CFC ALTERNATIVES: RECENT INFORMATION CONCERNING COSTS AND EFFICIENCY

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ABSTRACT

Due to the increased public concern over the role that chlorofluorocarbons (CFCs) play in depleting stratospheric ozone, a landmark international agreement, the Montreal Protocol, was signed in 1987 which regulated the production and consumption of CFCs. More recently, several nations, most notably Canada, the Federal Republic of Germany, Norway, Sweden, and the United States, have planned or implemented more stringent regulations than those required by the Montreal Protocol.

Unfortunately, many of the leading choices for replacing CFCs tend to be less energy efficient. Recent studies analyzing the energy impacts of CFC alternatives have concluded that the United States would possibly increase its overall energy consumption by 0.21-2.27 quadrillion Btu per year. These same reports have shown a tremendous opportunity for sizeable reductions in energy consumption if highly-efficient, advanced technologies are successfully developed and widely used.

This paper provides greater insight into the economic and efficiency trade-offs of leading CFC alternatives for many air conditioning and refrigeration processes. The applications investigated in this paper are household refrigerators and freezers, centrifugal chillers, commercial refrigeration and industrial refrigeration systems. Comparisons of efficiency and costs between the leading alternatives are presented. Technical issues which prevent the widespread use of these highly-efficient non-CFC technologies are discussed. These technical problems can form a basis for a concerted research program for accelerating the market implementation of these highly-efficient, non-CFC technologies.

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INTRODUCTION

In 1989, a comprehensive investigation of the potential energy and economic impacts of phasing out chlorofluorcarbons (CFCs) and halons was conducted (U.S. Department of Energy, 1989). The major applications covered by this analysis include air conditioning and refrigeration applications, mobile air conditioning, building insulation, fire extinguishants, and additional foam applications.

This paper briefly summarizes part of the effort regarding the energy and economic impacts of using alternative refrigerants for air conditioning and refrigeration applications (Arthur D. Little, 1989). The applications are household refrigerators and freezers, centrifugal chillers, commercial refrigeration systems, and industrial process refrigeration systems. Separate sections of this paper discuss each of the four air conditioning and refrigeration applications. A final section on summary and conclusions is presented to complete the paper.

REFRIGERATORS AND FREEZERS

The refrigerator and freezer industry in the United States is a three billion dollar industry, consisting mostly of six major appliance manufacturers. This market is growing at about 2 percent annually, while the growth in the use of CFCs in these appliances has been growing at around 4 percent. Last year, an estimated 13.9 million pounds (6.3 million kg) of CFC-11 were used as the foam blowing agent and 4.7 million pounds (2.1 million kg) of CFC-12 were used as the refrigerant. Roughly, 75 percent of CFC-12 was used in new appliances. The rest was used in servicing existing systems.

Alternative Refrigerants

There are many refrigerants that have been considered as potential replacements for CFC-12 in refrigerators and freezers. For this paper, the ones considered are R-22, R-134a, R-152a, blends (or near azeotropes), and nonazeotrope refrigerant mixtures (NARMs). Table 1 summarizes the information for alternative refrigerants for refrigerators and freezers regarding the development risks, energy impacts, economic impacts, and related technical issues.

R-22 - This refrigerant is widely used in air conditioners and heat pumps. However, it has not been used for refrigerators and freezers due to the increased condensing pressure of R-22 over CFC-12. Experimental data indicate that R-22 would probably have an 8-10 percent energy penalty over CFC-12. However, design changes may reduce the energy penalty to around 5 percent. A 5-10 percent loss in energy efficiency would correspond to using around 50-100 kWh/year more electricity.

Costs of converting refrigerators and freezers to use R-22 were estimated to range from $15-20, primary due to modifying the compressor. However, retooling costs for the compressors for industry were estimated to range from $100-150 million. The major technical risks for R-22 were the need for small-capacity, high-efficiency compressors; the high compressor discharge pressure; and potential regulations restricting the availability of R-22.

R-134a - This refrigerant has long been considered the refrigerant of choice for replacing CFC-12 in refrigerators. Recent experimental data indicate that R-134a would likely have an energy penalty of about 5-10 percent over CFC-12. This would increase the energy consumption of a typical refrigerator by 50-100 kWh/year. The cost of a refrigerator would increase by around $20-30. These costs are due to a larger compressor (reflecting a small drop in capacity with R-134a from CFC-12) and the use of a synthetic lubricating oil. Costs for industry to retool their compressor lines were estimated to range from $100-150 million. Technical issues concerning the use of R-134a in refrigerators and freezers are the need for compatible materials (primary with the lubricating oil and desiccant); a reduction in the transport properties; and a higher compressor ratio.

