Appendix G

Technical Support Document

Staff Analysis on Emissions and Economic Impact of Proposed Regulation for Small Containers of Automotive Refrigerant

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Staff Analysis on Emissions and Economic Impact of Proposed Regulation for Small Containers of Automotive Refrigerant

1. INTRODUCTION

As required by AB 32, the California Air Resources Board (the ARB, the Board) has developed a list of early action measures (ARB, 2007a). Six of these early action measures are related to Motor Vehicle Air Conditioning (MVAC). According to the U.S. EPA Vintaging Model, MVAC systems are the dominant user of HFC-134a (Thundiyil, 2005). One of the early action measures, reduction of HFC-134a emissions from do-it-yourself (DIY) servicing of MVAC systems, has been identified as a Discrete Early Action. DIY servicing involves recharging the AC system using small containers (small cans) of refrigerant typically containing about 12 ounces of refrigerant in weight, but ranging from 2 ounces to 2 pounds in weight. The initial proposal contemplated a ban on the sale and use of small cans. A small can industry association, Automotive Refrigeration Products Association (ARPI), proposed an alternative plan that they claim would achieve similar emission reductions at lower cost. Their proposal included self-sealing valve installed on the can, charging a refundable deposit upon sales of the cans, and setting up a can return and recycling program. Concerns about a ban were also expressed by the AB 32 Environmental Justice Advisory Committee (EJAC). The EJAC recommended removing the proposed can ban measure from the Early Action list because the committee believed that the measure seemed unlikely to achieve the goal of detection and repair of leaking auto air conditioning systems, and because it would place a large burden on low-income people (EJAC, 2007).

ARB staff explored the impact of adding firm recycling rate targets and a DIY education program to the industry proposal, and is proposing this approach as the Discrete Early Action. This document compares emission reductions and costs associated with the staff proposal and the alternative proposal of can ban. The reductions in emissions are calculated in terms of changes from business-as-usual (BAU). The following discussions will first provide an overview of the method to calculate emissions and costs, key data, key assumptions, and results. It will be followed by the details of the assumptions and calculation.

2. METHODS

2.1 Business-as-usual (BAU)

2.1.1 Practices

DIY practice involves puncturing a one-way can of refrigerant with a low cost apparatus consisting of a valve and hose, connecting the apparatus to the low pressure (suction) side of the AC system, and transferring refrigerant from one or more small cans to the AC system over the course of many minutes. There are two immediate sources of emissions resulting from this process. First, some refrigerant escapes from the can and apparatus during the servicing process, which is called servicing losses. Second, some of the refrigerant typically remains in the small can after the refilling process has been completed. This remainder is called the can heel. Because most cans do not include a means to close themselves, the entire can heel is emitted to the atmosphere shortly after the can is disconnected from the recharge apparatus.

In addition to the immediate emissions there are also delayed emissions that can be associated with DIY practice. The AC system that receives charge from the DIY small can has leaked, hence the need for recharge. Not all DIY service operations are necessarily on systems that leak more than properly functioning systems, but some DIY operators recharge their systems every few months. The information needed to determine the distribution of leak rates from DIY vehicles is not readily available. But because in most instances the DIY operator is not repairing the AC system, but simply re-filling the leaking system, the leak rate is very likely to be higher than properly repaired systems. The U.S. EPA Vintaging Model assumes that a properly functioning system should only need to be recharged after about 6 years (Thundiyil, 2008a). The difference in leak rates between DIY serviced and professionally serviced systems is an emission that can be attributed to DIY practice. Professional service technicians are required to fully diagnose the AC system before repairing or recharging it. A large fraction of customers choose to make repairs, even though some choose to simply recharge or top off, and some choose to reject repairs and forgo air conditioning (see 4.5.3).

2.1.2 Emissions

ARB's Survey of Consumer Products for 2006 estimates that California sales of HFC-134a in small containers are 654 metric tons in about 2 million cans (ARB, 2007b). Using a global warming potential (GWP) of 1300 for HFC-134a (IPCC, 2007), the annual sales correspond to 0.85 million metric ton CO_2 equivalent ($MMTCO_2E$) per year. Based on information from a MVAC trade association (Atkinson, 2008a; MACS, 2008), it is estimated that only 5% of small cans sales, or 0.04 $MMTCO_2E$ per year of HFC-134a, are made to automotive repair shops, suggesting that 95%, or 0.81 $MMTCO_2E$ per year of HFC-134a are used by DIY.

This analysis only considers small can operations performed by individual consumers as DIY emissions. We do not include emissions associated with small can use by professionals, nor do we include reductions of these emissions by the proposed mitigation measures.

The fraction of DIY can use apportioned to servicing losses, can heels, and system charge is estimated to be 11%, 22%, and 67%, respectively. These figures are based on research commissioned by ARB (Clodic et al., 2008). The immediate emissions are thus approximately 0.23 $MMTCO_2E$ per year and the delayed emissions are approximately 0.48 $MMTCO_2E$ per year. The following figure illustrates the emissions associated with DIY practice.

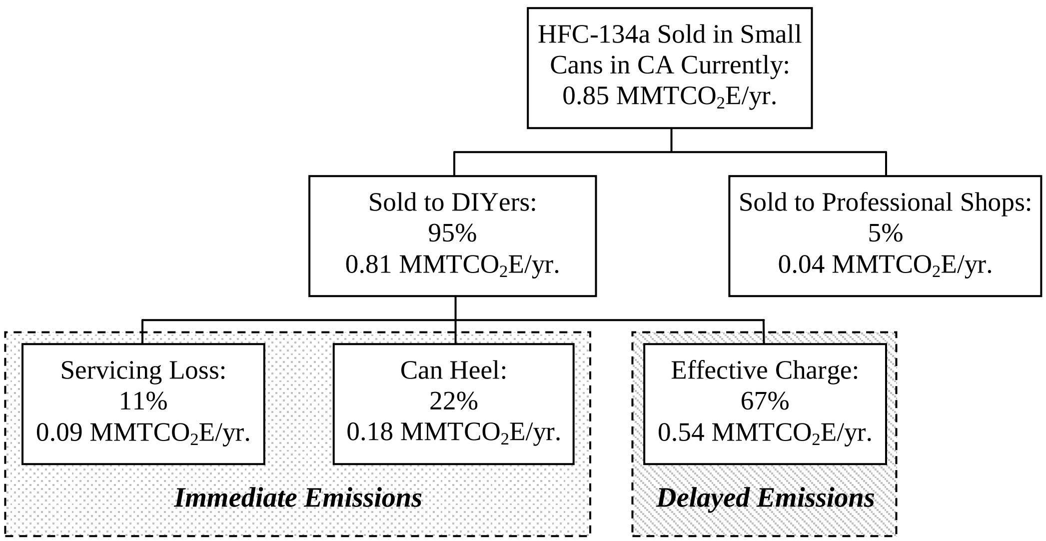

Figure 1. HFC-134a Emissions Associated with DIY Small Can Usage in 2006

In order to project BAU into the future, several major factors are analyzed. First, the increase of passenger vehicle population and better refrigerant containment would likely keep the number of leaky vehicles unchanged. Second, the decrease in AC nominal charge size and better refrigerant containment may keep the recharge frequency unchanged. Furthermore, the amount of refrigerant consumed per recharge will not change due to the characteristics of DIY recharging. Therefore, the annual emissions from DIY recharging of MVAC are projected to remain roughly constant (at 0.81 $MMTCO_2E$ per year) through 2020 under BAU. A detailed analysis is presented in 4.3.1.

2.1.3 Costs

The annual consumer costs associated with BAU are estimated based on the average retail cost per can. Based on the NPD Automotive Aftermarket Industry Monitor Data from the total U.S. auto parts chain retailers sales records (NPD, 2008), the cost average out to about $13 per can, including the cost of the transfer apparatus.

To estimate lifetime costs and costs per consumer, it is necessary to estimate vehicle life and the rate at which the vehicle needs service. Based on a study carried out by ARB staff in support of the AB 1493 regulation development (Vincent et al., 2004), the average vehicle lifetime in California is 16 years. Based on the I-MAC study (I-MAC Team, 2007), the average time for which a new vehicle will not need AC service is about 7 years. This is also consistent with ARB's study (Vincent et al., 2004). The estimated portion of time for which an average vehicle needs servicing is then 9 years. For vehicles receiving DIY servicing, it is assumed that the leaks are not repaired, and it is estimated that the vehicle is recharged about once per year, primarily during summer, based on various data sources. This generates 9 DIY servicing over the 9 years of service need.

To estimate costs per consumer, it is necessary to estimate the number of vehicles needing service. The ARB study data indicates that the average number of cans used per service is 1.3 (Clodic et al., 2008). Given that 1.8 million cans per year are used by DIY operators, about 1.4 million DIY service operations occur each year. Given a DIY service rate of once per year per vehicle, the total number of vehicles that have ever been DIY serviced in the whole in-use fleet is 1.4 million. They are referred to as "DIY vehicles" hereafter in this document. It should be noted that these vehicles have a spectrum of leakage rate. Some of them function normally and only need recharge every several years. Some of them have leaking problem and need frequent recharge, likely more than once per year. So the number of vehicles that actually get recharged in any year should be significantly less than 1.4 million. At 1.3 cans per service and about $13 per can, the average costs of one DIY service are about $17. The costs per vehicle per year are then about $17. The annual costs to consumers for 1.8 million cans at about $13 each are about $24 million per year. The costs of 9 DIY service operations over the life of the vehicle are about $152.

