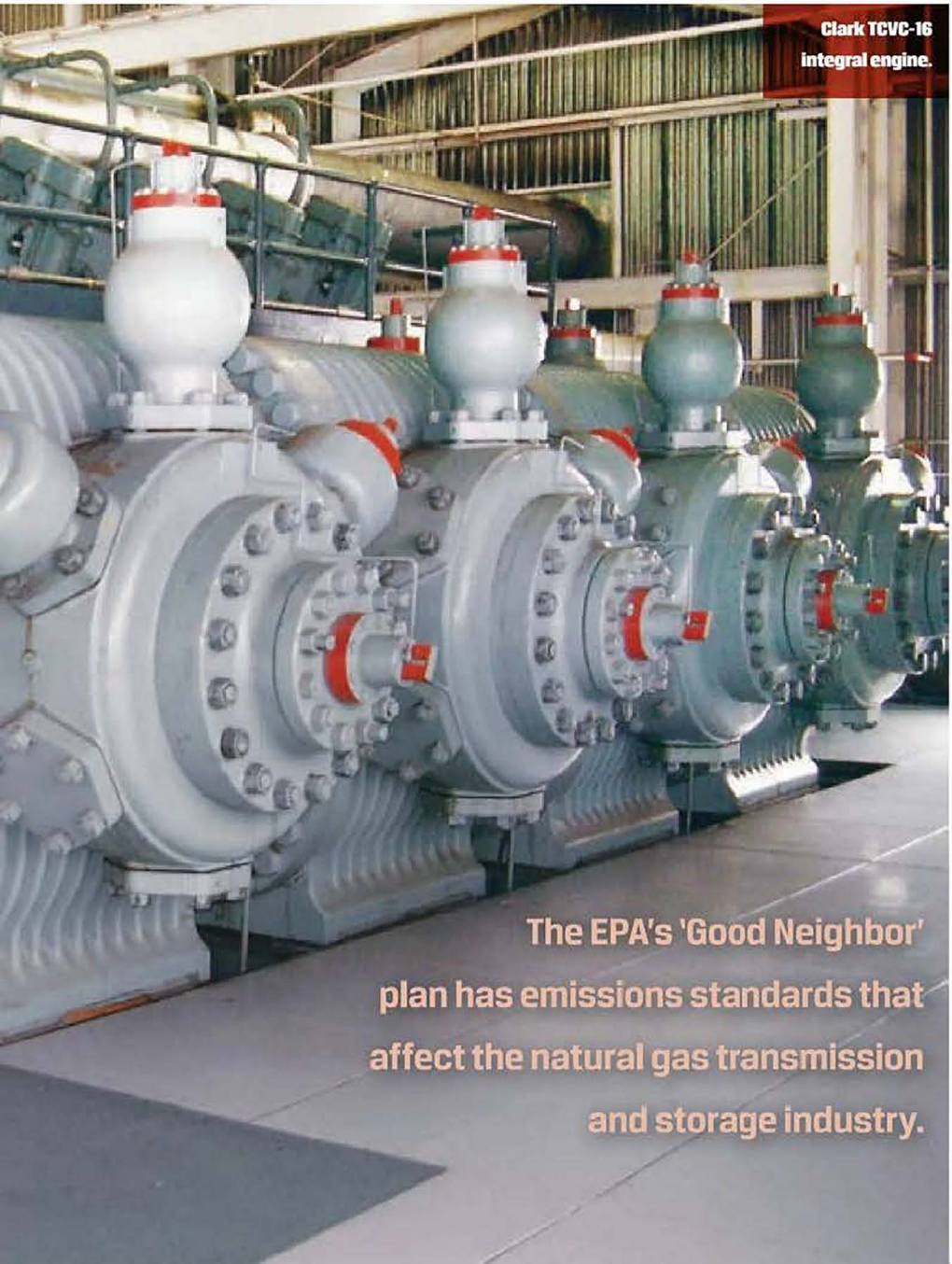
DOUGLAS BIRD project development manager, Siemens Energy, offers and overview of retrofit options available to achieve compliance with the upcoming "Good Neighbor" rule from the EPA.

