

The nexus of energy efficiency and low GWP refrigerants; Can we meet our greenhouse gas emission goals in commercial refrigeration?

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ABSTRACT

The California Air Resources Board has identified the transition away from hydrofluorocarbon refrigerants (HFCs) in supermarkets as one of the most impactful and cost-effective strategies to achieve the state's ambitious climate targets. Natural refrigerants - such as CO₂, ammonia, and propane – are climate-friendly alternatives with near-zero global warming potential (GWP) but have the potential to increase energy use. Intervention tools are needed to achieve the lowest possible direct emissions (GWP of leaking refrigerants) and indirect emissions (emissions from energy use).

This paper summarizes the most comprehensive study to date relating the impacts of energy efficiency and the phase out of HFCs. In the study, major industry stakeholders were surveyed to determine the state of existing California supermarket systems and plans for new and retrofit stores. Those data were used to develop a model of the refrigeration stock in California grocery stores and project turnover of those systems. Both direct and indirect emission impacts were evaluated in the projected results.

Refrigeration system computer modeling tools were also assessed for ease of use, capabilities, and technical gaps. The usefulness of those tools was evaluated relative to stakeholder needs, and one was used to estimate energy impacts.

The results of this study will be presented, including an update on how California's new Total System Benefit metric can reflect emission reductions from HFC retirements. Authors will uncover the complex interplay between energy efficiency and refrigerant emissions within the commercial refrigeration market, where high energy use and large volumes of refrigerant are the norm.

Introduction

The work here is based on research conducted under Southern California Edison's Emerging Technologies Program (2021, SCE) with some updates that pertain to policies that have changed since publication. Under that work, the goal was to characterize the existing market of refrigerant options in the California grocery/supermarket sector, and to determine to what extent the coming phase-down of hydrofluorocarbon refrigerants (in favor of refrigerants with lower global warming potential or GWP) might impact the expected energy use and CO₂ emissions in the sector.

In support of this aim, the project conducted three areas of investigation:

- A survey of stakeholders to determine current trends in the adoption of low GWP refrigerant options in new construction and retrofits.

- A review and gap analysis of available energy simulation platforms used to evaluate and compare the relative energy use and operating costs of various system types, for both established and emerging technologies.
- Creation of an analytical model to simulate the energy and emissions impacts (equivalent CO₂ emissions) under multiple scenarios of technology adoption, including the direct impacts due to refrigerant leaks, and indirect impacts due to changes in overall energy efficiency of system options.

This paper will touch briefly on the first two objectives for the background they provide but focus primarily on the third objective: using the analytical model to determine whether California can meet its greenhouse gas emission targets, or if course changes are necessary to do so. Additional information can be found in the cited reference.

Background

Hydrofluorocarbon (HFC) refrigerants are extremely potent greenhouse gases (GHGs) with thousands of times higher global warming potential (GWP) than carbon dioxide (CO₂). Once considered a suitable replacement for ozone-depleting substances (ODS), HFCs are now the world's fastest-growing GHG and one of the more potent drivers of climate change. Scientists estimate that swift mitigation of HFC emissions could avoid up to 0.5°C of global warming by the end of the century.

California Air Resources Board (CARB) has identified refrigeration as California's predominant source of HFC emissions (CARB 2021a) and the food retail sector as one of the most impactful and cost-effective opportunities for HFC emission reductions (CARB 2020).

Classified as short-lived climate pollutants (SLCPs), HFCs have a disproportionate impact on warming in the near term. In 2016, California's Senate Bill 1383 mandated the adoption of an SLCP reduction strategy and specifically required a 40% reduction in HFC emissions below 2013 levels by 2030. It authorized the State Air Resources Board (aka CARB) as the state agency required to set a plan for achieving these goals, as well as parallel reductions in methane (40%) and black carbon (50%). The law set in motion the HFC phaseout plan, now being implemented by CARB.

SB 1013 (Chapter 375, Statutes of 2018) established the Fluorinated Gases Emission Reduction Incentive Program (FRIP), to be administered by the state board, to promote the adoption of new refrigerant technologies to achieve short- and long-term climate benefits, energy efficiency, and other co-benefits, as specified.

This bill also requires the California Public Utilities Commission (CPUC) to consider developing a strategy for including low-global-warming-potential refrigerants in equipment funded by the energy efficiency programs overseen by the Public Utilities Commission. This effort has resulted in an approach to quantifying GHG reductions associated with refrigerant leakage and refrigerant retrofits by the CPUC (last bullet above). In 2020, the CPUC released a "Refrigerant Calculator" to calculate avoided cost benefits of GHG reductions due to refrigerant direct emissions – an approach that puts refrigerant reductions within the same cost/benefit approach as that used for energy efficiency programs.

Typical supermarket refrigeration systems contain a large amount of refrigerant, from 500 lbs for smaller stores up to more than 3,000 lbs of refrigerant for large “big-box” style stores. Leak rates are reported as an estimated 23% of its charge annually (CARB 2019). In addition to the emissions from annual leaks, the potential emissions of the installed base of HFCs is equal to 60% of annual statewide GHG emissions, and projections suggest that HFCs could be one of the largest remaining GHG sources in the state by 2045 (CARB 2021a).

As a result, supermarkets in California and across the United States are facing increasing regulatory pressures to transition to climate friendly alternatives. In California, new regulations that took effect January 1, 2022 prohibit the use of refrigerants above 150 GWP in new facilities with systems containing more than 50 pounds of refrigerant. California food retailers must also either attain a companywide weighted average GWP of less than 1,400 or attain a 55% reduction in Greenhouse Gas Potential (GHGp) below 2019 levels across all of their existing facilities by 2030 (CARB 2021b).