2.2 Staff Proposal

2.2.1 Practices

ARB staff is now proposing a comprehensive approach as the Discrete Early Action measure to reduce emissions associated with DIY servicing of MVAC using small cans. The emission reductions would be achieved through the use of a self-sealing valve on the can, improved labeling instructions, a recycling program for used cans, and an education program that emphasizes best practice techniques for vehicle recharging as well as highlights the environmental risks associated with this product. A mandatory return rate target will be set at 90% for the first two years of the regulation, and 95% for the following years. As an incentive to promote return of the cans, a deposit of $10 (approximately equivalent to the price of a 12-ounce can) will be collected at time of the sales and will be refunded when the consumer returns the cans. If the return rate target is not met by the end of the first two years, the deposit will be increased by $5. This process would continue until the target recycle rate is achieved.

Improved usage instructions on the small cans and DIY education program will better inform consumers of the potential risk to their AC and damage to the climate system from DIY recharging, thus discourage some of them continuing DIY recharging. However, this cannot be quantified at this point. In this analysis, it is assumed that no consumer would change DIY behavior due to this regulation.

2.2.2 Emissions

We expect that the consumer education program would increase the number of DIY users motivated to find and repair leaks. However, no data are available to quantify this change in consumer behavior. For purpose of analysis the delayed emissions of 0.54 $MMTCO_2E$ per year are assumed to remain the same and will be addressed through other regulatory approaches, such as improving professional servicing and identifying and repairing leaky MVAC systems via the smog check program.

The emissions due to can heels were 0.18 $MMTCO_2E$ per year under BAU. With the self-sealing valve, the heel will be contained in the can. If the target return rate of 90% is met for the first two years, these emissions will be reduced to 0.02 $MMTCO_2E$ per year. If the 95% return rate target is met for the years to follow, the can heel emissions will be reduced to 0.01 $MMTCO_2E$ per year.

It is anticipated that with self-sealing valve, improved can instructions, and DIY education program, the servicing losses would be reduced to minimal. Thus, the 0.09 $MMTCO_2E$ of annual emissions due to servicing are eliminated.

Therefore, the annual emissions under this proposal would be 0.56 $MMTCO_2E$ for the first two years, achieving annual emission reductions of 0.25 $MMTCO_2E$. For the following years, the emissions would be 0.55 $MMTCO_2E$ per year and emission reductions are thus 0.26 $MMTCO_2E$ per year (Figure 2). Figure 3 illustrates the detailed breakdown of the emissions impacts of the proposed regulation when the final return rate target of 95% is reached.

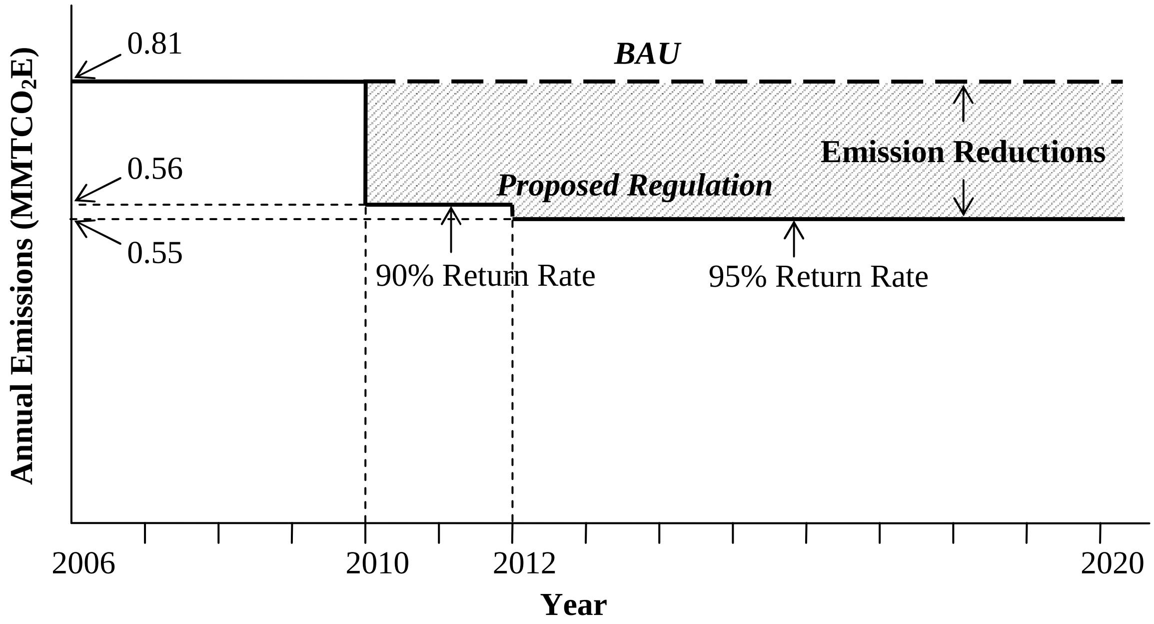

Figure 2. Emissions Impact of Proposed Regulation

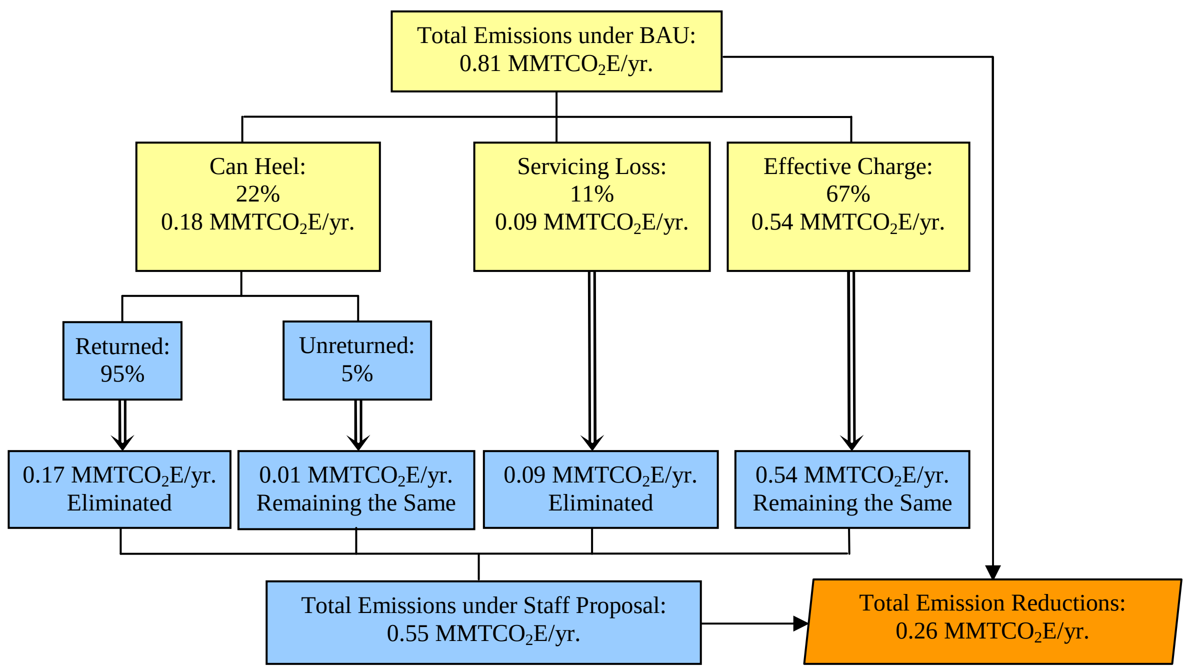

Figure 3. Detailed Emissions Impact under Proposed Regulation (95% Return Rate)

2.2.3 Costs

The extra cost of $1 per can due to the self-sealing valve and recycling program would be passed on to the consumer in the increased price of the can. At 1.8 million cans per year the increased consumer costs are $1.8 million. The extra costs include about $0.25 per can for the valve, and about $0.75 per can to cover the costs of return shipping for the cans, extracting and recycling the can contents, and reporting to ARB.

Given a 95% can return rate and a $10 deposit per can, the 5% of unclaimed deposits come to $0.9 million per year and will be additional costs to the consumers.

Total increased costs to the consumer are thus $2.7 million per year.

2.2.4 Cost-Effectiveness

Under this proposal, about 0.26 $MMTCO_2E$ of emissions would be reduced per year at an increased cost of $2.7 million per year. The cost-effectiveness is then about $11/$MTCO_2E$.

2.3 Can Ban (Original Proposal in AB 32 Early Action Report 2007)

2.3.1 Practices

The can ban remains as an alternative proposal. Ideally, there would no longer be any DIY servicing if a can ban is in place. All servicing would be done by professional shops. Some consumers would forgo air conditioning and some would take their vehicle to the professional shops. In practice, some DIY will evade the regulations and acquire HFC-134a for DIY operations. Professional shops in California are required by the California Bureau of Automotive Repair (BAR) to conduct complete diagnostics prior to recharging an auto AC system. Based on trade association survey data a large fraction of vehicles brought to a professional shop are repaired before being released in a recharged state. The repairs conducted by professional shops are expected to last 6 years (Thundiyil, 2008a), thus reducing the emission rate for former DIY vehicles to one sixth of its pre-repair value. During professional repair and recharge, a certain amount of refrigerant will be emitted due to servicing losses and cylinder heel emissions. There will also be some professionally serviced vehicles that may need repairs but receive a recharge only or a top off. There will also be professional serviced vehicles for which repairs are not effective. For purpose of analysis these vehicles are considered part of the group of vehicles that receive a professional recharge service or top off without repair.

2.3.2 Emissions

Under the ban, the treatment of the delayed emissions of 0.54 $MMTCO_2E$ per year from leaking vehicles is divided into categories based on consumer choices. The emission reductions are different for each category. Based on an ARPI commissioned survey (Frost and Sullivan, 2006), A MACS survey (Atkinson, 2008b), and an IMR survey (ARPI, 2008a), it is estimated that 32% of the original DIY consumers would pay for professional repair and recharge, 23% of them would have professional technicians recharge their AC without repair, 7% would choose topping off at professional servicing, 19% would continue DIY recharging using small cans obtained from alternative ways, and the remaining 19% would forgo AC.