EPA's 'Good Neighbor' ruling

stoichiometric conditions. This excess of air creates a lean mixture which can improve fuel efficiency and reduce carbon dioxide (CO_2) emissions. However, the lean-burn combustion process is associated with challenges related to NOx emissions reduction.

Lean-burn engines tend to operate at lower combustion temperatures. The excess air makes it difficult to ignite the mixture, which can lead to combustion instability. Technologies, such as precombustion chambers or advanced ignition systems are often needed to ensure stable combustion in lean-burn engines. Depending on the engine, these can contribute to NOx emission levels.

Rich-burn gas engines operate with a lower air-fuel ratio and are typically used in applications where power output and combustion stability are critical. Rich-burn engines generally operate at higher combustion temperatures compared to lean-burn engines. This can result in increased thermal NOx formation.



Rich-burn engines may experience incomplete combustion, leading to the emission of unburned hydrocarbons and carbon monoxide (CO). .

To address NOx emissions in rich-burn gas engines, combustion optimization and exhaust aftertreatment technologies, such as three-way catalysts are often utilized.

LEC options for lean-burn engines

Siemens Energy offers two basic hardware packages for its legacy 2-stroke and 4-stroke lean-burn engines. They are:

1. **2-Stroke Lean Burn (target NOx target level: 3.0 grams)** – Applicable engines include Clark (TCV, TLC, HBA, HRA, HBAT) and Worthington (UTC, SUTC, ML, MLV)
2. **4-Stroke Lean Burn (target NOx target level: 1.5 grams)** – Applicable engines include Ingersoll-Rand (KVS, KVR, KVT, KVSE, SVS) and Worthington (SLC)

Incorporating LEC conversion hardware essentially results in an engine that closely duplicates a Dresser-Rand (D-R) production low NOx integral gas engine.

At the heart of each LEC conversion is a water-cooled screw-in precombustion (SIP) chamber. The SIP is installed in existing power cylinder heads and prevents combustion issues and cylinder peak firing pressure balancing complications.

The major difference between 3-gram and 1.5-gram conversion packages relates to the different turbocharger combustion air systems and fuel injection modifications necessary for incremental increases in engine air-fuel ratio.

Port-4 fuel injection technology may be required for the 4-Stroke 1.5-gram solution to enable enhanced air-fuel mixing. The Port-4 injection system is electronically controlled and eliminates many of the characteristic problems of direct-injected,

RA, BA, HBA, HRA NON-TURBOCHARGED UNITS 2-stroke option (3 GR/BHP HR NOx)	HBAT TURBOCHARGED, TLA, TCV 2-stroke option (3 GR/BHP HR NOx)	KVS/KVSR UNITS 4-stroke option (1.5 GR/BHP HR NOx)
■ New or remanufactured power cylinder heads with water cooled SIP assemblies ■ Retrofit power cylinder heads with directional fuel injection valves (main combustion chamber) ■ SIP fuel system ■ New turbocharger conversion hardware including constant pressure jet assist turbocharger with scavenging air cooler, miscellaneous adapters, new "dry" exhaust manifold, and engine-mounted scavenging air manifold **Options:** ■ ePCI – Electronic Pre-Chamber Injector replacing the mechanical PCC fuel check valve ■ Air intake filter ■ New power cylinders and pistons (for units with deflector style power pistons only) ■ Exhaust silencer ■ Turbocharger tools and spare parts ■ Auxiliary SAC cooling system components ■ Replacement crankshaft counterweights (used if scavenging air cylinders are removed) ■ Installation and commissioning services	■ New or remanufactured power cylinder heads with water cooled SIP assemblies ■ Retrofit power cylinder heads with directional fuel injection valves (main combustion chamber) ■ SIP fuel system ■ Turbocharger upgrade modifications to existing Clark turbocharger including new turbocharger nozzle ring, one-piece high efficiency turbine wheel, turbine inner casing, turbine shaft with hydraulic fit, bearings, and overspeed shutdown in needed ■ New scavenging air cooler (if required) **Options:** ■ Updated auxiliary Scavenging Air Coolers (SAC) cooling system components ■ ePCI – Electronic Pre-Chamber Injector replacing the mechanical PCC fuel check valve ■ Installation and commissioning services	■ New or remanufactured power cylinder heads with water cooled SIP assemblies ■ Replace mechanical fuel injection with Port-4 fuel injection system ■ SIP fuel system ■ New Buchi pulse type turbocharger(s) complete with mounting hardware ■ Turbocharger overspeed shutdown ■ New air aftercoolers complete with air manifold hopper and adapters ■ New or remachine of existing air inlet manifold for the addition of air aftercoolers ■ Air manifold vent valve and vent piping for control of air manifold pressure **Options:** ■ ePCI – Electronic Pre-Chamber Injector replacing the mechanical PCC fuel check valve ■ Updated auxiliary SAC cooling system components ■ Installation and commissioning services


