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Benefits of GRI R&D Results That Have Been Placed in Commercial Use in 1996 Through 2000

Prepared by:

Athanasios D. Bournakis
Energy Resources Center
University of Illinois at Chicago

and

Gerald D. Pine
GRI

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Abstract

This report provides brief descriptions for twenty-four new GRI R&D products commercialized in 2000 and four enhancements of previously introduced products. The economic benefits are quantified for one hundred and sixteen items commercialized between 1996 and 2000 that are known to have produced significant economic benefits for their users. The calculated ratio of the benefits to gas customers to total GRI costs incurred in 1996 through the end of 2000 was 9.4 to 1.

In a similar analysis carried out in 2000 for one hundred and thirty-three R&D items placed in commercial use between 1995 and 1999, the calculated ratio of the benefits to gas customers to total GRI costs incurred during the same period was 9.4 to 1.

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Introduction

Between January 1, 2000 and December 31, 2000, twenty-four GRI R&D results were placed in commercial service. In addition, enhanced versions of four previously commercialized items were placed in use.* Those items are listed in Table 1, and brief descriptions of the 28 items are included in Appendix A. With these new additions, some 170 GRI R&D results have entered the commercial marketplace during the 5-year period between January 1996 and December 2000. The full list of the 170 items is included in Appendix B. As one measure of the value of the GRI R&D program, the economic benefits accruing to users of 116 out of the 170 products can be compared to the total outlays of GRI during the past five years. This paper highlights the new GRI products that have entered the market during the past year and presents the results of the benefit-to-cost analysis of GRI's R&D results during the past five years.

Notable additions to the list of GRI R&D results placed in commercial service in 2000 are the development of new guidelines for properly sizing and installing combination space-heating/water-heating systems; two product lines of gas engine-driven chillers using R-134a refrigerant; a single-stage absorption, hot water or steam-fired chiller line; an advanced integrated kiosk ventilation system designed specifically for non-traditional settings; an advanced bending and tempering systems for deep bend automotive glass; an IR microturbine cogeneration system; a precision pipe locator to detect the location of buried steel, cast iron, or metal-wire-traced plastic pipe; a computerized analytical tool to estimate the probability of breaks and leaks occurring in steel mains; a smart pig that uses ultrasound technology to inspect pipelines for defects due to stress corrosion cracking and long seam fatigue cracking in in-service natural gas and liquid pipelines; a leak detection and repair method for detecting leaks that are cost effective to repair at compressor stations and gas plants; development of through-casing logging tools that measure formation resistivity and pressure; and a new *"Portfolio of Emerging Natural Gas Resources – Rocky Mountain Basins"* portfolio that assembles geologic, reservoir and production data on those emerging natural gas plays in the Greater Green River, Piceance and Wind River basins that hold promise for large gas reserve additions.

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* For tangible products (hardware, software) we interpret "commercialized" to mean that the product is commercially available, economically viable without subsidies, and has been sold in meaningful quantities. For the less tangible reports and other information products, we require that the products have been used in a commercial enterprise and have generated demonstrable economic benefits to the users. "Enhanced" products have been augmented in a commercially significant way, with or without GRI support. The augmentation may be a technical improvement in a product line, expansion of a product catalog, or expansion of the product market into new areas not available to the original product at its time of introduction.

Table 1. GRI R&D Results That Have Been Placed in Commercial Use in 2000

RESIDENTIAL
1. NAECA Water Heater Assessment
2. Combo Systems Sizing and Installation Guidelines *

COMMERCIAL
3. Analysis of Commercial Sizing and Installation Guidelines
4. Gas Cooling Guide – Pro Version
5. BinMaker™ Pro *
6. York 600 RT 134a Chiller
7. Tecogen 150 RT 134a Chiller
8. Trane Single Effect Horizon Chiller
9. Chiller Application Briefs
10. Restaurant Kiosk Ventilation and High-Performance Gas Countertop

INDUSTRIAL
11. Forced Convection Heater (FCH) Systems - Automotive

POWER GENERATION
12. IR PowerWorks Microturbine Cogeneration Systems
13. DGen Pro™ Software *

TRANSPORTATION
14. Glass-Fiber-Wrapped Fuel Tanks for NGVs

DISTRIBUTION
15. Precision Pipe Locator
16. One-Step Paving
17. Bare Steel Maintenance Optimization System (BASMOS) Software
18. Soil Compaction Supervisor

PIPELINE
19. Emeritus Report B31.8 Code, Federal Pipeline Safety Regulations
20. Elastic Wave Vehicle Tool
21. Advanced Leak Detection and Repair at Gas Processing Plants – Hi-Flow™ Sampler

EXPLORATION AND PRODUCTION
22. Glycol Dehydrator Emissions Calculation Program – GLYCalc 4.0 *
23. ProTreat™ Software for Amine Gas Treating Applications
24. Cased Hole Resistivity Tool
25. Cased Hole Pressure Tool
26. Well Siting in Carbonates – EGI Report
27. Portfolio of Emerging Natural Gas Resources – Rocky Mountain Basins
28. Mercury Contamination Training Workshop

* Enhancement to a previous product.

Benefits Results

The full list of the 170 items placed in commercial use between January 1996 and December 2000 is included in Appendix B, but we chose to focus the benefits analysis of GRI's R&D on 116 of the 170 items that are known to have produced significant *economic* benefits for their users. The 116 items are listed in Table 2. Benefits to product users in typical applications were calculated by comparing the economics of the GRI-sponsored products with the economics of products that would have been used in the absence of the GRI product. Product cost and performance data were obtained from product vendors, from field test results, or from product users. The measure of product benefit is the net present value of the incremental cash flow to the user (cost savings minus incremental cost) over the product lifetime using a real discount rate of 5% (above inflation). The GRI Baseline [1] national average projections of energy prices were used, when appropriate, to estimate cost savings. Total benefits were calculated by multiplying the unit benefits by the sales projected by product vendors from the first year in which the product was sold through 2004. The results are shown in Table 2. A range of product sales is shown to protect proprietary vendor sales projections.

As shown in Table 2, calculated economic benefits for the 116 items are estimated to be between $6.1 to $11 billion. Table 3 shows the expected value of benefits, at about $7.9 billion, and the breakdown of the economic benefits by sector. We estimate that the 116 items account for most of the economic benefits that would be calculated for the entire set of 170 products. Omitted items often offer significant benefits to their users, but have not achieved widespread use as have the 116 high impact items. In addition, some of the omitted items are designed to produce benefits that are not easily expressed in economic terms. For example, R&D results provide test methods for new gas equipment, technologies to meet existing or anticipated air emissions requirements, and information that is useful to the gas industry in developing the gas resource and in delivering it to the customer.

