

# Demonstration of Natural Gas Engine Driven Air Compressor Technology at Department of Defense Industrial Facilities

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## ABSTRACT

Recent downsizing and consolidation of Department of Defense (DOD) facilities provides an opportunity to upgrade remaining facilities with more efficient and less polluting equipment. Use of air compressors by the DOD is widespread and the variety of tools and machinery that operate on compressed air is increasing. The energy cost of operating a natural gas engine-driven air compressor (NGEDAC) is usually lower than the cost of operating an electric-driven air compressor. Initial capital costs are offset by differences in prevailing utility rates, efficiencies of partial load operation, reductions in peak demand, heat recovery, and avoiding the cost of back-up generators. Natural gas, a clean-burning fuel, is abundant and readily available. In an effort to reduce its over-all environmental impact and energy consumption, the U.S. Army plans to apply NGEDAC technology in support of fixed facilities compressed air systems. Site assessment and demonstration results are presented in this paper.

## BACKGROUND

Although electricity only accounts for about one-third of DOD's energy consumption, it makes up two-thirds of its energy bill. Recent downsizing and consolidation of facilities provides an opportunity to upgrade remaining facilities with more efficient and less polluting equipment. DOD industrial facilities perform a wide variety of process operations in the manufacture of munitions, weapon systems, tactical vehicles, aircraft, and naval vessels. Use of air compressors by the DOD is widespread and the variety of tools and machinery that operate on compressed air is increasing. The energy cost of operating a natural gas fueled engine-driven air compressor is usually lower than the cost of operating an electric motor driven unit. Initial capital costs are off-set by differences in prevailing utility rates, efficiencies of partial load operation, reductions in peak demand, heat recovery, and avoiding the cost of

back-up generators. Natural gas, a clean-burning fuel, is abundant and readily available.

## OBJECTIVES

The objectives are to assess the viability of applying NGEDAC technology at six installations, identified by Army Materiel Command, and to provide a full technology demonstration at two installations. Favorable economics is the prime selection criterion for technology demonstration. The demonstration will evaluate operation & maintenance, compressed air quality, efficiency, reliability, and air emissions.

## Preliminary Site Assessments

The Project Team—consisting of U.S. Army Construction Engineering Research Laboratory (USACERL), Technology & Management Services, Inc., and XENERGY, Inc.—conducted six preliminary site assessments (Level I Audits) to screen candidate sites for the demonstration. The six candidate sites were:

- Picatinny Arsenal, New Jersey;
- Watervliet Arsenal, New York;
- Corpus Christi Army Depot, Texas;
- Lone Star Army Ammunition Plant, TX;
- Pine Bluff Arsenal, AR; and
- Combat Equipment Group-Afloat, SC.

Evaluation results are summarized below.

### *(1) Picatinny Arsenal*

The Picatinny Arsenal site showed favorable economics and presented a number of other positive aspects that help make it a good demonstration site candidate. Gas supply was readily accessible. Physical space was available and plant modifications would be minimal. Experience and confidence gained by Picatinny staff and contractors in developing and operating the existing 2.2 megawatts-electric (MWe) natural gas-fueled cogeneration system were a significant plus and could help reduce

cost estimates for maintenance contracts for the NGEDAC system.

### ***(2) Watervliet Arsenal***

The Watervliet Arsenal site demonstrated favorable economic conditions for implementation of a gas engine driven system. Such a system was estimated to cost \$210,000 annually in fuel expense and save \$98,000. Maintenance costs for the NGEDAC technology are \$15,000 higher annually based on a two-year maintenance contract. The resulting net operating cost of a NGEDAC system was estimated at \$83,000 less than the current electric system, when the pre-existing centrifugal compressor is operating.

