MEMORANDUM

To: Margaret Sheppard, U.S. EPA

CC: Rachel Schwartz, Sally Hamlin, Rebecca von dem Hagen, Bella Maranion, Cindy Newberg, U.S. EPA

From: Kasey Knoell, Becky Ferenchiak, Jenny Tanphanich, Ed Carr, Mark Wagner, ICF International

Date: February 24, 2014

Re: Assessment of the Potential Impact of Hydrocarbon Refrigerants on Ground Level Ozone Concentrations (EPA Contract Number EP-W-10-031 Task Order 305, Task 01)

In response to technical direction received from EPA, ICF has prepared an assessment of the potential impact on ground level ozone concentrations caused by release of hydrocarbon refrigerants across refrigeration and air conditioning end uses. Refrigerant emissions were modeled from the U.S. EPA's Vintaging Model (VM_IO file_V4.4_11.6.12) and their impacts on ground level ozone were modeled using the CMAQ model (version 4.7.1). Releases of isobutane and propylene were modeled in Los Angeles, Houston, and Atlanta under three emissions scenarios: 1) all refrigeration and air conditioning (ref/AC) end-uses, 2) ref/AC excluding motor vehicle air-conditioners (MVACs), and 3) ref/AC excluding MVACs and chillers. A final scenario was modeled, in which limitations on the properties of hydrocarbons (e.g., flammability) are considered to determine which end-uses were likely to transition to hydrocarbon refrigerants. The remainder of this memorandum summarizes the results of this assessment. A quantitative analysis of the uncertainty levels can also be performed by undertaking additional CMAQ simulations if requested by the EPA TOCOR.

Please contact Mark Wagner at 202-862-1155 with any questions or comments.

Potential Impacts of Hydrocarbon Refrigerants on Ground-Level Ozone Concentrations

1 Executive Summary

Hydrocarbons are increasingly being considered for use in a number of refrigeration and air-conditioning (ref/AC) end-uses. Although hydrocarbons have a low global warming potential (GWP) and are thus desirable alternatives to commonly used hydrofluorocarbons (HFCs), there is concern that use of hydrocarbons could negatively impact local air quality due to their high maximum incremental reactivity (MIR) values.

In order to evaluate their potential impact, three conservative hydrocarbon emission scenarios and one more realistic scenario were analyzed. The first three evaluate emissions of propylene and isobutane first from the entire refrigeration and air conditioning sector, second excluding motor vehicle air conditioning, and third excluding motor vehicle air conditioning and chillers. A fourth scenario, evaluating emissions of a mix of propylene, isobutane, and propane, was developed based on SNAP hydrocarbon applications and UL Standards and represents a more realistic transition to hydrocarbons. The hydrocarbon emissions from these scenarios were estimated based on U.S. EPA's Vintaging Model, and their potential contributions to ozone concentrations were assessed using U.S. EPA's Community Multiscale Air Quality (CMAQ) model.

CMAQ modeling was performed for April through the end of September, as these months presented the largest releases of hydrocarbon refrigerant as well as weather conditions favorable for ozone formation. The ozone concentrations were estimated for the Atlanta, Houston and Los Angeles regions, due to their distinctive geographic setting and chronic high levels of ground level ozone, and then scaled for national emission estimates. The results of the CMAQ modeling indicated that hydrocarbon refrigerants under the most conservative scenario could potentially increase ground level ozone by up to 9% compared to the national ozone standard, but less than a 0.2% increase under the most realistic scenario.

The analysis performed is based on several assumptions and projections that cannot be known with certainty at this time. These limitations are associated with both the unknown market penetration of alternatives and climate conditions, among other factors.

2 Introduction

Ozone-depleting substances (ODS) such as CFC-12, R-502, and HCFC-22 were historically used across the refrigeration and air-conditioning sector. Since identifying the damaging nature of CFCs and HCFCs, EPA moved swiftly to transition to alternatives. The phaseout of CFCs in 1996 and continued phasedown of HCFCs, has led the U.S. EPA Significant New Alternatives Policy (SNAP) program to review and approve a number of potential substitutes to these ODS. In particular, hydrocarbon refrigerants, which have zero ODP and low GWP, have already been recently approved for smaller refrigeration applications (e.g., domestic refrigeration, small retail food refrigeration, and vending machines) and have the potential to be used more broadly across the refrigeration and air-conditioning sector. Compared to the HFCs and HCFCs currently in use, which have high GWPs, hydrocarbons have the potential to significantly reduce climate impacts from the refrigeration and air conditioning sector.

