

Report 2: Cost-Effective Reciprocating Engine Emissions Control and Monitoring for E&P Field and Gathering Engines

Technical Progress Report

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Author

Kirby S. Chapman, Ph.D., Kansas State University

Submitted by

Kansas State University
National Gas Machinery Laboratory
245 Levee Drive
Manhattan, KS 66502

Significant Assistance Provided by

Coerr Environmental Corporation
400 Silver Cedar Court, Suite 240
Chapel Hill, NC 27514

Collaborative Research Associates, Inc.
1300 Deep Run Road
Naperville, IL 60540

Energy and Environmental Analysis
1655 N Fort Meyer Drive, Suite 60
Arlington, VA 22209

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Abstract

During the second reporting period, the project team focused on identifying promising technologies that can then be used to monitor and control emissions from E&P engines. These technologies include control and monitoring technologies and in most cases can be used to monitor engine performance as well as control and monitor engine emissions..

The project team also identified three potential sources to receive a Cooper Ajax engine that is approximately 100 bhp. The goal is to have this engine delivered to the project team by the end of the calendar year 2003. This will then allow the team to prepare the engine for testing at Ricardo in early 2004.

Table of Contents

Disclaimer.....	ii
Abstract.....	iii
Table of Contents.....	iv
Introduction.....	1
Research Progress.....	1
Task 2: Develop a database of existing E&P engine inventory.....	1
Task 3: Identify and assess commercial and emerging control and monitoring technologies	3
Further Work Planned.....	10
Task 2: Develop a database of existing E&P engine inventory.....	10
Task 3: Assess control and monitoring technologies.....	10
Task 4: Determine technology and market gaps.....	10
Task 5: Conduct controlled tests to evaluate promising technologies.....	11
Task 6: Determine on-engine control system and sensor requirements for remote emissions monitoring.....	11
Conclusions.....	11

Introduction

The objective of this project is to identify, develop, test, and commercialize emissions control and monitoring technologies that can be implemented by exploration and production (E&P) operators to significantly lower their cost of environmental compliance and expedite project permitting. The project team will take considerable advantage of the emissions control research and development efforts and practices that have been underway in the gas pipeline industry for the last 12 years. These efforts and practices are expected to closely interface with the E&P industry to develop cost-effective options that apply to widely-used field and gathering engines, and which can be readily commercialized.

The project is separated into two phases. Phase 1 work establishes an E&P industry liaison group, develops a frequency distribution of installed E&P field engines, and identifies and assesses commercially available and emerging engine emissions control and monitoring technologies. Current and expected E&P engine emissions and monitoring requirements will be reviewed, and priority technologies will be identified for further development. The identified promising technologies will be tested on a laboratory engine to confirm their generic viability. In addition, during Phase 2 a full-scale field test of prototype emissions controls will be conducted on at least ten representative field engine models with challenging emissions profiles. Emissions monitoring systems that are integrated with existing controls packages will be developed. Technology transfer/commercialization is expected to be implemented through compressor fleet leasing operators, engine component suppliers, the industry liaison group, and the Petroleum Technology Transfer Council.

Research Progress

Primary effort during this reporting period was focused on Tasks 2 and 3. The efforts in Task 2 developed a frequency distribution of the existing E&P engine fleet and the efforts in Task 3 focused on the identification and assessment of existing and emerging emission control and monitoring technologies. These tasks provide the research team with the information and data necessary to identify the engine(s) that will be used to evaluate the technologies in Tasks 4 and 5.

Task 2: Develop a database of existing E&P engine inventory

Rather than a database, the suggestion from the advisory committee was to sample the current fleet and then characterize the makes and models that are used in the E&P industry. This information would then be used to prioritize the work in Tasks 3 and 4.

The initial sampling of engines was developed from a lists of engines typically used in E&P operations. The database will be also be used to determine geographical distribution of engines and horsepower ranges.