### ***(3) Corpus Christi Army Depot***

The Corpus Christi Army Depot site had a number of positive aspects. Gas, electric, and water supplies are readily accessible. However, logistically, the site presents difficulties in installing a NGEDAC due to an on-going utility decentralization work. First, the design phase for the proposed compressed air decentralization plan needed to be moved forward enough for the NGEDAC project to be designed at the same time. Also, the decentralization plan needed to pick up certain costs associated with the NGEDAC project such as the cooling tower and other items that would only be constructed during the decentralization plan that would be needed after the NGEDAC Project is complete, *e.g.*, the heat recovery system with the NGEDAC unit. Second, the NGEDAC needs to be assigned to play a critical role in the decentralization plan and, as such, its accumulative savings do not need to be measured against the entire capital cost of the NGEDAC unit. Third, the NGEDAC needed to be able to claim the full theoretical savings of its peak shaving capability, which will be reflected in the electric bill paid by the Corpus Christi Naval Air Station, but not necessarily reflected in the electric bill paid by its tenant, the Corpus Christi Army Depot.

### ***(4) Lone Star Army Ammunition Plant***

The compressed air system at Lone Star Army Ammunition Plant is a very efficient and correctly applied system. The compressors have been recently serviced and the entire drying system upgraded. The system is well maintained. The plant enjoys very low electric rates, which average \$0.045 per kWh—about half of some of the other sites that have been considered. High system efficiency and low electric rates combine to give Lone Star one of the lowest cost structures among all the compressed air systems that were reviewed. The Lone Star site was not

considered as a viable NGEDAC site, unless prevailing operating and economic conditions change.

### ***(5) Pine Bluff Arsenal***

Pine Bluff Arsenal had a number of positive aspects. Gas supply is readily accessible. However, Pine Bluff demonstrates only marginally favorable economic conditions for implementation of a gas engine driven system to replace one of the existing electric units.

### ***(6) Combat Equipment Group—Afloat***

The preliminary assessment concludes that the Combat Equipment Group—Afloat (CEGA) is not a good candidate for additional consideration. The current system already consists of well-applied electric compressors and a well-managed distribution system. The distribution system has recently undergone a systematic leak repair program and is monitored effectively by a Johnson Controls energy system. In addition, the gas rates currently charged to the CEGA are disproportionately high relative to the electric rates being charged.

## **DEMONSTRATION SITE SELECTION**

While all of the sites could accommodate the NGEDAC, Picatinny and Watervliet represented the best sites in terms of economics, access, and ease of installation. Once the sites were selected, the Project Team developed the conceptual design for each site. The next step in the design phase was to prepare the *65 Percent Design Package* report followed by the *100 Design Package* report, which is essentially the “as-built” design. The highlights of that report, and most importantly, the as-built design are discussed below for each site.

## **PICATINNY NGEDAC SYSTEM**

Picatinny Arsenal met all of the criteria for the demonstration. Further, the site was relatively close to the other site selected, Watervliet Arsenal, New York; the close proximity allowed many of the same Project Team personnel to work at both sites and reduced travel costs.

### **Pre-Existing Equipment**

The pre-existing Picatinny compressed air system consisted of two 18½ x 11½ x 8½ inch stroke, double acting, reciprocating-type Ingersoll Rand compressors. Each unit is rated at 200 bhp (1,130 acfm at a design pressure of 100 to 110 psig) and has 5-step unloading capability. Near the start of the project, flow and pressure were measured for 24 hours to document “as-found” conditions. The data indicated an average 800 scfm (900 acfm) of

continuous demand over the 24 hours, which includes both production and non-production hours at Picatinny because the arsenal is essentially a one-shift operation. The pressure held steady at 79 to 80 psig during the entire test.

### NGEDAC Equipment

A Dearing Ultra Air Model GSR-125LA air-cooled natural gas engine and rotary screw compressor was installed as the best match for the gas/electric hybrid compressed air system. The compressor is designed to supply 80 psig discharge pressure to the plant with a maximum discharge capacity for the unit of 610 cfm. The prime mover is a Caterpillar G3306NA natural gas engine with a rating of 145 hp at 1,800 rpm. The unit has lubrication system heaters and a hospital type exhaust muffler with stainless steel flexible exhaust connector and a catalytic converter. The required natural gas pressure for the unit is 2–5 psig. The natural gas engine is equipped with a Miratech Model MEC 2001 Air Fuel Ratio Controller for emissions control. The controller automatically maintains the optimal fuel mixture to achieve emissions compliance without operator supervision. The system also optimizes catalyst management and provides system diagnostics.