The 32% of vehicles that receive professional repair are assumed to have their original recharge frequency of once per year reduced to once charge per 6 years. On the other hand, it is estimated that every professional recharge uses 1.6 times as much as the fresh refrigerant used in DIY recharge. Therefore, the delayed emissions of 0.17 $MMTCO_2E$ per year become 0.27 $MMTCO_2E$ per 6 years, or 0.045 $MMTCO_2E$ per year. A U.S. EPA testing study on the heel from disposable containers (U.S. EPA, 2007) suggests the average cylinder heels are about 2%. So the heel emissions are about 0.001 $MMTCO_2E$ per year. It is assumed there is no fresh refrigerant lost in the form of servicing losses during professional recharging.

The 23% of vehicles that receive professional recharge without repair would then leak at their pre-servicing rate. Nonetheless, the professional technicians have the equipment and skills to charge AC to their nominal charge. The next recharge will not take place until the AC loses 50% of the nominal charge again. In contrast, DIY on average undercharge their AC. It is estimated that a professionally recharged AC has 1.4 times as much refrigerant to lose as that of a DIY recharged AC. Therefore, a professionally recharged AC has longer interval between two recharges, 1.4 times as long as that of a DIY recharged AC. On the other hand, the average professional recharge uses 1.6 times as much as the refrigerant used by DIY. Therefore, the delayed emissions of 0.12 $MMTCO_2E$ per year are changed to 0.2 $MMTCO_2E$ per 1.4 years, or 0.14 $MMTCO_2E$ per year. The heel emissions work out to be about 0.003 $MMTCO_2E$ per year. No fresh refrigerant will be lost as servicing losses.

The 7% of vehicles that are topped off at professional servicing will emit at their original rate. Therefore, the delayed emissions of 0.04 $MMTCO_2E$ per year emitted by these vehicles remain the same. In addition, topping off would incur 0.013 $MMTCO_2E$ per year in heel emissions and 0.006 $MMTCO_2E$ per year in servicing losses.

The 19% that remain DIY recharging using small cans obtained from alternative ways will also emit at their original rate. Therefore, the delayed emissions of 0.1

MMTCO$_2$E per year emitted by these vehicles remain the same. Another 0.033 MMTCO$_2$E per year in heel emissions and 0.016 MMTCO$_2$E per year in servicing losses would occur.

The rest 19% of vehicles would forgo AC, thus no longer emit refrigerant. Therefore 0.1 MMTCO$_2$E of delayed emissions per year are reduced to zero. Apparently, there are no immediate emissions associated with this group of vehicles. Forgoing MVAC has potential consequences for indirect emissions because consumers without AC would likely drive with windows rolled down for a large share of vehicle-miles-traveled (VMT). The increased load due to increased drag force must be balanced against the reduced load due to non-operation of the AC compressor. At high speed, indirect emissions might be increased. At low speed, indirect emissions will be reduced. On average, the change in indirect emissions due to non-operation of the MVAC is expected to be a net reduction (i.e., forgoing AC would probably reduce indirect emissions). Changes in indirect emissions have not been included in this analysis.

The total annual emissions under can ban are thus 0.4 MMTCO$_2$E. The annual emission reductions are 0.41 MMTCO$_2$E. Figure 4 shows the emissions impact of the can ban approach.

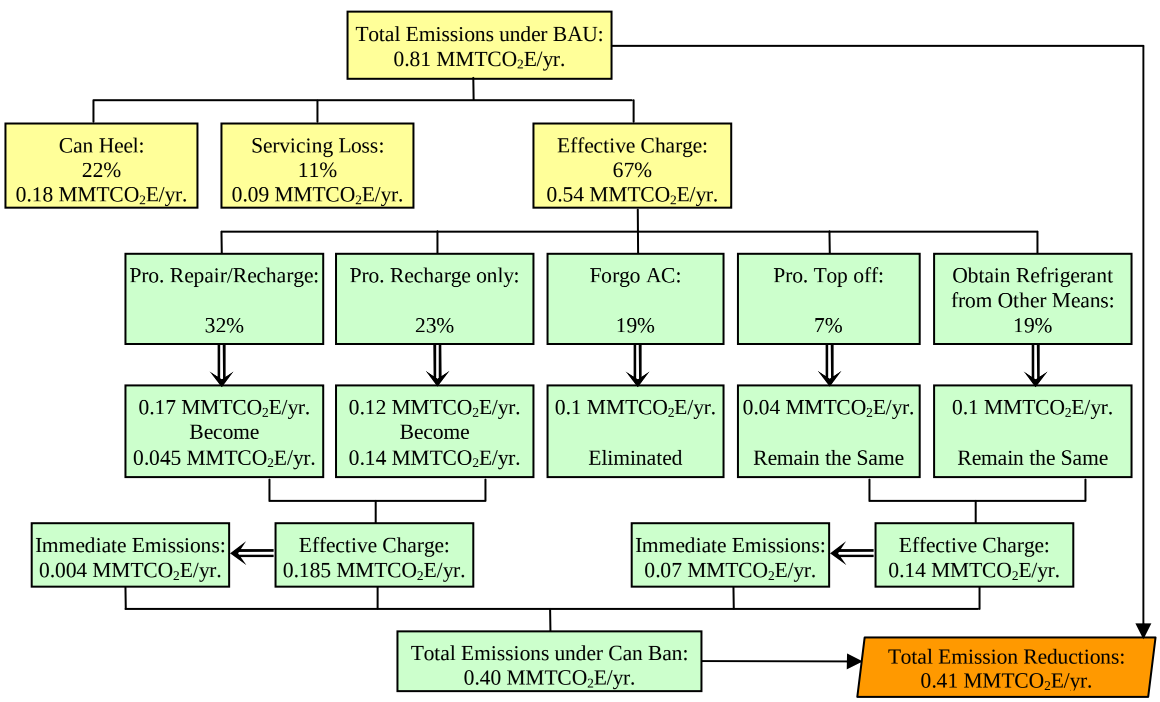

Figure 4. Detailed Emissions Impact under Can Ban

2.3.3 Costs

Under the can ban, consumer costs would be affected mainly by the difference between the cost of professional repairs and the cost of DIY recharges. DIY recharges were estimated to occur at a rate of once per year, at cost of about $17 per year. Professional diagnosis/repairs/recharges are estimated to cost about $650. This is based on the 2003 MACS Survey which shows that a professional repair costs $508 on average in 2003 (MACS, 2008), which is about $580 in 2007 dollars. We then add a $70 recharge charge on top of that. Professional repair/recharge is assumed to occur every 6 years on average for a cost of $108 per year for the 32% of consumers choosing professional repair. Professional recharge without repair is estimated to cost about $100 (Clodic et al., 2008) and is assumed to occur every 1.4 years for a cost of $71 per year for the 23% of consumers choosing professional recharge. Professional topping off is estimated to cost about the same as professional recharge, $100 (Clodic et al., 2008), and to occur once a year on average for a cost of $100 per year for the 7% of consumers choosing to have their system topped off. About 19% of consumers would still DIY recharge their vehicles once a year using refrigerant that they obtain from alternative ways, at a cost assumed to be 50% higher than under BAU, or about $25 per year. For the approximately 1.4 million vehicles involved, the total consumer costs increase from $24 million to $88 million, an increase of $65 million annually. For individual owners, the vehicle lifetime costs increase from $152 for 9 DIY recharges to $975 for 1.5 professional repair and recharge services, to $643 for 6.4 professional recharges, to $900 for 9 top offs at professional servicing, or to $228 for 9 DIY recharges using HFC-134a obtained by alternative means. In addition, about 19% of consumers do not pay the increased cost, and therefore have no air conditioning in their vehicles.

There would be no costs or charges imposed on the small can industry to comply with the ban, but there would be complete loss of revenue from the small can business in California. Annual can sales to DIY owners are about 1.8 million at an average retail price of about $13 including cost of transfer apparatus. The 0.1 million cans sold to professional AC shops are also assumed to be at $13 per can for purpose of analysis. Therefore, industry would lose annual revenues of about $25 million due to the can ban.

Under the can ban, the professional MVAC repair industry would see a revenue increase equal to the amount paid by former DIY operators to obtain professional repairs. This amount is estimated to be $82 million per year.

2.3.4 Cost-Effectiveness

The emissions reduction under the can ban is 0.41 $MMTCO_2E$ per year. The increase in consumer costs is $65 million per year. The cost per metric ton of reduction borne by the consumer is then about $159/$MTCO_2E$.

3. SUMMARY OF RESULTS

DIY recharging of MVAC systems with HFC-134a generates emissions of about 0.81 MMTCO_2E per year.

ARB staff proposes a comprehensive measure that could achieve emission reductions of 0.26 MMTCO_2E per year even if no DIY consumers change their behavior. The cost-effectiveness works out to be $11/MT$CO_2$E and industry would likely see no revenue losses.

The alternative can ban approach would eliminate approximately 0.41 MMTCO_2E per year of HFC-134a emissions from DIY recharging of MVAC using small cans at a cost of about $159/MT$CO_2$E to the consumer plus $25 million per year in lost revenues to industry.

Table 1: Emissions and Economic Impact of Regulatory Proposals

Scenario	Emissions MMTCO_2E/yr.	Emission Reductions MMTCO_2E/yr.	Cost-Effectiveness Dollars/MTCO_2E	Lost Revenue Million Dollars/yr.
BAU	0.81	NA	NA	NA
Staff Proposal*	0.55	0.26	11	0
Can Ban	0.4	0.41	159	25

* Calculation based on a can return rate target of 95%.