Table 2. Summary of Benefits of GRI R&D Results That Have Been Placed in Commercial Use in 1996 Through 2000

	Sales or Applications Projected Through 2005 (in units)			Year of First Sale	Net Present Value of Benefits** (Million 2000$)		
RESIDENTIAL							
Carrier "Chimney Friendly" Furnace	21,000	to	38,000	1996	$7.0	to	$12.9
Modulating Furnace	83,000	to	152,000	1996	$0.9	to	$1.6
Empire Gravity Vented Wall Furnace	16,000	to	31,000	1996	$70.8	to	$135.2
Advanced Gas Fireplace	18,000	to	38,000	1997	$7.6	to	$16.0
Outdoor Water Heater	114,000	to	199,000	1997	$5.9	to	$10.3
Flammable Vapors	11,000	to	20,000	1998	$98.1	to	$179.8
COMMERCIAL							
Trane Horizon™ Absorption Chiller	550	to	950	1996	$243.0	to	$446.0
Trane Modulating Rooftop Unit	3,600	to	6,300	1996	$17.2	to	$30.2
Separation Requirements in ASHRAE Standard 62-89R	18,000	to	37,000	1996	$178.5	to	$374.8
Pulse Combustion Hydronic Boiler	5,500	to	9,700	1997	$21.6	to	$37.9
TecoFROST™ Gas Engine Driven Refrigeration	90	to	190	1997	$20.5	to	$43.0
*TecoFROST™ Warehouse Refrigeration	40	to	90	1998	$13.9	to	$29.2
Alturdyne Hybrid Electric/Gas Engine Chiller	130	to	250	1998	$128.7	to	$235.9
kitchenCOST™ Software	550	to	1,000	1998/99	$31.0	to	$56.9
DesiCalc™ Software	350	to	650	1998	$3.6	to	$6.6
Low NOx Power Burner	1,300	to	2,300	1998	$11.5	to	$20.1
ASHRAE Standard 155P for Boilers	2,700	to	5,800	1998	$38.0	to	$79.7
Modulating Indirect-Fired Make-Up Air Unit with Clean Modulation	1,100	to	2,100	1999	$4.0	to	$7.3
GATC: AERCO Benchmark Boiler	900	to	1,800	1999	$14.7	to	$29.4
PITCO Gas Fryers	48,000	to	89,000	1999	$25.7	to	$48.8
AUTOFRY™ Deep Fat Fryer	1,500	to	2,900	1999	$4.9	to	$9.7
York 600 RT 134a Chiller	40	to	60	2000	$19.6	to	$30.7
Tecogen 150 RT 134a Chiller	40	to	65	2000	$1.5	to	$2.4
INDUSTRIAL							
Process Application of Composite Radiant Tubes	34,000	to	58,000	1994/99	$59.4	to	$102.9
High Performance Infrared Burners	100	to	190	1995/00	$405.5	to	$774.2
Multi-Variable Controls (MVC® for Industrial Applications)	13	to	23	1998	$114.5	to	$209.9
RAPIDFIRE™ Products	10	to	20	1998	$96.3	to	$168.5

	Sales or Applications Projected Through 2005 (in units)			Year of First Sale	Net Present Value of Benefits** (Million 2000$)		
Natural Gas Cofiring in Biomass-Fueled Stoker Boilers	10	to	15	1999	$83.0	to	$130.4
Ultra-Low NOx Boiler Burner	80	to	120	1999	$34.1	to	$51.2
METHANE de-NOX® Reburn Technology	5	to	8	1999	$99.0	to	$169.6
Forced Convection Heater (FCH) Systems - Automotive	7	to	11	2000	$7.8	to	$13.0
POWER GENERATION							
Low NOx Turbine Combustors: • Allison 501-K Low NO_x Combustor • Low-NO_x Turbine Combustor (GE LM 1600)	***			1997	$271.0	to	$503.4
SOAPP Modules	700	to	1,500	1998	$16.2	to	$34.1
IR PowerWorks Microturbine Cogeneration Systems	1,100	to	1,700	2000	$18.9	to	$29.7
TRANSPORTATION							
Fuelmaker-Quantum Vehicle Refueling Appliance Line	44,000	to	111,000	1997	$74.2	to	$185.4
CNG Cylinder Maintenance Handbook	250,000	to	500,000	1998	$28.7	to	$60.3
Ford Crown Victoria Natural Gas Vehicle - Extended Range Package	1,200	to	3,500	1998	$4.6	to	$13.8
Risk Management Program for Liquid Natural Gas Vehicle Refueling Stations	70	to	120	1998	$28.9	to	$50.6
NGV Cylinders Types 1 and 2	15,000	to	36,000	1999	$2.7	to	$6.5
DISTRIBUTION							
Plastic Pipe Across (and on) Bridges	3,800	to	7,800	1995/99	$55.5	to	$116.7
Anaerobic Cast Iron Joint Repair Guide	79,000	to	138,000	1996	$34.7	to	$60.7
Carbon Monoxide Detector Supplemental Standards	19,000,000	to	37,000,000	1996	$211.3	to	$403.4
Pipeline Current Mapper	650	to	1,100	1997	$67.5	to	$118.1
RENU™ Service Renewal Technology	8,500	to	15,000	1997	$2.4	to	$4.1
Pneumatic Tool Diagnostic System (Tool Tester)	30	to	60	1997	$10.9	to	$21.8
Contained Recovery of Oily Waste (CROW™) Technology for Soil Cleanup	2	to	5	1997	$1.1	to	$2.7
Plastic Pipe Reliability (PENT Test)	2,900	to	5,800	1997	$20.5	to	$40.9
Pipe Hawk™ (Buried Pipe Locator)	60	to	100	1998	$11.7	to	$20.5
Optical Methane Detector (OMD)	140	to	200	1998	$28.6	to	$42.9
Predictive Control District Regulators	260	to	470	1998	$61.7	to	$113.1
Split/Pull Service Replacement	6	to	12	1998	$7.7	to	$15.5
Main/Services Tester	270	to	500	1998	$49.9	to	$91.5

	Sales or Applications Projected Through 2005 (in units)			Year of First Sale	Net Present Value of Benefits** (Million 2000$)		
Distribution Internal Inspection System - Magnetic Flux Leakage (MFL)	14	to	25	1998	$19.6	to	$35.8
TUBIS™ Software for Repair/Replace Decisions	8	to	14	1999	$13.5	to	$24.8
DrillPath™ Software for Directional Drilling Operations	420	to	640	1996/99	$2.1	to	$3.2
Starline® 2000 Renewal Technology	38,000	to	70,000	1999	$0.5	to	$1.0
Guided Mole	30	to	60	1999	$3.3	to	$5.7
Gas Holder Manual of Practice	7	to	12	1999	$4.7	to	$8.6
One-Step Paving	160	to	300	2000	$1.0	to	$2.0
Bare Steel Maintenance Optimization System (BASMOS) Software	7	to	14	2000	$15.4	to	$30.9
Soil Compaction Supervisor	380	to	660	2000	$6.6	to	$11.6
PIPELINE							
Assessment of Gas Pipeline Non-Destructive Evaluation (NDE) Technologies	***			1996	$53.2	to	$117.1
Risk Assessment/Risk Management: • Risk Assessment/Risk Management Guidelines • Airborne Pipeline Integrity Monitoring (APIM) Assessment • Pipeline Inspection and Maintenance Optimization System (PIMOS) • Third-Party Damage Prevention Assessment	***			1996	$31.5	to	$55.2
Remote and Automatic Controlled Valves Guidelines	***			1996	$93.2	to	$163.0
Hydrostatic Test Water Discharge	350	to	620	1997	$49.9	to	$87.4
PCB Contaminated Pipeline Abandonment Protocol	1,100	to	2,000	1997	$51.9	to	$95.1
Low Cost Method for Formaldehyde Measurements	4,200	to	7,700	1997	$30.4	to	$55.8
Lomic SonicWare™	800	to	1,600	1997	$26.5	to	$55.7
NOx Portable Analyzer Operator Guidelines	130	to	200	1998	$24.1	to	$37.8
Oxidation Catalyst Costs for Aldehyde Control	100	to	180	1998	$21.2	to	$37.1
TurboCharger Testing Facility	400	to	700	1998	$3.8	to	$6.7
Magnetostrictive Sensor	300	to	500	1998	$4.7	to	$8.1
Breeze Haz™ Environment and Safety Offsite Consequence Modeling Software	3,000	to	5,300	1999	$12.1	to	$21.1
Emeritus Report B31.8 Code, Federal Pipeline Safety Regulations	***			2000	$10.6	to	$31.7
Elastic Wave Vehicle Tool	80	to	170	2000	$153.7	to	$333.0
Advanced Leak Detection and Repair at Gas	600	to	1,000	2000	$215.9	to	$385.6

