



Low Emission LPG Off-Road Engines

Brian X. Sun

**Technology & Automotive OEM Division
IMPCO Technologies, Inc.
Irvine, California**

“A company dedicated to a better world through cleaner air”

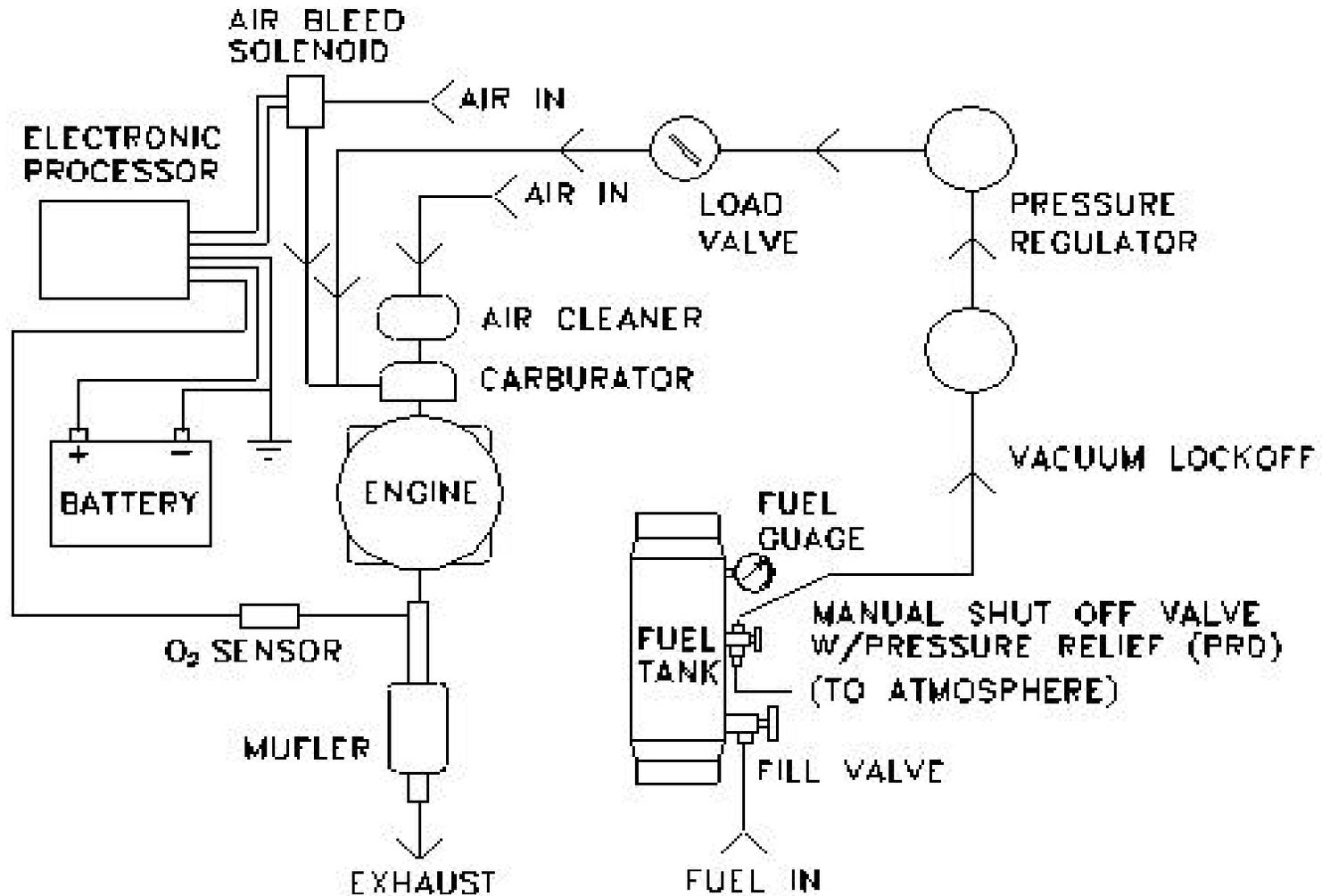
Lawn & Garden Equipment Studied

- **John Deere B-Series 5 HP 14SZ commercial walk-behind mower**
 - **Briggs & Stratton engine, single cylinder, four-cycle, air-cooled, 190cc**
- **TORO 6 HP ProLine SP Recycler mower**
 - **Briggs & Stratton engine, single cylinder, four-cycle, air-cooled, 189cc**
- **John Deere 13hp STX38 HYDRO lawn tractor**
 - **Kohler engine, single cylinder, four cycle, air-cooled, 398cc**
- **TORO 18 HP Gear Drive mower with 52" cutting deck**
 - **Kohler engine, two-cylinder, four cycle, air-cooled, 624cc**