High-pressure fuel injection (HPFi) system.

large-bore, natural gas-fired engines at a fraction of the cost of traditional combustion retrofit technology. The system enables exact control of the fuel gas to provide an optimally mixed air-fuel charge that produces combustion performance and emissions characteristics equivalent to well-designed, state-of-the-art internal combustion engines.

For 2-stroke engines, High-Pressure Fuel injection (HPFi) can be applied for enhanced air-fuel mixing and auto-balance.

Introduced in 1999, the HPFi was the first advanced combustion control technology for direct-injected, natural gas-fired industrial engines. The system is electronically controlled and combines several proven control components aimed at meeting very stringent operating, performance, and emissions requirements.

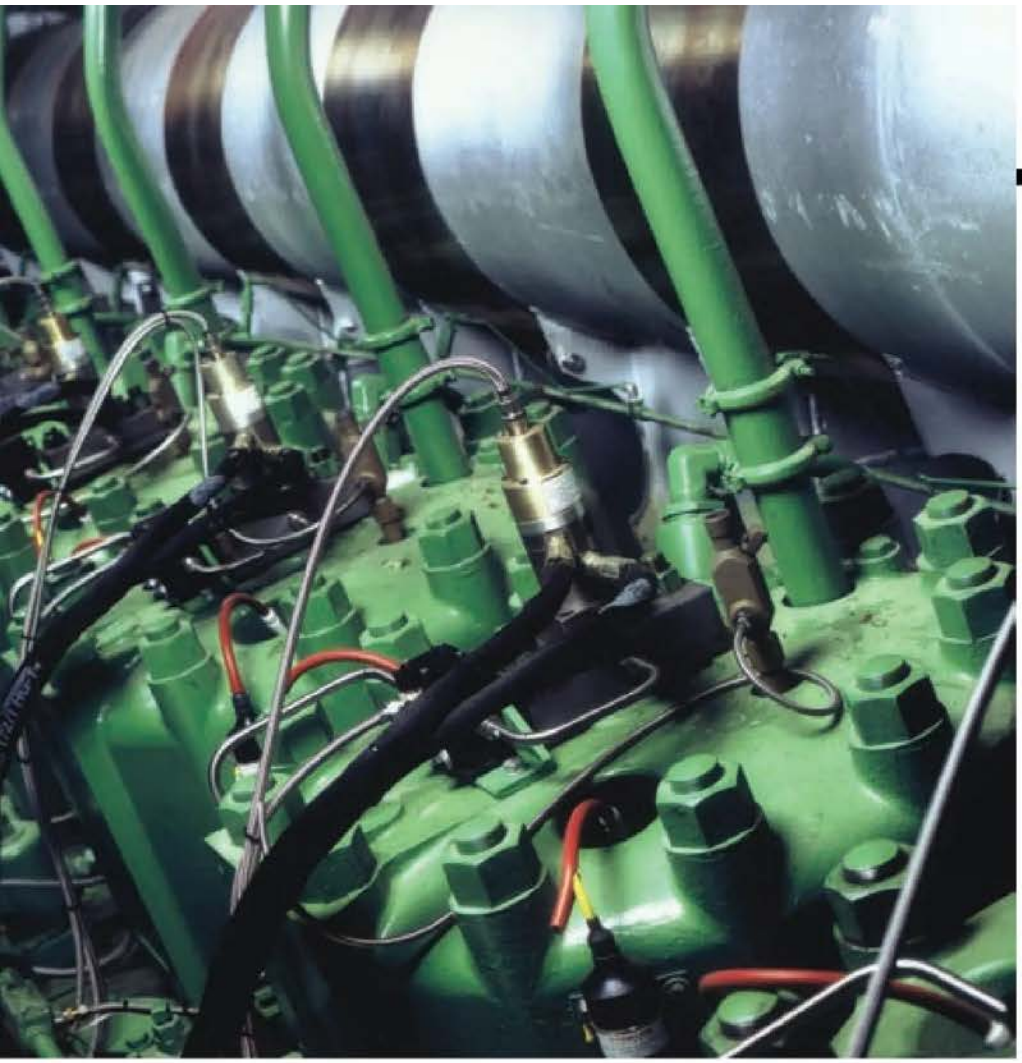
A more detailed description of 2-Stroke and 4-Stroke LEC conversion hardware is shown in the table below. Conversion equipment will vary slightly with engine serial number based on options and current engine configuration.