	Sales or Applications Projected Through 2005 (in units)			Year of First Sale	Net Present Value of Benefits** (Million 2000$)		
Processing Plants – Hi-Flow™ Sampler							
EXPLORATION AND PRODUCTION							
Atlases of Major Gas Reservoirs: • Appalachian Atlas • Offshore Atlas • Offshore Atlas, Vol 2.	6,700	to	8,800	1997/98	$516.2	to	$676.1
Scavenger CalcBase Database	90	to	150	1996	$29.0	to	$49.3
Title V Permitting Guidance	300	to	600	1996	$0.3	to	$0.6
Environmental Technology Information Center (ETIC)	12,000	to	22,000	1996	$1.6	to	$2.9
Granular Activated Carbon-Fluidized Bed Reactor (GAC-FBR)	7	to	12	1996	$5.7	to	$10.5
Emerging Resources in the Greater Green River Basin	1,500	to	3,000	1996	$320.6	to	$635.1
Underbalanced Drilling Manual	330	to	480	1997	$12.4	to	$18.1
Mercury Soil Contamination Program	72,000	to	125,000	1997	$204.1	to	$357.1
Glycol Dehydrator Controls/Monitoring	36,000	to	56,000	1997	$166.3	to	$261.3
Coalbed Methane Reservoir Gas-In-Place Analytical Techniques	150	to	270	1999	$45.1	to	$82.1
Freeze/Thaw for Production Water	70	to	110	1997	$105.4	to	$165.7
Gas Plant Emissions/Efficiency Report	380	to	660	1997	$14.9	to	$25.5
GRI Sulfur Recovery Workshop Proceedings	300	to	440	1998	$2.7	to	$4.0
Calcite Scale Handbook/ASTM Standards	1,000	to	1,600	1998	$26.7	to	$42.0
Drill String Safety Valves (DSSVs)	4,300	to	6,500	1998	$39.3	to	$59.0
Mesa-GRIP Seismic Survey Design Software	180	to	240	1998	$67.8	to	$93.3
Crosswell Seismic Imaging	150	to	280	1998	$109.1	to	$198.6
Fracturing Information and Diagnostics	10,000	to	20,000	1998	$141.8	to	$281.0
M-Site Advanced Diagnostics Insights							
Hydraulic Fracture Mapping System							
Downhole Tiltmeters							
Fracture Fluid Characterization Facility (FFCF) Insights							
Low Permeability Gas Resource Database (CD-ROM)	110	to	200	1999	$9.4	to	$16.6
Nitrogen Removal Requirements Report	20	to	35	1999	$0.6	to	$1.0
Downhole Gas/Water Separation CD-ROM	75	to	130	1999	$7.6	to	$13.1
Advanced Crosswell Seismic Source	200	to	400	1999	$29.1	to	$57.7
High Power VSP Mechanical Seismic Source	500	to	750	1999	$27.2	to	$39.6
Advanced Stimulation Technologies CD-ROM	120	to	220	1999	$13.2	to	$24.2
Coiled Tubing Standards	3	to	5	1999	$13.5	to	$26.1
GRI–MSTR™ Software and Report to Predict	360	to	560	1999	$13.2	to	$20.8

	Sales or Applications Projected Through 2005 (in units)			Year of First Sale	Net Present Value of Benefits** (Million 2000$)		
Toxicity of Produced Water Discharged to the Marine Environment							
Glycol Dehydrator Emissions Calculation Program - GLYCalc 4.0	700	to	1,300	1992/00	$56.3	to	$104.1
ProTreat™ Software for Amine Gas Treating Applications	45	to	75	2000	$117.6	to	$196.1
Cased Hole Resistivity Tool	800	to	1,300	2000	$10.6	to	$17.2
Cased Hole Pressure Tool	750	to	1,250	2000	$92.0	to	$157.8
Well Siting in Carbonates – EGI Report	90	to	140	2000	$62.4	to	$93.5
Portfolio of Emerging Natural Gas Resources – Rocky Mountain Basins	750	to	1,100	2000	$157.5	to	$236.3
Mercury Contamination Training Workshop	300	to	500	2000	$2.6	to	$4.4
TOTAL (million of 2000 dollars, 5% discount rate)					$6,148	to	$10,984

* Enhancement to a previous product for a new market application.

** Net present value calculations based on a real discount rate of 5% (excluding inflation), stated in 2000 dollars.

*** Benefits are based on user feedback about technical and market influence of the group of the information items.

Table 3. Total Expected Benefits by Sector (Millions of 2000$)

• Residential	$207
• Commercial	$949
• Industrial	$1,111
• Power Generation	$331
• Transportation	$199
• Distribution	$921
• Pipeline	$1,277
• Exploration and Production	$2,901
TOTAL	$7,896

GRI R&D Costs

Between January 1996 and December 2000, GRI outlays totaled $726.8 million. For comparison to the R&D benefits calculated above, the cost cash flow stream was converted to an equivalent net present value lump sum expenditure at the beginning of 2000. As with the benefits calculation, a 5% real discount rate was used in the net present value calculation. The calculated equivalent cost was $842 million. These costs include all outlays made by GRI during the past 5-year period, not just the costs incurred to produce the 170 R&D products. Consequently, a portion of the calculated cost will yet generate benefits as additional products are commercialized in the future.

Benefit-to-Cost Ratio

Dividing the calculated benefits by the costs results in a calculated benefit-to-cost ratio range of 7.3 : 1 to 13.0 : 1 (benefits of $6.1 to $11.0 billion divided by outlays of $842 million) with an expected value of 9.4 : 1 ($7.9 billion divided by $842 million). In a similar analysis carried out in 2000 for R&D items placed in commercial use between 1995 and 1999, the calculated ratio of the benefits to gas customers to total GRI costs incurred during the same period was 9.4 to 1 [Reference 2].

Continuing Successes of GRI R&D Results Commercialized Prior to 1996

Although the focus of this analysis has been on GRI's most recent successes, several past successes continue to significantly impact the markets in which they are used. GRI is proud of the continuing success of these products, and we believe that a few comments about three of them are appropriate here.

Blast Furnaces. Due to environmental regulations imposed on the pollutant emissions from coke ovens, metallurgical coke is increasingly scarce and expensive. In conjunction with this, the renewed steel demand has strained the productive capacity of the current blast furnace population. These two factors have poised the blast furnace industry to look for alternate fuel sources to decrease costs and increase productivity. The advantages of using high levels of natural gas include: reduced coke usage, improved furnace stability, increased iron-making productivity, lower operating costs, high quality (lower sulfur content) hot metal product, lower air pollution emissions, and gas-injection equipment has lower capital costs than pulverized-coal or oil-injection equipment. For over 25% of blast furnace coke requirements, high-level gas injection is an attractive substitute. GRI and Charles River Associates demonstrated the

technical merits and the operational advantages of injecting natural gas at high levels (up to 300 lb/ton of hot metal) in blast furnaces and developed information and guidelines for high level natural gas injection that were made available to iron and steel makers throughout North America. Over the past decade, gas use in blast furnaces has increased dramatically, from about 38 bcf in 1987 to 106 bcf in 1995.