4. DETAILS OF ASSUMPTIONS AND CALCULATION

4.1 Independent Parameters

Table 2: Independent Parameters

Notation	Definition	Estimate	References
S_{tot}	Number of small cans sold annually in CA	2 million	ARB, 2007b
E_{tot}	Amount of HFC-134a sold in small cans annually in CA	0.85 $MMTCO_2E$	Same as the above
Y	Vehicle's average lifetime	16 years	Vincent et al., 2004
Y_0	Average time after which a leaky vehicle's AC needs its first recharge	7 years	I-MAC Team, 2007
Y_1	Average time that a leaky MVAC recharged without repair lasts before it needs another recharge	1 year	ARB staff estimate (see 4.5.1)
Y_2	Average time that a leaky MVAC repaired and recharged by a professional shop lasts before it needs another repair and recharge	6 years	Thundiyil, 2008a
N_C	Average number of small cans needed for a DIY recharging event	1.3 cans	Clodic et al., 2008
P_0	Percentage of HFC-134a in small cans sold to DIY in CA	95%	ARB staff estimate (see 4.5.2)
P_{11}	Average percentage of can heels during DIY recharging	22%	Clodic et al., 2008
P_{12}	Average percentage of servicing leaks during DIY recharging	11%	Same as the above
P_2	Percentage of DIY that return the used cans (under hybrid approach)	90%, 95%	Targeted return rates in the mandatory small can return / recycling program
P_{31}	Percentage of original DIY (under BAU) that would pay for professional diagnosis, repair and recharge in case of a can ban	32%	ARB staff estimate (see 4.5.3)
P_{32}	Percentage of original DIY (under BAU) that would choose to evacuate and recharge at professional shops in case of a can ban	23%	Same as the above
P_{33}	Percentage of original DIY (under BAU) that would choose to top off with small cans at professional shops in case of a can ban	7%	Same as the above
P_{34}	Percentage of original DIY (under BAU) that would choose to continue DIY recharging AC using small cans obtained through alternative ways in case of a can ban	19%	Same as the above
P_{35}	Average percentage of fresh refrigerant lost due to can heels during professional recharge (in relation with total fresh refrigerant usage)	2%	U.S. EPA, 2007
P_{36}	Average percentage of fresh refrigerant lost due to servicing losses during professional recharge (in relation with total fresh refrigerant usage)	0%	Most conservative scenario based on Clodic et al., 2008

P_{37}	Percentage of increase in DIY cost for people seeking alternative ways to obtain small cans in case of a can ban	50%	ARB staff estimate
R_1	Average retail price for a small can	$13	NPD, 2008
R_{21}	Price increment for a small can under staff proposal	$1	ARPI, 2008b
R_{22}	Deposit for a small can under staff proposal	$10	Specified value to ensure high incentive for return of cans
R_{31}	Average price for a professional diagnosis, repair and recharge of a leaky MVAC	$650	ARB staff estimate based on 2003 MACS Survey (MACS, 2008)
R_{32}	Average price for a professional recharge of a leaky MVAC	$100	Clodic et al., 2008
F_1	Ratio of effective charge to be leaked out before next servicing from professionally recharged MVAC to that from DIY recharged MVAC	1.4	ARB staff estimate (see 4.5.4)
F_2	Ratio of effective charge during professional recharging to that during DIY recharging	1.6	Same as the above

4.2 Key Assumptions

1. The refrigerant charged into a MVAC during the last recharge in its useful lifetime is emitted in the same way and amount as the previous recharges. I.e. the effect of end-of-life emissions is not taken into account.

2. The owner of a DIY vehicle maintains his / her repair / recharge preferences unless there are regulatory changes. This may not always be the case in reality. For example, a consumer could DIY recharge the MVAC this year but have professional repair it the next year. Another example is when vehicle ownership changes, the new owner may make different decisions on the maintenance of the vehicle. But that would make the situation too complicated for the analysis to be feasible.

3. Each DIY consumer (household) owns one and only one DIY vehicle.

4. MVAC is used throughout a vehicle's lifetime.

5. A MVAC has to lose 50% of its refrigerant before a recharge takes place. This is based on findings from an ARB sponsored study (Clodic et al., 2008) and is consistent with an assumption made in the U.S. EPA Vintaging Model.

6. Under the staff proposal, no DIY consumer would change his behavior (switching to professional servicing, etc.). This is because the increased financial burden is mild as long as a consumer returns the used cans for a refund of the deposit. The potential risk of DIY recharging MVAC conveyed by the education

materials might discourage some consumers to continue DIY recharging. However, this effect cannot be quantified at this point.

7. Under the staff proposal, the effective charge is the same as under BAU. Having self-sealing valve and improved usage instructions would likely change the percentage. But no data are available to quantify this effect.

8. Under the staff proposal, servicing leaks can be reduced down to minimal due to better usage instructions to the DIY and having self-sealing valves on the can.

9. Under the staff proposal, the heel in the returned cans would be completely recovered, thus causing no emissions.

10. Under the staff proposal, unreturned cans would end up being disposed of and the heel would be emitted to the atmosphere eventually.

11. Under the staff proposal, the can heel percentage is the same as under BAU. Having self-sealing valve and improved usage instructions would likely change the percentage. But no data are available to quantify this effect.

12. The DIY education components of the staff proposal incur no additional costs to the consumers. In reality, having the education components might add some costs to the industry, which would probably pass the costs on to consumers. However, this cannot be quantified.

13. On average, DIY recharging under the staff proposal uses the same number of cans per recharge as under BAU. Having self-sealing valve and improved usage instructions would likely reduce the number of cans used per recharge. However, no data are available to quantify this effect.

14. In case of can ban, the behavior changes (switching to professional servicing, etc.) of the original DIY consumers are independent of the working conditions of the MVAC. The implication is that every new group of vehicles formed by the behavior changes of their owners will have the same average leak rate.

15. Topping off of a MVAC by a professional technician resembles DIY recharging at all aspects. It is reasonable to speculate that professional topping off using small cans or cylinder and manifold produces less immediate emissions and more effectively charges refrigerant into AC than DIY operation. However, no data are available to justify it.

16. In case of can ban, the revenue lost by the small can industry cannot be offset by the potential internet or out-of-state sales. Although part of the sales may generate revenue to the industry, the sales may depend on a lot of factors which are difficult to quantify.

4.3 Analysis

4.3.1 BAU

According to the ARB Consumer Products Survey for 2006 (ARB, 2007b), the small cans of HFC-134a sold in California in 2006 amounted to

$S_{\mathrm{tot}} = 2 \text{ million cans}$, and $E_{\mathrm{tot}} = 0.85 \text{ MMTCO}_2\text{E}$.

It is estimated (see 4.5.2) that P_0 = 95% of the cans are sold to DIY and the rest to professional servicing for topping off purposes. Thus, cans used by DIY constitute

$$\begin{aligned} E_{\mathrm{BAU}} &= P_0 \cdot E_{\mathrm{tot}} \\ &= 95\% \times 0.85 = 0.808\ (\text{MMTCO}_2\text{E}) \end{aligned}. \tag{4.3.1}$$

Per Assumption 1, this equals the annual emissions caused by DIY recharging. For purpose of analysis, we convert the emissions to the nominal number of cans by assuming 12 oz / can:

$$\begin{aligned} S_{\mathrm{BAU}} &= \frac{E_{\mathrm{BAU}}}{12\text{oz} \times 0.02835 \frac{\text{kg}}{\text{oz}} \times 10^{-9} \frac{\text{MMT}}{\text{kg}} \times 1300 \frac{\text{MMTCO}_2\text{E}}{\text{MMT}}} = 2.261 \times 10^6 \cdot E_{\mathrm{BAU}} \\ &= 2.261 \times 10^6 \times 0.808 = 1.826\ (\text{million cans}) \end{aligned}. \tag{4.3.2}$$

This number is used hereafter wherever the number of cans sold to DIY is needed.

The number of unique DIY vehicles is

$$\begin{aligned} N_{\mathrm{V}} &= \frac{Y_1 \cdot S_{\mathrm{BAU}}}{N_{\mathrm{C}}} \\ &= \frac{1 \times 1.826}{1.3} = 1.404\ (\text{million vehicles}) \end{aligned}, \tag{4.3.3}$$

where Y_1 is the interval between two consecutive recharges, and N_C is the number of cans used in each recharge. Note that a vehicle that gets multiple recharges during its lifetime is counted as one unique DIY vehicle. According to Assumption 2, these vehicles will be DIY recharged during their lifetime unless a regulation such as can ban takes effect. Based on Assumption 3, this is also the number of unique DIY consumers (households). It is worth noted that quite often a vehicle changes ownership. So the group of DIY vehicle owners changes over time.

It is assumed a MVAC does not need recharging until after Y_0 = 7 years in its lifetime. So the adjusted lifetime (referred to hereafter as 'lifetime') during which recharging happens is

$$\begin{aligned} Y_{\text{adj}} &= Y - Y_0 \\ &= 16 - 7 = 9 \text{ (years)} \end{aligned}, \tag{4.3.4}$$

where Y = 16 years is vehicle's lifetime and also the lifetime of MVAC (Assumption 4) in California.

The number of recharges in a DIY vehicle's lifetime is

$$\begin{aligned} N_{\text{R,BAU}} &= \frac{Y_{\text{adj}}}{Y_1} \\ &= \frac{9}{1} = 9 \text{ (times)} \end{aligned}. \tag{4.3.5}$$

The emissions under BAU can also be expressed by a bottom-up approach. Under BAU, a DIY recharges the AC when its refrigerant level drops to 50% of the nominal charge (Assumption 5). Define M_{DIY} (in $MMTCO_2E$) as the amount of refrigerant effectively charged into AC. This equals the amount of refrigerant that the AC needs to lose before another recharge becomes necessary. Then over Y_1 years the AC leaks until its charge drops to 50% again. Thus each year the AC leaks by the amount of M_{DIY}/Y_1. However, these gradual leaks (delayed emissions) are not the only source of emissions caused by DIY. Losses during servicing and due to can heels also need to be taken into account. Thus the total annual emissions are

$$E_{\text{BAU}} = \frac{N_{\text{V}} \cdot \frac{M_{\text{DIY}}}{Y_1}}{1 - P_{11} - P_{12}}, \tag{4.3.6}$$

where P_{11} and P_{12} are the fractions of refrigerant lost due to can heel and during servicing, respectively, during DIY recharging.