Items which are being included in the database include:

- Make and model
- Cycle
- Rated load and speed

- NA/T/TA
- Rich/lean
- Application

To date, the project has collected information on approximately 9,000 engines used in E&P operations. The information is being compiled into a single database so that any duplicates can be deleted and overall information can be queried. The sources of engine lists are provided in Table 1.

The EPA ICCR Database has a multitude of natural gas transmission engines. As such, the information from that database is not as meaningful at this stage of the project as the State of Wyoming and Universal Compression databases.

Tables 2 and 3 provide the inventories of engines from the Wyoming and Universal Compression databases. From the Wyoming database, the Waukesha and Caterpillar engines

Table 1. Sources of engine data and information.

Database	Number of Engines
State of Wyoming Engine Inventory Database	3,372
EPA ICCR Database	5,000*
GTI/PRCI Engine and Turbine Database	300 Gathering Engines
Database of Colorado and New Mexico Engines from Universal Compression	500

***Some of the engines in this database are used in interstate natural gas transmission and are being removed.**

Table 2. Natural gas E&P engine inventory from the Wyoming database by manufacturer.

Manufacturer	Lean Burn	Rich Burn	Total
Ajax	242	0	242
Caterpillar	607	557	1,164
Superior	0	1	1
Waukesha	1,417	535	1,952
White Superior	0	2	2

Table 3. Natural gas E&P engine inventory from the Universal Compression database by manufacturer.

Manufacturer	Total
Ajax	191
Caterpillar	150
Ford	24
Superior	4
Waukesha	126
Other	19
Grand Total	514

are dominate, while the Universal Compression database shows that the Cooper Ajax engine dominates, followed by the Waukesha and Caterpillar engines.

The conclusion from the information gathered to date is that the four-stroke cycle engine inventory is dominated by Caterpillar and Waukesha while the two-stroke cycle engine inventory is dominated by the Cooper Ajax.

Task 3: Identify and assess commercial and emerging control and monitoring technologies

Simultaneously with the engine inventory development, the project team also identified, categorized, and assessed commercially available and emerging emissions control and monitoring technologies. As with the database development, the project team depended on past experience with the pipeline industry. Several control and monitoring technologies have been developed to reduce HAPs and NOX emissions from pipeline engines, and expectations are that these same technologies can be modified and refined to work equally well on the higher speed engines used in the E&P industry. This task was separated into two subtasks. The first focuses on monitoring techniques, and the second focuses on emissions control techniques. In most cases, monitoring techniques are essential for precise emissions control.

With an understanding of emissions formation in engines and available emissions reduction technologies, the appropriate technologies can be identified for application as suitable retrofits for the fleet of gas engines in natural gas exploration and production (E&P) applications. Characterizing technologies include:

- Understanding the underlying science of each option;
- Identifying the overall costs to retrofit the technology and associated equipment;

- Estimating the recurring maintenance costs to operate in compliance;
- The incremental fuel costs; and
- Emissions monitoring requirements (and expenses).

The project team pursued an approach that included:

- Describing baseline information on emissions of gas engines;
- Identifying applicable retrofit technologies for the class of engines to be addressed;
- Gathering technical, operational, and economic information on available technologies and ancillary equipment; and
- Analyzing technologies based on cost effectiveness and applicability to E&P fleet of engines

Exhaust emissions are the primary environmental concern with reciprocating engines. The primary pollutants are oxides of nitrogen (NOX), carbon monoxide (CO), and volatile organic compounds (VOCs – unburned, non-methane hydrocarbons). Other pollutants such as oxides of sulfur (SO_x) and particulate matter (PM) are primarily dependent on the fuel used.

Emissions of sulfur compounds, primarily SO₂, are related to the sulfur content of the fuel. Engines operating on natural gas emit insignificant levels of SO_x. In general, SO_x emissions are an issue only in large, slow speed diesels firing heavy oils. Particulate matter (PM) can be an important pollutant for engines using liquid fuels. Ash and metallic additives in the fuel contribute to PM in the exhaust.

