Costs and Benefits of Proposed Measures to Reduce Refrigerant Leaks from Commercial Refrigeration Systems

Leak Reduction Measures Overview

Reducing the greenhouse gas impact of refrigerant leaks in supermarkets can be accomplished through a number of approaches, including the following:

1) Use of lower-GWP refrigerants
2) Reduction of refrigerant charge per unit of cooling capacity
3) Recovery of refrigerant during service and end-of-life
4) Inspection and maintenance program to repair leaks quickly
5) Leak-tight systems

The proposed leak reduction measures (LRMs) listed below concern themselves only with approach #5, leak-tight systems. Note that approach #4, inspection and maintenance program to repair leaks quickly, is currently being implemented by California under the ARB Refrigerant Management Program, which requires large commercial refrigeration system operators to employ best management practices for refrigeration equipment inspection, maintenance, and leak repair.[1]

Due to the integrated nature of supermarket refrigeration systems and the proposed LRMs, the estimated leak reduction benefits associated with each proposed measure have not been estimated in this analysis; rather, estimated leak reduction benefits are aggregated across the full suite of measures. Conversely, cost estimates are disaggregated by measure and, as appropriate, by store size. The three store types analyzed in this analysis are summarized below in Table 1.

Table 1: Summary of Store Types

Store Type	Size (Square Feet)	Refrigerant Charge (Pounds)
Big Box Stores	150,000	3,392
Large Supermarkets	60,000	2,812
Small Supermarkets	10,000	557

Proposed Leak Reduction Measures

Measure #1: *Piping runs using threaded pipe must not be used for refrigeration lines (e.g., if steel piping is used, it must be welded). This does not include threaded connections at the compressor rack.*

- **Leak Reduction Rationale:** This measure will result in reduced leakage as, over time, threaded joints can seep refrigerant. By threading steel pipe, wall thickness is reduced, thereby reducing the effective working pressure of the piping. In contrast welded piping is more durable and less prone to leakage in the long-term. According to Chapter 45 of the 2008 ASHRAE Handbook ("Pipes, Tubes, and Fittings"), welded steel pipe joints provide maximum long-term reliability as they can "accommodate greater vibration and water hammer and higher temperatures and

[1] Additional details on this program are at the ARB website at: http://www.arb.ca.gov/cc/reftrack/reftrack.htm.

pressures than other joints." The ASHRAE Handbook also refers to ASME Standard B31.5 for limits on threading for various refrigerants and pipe sizes.

- **Cost Implications:** This measure limits the use of threaded pipe, requiring the use of welded or brazed pipe instead. Smaller diameter tubing is easier to thread, while larger diameter tubing is easier to weld. In general, welded piping is often faster to install than threaded piping. Therefore, costs of welded or brazed pipe in lieu of threaded pipe will depend on the size of the pipe and the skill set of installers (i.e., installation may be slower for technicians less skilled in welding/brazing). Overall, costs associated with this measure are expected to be minimal. To estimate costs, it is assumed that a more skilled worker (at an incremental rate of $20 per hour) will be required to work an additional 8 hours to install the piping. Therefore, total incremental costs are estimated at $160 per store (regardless of store size).

<u>Measure #2:</u> *The use of copper tubing with an outside diameter (OD) smaller than ¼" is prohibited in all but systems with a refrigerant charge of 5 lbs or less. When using ¼" tubing, it must be securely clamped to a rigid base so that the vibration level is below 8 mils.*

- **Leak Reduction Rationale:** Small copper tubing is prone to failure when subject to severe vibration, whereas steel tubing is more resilient.
- **Cost Implications:** The estimated cost of this measure is roughly $30 per system, based on the assumption that approximately 30 minutes of additional labor is needed per system. Actual costs will depend on store size and are mainly related to labor. Steel tubing costs less than copper but is generally more difficult to bend, braze, or flare.

