IMPACT EVALUATION OF AN ENERGY SAVINGS
PLAN PROJECT AT THE LINDE DIVISION OF
UNION CARBIDE CORPORATION

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EXECUTIVE SUMMARY

This impact evaluation of an energy conservation measure (ECM) that was recently installed at the Linde Division of Union Carbide Corporation (Linde) was conducted for the Bonneville Power Administration (Bonneville) as part of an evaluation of its Energy Savings Plan (ESP) Program. The Program makes acquisition payments to firms that install energy conservation measures in their industrial processes. The objective of this impact evaluation was to assess how much electrical energy is being saved at Linde as a result of the ESP and to determine how much the savings cost Bonneville and the region.

The impact of the ECM was evaluated with a combination of engineering analysis, financial analysis, site visit and interviews, and submittal reviews (Linde's Completion Report and Abstract). The ECM itself consists of replacing the plant's nitrogen feed compressor with a larger unit, which allows the plant to meet its argon demand using less compressed air and which results in net energy savings.

Energy savings resulting from this ECM were 4,376,500 kWh/yr for the first two years after installation, but, because of a change in Linde's market position, long-term savings are expected to be lower at 2,549,200 kWh/yr. Linde considers energy consumption and savings on a per ton basis to be proprietary, so they are not reported here. The ECM cost \$361,496 to install, and Linde received payment of \$161,426 from Bonneville for the acquisition of energy savings. This ECM would not have been implemented without the acquisition payment from Bonneville. The levelized cost of these energy savings to Bonneville will be 4.5 mills/kWh over the ECM's expected 15-year life, and the levelized cost to the region will be 5.9 mills/kWh.

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IMPACT EVALUATION OF AN ENERGY SAVINGS PLAN PROJECT
AT THE LINDE DIVISION OF UNION CARBIDE CORPORATION

1.0 INTRODUCTION

This letter report describes Pacific Northwest Laboratory's (PNL's)^(a) evaluation of the impact of an energy conservation measure (ECM) installed at the Linde Division of Union Carbide Corporation (Linde) in Fife, Washington. The ECM at Linde is one of about thirty energy conservation projects to have its impact evaluated by PNL. All of the projects have received or will receive acquisition payments from the Bonneville Power Administration (Bonneville) under the Energy Savings Plan (ESP) Program.

The ESP is being offered to acquire electrical energy savings in the industrial sector of the Pacific Northwest. For the Linde project, the acquisition payment offered under the program was equal to the lesser of 5¢/kWh saved in the first year or 80% of eligible project costs, up to a limit of \$250,000.

The general objective of the impact evaluation was to determine how much electrical energy is saved by the ECM and at what cost to Bonneville and to the region. In support of this general objective, answers were sought to the following questions:

1. How much electrical energy is saved annually by the energy conservation measure in terms of kilowatt-hours and kilowatt-hours per unit of plant output? Also, did any fuel switching result from implementing this ECM?
2. If the ECM improved the productivity of the process, did the firm then increase output of the process to take advantage of the productivity improvement? Did the change in output result in a net increase or decrease in energy used by the process? Did the change in output cause changes in output at the firm's other plants in the region?

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3. What was the net impact to the serving utility in terms of electrical energy consumption (in kilowatt-hours) from implementing the ECM?
4. What are the levelized costs of the ECM from the perspectives of Bonneville and the region?
5. How much of the ECM's impact can be attributed to the ESP?

1.1 APPROACH FOR IMPACT EVALUATION

Before selecting individual energy conservation projects for impact evaluation, PNL developed a general impact evaluation methodology (Spanner et al., 1988). The major finding of the methodology development was that in the industrial sector, energy conservation projects must be considered on a case-by-case basis. Accordingly, the general methodology consists of a variety of impact evaluation techniques that can be applied to individual projects according to the specific circumstances.

To evaluate the impact of replacing the feed compressor at Linde, four techniques were selected from the general methodology: engineering analysis, financial analysis, site visit and interview, and review of Linde's submittals. On-site submetering by PNL was not necessary because the metering performed by Linde in accordance with ESP program requirements is adequate to determine the project's impact.

Representatives from PNL visited Linde on January 10, 1992, to view the ECM firsthand and to conduct an interview with the plant's General Superintendent.

