

Air Quality Policy Implications of the Highly Reactive Volatile Organic Compound Cap and Trade Program in the Houston Metropolitan Area

Debbie Denise Medlin

A thesis submitted to the faculty of the University of North Carolina at Chapel Hill in partial fulfillment of the requirements for the degree of Master of Science in the Department of Environmental Sciences and Engineering.

Chapel Hill
2006

Approved by:

Professor Harvey Jeffries

Professor Greg Characklis

Professor William Vizueté

ABSTRACT

Debbie D. Medlin: Air Quality Policy Implications of the Highly Reactive Volatile Organic Compound Cap and Trade Program in the Houston Metropolitan Area
(Under the direction of Prof. Harvey Jeffries)

The Texas Commission for Environmental Quality has designed an unprecedented, market-based emissions reduction program to trade four highly reactive VOCs (HRVOCs) in the Houston/Galveston/Brazoria (HGB) area, one of the most polluted regions in the country. These compounds, ethylene, propylene, the isomers of butene, and 1,3-butadiene, can form ozone very rapidly and lead to Transient High Ozone Events that have dominated the Ozone Design Values in the HGB area for more than two decades. The EPA proposed approval of the HRVOC Emissions Cap and Trade program in 2005 as a means to help meet the one-hour ozone standard of 0.12 ppm. Under the current eight-hour ozone attainment standard of 0.08 ppm, concerns have surfaced regarding the program's effectiveness in helping to achieve said standard by the 2010 deadline. Several policy implications of this uniquely complex program are examined against four other emissions trading programs and against uncertainties within the program itself.

ACKNOWLEDGEMENTS

I am most grateful to my advisor, Dr. Harvey Jeffries, whose guidance and tireless effort helped make this thesis possible. I would also like to acknowledge the valuable contributions and advice provided me by the other members of my thesis committee, Drs. William Vizuite and Greg Characklis. Finally, I must also recognize the academic and/or personal input of various UNC faculty members in helping me to realize this thesis, to include Drs. Ken Sexton, Douglas Crawford-Brown, Pete Andrews and Don Fox.

TABLE OF CONTENTS

LIST OF TABLES	IX
LIST OF FIGURES	X
LIST OF ABBREVIATIONS.....	XII
1. INTRODUCTION	1
2. HOUSTON AIR QUALITY.....	6
2.1 Area Description	6
2.2 Meteorology and Ozone Exceedances	10
3. SIP REVISIONS – THE ROAD TO CAP AND TRADE.....	13
3.1 TexAQS 2000	13
3.2 December 2000 SIP Revision	14
3.3 Emissions Inventories	16
3.3.1 Principal Sources	16
3.3.2 VOC Speciation	20
3.3.3 VOC Measurement Uncertainty	21
3.4 Other VOCs (OVOCs).....	25

3.5	January 2003 SIP Revision – HRVOC Controls	26
3.6	Non-Routine VOC (Event) Emissions.....	29
3.7	Grid Resolution.....	33
3.8	Implementation of the 8-Hour Ozone Standard.....	36
4.	CONTROLLING HRVOCS – CAP AND TRADE	39
4.1	Cap and Trade Programs.....	39
4.2	The Challenge of Reactivity-based VOC Trading.....	40
4.3	Reactivity Scales.....	42
4.3.1	Necessity and Applicability	42
4.3.2	MIR Scale	45
4.3.3	MIR Uncertainty	48
4.3.4	LS-RR	49
4.4	Air Shed “Hot Spots”	50
5.	HGB HECT PROGRAM.....	52
5.1	Documentation/Participation	52
5.2	Determining Baseline Activity and Allowance Allocation	54

5.3	VOC ERC Conversion to HRVOC Allowances	55
5.4	Trading.....	56
5.5	Administrative Controls.....	57
6.	LESSONS LEARNED – THE ROAD TO REACTIVITY-BASED CAP AND TRADE PROGRAMS	59
6.1	Previous Emissions Trading Programs – Lessons Learned	59
6.1.1	The National Sulfur Dioxide (Acid Rain) Trading Program	59
6.1.2	OTC NOx Budget Program	62
6.1.3	SCAQMD RECLAIM	66
6.1.4	Illinois’ EPA Emissions Reduction Market System (ERMS)	70
6.2	Measuring the HECT Program against Lessons Learned from Previous Emissions Trading Programs	73
7.	MEASURING THE HECT PROGRAM AGAINST UNCERTAINTIES.....	75
7.1	Temporal	77
7.2	Emission Events.....	77
7.3	Banking	78
7.4	Spatial	78

7.5	Photochemical Modeling Irregularities.....	79
7.5.1	One-Hour Case – H12.8HRB Project	79
7.5.2	Eight-Hour Case.....	86
7.6	OVOC Conversion to HRVOCs	87
7.7	Trading Regions.....	88
7.8	Measurement.....	88
7.8.1	Emissions Inventory Errors.....	88
7.8.2	Flare Efficiency.....	89
7.8.3	The Role of HCHO in O ₃ Formation	91
7.8.4	Projected/Current Emissions Inventory Development.....	93
8.	FUTURE NAAQS ATTAINMENT?	94
9.	DISCUSSION	97
9.1	Photochemical Modeling	97
9.1.1	The Use of Modeling to Test a Trading Program	101
9.1.2	Emissions Inventory/Program Cap	101
9.2	Program Rules/Environmental Justice.....	102

9.3	Operational Efficiency	104
9.4	Before Implementation	107
9.5	Gauging Effective Policy	109
10.	CONCLUSION.....	112
11.	RECOMMENDATIONS FOR FUTURE STUDIES	115
	APPENDIX – FINAL HRVOC ALLOCATIONS FOR THE HECT PROGRAM (TONS)	116
	REFERENCES	120

LIST OF TABLES

Table 3.1: Primary Objectives of TexAQS 2000.....	14
Table 3.2 : TexAQS 2000 Findings	14
Table 3.3: Methods and Percentage of VOC Measurement Use During the 2000 HGB Area Emissions Inventory	23
Table 3.4: Root Causes of Process Release, Petrochemical and Chemical Producing Facilities (Texas and Louisiana), 2001	32
Table 4.1: MIR Reactivities – Select VOCs	47
Table 5.1: HECT Program Source Characterization.....	53
Table 6.1: ERMS Program Source Characterization	71
Table 6.2: Applicable Lessons Learned from Selected Emissions Trading Programs	74
Table 7.1: Sources of Uncertainty in the HECT Program	75
Table 7.2: Conclusions Obtained in Project H12.8HRB by UNC Research Group	80
Table 7.3: Synthesis of Findings in Project H12/HRB by the UTA/Environ Corporation Research Group.....	82
Table 7.4: Key Modeling Improvements Needed in Project H12/HRB as Obtained by University of Houston Research Team	85

LIST OF FIGURES

Figure 1-1: Houston Petrochemical Production Capacity	2
Figure 2-1: HGB Eight-County Area and the Houston Ship Channel.....	7
Figure 2-2: Wind Trajectory for a THOE, August 21, 2000; wind reversal in the afternoon returns precursor rich air mass back over land; light winds and a large precursor mass increases THOE magnitude; arrows indicate location of ozone monitoring stations.....	11
Figure 3-1: Houston Ship Channel Reported VOC Emissions – Reactivity Weighted Percentages (Data Source: Environ, 2002)	16
Figure 3-2: 2000 HGB VOC Emissions by PSDB Point Type (Data Source: Cantu, 2004)	22
Figure 3-3: 2000 HGB Area VOC Emissions by County (tpd) (Data Source: Cantu, 2004)	29
Figure 3-4: Transient High Ozone Event (THOE), Houston, Texas, August 21, 2000. The purple line indicates the 1-hr O ₃ standard of 125 ppb (Source: TCEQ, 2000)......	30
Figure 3-5: Frequency of HRVOC Events by Emission Mass, Jan 31 – Dec 31, 2003. The largest number of events range from 100 – 1000 lbs. Most of mass associated with events that are > 1000 lbs. (Source: Jeffries, 2005).....	31
Figure 3-6: Effect of Horizontal Grid Resolution on Emission Event Simulation in 1-km and 4-km Regular Inventory. The X-axis is for hours of August 30, 2000 and Y-axis shows the peak ozone concentration for each hour of the day. The event release was 1,450 lb ETH and 10,188 lb OLE (one-hour); the event duration was two hours (annotated by the purple box). (Source: Jeffries, 2002).....	34
Figure 3-7: Effect of Grid Resolutions on Cell Concentrations Producing a Squared Concentration Effect of Reactants. Top: 1-km grid, Bottom: 4-km grid (Source: Jeffries, 2003).	36
Figure 3-8: EPA 8-hr Ozone Attainment Test (Concept: Tesche, 2005).....	37
Figure 5-1: HGB Trading Zones.....	57
Figure 6-1: NO _x Budget Trading Zones (Source: EPA, 2004)	64
Figure 7-1: Flares as a VOC Source, 19 flares (approximately 4% of all flares) account for 50% of total VOC emissions from flares (Source: Jeffries, 2003).....	91

Figure 8-1: Estimating Rate of Progress in Obtaining the 8-hr O₃ NAAQS in the HGB Region 4km Grid - Upper Bound, (Source: Tesche, 2006b) 95

Figure 8-2: Radar plots depicting effect of increased VOC controls on ethylene concentrations over three-year period, as measured at auto-GC monitors in the vicinity of the Houston Ship Channel. Highlighted numbers indicate concentration of C emissions in latest year of measurement. Brown dots indicate ethylene point sources. Dots are sized according to magnitude of facilities' emissions (Source: TCEQ, 2006)..... 96

LIST OF ABBREVIATIONS

AQMP – Air Quality Management Plan

BACT – Best Available Control Technology

BCCA – Business Coalition for Clean Air

CAAA – Clean Air Act Amendments of 1990

CAMx – Comprehensive Air Quality Model with Extensions

CMAQ – Community Multi-scale Air Quality model

COAST – Coastal Oxidant Assessment of Southeast Texas

C² – Command and Control

DV – Daily Value

DV_C – Current Daily Value

DV_F – Future Daily Value

EBIR – Equal Benefits Incremental Reactivity

EBTP – Emissions Banking and Trading Program

EGU – Electric Generating Unit

EI – Emissions Inventory

EIP – Economic Incentive Program

EKMA – Empirical Kinetic Modeling Approach

ERC – Emission Reduction Credit

GC – Gas Chromatograph

HAP – Hazardous Air Pollutant

HECT – Highly Reactive Volatile Organic Compound Emissions Cap and Trade Program

HGB – Houston Galveston Brazoria

HRVOC – Highly Reactive Volatile Organic Compound

IR – Infrared

km – kilometer

kph – kilometers per hour

lb/hr – pounds per hour

LDAR – Leak Detection and Repair

MACT – Maximum Available Control Technology

MCR – Mid-Course Review

MECT – Mass Emissions Cap and Trade

MIR – Maximum Incremental Reactivity

MOIR – Maximum Ozone Incremental Reactivity

NEGUs – Non-electric generating units

NESHAPS – National Emissions Standards for Hazardous Air Pollutants

NO_x – oxides of nitrogen (the sum of NO + NO₂)

NO_y – The sum of all nitrogen-containing species (NO + NO₂ + HNO₃ + PAN + HONO + NO₃ + N₂O₅ + organic nitrates, etc)

NSR – New Source Review

O₃ – Ozone

OTC – Ozone Transport Commission

OZIPP – Ozone Isopleth Plotting Program

OZIPR – Ozone Isopleth Plotting Program – Research

ppbv – parts per billion volume

ppm – parts per million

PSCF – Potential Source Contribution Function

psi – pounds per square inch

PSD – Prevention of Significant Deterioration

PSCF – Potential Source Contribution Function

PSDB – Point Source Data Base

RACT – Reasonably Available Control technology

RRF – Relative Reduction Factor

SAPRC90 – Statewide Air Pollution Research Center 1990

SCAQMD – South Coast Air Quality Management District

SOS – Southern Oxidant Study

TAC – Texas Administrative Code

TARA - Toxicological Risk Assessment Effects Evaluation Procedure

TCEQ – Texas Council for Environmental Quality

TexAQS 2000 – Texas Air Quality Study 2000

THOE – Transient High Ozone Event

TNRCC – Texas Natural Resources and Conservation Commission

tpd – tons per day

tpy – tons per year

TVA – Toxic Vapor Analyzer

UNC – University of North Carolina at Chapel Hill

UTA – University of Texas at Austin

VISTAS – Visibility Improvement State and Tribal Association of the Southeast

WOE – Weight-of-Evidence

1. Introduction

In December 2004, the Texas Council for Environmental Quality (TCEQ) approved a new policy as part of its ozone (O_3) attainment strategy for the eight-county Houston/Galveston/Brazoria (HGB) region, home to one of the most severe one-hour O_3 problems in the country. After requesting that restrictions be placed on the trade of highly reactive volatile organic compounds (HRVOCs) for other less reactive volatile organic compounds (VOCs), the U.S. EPA proposed approval of this policy in October 2005. The new policy, the (HRVOC) Emissions Cap and Trade program (HECT), is a market-based emission reduction system aimed at controlling the emissions of four highly-reactive VOCs: ethylene, propylene, 1,3-butadiene, and the isomers of butene, as a means of meeting the federal one-hour O_3 standard. By way of a complex series of chemical transformations, the emissions of VOCs and the oxides of nitrogen (NO_x) in the presence of sunlight can lead to excessive O_3 formation in urban areas. The TCEQ has chosen to allow trading as a means of controlling the emissions of specific highly reactive VOCs, thereby limiting the amount of O_3 formed in the HGB area.