The compressor component is a single-stage, positive displacement Gardner Denver Model SSQ Rotary Gas Compressor. The compressor and natural gas engine are in a weatherproof, sound attenuated acoustic enclosure with multiple access doors and ventilation fan. A two-year maintenance agreement was included as part of the project.

### Permitting and Emissions

The NGEDAC systems environmental emission levels are based on limits of 0.70 gm/bhp/hr for oxides of nitrogen and 0.48 gm/bhp/hr for carbon monoxide. The emission limits of the recommended NGEDAC equipment are:

- Oxides of Nitrogen 0.18 lb/10<sup>6</sup> Btu
- Carbon Monoxide 0.13 lb/10<sup>6</sup> Btu
- Total Hydrocarbons 0.37 lb/10<sup>6</sup> Btu
- Non-Methane Hydrocarbons 0.07 lb/10<sup>6</sup> Btu
- Sulfur Dioxide <0.05 lb/10<sup>6</sup> Btu
- Total Suspended Particles <0.05 lb/10<sup>6</sup> Btu
- Particulate Matter <0.05 lb/10<sup>6</sup> Btu

### Compressor Efficiency and Cost Analysis Results for Picatinny

After commissioning, the NGEDAC performance was measured.

### (1) Theoretical Performance

Exhibit 1-1 shows the theoretical performance parameters provided with the NGEDAC equipment specifications for various loading conditions. At full load, the unit produces 610 cfm and uses 978,460 Btu per hour. At about two-thirds load, the unit operates nearly as efficiently as at full load.

**Exhibit 1-1 NGEDAC Theoretical Performance Parameters**

Load (%)	Capacity (cfm)	BHP	Gas Use (Btu/bhp/hr)	Gas Use (Btu/hr)	Daily Energy Cost* (Dollars)	Air Cost (\$/1000cft)
100	610	116	8,435	978,460	125.85	0.14
65	395	80	8,250	660,000	87.64	0.15
40	244	72	8,850	637,200	84.90	0.24
28	175	—	—	637,200	84.90	0.34

\*At natural gas price of \$5.00/10<sup>6</sup> Btu and includes 96 kWh per day (or \$8.44) to operate the system fan.

At the low load conditions of 40 percent and 28 percent, the system loses considerable efficiency as the intake flow to compressor is throttled down, but the engine speed and, hence energy use, stays relatively constant. The NGEDAC system costs more than twice as much to operate on a unit basis at 28 percent than at full load.

### (2) Performance Measurement

The actual performance of the NGEDAC unit was measured in terms of gas consumption and air flow production. The daily gas totals for the unit are shown in Exhibit 1-2. The daily totals are relatively constant and fall within a range of 160 ± 8% hundred cubic feet (ccf), except for one of the nine days.

Continuous readings for the air flow are shown in Exhibit 1-3. The air flow numbers are less stable than the gas flow numbers, but cluster around 170 to 175 scfm with periods of flow ranging from a high of 300 scfm to a low of 0 scfm. With the full load capacity of the NGEDAC unit at 610 scfm, actual air flow use during the test period averaged 28 percent load and peaked at about 50 percent.

Exhibit 1-2 Picatinny Arsenal  
Natural Gas Use: Daily Totals

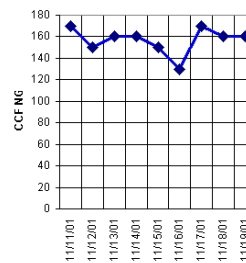
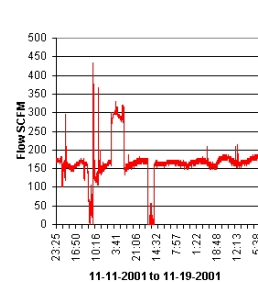