<u>Measure #3:</u> *Flared tubing connections are prohibited from use on all refrigerant applications with the exception of pressure controls, valve pilot lines, and oil lines. In these exception cases, the tubing on a flare connection must be either (1) double-flared or (2) single-flared with a multi-ring seal coated with an industrial sealant suitable for use with refrigerants. All flared tubing connections with a multi-ring seal must be properly tightened to the manufacturer's recommendations.*

- **Leak Reduction Rationale:** This measure will result in reduced leakage as flared fittings are more leak-prone than brazed or threaded fittings. While most industry experts believe that flare fittings result in more leaks, some stakeholders have voiced concern over prohibiting flare fittings, maintaining that they are extremely reliable if done correctly. Even so, flared fittings have a history of loosening over time, especially if subjected to vibration (e.g., on compressor racks) or when covered with ice and subjected to a freeze/thaw (e.g., on expansion valves). In addition, flare fittings on expansion valves may be difficult to access for leak checking, which could result in leaks going undetected for long periods. Therefore, only in certain cases—namely, oil, pilot, and control lines, where it is impractical or impossible to solder/braze a connection—should flare fittings be permitted for use.
- **Cost Implications:** Since the use of flare fittings in the restricted applications is uncommon in new stores, any incremental costs associated with this measure are likely to be incurred in the exception cases, where either double-flare fittings or single-flare fittings with a multi-ring seal and industrial sealant must be used. Double-flare fittings are estimated to take longer to install (relative to single-flare fittings), which would result in incremental labor costs. Alternatively, end-users can purchase and install multi-ring seals, which, according to manufacturers, for a large OEM are estimated to add roughly $1 to the cost of each connection. Since most end-users will not purchase the seals directly from the supplier, it is conservatively estimated that each seal will incrementally cost $3 per connection. As the incremental costs of multi-ring seals are

assumed to be less than the incremental labor costs of using double-flares, cost implications of this measure are based on the use of multi-ring seals (in the exception cases). This analysis assumes that 100 flares are used per store, resulting in a total incremental cost of $300 per store (regardless of store size).

Measure #4: *Pressure relief valves installed on a refrigerant vessel containing a high-GWP refrigerant shall have a rupture disc installed between the outlet of the vessel and the inlet of the pressure relief valve. The space between the pressure relief valve inlet and rupture disc shall have a pressure gauge, pressure transducer, or other device to indicate a disc rupture and discharge of the relief valve.*

- **Leak Reduction Rationale:** This measure will result in reduced leakage by providing a means for service technicians to quickly identify a valve that has discharged so that it may be checked for possible refrigerant seepage. Specifically, pressure relief valves are single event devices. Thus, once a valve is discharged, contaminants in the system may become embedded in the seat of the valve, preventing the pressure relief valve from sealing properly. In addition, a seeping valve that is piped by code to the outside may go undetected for long periods.
- **Cost Implications:** Rupture disc relief valve with a gauge is estimated at about $140 per pressure relief valve. Assuming 1-2 pressure relief valves per rack and 2-4 racks per centralized DX system, costs are estimated at $630 per store (regardless of store size).

Measure #5: *Only Schrader access valves (i.e., access fittings with a valve core installed) with a brass or steel body are permitted for use. For systems with a refrigerant charge of 5 lbs or more, valve caps shall be brass or steel (not plastic); a neoprene O-ring seal must be in place, if the cap is designed for it.*

- **Leak Reduction Rationale:** This measure will result in reduced leakage by prohibiting the use of valves that are more prone to leakage. Specifically, Schrader valves seal through a two-stage process. The primary seal is the spring loaded valve seat, which may seep over time, especially if contaminants become lodged in the seat. The secondary seal is the valve cap, which prevents the valve from becoming contaminated with contaminants. The cap is only effective if it is in place on the valve and not cracked, and if the O-ring cap seal is in place and not damaged. However, experience has shown that valve caps are commonly missing on Schrader valves as a result of damage or poor service practices. Brass and steel caps tend to be stronger than plastic caps and less apt to crack. Installed with the proper O-ring seal in place, the brass/steel cap is likely to reduce refrigerant loss from a seeping Schrader valve.
- **Cost Implications:** Incremental costs of brass or steel caps (versus plastic caps) are estimated to be up to $10 per valve. The number of valves will vary by store and are assumed to range between 50 and 200, based on store size. More specifically, total incremental costs are assumed to be $1,000 for small supermarkets, $1,500 for large supermarkets, and $2,000 for big box stores.

Measure #6: *Valves that are designed to have seal caps must be in place with chain tethers to fit over the stem. Valves with seal caps that are not removed from the valve during stem operation are exempted from using chain tethers.*

- **Leak Reduction Rationale:** This measure will result in reduced leakage by ensuring caps, which may be removed from the valve during operation, are installed with the proper O-ring seal in place. Caps are much less likely to be lost or misplaced if they have chained tethering.