Under the 1990 Federal Clean Air Act Amendments (CAAA), the HGB area was designated a severe-17 non-attainment area, and was required to attain the one-hour O_3 standard of 0.12-ppm by November 15, 2007. However, the eight-hour O_3 standard went into effect on June 15, 2005, and the one-hour standard was repealed. Under the more

restrictive standard of 0.08 ppm O₃, the HGB area is designated a moderate non-attainment area, and has until June 15, 2010 to attain compliance. The attainment demonstration must be submitted by November 2007. The TCEQ faces distinct challenges in instituting this first-of-its-kind program in the HGB area.

A unique and complex scenario of variables contributes to efficient O₃ formation in the HGB area, distinguishing it from other urban areas with comparable problems. Houston, Texas is the fourth largest city in the U.S. The population of the Houston Combined Metropolitan Statistical Area is over four million people. The absence of major public transportation facilities result in 2.7 million vehicles miles traveled daily. This equates to an abundance of VOC and NO_x emissions. As shown in Figure 1.1, Houston is home to one of the largest concentrations of petrochemical and chemical manufacturing facilities in the U.S.

Houston Petrochemical Production Capacity

<i>Compound</i>	<i>US%</i>	<i>Amount Produced</i>			<i>At 0.05% Loss</i>	
		billion lbs per year	million lbs per day	million lbs per hour	tons per day	lbs per hour
Ethylene	53%	27.6	75.6	3.2	18.9	1,575
Propylene	63%	10.9	29.9	1.2	7.5	622
Butadiene	63%	2.4	6.6	0.3	1.6	137
Xylene	38%	4.9	13.4	0.6	3.4	280
Benzene	36%	0.7	1.9	0.1	0.5	40
Toluene	25%	0.4	1.1	0.0	0.3	23

Sources: Business Houston, 2001; Houston Facts, 2000; Chemical Marketing Reporter 1996--1997; County Business Patterns, 1990; U.S. Census Bureau; after Deawon Byun

2.7 million vehicles drive 120 million miles each day

4 billion barrels of crude can be processed each day

Port of Houston is 2nd largest in US in tons loaded/unloaded
More than 100 commercial docks along ship channel.

Figure 1-1: Houston Petrochemical Production Capacity

These facilities produce large quantities of gaseous ethylene and propylene that are under pressures as high as 6000 psi and are moved by high pressure pipe lines and other pressurized vessels. The ethylene, propylene and other VOCs produced represent an unusual mix of O₃ precursor sources, emitting great quantities of NO_x and highly reactive VOCs, such as alkenes and aromatics. These factors are further coupled with a warm, sunny climate, a land-sea breeze, and meteorology that is conducive to slow-moving stagnant wind conditions that coincide with the industrial emissions area.

In addition to a scenario where O₃ formation is favored, there are both affirmative issues and concerns regarding implementation of the “cap-and-trade” method. The U.S. EPA has proposed approval of the TCEQ’s innovative program that is forward thinking in its intentions. It is an improvement over years of prior programs that had little effect on the principal source of precursor emissions, the petrochemical industry. The premise of the HECT program, to trade VOCs based on reactivity, is unprecedented. It is not the first state program to target reactivity as a measure to limit specific emissions; California and Louisiana also have programs that target reactivity in consumer products. It is only the second program of its kind in the nation to trade VOC emissions, after Illinois.

There is concern in that unlike with NO_x and SO₂, which experienced very popular emissions trading programs in the 1990s, VOCs are ill-suited to such. They are heterogeneous, abundant, and are emitted from many more sources within industrial facilities than is NO_x and SO₂. They have differing tropospheric lifetimes and rates of reaction, and exhibit a range of reactivities with respect to the formation of O₃. Measurement methods can be cumbersome and imperfect; fugitive VOC emissions are common. Some VOCs are

hazardous air pollutants (HAP) that require regulation by Maximum Available Control Technology (MACT) standards; 1,3-butadiene is such a pollutant. These differences increase both the difficulty of trading and elicit concern regarding environmental justice issues.

The results of several studies have elicited concern about the accuracy of emissions inventories and model reliability, the same model upon which SIP attainment demonstrations were conducted by the TCEQ. Research completed by Jeffries and Arunachalam (2005) for the EPA mandated Mid-Course Review (MCR) 2002 SIP reviews emissions inventories and conducts sensitivity tests of model reliability. It depicts modeling whose results are statistically similar to the SIP attainment modeling, but whose precursor conditions were dramatically different. Early results of SIP modeling studies completed by Jeffries and Kim (2006) for the HGB area eight-hour case highlights model irregularities similar to the one-hour MCR modeling results. Changes in inputs to the model's meteorology and an improved emissions inventory still produced results that indicated model performance problems.

Other research completed by Murphy and Stoeckinius (2004) for the Texas Environmental Research Consortium affirms successful implementation of the HRVOC trading program, assuming all emissions parameters are correct. Questions are raised, however, regarding the reliability of the emissions data, especially Other VOCs (OVOCs) that are emitted in greater quantities than HRVOCs, but are not proposed for any significant level of trading. All of these indicated circumstances prejudice the HECT program's objective: to bring O₃ levels in-line with federal standards.

There are a number of other conditions that make the ability of the tentatively approved HECT program to meet eight-hour ozone standards by the April 15, 2010 deadline

appear uncertain. There are model variances significant enough to be of concern.

Additionally, the magnitude of the number and severity of the current O₃ exceedances, an incorrect emissions inventory, a proposed implementation date of 2007 for the HECT program, a non-declining emissions cap, and the rapidly approaching federal deadline in which to meet the eight-hour O₃ standards make a successful outcome uncertain.

Regardless of the HECT program uncertainties, it must also be said that the four selected emissions trading programs against which the HECT is examined in light of, also encountered difficult beginnings and concern from various stakeholder groups regarding different components of the programs. Nonetheless, all four programs have achieved significantly larger reductions than what could have been achieved under command and control (C²) and, according to programs records, at a lesser cost. An examination of the impact each of the four programs has made on air quality policy better enables an understanding of the following three questions in relation to the HECT program:

- a. What constitutes “good” policy?
- b. How “bad” can various facets of a program be before it yields “wrong” policy?
- c. Is “terrible” policy better than a “perfect” one that cannot be instituted?

This paper applies these questions to aspects of the HECT program in an attempt to answer whether this program might adequately serve the HGB area in achieving HRVOC reductions.

2. Houston Air Quality

2.1 Area Description

Houston has an air quality problem, on the face of it, one of the worst in the nation. Since the inception of ozone (O_3) exceedance levels in the mid-1970s, Houston has not been in attainment of federal air quality standards for O_3 . The current benchmark is the eight-hour standard of 0.08 ppm, which went into effect on June 15, 2005. The HGB area must meet this standard no later than June 15, 2010. The difficulty that the Houston area has had in meeting the ozone standard can be drawn from the distinctive chemical and meteorological features that impact the HGB area. It is a very large metropolis with relatively poor mass transportation facilities, and the nation's largest combination of petrochemical facilities. Within the same manufacturing region are a large number of world class chemical manufacturing facilities. They are all primarily concentrated along the Houston Ship Channel, which flows southeast from near central Houston for about 20 kilometers (km) to the Galveston Bay from the eastern side of the city. Other facilities are scattered around in the metropolitan area, and a smaller compound of facilities are located southeast of Houston in Texas City, at the mouth of the Galveston Bay. Figure 2.1 depicts the eight-county non-attainment area and the Houston Ship Channel area.

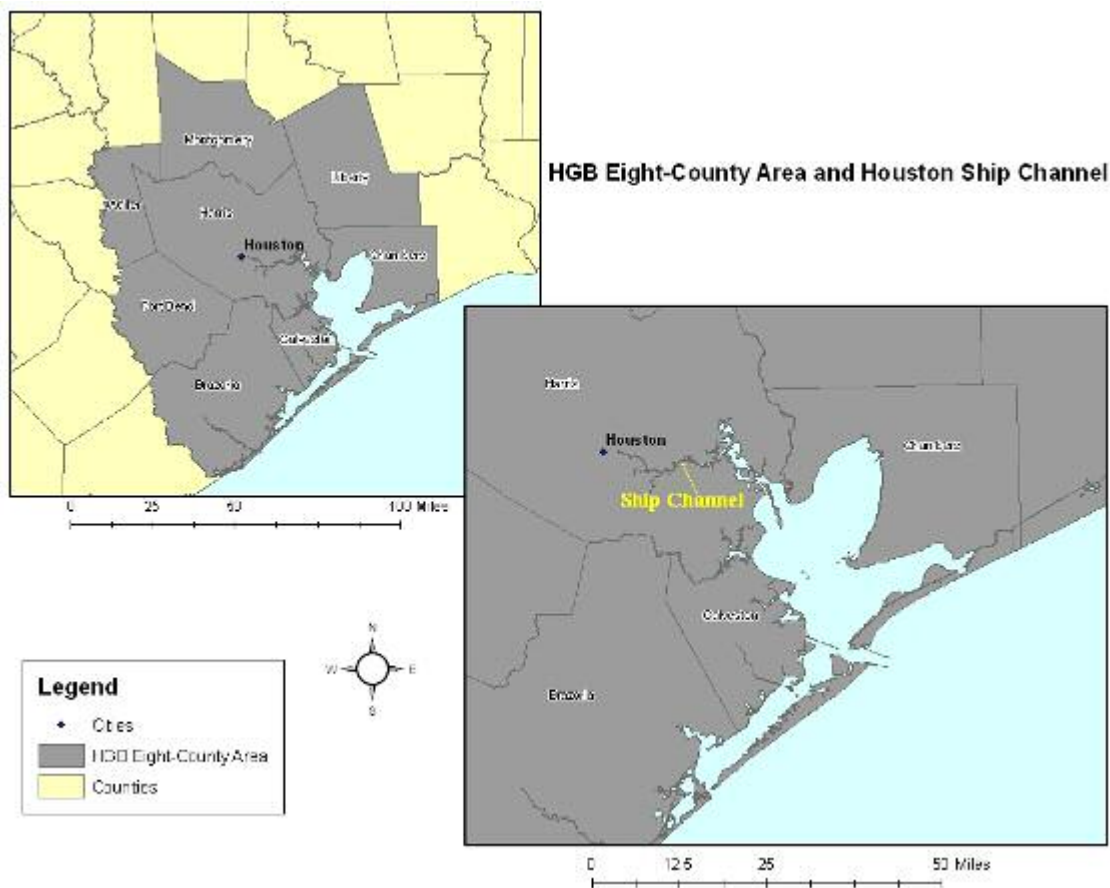


Figure 2-1: HGB Eight-County Area and the Houston Ship Channel

Together, these facilities can release an abundant, heterogeneous mixture of highly reactive VOCs, such as olefins and aromatics, and NO_x that under the right meteorological conditions results in very high ozone. These emission events are not all reportable, though many are. Under new rules, adopted in September 2002, 30 Texas Administrative Code (TAC) Section 101, paragraph (83) defines a reportable emissions event as “Any emissions event which, in any 24-hour period, results in an unauthorized emission equal to or in excess of the reportable quantity...”.