Exhibit 1-3 Picatinny  
Compressed Air Flow



Air flow during the test period averaged 174 scfm or 251,600 scf for a day. Gas flow during the test period averaged 170 ccf per day or 17,000 cubic feet per day. Thus, the ratio (in terms of ft<sup>3</sup><sub>air</sub>/ft<sup>3</sup><sub>gas</sub>) is 14.8. As indicated in Exhibit 1-4, at \$5.00/10<sup>6</sup> Btu for natural gas, the 28 percent load condition and 14.8 air

to gas ratio translate into \$93 of gas per day and 37 cents/1,000 ft<sup>3</sup> of air produced. The cost estimate based on the theoretical performance supplied with the equipment specifications assumes that the gas consumption of the NGEDAC unit will not change much for flow rates below 244 cfm or 40 percent of full load. The measurement results show that gas use was 11.1 percent more in the actual operation than predicted by the theoretical calculations. A swing of 11.1 percent is well within the level of the precision provided by the equipment specifications, the variability of the application conditions, and the measurement approach.

Exhibit 1-4 NGEDAC Measured Performance Parameters

Data Source	Load (%)	Capacity (cfm)	Gas Use (Btu/hr at load condition)	Daily Cost* (Dollars)
Equipment Specification	28	175	637,200	84.90
Measurement	28	175	708,000	93.34

\* At natural gas price of \$5.00/10<sup>6</sup> Btu and includes 96 kWh per day (or \$8.44) to operate the system fan.

### (3) NGEDAC Cost Effectiveness

The cost-effectiveness evaluation compares the operating cost of the NGEDAC unit with the existing electric unit. The electrical demand and daily electric cost for the unit are shown in Exhibit 1-5. At full load the existing electric unit produces 1,130 cfm at an electrical demand of 174.9 kW and an electric cost of \$370/day. At 15 percent loading, or the level that produces the current air flow requirement of the arsenal, the electric demand is 52.7 kW, and the electric cost is \$111/day.

Exhibit 1-5 Electric Air Compressor Theoretic Performance Measures

Load (%)	Air Flow Capacity (cfm)	Power Use (%)	Electric Demand (kW)	Daily Electric Cost* (Dollars)	Air Cost (\$/1000cf)
100	1130	100	174.9	369.36	0.23
75	848	83	145.2	306.66	0.25
54	610	63	110.2	232.71	0.26
50	565	59	103.2	217.95	0.27
35	395	45	78.7	166.22	0.29
25	282	33	57.7	121.86	0.30
22	244	32	56.0	118.20	0.34
15	175	30	52.7	111.30	0.40

\* Electricity cost at 8.8 cents per kWh.

Exhibit 1-6 depicts a cost comparison of the daily energy cost of the NGEDAC unit with that of the electric unit. The relative gas price varies from \$3.41/10<sup>6</sup> Btu, which was the gas price level at the time the original site review was conducted at Picatinny, to \$7.00 /10<sup>6</sup> Btu, which is a gas price level on the high end. The estimate of \$5.00/10<sup>6</sup> Btu represents a mid-range forecast.

Exhibit 1-6 Table of Daily Energy Costs of NGEDAC and Electric Air Compressors

Air Flow Capacity (cfm)	NGEDAC Unit: Annual Energy Cost*			Electric Unit: Annual Electricity Cost (Dollars)
	@\$3.41/10 <sup>6</sup> Btu	@\$5.00/10 <sup>6</sup> Btu (Dollars)	@\$7.00/10 <sup>6</sup> Btu	
610	32,300	45,900	63,100	84,900
395	22,800	32,000	43,600	60,700
244	22,100	31,000	42,100	43,100
175	22,100	31,000	42,100	40,600

\*Includes \$3,080 in annual electric cost to operate the system fan.