The annual costs for a DIY vehicle are

$$\begin{aligned} C_{\text{BAU}} &= \frac{N_{\text{C}} \cdot R_1}{Y_1} \\ &= \frac{1.3 \times 13}{1} = 16.90 \text{ (dollars)} \end{aligned}, \tag{4.3.7}$$

where R_1 is the retail price of a can of HFC-134a.

Therefore the annual costs for all DIY vehicles are

$$\begin{aligned} C_{\text{all,BAU}} &= N_{\text{V}} \cdot C_{\text{BAU}} = S_{\text{BAU}} \cdot R_1 \\ &= 1.826 \times 13 = 23.73 \text{ (million dollars)} \end{aligned} \tag{4.3.8}$$

The lifetime costs for a DIY vehicle are

$$\begin{aligned} C_{\text{L,BAU}} &= Y_{\text{adj}} \cdot C_{\text{BAU}} \\ &= 9 \times 16.90 = 152.10 \text{ (dollars)} \end{aligned} \tag{4.3.9}$$

In order to project BAU into the future, several major factors need to be taken into account. First, the increase of passenger vehicle population and better refrigerant containment in newer MVAC will keep the number of leaky vehicles unchanged. The EMFAC Model 2007 estimates that the population of passenger vehicles in California will increase by around 400,000 each year through 2020. But newer MVAC systems have improved designs and improved production controls so that they are tighter and have reduced probability of becoming leaky. The latter cannot be quantified at this point. So a conservative assumption is made that the increased population and decreased probability produces a steady multiplication, i.e. the number of leaky MVAC.

Second, the decrease in MVAC nominal charge size and improvement of refrigerant containment will keep the recharge frequency unchanged. The average nominal charge size for a new single evaporator MVAC decreases from 26.9 oz in 2000 to 22.3 oz in 2006 (Atkinson, 2008b). The trend will likely continue, but with reduced pace over years. On the other hand, the improved refrigerant containment will reduce the leak rate of a leaky AC. In the absence of data to quantify the containment improvement, it is reasonable to assume that these two factors cancel out the effects from each other, making the recharge frequency unchanged. This is consistent with the approach used in the GREEN-MAC-LCCP Model, which does not differentiate recharge frequency for different model year vehicles (Papasavva et al., 2008). As a side note, in the development of AB 1493 regulation, ARB staff estimated that California's MVAC emits 55 grams per year on average (ARB, 2004). The MVAC refrigerant emissions testing studies conducted by the European Automobile Manufacturers Association (ACEA) and Japan Automobile Manufacturers Association (JAMA) suggest that newer vehicles leak around 10 grams per year and very few vehicles emit significantly more than that (Atkinson, 2008c; Clodic, 2006). This substantial difference in leak rate may be attributed mainly to improved refrigerant containment of newer AC models as well as deterioration of containment over time.

Lastly, the amount of refrigerant consumed per recharge will not change due to the characteristics of DIY recharging. A DIY has no means to know the remaining refrigerant level in an MVAC or to determine the proper amount of refrigerant to be charged. A DIY terminates charging based on empirical or arbitrary criteria, such as the outflow air temperature, depletion of a can, and pressure gauge reading falling into a range specified in charging kit instructions. None of these criteria presents solid ground for charging the proper amount of refrigerant (Clodic et al., 2008). DIY on average undercharge the current MVAC systems. With AC nominal charge decreased, DIY may charge close to the correct amount or overcharge. But the number of small cans used per recharge is not dependent on the nominal charge size.

Therefore, the BAU emissions from DIY recharging are projected to remain roughly constant at 0.81 $MMTCO_2E$ per year through 2020. ARPI had projected a 1-2% annual sales growth under BAU, likely based on national sales trend (ARPI, 2006). It may not reflect with precision California's unique usage patterns and the various trends discussed above. The uncertainties carried with the assumptions in the staff analysis to support this document may overshadow a 1-2% annual change. Therefore, no attempt has been made to empirically adjust the BAU trend to match ARPI's projection.

Note that this BAU projection does not account for the potential climate impact from other Early Action measures, such as "Addition of AC leak test and repair requirement to smog check", "Requirement of low-GWP refrigerants for new MVAC", and "Reductions of HFC-134a emissions from professional servicing of MVAC".

4.3.2 Staff Proposal

ARB staff now proposes a comprehensive approach to reducing the emissions from DIY recharging of MVAC. This approach incorporates some of the key elements that were proposed by the small can industry association, ARPI, and also reflects staff's modifications.

Per Assumption 6, all the original DIY consumers would continue DIY recharging their MVAC. They would charge the same amount of refrigerant as under BAU (Assumption 7). Based on Assumption 8, there are no servicing losses due to improved usage instructions and effects of self-sealing valves. Because of the mandatory return requirement for the cans and the deposit / refund mechanism, most of the DIY consumers (P_3) are anticipated to return the used cans, thus causing no emissions from can heels (Assumption 9). Those who do not return the can will incur heel emissions (Assumption 10) at the same percentage as under BAU (Assumption 11). Since the effective charge and leak rate are the same as under BAU, the recharging frequency is still once every Y_1 years. The annual emissions are then

$$E_{\text{prop}} = P_2 \cdot N_{\text{V}} \cdot \frac{M_{\text{DIY}}}{Y_1} + \frac{(1-P_2) \cdot N_{\text{V}} \cdot \dfrac{M_{\text{DIY}}}{Y_1}}{1-P_{11}} . \qquad (4.3.10)$$

Thus,

$$\begin{aligned} E_{\text{prop}} &= (P_2 + \frac{1-P_2}{1-P_{11}}) \cdot (1-P_{11}-P_{12}) \cdot E_{\text{BAU}} \\ &= (95\% + \frac{1-95\%}{1-22\%}) \times (1-22\%-11\%) \times 0.808 = 0.549 \text{ (MMTCO}_2\text{E)} \end{aligned} \quad (4.3.11)$$

The annual emission reductions are

$$\begin{aligned} ER_{\text{prop}} &= E_{\text{BAU}} - E_{\text{prop}} \\ &= 0.808 - 0.549 = 0.259 \text{ (MMTCO}_2\text{E)} \end{aligned} \quad (4.3.12)$$

Having self-sealing valve installed on the cans, managing the can return / recycling, and handling the deposit would cause additional costs, which would most probably be passed on to consumers in the form of price increase of R_{31} per can. Those who do not return the cans would lose the deposit of R_{32} per can. Per Assumption 12, no additional costs to the consumers would occur as a result of the education components.

The number of DIY recharging is the same as under BAU ($N_{\text{R,BAU}}$).

$$\begin{aligned} N_{\text{R,prop}} &= \frac{Y_{\text{adj}}}{Y_1} \\ &= \frac{9}{1} = 9 \text{ (times)} \end{aligned} \quad (4.3.13)$$

The annual costs for a vehicle whose owner returns the used cans are

$$\begin{aligned} C_{1,\text{prop}} &= \frac{N_{\text{C}} \cdot (R_1 + R_{21})}{Y_1} \\ &= \frac{1.3 \times (13+1)}{1} = 18.20 \text{ (dollars)} \end{aligned} \quad (4.3.14)$$

Note that every recharge uses the same number of cans as under BAU (Assumption 13).

The lifetime costs for such a vehicle are

$$\begin{aligned} C_{1,\text{L,prop}} &= Y_{\text{adj}} \cdot C_{1,\text{prop}} \\ &= 9 \times 18.20 = 163.80 \text{ (dollars)} \end{aligned} \quad (4.3.15)$$

The annual costs for a vehicle whose owner does not return the used cans are

$$C_{2,\text{prop}} = \frac{N_{\text{C}} \cdot (R_1 + R_{21} + R_{22})}{Y_1} = \frac{1.3 \times (13+1+10)}{1} = 31.20 \text{ (dollars)}. \tag{4.3.16}$$

The lifetime costs for such a vehicle are

$$C_{2,\text{L,prop}} = Y_{\text{adj}} \cdot C_{2,\text{prop}} = 9 \times 31.20 = 280.80 \text{ (dollars)}. \tag{4.3.17}$$

Then the annual costs for all DIY vehicles are

$$C_{\text{all,prop}} = P_2 \cdot N_{\text{V}} \cdot C_{1,\text{prop}} + (1-P_2) \cdot N_{\text{V}} \cdot C_{2,\text{prop}} = 95\% \times 1.404 \times 18.20 + (1-95\%) \times 1.404 \times 31.20 = 26.47 \text{ (million dollars)}. \tag{4.3.18}$$

The annual extra costs for all DIY vehicles are

$$EC_{\text{all,prop}} = C_{\text{all,prop}} - C_{\text{all,BAU}} = 26.47 - 23.73 = 2.74 \text{ (million dollars)}. \tag{4.3.19}$$

The cost-effectiveness to consumers is

$$CE_{\text{cons,prop}} = \frac{EC_{\text{all,prop}}}{ER_{\text{prop}}} = \frac{2.74}{0.259} = 10.58 \text{ (dollars/MTCO}_2\text{E)}. \tag{4.3.20}$$