1.2 PROJECT DESCRIPTION

Linde is an air separation plant that produces liquid nitrogen, oxygen, and argon. In the energy conservation project at Linde, a larger feed compressor was installed between the upper column and the nitrogen liquifier (see Figure 1.1). Even though this new compressor is larger than the compressor it replaced, it allows the plant on the whole to operate at greater energy efficiency because less air needs to be compressed to meet argon demand. With the smaller feed compressor installed it was necessary to supplement the feed

(a) This compressor was replaced in this project.

FIGURE 1.1. Linde Air Separation Process

compressor output with high pressure nitrogen from the lower column to feed the liquefier. The source of this high pressure nitrogen was the air compressor upstream of the lower column. With the larger feed compressor installed, it is not necessary to use high pressure nitrogen from the lower column to feed the liquefier. The net result of this change is that less air needs to be compressed initially to produce the desired amount of argon, thereby saving energy for the plant as a whole.

When the decision to install this ECM was made in 1988, Linde had contracts to supply customers with large amounts of argon and oxygen. With this high production demand, it made economic sense to replace the feed compressor with a larger unit so that the large argon and oxygen demand could be met with greater efficiency. This larger compressor was installed in April 1989 with an acquisition payment from Bonneville. In August 1991, however, Linde lost a large contract for oxygen so that the plant is no longer required to operate at such high output at all times. Under these conditions, the larger feed compressor still results in energy savings, although the savings are lower than they were with the large oxygen demand.

To verify the savings for this project, 7 instantaneous readings were taken of 13 parameters over a one-week period before the feed compressor was replaced, and the readings were repeated 7 times after compressor replacement. The 7 readings taken before compressor replacement were averaged for each of the 13 parameters, as were the readings taken after replacement. To make the before and after readings comparable, it was necessary to normalize them for 3 factors. First the data were normalized to a common ambient temperature, 59°F. Next, the data were normalized for equivalent liquid nitrogen production. Finally, the data were normalized for equivalent crude argon production.

After all of the normalizations were calculated, the energy savings in instantaneous power were found to be 515 kW. Multiplying this power savings times the annual hours of operation results in annual savings of 4,376,500 kWh/yr as reported in Linde's Completion Report.

To calculate energy savings after the oxygen demand was reduced by the lost contract, a computer model at Linde's headquarters was used. The model showed that savings under current production conditions are 2,549,200 kWh/yr.

To participate in the ESP Program, Linde submitted two documents to Bonneville: an Abstract and a Completion Report. The Abstract described the ECM and presented Linde's expectations with regard to costs and benefits. Included was a calculation of the ECM's expected simple payback. A Completion Report was submitted to Bonneville after the ECM was installed and Linde had verified the resulting energy savings. This document listed the actual costs

of the ECM along with a calculation of the energy savings that had been achieved. A copy of the cover sheet from the Completion Report is included as Appendix B.

The total cost to Linde for this ECM was \$361,496 and Bonneville paid \$161,426 for the energy saved. The acquisition payment was based on the energy savings in Linde's Proposal and the cost sharing percentage that applies to customers of Tacoma City Light ($5\text{¢/kWh} \times 3,798,248 \text{ kWh} \times 0.85 = \$161,420$).

1.3 SUMMARY OF PROJECT IMPACTS

This E\$P project, or ECM, saved 4,376,500 kWh/yr in its first 28 months of operation (beginning in April 1989), and it is expected to save 2,549,200 kWh/yr after the first 28 months and into the future.

Over the assumed 15-year life of this ECM, with energy savings decreasing after the first 28 months, levelized costs to Bonneville will be 4.5 mills/kWh (1 mill = 1/1000 of a dollar), and cost to the region will be 5.9 mills/kWh. These costs are in real dollars and do not include additional savings that accrue if transmission and distribution losses are considered. The levelized cost to Bonneville including transmission and distribution losses will be 4.2 mills/kWh and the cost to the region will be 5.5 mills/kWh.

Without the acquisition payment from Bonneville, this ECM did not meet Linde's funding criteria; however, it did meet the criteria with the acquisition payment. Therefore, we conclude that it would not have been installed in the absence of the E\$P.

2.0 IMPACT EVALUATION

The following section addresses the five major objectives of the impact evaluation as stated in the introduction.