At the federal level, the American Innovation and Manufacturing (AIM) Act of 2020 directed the United States Environmental Protection Agency (EPA) to reduce HFC emissions by phasing down the production and consumption of HFCs by 85% by 2036, facilitating the transition to next-generation technologies, and establishing regulatory requirements for the management of refrigerants (US EPA 2020).

Natural refrigerants, such as CO₂, ammonia, and propane, have zero and near-zero GWP and are considered technically viable, future-proof, and climate-friendly alternatives to HFCs. However, they are not “drop-in” solutions and thus require an extremely costly and logistically challenging full system replacement in existing facilities. Conversely, hydrofluoroolefin-blends (HFO-blends) with nearly 1,400 GWP are considered a drop-in solution but are an interim step towards achieving California’s HFC reduction targets and will result in continued refrigerant emissions in the near term.

CARB has projected that even when accounting for AIM Act emissions reductions, existing regulations alone will not meet California’s HFC reduction targets (CARB 2021a). Additional interventions that enable the transition to natural refrigerants, such as building code updates, increased refrigeration technology options for existing facilities, and funding support for ultra low GWP refrigerants, will help the state bridge their emission reduction gap.

The following are significant CARB policies that currently provide the basis of the regulatory environment in California. The following regulations result in four major driving forces that will shape the landscape of choices stakeholders face in the commercial refrigeration market in California.

- New and retrofit supermarket systems were prevented from using some of the most common HFC refrigerants beginning in 2019. The “California SNAP” regulations (2018? EPA) prohibited the use of R-404a, R-407b, R-507a and other less common refrigerants on a more aggressive timetable than Federal EPA regulations.
- New commercial refrigeration facilities (with charges over 50 lbs) will be required to use refrigerants with a GWP of 150 or less, beginning in 2022.
- Existing commercial refrigeration facilities with more than 20 stores with over 50 lbs of refrigerant will, by 2026, need to:
 - Achieve a weighted average GWP below 2500; or
 - Lower the GWP of the portfolio by at least 25%.AND, by 2030, all food retailers will need to:

- Achieve a weighted average GWP below 1400; or
- Lower the GWP of the portfolio by at least 55%.
- CARB and the California Public Utilities Commission (CPUC) are cooperating to recognize parallel policy objectives in energy efficiency and GHG reduction efforts. To date this has been limited to the CPUC recognizing the equivalent GHG reductions of HFC emissions in the calculation of avoided costs used to evaluate the costs and benefits of energy efficiency. However, this is a work-in-progress and has not yet been used in practice to incentivize refrigerant retrofits through energy efficiency programs to evaluate a program's impacts.

The regulations described in the first item above were put in place by CARB to begin the phase out of HFC's in California with regulations like those first passed under the EPA's Significant New Alternatives Policy (SNAP) rules. The second and third are part of CARB regulations passed Dec. 10, 2020. The last item was ordered by SB 1013 (see below) and to date has resulted in a calculation methodology for assessing the avoided costs of GHG retrofits (CPUC 2021).

Modeling Tools used in Commercial Refrigeration

Stakeholder Survey

A stakeholder survey was used to explore the needs and awareness of existing tools for modeling the energy use of commercial refrigeration systems. The needs assessment included two primary activities. The first was to reach out to Subject Matter Experts (SMEs) for direct feedback on the state of industry tools, with emphasis on needs for low GWP refrigerants. The second was a review of existing tools by in-house energy modeling experts to clearly delineate available options and evaluated along the priorities given by stakeholders for these tools.

Overall, the stakeholders in our survey group reported very little use of modeling tools in their existing work. Most system designers make little use of existing modeling tools. They reported that the design process has little room in the budget for optimization and design decisions tend to rely more heavily on peak conditions than average use. Most designers report little familiarity with existing design tools. Owners and operators typically do not have the time for detailed modeling activities, trusting their design engineers to fill any related needs. Manufacturers typically rely on their own test data to determine system performance and needs and have little need for modeling approaches.

Interviews with industry stakeholders paint a somewhat contradictory picture of the current use and projected needs for modeling tools to assist with the energy efficient design of supermarkets in California. While the reported use of existing tools is very low, there is interest in future tools, particularly by and in support of regulators and utilities. The desired qualities of such tools represent a somewhat "heavy lift" of qualities. The desired tools would need to represent a large number of emerging technical approaches to grocery store refrigeration, while also being independent, verified/verifiable, easy-to-use, while capturing complicated interactive effect between HVAC and refrigeration systems.

Gap Analysis

While there is currently not a single modeling tool that meets the ideal criteria requested by stakeholders, there are alternatives that meet subsets of requested features. The primary element requested by stakeholders that are missing from available alternatives are:

- A simple interface for building typical commercial refrigeration systems for quick and accurate simulations of all options that stakeholders would like to consider
- A modeling tool that includes the complexity of current system options that also includes system interactive effects with HVAC equipment and indoor humidity

For our market analysis (see next section) we decided to use Pack Calculation Pro as the option that had the capability to simulate the largest set of system options, refrigerants, and climates. Using this option meant sacrificing the interactive effects with HVAC but was deemed the most appropriate selection for the purposes of this study.

Forecasting Market Adoption and Emissions

The primary task of the investigation was to create an analytical model to simulate the energy and emissions impacts (equivalent CO₂ emissions) under multiple scenarios of technology adoption. This model included an estimate of the direct impacts of refrigerant emissions due to refrigerant leaks, and an estimate of indirect impacts due to changes in overall energy efficiency of system options. In this section the methods, assumptions and results of this analysis are presented.