Nitrogen Oxides (NOX) – Nitrogen oxide emissions are usually the primary concern with natural gas engines and are a mixture of (mostly) NO and NO₂ in variable composition. In measurement, NOX is commonly reported in units of g/hp-hr. Other units are g/kWhr (power generation applications) and as parts per million by volume in which both species count equally (e.g., ppmv at 15% O₂, dry). Other units include output rates such as lbs/hr.

NOX is formed by three mechanisms: thermal NOX, prompt NOX, and fuel-bound NOX. The predominant NOX formation mechanism associated with reciprocating engines is thermal NOX. Thermal NOX is the fixation of atmospheric oxygen and nitrogen, which occurs at high combustion temperatures. Flame temperature and residence time are the primary variables that affect thermal NOX levels. The rate of thermal NOX formation increases rapidly with flame temperature. Prompt NOX is formed from early reactions of nitrogen molecules in the combustion air and hydrocarbon radicals from the fuel. It forms within the flame and typically is on the order of 1 ppm at 15% O₂, and is usually much smaller than the thermal NOX formation. Fuel-bound NOX forms when the fuel contains nitrogen as part of the hydrocarbon structure. Natural gas has negligible chemically bound fuel nitrogen. Fuel-bound NOX can be at significant levels with liquid fuels.

The control of peak flame temperature through lean burn conditions has been the primary combustion approach to limiting NOX formation in gas engines. Diesel engines produce higher combustion temperatures and more NOX than lean burn gas engines, even though the overall diesel engine air/fuel ratio may be very lean. There are three reasons for this: (1) heterogeneous near-stoichiometric combustion; (2) the higher adiabatic flame temperature of distillate fuel; and (3) fuel-bound nitrogen. The diesel fuel is atomized as it is injected and dispersed in the combustion chamber. Combustion largely occurs at near-stoichiometric conditions at the air-droplet and air-fuel vapor interfaces, resulting in maximum temperatures and higher NOX. In contrast, lean-premixed homogeneous combustion used in lean burn gas engines results in lower combustion temperatures and lower NOX production.

For any engine there are generally trade-offs between low NOX emissions and high efficiency. There are also trade-offs between low NOX emissions and emissions of the products of incomplete combustion (CO and unburned hydrocarbons). There are three main approaches to these trade-offs that come into play depending on regulations and economics. One approach is to control for lowest NOX accepting a fuel efficiency penalty and possibly higher CO and hydrocarbon emissions. A second option is finding an optimal balance between emissions and efficiency. A third option is to design for highest efficiency and use post-combustion exhaust treatment.

Carbon Monoxide (CO) – Carbon monoxide and volatile organic compounds (VOCs) both result from incomplete combustion. CO emissions result when there is inadequate oxygen or insufficient residence time at high temperature. Cooling at the combustion chamber walls and reaction quenching in the exhaust process also contribute to incomplete combustion and increased CO emissions. Excessively lean conditions can lead to incomplete and unstable combustion and high CO levels.

Unburned Hydrocarbons – Volatile hydrocarbons also called volatile organic compounds (VOCs) can encompass a wide range of compounds, some of which are hazardous air pollutants. These compounds are discharged into the atmosphere when some portion of the fuel remains unburned or just partially burned. Some organics are carried over as unreacted trace constituents of the fuel, while others may be pyrolysis products of the heavier hydrocarbons in the gas. Volatile hydrocarbon emissions from reciprocating engines are normally reported as non-methane hydrocarbons (NMHCs). Methane is not a significant precursor to ozone creation and smog formation and is not currently regulated.