This is a unique feature of petrochemical plumes in that a substantial amount of

reactive hydrocarbons can be co-emitted with NO_x . Such a characteristic stands in contrast to power plant plumes into which reactive hydrocarbons must be incorporated from the surrounding atmosphere. Plumes downwind of petrochemical facilities routinely report higher mixing ratios of O_3 . Plumes from the city core and the electric generating units (EGUs) or power plants have O_3 plumes typical of other cities in the U.S. As such, facility location is irrelevant; “ O_3 production is magnified in light of the co-emissions” (Ryerson et al, 2003).

Additionally, Sexton and Westberg (1983) discovered that the fastest rates of O_3 formation and the highest yields per NO_x molecule emitted are predicted for conditions where strongly elevated concentrations of NO_x and reactive VOCs are simultaneously present. This happens at a young “photochemical age” with freshly emitted NO_x , before the NO_x becomes NO_z , which is usually in the form of HNO_3 , a “sticky” molecule, which will quickly precipitate out (Figure 2-2).

Photochemical Age



$$\text{NO} + \text{NO}_2 = \text{NO}_x$$

$$\text{Age} = [1 - (\text{NO}_x / \text{NO}_y)]$$

Age = 0.0 (fresh, just emitted; NO_x = NO_y)

Age = 1.0 (old; NO_x = NO_y; no O₃ production)

Figure 2-2: Photochemical Age

It is without accident that Houston was found to have the highest O₃ mixing ratios routinely encountered in the continental U.S., with surface sites yielding values exceeding 200 ppbv hr⁻¹ (Ryerson et al, 2003). Ozone values have been measured as high as 250 ppb in 2002, which at that time was the highest level recorded in the U.S. since 1997 (Kleinman et al, 2002). However, the O₃ plume was narrow and spatially-limited. Ozone production has a nonlinear response to precursors and varying environmental conditions, such as wind speed and direction.

To better understand the causes of the unique and characteristically high O₃ levels associated with Houston, the Texas Air Quality Study (TexAQS) 2000 field project was conducted in August and September 2000. It was developed as a method to improve understanding of the factors that control the formation and transport of air pollutants along the Gulf Coast of southeastern Texas. These results, coupled with photochemical modeling, have revealed that the HGB area is affected by two types of O₃ precursor emissions events.

There is the routine background O₃ levels associated with a metropolitan area of four million people with a heavy industrial presence. The second type of emission is unique to Houston; it is characterized by highly variable short-term emissions of HRVOCs that can then lead to spatially limited, very high O₃ concentrations. When this O₃ plume is then advected over fixed monitors, it leads to transient high ozone events (THOEs). THOEs are generally characterized by an increase of at least 40 ppb O₃ the hour before the high ozone, and a decrease of at least 40 ppb O₃ afterwards.

Another related concern is that Houston is the largest city in the U.S. without zoning restrictions. As a result, manufacturing facilities can be found in the same neighborhoods as residential communities. Such a heavy concentration of manufacturing facilities adjacent to residential areas invites concern about environmental justice issues, and deepens the concern to create a program that will have a positive impact on historically high O₃ levels.

2.2 Meteorology and Ozone Exceedances

A key component of the high O₃ levels in the HGB area come as a result of meteorology that is favorable to O₃ formation. During the summer, high pressure systems typically preside over the Gulf of Mexico. These synoptic scale winds typically lead to stagnant conditions and weak pressure gradients in southeastern Texas. As a result, local wind patterns tend to dominate area weather (Allen et al, 2002). Local sea-land breeze circulation patterns include a daily rotation, with morning winds coming out of the northwest. This occurs until afternoon winds bring in aged air masses, which were initially over source areas of the Ship Channel, back over land.

The absence of strong winds from one specific direction, and the presence of high

levels of ozone precursors, is critical to the formation of high ozone events. An example of a THOE formation is depicted in Figure 2-2. The most favorable wind conditions for ozone exceedances take place when winds occur in three or four quadrants. The presence of an afternoon wind reversal combines with an emissions event of O_3 precursors in the Ship Channel area to produce the THOE.

In an analysis of local wind patterns, Jeffries (2004) discovered that such conditions exist more than half of the time (Figure 2-3). Of this, only one in eight days, six percent of the 4,587 site-days, actually has an exceedance, or violation of the one-hour O_3 standard. Two-thirds of the O_3 exceedances occur when winds come from four quadrants over the course of the day. These exceedances occur from August through October, peak O_3 season in the HGB area.



Figure 2-2: Wind Trajectory for a THOE, August 21, 2000; wind reversal in the afternoon returns precursor rich air mass back over land; light winds and a large precursor mass increases THOE magnitude; arrows indicate location of ozone monitoring stations

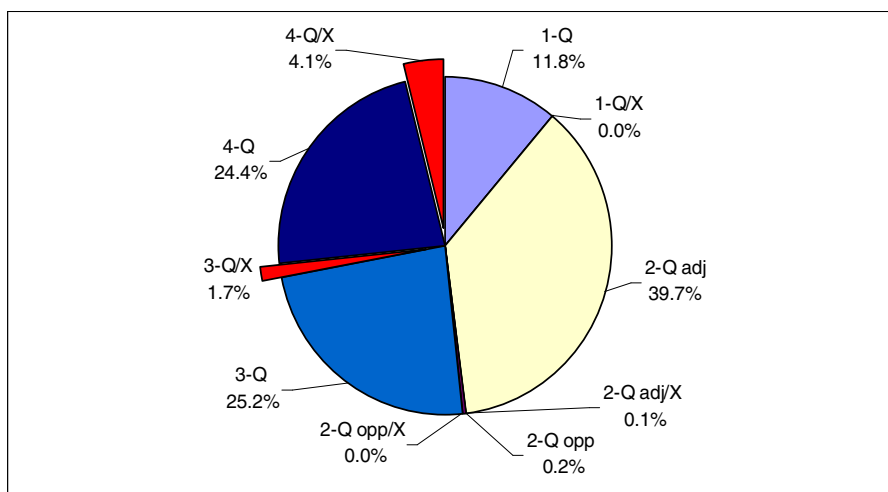


Figure 2-3: HGB Area Monitor Site Days, August – October, 1998 – 2000, Exceeding and Not Exceeding 1-hour Ozone Standard, Sorted by Number of Wind Quadrants During Day; Six Percent of 4,587 Site-Days were Exceedances

3. SIP Revisions – The Road to Cap and Trade

3.1 TexAQS 2000

The TCEQ eventually devised a two-part strategy to deal with the high ozone situation in the HGB area. This included the cap and trade program, which places an annual cap on steady-state and routine emissions, and an hourly emission limit for variable short-term emissions management. The data basis for these programs was the Texas 2000 Air Quality Study (TexAQS 2000), which primarily took place from August 15 – September 15, 2000 in the central and east Texas regions that included the HGB area. It involved 340 scientists and investigators along with 40 research organizations such as the National Center for Atmospheric Research, the EPA, the National Aeronautics and Space Administration, the Department of Energy, the Texas Natural Resources and Conservation Commission (TNRCC, forerunner of the TCEQ), and several universities.

The need for the study was evidenced by outdated information, the results of a 1993 Coastal Oxidant Assessment of Southeast Texas (COAST), fed into previous modeling studies of the area. The TexAQS study would focus on three areas of uncertainty: the emission inventories, chemical and physical atmospheric processes, and the photochemical air quality models used (Allen and Murphy, 2004). The study's primary objectives and findings are listed in Tables 3.1 and 3.2.

Table 3.1: Primary Objectives of TexAQs 2000

1. Characterization of O ₃ and particulate matter formation in extended metropolitan areas.
2. Understanding of diurnal cycles in chemistry and meteorology (especially nighttime chemistry)
3. Characterization of meteorological effects on O ₃ and particulate matter formation (especially boundary layer and marine interaction).
4. Characterization of the composition of particulate matter.
5. Improve emission inventories (especially biogenics, particulate matter, and selective reactive compounds).

Source: Forswall and Higgins, 2005

Table 3.2 : TexAQs 2000 Findings

1. VOCs from industry are primarily responsible for high ozone in Houston.
2. VOC emissions are substantially underreported by industry.
3. VOC concentrations in Houston are very different from other urban areas.
4. Ozone is produced faster and yields more in Houston than in other cities.

Source: TCEQ, 2003

3.2 December 2000 SIP Revision

Several SIP revisions took place before the TCEQ finally settled on the two-pronged strategy. As part of a December 2000 SIP revision, the TCEQ had emphasized a 90% NO_x reduction, and essentially no VOC-based controls. Such a strategy was adopted as the second part of a two-phase plan initiated by the Federal government in 1995, as a method by which states could achieve goals outlined in the 1990 CAAA. Per the Federal government, the second phase of the plan focused on results of modeling and transport. Modeling results showed that a decrease in NO_x emissions would actually result in increases in O₃ levels.

When the results of the modeling were released in the mid-1990s, the EPA allowed a NO_x waiver to take effect, which suspended NO_x controls if a disbenefit was shown.

By 1997, modeling showed that NO_x reductions were, in fact, needed. The December 2000 SIP revisions encompassed this to the exclusion of any VOC controls. It included such things as a NO_x Mass Emissions Cap and Trade (MECT) Program, and a 90 percent reduction from 1997 NO_x levels from point source emissions. The TCEQ and the EPA believed that the December 2000 SIP Revision would help achieve attainment, despite an acknowledged shortfall of 56 tons per day of NO_x, known as the “NO_x gap” (Soward, 2004). This level of reductions, however, proved controversial with the business community, which suggested an alternative 80 percent reduction plan, coupled with highly-reactive VOC controls. The business community cited a “sharp increase in the marginal costs associated with a 90 percent reduction, the diminished returns expected and the resulting lack of economic space for industries to grow their facilities” (Forswall and Higgins, 2005). The business community also felt a near certainty that even with 90 percent NO_x reductions for point sources, the failure to reduce the HRVOCs would produce O₃ violations from NO_x from non-industrial sources contributions.

Following a lawsuit by the Business Coalition for Clean Air (BCCA), the TCEQ, then the TNRCC, agreed under a court-ordered settlement to take up to 18 months to evaluate the causes of the rapid O₃ formation. It was also required to identify potential measures not yet identified in the HGB attainment demonstration. This resulted in an accelerated evaluation of the data from the TexAQS 2000 study, for which the major findings were released as early as February 2001.

One of the findings was that the mechanism for O_3 formation was different in Houston than it was for other cities in the Southern Oxidant Study, SOS. The SOS was a 14-year research and assessment program, ending in 2002, concerned with the formation/accumulation of O_3 , other oxidants, and fine particulate matter in ten southern states. Houston's problem was seen as the HRVOCs that were emitted from the industrialized Ship Channel region (see figure 3-1). The petrochemical industry emitted extremely high levels of HRVOCs, four of which are to be regulated via the HECT program.

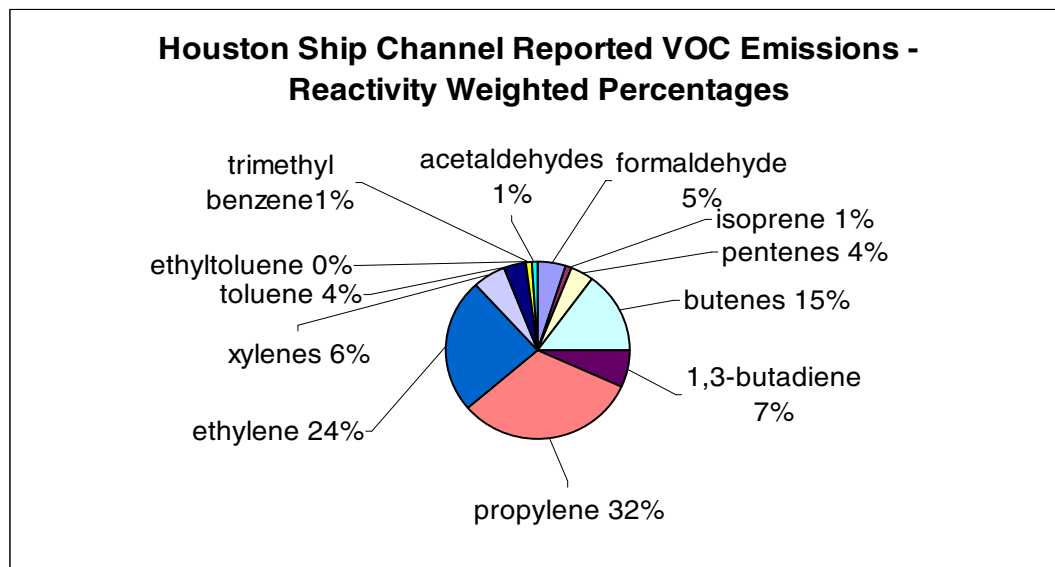


Figure 3-1: Houston Ship Channel Reported VOC Emissions – Reactivity Weighted Percentages (Data Source: Environ, 2002)

3.3 Emissions Inventories

3.3.1 Principal Sources

Another key finding of the TexAQS 2000 study was the level at which modeled VOC

concentrations had been underestimated. This was a result of the inventory calculation process. The TCEQ derived the emissions inventory used for model development in the 2000 SIP from a number of sources. These included Texas point sources, Special Inventory, Region 12 upset/maintenance database, Louisiana point sources, regional point sources, offshore point sources, and Mexico point sources. Questionnaires were issued to EPA-defined major point sources, those facilities emitting more than 10 tpy VOC, 25 tpy NO_x, or 100 tpy of other criteria pollutants. Completed questionnaires were entered into the point source data base (PSDB).