Advanced Stimulation Technologies (AST). In the early 1980s, GRI began a comprehensive research effort to evaluate and enhance technologies associated with hydraulic fracturing in gas wells to increase gas production. Through a series of cooperative research and Staged Field Experiment wells, GRI collected evidence that challenged traditional hydraulic fracturing methodologies and theories. By analyzing detailed reservoir data and real-time fracture treatment data, new insights into the fracturing process were gained, and critical factors associated with successful fracture treatments were identified. Significant improvements were made in onsite treatment quality control, pretreatment stress profiling and the use of 3-D fracture models, fracture treatment pressure history matching, and performing fracture treatment diagnostics onsite to identify well-specific fracturing mechanisms at competitive prices. GRI AST tools and information are now widely used by gas producers. Fracture treatment cost savings of about $200 million in 1998 have been documented by GRI. These savings have increased the amount of economically attractive gas that can be produced from tight formations and have been an important element in enabling gas producers to survive in today's low gas price world.

Secondary Gas Recovery. GRI's Secondary Gas Recovery program involves the integration, application and interpretation of geophysics, geology, reservoir engineering, formation evaluation and well log petrophysics. New methods were developed to interpret seismic/geologic/reservoir engineering data for infill drilling of existing, mature fields, for locating of missed zones due to compartmentalization of the producing formation, and incompletely drained and bypassed reservoirs. A series of short courses and "How-to" manuals were initiated and technical lectures, videotapes, CD-ROM's, and 3-D seismic data sets with digitized well logs were distributed. Over 500 workshop participants from 264 different companies have attended the short courses. The SGR program increases reserves, specifically to infill drilling within mature producing areas and reduces dryhole wells. According to a 1995 survey by Gelb of 98 operators familiar with GRI's research, nine companies claimed 120 Bcf in enhanced production due to GRI's SGR project in Gulf Coast. In 1998, Gelb revisited participants who could not quantify reserves in 1995 and fourteen companies claimed enhanced production of 91Bcf in 1997 and two companies claimed 97 Bcf of enhanced production in 1998.

Conclusions

GRI's planning and budget allocation process strives to put in place a program with the maximum ratio of benefits to R&D costs for the mutual benefit of the gas customer and the gas industry. The economic evaluation of GRI's commercially successful R&D results have consistently shown that benefits far exceed the costs of the R&D program.

Analysis of the benefits of approximately 116 of the 170 GRI R&D items placed into commercial service between January 1996 and December 2000 shows that GRI R&D will return about $9.40 for every dollar invested in GRI during the same period. In addition to the fact that only portion of GRI's commercialized R&D items are included in the benefits calculation, all of the costs of GRI's operations during the 1996 to 2000 period have been included in the calculation of the benefit-to-cost ratio.

References

1. P.D. Holtberg, J.C. Cochener, "Baseline Projection Data Book: 2001 Edition of the GRI Baseline Projection of U.S. Energy Supply and Demand to 2020," GRI-01/0002.1 and GRI-01/0002.2, GRI, March 2001.

2. A.D. Bournakis, and G.D. Pine, "Benefits of GRI R&D Results That Have Been Placed in Commercial Use in 1995 Through 1999," Gas Research Institute, May 2000, GRI-00/0086.

Appendix A
GRI R&D Results That Have Been Placed in Commercial Use in 2000

RESIDENTIAL

NAECA Water Heater Assessment. This report, produced and released by GRI, served as the technical basis for many gas industry comments submitted to the Department of Energy (DOE) in 2000 as part of the efficiency standards rulemaking process for water heaters. DOE determined that three design options were economically justified for gas water heaters. These options were the use of heat traps, additional water heater insulation, and increased recovery efficiency. DOE's life-cycle cost analysis showed that the consumer would more than recover the added first cost of these design options through lower operating costs over the life of the water heater. GRI's analysis showed that the use of heat traps is, indeed, justified, but the other two options are not. DOE's analysis neglected the added installation costs for fitting larger diameter water heaters into homes with tight space. GRI questioned this determination because it might unnecessarily add to the life-cycle cost of gas water heaters. Consumers will benefit if the gas industry comments succeed in preventing unwarranted NAECA (National Appliance Energy Conservation Act) requirements on gas water heaters.

***Combo Systems Sizing and Installation Guidelines.** New guidelines have been developed for properly sizing and installing combination space-heating/water-heating systems, often termed "combo" systems. These sizing guidelines are applicable across North America, and take into account the calculated design space heating and cooling loads, as well as the local coldest water supply temperature. Secondary sizing considerations include the duration of showers desired, the presence of laundry facilities, and whether or not nighttime setback may be used. The proper sizing for water heaters includes both the burner input and the tank volume, and for air handlers both the heating and cooling loads plus air flow. Five combo sizing charts are included in this guideline to cover the five basic heating zones in the U.S. The sizing charts cover a range of cold water supply temperatures from 35°F to 70°F, design heating loads from 0 to 40,000 Btu/hr, shower duration from 5 to 15 minutes, and night-time setbacks of 0, 5, and 10°F. Suggestions are given for general installation guidelines, system checkout, startup procedures, and problem solving.

COMMERCIAL

Analysis of Commercial Sizing and Installation Guidelines. This report, released by GRI, showed that the 1999 revision of Standard 90.1 would result in no meaningful national reduction of source energy consumption, site energy cost, or site energy consumption. The mechanical and lighting portions of the revised standard would lead to source and site energy reductions and reduced energy cost, but the envelope portion of the standard would lead to increases. These results should affect Federal and state policy on setting commercial building energy codes. DOE should use this analysis in its assessment of energy savings that would result from the 1999 revision of Standard 90.1. If the report helps convince DOE that the changes suggested by Standard 90.1 need not be implemented through regulations, gas consumers will avoid having to pay for unwarranted upgrades of equipment and facilities. DOE has not yet accepted the GRI's recommendations and modified its intended regulations.

Gas Cooling Guide - Pro Version. In 1998, GRI released the Gas Cooling Guide, a software tool to estimate annual or monthly cooling loads and the costs associated with air-conditioning a given building and location. The Guide compares the performance and cost of electric equipment with absorption, natural-gas-engine-driven, or desiccant cooling systems. It features easy-to-understand technology descriptions, a large library of case studies, an extensive product catalog, templates for 14 typical buildings, weather data for more than 200 cities, user-modifiable energy rate formats, and typical utility

rates for 16 locations. This user-friendly program performs quick economic analyses for gas cooling applications. It is designed for use by HVAC (heating, ventilating, and air conditioning) consultants, system designers and operators, marketing professionals from gas and electric utilities, and gas cooling equipment vendors. A new Pro Version was developed for retrofit applications of commercial chillers. The Pro Version allows easy calibration of the computer model to match existing applications, accepts user input of existing energy consumption profiles, and uses these profiles during computer model calibration. The software quickly analyzes various chiller equipment retrofit options in existing buildings without extensive engineering studies. The Gas Cooling Guide is the only software that can conveniently analyze complex day/night utility rates and show how to optimize a hybrid system including both electric and gas chillers. The guide includes an extensive product catalog with photos and easily understood equipment descriptions. It features a large library of successful applications case studies. The software enables end users to make the best possible choices among competing cooling options based on size and cost.