Carbon Dioxide (CO₂) – While not considered a pollutant in the ordinary sense of directly affecting health, emissions of carbon dioxide are of concern due to its contribution to climate change (global warming). Atmospheric warming occurs since solar radiation readily penetrates to the surface of the planet but infrared (thermal) radiation from the surface is absorbed by the CO₂ (and other polyatomic gases such as methane, unburned hydrocarbons, refrigerants and volatile chemicals) in the atmosphere, with resultant increase in temperature of the atmosphere. The amount of CO₂ emitted is a function of both fuel carbon content and system efficiency. The fuel carbon content of natural gas is 34 lbs carbon/MMBtu.

Subtask 3.1: Monitoring technologies

Several different monitoring technologies have been successfully implemented on the slow speed engines used in natural gas transmission. These technologies range from very precise in-cylinder monitoring to the measurement of certain parameters that can then be used to infer emissions and performance of the engine.

One key technology that holds promise for the E&P industry high speed engines are ion sensing. Ion sensing measures the thermal conductivity between two electrodes. By sensing the thermal conductivity, studies have shown that it is possible to infer the gaseous species concentrations within the cylinder during the combustion and post-combustion processes. By doing so, one can determine the in-cylinder air-to-fuel ratio, the engine average air-to-fuel ratio, and also identify combustion anomalies. Ultimately, this same process can be used to determine NO_x production and emission within the cylinder. By interfacing this relatively inexpensive sensor with an engine control system, an inexpensive closed-loop control system can be developed.

Recent laboratory tests proved that ion sensing technology can be implemented in lean-burn and rich-burn engines. The tests clearly showed that in-cylinder NO_x could be determined, providing the benefit of knowing precisely how much NO_x is being generated on a per cylinder basis. Future plans are to continue processing this data, and then exploring the use of this technology on E&P engines.

Subtask 3.2: Control technologies

NO_x control has been the primary focus of emission control research and development in natural gas engines. The following provides a description of the most prominent emission control approaches. The production and control of NO_x are affected by a wide range of engine design and operating parameters:

- Air/Fuel ratio and changing method
- Ignition timing
- Combustion chamber design
- Engine combustion cycle
- Operating load and speed

Combustion Process Emissions Control

Control of combustion temperature has been the principal focus of combustion process control in gas engines. Combustion control requires tradeoffs – high temperatures favor complete burn up of the fuel and low residual hydrocarbons and CO, but promote NO_x formation. Very lean combustion dilutes the combustion process and reduces combustion temperatures and NO_x formation, and allows a higher compression ratio or peak firing pressures resulting in higher efficiency. However, if the mixture is too lean, misfiring and incomplete combustion occurs, thereby increasing CO and VOC emissions.

Lean burn technology was developed and commercialized during the 1980s as a direct response to the need for cleaner burning gas engines. As discussed earlier, thermal NO_x

formation is a function of both flame temperature and residence time. The focus of lean burn developments was to lower combustion temperature in the cylinder using lean fuel/air mixtures. Lean combustion decreases the fuel/air ratio in the zones where NOX is produced so that peak flame temperature is less than the stoichiometric adiabatic flame temperature, therefore suppressing thermal NOX formation. Improvements in mixing may be accomplished through swirling and tumbling the air (or air/fuel mixture) within the cylinder, improving fuel injection or location, increasing fuel injection pressure, and enhancing flame speed. Most lean burn engines use turbocharging to supply excess air to the engine and produce the homogeneous lean fuel-air mixtures. Lean burn engines generally use 50 to 100% excess air (above stoichiometric). The typical emissions rate for lean burn natural gas engines is between 0.5 to 2.0 g/bhp-hr.

An added performance advantage of lean burn operation is higher output and higher efficiency. Optimized lean burn operation requires sophisticated engine controls to ensure that combustion remains stable and NOX reduction is maximized while minimizing emissions of CO and VOCs.