System Description

- **Pressure Regulator**
- **LPG Carburetor**
- **Fuel Lock-Off**
- **Electronic Control Unit**
- **Oxygen Sensor**
- **Air Control Valve**
- **LPG Fuel Tank**

CLOSED LOOP LPG SYSTEM SCHEMATIC

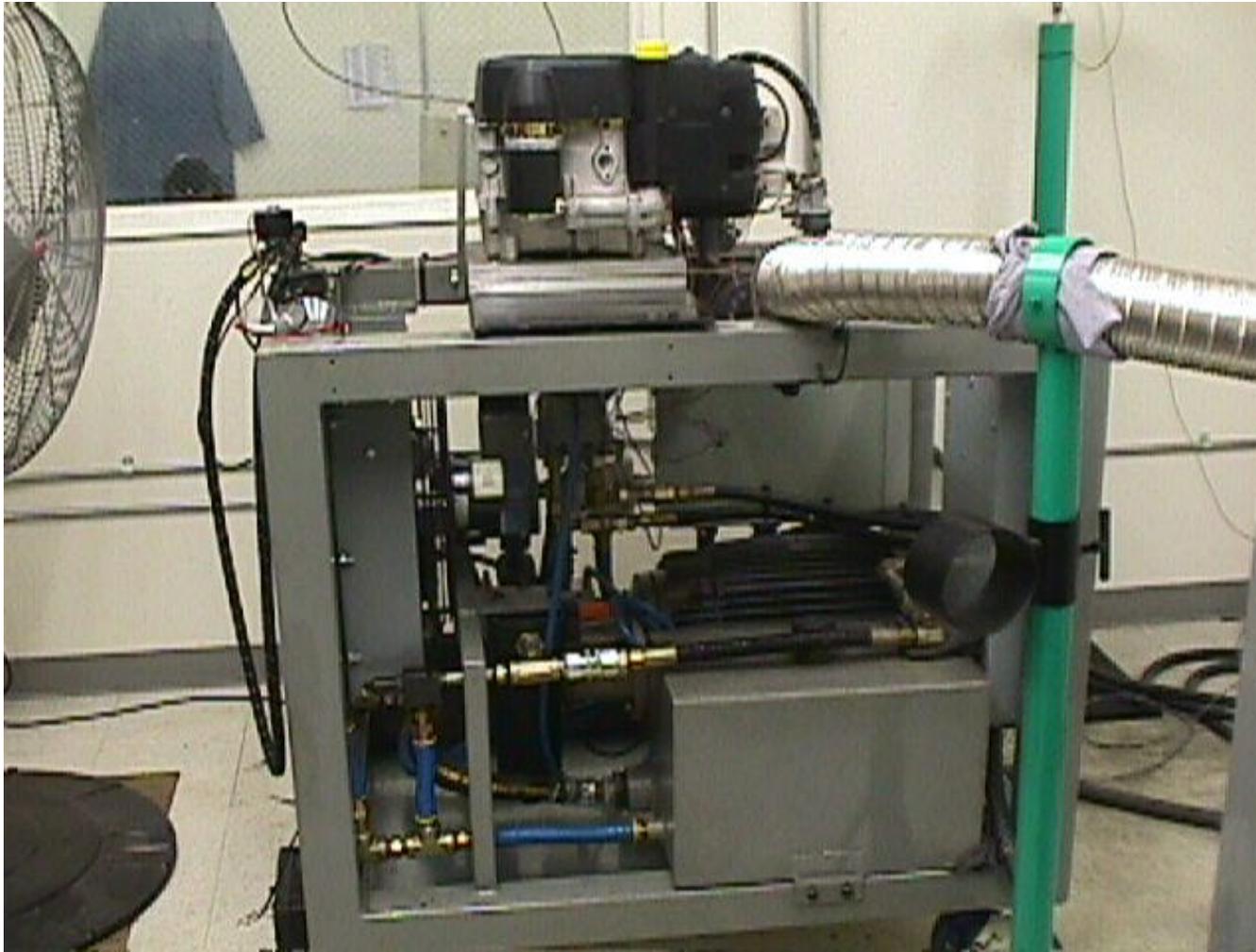


Experimental Apparatus

- **Hydraulic Dynamometer**
- **Dynamometer Controller**
- **CVS System**
- **Data Acquisition System**
- **Emissions Bench**