***BinMaker ä Pro.** The BinMaker™ software tool, developed by GARD Analytics, Inc., Quantitative Decision Support, Linric Co., and Bluejay Software Associates, upgrades bin energy analysis by creating a wide range of accurate summaries of U.S. hourly weather data for 239 locations. Weather data files used by BinMaker are based on the TMY-2 (Typical Meteorological Year) data produced by the National Renewable Energy Laboratory in Golden, CO. The files reflect typical weather for all 8760 hours per year at 239 locations. They contain actual weather observations rather than smoothed or adjusted data, ensuring of a good presentation of weather behavior in the real world. The resulting electronic file can be exported for use in spreadsheets or other computer analysis programs. BinMaker CD-ROM-based program runs under Windows® 95 or 3.1. Among its other features, BinMaker avoids the error of underestimating loads associated with coincident variables by creating a joint-frequency table of hours at each combination of temperature and humidity.

York 600 RT 134a Chiller. York International Corporation, with GRI support, developed a top mounted driveline revision of its 550 TR Gas Engine Driven (GED) Chiller that uses the Caterpillar G3408 Engine using natural gas and uses R-134a refrigerant. The York chiller includes easier installation, width reductions of over 50% and has the lowest operating cost/highest COP (HHV) in the industry at full load and NPLV.

Tecogen 150 RT 134a Chiller. The TECOCHILL products, developed with GRI support by Tecogen, offer high efficiency and low operating costs and are now available with R-134a, an alternative refrigerant that has no adverse impact on the ozone layer. The chillers integrate a natural-gas engine with a standard screw or reciprocating compressor. The variable-speed capability of the engine allows the load to be followed more closely than with an electric motor, optimizing energy consumption. A high-temperature heat recovery option (up to 225 °F) supplies hot water without additional fuel consumption, further improving operating savings. Microprocessor controls provide automatic operation plus continuous monitoring, digital-display fault diagnostics, and optional tie-in to an energy management system. The Tecogen R-134a models are available from 150 to 500 tons.

Trane Single Effect Horizon Chiller. The Horizon family of chillers includes a single-stage, hot water or steam-fired chiller line. The single effect absorption chiller, developed by Trane with GRI support, is able to produce chilled water in the range of 40 to 60°F and use 12 psig low-grade steam or 270°F hot water. Making chilled water from these comparatively low temperature inputs, is particularly important for energy conserving applications such as waste heat recovery, co-generation equipment and solar-energy powered cooling. Using refrigerant water helps eliminate refrigerant management or availability concerns. Additionally, absorption technology reduces the use of electric energy especially during the summer season when electricity supplies are tight.

Chiller Application Briefs. GRI developed a series of six application briefs, which are fact sheets, on the cost advantages that gas-fired air conditioning offers relative to electric air conditioning. The application briefs will help commercial energy consumers take the first step in evaluating whether it is in their best interest to install gas-powered chillers. These sheets allow building operators to quickly assess whether they should consider installing either gas-fired absorption chillers or gas-engine-driven chillers. The application briefs are based on GRI-developed information on typical air conditioning loads and equipment energy use for hospitals, office buildings, and educational facilities. The fact sheets were published in 2000 and are available from GRI and the American Gas Cooling Center. The application briefs will help commercial energy consumers take the first step in evaluating whether it is in their best interest to install gas-powered chillers.

Restaurant Kiosk Ventilation and High-Performance Gas Countertop. With the rapid growth in non-traditional fast food restaurant formats including food carts, kiosks, and downsized kitchens, gas cooking equipment is at a disadvantage to electric. Working with equipment manufacturers and food industry experts, GRI developed the Advanced Integrated Kiosk ventilation system, a total cooking system designed specifically for non-traditional settings. GRI also develop a high-performance countertop fryer, a griddle, and an oven for kiosks. These appliances can also be used independently of the kiosk. Blodgett Corporation - a Maytag Company made the high-performance gas countertop fryer commercially available in 2000 under the Solstice line of its Pitco brand.

INDUSTRIAL

Forced Convection Heater (FCH) Systems - Automotive. Glasstech's Advanced Bending and Tempering Systems for Deep Bend Automotive Glass (available with electric radiation or gas-fired, forced-convection heaters), developed with the help of GRI, produce high-optical-quality glass to precise tolerances and in complex shapes that enable designers to develop exciting new concepts. Tooling has been simplified; the system, in quick sag mode, uses only one forming ring. This results in lower costs and minimal downtime for part changeovers. The Deep Bend operation adds only a mold and press ring. Glass produced on these systems has exceptional optical quality and uniformity of shape. Coated and tinted glass can be processed without difficulty. These production-proven systems are superior in creating complex backlites, sidelites and quarterlites to U.S. and international fracture standards. The Gas-Fired Forced Convection Heater (FCH) is part of an architectural flat or automotive glass tempering system that can significantly increase throughput and cut energy costs when compared to electric radiation heaters (ERH). The FCH blends heat from enclosed gas burners with recirculating forced air and heats glass by controlled, forced-convection heat transfer. The FCH heats most glass in about 30 second per millimeter of thickness. By contrast, ERH systems heat clear float glass in about 40 seconds and reflective or Low-E coated glass in 50 to 60 second per millimeter of thickness. Shorter processing time means the glass spends less time in contact with the system's rollers, in turn allowing higher optical and surface quality.

POWER GENERATION

IR PowerWorks Microturbine Cogeneration Systems. Ingersoll-Rand Energy Systems (IRES), through its former subsidiary, Northern Research and Engineering Corporation, with GRI support, developed microturbines that meet market needs much better than previous turbines. The turbines were incorporated into cogeneration systems that also include improved heat recuperators. IRES is now beginning to market complete 70 kW cogeneration packages. Distributed generation microturbine systems use gas turbines that were developed for use on aircraft or in other industrial applications. However, these small turbines need improved efficiency, size, and operational lifetimes to be fully acceptable for distributed generation applications. The PowerWorks systems have higher efficiency and longest life of

any microturbine cogeneration system on the market. They are much more reliable and have longer service intervals than reciprocating engine systems, and they also have lower installation cost, emissions, and noise levels than reciprocating engines. They expand the range of energy users who can benefit from the cost savings and reliability of cogeneration systems.

***DGen Pro® Software.** GRI and Architectural Energy Corp. (AEC) have developed a new version 3.0 of the software tool, named DGen Pro™ (formerly known as DG Pro), for evaluating the economic viability of on-site and distributed generation for specified installations. The software offers a flexible interface that accesses a large database library which includes cost and performance data for natural gas reciprocating engines, gas turbines and microturbines; electric and gas rates for utilities across the country; and prototypical building loads. DGen Pro generates color graphic sales and marketing reports on the economics of each project and may be customized with customer specific data inputs. DGen Pro runs on Windows 3.1, Windows 95, Windows for Workgroups, and Windows NT. The DGen Pro software is exclusively licensed through AEC.

TRANSPORTATION

Glass-Fiber-Wrapped Fuel Tanks for NGVs. Glass fiber wrapping of steel tanks increases their strength and allows lighter tanks to be used for NGV fuel storage. However, some glass-wrapped tanks in the U.S. and Argentina were found to corrode and crack due to exposure to moisture and acids. To remedy this problem, GRI tested and validated improved wrappings based on Owens-Corning's Advantex™ glass fibers for use in severe NGV service. This information was distributed to NGV tank manufacturers. The glass fibers are available from Owens-Corning at no cost premium over other glass fibers. This development is an improvement in NGV safety. It enables confident use of lighter NGV fuel tanks, which increases vehicle range and efficiency.