R-152a - There is some interest in replacing CFC-12 with R-152a; because it is commercially available, does not deplete ozone, and is slightly more efficient than CFC-12 under normal conditions for refrigerators. Two key concerns for R-152a are that it is moderately flammable and having a compatible lubricating oil. The Department of Energy has investigated the flammability issue with R-152a in refrigerators to better quantify the risks associated with flammable refrigerants (Pelto and Harris, 1990). This effort is now being examined in greater detail by the Environmental Protection Agency. These efforts will provide better information on risks associated with flammable refrigerants--it then will be up to the industry to determine whether these risks are low enough so that flammable refrigerants (R-152a) are acceptable. As little information was available in modifying a refrigerator to use R-152a, no estimate of costs was made. In addition to flammability, other technical issues with R-152a include its lowered capacity and a higher compressor discharge temperature.

Blends - Refrigerant blends, particularly one ternary blend (R-152a, R-22, R-124), may result in up to a 5 percent efficiency improvement, resulting in saving 50 kWh/year of electricity. As the development effort on refrigerant blends is focused mostly on determining their thermodynamic and transport properties, little systems research has been conducted. Consequently, the economic impacts are not fully known; but, they are believed to be relatively minor as some blends may be a near "drop-in" substitute for CFC-12.

NARMs - The use of NARMs may result in a most promising opportunity to save energy in refrigerators. Conservative estimates of energy savings range from 10-15%, resulting in saving about 100-150 kWh/year of electricity. The developmental risks associated with NARMs include a comprehensive investigation of potentially interesting NARM candidates; realizing that some refrigerants being considered in a NARM are considered "research chemicals" and are not TOSCA listed; and that substantial hardware changes are needed in conventional refrigerators to take full advantage of the savings afforded by NARMs. The equipment changes include much larger heat exchangers, incorporation of interchangers, and improved controls. These changes are estimated to increase the cost of a refrigerator by $20-40. An additional concern may be that highly-efficient, small-capacity compressors may be required.

Alternative Cycles

Dual-Evaporator Cycle - A dual evaporator refrigerator may be used to improve the efficiency when alternative refrigerants are used. This may result in 12-14 percent efficiency improvement at an increased cost of $100-150 per refrigerator. These savings are similar to ones made possible by using NARMs, but a much greater cost penalty. Unless novel and innovative approaches are found with dual-evaporator cycles, they may have little success in the marketplace.

Stirling Refrigerators - A reverse Stirling refrigeration cycle using helium may be used in a refrigerator. A few small R&D firms are making progress in this technological development. In fact, under the Department's Small Business Innovation Research (SBIR) program, one company is developing a free-piston Stirling refrigerator concept which is claimed to be as efficient, if not more so, than conventional refrigerators using CFC-12.

CENTRIFUGAL CHILLERS

Centrifugal chillers are commonly used to cool large commercial buildings in the United States. The centrifugal chiller industry, which has annual sales of nearly 300 million dollars, consists of 3 major manufacturers who together have captured over 80 percent of the market. Approximately 80,000 centrifugal chillers are in use today. Recent sales have been relatively flat, with about 30-40 percent of all chillers sold replacing existing ones. An estimated 17 million pounds (7.7 million kg) of CFC-11 and 2.1 million pounds (0.95 million kg) of CFC-12 are used by this industry for servicing new and existing equipment. Small amounts of CFC-114 and R-500 also are used in specialty applications. About 80-85 percent of the CFCs are estimated to be used for servicing existing equipment.

Alternatives for Existing Chillers

Table 2 summarizes the information on development risks, energy impacts, economic impacts, and technical issues concerning using alternative refrigerants for existing equipment.

R-123a - R-123a has been considered to be the refrigerant of choice for replacing CFC-11 in centrifugal chillers. It is estimated to result in 3-8 percent drop in capacity. The major development risks and technical challenges are developing compatible lubricants and materials. The economic impacts include possibly replacing elastomers, hermetic motors, compressors, tubes; and, possibly, adding a new centrifugal chiller to restore the loss capacity in switching from CFC-11 to R-123a. Conversion costs are expected to be considerable.