Method

The market analysis used a combination of assumptions from various sources to develop a comprehensive picture of the grocery market sector in California as of 2020. The penetration of existing refrigerant systems was estimated by beginning with data from CARB's Refrigerant Management Program. Because this does not include existing low GWP systems that do not require reporting, these numbers were adjusted by adding known counts of existing systems that use natural refrigerants. The assumed beginning market penetrations are shown in Figure 1 below.

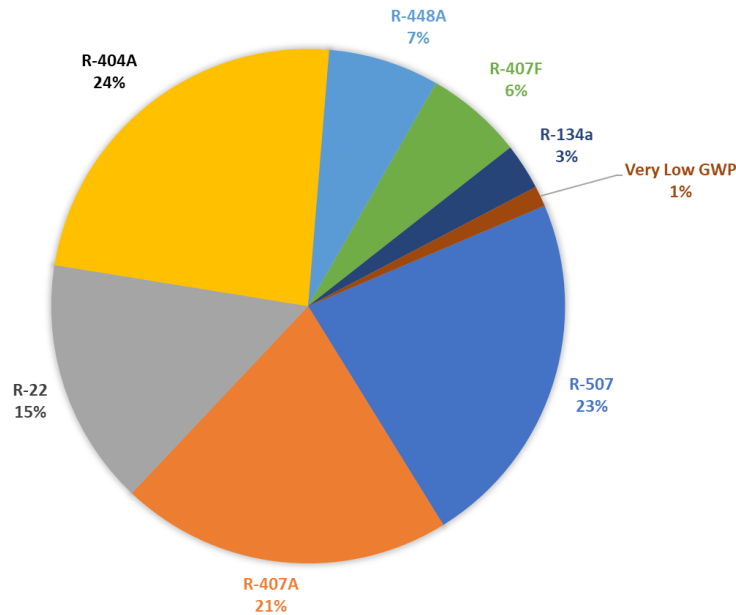


Figure 1. Refrigerant penetrations in California in 2020, based upon data from CARB's Refrigerant Management Program reporting, adjusted using counts of known natural refrigerant systems in the state.

This base model was then projected into the future using the assumptions stated below. The market was characterized first in terms of approximate floor area (millions of square feet or Msf), baseline energy consumption (GWh annually), and approximate fraction of system types (by refrigerant, and cooling type). The model then used an assumed rate of new store growth and remodel rates to determine the floor area added or remodeled each year. The new/remodeled space was assumed to adopt code-compliant new equipment based on the year. It was assumed that through 2022 most new facilities, and major remodels would incorporate low GWP blends in accordance with current regulations and predominant practice, using moderately low GWP HFO blends such as R-448a and R-449a. In 2022 and beyond, it was assumed that new store development and end-of-life replacements would be, according to CARB regulations, made using low GWP refrigerant systems.

Direct refrigerant emissions impacts were estimated based on the system types, typical refrigerant leakage rates, and the GWPs of the refrigerants used. For the analysis 20-year lifetime GWPs were used to align with the CPUC's Avoided Cost Calculation methods. Typical leak rates and refrigerant volumes were used to determine direct emission impacts.

Indirect impacts were estimated for two scenarios. The first was done using the current average CO₂ emissions for the California power grid of 0.2279 metric tons of CO₂ equivalent per Megawatt-hour of electricity generated (MTCO₂e/MWh) (CARB 2019). The second used that same value for 2020 but included a "grid greening" rate to reflect the growth in the renewable supply, or more specifically, the decay in CO₂ emissions over time. In the tables and graphs below, only the results of the latter assumption are presented, assuming that the current rate of decay in the use of CO₂-based energy sources is maintained (in alignment with SB 350 goals). A summary of this trend is shown in the following chart, showing the average annual decay in equivalent CO₂ emissions of 6.0% over the most recent 5-year period.

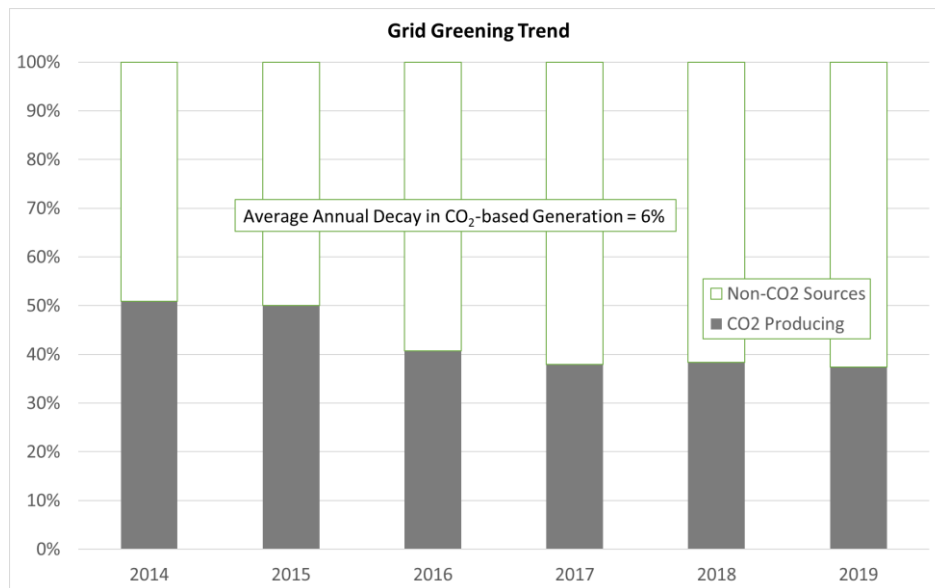


Figure 2. Historical decrease in CO₂-producing electricity generation statewide in California. Percent of total statewide supply mix is shown.