Although the use of hydrocarbons could potentially mitigate greenhouse gas (GHG) emissions, it could also potentially contribute to increased levels of ground level ozone. Hydrocarbons have high MIR values, and may influence local air quality if emitted in sufficiently high quantities. Table 1 provides a summary of the propensity of these refrigerants to form tropospheric ozone. [1]

Table 1: Propensity of Refrigerants to Form Tropospheric Ozone

Compound	North America Maximum Incremental Reactivity (MIR) Scale ($g\text{-}O_3$/g-substance)	Europe POCP Scale[a] (Relative Units)
HCFC-22	<0.1	0.1
HFC-134a	<0.1	0.1
Propylene	11.57	112
Ethane[a]	0.28	12
Isobutane	1.34	31
Propane	0.56	18
Ethylene	9.07	100

Source: IPCC 2005

[a]The POCP value is the ozone creating potential of a compound relative to ethylene (ethene), expressed as an index where ethylene = 100.

[b]EPA uses the reactivity of ethane as the threshold for determining whether a compound has negligible reactivity. Compounds that are less reactive than, or equally reactive to, ethane under certain assumed conditions may be deemed negligibly reactive and therefore suitable for exemption from the definition of a VOC (EPA 2012).

It should be noted that EPA is currently considering exempting certain hydrocarbons in certain end-uses from the ban on venting of refrigerant under §608 of the Clean Air Act. In order to evaluate the potential impact of the release of hydrocarbons during disposal, ICF modeled conservative and realistic hydrocarbon emission scenarios from the refrigeration/AC sector and assessed their impacts on ground-level ozone, taking into consideration this revision to the end-of-life management requirement.

The remainder of this report summarizes the methodology used and results in the following order:

- Section 3: Hydrocarbon Emission Scenarios
- Section 4: Impact on Ground-Level Ozone Concentrations
- Section 5: Analysis Limitations
- Section 6: Summary of Findings
- Section 7: References

[1] Reactivity scales rank the propensity of organic compounds to form ozone. The MIR scale assesses their contributions to the photochemical ozone formation in urban plumes and is reflective of its use in North America, where ground-level ozone formation is considered an urban issue. In contrast, the POCP scale addresses long-range trans-boundary formation and transport of ozone and was developed for use in Europe, where ground-level ozone formation occurs on the regional scale in multi-day episodes (IPCC 2005). As the MIR scale is more applicable to conditions within the United States, the remainder of this report references the MIR scale.

3 Hydrocarbon Emission Scenarios

Under this analysis, isobutane and propylene were each modeled under three conservative emissions scenarios for the refrigeration and air conditioning sector. A fourth, more realistic emissions scenario was also modeled, which considered more likely transitions to a variety of hydrocarbon refrigerants (i.e., isobutane, propylene, and propane) by end-use in the sector. The four emission scenarios considered are as follows:

1) **Scenario 1:** the **entire ref/AC sector**: chillers, motor vehicle air conditioners (MVACs) (i.e., light-duty trucks and vehicles, trains, transit buses, school buses, and tour buses), residential and light commercial AC and heat pumps,[2] retail food,[3] cold storage warehouses, industrial process refrigeration, refrigerated transport, and household refrigeration and freezers;
2) **Scenario 2:** the ref/AC sector **excluding MVACs**;
3) **Scenario 3:** the ref/AC sector **excluding MVACs and chillers;**[4] and
4) **Scenario 4:** the ref/AC sector for end-use applications in which a SNAP submission has been received for a hydrocarbon or in which a UL Standard addressing flammable refrigerant is in place. See Appendix B for more information on the end uses included in this scenario.

In order to estimate their potential impact on ground-level ozone concentration, the national scale hydrocarbon emissions from each scenario were estimated using EPA's Vintaging Model (VM).[5] These national emissions were then proportionally scaled to each urban area by population by county. For Los Angeles, three counties were used representing about 4.4% of the U.S. population; for Houston, eight counties representing about 2.0% of the U.S. population were used; and for Atlanta, ten counties representing about 1.4% of the U.S. population were used. These county level emissions were then spatially allocated to each emission grid cell based on population density. The remainder of this section provides a summary of the methodology used to estimate the national inventory of hydrocarbon emissions, as well as a description of each scenario considered.