- **Cost Implications:** Since valves are typically sold with seal caps, the incremental cost is associated with the tether, estimated at no more than $5 per valve. The number of valves will vary by store and are assumed to range between 50 and 200, based on store size. More specifically, total incremental costs are assumed to be $500 for small supermarkets, $750 for large supermarkets, and $1,000 for big box stores.

<u>Measure #7:</u> *Refrigerated service cases holding food products containing vinegar and salt shall have evaporator coils coated to prevent corrosion from these substances or be made of a corrosion-resistant material, such as stainless steel. The heat transfer efficiency of the coil coating should be considered when selecting the coating to ensure maximum energy efficiency.*

- **Leak Reduction Rationale:** his measure will reduce refrigerant leakage by protecting coils in deli cases, which can corrode over time and lead to significant leaks.
- **Cost Implications:** Costs are estimated to range between $300 and $700 per coil for coating, based on the size of the coil, the manufacturer supplying the service, and the type of coating used. The number of deli cases per store may range from 1-5. The incremental cost associated with this measure is estimated at $1,000 for small supermarkets and $2,000 for large supermarkets and big box stores, assuming $500 per coil and 2 to 4 deli cases per store. These costs for coating will likely decline if its application becomes more widespread across California.

<u>Measure #8:</u> *Refrigerant piping shall be installed in such a way so that it is accessible for leak detection and repairs.*

- **Leak Reduction Rationale:** This measure will reduce refrigerant leakage by prohibiting the installation of piping that is difficult to access. Piping that can't easily be leak checked or replaced is more susceptible to undetected and prolonged leaks.
- **Cost Implications:** Costs are expected to be negligible since this measure can be addressed as part of the design process. If costs are incurred, they will vary on a store by store basis.

<u>Measure #9:</u> *Refrigerant receivers with capacities greater than 200 lbs. shall be fitted with a device that indicates the level of refrigerant in the receiver.*

- **Leak Reduction Rationale:** This measure will reduce refrigerant leakage by allowing the monitoring of the receiver level, and in turn the detection of leaks that may not otherwise be easily detected. Although the information from a receiver level sensor can be difficult to interpret—with the level of refrigerant in the receiver dependent on system load, general system operation, weather conditions, and other external variables in addition to refrigerant leakage—there is value in monitoring the maximum and minimum receiver levels over time to detect significant changes in refrigerant. This measure is believed to be complementary to CARB's refrigerant management program requirements.[2]
- **Cost Implications:** A variety of devises can be used to measure the receiver level, with certain types of sensors being most appropriate for specific types of receivers (e.g., horizontal versus vertical). Any receiver level sensor may be used, regardless of its sophistication (e.g., dial

[2] Receiver level monitoring is not a requirement for systems under CARB's existing regulations that take effect January 1, 2011. The only exception to this is if the facility is implementing a parametric continuous monitoring system that uses receiver level in its model of system operation to alert the operator to leaks. This type of monitoring system is only required of large facilities (i.e., equipment containing >2,000 lbs).

indicators or electronic indicators). The incremental cost associated with this measure is estimated at $150 per store, assuming an incremental cost of $50 per rack and three racks per store (regardless of store size).

<u>Measure #10:</u> *Pressure test system during installation prior to evacuation & charging: (1) Charge the system with regulated dry nitrogen and the appropriate tracer gas to bring system pressure up to 300 psig minimum; and (2) after the system has been checked for leaks and all leaks have been repaired and retested, the system must stand, unaltered, for 24 hours with no more than a +/- 1 pound pressure change from 300 psig, using the same gauge.*

- **Leak Reduction Rationale:** This measure will reduce refrigerant leakage by ensuring leak tightness at equipment installation. Holding the system at a high pressure for a long period of time will pick up even small leaks, thus ensuring leak tightness of equipment at installation.[3]
- **Cost Implications:** Costs are mainly associated with the isolation requirements, which could result in additional labor time (and potentially, a delay in the store opening). To estimate costs, it is assumed that an additional 8 hours of labor are needed at $60/hour. Therefore, total incremental costs are assumed to be $480 per store (regardless of store size).