Regional inventories consisted of inventories from any areas outside of Texas and Louisiana that were included within the modeling domain. A growth factor was applied to the 1992 version of the Minerals Management Service (MM5) offshore emissions inventory to account for the growth of offshore oil platforms. The Mexico Emissions Inventory was accounted for from the 1999 Big Bend Regional Aerosol and Visibility Observation Study (BRAVO). The Special Inventory was limited to those major point sources emitting at least 250 tpy of non-methane organic compounds, or at least 1000 tpy of NO_x, and more than five percent HRVOC in their inventory.

The Special Inventory came about as a result of an unexplainable difference between the observations and reported emission inventory data, which inadequately described HRVOC presence in the HGB area. Data used thus far contained the annual average inventories, which spread all emissions reported, even those from emission events which released as much as 8,000 lb/hr of ethylene, over 365 days. A correction was needed to allow modeled O₃ levels to better fit with observed. The TCEQ developed the Special

Inventory, which consisted of data from 81 industries; this corrected for some of the inventory shortfall. This data was used to develop more than 9,000 new emission composition profiles that better described VOCs emitted from facilities producing HRVOCs. The new data produced little more mass than did the original method of reporting emissions, but represented better speciation. This Special Inventory was added to other regional sources, collectively known as the Ozone Seasonal Daily, inventory. Together these two inventories became known as the “regular inventory”, which became the “unadjusted” inventory used in MCR SIP modeling.

Using this data, the TCEQ still could not replicate observations that occurred during the TexAQS. According to Jeffries and Arunachalam (2005) predictions of O₃, ethylene, olefin and formaldehyde were significantly less than what was observed. This disparity between observed and modeled O₃ levels was insufficient to pass EPA statistical muster. In correcting for this disparity, the TCEQ imputed 1,092 tons of 12 terminal olefins (Table 3.1). Justification for adding this level of olefins to the inventory was based on a single observation made by an instrumented Baylor University aircraft on October 19, 2001 in which a number of industrial plumes had high concentrations of terminal olefins that matched high NO_y concentrations. Four of the plumes had ratios of NO_y to olefins ranging from 0.8 to 1. (TCEQ, 2004).

Table 3.1: Terminal Olefins Selected for Imputation

Species		
Ethylene	1,3-butadiene	Toluene
Propylene	Isoprene	Ethyltoluene, all isomers
Butene, all isomers	Tri-methylbenzene, all isomers	Formaldehyde
Pentene, all isomers	Xylene, all isomers	Acetaldehyde

Source: TCEQ, 2004

Given this information and because of time constraints in developing the MCR SIP, a 1:1 ratio of NO_x to olefins was assumed for the MCR SIP modeling. Over the course of the modeled period, August 25th – 31st, 2000, this equated to an addition of 1,092 tons of VOC. This inventory became known as the “psito2n2” inventory. Table 3.2 lists the quantity of HRVOC in the modeling inventory for the MCR SIP. The adjusted 2000 inventory is the regular ozone season daily totals plus the imputed inventory of 12 terminal olefins. The 2007 adjusted modeling inventory is that which remains after controls have been added to the model. The 2007 inventory, still inclusive of the imputed inventory but with HRVOC controls, is larger than the unadjusted “regular” inventory, which does not include the imputation of terminal olefin emissions.

Table 3.2: HGB Modeled 8-County HRVOC Summary

HGB Source	2000 Unadjusted Modeling Inventory O ₃ Season Daily HRVOC (tpd)	2000 Adjusted Modeling Inventory O ₃ Season Daily HRVOC (tpd)	2007 Adjusted Modeling Inventory O ₃ Season Daily HRVOC (tpd)
Harris County	20.6	115.0	22.6
Seven Surrounding Counties	10.0	56.3	22.0

Source: TCEQ, 2004

3.3.2 VOC Speciation

Other concerns developed regarding the inventories used during the MCR SIP. Not all sources produced well-speciated profiles. According to the TCEQ, some point sources in Texas and Louisiana reported little or no speciation of their hydrocarbon emissions (TCEQa, 2004). For modeling purposes, any source that reported less than a 75% speciation were assigned a default EPA emissions, or Texas Source Specific Category (SCC) code (Cantu, 2004). Emissions factors were used in obtaining emissions inventories when source records were not well speciated, or maintained. “Emission factors” compiled by the EPA for a number of sources and activities in the “AP-42 Compilation of Air Pollution Emission Factors”, were used to calculate emissions from a range of inputs. However, emissions factors can only represent average values for a given VOC population; variances from mean values can be relatively large.

One issue with the speciation method for those sources that reported less than 75% speciation was that the speciated portion of the emissions was still assigned a default profile.

Beginning in 2002, in response to industry requests, the TCEQ started retaining compound specific emissions as reported for all sources. From that time, the “default” profile was only applied to the unspiciated portion.

3.3.3 VOC Measurement Uncertainty

A significant problem with measuring VOCs comes as a result of their volatility. In petrochemical processes, VOCs are often present in the liquid state, from which they can volatilize at almost any point during the same. Controlling possible eruptions, or fugitive emissions, of VOCs from potential points is central to creating a more reliable inventory, something not easily achieved.

For the 2000 Emissions Inventory (EI) the PSDB classified all sources as stacks, flares and fugitive emissions (Cantu, 2004). The stack emissions were vented from a stack, the flare emissions were those that were emitted from a flare even after burning. About one to two percent of the VOC emissions were sent to the flare. The fugitive emissions were the most difficult to control, as they were emitted directly into the air from leaking pipes, flanges and valves. As depicted in Figure 3-2, the TCEQ has determined that 46% of the 2000 HGB EI area point source emissions are fugitive (Cantu, 2004). This is significant in the development of an emissions baseline, which must be accurately completed to institute a successful cap and trade program.

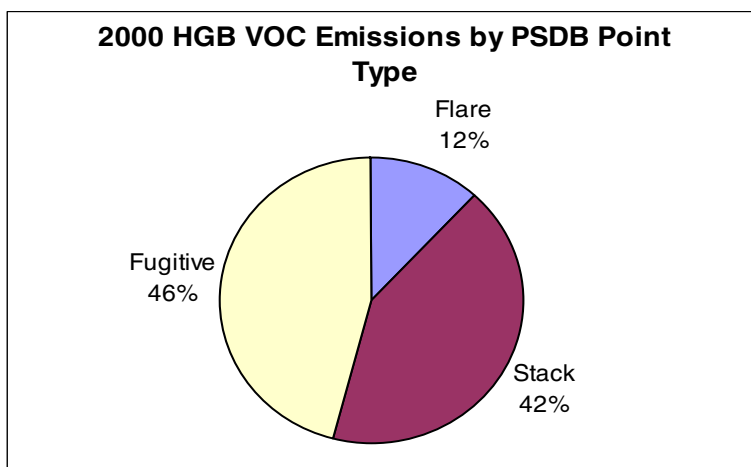


Figure 3-2: 2000 HGB VOC Emissions by PSDB Point Type (Data Source: Cantu, 2004)

A variety of methods was used to determine all types of emissions counted in the 2000 HGB area VOC emissions inventory, as described in Table 3-3 and pictured in Figure 3-2. AP-42, the EPA national factors, was one method used to measure fugitive emissions; it accounted for 23 percent of the methods utilized. This method is not as accurate as unit correlation equations, which were later instituted as part of the Leak Detection and Repair (LDAR) program.

Table 3.3: Methods and Percentage of VOC Measurement Use During the 2000 HGB Area Emissions Inventory

Method	Definition	Percentage
Calculated	Calculated from engineering principles	34
Estimated	Estimated from production data	26
AP-42 emissions factors	Calculated from EPA emissions factors or tank calculations based upon them	23
Measured	Based upon single stack test	8
Materials Balance	Calculated from material handled, e.g. paint applied	5
Continuous monitoring	Measured by a continuous stack monitor	4

Data Source: Cantu, 2004

A number of researchers indicate that the emissions of HRVOC are not well defined (Murphy and Allen, 2004; Jolly, J. et al, 2004; Murphy and Stoeckinius, 2004; Ryerson et al, 2003). Allen and Olgauer (2004) indicate that in reconciling ambient emissions to reported inventory, the greatest degree of underestimation in VOC emissions is consistently found to be the eastern Ship Channel area, which carries a high density of petrochemical and chemical refineries.

Research also suggests that light alkenes, moderately reactive VOCs such as paraffins that are less than C₄, and aromatics such as toluene and C₃-C₅ alkylbenzenes are significantly under-represented in the emissions inventory (Murphy and Allen, 2004). However, their degree of underestimation may be less than for the HRVOCs since the processes that emit HRVOCs are often under very high pressure. This could increase the degree of underestimation more than would occur for emissions in lower pressure processes,

or that are liquid at ambient temperatures.

Also, many less-reactive VOCs are much lower in volatility than the HRVOCs, which could also serve to reduce the amount of emissions. Regardless, some less reactive VOCs that are emitted, such as pentane and butane, carry a reactivity-weighted concentration higher than that of several HRVOCs, namely the isomers of butene and 1,3-butadiene. All of these VOCs may figure more prominently in eight-hour O₃ standard calculations as a result of the longer averaging times used to obtain such a standard.

Recent research points to other air emissions that impact O₃ formation in the HGB area, which were not included in the inventory used for attainment demonstration purposes. Regional scale photochemical modeling and ambient observations in the southeastern Texas area suggests that chlorine radical chemistry enhances ozone formation. Estimates suggest that molecular chlorine emissions can enhance ozone mixing ratios by 11- 16 ppbv (Chang et al 2002). The chlorine precursors are principally emitted by anthropogenic sources, such as industrial cooling towers and area swimming pools. Preliminary inventories suggested that these sources contribute 11.04 tpd of chlorine emissions (Chang et al, 2002).

Despite the flaws indicated in the emission inventory resulting from the TexAQS 2000 study, it represents one of the most advanced and refined local emissions inventories to date (NARSTO, 2005). An accurate emissions inventory is one of the most important parts of a successful cap and trade program. Without it, the baseline is only one of many things that will be incorrect. Any photochemical modeling dependent upon base data will not produce reliable results. This being said, improvements in emissions monitoring methods in preparation for the first HRVOC trading season in 2007, are being passed on to update the

2000 EI (Allen, 2006). Updates will need to be reflected in the baseline level upon which participating industry receives its trading quotas.

3.4 Other VOCs (OVOCs)

One concern regarding the inadequate emissions inventory is the presence of OVOCs, which were not included in the HECT program, and could possibly change the level of O₃ formation as a result of their sheer volume. “OVOCs are dominated by alkanes up to C₆ and substituted aromatics, especially xylenes and toluene” (Murphy and Allen, 2004). There has been considerable research and concern by scientists, and stakeholder groups, such as Mothers for Clean Air, Environmental Defense and the Galveston-Houston Association for Smog Prevention (GHASP) that the quantity of OVOCs had been underestimated in the 2000 emissions inventory, which could result in increased O₃ production. Their common concern was of the TCEQ’s narrow focus on HRVOCs, which account for less than one-half of the ozone reactivity regularly measured in the region. Modeling studies completed/authorized by the TCEQ has indicated that the targeted HRVOCs yield less than one-half the region’s detectable tropospheric ozone reactivity.