Combustion-based Control Technologies have been developed and demonstrated on several classes of gas engines. They include:

- *Retard Ignition Timing* – Ignition timing retard is a low cost option applied to achieve small decreases in NOX emissions. This option is based on delaying and lowering the peak firing temperature within the power cylinder. The corresponding reduction in peak firing temperature results in lower combustion temperature and consequently lower NOX emissions. By simply retarding the ignition timing five degrees from its current setting, the engine's NOX emissions could be reduced by about 10%. Even though there are no significant hardware costs associated with this change, the engines fuel consumption and exhaust temperature will increase.
- *High Energy Ignition* – High energy ignition refers to hot sparking systems. The basic concept behind these technologies is the ability to ignite a leaner air/fuel mixture within the power cylinder. These systems are typically quoted for engine retrofits with targeted NOX emissions of 3 to 6 g/bhp-hr. In addition to the high energy ignition system, there will likely be requirements to upgrade the engine's air delivery system to provide additional boost pressure and lower air manifold temperatures. It may also require upgraded electrical equipment, new spark plug gap settings, spark plug extensions or specialty spark plugs. Many high energy ignition systems are designed with additional diagnostic features to detect ignition problems before combustion problems in the cylinder begin to occur.
- *Pre-combustion Chambers* – Pre-combustion chambers (some times referred to as jet cells) are used to ignite extremely lean air/fuel mixtures. A secondary fire chamber is integrated into the power cylinder head. These systems use a secondary fuel supply to richen the chambers lean mixture to an easily ignitable mixture. These require upgrades to the air delivery system. The integral design assures proper cooling and eliminates water leakage problems into the power cylinder. These systems have been

shown to operate continuously at NOX emissions levels below 1 g/bhp-hr. These approaches are currently offered by OEM's.

- *Micro Pre-combustion Chamber* – This approach is a hybrid between the high energy ignition systems and a pre-combustion chamber. It reduces NOX by providing sufficient energy to ignite a lean air/fuel mixture. This system is typically a spark plug fitted with a small fuel supply line directed at the spark plug's electrode. Similar to a pre-combustion chamber, the secondary fuel is fed through a check valve in the cavity in and around the spark plug's electrodes. As the piston rises, the secondary fuel mixes with the cylinder's air/fuel mixture to generate a localized rich mixture. When the spark is initiated, the localized rich mixture ignites and provides sufficient energy to continue the combustion process through the remaining lean mixture in the cylinder. This approach has proven to achieve NOX emissions levels of 2-4 g/bhp-hr. The approach requires upgrades to the air delivery system and the addition of a secondary fuel system. The key primary benefit is that this approach is lower in costs than the OEM integral pre-combustion chamber since the micro pre-combustion chamber fits into the existing power cylinder spark plug holes. However, specialized micro pre-combustion chamber spark plugs are more expensive than standard plugs and must be replaced in comparable time intervals.
- *Screw-in Pre-combustion Chambers* – Screw-in pre-combustion chambers are a lower cost alternative to pre-combustion chambers and provide similar effective combustion and emission performance. These systems are retrofit options that provide additional ignition energy from a separate rich burning chamber capable of firing a lean air/fuel mixture in the main chamber. It works similar to the micro pre-combustion approach described above in that a secondary fuel supply is used to "richen" a localized mixture. They are designed for installation on existing cylinder heads with little or no modifications. They work in conjunction with a lean air/fuel mixture, which is likely to require an upgrade to the air delivery system. These screw systems are available from OEM's and third party suppliers. Differences between OEM and third party systems typically involve the method used to cool the chamber. Third party systems use external water cooling systems that do not require permanent power cylinder head modifications.
- *Pre-stratified Charge* – The pre-stratified charge system is an option available for 4-cycle carbureted engines. In general, a secondary air supply for dilution is piped into the fuel manifold for each cylinder. The dilution air is maintained at a slightly higher pressure than the air/fuel pressure. While the cylinder fuel valve is closed, fresh air is forced into the fuel header pushing the air/fuel mixture back. Once the fuel valve opens, the fresh air and lean mixture is the first to enter the cylinder and moves toward the piston. The dilution air is displaced and the carbureted mixture continues flowing into the cylinder, leaving near the top of the cylinder. Once the fuel valve closes and the spark plug is ignited, the richer carbureted mixture ignites and begins burning downward into the lean mixture. The combination of rich then lean reduces the combustion temperature and subsequently NOX emissions.