<u>Measure #11:</u> *Evacuate system following pressure testing & prior to charging: (1) Pull a system vacuum down to at least 1000 microns (+/- 50 microns) and hold for 30 minutes; (2) Pull a second vacuum to a minimum of 500 microns and hold for 30 minutes; and (3) Pull a third vacuum to a minimum of 300 microns and hold for 24 hours with a maximum drift of 100 microns over the 24-hour period.*

- **Leak Reduction Rationale:** This measure will reduce refrigerant leakage by ensuring leak tightness at equipment installation. Pulling the vacuum three times will ensure that systems are free of impurities prior to charging.[4]
- **Cost Implications:** Costs are mainly associated with the evacuation and isolation requirements, which could result in additional labor time (and possibly, a delay in the store opening). To estimate costs, it is assumed that an additional 8 hours of labor are needed at $60/hour. Therefore, total incremental costs are assumed to be $480 per store (regardless of store size).

<u>Measure #12:</u> *Short radius elbows are prohibited from use on commercial refrigeration systems unless space limitations physically prohibit the use of long radius elbows. Only under these circumstances can short radius elbows be installed. [Note: definitions of "short" and "long" radius elbows are based on catalogued terminology.]*

- **Leak Reduction Rationale:** This measure will reduce refrigerant leakage by minimizing the use of short radius elbows, which are more susceptible to stress on refrigeration lines (especially where there is thermal expansion and vibration).
- **Cost Implications:** An incremental cost of $2 per elbow is assumed (for short versus long radius elbows). It is also assumed that each store uses up to 200 elbows, depending on the size of the

[3] This measure was adapted from the U.S. EPA GreenChill "Best Practices Guideline Ensuring Leak-Tight Installations of Refrigeration Equipment." The Guideline is intended to be a minimum for best practices. Some GreenChill partners have exceeded this Guideline by using a hydrogen mixture to pressurize the system and conduct a leak test with a hydrogen leak detector.

[4] As with Measure #10, this measure was adapted from the U.S. EPA GreenChill "Best Practices Guideline Ensuring Leak-Tight Installations of Refrigeration Equipment." The Guideline is intended to be a minimum for best practices. Some GreenChill partners have exceeded this Guideline by reducing the minimum evacuation pressure.

store. More specifically, total incremental costs are assumed to be $200 for small supermarkets, $300 for large supermarkets, and $400 for big box stores.

Net Impact of Leak Reduction Measures

To determine the contribution to a reduced leak rate from the proposed LRMs in isolation is difficult, given that all available refrigerant emission studies (e.g., Bivens and Gage [2004], UNEP [2010], IPCC [2005]), show programmatic leak reductions as an accumulation of all measures, whether they be in design, implementation, operating practice, leak repair practices, or refrigerant recovery during repair and at equipment end-of-life. However, a range of leak reduction can be estimated within reasonable parameters.

Collectively it is estimated that the above LRMs will reduce a store's leak rate by 1-3% from the business as usual (BAU) leak rate of 10%. The BAU leak rate reflects the assumed average leak rate of supermarkets in California following the implementation of ARB's recently adopted Refrigerant Management Program.[5] The proposed LRMs are expected to reduce annual leak rates by up to 3%, resulting in an achievable annual leak rate of 7%. Based on the experience of some supermarkets in the U.S. and Europe, 7% is assumed to represent the lowest reasonable leak rate that can be expected (Anderson, 2005; Giant Eagle, 2009).[6] The actual impact of specific measures on leak reduction may in fact be greater than that estimated here. For example, refrigerant loss data indicate that leaks from flared joints account for approximately 50% of all refrigerant losses in a typical supermarket (IOR, 2010). However, given the already low leak rate (of 10%) assumed in the BAU, a reduction of only 1-3% is conservatively assumed in this analysis. Assuming an average leak reduction of 2% and an assumed equipment lifetime of 15 years, the GHG emission savings per store are presented in Table 2 below.

Table 2: Summary of GHG Savings Per Store

	Big Box	Large	Small
Annual Refrigerant Savings (pounds)	68	56	11
Annual Refrigerant Savings ($MTCO_2eq$)	123	100	20
Lifetime Refrigerant Savings ($MTCO_2eq$)	1,839	1,501	297

Total annual GHG reductions for the state of California from 2014-2030 are presented in Table 3 and graphically displayed in Figure 1. The reductions are estimated based on the assumption that in 2010 there were 400 big box stores, 3,600 large supermarkets, and 500 small supermarkets in California (ARB 2009), and that the supermarket industry is growing at a conservative rate of roughly 1% per year. Since the measures only apply to new construction and remodels, the total annual GHG reduction benefits of implementing these measures gradually increase over time, as existing stores are remodeled and subject

[5] The ARB Initial Statement of Reasons (ISOR) for Proposed Regulation for the Management of High Global Warming Potential Refrigerants for Stationary Sources (ARB, 2009) states that existing facilities, which use "business as usual" equipment design and installation practices can be expected to lower the annual refrigerant leak rate from the current 18% - 20% for supermarkets (state average) to a 10% annual leak rate, based on more stringent inspection and maintenance practices (repair all leaks within 14 days and other practices).