With a flow rate at the full load condition of the NGEDAC unit, *i.e.*, 610 cfm, the NGEDAC unit enjoys an energy cost advantage ranging from \$21,800 to \$52,700 per year, depending on the gas price scenario. For load conditions closer to the levels currently experienced by the arsenal, *i.e.*, 175 cfm, the comparison is much closer. The gas unit is cheaper to operate by \$17,500 if gas prices are \$3.41/10<sup>6</sup> Btu, while the electric unit is cheaper to run by \$1,500 if gas prices are \$7.00/10<sup>6</sup> Btu. The NGEDAC breaks even with the pre-existing electric air compressor when natural gas prices reach \$6.50/10<sup>6</sup> Btu and electricity is 8.8 cents per kWh.

A couple of potential adjustments should be noted. First, the measurement analysis found that the daily energy cost was closer to \$93, not \$85 for the NGEDAC, when the price of gas is at \$5.00/10<sup>6</sup> Btu. This is a swing of \$3,000 per year at low load conditions.

A second potential adjustment centers on the maintenance contract. As part of the NGEDAC demonstration project, the arsenal has a two-year maintenance contract on the NGEDAC engine and compressor. As such, the arsenal could disregard the maintenance cost issue in establishing protocols of whether to use the NGEDAC unit or the electric unit.

The maintenance contract on the NGEDAC unit is priced at about \$20,000 per year or \$55 per day. If Picatinny wanted to include the maintenance costs in the total cost picture, it could simply add that figure to the NGEDAC daily costs. However, the maintenance costs for a contract to cover the electric unit would also have to be added in order to maintain an “apples-to-apples” comparison. The cost of a maintenance contract on the rather old XLE unit would be \$16,000 per year or \$45 per day—for a savings advantage of \$10 per day or \$3,600 for the electric air compressor.

### (4) NGEDAC Application Guide

From this assessment, an overall guideline can be developed that defines when it is preferable to operate the NGEDAC unit. The amount Picatinny

spends on compressed air has been reduced from \$100,000 in the main system to less than \$35,000, when gas prices are \$5.00/10<sup>6</sup> Btu.

Having the ability to operate either unit, gives Picatinny the greater operating flexibility and control to address rapid spikes in fuel prices or electric curtailments and to manage compressor equipment shut downs. Note also that for a large operating band of assumed gas prices and operating load conditions, the difference in operating costs between the two units is not terribly significant on an annual basis.

A general guide to operating the compressor units would include the following:

- For main system loads greater than 400 cfm (or 65 percent of the full load capacity of the NGEDAC), operate the NGEDAC unit as long as gas prices are less than approximately \$9/10<sup>6</sup> Btu and electric costs average 8.8 cents per kWh.
- For main system loads less than 250 cfm (or 40 percent of the full load capacity of the NGEDAC unit), operate the NGEDAC as long as gas prices are less than \$6.50 /10<sup>6</sup> Btu and electric costs average 8.8 cents per kWh.
- All other conditions would entail operating either system or operating just the electric unit.

### **WATERVLIEET ARSENAL DEMONSTRATION**

The NGEDAC unit is part of a gas/electric hybrid system capable of delivering 100 percent of the base load requirements with the NGEDAC as the primary air compressor. Watervliet will use the NGEDAC unit as their primary compressed air delivery system with the pre-existing electrically driven Ingersoll Rand unit kept in reserve service. The electric compressor will be maintained for full demand capability so that no interruptions to the compressed air service will be experienced during installation, maintenance, or unplanned downtimes of the NGEDAC system.

#### **Pre-Existing Equipment**

The pre-existing compressed air system at Watervliet is supplied by a number of compressors spread over a large geographical area. The current distributed air system reaches most of the production areas in the arsenal and runs from building to building on a closed loop system. The current air flow requirement of the main system is approximately 2,000–2,500 acfm at a supply pressure of 83–85 psig. The majority of the system is compressed air supply is being generated in Building 110 with the use of two 125-hp water-cooled Ingersoll Rand XLE (650 cfm per machine) reciprocating compressors. The two main

compressors feed into a 3-inch compressed air line that connects to the main distribution loop. In addition to these two large compressors, there are six smaller type compressors tied in to the main air system in surrounding buildings that serve as a backup system and provide additional capacity.