IMPCO[®]

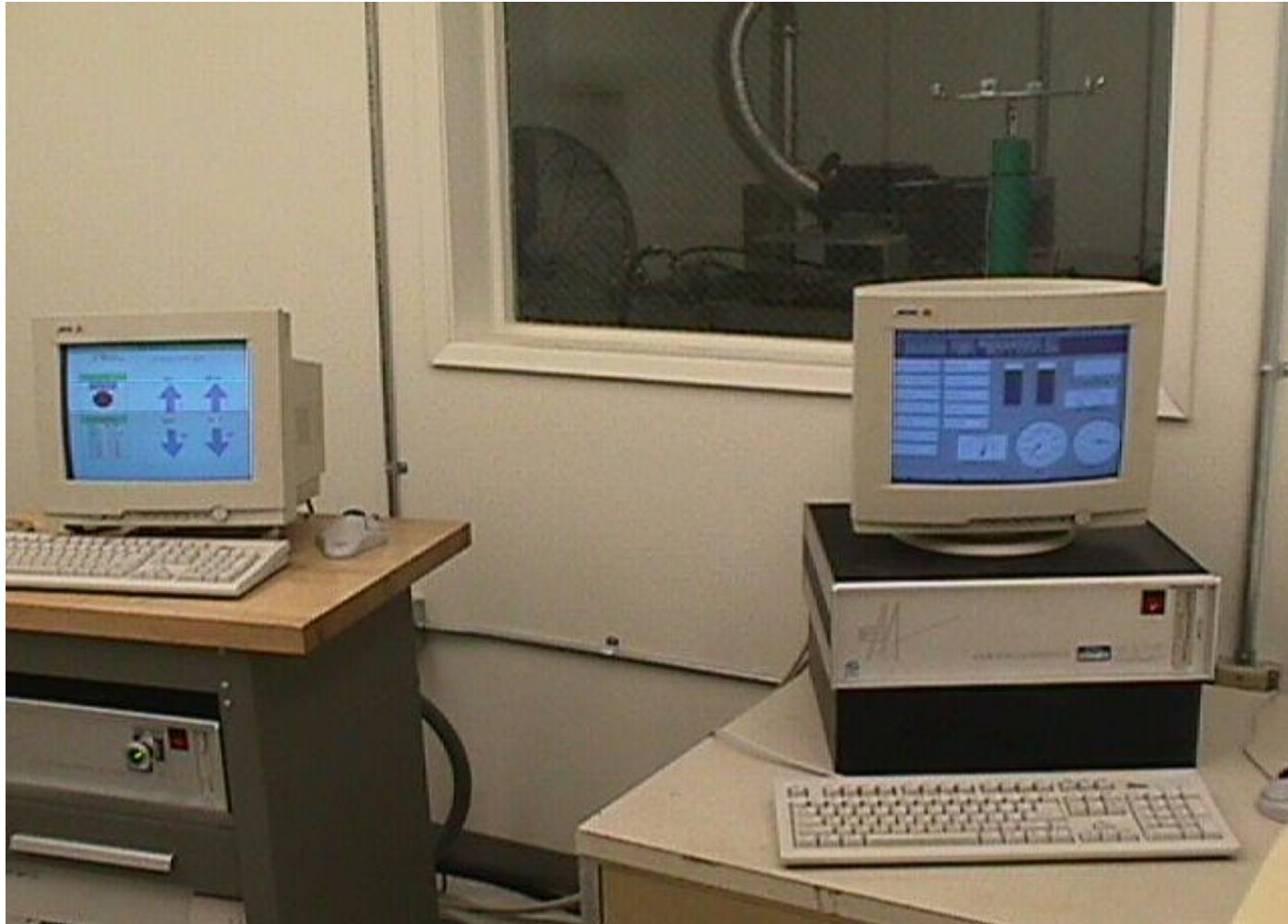
Small Engine Dynamometer



“A company dedicated to a better world through cleaner air”

IMPCO[®]

Dynamometer Controller



“A company dedicated to a better world through cleaner air”

IMPCO[®]

13hp LPG Lawn Tractor



“A company dedicated to a better world through cleaner air”

IMPCO[®]

18hp LPG Lawn Mower



“A company dedicated to a better world through cleaner air”