Murphy and Stoekinius conducted photochemical modeling of potential cap and trade situations using the 2000 emissions inventory and other data from the TexAQS 2000 study. Modeling was conducted using a 4-km grid resolution. In their report entitled *Survey of Technological and Other Measures to Control HRVOC Emission events* (2004), they indicate that emission reductions of OVOCs due to HRVOC controls appear to be significant. They estimate the mass of the ancillary OVOC emissions to be three times the mass of the HRVOC reductions, and the reactivity, when weighted by the Maximum

Incremental Activity (MIR) method, to be 50% that of the HRVOC reactivity. In a 2004 memo to the TCEQ, J. Wilson, GHASP president, states that “the TCEQ does not indicate that its plan will actually control highly reactive VOC emissions and completely neglects the role of other highly reactive VOC emissions.”

As part of the evolution of the SIP attainment process, the TCEQ has decided to trade OVOCs that were used in its Emissions Banking and Trading Program (EBTP) for up to five percent of the mass of the HECT program cap. The unit of trading in the EBTP is the Emission Reduction Credit (ERC). It is a permanent reduction in the VOCs, NO_x and certain other criteria pollutants from the stationary, mobile, and area sources. They must be real, quantifiable, permanent, surplus and enforceable. As far as trades are concerned for the ERCs within the HECT program, the trades are only for OVOCs, not NO_x, or other criteria pollutants. Unlike with the EBTP, trades of OVOC ERCs for HRVOC credits are only good for two years within the same non-attainment trading area in which it was generated.

3.5 January 2003 SIP Revision – HRVOC Controls

Results of the TexAQS 2000 study prompted a shift in the O₃ attainment strategy from a NO_x-only based strategy to a strategy detailing specific reductions in both VOCs and NO_x. As part of a settlement agreement with the BCCA, several parts of the MCR were accelerated to determine if the industrial NO_x controls should be partially replaced with HRVOC controls. A confirmation that the HRVOC reduction would also reduce ozone led to implementation of HRVOC controls to the SIP Revision in two stages. The first phase was with the 2003 SIP revision; the second in the 2004 MCR. NO_x controls were reduced from the controversial 90% level to 80%. TCEQ’s analyses indicated that an 80% NO_x

reduction coupled with HRVOC controls would be equivalent to the original 90% NO_x reduction. However, the model used to determine the necessity of a 90 percent NO_x reduction had never showed attainment. Ozone values were predicted to be 142 ppb (Jeffries, 2006). Thus, the model that demonstrated attainment at 80 percent was initiated on a flawed foundation. The 80 percent attainment model results indicated that HRVOC controls accounted for approximately a 36 percent reduction in emissions via better monitoring/control of fugitives, flares, cooling towers and vents (Forswall and Higgins, 2005).

Emissions of HRVOCs were to be limited through the emplacement of site caps, based on a rolling 24-hr average, at major facilities, those facilities with HRVOC releases greater than 10 tpy. A medium to large refinery can have 600,000 points capable of producing VOC leakage. VOCs released through flares and vents come under concern since the VOCs released there are frequently the products of incomplete combustion. Fugitives and cooling tower releases are the results of leaks within the process stream. Cooling tower VOC emissions are the result of leaks into the cooling water, which then volatilizes in the cooling tower. Of the four emission sources of VOCs, the most difficult to control are the fugitives. They can only be controlled through better monitoring and leak detection. The Leak Detection and Monitoring (LDAR) program was updated in 2002 to require monitoring of VOC emission sources on a varying schedule, based on the equipment's previous history of routine and unscheduled maintenance. As an assurance of maintenance and equipment compliance, an audit by an independent third party is required every two years.

In Harris County, which contains Houston and the Ship Channel, four HRVOCs were

viewed as disproportionately contributing to O₃ formation: ethylene, propylene, 1,3-butadiene and the isomers of butene. Harris County also contributes the majority of the HRVOC emissions, which ultimately lead to ozone exceedances (see Figure 3-3). In the surrounding seven counties of the HGB area, only two VOC species were listed as highly reactive: propylene and ethylene.

In recognition that the characterization of event emissions was critical to the development of an accurate and more representative emissions inventory within the HGB, in January 2003 the TCEQ instituted a new rule requiring reporting of VOC emissions at least 100 lbs over permitted amounts; previous reporting requirements necessitated reporting VOC emissions only when the event exceeded 5,000 lb over permitted limits. Earlier modeling studies had assumed averaged hourly emissions rates from refineries and other such non-electric generating units (negus) over the day, given that they operated over a 24-hour, 7-day per week period with relatively uniform material throughout. In fact the emissions were highly variable in space and time. Non-routine emissions, or emission events, were recorded at greater than 5,000 lbs in a 24-hour period. Despite the fact that these emission events could lead to THOEs, the modeling studies averaged these events over time, which translated to a small increase in uniform emission levels (Murphy and Allen, 2004). This had a deleterious effect on a model's ability to accurately predict O₃ levels in the area.

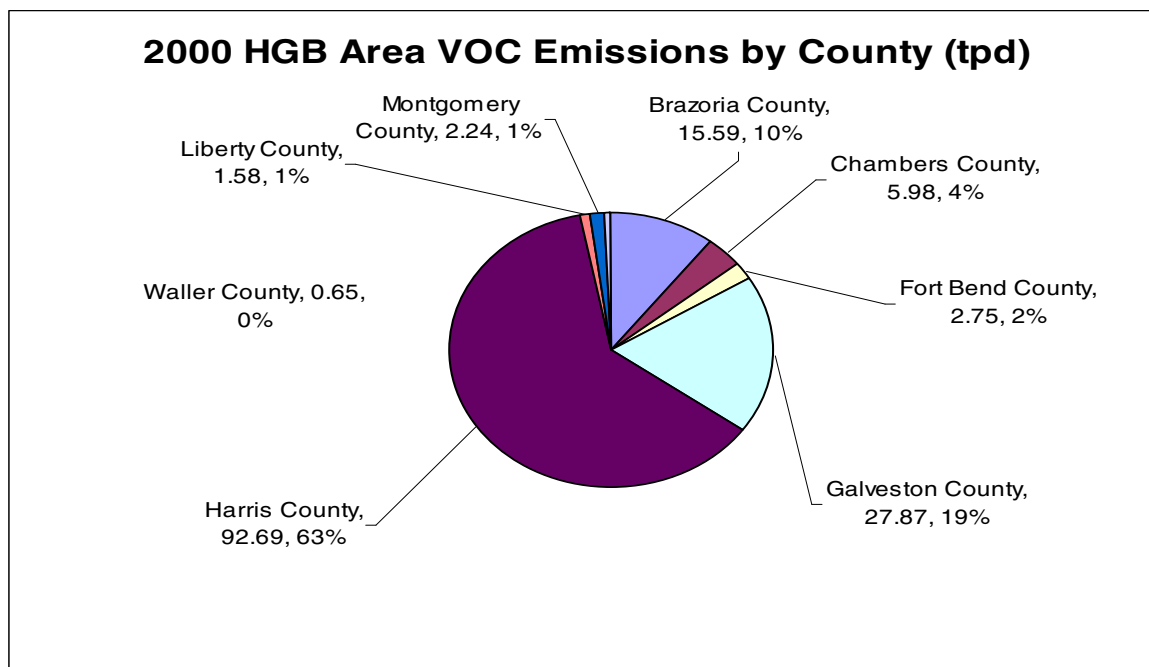


Figure 3-3: 2000 HGB Area VOC Emissions by County (tpd) (Data Source: Cantu, 2004)

3.6 Non-Routine VOC (Event) Emissions

Ozone control plans have conventionally been designed on the assumption that the emissions are relatively constant. Changes in levels of air pollution have usually been confined to explanations of meteorological variability. The HGB area is unique in that its difficulties with ozone pollution stem from the combination of two types of emissions: normal routine emissions and large non-routine HRVOC emissions (emission events). In these non-routine emissions, for short periods of time, usually less than 24 hours, greater than normal quantities of emissions are released. Murphy and Allen (2004) indicate that the TCEQ Event Emissions Database suggests that such releases can have great mass, can be frequent, and are exceptionally localized (Figure 3-4).

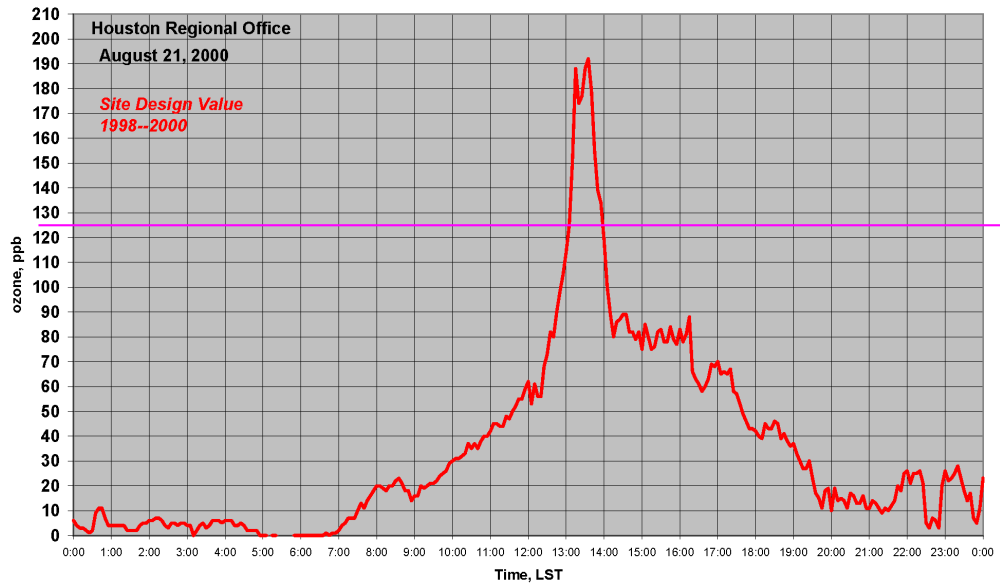


Figure 3-4: Transient High Ozone Event (THOE), Houston, Texas, August 21, 2000. The purple line indicates the 1-hr O₃ standard of 125 ppb (Source: TCEQ, 2000).

Evidence reveals that some emissions of VOCs from non-EGUs, consisting of petroleum refineries, chemical manufacturing plants and other industrial operations can vary from average annual emissions by a factor of 10-1000 (Allen and Jeffries, 2004). Variations such as this may occur only a few times a year, but the number of facilities with capabilities of this happening equates to a larger daily occurrence of such an event. Figure 3-5 depicts the frequency of emission events in 2003.

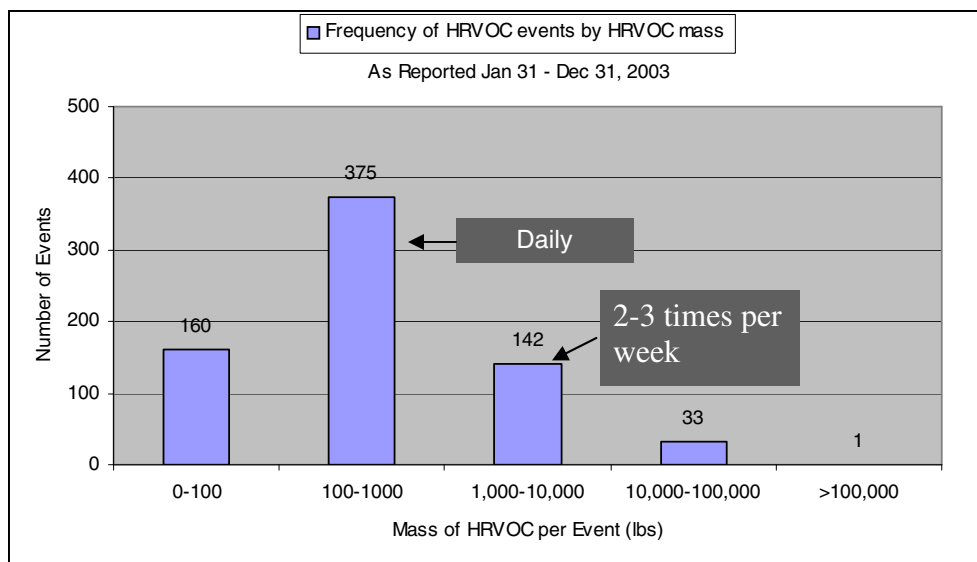


Figure 3-5: Frequency of HRVOC Events by Emission Mass, Jan 31 – Dec 31, 2003. The largest number of events range from 100 – 1000 lbs. Most of mass associated with events that are > 1000 lbs. (Source: Jeffries, 2005)

The problem with these event emissions occurs with photochemical modeling and emission inventories. Although they only constitute about 12 percent of the total annual HRVOC emissions, HRVOC emission events are extraordinarily concentrated in space and time (Murphy and Allen, 2004). When these short-term events are averaged into the emission inventories that are used in photochemical modeling, the resulting predicted ozone values may be significantly different than observations. The magnitude of the impact or the “increase in peak ozone per pound of event emission” (Allen and Jeffries, 2004) depends on the location and time of the release, and on other emissions present. The value of the range of the ozone impact is between 1 and 4 ppb per 1000 lb of release (Allen and Jeffries, 2004).