The pre-existing compressor units are capable of delivering the required peak load of approximately 2,000–2,500 acfm at 80–85 psig. The compressed air demand measured was determined to be relatively constant and assumed to be supplied to the system 8,760 hours per year. The complete air system appears to be well laid out, well maintained, and operated consistently with the type of controls on each compressor unit.

#### **NGEDAC Equipment**

The Project Team chose a Dearing Ultra Air Model GSR-300 LW NGEDAC unit as the best match for the hybrid compressed air system. The prime mover is a Waukesha F18GLD turbocharged, liquid-cooled, natural gas engine. The engine drives a Gardner Denver rotary screw air compressor sized to deliver a maximum 1,400 acfm at 100-psig system pressure. The Ultra Air is enclosed and equipped with a Riley-Beaird model M5 hospital grade muffler. A Dearing Ultra-Air TR5 Control system was installed providing a remote shut-off option. The overall dimensions of the compressor are approximately 106 inches wide by 192 inches long by 108 inches high. Maximum engine fuel requirements are approximately 4,000 scf/hr of natural gas at 20 inches w.c. A pressure regulator is used to reduce the gas pressure from approximately 5 psig to 1 psig. The new compressor is located outside in a weatherproof enclosure.

#### **Permitting and Emissions**

The NGEDAC nameplate rating was 362 bhp, which is below the trigger level of 400 bhp for New York state air permitting requirements. The emission limits of the recommended NGEDAC equipment are:

- Oxides of Nitrogen 941.2 grams/hr
- Carbon Monoxide 633.5 grams/hr
- Hydrocarbons 1,810 grams/hr
- Non-Methane Hydrocarbons 271.5 grams/hr

#### **Compressor Efficiency and Cost Analysis Results for Watervliet**

After commissioning, the NGEDAC performance was measured.

### (1) Theoretical Performance

Exhibit 1-7 shows the theoretical performance parameters provided with the NGEDAC equipment specifications for various loading conditions. At full load, the unit produces 1,480 cfm and uses 2,675,180 Btu per hour of natural gas. At about two-thirds load, the unit operates 15–20 percent less efficiently as at full load. At a low load condition of 40 percent, the system loses considerable efficiency as the intake flow to compressor is throttled down, but the engine speed and, hence energy use, stays relatively constant. The NGEDAC system costs nearly twice as much to operate on a unit basis at 40 percent than at full load.

Exhibit 1-7. NGEDAC Theoretical Performance Parameters

Load (%)	Capacity (cfm)	BHP	Gas Use (Btu/bhp/hr)	Gas Use (Btu/hr)	Daily Energy Cost* (Dollars)	Air Cost (\$/1,000 cf)
100	1,480	362	7,390	2,675,180	352.70	0.17
74	1,100	304	7,380	2,243,520	300.90	0.19
65	960	285	7,375	2,101,875	283.90	0.20
40	590	265	7,495	1,986,175	270.02	0.32

\*At natural gas price of \$5.00/10<sup>6</sup> Btu and includes 288 kWh per day (or \$31.88) to operate the cooling pump.

### (2) Performance Measurement

The actual performance of the NGEDAC unit was measured in terms of gas consumption and air flow production. The daily gas totals for the unit are shown in Exhibit 1-8. The gas meter was only read at the beginning of the period, after the first day, and after the seventh day. Average use over the seven-day period was 468 ccf per day with the first day being 384 ccf and the average for the other six days being 482 ccf per day. Continuous readings for the air flow are shown in Exhibit 1-9. The air flow numbers are less stable than the gas flow numbers, but cluster around 1,050 to 1,100 scfm with periods of flow ranging from a high of 1,350 scfm to a low of 900 scfm. With the full load capacity of the NGEDAC unit at 1,480 scfm, actual air flow use during the test period averaged 74 percent load and peaked at about 91 percent. Air flow during the test period averaged 1,100 scfm or 1,584,000 scf for a day. Gas flow during the test period averaged 482 ccf per day or 48,200 cubic feet per day. Thus, the ratio (in terms of ft<sup>3</sup><sub>air</sub>/ft<sup>3</sup><sub>gas</sub>) is 33.8. As indicated in Exhibit 1-10, at \$5.00/10<sup>6</sup> Btu for natural gas, the 74 percent load condition and 33.8 air to gas ratio translate into \$289.16 of gas per day. This results in a cost of 19 cents/1,000 ft<sup>3</sup> for air production. The measurements show that gas use was four percent less in the actual operation than predicted by the theoretical calculations (2.146 x 10<sup>6</sup> Btu/hr versus 2.244 x 10<sup>6</sup> Btu/hr). A swing of four percent is well within the level of the precision provided by the equipment specifications, the variability of the application conditions, and the measurement approach.