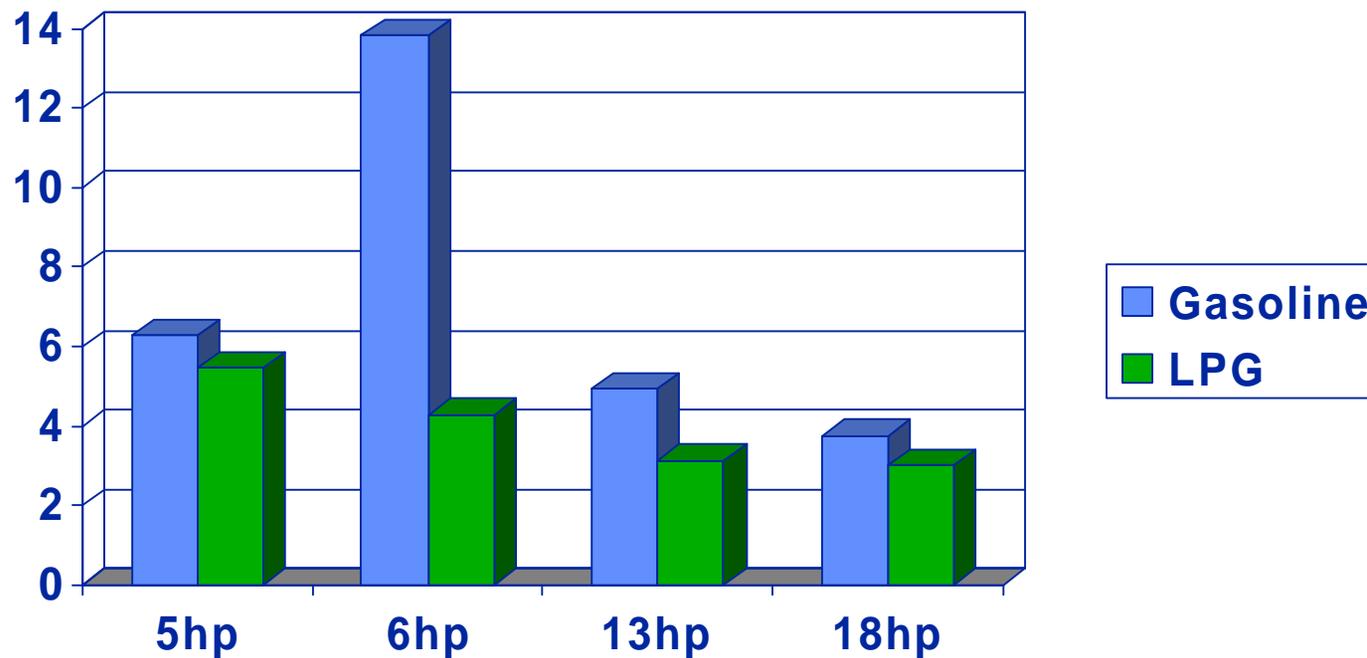
IMPCO[®]

6hp LPG Lawn Mower



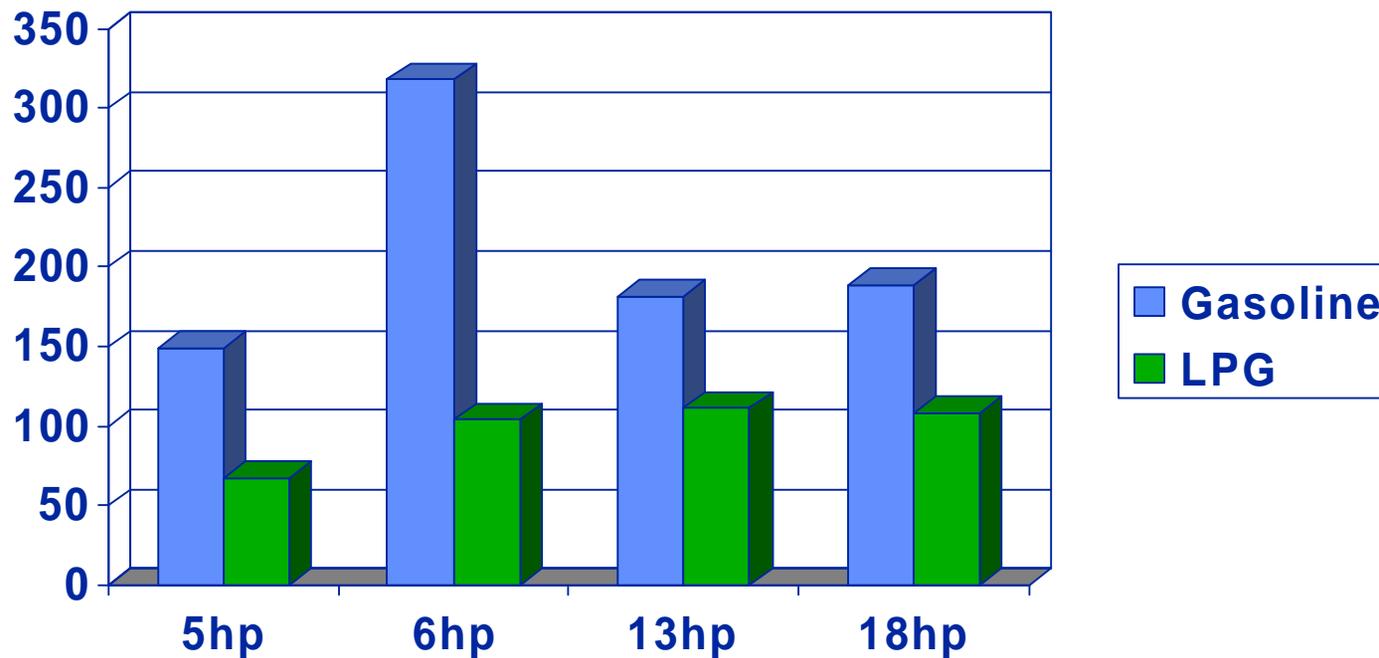
“A company dedicated to a better world through cleaner air”