4-stroke rich-burn engine conversions

4-cycle rich-burn engines (KVG, SVG and XVG models) require a different approach than lean-burn units. These engines are naturally aspirated, non-turbocharged and use a carbureted fuel system. As previously mentioned, to reduce NOx, they require aftertreatment of exhaust, typically with a three-way NSCR catalyst.

Siemens Energy LEC conversion package also utilizes an air-fuel ratio control system known as E6, which continuously monitors and adjusts based on post-catalytic oxygen sensor measurements. They system features stable senor technology to avoid hydrogen passivation upstream and downstream of 02 sensors, which can cause issues with maintaining the correct air -fuel ratio control across the operating envelope.

Speed inputs, manifold air temperature, and air pressures are used to provide a surrogate load calculation, thus ensuring air-fuel ratio control at all process conditions.



If the engine is driving a generator, a kW transmitter provides the same surrogate load calculations, along with fluctuation of the air-fuel ratio.

A slightly rich to slightly lean air-fuel mixture is achieved through dithering (i.e., modulation), which involves intentionally varying the fuel delivery to the engine in a controlled manner. Dithering also provides the added benefit of improved catalyst performance, further reducing emissions.

Preparing for 2026

The 1000-hp threshold outlined in the new GNR provision, along with the proposed date for the rule taking effect (May 2026) has come as a surprise to the marketplace. Operators with large installed bases of legacy combustion engines now face the challenge of retrofitting their fleet to avoid penalties.

The time for companies to begin addressing this is now, as OEMs will likely be flooded with requests for retrofits as the deadline approaches. Siemens Energy is already taking steps to accommodate customers by ramping up its manufacturing and service capabilities.

By engaging early, OEMs can begin planning and ordering the necessary components to ensure compliance. In certain states, even stricter regulations may apply that necessitate additional emissions control measures. Moreover, there may be opportunities to minimize downtime by implementing LEC systems during planned engine overhauls, or to reduce the number of engines that require retrofitting in a station by increasing the horsepower of other engines.

The optimal retrofit solution will ultimately depend on existing hardware, location, and station boundary conditions, along with operator objectives with respect to OPEX, CAPEX, and maintenance.

3g/bhp-hr NOx for 2-stroke cycle lean burn engines1.5g/bhp-hr for 4-stroke cycle lean burn engines, and 1g/bhp-hr for 4-stroke cycle rich burn engines. CT2

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