For the emissions model, this average annual decay in CO₂ emissions produced per kWh of electricity consumed was expected to continue over the 25-year projection period.

The indirect emissions of the stores were calculated based on estimates of the energy efficiency of each store type, as represented by the relative Energy Efficiency Ratio (EER) of the systems represented. The model used the average fraction of the refrigeration system relative to the total building load to find the energy use of the refrigerated systems, and then adjusted the energy use of each market segment based on the relative efficiency (and EER) of each system type as compared to the average. EERs for each system type were based on simulations in Pack Calculation Pro for representative climate zones in California. For the statewide study results, a weighted average of climate zones was calculated for each system type, based on the reported prevalence stores according to the RMP.

The indirect emissions impact was found by calculating the energy use for each market segment, using the average EER for that system type (as weighted by climate zone) and by multiplying the resulting energy use times the emission factor for each year. The indirect and direct equivalent CO₂ emissions were then summed to find the Total Equivalent Warming Index (TEWI) in terms of million metric tons (Mtons) of CO₂ equivalent.

Assumptions

Market impacts were based on the best available assumptions for existing make-up, and then the impact of refrigerant retrofits was applied to that sample over time. The primary data sources, and calculation methods are summarized as follows:

1. Commercial sector energy use was based upon the California Energy Commission's (CEC) 2018 demand forecast. (CEC 2018)
2. Grocery sector energy use was estimated at 8.8% of the total commercial sector, based on the most recent California Commercial End-Use Survey.

3. The sector consumption data was then converted to estimated grocery sector floor space using average energy use intensities (EUI)s, from multiple sources. (CEUS 2006)
4. Prevalence of existing refrigerants was extrapolated from 2019 refrigerant leak data from CARB's Refrigerant Management Database and adjusted to include approximate penetration of unlisted refrigerants (CO₂, ammonia, and hydrocarbons are not required to report due to low GWP).¹
5. Grocery sector growth was extrapolated using a historical market growth of 1.21% per the US Department of Agriculture (USDA).
6. Given the expense of very low GWP options, and current regulations for HFC phase outs in California, it was assumed that existing stores, where practical, would opt to replace existing refrigerants with allowable "gas-only" retrofit alternatives until retirement.
7. Penetration of very low GWP "natural" options was assumed to occur at the market turnover rate. This rate was assumed to be 3% based on industry feedback. The sensitivity of projections to this assumption was tested and is presented in a following section.
8. The existing, relatively small stock of low GWP natural refrigerants was estimated based on a store count from the North American Sustainable Refrigeration Council (NASRC). Growth of naturals was assumed to be divided equally among the three primary market leaders based on industry input from interviews; micro-distributed hydrocarbon, CO₂ trans-critical, and ammonia/CO₂ systems. This distribution is highly speculative, however assumptions of market penetration of very low GWP options has small impact on CO₂ emissions targets.
9. Leak rates were assumed based on historical averages from CARB and held constant. Sensitivity of results to leak rate assumptions was tested.
10. The energy performance of R-448a was modeled as an improvement of 11.2% of the EER compared to R-404a, who's properties are the closest relative to other refrigerants.

Using these assumptions, a model was constructed based on estimated existing building stock and projected growth/remodel rates to estimate the prevalence of various system types for the next 25 years. The environmental impacts of that building stock were then estimated in terms of equivalent CO₂ emission from direct impacts (refrigerant leakage) and indirect impacts due to electricity consumption. The relative numbers of the specific system types within the low GWP (natural refrigerant) category has no significant impact on the attainment of emissions reduction goals.

Forecasts

Using the data above, a baseline scenario was developed to characterize the current market make-up in terms of approximate penetration of system types, refrigerants, and equipment efficiencies. Results of this baseline analysis are presented below.

¹ The final EUI used was from the LBL building performance database, selected for grocery stores in California in 2014. This data is more recent, though in close agreement with other sources for EUI's such as CEUS (above) and the U.S. DOE's Commercial Building Energy Consumption Survey (EPA, 2012).