2.1 ENERGY SAVINGS AND FUEL SWITCHING

1. *How much electrical energy is saved annually by the ECM in terms of kilowatt-hours and kilowatt-hours per unit of plant output? Also, did any fuel switching result from implementing this ECM?*

Energy Savings

When the decision was made to replace the nitrogen feed compressor, Linde had sales contracts for large quantities of argon and oxygen. To meet these contracts, the plant was compressing more raw air than desirable and venting excess nitrogen. Operating the plant this way is inefficient because energy was being used to compress nitrogen in the air that would ultimately be vented. Even operating in this inefficient manner was not sufficient to meet argon demand, so Linde was also "importing" liquid argon by rail from its plant in Utah for distribution in the Puget Sound area.

By installing a larger nitrogen feed compressor, Linde was able to yield more argon per cubic foot of air compressed, and thereby reduce the amount of raw air required to meet argon and oxygen demand. Energy savings result from this ECM because the energy saved by running the air compressor at lower throughput is greater than the increased energy required to run the larger nitrogen feed compressor.

During the first 28 months after the compressor replacement, the plant was operated as intended with energy savings as measured for the Completion Report: 4,376,500 kWh/yr. However, Linde later lost a large oxygen contract so that it was no longer necessary to run the plant at such a high output. In this situation, the net savings with the larger nitrogen feed compressor are substantially lower: 2,549,200 kWh/yr. For purposes of this impact evaluation, savings are assumed to remain at the lower figure for the remaining life

of the project. In fact, the savings may climb back up to the earlier levels if Linde is able to sell more oxygen contracts in the future; something it is actively pursuing. In the future, energy savings will most likely be between 2.5 million kWh/yr and 4.5 million kWh/yr. The lower figure is used in the financial analysis of this project because it is more conservative.

Energy savings per unit of plant output are not reported in this impact evaluation because Linde considers this information proprietary.

Fuel Switching

Electricity is the sole source of energy for this plant, so no fuel switching resulted from installing this ECM.

2.2 IMPACTS TO THE FIRM

2. *If the ECM improved the productivity of the process, did the firm then increase output of the process to take advantage of the productivity improvement? Did the change in output result in a net increase or decrease in energy used by the process? Did the change in output cause changes in output at the firm's other plants in the region?*

Installation of this ECM did indeed improve the productivity of the production process by reducing the amount of electricity required to satisfy Linde's argon demand. Output from the plant was not increased as a result of this ECM because Linde produces only enough argon to satisfy its contracts; the purpose of the ECM is to reduce energy consumption, and hence, operating costs. Before the ECM was installed, Linde imported liquid argon from its Utah plant by rail car to help satisfy argon demand in the Northwest. Linde now imports much less argon.

2.3 IMPACTS TO THE UTILITY

3. *What is the net impact to the serving utility in terms of electrical energy consumption (in kilowatt-hours) from implementing the ECM?*

Because there are no cogeneration or other complicating factors in this project, all of the energy savings from this ECM will be reflected in reduced load at the utility, Tacoma City Light. The net impact to the servicing

utility from this ECM was a 4,376,500 kWh/yr reduction in electrical load for the first 28 months after installation, and it will be at least a 2,549,200 kWh/yr reduction for the foreseeable remaining life of the ECM.

2.4 LEVELIZED COSTS

4. *What are the levelized costs of the ECM from the perspectives of Bonneville and the region?*

Levelized annual costs are used to compare the attractiveness of various projects or investment alternatives. The levelized cost is the annual cost that would be incurred over the life of the project, accounting for the time value of money. (See Appendix A for complete definition and formula.) Levelized costs provide a single figure of merit for comparing energy conservation alternatives. In addition, levelized costs can be used to compare conservation projects with options for new generating capacity and to optimize the ranking of these options. The objective of using levelized costs to evaluate these energy conservation measures is to determine the financial impact of each ECM to Bonneville (\$/kWh saved) and to the region (Bonneville and Linde combined).

In the industrial sector, it is not possible to accurately predict the life of an ECM because any number of external factors could cause the ECM to have a longer or shorter life than expected when it is installed. To allow comparisons of levelized costs among projects installed under the ESP, all ECMs are assumed to have a life of 15 years. Even though some ECMs will have longer or shorter lives, for purposes of impact evaluations, 15 years is considered a conservative but likely life for typical ECMs in the industrial sector.

2.4.1 Bonneville Perspective

To determine the levelized costs to Bonneville and to the region, we must know the project costs (acquisition payment paid, capital costs, etc.) and the energy savings, and must assume a discount rate and ECM life. With energy savings of 4,376,500 kWh/yr for the first 28 months and 2,549,200 kWh/yr thereafter, the project's levelized cost from Bonneville's perspective will be 4.5 mills/kWh (see Appendix A). Bonneville's levelized

cost decreases to 4.2 mills/kWh when transmission and distribution losses are considered. These losses increase the energy savings at the point of generation by 7.5%.