Such inconsistencies thus render the model of little or no effect. The possibility of such an outcome requires that this characteristic be accounted for within emissions

inventories and photochemical models.

Prior to a rule change in September 2002, non-routine emissions were not reportable unless they exceeded the daily permitted emissions by more than 5000 lbs. The limit for a reportable event has since been reduced to those that are at least 100 lbs. Additionally, Texas HB 2912 required that emission events be filed electronically, and be available in a public database, something that was not previously done. Reporting requirements for alkane releases remained at the 5000 lb limit, as long as such releases contained less than 0.02% of specific olefins, NO_x and other reportable compounds.

The non-routine emissions, both scheduled and unscheduled, occur for a variety of reasons. In 2001 the EPA the Texas Natural Resource and Conservation Commission (forerunner to the TCEQ), and the Louisiana Department of Environmental Quality collaborated with representatives from thirteen petroleum refining and chemical-producing facilities to evaluate and implement methods for emissions reduction, and for the measurement and reporting of progress. Table 3-4 summarizes what they discovered to be the principal causes among participants of process releases or upsets.

Table 3.4: Root Causes of Process Release, Petrochemical and Chemical Producing Facilities (Texas and Louisiana), 2001

Type of Release	Percentage	Root Cause of Release	Percentage
Equipment Failure	27	Corrosion	7
Process Upsets	14	Instrument Failure	5
Human Factors	10	Other	5
Startup/Shutdown	9	Seal or Gasket	3
Equipment Design	8	Pressure Relief Valve	2
Procedures	8	Piping or Tubing	2

Source: U.S. EPA et al, 2001

Unscheduled emission events accounted for a total of 30.3 percent of such emissions in 2003 (Murphy and Allen, 2004). In the same year, emissions variability above the level of the continuous emissions, greater than 10,000 lbs/hr, occurred approximately three times per month. In the same year, for two – three times per week, emissions variability increased to over 1,000 lbs/hr. Air quality modeling suggests that at the most sensitive locations and at the most sensitive times of the day, releases over a two- to three-hour period can result in increases in 2-3 ppb in peak ozone concentration per 1,000 lb of additional HRVOC emissions (Allen and Jeffries, 2004).

For the HGB area, therefore, it was important to design a base case for air quality modeling purposes that contained a proper balance between emissions events and routine emissions. The base case (2000) inventory would affect the future case (2007), which in turn, affects control strategy effectiveness.

3.7 Grid Resolution

Designing a proper base case also entails consideration of the impact of the grid resolution on emission events. Air quality models such as CAMx, the Comprehensive Air Quality Model with Extensions, used by the TCEQ, typically calculate ozone concentrations at the 4-km horizontal or, in some cases, the 1-km horizontal resolution level. Figure 3-6 depicts the difference in peak ozone concentrations, calculated for the same emission event, but at different resolutions. A 1-km ozone peak, not created by an emission event, is also depicted. The event simulated at the 1-km grid resolution produces nearly 80 ppb more ozone than does the 4-km resolution.

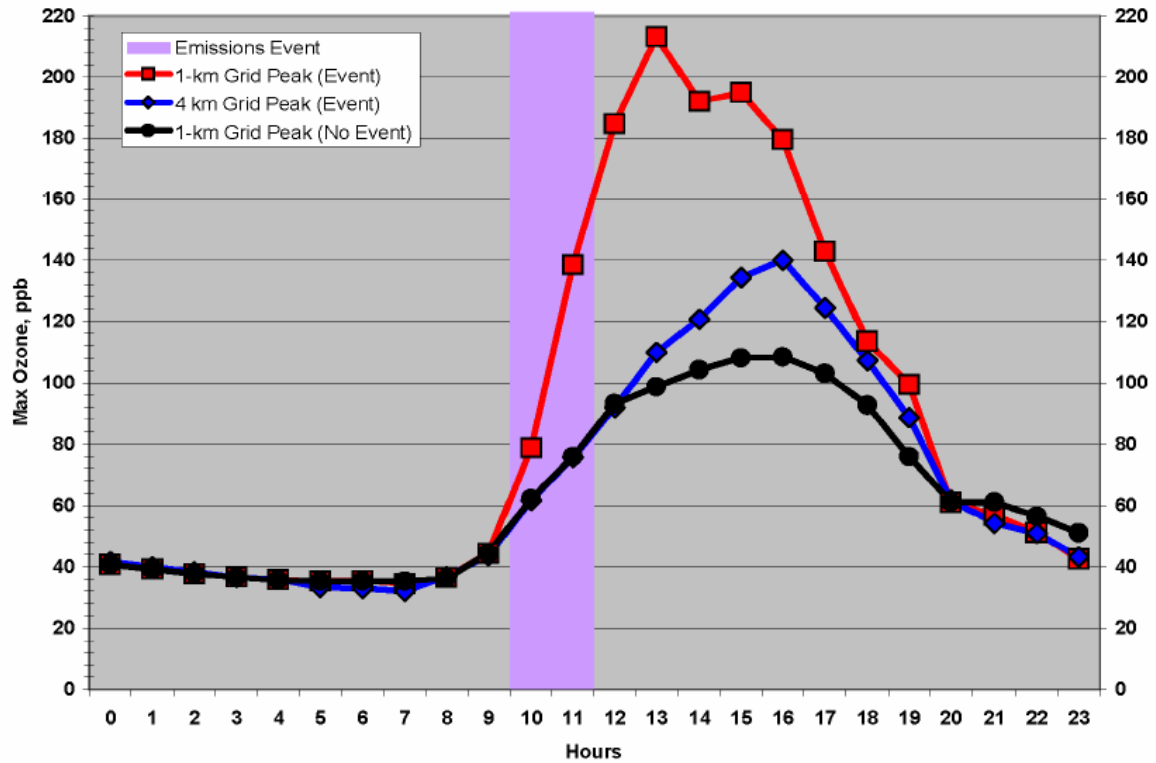


Figure 3-6: Effect of Horizontal Grid Resolution on Emission Event Simulation in 1-km and 4-km Regular Inventory. The X-axis is for hours of August 30, 2000 and Y-axis shows the peak ozone concentration for each hour of the day. The event release was 1,450 lb ETH and 10,188 lb OLE (one-hour); the event duration was two hours (annotated by the purple box). (Source: Jeffries, 2002)

Cook et al (2005) found that ozone precursor plumes tend to be less diffuse when simulated on a 1-km horizontal grid rather than on a 4-km grid. Coarser grids were found to dilute emissions and diminish the impact of ozone formation. This is, in part, due to the smoothing effect of coarser grid resolutions on winds and advective currents.

The necessity of using the correct grid resolution was demonstrated in the H12 project conducted by UNC and UT researchers. In said study, it was found that highly significant emission events of HRVOCs occurred that contributed to increased ozone levels. It also demonstrated that simulations conducted at a 1-km grid resolution were necessary to reproduce the high concentrations of ozone observed over the HGB area because of the lessening of the very localized nature of some of the emissions, such as olefin species or ethylene. These emissions could be small enough to limit themselves to a 1-km grid cell (Jeffries and Arunachalam, 2005). However, the TCEQ SIP modeling was only performed at a 4-km resolution.

The modeling of emission event simulations is essentially a “race between chemistry and dilution”. Within the model, there is competition between the physical dispersion and the chemical oxidation of the NO_x. Each of the 1-km sized boxes has less area in which the reactants disperse. At this resolution, the chemistry dominates the process due to the quadratic effect that the box size imparts. The effect, depicted in Figure 3-6, is production of a “squared” concentration effect of ([HRVOC]*[NO_x]) in which the organic radicals could oxidize the NO more times in the cell, relative to the linear rate at which the NO_x and HRVOC were being transported out of the cell and diluted” (Jeffries and Arunachalam, 2005).

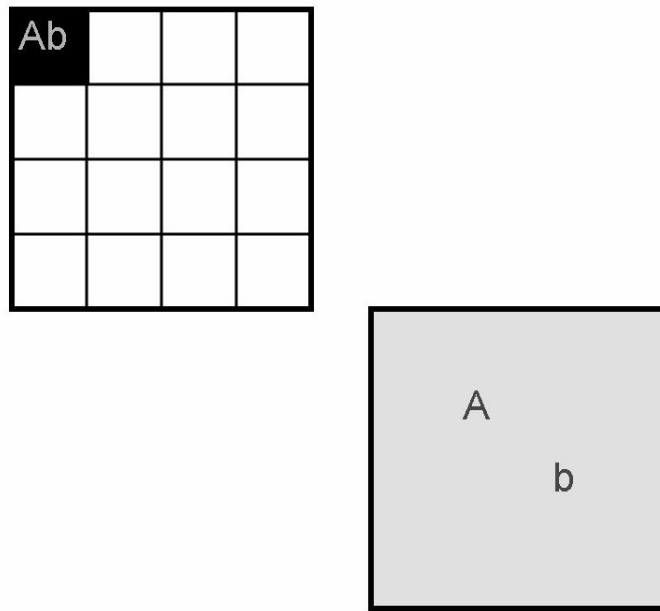


Figure 3-7: Effect of Grid Resolutions on Cell Concentrations Producing a Squared Concentration Effect of Reactants. Top: 1-km grid, Bottom: 4-km grid (Source: Jeffries, 2003).

3.8 Implementation of the 8-Hour Ozone Standard

The June 15, 2005 implementation of the 8-hr ozone standard in the HGB non-attainment area brought about additional concerns to the modeling and attainment expectations, and a greater need for an effective HECT program. Given the EPA's "moderate" designation for the HGB area under the 8-hr standard, attainment is required by 2010, with control activities expected in place by 2009. The 8-hr SIP is due to the EPA by 2007. This deadline does not leave sufficient time to develop an 8-hr SIP modeling scenario. Therefore, the TCEQ has instead decided to set up the base year (2000) and future year (2007) modeling frameworks used in 1-hr HGB SIP revisions to model residual 8-hr

“non-attainment” beyond the current 1-hr SIP revision controls (Teschke et al, 2005).

Additionally, the TCEQ will examine the effectiveness of various emission reduction scenarios in the 2007 model framework to estimate levels of control that may likely be needed for 8-hr ozone attainment.

The method used to determine the 8-hr ozone standard differs from the methods used to obtain 1-hr controls. It is based upon a relative, rather than an absolute, sense of photochemical model estimation. The standard is based upon relative reduction factors, RRFs, as depicted in Figure 3-7. The RRF is the ratio of the future 8-hr daily maximum concentration predicted near a monitor, averaged over multiple days, to the baseline 8-hr daily maximum concentration predicted near the monitor, averaged over the same multiple days (EPA, 2005a).