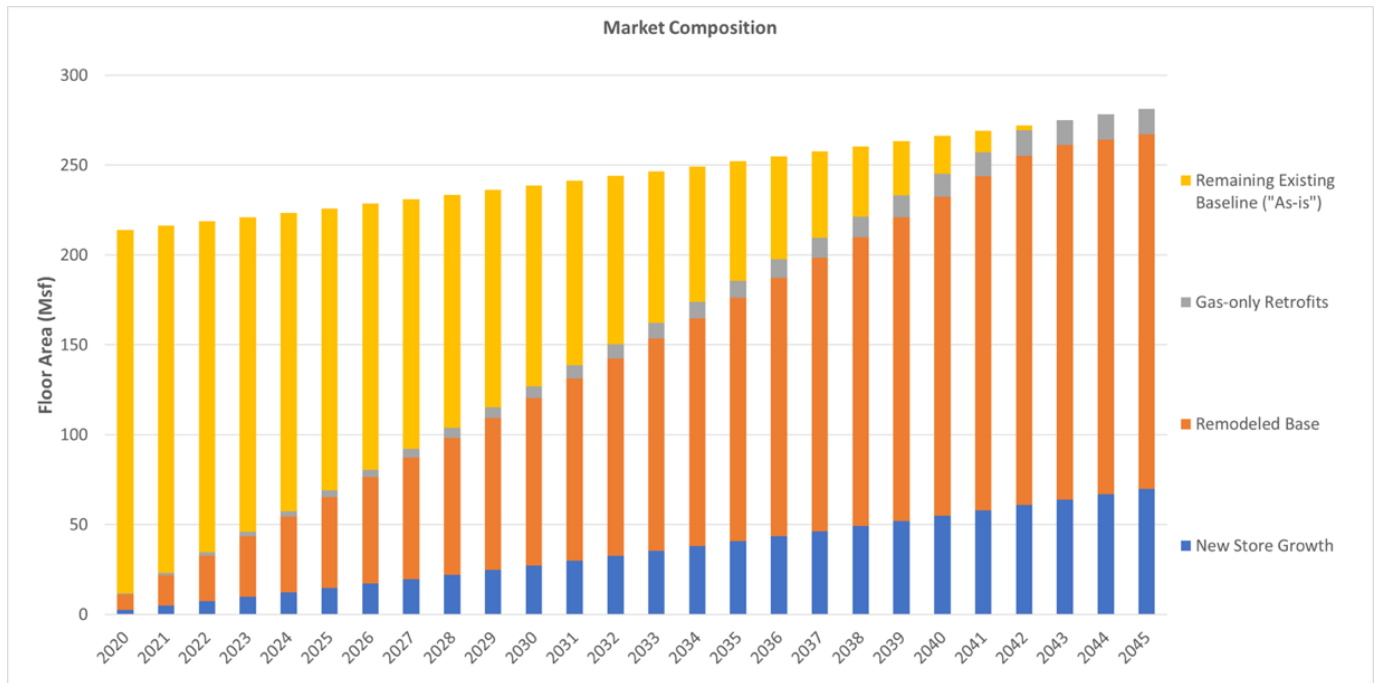


Figure 3. Market composition projection for California.

By including current market share estimates for refrigerant and system types, the analysis was converted into approximate penetration of system types over time (see below). Note that the goal of this study was to determine GWP impacts, not relative penetrations of competing system types (e.g., CO₂ vs. propane, etc.). For this reason, the relative market shares of these were based on systems installed to date, and future sales could differ significantly from those assumptions. However, those market penetrations have almost no impact on attainment of GHG reduction goals since all future refrigerant alternatives have very low warming potential compared to traditional HFCs.

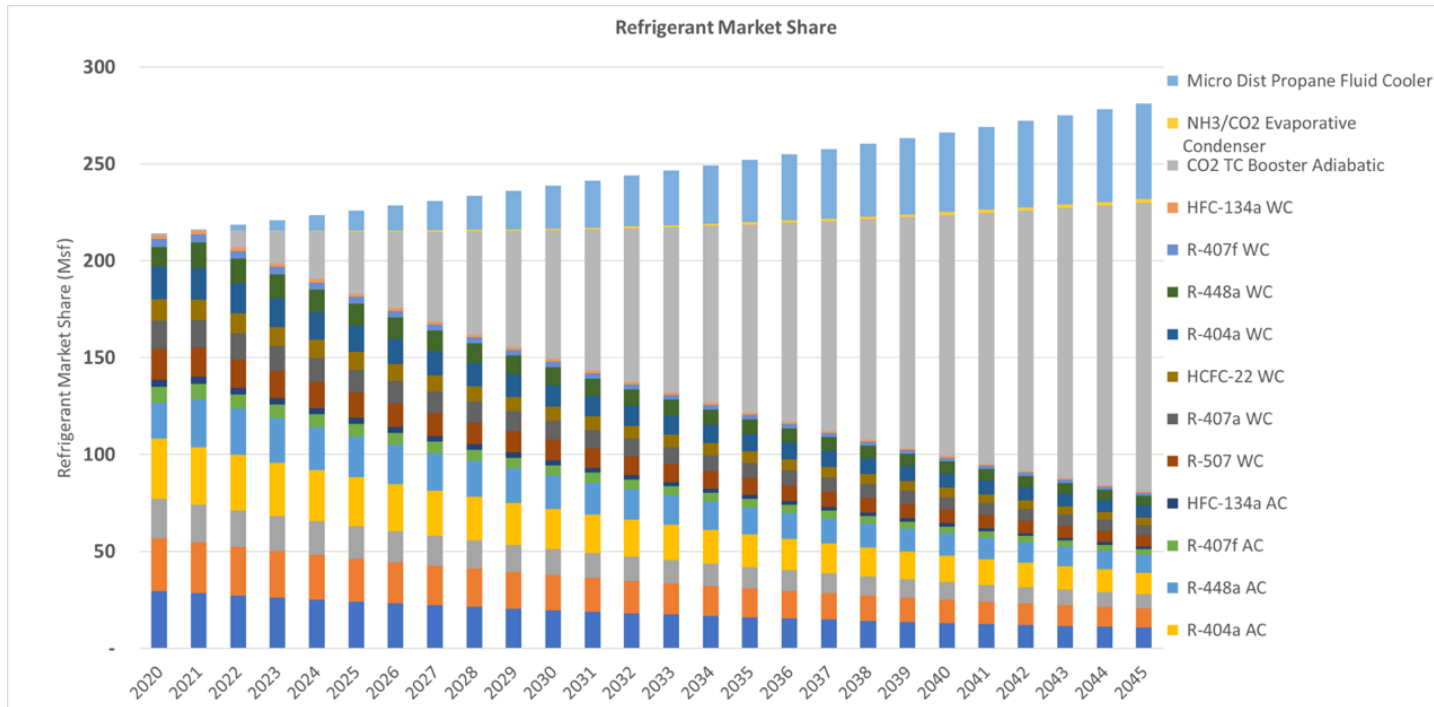


Figure 4. Market share of system and refrigerant combinations.
AC = Air-cooled, WC = Water cooled (primarily evaporative condensers).