R-134a - R-134a may be a possible substitute for existing CFC-12 chillers, and may result in a 4-8 percent drop in efficiency. The major developmental risks and technical issues is developing compatible lubricants and materials. Economic impacts include a thorough flushing of the existing chiller to completely remove CFC-12 and its oil as well as replacing the impeller and heat exchanger tubes. Conversion costs, again, are expected to be considerable.

Blends - Refrigerant blends may be a potential substitute for existing centrifugal chillers. Unfortunately, little information is known on whether refrigerant blends are considered as serious alternatives for CFCs in existing centrifugal chillers.

Alternatives for New Chillers

Table 3 presents information on the developmental risks, energy impacts, economic impacts, and technical issues in alternatives for CFCs in new centrifugal chillers.

R-22 - R-22 is currently used in chillers ranging from 1,500 to over 8,000 tons. A recent trend by industry is to develop R-22 screw compressors under 1,500 tons of capacity to capture part of the market now served by CFC-11 centrifugal chillers. This may result in up to an estimated 10 percent loss in efficiency for an added energy penalty of 0.07 kW/ton. The cost premium may range from 10-20 percent (about $24-48/ton). The developmental and technical risks would be adapting smaller capacity screw compressors to air conditioning applications; better oil separation and management; and, possibly, the development of oil-free compressors.

Centrifugal compressors using R-22 may possibly be redesigned from its present lower limit of capacity of around 1,500 tons to 200 tons. This may result in a 5-15 percent cost premium, resulting in price increases of $12-26/ton. The energy penalty is estimated to be up to 10 percent for a loss in efficiency of up to 0.07 kW/ton. The developmental and technical risks involve developing highly-efficient, smaller R-22 centrifugal compressors with related improvements in developing high speed gears and gear boxes. An added concern would be the increased sound levels produced by these higher speed chillers.

R-123 - R-123 is the refrigerant of choice for replacing CFC-11 in centrifugal chillers. Using R-123 may result in a slight loss in efficiency of about 0.02 kW/ton, with a modest cost premium of about 5-15 percent ($12-36/ton). The development and technical risks include developing compatible materials and lubricants; improving heat transfer by novel enhanced heat exchanger surfaces; and resizing system components. The industry has made considerable progress on these technical issues and are introducing centrifugal chillers claimed to be compatible with R-123.

COMMERCIAL EQUIPMENT

Commercial refrigeration equipment covers all applications covering the chilling and refrigerating of food in retail establishments. The main areas are supermarkets, small markets, convenience stores, and food service (restaurants, bars, cafeterias). Roughly, 26 million pounds (12 million kg) of CFC-12 and 26 million pounds (12 million kg) of R-502 are used in commercial refrigeration equipment. An estimated 5.7 million pounds (2.6 million kg) of CFC-12 and 7.9 million pounds (3.6 million kg) of R-502 are used annually in commercial refrigeration. Over 80 percent of the CFCs are used in servicing existing systems, including most of the CFC-12.

Alternatives for Existing Commercial Equipment

Table 4 summarizes the developmental risks, energy impacts, economic impacts, and technical issues with alternatives for CFCs in existing commercial refrigeration equipment.

R-22 - For medium temperature applications, a single-stage R-22 system can be readily used to replace systems with CFCs, with an estimated drop in efficiency of around 2-3 percent. The cost would be around $750/ton. While the development risk is minimal, the technical issues include replacing the compressor and ensuring the entire system can safely operate at the higher pressures.

Two-stage R-22 systems may be used for low temperature applications. When these systems replace CFCs in single-stage systems, a potential 25 percent efficiency improvement may be possible. This would be equivalent to a 0.75 kW/ton reduction in power. The costs associated in installing a two-stage R-22 system are estimated to range from $1,000-$1,100/ton. The costs are mostly due to replacing the compressor and controls.

R-134a - This is the refrigerant of choice for replacing systems with CFC-12. There may be a 6-10 percent loss in efficiency for an increase in power of about 0.10-0.15 kW/ton. The costs are estimated to be about $200-250/ton. The developmental and technical issues include finding compatible lubricants and materials, as well as system reliability.

R-152a - This may be a potential alternative for medium temperature applications. Using R-152a may result in a slight (3 percent) efficiency improvement with a modest 0.03 kW/ton savings in power. The costs are estimated to range from

$150-175/ton; however, these costs can rise substantially if safety measures for using a flammable refrigerant are included.

Blends - Refrigerant blends may be a possible solution, with a slight change in efficiency. The costs may range from $200-250/ton. Unfortunately, the developmental risks are high as little information on blends for commercial refrigeration applications is available. Technical issues include compatible materials and lubricants and system reliability.