- *Advanced In-cylinder Mixing* – Almost all the combustion approaches described above require significant upgrades to the air delivery system. It may entail a redesign of turbochargers on those engines that are already turbo charged or the addition of a turbocharger on engines that don't already have one. This may be very expensive for the smaller horse power engines targeted in E&P applications. Goals of advanced in-cylinder mixing approaches have been to develop a system that can be retrofitted to an engine that will significantly improve the emission signature of engines without compromising the economic advantages they currently exhibit. Poor in-cylinder mixing due to ineffective fuel delivery can lead to combustion variability and be problematic. Advanced commercially available options include high pressure fuel and super sonic injection into the power cylinder. Several companies are pursuing this technology and have been offering retrofits since 2000. Initial results have indicated significant reductions (30-70%) in NOX emissions without the need for costly air supply upgrades and improved fuel efficiency. It is not known if these systems have been demonstrated to be as effective when less than high pressure pipeline gas is available. This is the case in many E&P applications.

Post-Combustion Emissions Control

There are several types of catalytic exhaust gas treatment processes that are applicable to gas engines:

- *Three-way Catalyst* – The catalytic three-way conversion process (TWC) is the basic automotive catalytic converter process that reduces concentrations of all three major criteria pollutants – NOX, CO and VOCs. The TWC is also called non-selective catalytic reduction (NSCR). NOX and CO reductions are generally greater than 90%, and VOCs are reduced approximately 80% in a properly controlled TWC system. Because the conversions of NOX to N₂ and CO and hydrocarbons to CO₂ and H₂O will not take place in an atmosphere with excess oxygen (exhaust gas must contain less than 0.5% O₂), TWCs are only effective with stoichiometric or rich-burn engines. Typical “engine out” (i.e., untreated exhaust) NOX emission rates for a rich burn engine are 10 to 15 g/bhp-hr. NOX emissions with TWC control are as low as 0.15 g/bhp-hr.

Stoichiometric and rich burn engines have significantly lower efficiency than lean burn engines. The TWC system also increases maintenance costs by as much as 25%. TWCs are based on noble metal catalysts that are vulnerable to poisoning and masking, limiting their use to engines operated with clean fuels – e.g., natural gas and unleaded gasoline. Also, the engines must use lubricants that do not generate catalyst poisoning compounds and have low concentrations of heavy and base metal additives. Unburned fuel, unburned lube oil, and particulate matter can also foul the catalyst. TWC technology is not applicable to lean burn gas engines.

- *Selective Catalytic Reduction (SCR)* – This technology selectively reduces NOX to N₂ in the presence of a reducing agent. NOX reductions of 80 to 90% are achievable with SCR. Higher reductions are possible with the use of more catalyst or more reducing agent, or both. The two agents used commercially are ammonia (NH₃ in anhydrous liquid form or aqueous solution) and aqueous urea. Urea decomposes in the hot

exhaust gas and SCR reactor, releasing ammonia. Approximately 0.9 to 1.0 moles of ammonia is required per mole of NOX at the SCR reactor inlet in order to achieve an 80 to 90% NOX reduction.

SCR systems add a significant cost burden to the installation cost and maintenance cost of an engine system, and can severely impact the economics. SCR requires on-site storage of ammonia, a hazardous chemical. In addition ammonia can “slip” through the process un-reacted, contributing to environmental health concerns.