The expected trends due to HFC phase-out, retrofits, and eventual replacement with low GWP options are reflected in the charts. As the existing market is turned over through remodels and new store growth, the stock of existing refrigerants is replaced with low GWP alternatives.

Equivalent CO₂ Emissions

Using the above estimates for refrigerant market penetrations, the analysis focused on estimating the direct GWP impacts of refrigerant leaks, and the indirect equivalent CO₂ emission impacts due to energy consumption. The results of that model are shown in Figure 5 below.

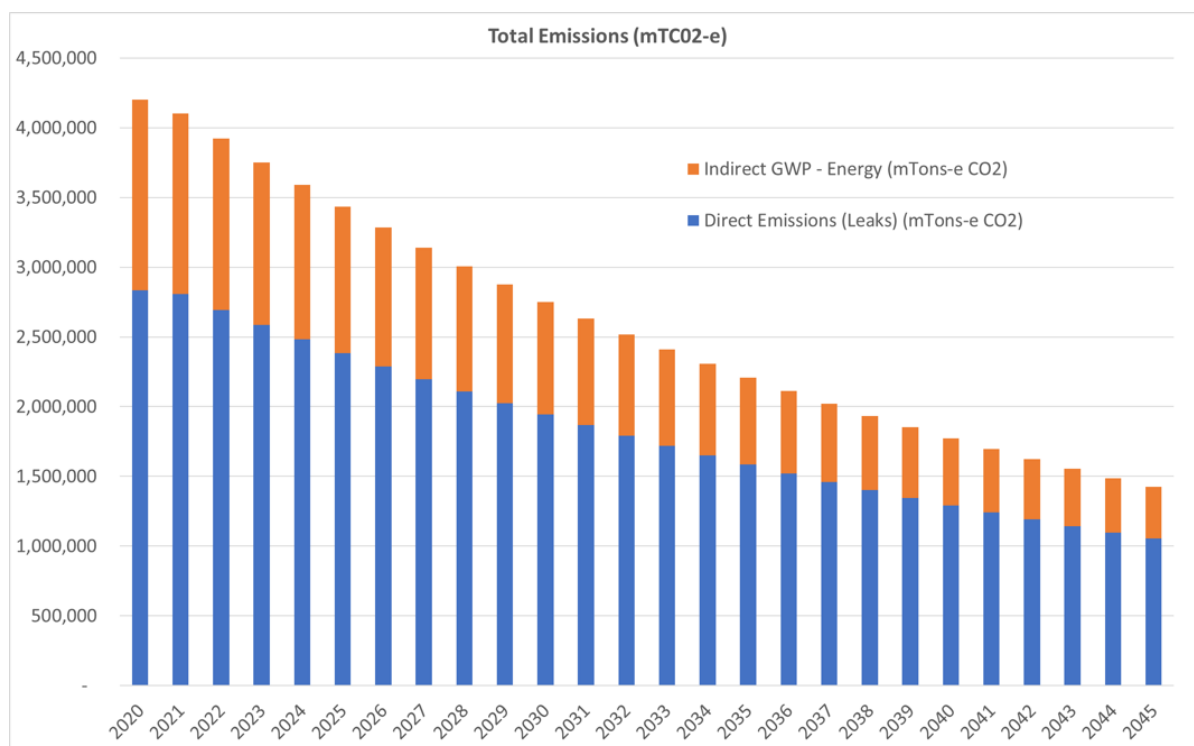


Figure 5. Projected total equivalent emissions (MTCO₂-e) due to the grocery sector in California.

As one can see in the graph above, the total emissions from both direct and indirect contributions are projected to decline steadily due to expected replacement of systems with low GWP refrigerants and due to the overall greening of the electricity supply. The speed of this decline relative to changes in assumptions made in this analysis are addressed below.

Meeting California's CO₂ Emission Targets

Senate Bill (SB) 1383 requires California to reduce HFC emissions 40% below 2013 levels by 2030. The most recent CARB estimate of the HFC inventory for retail food and commercial refrigeration totals 3.3 MmTCO₂-e in 2018. This aligns well with our estimate of 3.6 MmTCO₂-e of emissions for the sector in 2020. Since the policy targets are stated with reference to percent reductions relative to baseline, we took this agreement as significant for our purpose – to determine what assumptions and policy changes would have the greatest impact on goal attainment.

While SB 1383 uses 2013 as a baseline, we did not have a means of connecting our 2020 sector data with the market in 2013. Therefore, our comparison was based on “back-casting” our 2020 emissions rate to 2013 levels with historical sector growth targets and assuming a constant composition of refrigerants. We then varied inputs to determine what adoption rates would be required to meet goals.

With our baseline market impact assumptions, our model predicted that a 40% reduction from 2013 direct equivalent GHG emissions would only be met by 2041. Given the assumption of a greening grid, total direct and indirect emissions would be 40% lower than 2013 total emissions by 2037 (although this does not meet the mandatory requirements).

Assumptions and Impacts on Results

Sensitivity analysis was conducted to determine which assumptions used in the model had the greatest impact on the conclusions drawn. The sensitivity analyses included an examination of the following variables, and their impact on modeled outcomes.