R-125 - This may possibly be used for low temperature applications. Even though little information is known about R-125, it is thought that using R-125 in commercial systems may result in 10-15 percent loss in efficiency (or a 0.30-0.45 kW/ton increase in power).

Alternatives for New Commercial Equipment

Table 5 summarizes the developmental risks, energy impacts, economic impacts, and technical issues for using alternatives for CFCs in new commercial equipment.

R-22 - As R-22 is currently used in many single-stage medium temperature applications, it would simply expand its market share. Using R-22 would have little impact on efficiency and may result in decreasing costs by $150/ton. R-22 may also be used in two-stage low temperature applications, with minimal risk. For an estimated cost premium of about $150/ton, these systems may result in an estimated 20-30 percent efficiency improvement. The savings of up to 0.75 kW/ton of power is attributed to the successful development of highly-efficient, two-stage systems.

R-134a - For medium temperature applications, R-134a may be used in new commercial systems for a possible 4-8 percent efficiency loss. This would increase power by about 0.06-0.12 kW/ton. The estimated additional cost in using R-134a would be around $150/ton. The developmental risks and technical issues include compatible materials and lubricants and system reliability.

R-152A - R-152a may be used for medium temperature applications, for a slight efficiency gain of 3 percent. However, this gain would be realized at a moderate to significant increase in cost, due to the safe handling of the moderately flammable refrigerant. Developmental and technical issues include the safety concerns of the flammable refrigerant and the effect of R-152a on lubricating oils.

Blends - Refrigerant blends may be used in new commercial refrigeration systems, with, perhaps, a slight change in efficiency. The costs would increase by an estimated $100-150/ton. The developmental risks and technical issues would include the availability of the refrigerants in the blend, compatible materials and lubricants, handling blends and servicing equipment, and, perhaps, using moderately flammable mixtures.

R-125 - This may be a possible low temperature refrigerant with an estimated 10 percent efficiency loss. Power would increase by about 0.3 kW/ton. Costs would increase by about $100-150/ton. The developmental risks are significant as so little is known about R-125.

INDUSTRIAL REFRIGERATION SYSTEMS

Industrial refrigeration applications cover a wide range of applications; including chemical-refinery-gas manufacturing processes, specialized cooling requirements for mining and construction industries, commercial ice making, and cold storage warehousing. The industrial refrigeration industry is a $500 million industry with around 10 major vendors. Last year, about 2.3 million pounds (1.0 million kg) of CFC-12, 1.2 million pounds (0.5 million kg) of R-502, 20 million pounds (9.1 million kg) of R-22, and 23 million pounds (10 million kg) of ammonia were used.

Alternatives for Existing Industrial Refrigeration Systems

Table 6 summarizes information on the developmental risks, energy impacts, economic impacts, and technical issues for alternatives to CFCs in existing industrial refrigeration systems.

R-22 - When R-22 replaces CFC-12, an estimated 5 percent loss in efficiency may occur at an added cost ranging from $100-400/ton. When R-22 replaces R-502, a 15-25 percent efficiency gain may be realized at a cost ranging from $300-700/ton. There are relatively minor developmental risks in switching to R-22.

R-134a - This is the refrigerant of choice for replacing CFC-12. For existing industrial refrigeration applications, an estimated 5-10 percent efficiency loss may occur. The estimated costs range from $200-500/ton; but, may be substantially higher when the compressors are replaced. Developmental risks include compatibility issues with oils and materials.

Blends - Refrigerant blends may be used; however, little information is available in using refrigerant blends in industrial applications. There may be little change in efficiency. Costs could vary from $100-300/ton; but, could be substantially higher if compressors are replaced. The development risks are perceived to be fairly high as so little information is known about refrigerant blends in industrial refrigerant applications.

Alternatives for New Industrial Refrigeration Systems

Table 7 summarizes the information on developmental risks, energy impacts, economic impacts, and technical issues for alternatives to CFCs for new industrial refrigeration systems.

R-22 - As R-22 is widely used in many industrial refrigeration systems, it would simply expand its market. Consequently, the developmental risks are minimal, unless a two-stage system is used. A single-stage R-22 system could have a 5 percent efficiency loss at a corresponding $100-200/ton cost savings. However, a two-stage system would have an estimated 15-30 percent efficiency gain at a modest difference in cost. The only technical issue would be the development of more efficient two-stage R-22 systems.

R-134a - This may be a possible alternative for new industrial refrigeration systems. There would perhaps, be a 5-10 percent efficiency loss. The added costs would be about $100/ton. The developmental risks and technical issues with using R-134a include system reliability and developing compatible materials and oils.