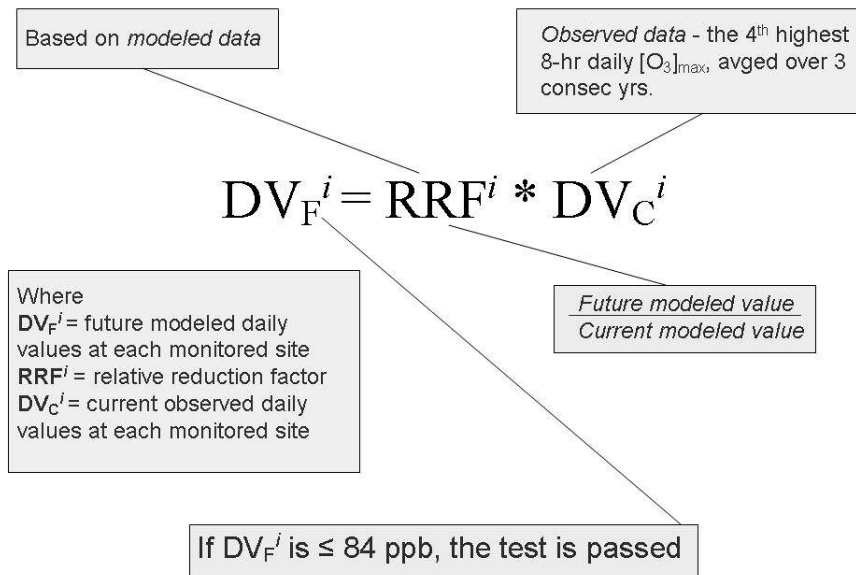


Figure 3-8: EPA 8-hr Ozone Attainment Test (Concept: Tesche, 2005)

The maximum concentration predicted near the ozone monitors are influenced by ozone and precursor concentrations at grid cells surrounding the monitor. This is of great import in Houston given the use of the 1-hr attainment demonstration as the basis for attainment of the 8-hour standard. Thompson et al (2005) conducted research identifying the limiting monitors in the Houston area for the 8-hr ozone attainment test. Without including the ozone values at the two limiting monitors, calculations indicated that the magnitude of reductions needed to meet the 8-hr ozone attainment test include reductions of 72 percent of area source VOCs, 90 % of the point source VOCs and 100% of all other VOC sources. The amount of reductions needed if the limiting monitors were included would increase from the indicated levels. Such levels of reductions would be very difficult to achieve.

Such levels of reductions may be difficult to obtain at any cost. The HECT program is an important element in the 1-hour ozone attainment demonstration plan. However, the task is made more difficult by an incomplete emissions inventory, such as previously discussed with the presence of the chlorine radical, which is not accounted for in said inventory. Recent research details the contribution of the chlorine radical and molecular chlorine to ozone formation in the HGB area (Chang et al, 2002; Tanaka et al, 2000; Tanaka et al, 2003).

4. Controlling HRVOCs – Cap and Trade

4.1 Cap and Trade Programs

Given the level of oversight required, and the necessary baseline data needed before implementation, the cap and trade program is, arguably, the most complex type of emissions trading program. Trading VOCs increases the level of difficulty given VOC heterogeneity. Several key elements of the cap and trade program include the necessary complete baseline inventory, comprehensive and consistent emissions monitoring, and an accounting system to ensure the integrity of the trading system. Other elements of the cap and trade program include determining an acceptable allowance allocation plan, establishing a relevant trading area, and determining a reliable and cost effective monitoring standard. Establishing a reliable monitoring standard is especially difficult given VOC heterogeneity. An advantage to the program is that trades do not have to be pre-certified. Therefore, the cap and trade system generally results in the presence of more fluid markets.

Allowances are granted to the participating firms based on a thorough emissions inventory. These allocations are made as a percentage of the cap roughly according to the size of inventoried emissions, unless the emissions were out of compliance with permitted limits, which would further decrease final allocations. Usually the total emissions cap declines over a portion of the period for which it is in effect, thereby decreasing what each participating source receives in annual allotments. Participation in the cap and trade program

is usually involuntary for the largest sources, such as power plants, chemical manufacturing facilities or refineries. Not participating in state sanctioned operations, such as cap-and-trade programs, can result in the withdrawal of air pollution permits, effectively shutting a firm down.

Once allowances are used up, participating firms must buy more allowances from other firms who did not need all of their given allowances. Firms can also buy credits from a bank of stored allotments that is run by the program administrator. Following the conclusion of a trading period, such as one year, a reconciliation period is realized in which all accounts are required to have sufficient allotments or purchases to cover affected emissions. There is a penalty for exceeding emission limits without having sufficient allowances to cover the overage at the end of the reconciliation period. This penalty is usually accessed via the imposition of monetary fines and/or loss of allowances for the next trading season.

Administered correctly, this type of trading program represents the greatest certainty of providing both an environmental and economic benefit (NAPA, 2000). Conversely, such a program can also be the most complicated to administer, given the difficulty of establishing an accurate emissions inventory, and of ensuring accuracy in emissions monitoring.

4.2 The Challenge of Reactivity-based VOC Trading

The advent of VOC trading programs in the mid-1990s represented a departure from previous thinking on emission trading schemes. VOCs are uniquely difficult to trade for many reasons. VOCs have varying and environmentally dependent reactivity. In the presence of NO_x and sunlight, VOCs undergo a complex photochemical process that produces O₃ via a feedback-controlled, non-linear progression. Individual VOCs differ

significantly in both their rates of reaction and the products of their oxidation reactions. According to Doyle et al (2004) the photodegradation of 1,3-butadiene and isoprene, the latter being primarily of biogenic origin and abundant in the HGB area, yields products which themselves display toxicity characteristics to human lung cells. This necessitates consideration of residual primary, secondary, and tertiary products formed from VOC reactions. Additionally, ozone production is not related in any linear fashion to the carbon mass from the VOC emissions. This underscores some of the many reasons that the VOC emissions trading program has met with some resistance by stakeholder groups.

As a result of their heterogeneity, fugitive VOCs from process streams are more difficult to measure. Mass emission reporting is generally stipulated in regulations such as SIPs, and for emissions inventories. Determining the mass emission requires sampling the stream for a representative concentration of the pollutant. The flow rate and molecular weight of the compound in question determine the mass emission. This process is much easier for compounds such as SO₂ and NO_x, than it is for the variety of VOCs usually present in a process stream from a chemical manufacturing facility or a refinery.

Leak detection at a large refinery, with potential leak points numbering in the hundreds of thousands, is a labor intensive task. Current EPA approved methods for leak detection involve use of a hand-held toxic vapor analyzer (TVA), which is accurate but labor intensive in that inspections must be conducted as point-to-point surveys in close proximity to valves, pipes or other VOC carrying components.

Further, VOC leaks can be misleading in that small leaks can exhibit a high concentration of a VOC, while a larger leak can have a lower concentration, though it may be

leaking a larger quantity of the VOC. Fortunately for the petrochemical industry, the new IR imaging camera by FLIR Systems is able to visualize VOC leaks. The establishment of this method of leak detection has already saved countless man-hours at those refineries, or in other industrial applications. One drawback to this new technology is in the relatively limited range of VOCs it can detect (FLIR Systems, 2005). Of the four HRVOCs proposed for trading, the new IR camera can detect only two of them, ethylene and propylene.

Adverse health effects can be exacerbated when toxic VOCs are traded. Maximum Available Control Technology (MACT) standards, as dictated by the National Environmental Standards for Hazardous Air Pollutants (NESHAPS), must be invoked. This increased level of scrutiny increases transaction and compliance costs, thereby decreasing monetary incentives to trade.

4.3 Reactivity Scales

4.3.1 Necessity and Applicability

The reason for reactivity-based trading is that the varying ozone forming potentials of individual VOCs can differ by an order of magnitude from one compound to another. The use of reactivity scales narrows the focus to those VOCs with the greatest reactivity. Reactivity-based methods are significantly more complex than mass-based methods. Mass-based VOC control methods reduce all VOCs emitted, without regard to reactivity.

Although a reactivity-based control may reduce selected, reactive VOC emissions more than mass-based controls, a number of unresolved concerns linger. Enforcement of selective VOC reduction is more difficult due to the variety of VOCs present in a process

stream. Additionally, not all the products of an incomplete combustion process, such as those vented through a flare, are known. Such conditions lead to increased costs, in determining emissions composition, over costs for the mass-based methods.

According to Russell et al (1995), considerations must be accounted for the dependence of reactivity measures on three factors: environmental conditions, particularly meteorology and precursor emissions, the level of chemical and physical detail and uncertainty in the models used for quantifying reactivity, and the uncertainties in emissions composition. Additionally, regional geography, East versus West, impacts the applicability of any accepted reactivity scale.

A variety of reactivity scales have been devised to quantify the degree to which different VOCs affect ozone formation. VOC reactivity is of increasing concern because of the difficulty in controlling area sources of air pollution such as dry cleaners, vehicle exhaust emissions, and paint coating operations. Since the early 1990's, especially in California, there has been an increasing emphasis on developing VOC-based products that limit the potential for O₃ formation. Enhanced photochemical modeling capabilities and improvements in the understanding of atmospheric chemistry is allowing the EPA to move away from its long held position on reducing the total mass of VOCs as the precursor to ozone formation.

EPA reactivity policy is still officially guided by its 1977 "Recommended Policy of Control of Volatile Organic Compounds". The policy focuses on the exemption of compounds it deems less reactive than ethane, or "negligibly reactive"; ethane is considered the "cut point" or "bright line". Ethane was selected as the "cut point" based upon

experimental smog chamber data (Dimitriadis, 1999). A compound was deemed negligibly reactive if its molar rate constant, the “ k_{OH} ” value, for reactions between said compound and the hydroxyl radical ($OH\bullet$), yielded a value less than that of ethane. The $OH\bullet$ reactivity scale is a measure of how rapidly a compound begins participating in ozone formation. It is critical to the formation of photochemical smog. It is also the oldest and least reliable of the ozone reactivity scales (Jeffries and Arunachalam, 2005). However, more rate constants have been determined for this VOC loss pathway than for any other loss mechanisms. Additionally, the $OH\bullet$ is the dominant loss pathway for VOCs in the lower troposphere (Finlayson-Pitts and Pitts, 2000).

One problem with this method of classifying VOCs was the tendency for reactive high-molecular weight VOCs to be classified as negligibly reactive (Dimitriadis, 1999). In doing so, the EPA required the VOCs to be subject to control and inventory regulations. It also exempts non-VOCs from these same regulations, and does not allow their use in emissions trading activities. As a result, certain halogen species such as chlorine, which have shown to be reactive in ozone formation, are generally excluded, or overlooked, in regulatory methods to limit ozone formation.

The EPA, however, is moving towards policy that takes VOC reactivity-based applications into account. In September 2005 the EPA published the “Interim Guidance on Control of Volatile Organic Compounds in Ozone State Implementation Plans”. It encourages states to consider recent scientific information on the reactivity of VOCs in the development of SIPs designed to meet the O_3 NAAQS. The guidance summarizes recent scientific findings, and clarifies the relationship between modern reactivity-based policies

and EPA's current definition of VOC.

The EPA has also considered the development of a national reactivity scale. In 1998, the EPA participated in the formation of the Research Reactivity Working Group (RRWG), a group of scientists and stakeholders organized to help develop an improved scientific basis for regulatory-related regulatory policies (EPA, 2005b). It found that despite the large degree of environmental variability in reactivities, careful choice of metrics could alleviate the differences in VOC behavior throughout the country and throughout the year. There are certain considerations that must be taken into account. Any scale selected must fit into existing, approved state SIP rules. It must be standardized for use in any U.S. geographical location.

4.3.2 MIR Scale

The MIR scale is what the TCEQ has adopted as the means to transfer between Emission Reduction Credit (ERC) VOCs, or non-highly reactive VOCs, and HRVOC credits. William Carter, an early pioneer in the use of reactivity scales, reasoned that no single reactivity scale can predict incremental reactivities under all conditions. For certain regulatory applications, however, one scale would have to suffice. The only other feasible alternative would be to have no scale (Carter, 1994a). He developed a series of 18 scales for use by the California Air Resources Board (CARB) in its "Low Emissions Vehicle and Clean Fuels" regulations. Given its high-profile use in California, Louisiana, and now Texas, one of the most widely used scales is the Maximum Incremental Reactivity (MIR) scale, one of the 18 original scales. The original purpose behind its development was to quantify vehicle exhaust emissions from alternatively fueled vehicles. It is now employed widely as a

reactivity scale throughout the United States in a variety of uses including reactivity quantification in solvents.