Table 1. Summary of sensitivity testing approach for inputs and outcomes.

Input Variables	Outcomes
Market Growth Rate Equipment Turnover Rate Adoption Rate of Gas-only Retrofits Variance in EER Assumptions Variance in Leak Rate Assumptions	Direct Emissions Indirect Emissions Year of CO ₂ Reduction Goal Attainment TEWI

Sensitivity results are shown below in spider plots. In each, the center point of the plot (0,0) represents the baseline assumptions stated above. Each of the tested variables is shown as a separate line, with the percent change in the assumption shown on the x-axis, and the relative impact shown in percent change of the outcome, shown on the y-axis.

Total Equivalent Warming Impact (TEWI)

The TEWI is the sum of direct and indirect emissions and for the sensitivity analysis we used the sum of the 20-year totals as above. Figure 6 below shows the impact of key assumptions on total equivalent GHG emissions.

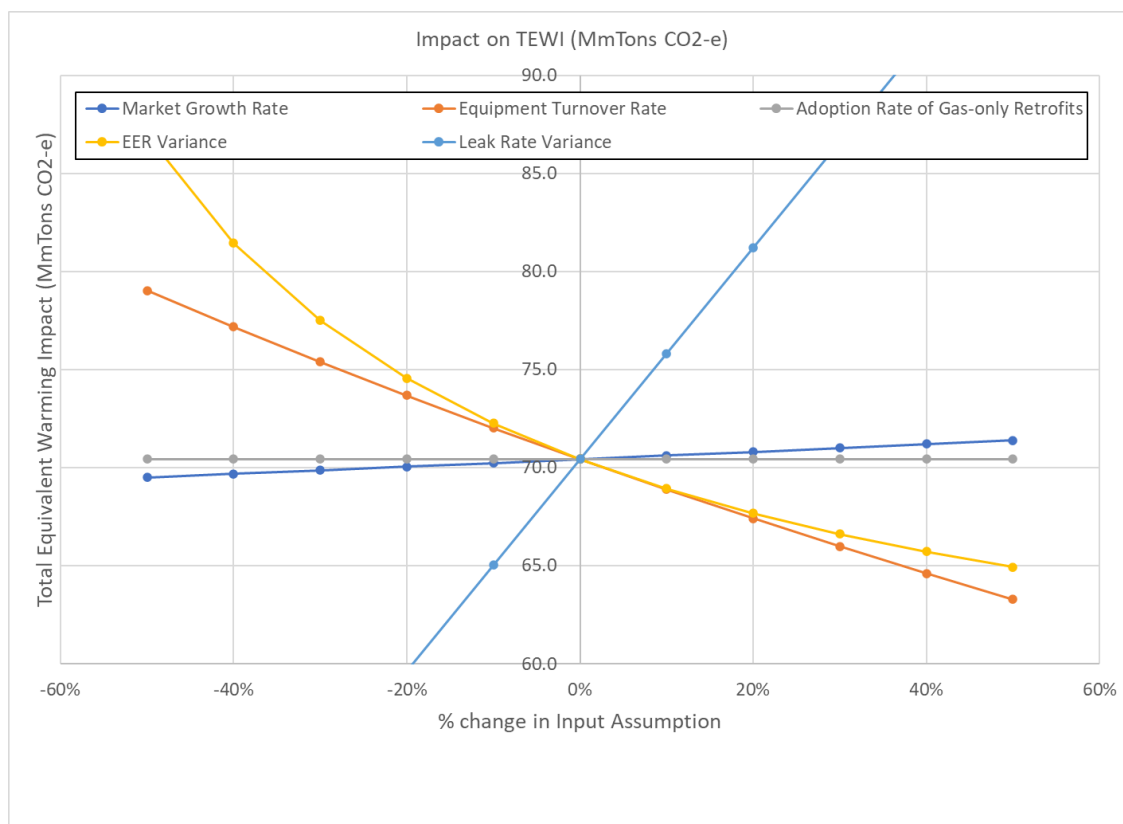


Figure 6. Impact of assumptions on Total Equivalent Warming Impact (TEWI)

For the combined TEWI sensitivity, the variance in EER, equipment turnover, and leak rate assumptions were those most influential in their impact on projections. Both market growth rate and gas-only adoption rate assumptions had much smaller impacts on results.

From a policy perspective, the clear indication is that equipment turnover rate and leak rate are the key variables to influence to have the greatest impact on overall GHG mitigation. While EER assumptions for refrigeration systems also has a significant impact on indirect emissions and TEWI, large changes in EER are difficult to achieve. For example, to achieve the same impact on TEWI as a 20% improvement in EER (a major technological achievement in terms of system efficiency) would only require a reduction of leak rates by 5% (from the assumed 23.0% to 21.9% annually). Similarly, one could achieve the same savings by increasing equipment turnover from 3% annually to 3.5% annually.

Meeting CO₂ Reduction Goals

Using the model projections, we estimated the year in which baseline attainment of California's HFC emissions goals would be met. We found goal attainment by approximately 2041 using baseline assumptions.

The goal, as stated in SB 1383, is to “achieve a reduction in the statewide emissions of methane by 40 percent, hydrofluorocarbon gases by 40 percent, and anthropogenic black carbon by 50 percent below 2013 levels by 2030.” In the study approach we assumed that the grocery

sector would need to achieve its “pro rata” share of that goal, in other words, to reduce direct HFC emissions by 40% relative to a 2013 baseline.