3.1 Methodology for Emissions Estimates

The year 2030 was chosen as the analysis year for all scenarios, in order to conservatively estimate the impact of hydrocarbons. The majority of non-hydrocarbon equipment will have been retired by the year, due to the lifetimes of equipment (i.e., 5 to 27 years). In addition, a 2030 nationwide emission inventory was available for other emission sources and was used to estimate the baseline ozone concentration (without hydrocarbon refrigerants). It was assumed that the hydrocarbon refrigerants would enter the market in 2012, and reach 100% market penetration in 2030. Output from the VM is provided on an annual basis; for the purposes of this analysis, the annual data was weighted on a monthly basis, and

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[2] The residential and light commercial AC and heat pumps end-use includes the following applications: window AC units, residential unitary AC, small commercial unitary AC, large commercial unitary AC, packaged terminal AC and heat pumps (PTAC/PTHP), and water and ground source heat pumps.

[3] The retail food end-use includes the following applications: ice makers, small retail food systems, medium retail food systems, and large retail food systems.

[4] Chillers are large-scale air conditioning systems for large commercial and institutional buildings, such as for office buildings, hotels, hospitals, and the like.

[5] EPA's Vintaging Model estimates the annual chemical emissions from industry sectors that have historically used ODS, including AC, refrigeration, foams, solvents, aerosols, and fire protection. Within these industry sectors, there are over 60 independently modeled end-uses. The model uses information on the market size and growth for each end-use, as well as a history and projections of the market transition from ODS to alternatives. The model version used in this analysis is VM_IO file_V4.4_11.6.12.

assumed that 11.9% of annual emissions occurred during each month from April to August. Emissions of refrigerant are reasonably anticipated to occur primarily during the warmer spring and summer months, when air conditioning equipment is increasingly used. Emissions due to servicing MVACs are also expected to be higher during the spring and summer, with up to 80% of emissions due to repairs occurring April through August (MACS 2009). Furthermore, refrigerant emissions from servicing motor vehicle air conditioning systems were estimated at 47% of annual refrigerant emissions from motor vehicles (EPA 2008). This assumption was also applied for all scenarios to all stationary AC end-uses based on the assumption that seasonal emissions would follow similar patterns. Emissions of refrigerant from refrigeration equipment were assumed to occur equally year-round.

Smaller end-uses (i.e., end-uses with a charge size less than 200 kg) were assumed to have a 100% release of refrigerant upon disposal. Disposal release rates for larger end-uses (i.e., chillers, industrial process refrigeration systems, and large retail food systems) and servicing release rates for all end-uses were assumed to remain consistent with current VM assumptions, due to the assumed regulations and financial incentives for the end-user.

Each state implements individual emission and VOC regulations that inhibit venting. For example, Regulation 7:27-16.1a for New Jersey (which is a nonattainment area) requires the use of reasonably available control technology for equipment. Venting would violate this regulation. Maryland implements a regulation that states that a person may not cause or permit the discharge of VOC from any installation constructed on or after November 15, 1992 in excess of 20 pounds (9.07 kilograms) per day unless the discharge is reduced by 85 percent or more overall. In addition to state regulations, industry standards also restrict venting. Under OSHA regulations, facilities are required to demonstrate that 25 percent of the lower flammability limit (LFL) would not be exceeded at any point during venting of hydrocarbon refrigerants. Chillers and other large charge size commercial refrigeration systems do not currently implement the proper engineering controls that would be needed to allow for safe venting. The use of flares, stacks, or rapid emission controls may likely be required to meet these industry standards. Equipment would have to be modified to incorporate these controls, or venting would not be allowed. Furthermore, assuming 100% is vented during servicing of equipment is unrealistic from an economic perspective. Even with a low cost refrigerant, such as propane or isobutane, venting a charge size of over 1,000 grams still represents a significant cost and provides an incentive to collect refrigerant, which also is in keeping with good maintenance and technician practices.

The reader is referred to Appendix A for a summary of detailed assumptions used in this analysis.

3.2 Conservative Emissions Scenarios

Hydrocarbons are currently being proposed for use in a wide range of ref/AC end-uses. To estimate the most conservative impact that releases of hydrocarbons could have on ground-level ozone, the first scenario considered under this analysis assumes release from the entire ref/AC sector. However, due to the characteristics associated with hydrocarbons (e.g., flammability), this may not be realistic. To assess more realistic, but still conservative scenarios, two additional scenarios were considered. All three scenarios assume that the end-uses would be replaced with either propylene or isobutane. Propylene exhibits the highest MIR of hydrocarbons, and therefore represents the most conservative estimates. Propylene is also a proxy for the hydrocarbon blend R-443A, a substitute refrigerant under evaluation for use in residential air conditioning, because that blend contains more than 50% propylene. Isobutane has the highest MIR of the saturated hydrocarbons under evaluation and was used as a conservative proxy for isobutane, propane, and the hydrocarbon blend R-441A. R-441A contains more than 50% propane, as well as isobutane and other saturated hydrocarbons.