Blends - Refrigerant blends may be attractive alternatives to CFCs in new industrial refrigeration systems. The energy impact would be slight. The systems would possibly cost about $100/ton more. The developmental risks and technical issues include refrigerant availability, compatibility materials and lubricants, handling blends, and recharging systems.

Ammonia - Ammonia is widely used in many industrial refrigeration systems; it would simply increase its market share. Using ammonia would result in a 10-30 percent efficiency gain at an added cost ranging from $100-450/ton. There are no developmental risks. Technical issues with ammonia relate to its toxicity and that it would likely be only used in central plants.

SUMMARY AND CONCLUSIONS

Based on identifying the most promising alternative refrigerants, due to their potential energy savings, the major conclusions for this investigations are:

- NARMs are the leading alternative choice for replacing CFC-12 in refrigerators and freezers, as they could result in sizeable gains (10-15 percent) in efficiency with modest impact on costs ($20-40).

- A concerted research effort is needed in developing a NARM refrigerator that would accelerate the introduction of this highly-efficient technology into the marketplace.

- R-123 is the leading refrigerant of choice for replacing CFC-11 in new and existing centrifugal chillers; with, perhaps, a slight loss in efficiency.

- A comprehensive research program on developing compatible materials and lubricants for R-123 in chillers is needed to advance this key technology into the marketplace.

- R-22, whether in single-stage medium temperature applications or in two-stage low temperature applications, appears to be the leading alternative refrigerant for replacing CFCs in new and existing commercial refrigeration equipment.

- Research in developing highly-efficient R-22 two-stage systems in commercial refrigerator applications is needed to fully realize the potential of 20-30 percent efficiency gains that these systems may have over single-stage systems using CFCs.

- As both R-22 and ammonia are widely used in many industrial refrigeration applications, they would simply increase their market shares as CFCs are replaced; little research is required for industrial refrigeration applications.

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TABLE 1.
ALTERNATIVE REFRIGERANTS FOR REFRIGERATORS AND FREEZERS

Refrigerants	Developmental Risk	Energy Impact	Economic Impact	Technical Issues
R-22	Concern whether 22 will be phased out	5%-10% loss, resulting in using 50-100 kWh/yr more electricity	$15-20, with $100-150 million retooling costs for compressors	Need for development of small-capacity, high-efficiency compressors; high compressor discharge temperature
R-134a	Toxicity, technical concerns on lubricity, compressor design, etc.	5-10% loss, resulting in using 50-100 kWh/yr more electricity	$20-30, with $100-150 million retooling costs for compressors	Need for compatible lubricating oil and desiccant; reduced transport properties; higher compressor ratio
R-152a	Safety concerns with flammability; effect on oil	5-10% gain, resulting in saving 50-100 kWh/yr of electricity	Not fully known	Concern over flammability; lowered capacity; high compressor discharge temperature
Blends	Full properties not yet known	Up to 5% gain, resulting in saving 50 kWh/yr of electricity	Not fully known	Some blends are not commercially available; properties of R-124 not fully known
NARMs	Many potential combinations; some refrigerants (R-123) may require TOSCA listing	10-15% gain; resulting in saving 100-150 kWh/yr of electricity	$20-40 for additional evaporator, tubing and advanced controls	Requires larger heat exchangers, interchangers; may require small-capacity compressors

TABLE 2.
ALTERNATIVE REFRIGERANTS FOR EXISTING CHILLERS

Refrigerants	Developmental Risk	Energy Impact	Economic Impact	Technical Issues
R-123a	Compatibility issues with materials and oils	3-8% loss in capacity	Replace elastomers, hermetic motors, compressors, tubes; add chiller to restore capacity	Compatible lubricants and materials
R-134a	Compatibility issues with materials and oils	Slight loss	Replace impeller and heat exchanger tubes	Compatible lubricants and materials
Blends	Refrigerant availabiity; little experience in handling blends	Little change	Minor changes	Handling blends; recharging chillers; compatible materials and lubricants