Exhibit 1-8. Watervliet Arsenal Natural Gas Use: Daily Totals

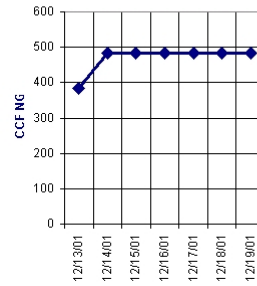


Exhibit 1-9. Watervliet Measured Compressed Air Flow

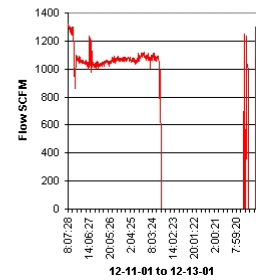


Exhibit 1-10. NGEDAC Measured Performance Parameters

Data Source	Load (%)	Capacity (cfm)	Gas Use (Btu/hr at load condition)	Daily Cost* (Dollars)
Equipment Specification	74	1,100	2,243,520	\$300.90
Measurement	74	1,100	2,145,700	\$289.16

\*At natural gas price of \$5.00/10<sup>6</sup> Btu and includes 288 kWh per day (or \$31.88) to operate the cooling pump.

### (3) NGEDAC Cost Effectiveness

The cost-effectiveness evaluation compares the operating cost of the NGEDAC unit with the existing electric unit. The pre-existing electric units are two 125 Ingersoll-Rand XLEs with 687 cfm at 115 psig and 128 bhp. The electrical demand and daily electric cost for the unit are shown in Exhibit 1-11. At full load the existing electric unit produces 1,374 cfm at an electrical demand of 212.2 kW and an electric cost of \$560.21/day. At 80 percent loading, or the level that produces the current air flow requirement of the arsenal, the electric demand is 176.1 kW and the electric cost is \$464.97/day.

Exhibit 1-11. Electric Air Compressor Theoretic Performance Measures

Load (%)	Air Flow Capacity (cfm)	Power Use (%)	Electric Demand (kW)	Daily Electric Cost* (Dollars)	Air Cost (\$/1000cf)
108	1,480	108	238.6	603.50	0.28
100	1,374	100	212.2	560.21	0.28
80	1,100	83	176.1	464.97	0.29
70	960	75	160.0	422.40	0.30
43	590	54	114.3	301.75	0.36

\*Electricity cost at 11 cents per kWh.

Exhibit 1-12 depicts a cost comparison of the daily energy cost of the NGEDAC unit with that of the electric unit. The relative gas price varies from \$3.50/10<sup>6</sup> Btu, which is the gas price at the low end of the spectrum, to \$7.00 /10<sup>6</sup> Btu, which is a gas price level on the high end. Gas prices peaked over a short time period during the winter of 2000-01 at about \$10/10<sup>6</sup> Btu. The estimate of \$5.00/10<sup>6</sup> Btu represents a mid-range forecast. With a flow rate at the full load condition of the NGEDAC unit, *i.e.*, 1,480 cfm, the NGEDAC unit enjoys an energy cost advantage ranging from \$44,700 to \$127,600 per year, depending on the gas price scenario. For load conditions closer to the levels currently experienced by the arsenal, *i.e.*, 1,100 cfm, the comparison is much closer. The gas unit is cheaper to operate by \$89,400 if gas prices are \$3.50/10<sup>6</sup> Btu and by

\$20,600 if gas prices are \$7.00/10<sup>6</sup> Btu. The NGEDAC breaks even with the pre-existing electric air compressor when natural gas prices reach about \$8/10<sup>6</sup> Btu and electricity is 11 cents per kWh.