HC+NO_x Emissions g/kw/h



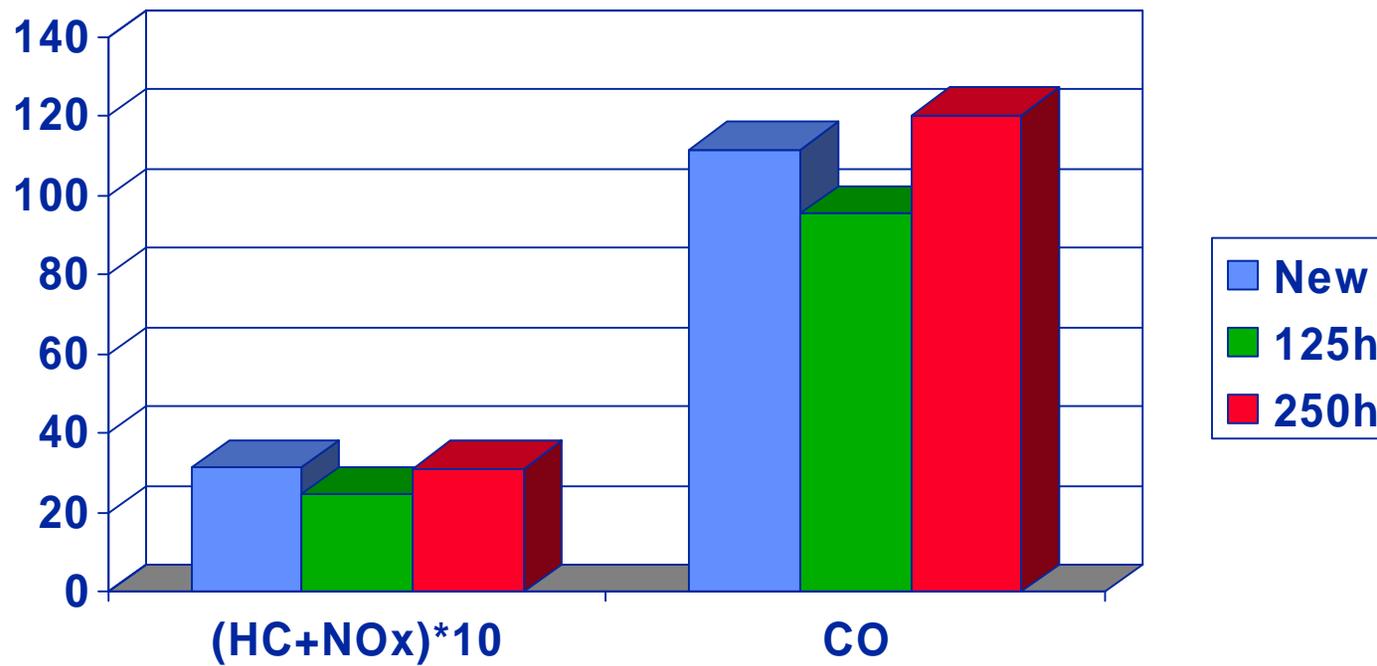
“A company dedicated to a better world through cleaner air”