[6] Anderson (2005) concluded that the average annual leak rate for commercial refrigeration equipment in the Netherlands is close to 6.9%. In the U.S., Giant Eagle received GreenChill's 2008 Best Partner Emissions Rate Award for achieving the lowest refrigerant leak rate of all GreenChill partners, with a corporate-wide refrigerant leak rate below 8%.

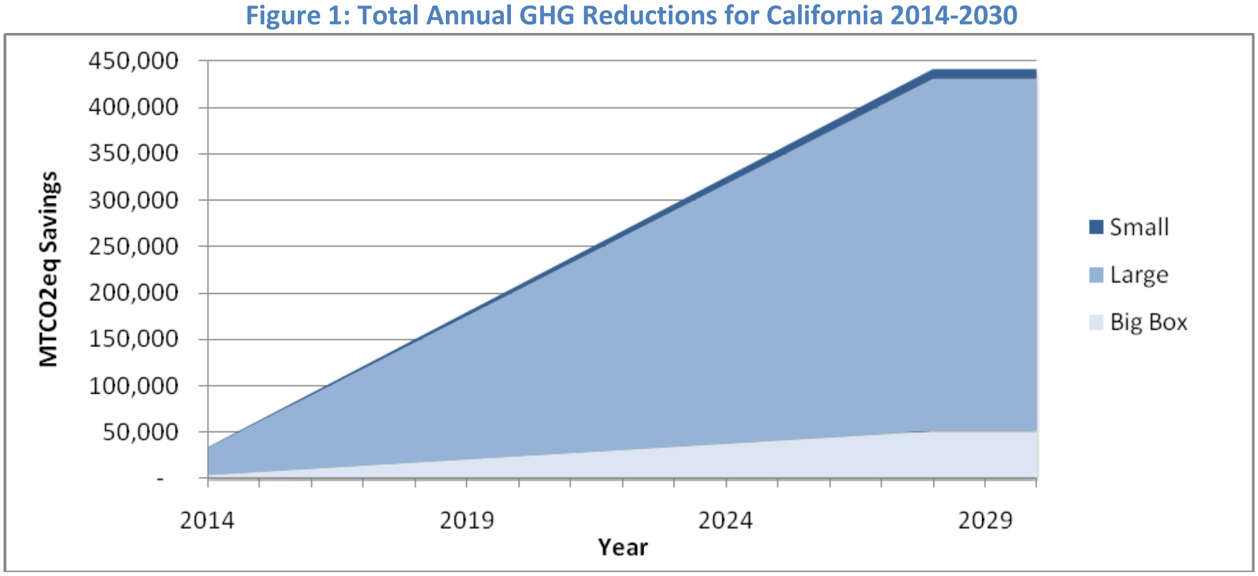
to the leak reduction measures. By 2028 it is assumed that all existing stores have undergone major remodels, resulting in cumulative statewide emissions reductions of roughly 440,000 $MTCO_2eq$ by 2030.

Table 3: Summary of Total Annual GHG Reductions for California ($MTCO_2eq$)

Year	Big Box	Large	Small	Total
2014	3,908	28,702	790	**33,400**
2015	7,316	53,730	1,478	**62,524**
2016	10,724	78,758	2,167	**91,648**
2017	14,132	103,786	2,856	**120,773**
2018	17,539	128,815	3,544	**149,898**
2019	20,947	153,844	4,233	**179,024**
2020	24,355	178,873	4,921	**208,150**
2021	27,764	203,903	5,610	**237,277**
2022	31,172	228,934	6,299	**266,404**
2023	34,580	253,964	6,987	**295,532**
2024	37,988	278,995	7,676	**324,660**
2025	41,396	304,027	8,365	**353,788**
2026	44,805	329,059	9,054	**382,917**
2027	48,213	354,091	9,742	**412,047**
2028	51,622	379,124	10,431	**441,177**
2029	51,627	379,167	10,432	**441,226**
2030	51,633	379,210	10,433	**441,276**

As shown in Figure 1, the majority of emissions reductions (~86%) result from implementation of the leak reduction measures in large supermarkets. Due in part to their smaller makeup of the industry, approximately 12% of the reductions come from big box stores, while only about 2% of the reductions come from small supermarkets.