Exhibit 1-12 Table of Daily Energy Costs of NGEDAC and Electric Air Compressors

Air Flow Capacity (cfm)	NGEDAC Unit: Annual Energy Cost*			Electric Unit: Annual Electricity Cost (Dollars)
	@\$3.50/10 <sup>6</sup> Btu	@\$5.00/10 <sup>6</sup> Btu (Dollars)	@\$7.00/10 <sup>6</sup> Btu	
1,480	93,600	128,700	175,600	220,300
1,100	80,300	109,800	149,100	189,700
960	76,000	103,600	140,400	154,200

\*Includes \$11,560 in annual electric cost to operate the cooling pump.

A potential adjustment on this analysis centers on the maintenance contract. As part of the NGEDAC demonstration project, the arsenal has a two-year maintenance contract on the NGEDAC engine and compressor. As such, the arsenal could disregard the maintenance cost issue in establishing protocols of whether to use the NGEDAC unit or the electric unit.

The maintenance contract on the NGEDAC unit is priced at about \$45,000 per year or \$123 per day. If Watervliet wanted to include the maintenance costs in the total cost picture, it could simply add that figure to the NGEDAC daily costs. However, the maintenance costs for a contract to cover the electric unit would also have to be added in order to maintain an “apples-to-apples” comparison. The cost of a maintenance contract on the pre-existing XLE units would be \$22,000 per year or \$60 per day—for a savings advantage of \$60 per day or \$21,900 for the electric air compressor.

#### (4) NGEDAC Application Guide

From this assessment, an overall guideline can be developed that defines when it is preferable to operate the NGEDAC unit. The amount Watervliet will be spending on compressed air has been reduced from \$360,000 (*i.e.*, the electric cost the arsenal would have incurred in the Main System using 11 cents per kWh and the centrifugal compressor units) to less than \$120,000. About a third of this reduction (\$80,000) is the result of lower production costs for the NGEDAC unit and the other two-thirds of the reduction (\$160,000) is the result of reducing air flow requirements by almost half as a result of implementing the demand-side recommendations.

Having the ability to operate either the NGEDAC or the electric units, gives Watervliet the greater operating flexibility and control to address rapid spikes in fuel prices or electric curtailments and to manage compressor equipment shutdowns and maintenance expenses. A general guide to operating the compressor units is quite simple:

- Use the NGEDAC unit as long as air requirements are above 960 cfm and gas is less than \$8.00/10<sup>6</sup> Btu and electric costs average 11 cents per kWh.
- If electric costs go up, then a higher threshold gas price would be applicable.
- If electric costs go down, then a lower threshold gas price would be applicable.
- The gas price cut-off might move down to \$7.00/10<sup>6</sup> Btu if the maintenance contract costs are included.

## CONCLUSIONS AND RECOMMENDATIONS

This program established the viability of applying NGEDAC technology at DOD industrial facilities. The demonstration also provided hands-on operating experience that formed the basis for developing USACERL guidelines for NGEDAC installation and operations. At Picatinny, annual energy costs to produce the required air flow in the main system have decreased from \$99,500 to \$31,000, assuming a gas price of \$5.00/10<sup>6</sup> Btu. At Watervliet, annual energy costs to produce the required air flow in the main system have decreased from \$360,000 to \$109,800. The total annual savings for both sites range from a low of \$268,000 to a high of \$357,000. This equates to a simple payback of 4.5 to 6.0 years.

Both Picatinny and Watervliet Arsenals should continue to manage and reduce their air requirements.

The Watervliet site has the additional opportunity of incorporating the NGEDAC performance data directly into their overall energy management control system.

All Army industrial installations will be screened for technology application. Technology transfer will be coordinated with Air Force, Navy, and Defense Logistics Agency. Cost sharing for web site development (<http://www.aircompressor.org>) and application screening by the Industrial Center, Inc. and utility companies could further facilitate technology transfer to public and private sectors.