CO Emissions g/kw/h



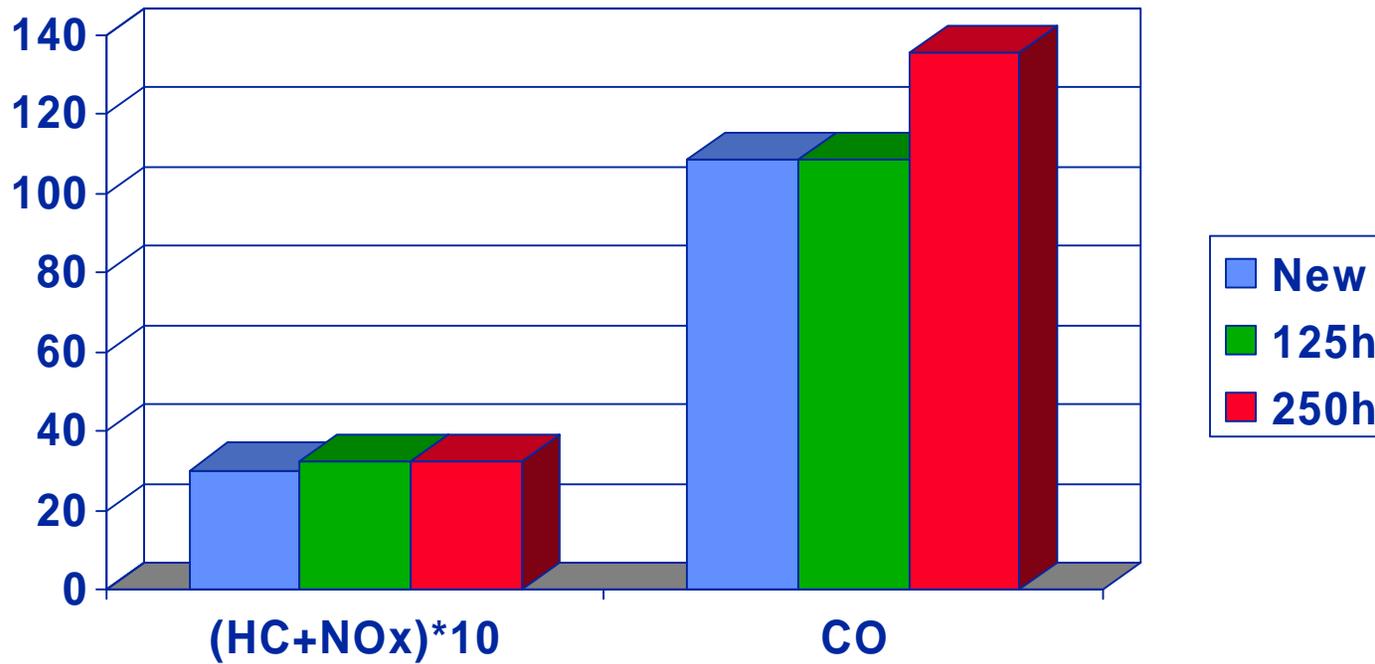
“A company dedicated to a better world through cleaner air”