The annual revenue losses by small can industry are

$$RL_{\text{prop}} = 0. \tag{4.3.21}$$

4.3.3 Can Ban

If a can ban is in place, a portion of the original DIY consumers would change their behavior based on costs, convenience and other personal preferences, but not the MVAC's working conditions (Assumption 14). A fraction (P_{31}) of the same leaky vehicles would be brought into professional shops for diagnosis, repair and recharge by M_{Pro} (in $MMTCO_2E$) of fresh refrigerant. They originally would lose 50% of their nominal charge over Y_1 years (Assumption 14) if DIY recharged. But now they would leak at reduced rates during Y_2 years until they lose 50% of their nominal charge again. A second part (P_{32}) of the leaky vehicles would be taken to professional shops for recharge without repair. The serviced AC will then leak at the same rate as DIY (Assumption 14), but during a modified (prolonged) period. This is because DIY generally undercharge AC due to lack of equipment and skills to know the proper amount of effective charge. On the contrary, professional technician can charge AC to its nominal level. Defining F_1 as the ratio of charge to be leaked out before next servicing from a professionally recharged AC to that from a DIY recharged AC, a professionally recharged AC needs another recharging after a period of $F_1 \cdot Y_1$. Another fraction (P_{33}) of the leaky vehicles would be taken to professional shops for topping off using small cans or cylinder and manifold. According to Assumption 15, they will be charged by M_{DIY} and the charge will leak out during Y_1 years, essentially the same as DIY. A fourth portion (P_{34}) of the vehicles would still be DIY recharged with refrigerant obtained from alternative ways, resulting in exactly the same emissions as under BAU (Assumption 14). The rest of the leaky vehicles would not get repair and recharge and hence would eventually go without AC, generating no refrigerant emissions. The total annual emissions should include not only the amount of fresh refrigerant effectively charged into the AC, but also the fresh refrigerant lost during servicing (DIY or professional) and due to container (can or cylinder) heels.

$$E_{ban} = \frac{P_{31} \cdot N_V \cdot \frac{M_{Pro}}{Y_2} + P_{32} \cdot N_V \cdot \frac{M_{Pro}}{F_1 \cdot Y_1}}{1 - P_{35} - P_{36}} + \frac{P_{33} \cdot N_V \cdot \frac{M_{DIY}}{Y_1} + P_{34} \cdot N_V \cdot \frac{M_{DIY}}{Y_1}}{1 - P_{11} - P_{12}}, \quad (4.3.22)$$

where P_{35} and P_{36} are the fractions of fresh refrigerant lost due to can heel and during servicing, respectively, during professional recharging. Note that P_{36} is assumed to be negligible in this analysis.

Define

$$\frac{M_{Pro}}{M_{DIY}} = F_2 .$$

Then

$$\begin{aligned} E_{\text{ban}} &= [\frac{1-P_{11}-P_{12}}{1-P_{35}-P_{36}} \cdot F_2 \cdot (\frac{Y_1}{Y_2} \cdot P_{31} + \frac{P_{32}}{F_1}) + P_{33} + P_{34})] \cdot E_{\text{BAU}} \\ &= [\frac{1-22\%-11\%}{1-2\%-0\%} \times 1.6 \times (\frac{1}{6} \times 32\% + \frac{23\%}{1.4}) + 7\% + 19\%)] \times 0.808 = 0.402 \text{ (MMTCO}_2\text{E)} \end{aligned} \quad (4.3.23)$$

The derivation of P_{31}, P_{32}, P_{33}, P_{34}, F_1, and F_2 can be found in 4.5.3 and 4.5.4.

The annual emission reductions are

$$\begin{aligned} ER_{\text{ban}} &= E_{\text{BAU}} - E_{\text{ban}} \\ &= 0.808 - 0.402 = 0.405 \text{ (MMTCO}_2\text{E)} \end{aligned} \quad (4.3.24)$$

The number of professional servicing that involves repair in a vehicle's lifetime is

$$\begin{aligned} N_{\text{R,rep}} &= \frac{Y_{\text{adj}}}{Y_2} \\ &= \frac{9}{6} = 1.5 \text{ (times)} \end{aligned} \quad (4.3.25)$$

The annual costs for such a vehicle are

$$\begin{aligned} C_{\text{1,ban}} &= \frac{R_{31}}{Y_2} \\ &= \frac{650}{6} = 108.33 \text{ (dollars)} \end{aligned} \quad (4.3.26)$$

The lifetime costs for such a vehicle are

$$\begin{aligned} C_{\text{1,L,ban}} &= Y_{\text{adj}} \cdot C_{\text{1,ban}} \\ &= 9 \times 108.33 = 975 \text{ (dollars)} \end{aligned} \quad (4.3.27)$$

The number of professional recharging that does not involves repairs in a vehicle's lifetime is

$$\begin{aligned} N_{\text{R,rec}} &= \frac{Y_{\text{adj}}}{F_1 \cdot Y_1} \\ &= \frac{9}{1.4 \times 1} = 6.4 \text{ (times)} \end{aligned} \quad (4.3.28)$$

The annual costs for such a vehicle are

$$\begin{aligned} C_{2,\text{ban}} &= \frac{R_{32}}{F_1 \cdot Y_1} \\ &= \frac{100}{1.4 \times 1} = 71.43 \text{ (dollars)} \end{aligned} . \quad (4.3.29)$$

The lifetime costs for such a vehicle are

$$\begin{aligned} C_{2,\text{L,ban}} &= Y_{\text{adj}} \cdot C_{2,\text{ban}} \\ &= 9 \times 71.43 = 642.86 \text{ (dollars)} \end{aligned} . \quad (4.3.30)$$

The number of professional topping off in a vehicle's lifetime is the same as under BAU ($N_{\text{R,BAU}}$).

$$\begin{aligned} N_{\text{R,top}} &= \frac{Y_{\text{adj}}}{Y_1} \\ &= \frac{9}{1} = 9 \text{ (times)} \end{aligned} . \quad (4.3.31)$$

The annual costs for such a vehicle are

$$\begin{aligned} C_{3,\text{ban}} &= \frac{R_{32}}{Y_1} \\ &= \frac{100}{1} = 100 \text{ (dollars)} \end{aligned} . \quad (4.3.32)$$

The lifetime costs for such a vehicle are

$$\begin{aligned} C_{3,\text{L,ban}} &= Y_{\text{adj}} \cdot C_{3,\text{ban}} \\ &= 9 \times 100 = 900 \text{ (dollars)} \end{aligned} . \quad (4.3.33)$$

The number of DIY recharging using refrigerant obtained through alternative ways is the same as under BAU ($N_{\text{R,BAU}}$).

$$\begin{aligned} N_{\text{R,alt}} &= \frac{Y_{\text{adj}}}{Y_1} \\ &= \frac{9}{1} = 9 \text{ (times)} \end{aligned} . \quad (4.3.34)$$

The annual costs for such a vehicle are

$$\begin{aligned} C_{4,\mathrm{ban}} &= \frac{N_{\mathrm{C}} \cdot (1+P_{37}) \cdot R_1}{Y_1} \\ &= \frac{1.3 \times (1+50\%) \times 13}{1} = 25.35 \text{ (dollars)} \end{aligned}, \quad (4.3.35)$$

where P_{37} is the percentage of cost increase for those who seek alternative ways of obtaining refrigerant.

The lifetime costs for such a vehicle are

$$\begin{aligned} C_{4,\mathrm{L,ban}} &= Y_{\mathrm{adj}} \cdot C_{4,\mathrm{ban}} \\ &= 9 \times 25.35 = 228.15 \text{ (dollars)} \end{aligned}. \quad (4.3.36)$$

Note that the owners for the rest of the original DIY vehicles would choose to forgo AC under can ban, thus incur no costs.
The annual costs for all original DIY vehicles are

$$\begin{aligned} C_{\mathrm{all,ban}} &= P_{31} \cdot N_{\mathrm{V}} \cdot C_{1,\mathrm{ban}} + P_{32} \cdot N_{\mathrm{V}} \cdot C_{2,\mathrm{ban}} + P_{33} \cdot N_{\mathrm{V}} \cdot C_{3,\mathrm{ban}} + P_{34} \cdot N_{\mathrm{V}} \cdot C_{4,\mathrm{ban}} \\ &= N_{\mathrm{V}} \cdot (P_{31} \cdot C_{1,\mathrm{ban}} + P_{32} \cdot C_{2,\mathrm{ban}} + P_{33} \cdot C_{3,\mathrm{ban}} + P_{34} \cdot C_{4,\mathrm{ban}}) \\ &= 1.404 \times (32\% \times 108.33 + 23\% \times 71.43 + 7\% \times 100 + 19\% \times 25.35) = 88.36 \text{ (million dollars)} \end{aligned}. \quad (4.3.37)$$

The annual extra costs for all original DIY vehicles are

$$\begin{aligned} EC_{\mathrm{all,ban}} &= C_{\mathrm{all,ban}} - C_{\mathrm{all,BAU}} \\ &= 88.33 - 23.73 = 64.62 \text{ (million dollars)} \end{aligned}. \quad (4.3.38)$$

The cost-effectiveness to consumers is

$$\begin{aligned} CE_{\mathrm{cons,ban}} &= \frac{EC_{\mathrm{all,ban}}}{ER_{\mathrm{ban}}} \\ &= \frac{64.62}{0.405} = 157.85 \text{ (dollars/MTCO}_2\text{E)} \end{aligned}. \quad (4.3.39)$$

The annual revenue losses by small can industry are

$$\begin{aligned} RL_{\mathrm{ban}} &= \frac{S_{\mathrm{BAU}}}{P_0} \cdot R_1 \\ &= \frac{1.826}{95\%} \times 13 = 24.98 \text{ (million dollars)} \end{aligned}. \quad (4.3.40)$$

Note that the above equation accounts for the revenue from the can sales to professional servicing that would be lost in case of can ban. Also note that the potential revenue increase through sales via internet or from out-of-state is not included per Assumption 16.