- *Oxidation Catalysts* – Oxidation catalysts generally are precious metal compounds that promote oxidation of CO and hydrocarbons to CO₂ and H₂O in the presence of excess O₂. CO and NMHC conversion levels of 98 to 99% are achievable. Methane conversion may approach 60 to 70%. Oxidation catalysts are now widely used with all types of engines, including diesel engines. They are being used increasingly with lean burn gas engines to reduce their relatively high CO and hydrocarbon emissions.
- *Lean-NOX Catalysts* – Lean-NOX catalysts utilize a hydrocarbon reductant (usually the engine fuel) injected upstream of the catalyst to reduce NOX. While still under development, it appears that NOX reduction of 80% and both CO and NMHC emissions reductions of 60% may be possible. Long-term testing, however, has raised issues about sustained performance of the catalysts. Current lean-NOX catalysts are prone to poisoning by both lube oil and fuel sulfur. Both precious metal and base metal catalysts are highly intolerant of sulfur. Fuel use can be significant with this technology – the high NOX output of diesel engines would require approximately 3% of the engine fuel consumption for the catalyst system.

Further Work Planned

During the next quarter, the research team will direct most of its effort on Task 2, which will lay the groundwork for Tasks 3 and 4. Upon completion of Task 2, the research team will shift their effort to the identification of control technologies and market gaps.

Task 2: Develop a database of existing E&P engine inventory

Additional work will continue to identify and characterize the E&P engine fleet. Once complete, this information will be used to further prioritize the work in Tasks 3 and 4, as well as Tasks 5 and 6. This work is expected to be completed during the third quarter of the project, July 1, 2003 through September 30, 2003.

Task 3: Assess control and monitoring technologies

During the next reporting period, the project team plans to contact several aftermarket and vendor companies to obtain specific information (performance and cost) for emission reduction technologies. Work will continue on this task during the third quarter of 2003.

Task 4: Determine technology and market gaps

This task will use the emissions control approaches identified in Task 3.0 to determine the practical targets for the magnitude of emissions reduction in E&P engines. Once the reduction magnitudes are determined, each will be ranked by how applicable it is to the specific inventory of field engines, its expected cost of implementation, and the overall emissions

reduction that can be reasonably anticipated from further development and commercialization of the technology.

The second portion of this task will compare the expected emissions reduction performance to the current and expected emissions permitting requirements facing the E&P industry. Doing so will identify the high-impact control technologies that are expected to be widely utilized by the E&P industry, and which should be targeted either for immediate testing, or require more fundamental component development.

This work will be performed during the third quarter of 2003, in parallel with Task 3, and during the fourth quarter of 2003. It is expected that work will center on three major areas: 1) engine controls; 2) ignition systems; and 3) exhaust gas treatment options.

Task 5: Conduct controlled tests to evaluate promising technologies

The most promising technologies identified in Tasks 3 and 4 will be tested under controlled conditions on an Ajax engine, which is in very wide use in E&P operations. The tests will most undoubtedly be conducted at Ricardo, Inc. in Burr Ridge, IL. Ricardo operates a set of state-of-the-art, fully instrumented test cells that can accommodate engines up to 1,000 HP. Up to 160 hours of test time at Ricardo are planned to conduct preliminary performance testing of the array of promising technologies identified in Task 3.

Assuming that an engine can be located, the tests will be conducted during the first quarter of 2004.

Task 6: Determine on-engine control system and sensor requirements for remote emissions monitoring

This task will identify the necessary sensors, software, and hardware to provide remote engine emissions and performance monitoring. The results from Task 3.1 will be used to determine the scope and content of a monitoring system. The project team has expertise in this area, and has actually developed and implemented remote sensing technologies for pipeline engines for what is arguably the most stringent real-time emissions monitoring program in the world (California's RECLAIM program).

Conclusions

The primary conclusion drawn from the work that was completed during the second quarter is that several promising technologies were identified that are candidates for E&P engines. These technologies include control and monitoring technologies and in most cases can be used to monitor engine performance as well as control and monitor engine emissions.

The project team also identified three potential sources to receive a Cooper Ajax engine that is approximately 100 bhp. The goal is to have this engine delivered to the project team by the end of the calendar year 2003. This will then allow the team to prepare the engine for testing at Ricardo in early 2004.