TABLE 3.
ALTERNATIVE REFRIGERANTS FOR NEW CHILLERS

Refrigerants	Developmental Risk	Energy Impact	Economic Impact	Technical Issues
R-22 Centrifugal	Extremely high compressor speeds; high sound levels	0-10% loss; 0-0.07 kW/ton increase in power	5-15% premium; $12-36/ton	Develop smaller size compressors, high speed gears and gear box
R-22 Screw compressor	Adapt refrigeration units to air conditioning duty; effective oil management systems	0-10% loss; 0.07 kW/ton increase in power	10-20% premium; $24-48/ton	Adapting screw compressors to air conditioning duty; oil separation and management; oil-free compressors
R-123	Compatibility with materials and lubricants; improved or enhanced heat exchanger surfaces	Slight loss up to 0.02 kW/ton increase in power	5-15% premium; $12-36/ton	Compatible materials and lubricants; resizing components

TABLE 4.
ALTERNATIVE REFRIGERANTS FOR
EXISTING COMMERCIAL EQUIPMENT

Refrigerants	Developmental Risk	Energy Impact	Economic Impact	Technical Issues
R-22 Single-stage; medium temperature	Minimal	Slight 2-3% loss	$750/ton	Replace compressor, ensure can operate safely at higher operating pressures
R-134a Medium temperature	Compatibility issues with oils and compressor materials	6-10% loss; 0.10-0.15 kW/ton increase in power	$200-250/ton	System reliability; compatible materials and lubricants
R-152a Medium temperature	Moderate flammability	Up to 3% gain; 0.03 kW/ton reduction in power	$150-174/ton	Costs do not include safety measures for using flammable refrigerant
Blends Medium temperature	Refrigerant availability; little experience in handling blends; flammability	Slight change	$200-250/ton	System reliability; compatible materials and lubricants
R-22 Two-stage; low temperature	None	Up to 25% gain; 0.75 kW/ton reduction in power when single-stage systems are replaced	$1,000-1,100/ton	Replace compressor and controls
R-125 Low temperature	Toxicity, compatible lubricants and compressor materials	10-15% loss; 0.3-0.45 kW/ton increase in power	Little is known about R-125	

TABLE 5.
ALTERNATIVE REFRIGERANTS FOR NEW COMMERCIAL EQUIPMENT

Refrigerants	Developmental Risk	Energy Impact	Economic Impact	Technical Issues
R-22 Single-stage, medium temperature	None	None	Decrease cost by $150/ton	Requires complete compressor change out; increased operating pressures
R-134a Medium temperature	Compatibility issues with oils and compressor materials	4-8% loss; 0.06-0.12 kW/ton increase in power	$150/ton	System reliability; compatible materials and lubricants
R-152a Medium temperature	Safety concerns with flammability; effect on oil	Up to 1-3% gain; up to 0.03 kW/ton reduction in power	Moderate to significant increase in cost	Concern over flammability
Blends Medium temperature	Refrigerant availability; little experience in handling blends; flammability	Slight	$100-150/ton	Handling blends; recharging chillers; compatible materials and lubricants
R-22 Two-stage, low temperature	Minimal	20-30% gain; 0.75 kW/ton reduction in power	$150/ton	Development of more efficient two-stage systems
R-125 Low temperature	Full properties not yet known	10% loss; 0.3 kW/ton increase in power	$100-150/ton	Not fully known

TABLE 6.
ALTERNATIVE REFRIGERANTS FOR
EXISTING INDUSTRIAL REFRIGERATION SYSTEMS

Refrigerants	Developmental Risk	Energy Impact	Economic Impact	Technical Issues
R-22 in place of R-12	None	Up to a 5% loss	$100-400/ton	Substantial flushing and cleaning costs
R-22 in place of R-502	None	15-25% gain	$300-700/ton	Compressor change out
R-134a in place of R-12	Compatibility issues with oils and compressor materials	5-10% loss	$200-500/ton	Substantially higher costs if compressor is replaced
Blends	Refrigerant availability; little experience in handling blends	Slight	$100-300/ton	Substantially higher costs if compressor is replaced

TABLE 7.
ALTERNATIVE REFRIGERANTS FOR NEW INDUSTRIAL REFRIGERATION SYSTEMS

Refrigerants	Developmental Risk	Energy Impact	Economic Impact	Technical Issues
R-22 Single-stage	None	Up to a 5% loss	$100-200/ton savings	None
R-22 Two-stage	Minimal, due to added system complexity	15-30% gain	Slight	Development of more efficient two-stage systems
R-134a	Compatibility issues with oils and compressor materials	5-10% loss	$100/ton	System reliability; compatible materials and lubricants
Blends	Refrigerant availability; little experience in handling blends	Slight	$100/ton	Handling blends; recharging systems; compatible materials and lubricants
Ammonia	None	10-30% gain	$100-450/ton	Toxicity; use of central plants