Figure 1: Total Annual GHG Reductions for California 2014-2030



Cost Effectiveness Analysis

The assumptions and calculations used to estimate cost implications for each leak reduction measure are summarized below in Table 4. The total one-time cost estimates for small supermarkets, large supermarkets, and big box stores are also provided; these costs are assumed to be incurred at the initial design and installation of the refrigeration equipment, which is assumed to have a lifetime of 15 years.

Table 4: Cost Assumptions and Calculations

LRM #	Implications	Assumptions	Estimated Costs by Store Type		
			Big Box	**Large**	**Small**
1	Skilled labor required	Hours = 8 Incremental Labor Rate = $20/hr	$160	$160	$160
2	Additional labor required	Hours = 0.5 Labor Rate = $60/hr	$30	$30	$30
3	Use of single-flare fittings with a seal	Flares = 100/store Incremental costs = $3/seal	$300	$300	$300
4	Purchase of pressure relief valves	$140 /pressure relief valve 1-2 pressure relief valves/rack 3 racks/store	$630	$630	$630
5	Use of brass over plastic	Incremental cost = $10/valve Valves/store = 200 (big box), 150 (large), 100 (small)	$2,000	$1,500	$1,000
6	Use of a tether	Incremental cost = $5/valve Valves/store = 200 (big box), 150 (large), 100 (small)	$1,000	$750	$500
7	Use of coated coils	$500/coil Coils/store = 4 (big box/large), 2 (small)	$2,000	$2,000	$1,000
8	Store design	Negligible	-	-	-
9	Use of receiver level sensors	$50/rack 3 racks/store	$150	$150	$150
10	Additional labor required	Hours = 8 Labor Rate = $60/hr	$480	$480	$480
11	Additional labor required	Hours = 8 Labor Rate = $60/hr	$480	$480	$480
12	Use of long radius elbows over short radius elbows	Incremental Cost = 2$/elbow Elbows/store = 200 (big box), 150 (large), 100 (small)	$400	$300	$200
TOTAL			**$7,630**	**$6,780**	**$4,930**

Based on the above one-time costs and lifetime GHG emission savings, cost-effectiveness of the LRMs was calculated in terms of cost per metric ton of carbon dioxide equivalent ($MTCO_2eq$) reduced using the following formula:

$$\$/MTCO_2eq = \frac{\text{[Total Cost of LRMs – (Refrigerant Savings + Avoided Leak Repair Costs)]}}{MTCO_2eq \text{ reductions as a result of LRMs}}$$

The results by store type are summarized below in Table 5. As shown, there is a cost savings of almost \$40/$MTCO_2$eq associated with implementing the leak reduction measures in all supermarkets, benefit/cost ratios greater than 3, and payback periods of 1-3 years.

Table 5: Summary of Costs and Benefits per Store

	Big Box	Large	Small
Initial Cost of LRMs	\$7,630	\$6,780	\$4,930
Annualized Costs of LRMs [1]	\$509	\$452	\$329
Annual Refrigerant Reductions (pounds)	68	56	11
Refrigerant Cost (\$/pound)	\$10	\$10	\$10
Lifetime Refrigerant Reductions ($MTCO_2$eq)	1,839	1,501	297
Lifetime Refrigerant Savings (avoided cost) [2]	\$70,694	\$57,795	\$11,449
Lifetime Avoided Leak Repair Costs [3]	\$7,640	\$7,640	\$7,640
Net Lifetime Cost Savings (\$ Saved/Store)	\$70,704	\$58,655	\$14,159
Cost-Effectiveness (\$ Saved/$MTCO_2$eq Reduced)	**\$38.44**	**\$39.08**	**\$47.62**
Benefit/Cost Ratio	10.27	9.65	3.87
Simple Payback (years)	**1**	**1**	**3**

[1] Assumes equipment lifetime of 15 years
[2] Discounted at a rate of 3% per year to 2011 dollars. Accounts for the costs of environmental externalities.
[3] Discounted at a rate of 3% per year to 2011 dollars.

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