Figure 7 below shows the impact of various assumptions on the date by which the sector would meet the 40% goal for direct emissions.

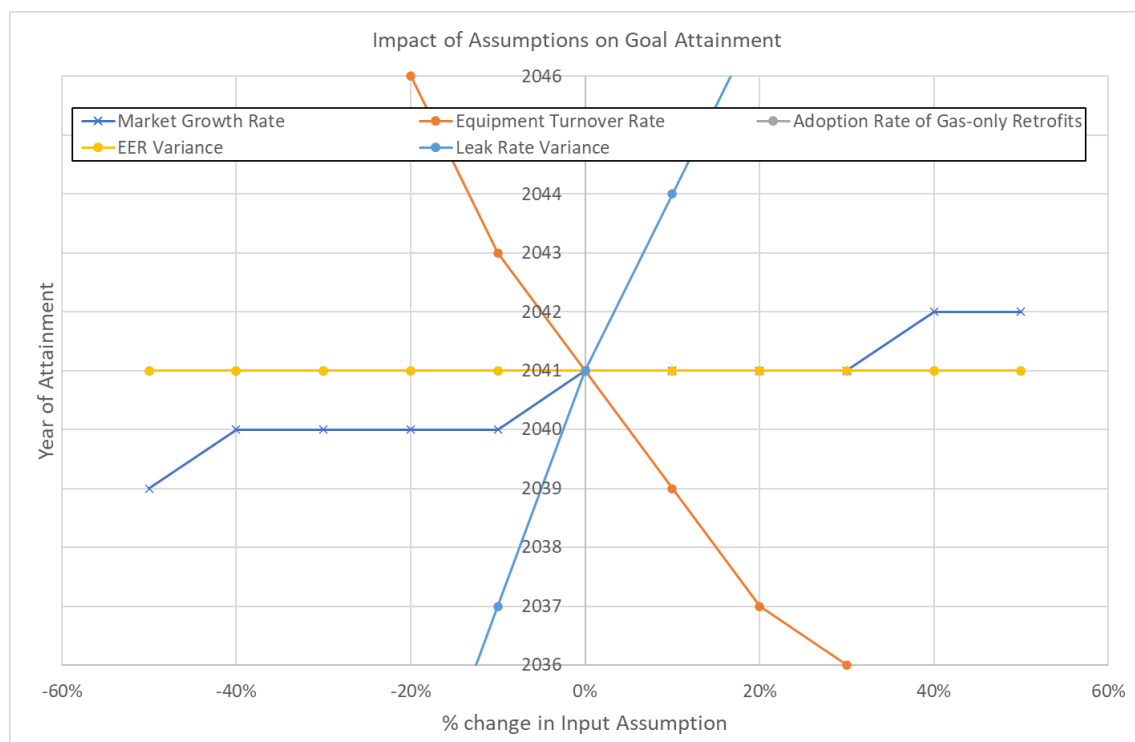


Figure 7. Impact of assumptions on year of CO₂ goal attainment.

As shown above only equipment turnover rate and leak rate assumptions have a significant impact on the year of goal attainment. These two factors are clear drivers of GHG reductions.

Conclusions

Given the above conclusions and experience conducting this study, the following observations are made, and recommendations are suggested to ensure that California’s important efficiency and GHG reduction goals are met.

- Accelerating the transition of existing equipment to low GWP options and systematically reducing the leak rates of existing equipment are critical to the attainment of the state GHG reduction goals. While existing leak rates are tracked through CARB’s Refrigerant Management Program, low GWP refrigerants, market turnover and growth are not. It will therefore be critical to carefully monitor actual turnover rates for retrofitting existing equipment to ensure the state is on track. Recent trends towards more distributed

shopping options may complicate monitoring trends if facilities utilize low refrigerant charges that do not require reporting through the RMP.

- Market turnover rate is a key to success. Since low GWP remodels are not generally cost effective vs. a “do nothing” or “gas only” retrofit scenario, financial incentives for these retrofits may be needed to spur technology acceptance and help transform the market beyond early adopters and pilot projects.
- Industry participants and stakeholders noted in interviews that there is a lack of experience with low GWP refrigerants among technicians responsible for installing and maintaining these systems. New technology options such as CO₂ transcritical, ammonia, and hydrocarbon-based systems all have unique characteristics making them unlike traditional refrigerant options, such as high operating pressures, toxicity, flammability, material compatibility, new lubricant requirements, and others. Workforce education and training will be a necessary component of any market transformation approach, so that the necessary infrastructure is in place to support these changes.
- California regulators have collaborated to provide a means for evaluating the avoided costs associated with the GHG reductions of refrigerant retrofits in a manner consistent with how avoided costs are attributed to energy efficiency improvements. However, there is not yet a mechanism for recognizing GHG reductions from energy efficiency programs beyond their potential impact to cost effectiveness treatment of energy efficiency projects. To fully integrate refrigerant retrofits with energy efficiency in program implementation, there needs to be a mechanism for equivalency in program deployment for the two strategies so that goal attainment, cost effectiveness and reward mechanisms are aligned.
- Further development of comprehensive modeling tools is needed, that include the full spectrum of available technologies and refrigerants. Market stakeholders desire tools that are easy-to-use, can account for interactive effects between HVAC (including humidity) and refrigeration, model whole-building performance, closely model cost impacts and rate treatment and can accurately compare the energy performance between disparate system options. We would recommend Pack Calculation Pro as the most capable of the modeling tools we used although under this project we did not verify the results with real-world results for verification not is it applicable for whole building consumption.

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