4.4 Detailed Summary of Results

Table 3: Detailed Emissions and Economic Impact of Regulatory Proposals

	BAU	Staff Proposal*	Can Ban
Annual Can Sales to DIY (million cans)	1.8	1.8	NA
Annual Emissions ($MMTCO_2E$)	0.81	0.55	0.40
Annual Emission Reductions ($MMTCO_2E$)	NA	0.26	0.41
Annual Costs for All Original DIY Vehicles (million dollars)	23.73	26.47	88.36
Annual Extra Costs for All Original DIY Vehicles (million dollars)	NA	2.7	64.6
Cost-effectiveness to Consumers (dollars/$MTCO_2E$)	NA	11	159
Annual Revenue Loss (million dollars)	NA	0	25

* Calculation based on a can return rate target of 95%

4.5 Derivation of Key Independent Parameters

4.5.1 Y_1

Definition

The average interval between two DIY recharging is estimated by several approaches and data sources in this document. In most cases, it is calculated based on responses from surveyed individuals about their recharge intervals. It needs to be noted that the average recharge interval should not be defined as the straight mean of the recharge intervals from all the samples because this does not make physical sense. Rather, it should be defined as the reciprocal of the average leak rate and the average leak rate is the mean of the leak rate for all responses. In other words, it is the harmonic mean of the recharge intervals of all the samples:

$$\frac{1}{\overline{\overline{Y}}} = \frac{1}{N}\sum_{i=1}^{N}\frac{1}{Y_i} \quad (4.5.1)$$

This is because, by definition, the average delayed emissions per vehicle are the arithmetic mean of the delayed emissions of all the vehicles under consideration:

$$\overline{E} = \frac{1}{N}\sum_{i=1}^{N}E_i \ , \quad (4.5.2)$$

where

$$E_i = \frac{M}{Y_i} \ , \quad (4.5.3)$$

and

$$\overline{E} = \frac{M}{\overline{\overline{Y}}} \ , \quad (5.5.4)$$

where M is the effective charge that is to be emitted over the period of Y_i, which will incur the next recharge. Equations (4.5.2) through (4.5.4) lead to Equation (4.5.1).

In case the intervals are accompanied with percentages of DIY, the mean becomes weighted mean:

$$\frac{1}{\overline{\overline{Y}}} = \sum_{i=1}^{N}P_i \cdot \frac{1}{Y_i} \quad (4.5.5)$$

ARB El Monte Survey

During the ongoing study on non-professional servicing of MVAC sponsored by ARB, Denis Clodic's team interviewed 16 people who participated in the study. 10 out of them provided relevant responses. Out of these 10, 3 responded with an ambiguous answer, "long time ago". The vintage of their vehicles was as early as 1996 and as late as 2003. These 3 responses are hence deemed invalid and excluded from the analysis. The valid responses are compiled in Table 4.

Table 4: Recharge Interval in ARB El Monte Survey

Vintage	Time of last recharge	Recharge interval (months)
1999	5 months ago	5
1994	4 months ago	4
1997	10 years ago	120
1994	1994	156
2001	4 years ago	48
2004	3 years ago	36
1997	1 year ago	12

Using Equation (4.5.1), the average recharge interval is 11.7 months.

2008 ARPI DIY Survey

ARPI conducted a survey in May, 2008 in California to characterize DIY consumer profiles. 200 survey were handed out in participating Autozone stores in Southern California and 20 responses were received (ARPI, 2008c). Two of the questions are related to estimating recharge intervals. The relevant results are compiled in Table 5.

Table 5: Recharge Interval in 2008 ARPI DIY Survey

Time of last recharge	Recharge interval (months)	Percentage	Combined Percentage	Normalized Percentage
< 3 months	3	5%	5%	5.4%
3 months to 1 year	7.5	20%	20%	21.6%
1 to 2 years	18	30%	30%	32.4%
>2 years	72	15%	37.5%	40.5%
never		30%		
Time of owning the vehicle		**Percentage**	**Percentage: never recharged**	
<1 yr.		25%	7.5%	
1 to 2 yrs.		35%	10.5%	
2 to 3 yrs.		15%	4.5%	
3 to 4 yrs.		5%	1.5%	
> 4 yrs.		20%	6.0%	
Own for >1yr.; never recharged			22.5%	

Although 30% of the respondents said that they never recharged their AC before, it is noticeable that most of the survey participants have not own their cars for very long. As the second part of the table shows, 80% of these people have their cars for less than 4 years. Therefore, having never charged does not necessarily mean the recharge interval would be very long (longer than 4 years). Assuming the vehicle ownership profile holds true for those who never charged their AC, 7.5% own their vehicle for less than one year and never charged the AC, and 22.5% own their vehicle for more than one year and never charged the AC. To be conservative, add the 22.5% to the 15% that had their last recharge more than 2 years ago, and assign a 6-year recharge interval for the total 37.5%. Exclude the 7.5% that have owned their vehicle for less than a year and never recharged the AC, and normalize the rest of the population. Using Equation (4.5.5), the average recharge interval is 14.2 months.

Frost and Sullivan Study

Commissioned by the ARPI, the Frost and Sullivan Co. conducted an online survey to investigate consumer purchase and usage behavior of small cans (Frost and Sullivan, 2006). Its California sample includes 400 respondents. The questionnaire did not explicitly ask about the recharging intervals. However, this information can be derived from the response to some other questions when making a few assumptions.

According to the study, out of the 400 respondents, 38% or 152 of them generally would not use the full can of HFC-134a. Since whether a full can is used is a natural outcome of the recharging process, instead of an arbitrary decision, any other aspects of the can usage of these 152 people should be representative of the California respondents as a whole. So we only need analyze these 152 samples. Among them, 62% or 95 would store the partial can, and the rest 38% or 57 would dispose of it. Of the 95 people that stored the partial cans, 22% of them said that they had not tried to re-use them. This can be conservatively interpreted as the fraction of people that had only recharged once.

The study provides the storage period for those who would store the partial cans. This information is included in the first and third columns of Table 6. Each storage period range is assigned a storage period as the middle value of the range in the second column, where storage period of longer than 18 months is conservatively assigned the value of 72 months. Some of them are first time DIY and we need to exclude them when estimating the recharge intervals. However, 12% of the people stored the cans for over a year and they are certainly not the first time DIY. This is because the survey respondents all had recharged AC in the past 12 months. If they are the first time users, the recharge events happening within the 12 months were their only experience and their storage periods are definitely less than 12 months. We have shown that 22% of the people had only charged once. This translates into 25% out of the 88% whose storage periods were less than a year (25% = 22% ÷ 88%). Evenly allocating

25% to all these 88% people, we get the percentage of the first time DIY in column 4, totaling 22% as expected. Only the rest 78% are the non-first time DIY, which is tabulated in column 5 and normalized in column 6. Finally, we use 62% to adjust the normalized percentages since 62% of all DIY consumers would store the cans.

Table 6: Storage Period for People Who would Store Partial Cans

Storage Period Range	**Storage Period (months)**	**Percent of DIY**	**First Time DIY**	**Non-first Time DIY**	**Normalized Non-first Time DIY**	**Non-first Time DIY Multiplied by 62%**
0-3 mon	3	27%	7%	20%	26.0%	12.6%
3-6 mon	4.5	19%	5%	14%	18.3%	8.8%
6-9 mon	7.5	25%	6%	19%	24.0%	11.6%
9-12 mon	10.5	17%	4%	13%	16.4%	7.9%
12-18 mon	15	6%	0%	6%	7.7%	3.7%
>18 mon	72	6%	0%	6%	7.7%	3.7%
	Total of First 4 Lines	88%	22%			
	Total of First 4 Lines Divided by 22%	25%				

On the other hand, of all the California respondents (348 valid responses), 42% had only recharged their present and past vehicles once. As an approximation, we assume all the recharges happen to their present vehicles. This percentage should hold true for the 152 people that would not use up the full cans. Therefore,

$$22\% \times 62\% + P_{\text{disp}} \times 38\% = 42\% \text{ ,}$$

where P_{disp} is the percentage of the first time DIY out of those who would dispose of the can. And

$P_{\text{disp}} = 75\%$.

It indicates that most people disposing of partial cans are first time users. This is consistent with intuition since experienced consumers would know that once the vehicle starts needing recharge, it is likely that it has some leaking problem and may need repeated recharge within a certain time frame.

Assuming disposing of or store partial cans is more related to personal preference than recharging practices, we can apply the same apportionment as in Table 6 for those who choose to dispose of partial cans by “virtual storage period”. This is the period that they would store cans should they choose to store the cans. This is shown in Table 7.

Table 7: Virtual Storage Period for Those Who would Dispose of Partial Cans

Storage Period Range	Storage Period (months)	Percent of DIY	First Time DIY	Non-first Time DIY	Normalized Non-first Time DIY	Non-first Time DIY Multiplied by 38%
0-3 mon	3	27%	23%	4%	16.0%	1.5%
3-6 mon	4.5	19%	16%	3%	11.2%	1.1%
6-9 mon	7.5	25%	21%	4%	14.8%	1.4%
9-12 mon	10.5	17%	14%	3%	10.0%	1.0%
12-18 mon	15	6%	0%	6%	24.0%	2.3%
>18 mon	72	6%	0%	6%	24.0%	2.3%
	Total of First 4 Lines	88%	75%			
	Total of First 4 Lines Divided by 75%	85%				

Adding the last columns of the above two tables, we obtain the storage period for the overall California samples (Table 8). It is important to note that this study restrict the survey panel to those who had charged their MVAC during the last 12 months. Thus, the survey panel members with recharge intervals of less than 12 months are not filtered. But for those with recharge intervals of more than 12 months, only a fraction will be able to participate in the survey. For example, for the group that has recharge intervals of 6 years, approximately 1/6 of them would have performed recharging during the last 12 months and would have been captured by the survey. Their percentages in the following table should then be multiplied by 6 to account for that. This is also true for the group with recharge interval of 15 months. After this adjustment and then normalization, around half of the samples have a recharge interval of more than a year. Using Equation (4.5.5), the average recharge interval is 8.5 months.