The levelized costs calculated in this impact evaluation include the acquisition payment paid by Bonneville but ignore any administrative or evaluation costs for the program. Data are not available to calculate these costs on a project-by-project basis, but they will be included in an impact evaluation report on the overall program.

2.4.2 Regional Perspective

To calculate the levelized cost to the region, the costs to Bonneville and Linde are combined. The acquisition payment paid by Bonneville is included as a cost to Bonneville and as a reduction in cost to Linde. This approach is taken because the acquisition payment has federal income tax consequences to the company and, therefore, is not a net zero cost to the region.

The levelized costs to the region for acquiring annual energy savings of 4,376,500 kWh at first and 2,549,200 kWh/yr later is 5.9 mills/kWh saved. Including transmission and distribution losses, the levelized cost decreases to 5.5 mills/kWh saved.

2.5 IMPACT ATTRIBUTABLE TO ESP

5. *How much of the ECM's impact can be attributed to the ESP?*

Linde uses simple payback to select energy conservation projects, with a desired threshold of three years or less. When this project was initially presented to Bonneville, it was expected to cost \$457,000 and result in electrical savings of \$63,440/yr for a simple payback of 7.2 years, which is too long to meet Linde's threshold. By the time Linde submitted its final proposal for the project, costs were expected to be \$372,000 with electrical savings of \$67,039/yr for a simple payback of 5.6 years, which was still too long. With Bonneville's acquisition payment of \$161,426, the expected simple payback was reduced to 3.1 years, which was close enough to meeting Linde's threshold.

The decision to install this ECM was based largely on a market forecast that called for the plant to produce high levels of argon and oxygen. If the market forecast did not hold up, the ECM would not save as much energy as planned. Bonneville's acquisition payment reduced Linde's exposure to a change in the market.

Considering the facts presented above, we conclude that this project would not have been implemented without the acquisition payment from Bonneville and that all of the project's impact can be attributed to the ESP.

3.0 REFERENCES

Spanner, G. E., D. R. Brown, D. R. Dixon, B. A. Garrett, R. W. Reilly, J. M. Roop, and S. A. Weakley. 1988. *Potential Techniques for Evaluating the Impact of Industrial Energy Conservation Projects under Bonneville's Energy Savings Plan*. Letter Report. PNL-6628, Pacific Northwest Laboratory, Richland, Washington.

APPENDIX A

FINANCIAL EVALUATION DETAILS

APPENDIX A

FINANCIAL EVALUATION DETAILS

A.1 DEFINITIONS

Levelized Cost - A single figure of merit that expresses the cost per unit of benefit (in this case, energy savings) accounting for the time value of money. This annualized cost would be constant over the entire project life. An infinite number of cash flow scenarios (costs incurred at different times in the project life) could result in the same annualized cost.

Levelized Cost to Bonneville - The annualized costs to Bonneville, direct and indirect, per unit of energy saved by the conservation measure. Costs included are the acquisition payment paid and the program administrative costs (although no administrative costs are included in this analysis of the ECM at Linde).

Levelized Cost to Region - The sum of annualized costs to Bonneville and Linde per unit of energy saved by the energy conservation measure. This would include the same costs to Bonneville as above, plus the initial capital and ongoing incremental production costs to the firm. Any non-electrical savings that result from the ECM are not considered in this analysis.

A.2 LEVELIZED COST FORMULA

$$LC = \{ [PVC I + PVIC I + (PVOM + PVPT + PVOTE) \cdot (1-itf) - PVD \cdot itf] / (1-itf) \} \cdot (CRF/AES)$$

where LC = levelized cost (real \$)

PVCI = present value of initial capital costs

PVIC I = present value of interim capital costs

PVOM = present value of operating and maintenance (O&M) costs

PVPT = present value of property taxes

PVOTE = present value of one-time expenses

itf = combined state and federal income tax fraction
 PVD = present value of depreciation
 CRF = capital recovery factor (spreads the costs over the project life in real dollar terms)
 AES = annual energy savings (kWh/yr).