DISTRIBUTION

Precision Pipe Locator. The Precision Pipe Locator, developed with GRI support and available from Radiodetection Corporation, uses four magnetometers to detect the location of buried steel, cast iron, or metal-wire-traced plastic pipe. The device includes a sensor array and associated digital signal processing electronics within a rugged weatherproof housing. The use of four magnetometers plus real-time digital signal processing makes this locator far more accurate than previous devices. A very low frequency alternating current signal is used, and this practically eliminates interference from current induction on other utilities. Sophisticated vector analysis software determines the position of the pipe relative to the unit and transmits this information via a short-range radio link. Advanced digital signal processing techniques allow the locator to compensate for interference, enabling it to be used in places where previously it was not possible to use electronic locators. If the interference is too great, the system warns the operator that the results are less accurate than normal. Significant expense and damage to gas pipelines is caused by third-party damage due to failure to accurately locate the pipeline when digging for other services. This portable battery-powered device reliably identifies and locates buried pipe from the ground surface. It accurately indicates the pipe location and depth without the need to dig. The kit consists of a PPL receiver, a SensorBar, and a PCM transmitter. The manufacturer is Radiodetection Corporation.

One-Step Paving. Pavement repairs are less costly if street crews can complete them when an excavation is filled, rather than coming back to complete the work later. One-step repair also leaves the pavement in a safer state. GRI funded the evaluation of several products for quickly restoring excavation holes in pavement. A number of cold-patch materials were installed at several sites with varying operation

conditions. They were evaluated and their performance measured. Asphalt cold-repair products that performed reliably were identified. Originally, none of them worked adequately; but, as a result of the tests, two manufacturers developed one-step-paving materials that met performance requirements in subsequent tests. Although these materials do not work in all situations, they are nevertheless an improvement over older materials. Two pavement repair products became commercially available in 1999, one through QPR Division of Blue Circle Aggregates and one through UPM Corporation. A report was written to communicate the results. Gas utilities and others that cut asphalt to maintain buried facilities can gain benefits from these pavement repair products which can be applied more quickly, less costly, and without the need for hot/patch equipment and labor.

Bare Steel Maintenance Optimization System (BASMOS) Software. Gas utilities now have the option of using a computerized analytical tool, developed by URS Corporation for GRI, to estimate the probability of breaks and leaks occurring in steel mains. This geographic information system (GIS) has the capability of being added to GRI's Cast Iron Maintenance Optimization System program (CIMOS) which has been on the market since 1990. This model allows users to optimize replacement and repair schedules by evaluating whether it would be more economical to replace a segment of pipe in the current year, or to maintain it for a year with repairs. The software is marketed by URS Corporation.

Soil Compaction Supervisor. Backfill subsidence and pavement failure after excavation of gas mains can only be prevented by consistent application of sound soil reinstatement practices. In 1996, the GRI developed the Soil Compaction Meter. It overcame the factors that limited widespread regular use of quality control tools in everyday backfill operations. This low-cost, hand-held, quality control tool required little training for proper use and avoids the cost of re-repairing the pavement. The Soil Compaction Supervisor is a spin off of the meter. It adds data-recording features. The Supervisor includes all of the features of the Meter - a small sensor (placed at the bottom of the excavation), a connecting wire, and an electronic readout box - and data acquisition hardware. Data acquisition and storage allows the operator to record job specific information such as site number, time date, number of lifts, compaction time per lift, and total work time. Use of the Soil Compaction Supervisor reduces gas distribution costs by lowering the risk of pavement failure, eliminating callbacks, and taking the guesswork out of soil reinstatement. Automatic recording of the data by the Soil Compaction Supervisor decreases errors. The Supervisor is available through MBW Inc.

PIPELINE

Emeritus Report B31.8 Code, Federal Pipeline Safety Regulations. This report presents a summary and assessment of design margins used in domestic and international pipeline codes throughout the world. Potential changes to the design factors contained in the U.S. pipeline regulations and codes have been recommended as a result of this review. The recommendations allow an increase in the design pressure in many pipelines. The historical development of the design factors in the ASME B31.8 code is traced. Pipeline design codes were researched to establish the design factors and the methods used in determining the factors. Risk-based methods were examined to ascertain the validity of using them to improve upon the current factors. Based on this review, it is recommended that the B31.8 Code Committee begin an in-depth study of the current design practices to take advantage of major improvements in design, construction, materials, welding, and other quality related factors over the last 65 years. It is also recommended that the Committee incorporate some form of reliability-based, limit states design or some specified risk assessment concepts in pipeline design in order to remain competitive in the international market. The incorporation of risk-based principles should result in reduced risk, improved safety, reduced losses, and more economic design, construction and operations of pipelines. It is also recommended that the U.S. Department of Transportation (DOT) incorporate the current ASME B31.8 Code requirements in its Pipeline Safety Regulations, Code of Federal Regulations CFR Part 192. The recommended changes in

the design factors would result in increases in the DOT allowable design pressure on the order of 6% to 15% depending on the class location. An additional recommendation is that B31.8 Committee take a leadership role in the development and incorporation of rigorous risk-based design rules. A number of international codes have adopted some forms of reliability based or limit states design and some specified risk assessment concepts in pipeline design. To date, none of the international codes have begun to incorporate design rules based on rigorous risk principles. Such an undertaking will re-establish the historical leadership role of B31.8 and ASME in the development of international pipeline and pressure equipment standards. More importantly, the incorporation of risk based principles should result in reduced risk, improved safety, reduced losses and more economic design, construction and operations of pipelines.

Elastic Wave Vehicle Tool. The Elastic Wave Vehicle (EWV) Tool, developed by British Gas Technology, is the first smart pig to use ultrasound technology to inspect pipelines for defects due to stress corrosion cracking (SCC) and long seam fatigue cracking in in-service natural gas and liquid pipelines. With the enhanced ability to detect SCC without digging up the pipe, pipeline operators can plan for safe, cost-effective remediation of pipes in which a significant degree of SCC is found. The EWV tool can discriminate between cracks and non-cracks thereby reducing the number of false calls and improve the economics of using the EWV for pipeline integrity management. This tool can be used in 24-inch and 42-inch diameter lines.

Advanced Leak Detection and Repair at Gas Processing Plants – Hi-Flow® Sampler. GRI developed a leak detection and repair method for detecting leaks that are cost effective to repair at compressor stations and gas plants. This research was a joint venture with EPA and natural gas industry utility companies. The GRI Leak Detection and Measurement Service can reduce leakage, increase earnings and provide an accurate "baseline" for methane emissions from natural gas facilities. GRI data shows that when this procedure is implemented at natural gas compressor stations, emissions can be reduced by 80 to 90 percent with a payback period of 6 to 12 months. The key to this approach is a new instrument -- the Hi-Flow™ sampler -- developed by GRI that is the only practical way of measuring the size of the leak. With an estimate of the repair cost and the measured leak rate, leaks can be rank ordered by payback period. Since the data show that 10 percent of the leaks are responsible for 80 to 90 percent of the emissions from a facility, significant reductions can be achieved by repairing a relatively small number of leaks. In the conventional approach to leak detection and repair, the decision to repair is based on measuring the maximum concentration at the leak. The problem is that concentration is a very poor indication of leak rate and 10 times as many leaks are repaired than necessary to obtain a significant reduction in emissions. Also, the conventional approach does not provide an accurate measurement of either the baseline emissions from the facility or the amount of emissions reduced (error is ± 300%). GRI and the U.S. EPA have tested the Hi-Flow sampler extensively in the laboratory and the field. Test results demonstrate that the leak rate can be measured within ±10 to 15 percent. The Hi-Flow sampler has also been used to make measurements at over 250 natural gas facilities including compressor stations, processing facilities, city gates, metering and regulating stations, and liquefied natural gas plants. It has been the basis of leak rate measurement programs sponsored by GRI, EPA, PRCI, and several GRI member companies.