Emissions Durability Test 13hp Kohler Engine, g/kw/h



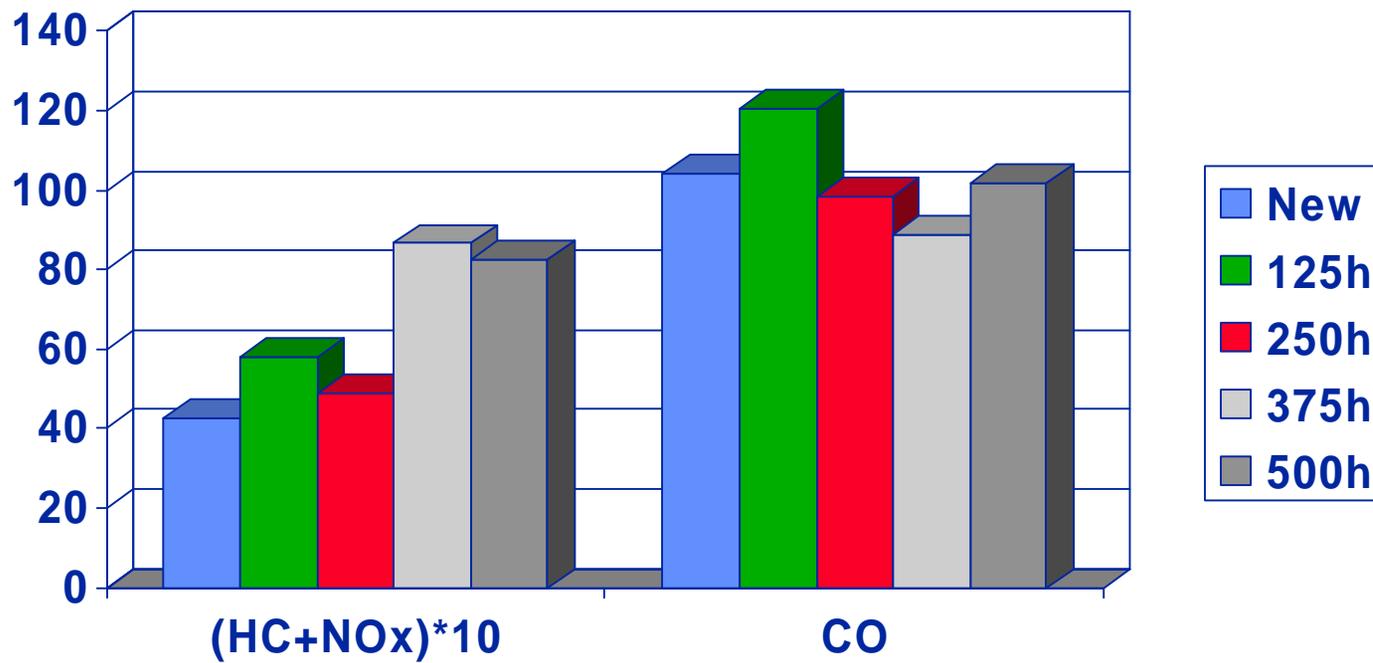
“A company dedicated to a better world through cleaner air”

Emissions Durability Test 18hp Kohler Engine, g/kw/h



“A company dedicated to a better world through cleaner air”

Emissions Durability Test 6hp Briggs & Stratton Engine, g/kw/h





LPG-Fueled Lawn & Garden Equipment – Summary

- **Low exhaust emissions**
- **Easy to convert**
- **Easy to refuel**
- **Easy to maintain**
- **Safe**

“A company dedicated to a better world through cleaner air”

LPG-Fueled Industrial Engines

- LSI 25 hp and above
- Material handling (forklift, etc.), generator set, construction equipment, compressor, pump
- Current technology
 - Open-loop System
 - Air valve-based closed loop control system
- Technology in development
 - Spectrum Project - migrate IMPCO's automotive gaseous fuel injection technology to off-road and industrial SI engine applications.
 - Tier II (2004) emission standards and durability requirements will be exceeded.

Gas Injectors–Background

- **Designed Specifically for Gaseous Applications**
 - Existing designs suffered from:
 - Frictional wear with dry gas
 - Contamination (clogging) of the orifices
 - Insufficient flow capacity for today's applications
- **To address these issues IMPCO:**
 - Sized the orifice to prevent clogging / sticking
 - Pressure was determined by the flow required
 - 3 Bar (45 PSI) CNG
 - 1.17 Bar (17 PSI) LPG
- **Both ball type and disc types were evaluated**
 - Disc type was determined to be a superior design

Gaseous Injectors–Features

- **Ease of Manufacturing (Low Cost)**
 - **Adaptation of high volume production components**
 - **No critical concentric alignment dimensions required**
 - **Simple calibration to specific application**

- **Freedom from Frictional Wear (Durability)**
 - **No linear moving components**
 - **No tight concentric tolerances**