A.3 GENERAL ASSUMPTIONS

The following general assumptions were made in the levelized cost calculations:

1. All cash flows are expressed in nominal terms (with inflation) and are discounted to present value at a nominal discount rate of 8.15% (combines a real discount rate of 3.0% and an inflation rate of 5.0%). The costs are annualized over the life of the project using the capital recovery factor at a real discount rate of 3.0%.
2. Energy savings were 4,376,500 kWh/yr for the first 28 months of the ECM's operation, and dropped to 2,549,200 kWh/yr for the remaining life of the ECM. This assumes no intrinsic loss in efficiency of the equipment with time.
3. Transmission and distribution losses equal 7.5%, increasing the energy savings at the source by a corresponding 7.5%.
4. In the regional cost calculation, the acquisition payment from Bonneville is treated as a cost to Bonneville and, at the same time, a cash inflow to Linde rather than a net zero cost. This is done because Linde will incur a tax liability from the acquisition payment, thus a net cost to the region.

A.4 BONNEVILLE LEVELIZED COST CALCULATIONS

Input: one-time expenses

Acquisition payment paid (year 0)	= \$158,460
Administrative costs (year 0)	= \$0
Tax rate	= 0%
Energy savings (annual)	= 4,376,500 kWh for 28 months, 2,549,200 kWh for 152 months

Output: levelized cost = 4.5 mills/kWh

A.5 REGIONAL LEVELIZED COST CALCULATIONS (BONNEVILLE + LINDE)

A. Linde

Input: initial capital

Equipment = \$361,496

One-time expenses (revenues)

Acquisition payment received = (\$161,426)

Annual recurring expenses (revenues and savings)

None

Tax rate = 34%

Project Life = 15 years

Depreciation = 5 years

Energy savings (annual) = 4,376,500 kWh for 28 months,
2,549,200 kWh for 152 months

Output: levelized cost = 1.4 mills/kwh

B. Regional levelized cost = Bonneville levelized cost + Linde
levelized cost

= 4.5 mills/kWh + 1.4 mills/kWh

= 5.9 mills/kWh

A.6 LEVELIZED COSTS ALLOWING FOR TRANSMISSION AND DISTRIBUTION LOSSES

Input: transmission and distribution losses = 7.5%

Bonneville levelized cost = 4.5 mills/kWh/1.075 = 4.2 mills/kWh

Regional levelized cost = 5.9 mills/kWh/1.075 = 5.5 mills/kWh

APPENDIX B

COVER SHEET FROM LINDE'S COMPLETION REPORT

APPENDIX B

Exhibit A
Page 1

COVER SHEET FROM LINDE'S COMPLETION REPORT

Directions: Complete Sections I through IV and submit with Project Abstract. Photocopy and complete Section V to submit with Project Proposal. Photocopy and complete Section VI to submit with the Completion Report.

I. SPONSOR INFORMATION

Name and Full Address of Sponsoring Entity

UNION CARBIDE CORPORATION, Linde Division
39 Old Ridgebury Road
Danbury, CT 06817-0001

II. PROJECT IDENTIFICATION

Title Feed Compressor Upgrade	Name and Title of Project Manager or Other Contact Mr. Steve George - Administrative Mr. Tim Hess - Technical	
Location of Proposed Project UNION CARBIDE CORPORATION Linde Division 2902 20th Street East Fife, WA 98424	Area Code & Telephone No. (716)879-7213 T. Hess (203) 794-5597 S. George	
Standard Industrial Classification Code (SIC) 2813	Utility Service Area Tacoma	Portion of kWh purchased from servicing Utility 100 %

III. PROJECT SUMMARY

Brief Description of Proposed Project

Replace existing Cooper IA-35 Feed Compressor with larger Ingersoll-Rand CENTAC II. The increased compressor capacity will allow plant air flow to be reduced.

IV. ESTIMATED ENERGY SAVINGS AND COSTS (submit with Project Abstract)

Average Annual Energy Savings kwh/yr	Total Project Costs \$	Incentive Estimate \$	Incentive Type _5¢ per kWh _80% of Project Costs	Ratio of Incentive Estimate to Total Project Costs %

V. ESTIMATED ENERGY SAVINGS AND COSTS (submit with Project Proposal)

Average Annual Energy Savings 3,798,248kwh/yr	Total Project Costs \$372,000	Incentive Limit \$161,426	Incentive Type X _5¢ per kWh _80% of Project Costs	Ratio of Incentive Limit to Total Project Costs 43 %

VI. MEASURED ENERGY SAVINGS AND COSTS (submit with Completion Report)

Average Annual Energy Savings 3,376,496 kwh/yr	Total Project Costs \$361,496	Ratio of Actual Savings to Estimated Savings 115 %