EXPLORATION AND PRODUCTION

***Glycol Dehydrator Emissions Calculation Program - GLYCalc 4.0.** Glycol dehydration units are commonly used for removing water vapor from natural gas. Glycol dehydration of natural gas streams helps prevent corrosion and the formation of hydrates in pipelines. An estimated 40,000 glycol dehydration units are operating in the United States. In the glycol dehydration process, the glycol picks up other compounds from the natural gas that can become part of the glycol dehydrator emissions and waste

streams. Air emissions from the reboiler still vent are the most significant issue. Stricter regulations have made emissions of benzene, toluene, ethylbenzene, the xylene isomers (BTEX) and volatile organic compounds (VOCs) from the reboiler still vent a major concern of the natural gas industry. GRI-GLYCalc™ Version 4.0 is a Windows™-based program for estimating air emissions from glycol units using triethylene glycol (TEG), diethylene glycol (DEG) or ethylene glycol (EG). Version 4.0 is the successor to GRI-GLYCalc Version 3.0 and includes a number of new features, along with several improvements and enhancements. Like previous versions, the program is based on fundamental engineering thermodynamics and empirical correlations. GRI-GLYCalc 4.0 focuses on estimating air emissions and helping users to comply with the Oil and Natural Gas Production and Natural Gas Transmission and Storage MACT standards. GLYCalc can be used to help identify units that may require rigorous sampling to determine the need for emission control. The program can also be used to predict the impact of combustion devices and condensers on emission rates.

ProTreat™ Software for Amine Gas Treating Applications. ProTreat™ is a rate-based simulator for amine gas treating applications using advanced thermodynamics and tower models. ProTreat is designed to help process engineers perform detailed evaluations of existing process plants for such purposes as improving process efficiency, operation, and evaluating process ability to handle new sour gas streams. Plant engineers and operators, equipment vendors, engineering firms, and university researchers could use the software. ProTreat can be used for the highly complicated calculations for slipping carbon dioxide with or without hydrogen sulfide being present. It will be useful for analyzing the treatment of about 20% of total U.S. gas production and can reduce processing costs by about 5% through better processing designs, solvent selection and plant operations. ProTreat has the unique ability to model mixed-amine systems. Competitive conditions in the gas industry will cause at least some of these cost savings to be passed on to consumers. Optimized Gas Treating, Inc. releases the program.

Cased Hole Resistivity Tool. With an estimated 400 trillion cubic feet of new natural gas reserves to be found in existing fields in the United States (nearly enough to meet 20 years of the country's total natural gas demand), reliable through-casing logging tools which measure reserves could help the industry better manage its existing reservoirs and recover millions of dollars worth of bypassed gas. In addition, if producers were able to place casings into exploratory wells and then run cased-hole logs to evaluate a formation, they could avoid the costs associated with trying to keep some wells open long enough to run open-hole logs, potentially saving millions of dollars in exploration costs. GRI has recognized the need for reliable tools to evaluate reserves behind well casings and has sponsored research and development of several through-casing logging tools that measure formation density, resistivity, and pressure. The Cased Hole Resistivity Tool is an attempt to overcome the limitations for measuring formation apparent resistivity and identifying the presence of hydrocarbons in cased holes. Open-hole resistivity logging tools are the most commonly used indicators of hydrocarbon saturation in formations, with a 70-year history and large body of knowledge available for interpretation of measurements. Because the salt water present in subsurface formations conducts electricity relatively well (whereas hydrocarbons are good insulators), measuring electrical resistivity in open wells helps producers distinguish formations that contain hydrocarbons from those saturated with brine. The problem is that steel casings are very good conductors of electricity and if used in an open-hole resistivity logging tool in a cased well, all that will be detected is the very low resistivity of the casing which basically acts like a wire. To overcome this problem, GRI worked with Houston-based Baker Atlas Logging Services since 1994, which licensed the technology to develop a commercially reliable cased-well resistivity logging tools. A consortium of oil and gas producers have provided advice on the tool design, application, and interpretation of measurements. The tool is used to determine behind pipe water saturation's, measure resistivities in wells where open hole resistivity logs cannot be run, or relog old wells that do not have resistivity logs. This tool will enable operators to find bypassed gas that can be economically produced by perforating the casing of existing wells. Baker Atlas Logging Services markets the tool.

Cased Hole Pressure Tool. Natural gas can be produced more readily from high-pressure zones than from low-pressure zones in a formation. Therefore, the industry can benefit from a device that could measure pressure behind cased wells to identify zones that have production value. GRI has been working with Schlumberger Well Services of Texas since 1995 to design, construct, test, and commercialize a tool that can be locked into a well casing, drill a hole through casing and cement, measure reservoir pressure, take a fluid sample, then reseal the hole with a mechanical plug. The plug, made of an alloy that will not cause corrosion in the casing, consists of two concentric parts with a tapered center. When the plug is inserted into the hole, the tapered center expands to form a tight seal against the rim of the hole. Six holes can be drilled and sealed in one logging run. The tool is marketed through Schlumberger Well Services.

Well Siting in Carbonates – EGI Report. This new methodology uses 3-D seismic data to guide the development of compartmentalized karsted reservoirs. It will help operators choose well site locations through better understanding of producing carbonate formations. The methodology will lead to the finding and producing more gas from these formations and this will make more, lower-cost gas available to consumers. A report, created by Energy & Geoscience Institute at the University of Utah (EGI), is distributed through GRI.

Portfolio of Emerging Natural Gas Resources - Rocky Mountain Basins. The idea of "emerging natural gas resources" in the basins of the Rocky Mountains suggests untapped potential, but also high risk. However, GRI recognizes that fresh ideas can help fuel the development of economic reserves from historically underdeveloped basins. Numerous times in the past, GRI has successfully compiled information that efficiently characterizes the potential risks and rewards of developing reserves that require technological innovation. Produced with the help of Advanced Resources International, Inc. and Barlow & Haun, Inc., the new *"Portfolio of Emerging Natural Gas Resources – Rocky Mountain Basins"* continues that trend. This three-part portfolio addresses underdeveloped natural gas basins in a comprehensive manner, but goes beyond the perspective of *"this is what the plays are"* to *"this is what they could be"*, helping define the resource potential. Any producer active in the Rockies will find it a valuable reference. The guide assembles geologic, reservoir and production data on those emerging natural gas plays in the Greater Green River, Piceance and Wind River basins that hold promise for large gas reserve additions. Special emphasis is given to play types that cross basin boundaries and to exploration and development strategies that potentially have wide-spread application in the Rockies. This publication was made available in late 1999 and is distributed by GRI.