- **Freedom from sticking (Durability)**
 - **Completed sour gas test**

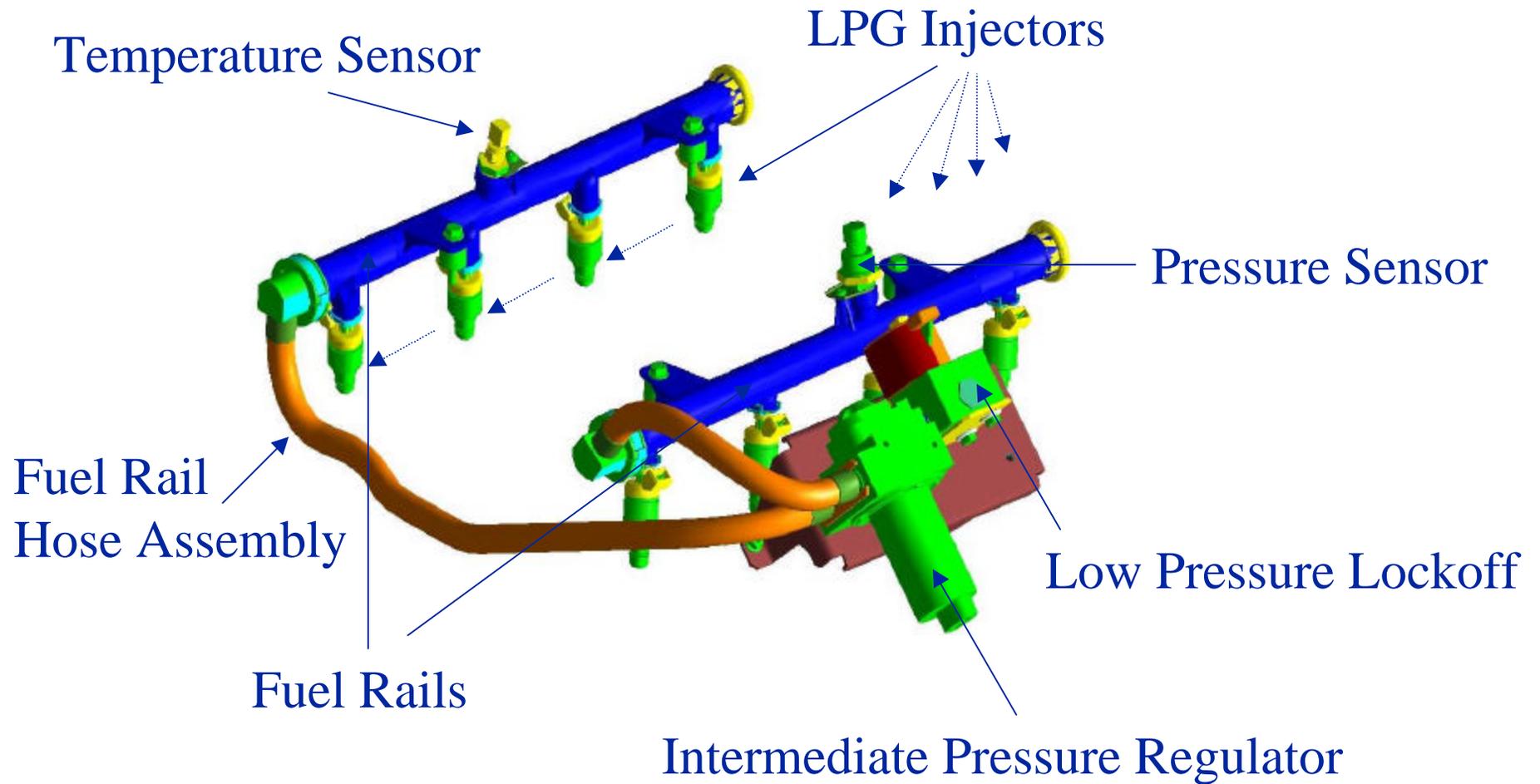
Gas Injectors–Performance

- **Fast Response**
 - 0.0012 seconds on (1.2 millisecond)
 - 0.0010 seconds off (0.5 millisecond)
- **High Flow Rate**
 - 2.5 grams / second CNG @ 4.14 bar
 - Capable of fueling >220 Kilowatt (300 hp) 8 cylinder
- **Low Leak Rate**
 - <0.5 sccm @ 4.14 Bar (60 PSI)
- **Completed 435,000,000 cycles of operation**
 - Additional units are now being tested to 500,000,000
 - A Methanol injector used in competitive gaseous applications failed after 30,000,000 cycles

Technical Specifications

➤ Length	3.07”
➤ Diameter (Max)	0.98”
➤ Flow Capacity (Static)	2.5 g/s CNG
➤ Dynamic Range	12.0
➤ Working Pressure (CNG)	60 psi
➤ Working Pressure (Propane)	17 psi
➤ Fatigue Life	>500,000,000 cycles

Typical Fuel Pressure & Fuel Management Subsystem



Validation Test Performed

- **High and Low Temperature**
- **Vibration**
- **Thermal Shock**
- **Water Intrusion**
- **Exterior Corrosion**
- **Internal Corrosion**
- **Immunity to Conducted Transients**
- **Immunity to Jumpstart Voltages**