Table 8: Overall Storage Period

Storage Period Range	Storage Period (months)	Combined Non-first Time DIY	Adjusted Combined Non-first Time DIY	Normalized Non-first Time DIY
0-3 mon	3	14.1%	14.1%	15.8%
3-6 mon	4.5	9.9%	9.9%	11.1%
6-9 mon	7.5	13.0%	13.0%	14.6%
9-12 mon	10.5	8.9%	8.9%	9.9%
12-18 mon	15	6.0%	7.5%	8.4%
>18 mon	72	6.0%	36.0%	40.3%

NPD Sales Data

The NPD Automotive Aftermarket Industry Monitor provides cashier transaction information from the U.S. auto parts chain retailers (NPD, 2008). The data come from nine participants including Advance, AutoZone, CSK/Murrays, PepBoys, O'Reilly's, CarQuest, NAPA, Strauss Auto and Parts Alliance. As shown in Table 9, in 2006 and 2007, average annual sales of HFC-134a units without charging kits were 14 million. Given that every recharging uses about 1.3 cans on average, this suggests 11 million DIY recharging operations each year. The Average annual sales of charging kits were just over 1 million. Assuming a vehicle's "effective lifetime" during which it needs recharging is 9 years and every DIY user only purchase one charging kit and use it throughout his vehicle's lifetime, the number of DIY vehicles should be equal to the total sales of charging kits in 9 years, which is about 10 million. Thus, on average, a DIY vehicle gets 1.1 recharging per year and the recharge interval is 10.8 months.

Table 9: NPD Data on HFC-134a Units Sold in the U.S.

	2006 & 2007 Total
Total HFC-134a Units without Charging Kits	14,079,386
AC Charging Kits	1,086,872
DIY Recharge Operations per Year	10,830,297
AC Charging Kits Sold in 9 Years	9,781,848
DIY Vehicles	9,781,848
Recharges per Vehicle per Year	1.1

Summary

The recharge interval estimates range from less than three quarters to slightly over 14 months (Table 10). Therefore, it is reasonable to assume a recharge interval Y_1 = 1 year.

Table 10: Summary of Recharge Interval Estimates

Data Source(s)	**Sample Size**	**Recharge Interval Estimate (months)**
ARB El Monte Survey	7	11.7
2008 ARPI DIY Survey	20	14.2
Frost and Sullivan Study	152	8.5
NPD Survey		10.8

4.5.2 P_0

SAE supplied data that indicate that of all the HFC-134a used in MVAC nationwide in 2003, factory fill, 30-lb cylinders and small cans share 30%, 39% and 31%, respectively (Atkinson, 2008a). 30-lb cylinders are apparently exclusively used by professional servicing. But some professional technicians also use small cans, which is about 3.5% of the total usage by professional shops (MACS, 2008). Thus, out of all the HFC-134a used in MVAC, the percentage of HFC-134a in small cans used by professional shops is

$$\frac{3.5\%}{1-3.5\%}\times 39\% = 1.4\% .$$

So the percentage of small cans used by professional servicing in relation with the total small can usage is

$$\frac{1.4\%}{31\%} = 4.6\% .$$

Therefore, 96.4% of small cans are sold to DIY. Rounding it off, we have P_0 = 95%.

4.5.3 P_{31}, P_{32}, P_{33}, and P_{34}

A study of small can consumers commissioned by the ARPI estimates that 12% of former DIY owners would opt to have no air conditioning rather than go to a professional shop, 49% would go to the professional shop, and 39% would look for other options of obtaining refrigerant (Frost and Sullivan, 2006). The 39% of consumers seeking alternative options will contribute to illegal internet or out of state sales, but given the inconvenience of doing that, it is unlikely that all of them will have the perseverance to circumvent the can ban. The true rate of DIY circumventing the ban will probably be somewhere between 0% and 39%. In the absence of further data on which to assign a fraction, we take the midpoint of this range, or 19%, to maximize the probability of being close to reality. We assume that the remainder of those looking for alternative sources of HFC-134a will choose one of the legitimate options which are: obtain professional repairs, obtain professional recharge without repair, obtain professional top off, forgo air conditioning, or go to professional servicing without deciding on actions. We assign the rest half (20% of total) of the former DIY equally among those five legitimate options: 4% forgo air conditioning; 4% go to the shop for repair and recharge; 4% go to the shop for recharge without repair; 4% go to the shop for topping off; and 4% go to the shop undecidedly. The percentages in each category become: forgo air conditioning 12% + 4% = 16%; go to the shop undecidedly 49% + 4% = 53%; go to the shop with the specific objective of repair 4%; go to the shop specifically for recharge without repair 4%; go to the shop specifically for topping off 4%; and obtain HFC-134a by alternative means 19%.

A 2005 MACS study showed the choices of customers who currently visit professional shops for diagnosis and repair (Atkinson, 2008b). The study surveyed 7 service facilities located in Pennsylvania, Ohio, Arizona, California and Florida and included over 1,400 repair orders. In that study, among those with refrigeration circuit problems, 88% chose to have their system repaired or recharged, 7% chose to simply be topped off, and the other 5% choose to reject recharges and forgo air conditioning. The first two categories, adding up to 95%, represent all the operations that involve adding refrigerant. An IMR Continuing Consumer Auto Maintenance Survey (CCAMS) data supplied by ARPI (ARPI, 2008a) suggest that of all professional servicing that involve adding refrigerant, only 56% involves repair. This translates into 53% in context of the 95%, whereas the other 42% of the 95% are either topping off (7%) or recharge without repair (42% - 7% = 35%).

Assuming the 53% of consumers described in the first paragraph who go to professional shops without deciding on actions would behave the same way as normal customers at professional shops, they are reapportioned into categories as described in the preceding paragraph: 28% of former DIY consumers have AC repaired; 19% get recharge without repair; 3% receive topping off; and another 3% forgo AC. Recombining them with those who already have specific goals, P_{31} = 32% get professional repair, P_{32} = 23% receive professional recharge, P_{33} = 7% top off at professional servicing, P_{34} = 19% continue DIY recharging AC using refrigerant obtained through alternative means, and the other 19% forgo AC. The figure below shows how the various fractions were apportioned and combined, with the final values on the right.

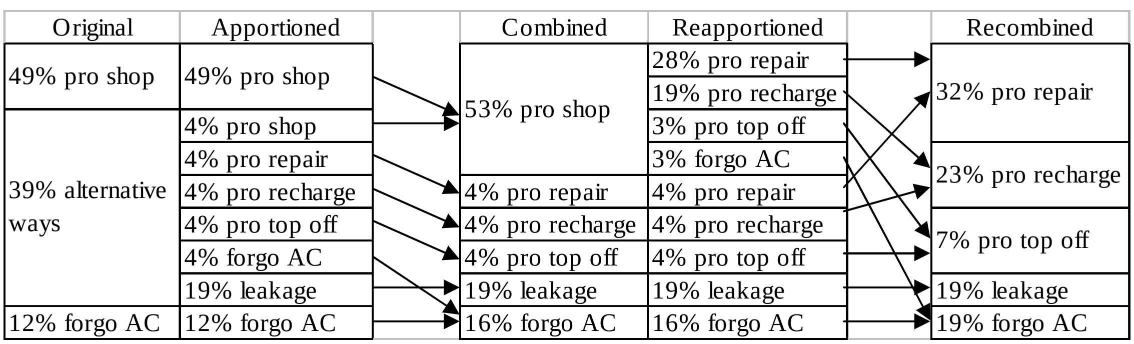

Figure 5. DIY Behavior Change under Can Ban

4.5.4 F_1 *and* F_2

The average nominal charge size of passenger vehicles in the U.S. is 824 grams (Thundiyil, 2008b). It assumed the AC average to 50% empty when brought in to the professional servicing facility for recharge (Assumption 5), which indicates that 412 grams of refrigerant remains in the AC.

Every DIY recharge uses 445 grams of refrigerant (all fresh), with 98 grams (22%), 49 grams (11%), and 298 grams (67%) as can heel, servicing loss, and effective charge, respectively. Apparently DIY on average recharge AC at 86% (412 grams remaining refrigerant + 298 grams fresh refrigerant) of nominal level. A DIY recharged AC has 298 grams of refrigerant to lose before the next recharge is needed.

In comparison, a professional technician has the equipment and skills to restore AC charge to its nominal level, rendering more refrigerant (412 grams) in the systems to be emitted before the next servicing is needed. When no repair is conducted, the recharged AC will leak at the same rate as a DIY recharged AC, but at a prolonged period. The recharge interval for a professionally recharged AC to that for a DIY recharged AC is

$$F_1 = \frac{412}{298} = 1.4 .$$

It should be noted that during professional servicing (with or without repair), the amount of fresh refrigerant effectively charged into AC is not 412 grams because the remaining refrigerant needs first to be recovered and stored in a cylinder. Then it will be recharged back into the AC. These operations will incur losses due to servicing losses and cylinder heels. The refrigerant lost during incomplete recovery is by far the main source of servicing losses. For purpose of analysis, we assume the refrigerant recovery rate by professional servicing using the current prevailing equipment and practices is 85%. Thus, 62 grams (15% of 412 grams) will be lost due to incomplete recovery. A new SAE standard for refrigerant recovery and recharge, J2788, has taken into effect, to replace the old SAE J2210 standard. Using the equipment and practices compliant with the new standard, the recovery rate will be increased to at least 95% (about 21 grams of servicing loss). However, there is no requirement for the professional servicing to replace their current recovery machines, and the phase-in of the new machines will likely be slow. The recovered 350 grams will be stored in cylinder for future use. Not all of them will be effectively charged into AC during the next servicing due to cylinder heels. The U.S. EPA Disposable Container Heel Testing Study found that the cylinder heel in professional servicing is about 1.8% (U.S. EPA, 2007). This translates into about 7 grams loss in cylinder heel out of the recovered 350 grams. The rest of 343 grams will be effectively charged into AC during the next recharge. To add up to the nominal charge of 824 grams, another 481 grams of fresh refrigerant needs to be effectively charged into the AC, which will cause another 10 grams of losses in cylinder heel. Therefore, the ratio of fresh refrigerant effectively charged into AC during professional recharging to that during DIY recharging is

$$F_2 = \frac{481}{298} = 1.6 .$$

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