Mercury Contamination Training Workshop. GRI developed a workshop to train gas and other industry workers on how to identify and clean-up mercury spills. Sampling techniques and analytical methods appropriate for assessing mercury contamination within the gas industry are examined in this workshop. The emphasis of the reported research on sampling and analytical techniques, especially the ultra clean techniques, and on factors which make mercury a global pollutant, is of utmost importance to gas industry environmental managers, chemists, and sampling crews. Only a clean sample properly analyzed will determine whether there is a problem. Analytical capabilities for mercury and mercury speciation have improved dramatically in the past decade. Researchers are now able to assess lower levels of mercury in the environment and the processes, which control the fate, and effects of this pollutant. Environmental factors, most of which are strongly influenced by anthropogenic activity, may have at least as great an effect upon mercury accumulation in the food chain as do the initial mercury emissions themselves. Thus, knowledge of the global biochemical cycle is critical in developing effective pollution control strategies for mercury.

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* Enhancement to a previous product.

Appendix B
GRI R&D Results That Have Been Placed in Commercial Use in 1996 Through 2000

RESIDENTIAL

1. Combo Systems Sizing and Installation Guidelines – 1992/2000
2. Carrier "Chimney Friendly" Furnace - 1996
3. Empire Gravity Vented Wall Furnace - 1996
4. Modulating Furnace by RHEEM - 1996
5. Utility-to-Customer Communication (Whisper) - 1996
6. Hearth Products Technology Base - 1996
7. Outdoor Gas Water Heater (American Water Heater Co.) - 1997
8. Advanced Gas Fireplace (Lennox) - 1997
9. Flammable Vapors – 1998
10. NAECA Water Heater Assessment - 2000

COMMERCIAL

11. Pulse Combustion Hydronic Boiler - 1989/91/97
12. GATC Quick Response Activities – 1995/1999
    (Life-Cycle Cost Model for Food Service Technologies)*
13. Trane Modulating Rooftop Unit - 1996
14. Trane Horizon Absorption Chiller - 1996
15. Low Emissions Package for Engine Chillers - 1996
16. Separation Requirements in ASHRAE Standard 62-89R - 1996
17. Food Service Ventilation Code Data - 1996
18. BinMaker™ Pro: The Weather Summary Tool – 1997/2000
19. TecoFROST™ Gas Engine Driven Refrigeration - 1997/98
20. York Millennium™ GED, Model YB - 1997
21. Alturdyne Hybrid Electric/Gas Engine Chiller - 1998
22. kitchenCOST™ Software- 1998/99
23. DesiCalc™ Software - 1998
24. Low NO_x Power Burner - 1998
25. ASHRAE Standard 155P for Boilers - 1998
26. Modulating Indirect-Fired Make-Up Air Unit - 1999
27. GATC: AERCO Benchmark Boiler - 1999
28. Engine Rooftop Heat Pump (Goettl 15-20 ton) - 1999
29. PITCO Gas Fryers - 1999
30. AUTOFRY™ Deep Fat Fryer - 1999
31. Analysis of Commercial Sizing and Installation Guidelines - 2000
32. Gas Cooling Guide – Pro Version - 2000
33. York 600 RT 134a Chiller - 2000
34. Tecogen 150 RT 134a Chiller - 2000
35. Trane Single Effect Horizon Chiller - 2000
36. Chiller Application Briefs - 2000
37. Restaurant Kiosk Ventilation and High-Performance Gas Countertop - 2000

INDUSTRIAL

38. Process Application of Composite Radiant Tubes (and Case Studies) - 1994/99
39. Industrial Boiler Gas Cofiring (including Biomass) - 1995/99
40. High Performance Infrared Burners (and Application Tools) – 1995/99
41. ALZETA Pyrocore® Ceramic Fiber Burner for Various Heating Applications - 1985/96
42. Volatile Organic Compound Abatement Technology - 1996
43. CYCLOMAX® Low NO_x Industrial Burner - 1996
44. RAPIDFIRE™ Products - 1998
45. METHANE de-NOX® Controls for Stoker Boilers - 1999
46. Ultra-Low NO_x Burner for Boiler Retrofit - 1999
47. Forced Convection Heater (FCH) Systems **-** Automotive - 2000

POWER GENERATION

48. DGen Pro™ Software – 1998/99/2000
49. SOAPP™ Modules – 1998/99
50. Fuel-Lean Gas Reburn (including Amine-Enhanced FLGR) - 1998
51. Microturbines (Capstone and Honeywell) - 1999
52. Distributed Generation Guidebook for Municipal Utilities - 1999
53. IR PowerWorks Microturbine Cogeneration Systems - 2000

TRANSPORTATION

54. Ford Crown Victoria Natural Gas Vehicle - 1995/98
55. Cummins C8.3G Engine - 1996
56. John Deere 8.1L Engine – 1996/99
57. DDC Series 30G - 1996
58. Caterpillar Dual-Fuel Truck Engine - 1996/98
59. MACK E7G Refuse Hauler - 1996
60. Ford Vans and Pickups - 1996
61. GFI/GEM Forklifts - 1996
62. FuelMaker-Quantum Vehicle Refueling Appliance Line - 1997
63. AccuFill Dispenser Fill Algorithm - 1997
64. NGV-1 Receptacle/Nozzle Standard Design - 1997
65. John Deere 6.8L – 1998/99
66. CNG Cylinder Maintenance Handbook - 1998
67. Risk Management Program for Liquid Natural Gas Vehicle Refueling Stations - 1998
68. NGV Cylinders (Types 1 and 2) - 1999
69. Glass-Fiber-Wrapped Fuel Tanks for NGVs - 2000

DISTRIBUTION

70. Design Methods to Prevent Rapid Crack Propagation in Polyethylene Pipe - 1984/98
71. Field Failure Catalog for Polyethylene (PE) Pipe - 1987/98
72. Plastic Pipe Across Bridges – 1995/99
73. Anaerobic Cast Iron Joint Repair Guide - 1996

74. DrillPath™ Guided Boring Software – 1996/99
75. Cast-Iron Maintenance and Optimization System (CIMOS) - 1989/96
76. Carbon Monoxide Detector Supplemental Standards - 1996
77. Manufactured Gas Plant (MGP) Site Management Guidebooks (4 Volume set) - 1996
78. Cost Model for MGP Site Cleanups - 1996
79. Soil Cofiring in Utility Boilers at MGP Sites - 1996
80. Thermal Desorption for Soil Cleanup at MGP Sites - 1996
81. Pipeline Current Mapper - 1997
82. RENU™ Service Renewal Technology - 1997
83. Pneumatic Tool Diagnostic System (Tool Tester) - 1997
84. Horizontal Directional Drilling Guidelines - 1997
85. Contained Recovery of Oily Waste (CROW™) Technology for Soil Cleanup - 1997
86. CBT (Chemical-Biological Treatment) Cleanup Technology - 1997
87. Plastic Pipe Reliability (PENT Test) - 1997
88. Utility Communications Architecture (UCA™) Protocol for Gas Distribution Systems - 1998
89. Optical Methane Detector (OMD) - 1998
90. Distribution Internal Inspection System - Magnetic Flux Leakage (MFL) - 1998
91. Pipe Hawk™ (Buried Pipe Locator) - 1998
92. Predictive Control District Regulators - 1998
93. Split/Pull Service Replacement - 1998
94. Main/Services Tester - 1998
95. TUBIS™ Software for Repair/Replace Decisions - 1999
96. Pipe Ovality and Scratch Depth Measurement Device and Guidelines - 1999
97. Plastic Pipe Repair Techniques - 1999
98. Starline® 2000 Renewal Technology - 1999
99. Guided Mole - 1999
100. Gas Holder Manual of Practice - 1999
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