Carter created the MIR scales from OZIPR, Ozone Isopleth Plotting Program – Research, a simple photochemical trajectory model based on EPA’s Ozone Isopleth Plotting Program (OZIPPP) model. OZIPR contains a more chemically-detailed mechanism than OZIPPP. Using this program, Carter quantified the O_3 from 180 different VOCs in 39 cities across the U.S. (Russell et al, 1995). The cities were selected based on 1980’s SIP modeling with OZIPR. Representative high O_3 episodes were chosen for each city. To quantify the O_3 produced Carter used “incremental reactivity”. It is defined as the incremental change in peak O_3 generated resulting from addition of a VOC to a VOC/ NO_x mixture (Carter and Atkinson, 1987). The use of incremental reactivity removes the dependence of O_3 on changing emissions. It also negates the effect that can occur when the VOC is either being added to, subtracted from, or replacing a portion of the base emissions.

Different reactivity scales describe different conditions. The 18 scales Carter created are all dependent upon NO_x to varying degrees (Carter, 1994c). They are based on three different methods for quantifying ozone impacts and on six different approaches for dealing with the dependence of reactivity on NO_x . The MIR scale is more depictive of a dense source, or urban, region, which displays low VOC/ NO_x ratios (~4-6 ppm C:1 ppm NO_x). And, it is more applicable to such heavily urban conditions where VOC control is more effective (Russell et al, 1995). It is commonly expressed in units of grams of ozone produced per gram of VOC emitted.

Table 4-1 lists the MIR values for some VOCs including the four proposed,

scheduled to be regulated in the HECT program.

Table 4.1: MIR Reactivities – Select VOCs

VOC Group Name	Compounds in the Group	Average MIR Values for Species in the Group
Propylene	Propylene	11.58
Ethylene	Ethylene	9.08
Butadiene	1,3-butadiene	13.58
Butene	1-butene, c-2-butene, t-2-butene	12.48
Pentene	1-pentene, c-2-pentene, t-2-pentene	9.42
Isoprene	Isoprene	10.69
C ₂ C ₃	Ethane, Propane, Acetylene	0.71
Butanes	n-butane, Isobutane	1.34
Pentanes	n-Pentane, Isopentane	1.60
Alkanes	n-hexane, 2-Methylpentane, 3-Methylpentane, 2,2,4-Trimethylpentane, 2,3,4-Trimethylpentane, n-Heptane, -Octane, n-Nonane, n-Decane, 2-Methylheptane, 2-Methylhexane, 3-Methylheptane, 3-Methylhexane, 2,2-Dimethylbutane, 2,3-Dimethylbutane, 2,3-Dimethylpentane, 2,4-Dimethylpentane	1.39
Toluene	Toluene	3.97
Xylenes	o-Xylene, p-Xylene	5.87
Trimethylbenzenes	1,2,3-Trimethylbenzene, 1,2,4-Trimethylbenzene, 1,3,5-Trimethylbenzene	9.89

Aromatics	Benzene, Styrene, Isopropyl benzene, (Cumene), Ethylbenzene, m-Diethylbenzene, p-Diethylbenzene, n-Propylbenzene	3.13
Cyclos	Cyclopentane	2.14
Ethyltoluenes	o-ethyltoluene, m-ethyltoluene, p-ethyltoluene	6.61

Source: Forswall and Higgins, 2005

4.3.3 MIR Uncertainty

There are concerns regarding use of reactivity scales, specifically, the MIR scale. According to Yang et al (1995), one major concern is whether the atmospheric organic chemistry in the ambient, albeit, polluted air is well enough understood to predict the impacts on air quality. An error in the measurement of rate constants or specific product yields can create uncertainties. Moreover, the rates of many gas phase reactions have not been directly measured, but are instead inferred by analogy with better known reactions such as the rate constants of reactions with the hydroxyl radical.

Another concern with the MIR scale is its lack of ability to include particulars of atmospheric significance, such as wind shear and the spatial and temporal details of emissions. As a result, this scale fails to address issues of pollutant transport and mixing, both of which may affect reactivity. These uncertainties are further exacerbated when “condensed” chemical mechanisms are used, in which chemical species and reactions are combined, for more manageable inclusion into photochemical models. Carter used a chemical mechanism he created for use by the California Air Resources Board (CARB) for use in air pollution mitigation issues. The mechanism, SAPRC90, the Statewide Air Pollution Research Center, created in 1990, condensed 120 different species together to

create simplified photochemical reaction mechanisms (Carter, 1994).

The MIR scale was created by Carter for individual VOCs with OZIPR, using 10-hr simulations. This simplistic trajectory model does not favorably compare with a modeled 3-D airshed in which spatial and temporal distributions of pollutants are predicted. Multi-day ozone episodes are common; the carryover of pollutants from one day to the next is critical since a larger fraction of the less reactive VOCs will remain over the following days (McNair, 1992). Further, the MIR scale sums individual compound reactivities to estimate the combined impact of the mixture, which is not what happens in the ambient atmosphere. Products formed have varying reactivities, which do not equate to the sum of the reactants' reactivities.

One study did find a more favorable comparison of the MIR 0-D model with 3-D Eulerian models. Bergen et al (1995) found that the use of average reactivities, such as what the MIR scale employs, can lessen the effect of environmental variability. The researchers employed a 3-D air quality model for the Los Angeles basin area with MIR value inputs using only the Los Angeles inputs, one of the 39 cities whose input parameters the MIR scale is based upon. The MIR results, obtained using the average of all 39 cities from which the MIR scale was devised, were used as a comparison tool. Bergen's results indicated a better correlation between the MIR average of the 39 cities and the 3-D model than did the Los Angeles MIR inputs.

4.3.4 LS-RR

There are other scales that do consider the temporal and spatial differences inherent in various geographical locations, such as the LS-RR, least squares-relative reactivity, scale.

The LS-RR uses an airshed model to calculate the slope of the line that represents the absolute reactivity of each species versus the reactivity of the base mixture (Hakami et al, 2004). The EPA finds its greatest advantage is that it appears “to be robust over different regions of the country, meteorological episodes, year of analysis, averaging times, and models” (EPA, 2005). As a 3-D metric, it allows for temporal and spatial fluctuations. It is not as widely known, however, or used in practical applications, as is the simpler MIR 0-D scale.

4.4 Air Shed “Hot Spots”

Issues surrounding the non-uniformity of concentrations that result from VOC trading usher in concerns about toxic “hot spots”, or over accumulation of a VOC, especially a HAP, in one location. This inevitably leads to discussion of environmental justice issues. Some pollutants, such as greenhouse gases, can be considered uniformly mixed. By the time it takes for the impacts of such pollutants to occur, they have dispersed over a wide region. In contrast VOCs are spatially heterogeneous and have varying reactivity resulting in immediate adverse reactions.

For air pollutants in general, the location and extent of damage caused by one unit of emissions will vary according to the emissions location. The potential for emissions concentration occurs when emissions at different locations are treated as interchangeable (Nash and Revesz, 2002). This is always of concern, given that emissions from the same local area may still have varying exit velocities, gas temperature, stack height and stack diameter (Krupnick et al, 1983). Prevailing winds and topography may play an even stronger factor in determining the potential for “hot spots”.

In cases where prevailing winds and topography are a factor, a usual solution is to institute multiple trading zones, and restrict trading accordingly. Other solutions proposed by Nash and Revesz include designing markets in units of environmental degradation, rather than units of emissions, and designing markets in which the trading does not take place on a one-to-one ratio.

A market priced in terms of units of environmental degradation is still economic theory, and involves increased costs in terms of necessary computer modeling for each transaction, as well as a closely supervised market. Markets designed with offset pricing, a trading ratio greater than unity, can be used as a means to counteract the perceived environmental harm done by trading between otherwise restricted zones. Such pricing methods might take place when market density is thin, with few buyers and sellers, as a means of increasing trading volume.

The many side effects that can occur with VOC trading explains why more states have not adopted it for a trading issue, deeming the issues too complex, citing uncertainty about the environmental benefits or the ability to meet the NAAQS attainment goals. The South Coast Air Quality Management District (SCAQMD), which covers Los Angeles, considered VOC trading as part of its 1994 RECLAIM program. The District decided against VOC trading because of the complexity involved.

5. HGB HECT Program

5.1 Documentation/Participation

The rules governing HECT regulations are listed in Division 6, Subchapter H, Chapter 101 of Title 30, Part I to the Texas Administrative Code. There are several categories of facilities subject to this involuntary program. Most of the facilities governed by this program are chemical plants and petroleum refineries, emitting at least 10 tons per year (tpy) of HRVOCs, or that have the potential to emit more than ten tpy of HRVOC, from all covered facilities at the site. Facilities emitting less than 10 tpy that desired to participate in the trading program were allowed entrance. Election of such had to occur prior to May 1, 2005. Exempt sites that later increase potential to emit greater than 10 tpy of HRVOC will have to purchase all allowances needed from the open market. Once a facility is subject to the HECT program, it is always subject to it. The various categories are summarized in Table 5.1. The categories titles are the author's, and not those named by the TCEQ.

Table 5.1: HECT Program Source Characterization

Category	Description	Allowance Source
Participating Sources	Emits >10 tpy HRVOCs; participation involuntary	Allowances granted from TCEQ (distinction made between refineries and other sources using HRVOCs in a process)
New Participating Sources	Emits <10 tpy, but opts in prior to May 1, 2005.	Allowances granted from TCEQ
Formerly Exempt Sources	Increased the potential to emit >10 tpy after May 1, 2005	Allowances must be purchased on open market
“Set-Asides”	Units do not use or produce HRVOC but have potential for HRVOC emissions	Receives set percentage from TCEQ based upon percentage of source’s throughput or storage of HRVOCs

This program establishes an annual, non-declining, mandatory cap on participating sites. They are subject to the HRVOC control requirements detailed in Chapter 115, Subchapter H, Division 1 and 2. The TCEQ used the average annual emissions from 2000 – 2004 and attainment demonstration modeling as the baseline from which an HRVOC emissions cap would be established (TCEQ, 2004). This cap was reduced by five percent as a compliance margin to address the uncertainty in what it terms “geographical emission shifts” inherent in cap and trade programs. As of July 2006, the number of major accounts within Harris County was 51 (Appendix). Following in Table 5-3 are a list of the basic rules of the HGB HECT program:

Table 5.2: Basic Provisions of the HGB HECT Program

Trading Zones	2 zones - Intra-Harris County and inter-, intra-surrounding seven counties
Number of Major Accounts	Harris County: 51

Species Traded (Harris) or controlled (surrounding counties)	Harris County: ethylene, propylene, 1,3-butadiene, isomers of butene Surrounding seven counties: ethylene, propylene
Allowance	The authorization to emit one ton of an HRVOC, expressed in tenths of a ton, during a control period
Allowance Distribution	Based on trading zone, type facility (refinery, sites with HRVOC in process stream, sites without HRVOC in process stream), and percentage facility contributes to baseline of activity
Banking	Allowed for one year
Property Rights	An allowance does not constitute a security or property right
Penalty for Excess Emissions	Reduction in site's allowances by 110% of the excess amount in following control period
Control Period	April – December
Reconciliation Period	January – March
Annual Compliance Report	Due in reconciliation period; must include total amount of HRVOC emissions from each covered facility at site, and a summary of all final trades
Conversions from other programs	Conversion is allowed for VOC ERCs for HRVOC allowances, based upon MIR reactivity level, up to a maximum of 5% of facility emission allowances
Program Audit	Required every 3 years

5.2 Determining Baseline Activity and Allowance Allocation

The TCEQ will allocate allowances for all HRVOCs traded. Certain sites in the eight-county region receive allocations as a “set aside” from the total cap: loading and storage facilities, and petroleum refineries, which do not use or produce HRVOC but have potential for HRVOC emissions. All other sites receive a percentage allocation based on the

total baseline of activity for all sites within their specific trading zone. The TCEQ (2004) defines baseline activity as the amount of HRVOC produced as an intermediate, byproduct or final product or used by a process unit that is not recycled internal to the process unit.

The level of baseline activity for each process unit at a site is to be calculated as the level of activity for any consecutive 12 months chosen for the period of calendar years 2000 – 2004. The TCEQ determined the total level of activity at a site by summing all process units' activity levels at that site that produces one or more types of HRVOCs as a final, intermediate or byproduct. Each process unit chooses the 12-month period that best describes its operational level. Facilities, which would otherwise be exempt, that choose to opt-in to the program receive a minimum allocation of five tons. This amount is subtracted from the allocations to remaining sites.

5.3 VOC ERC Conversion to HRVOC Allowances

A controversial new section was added to the SIP prior to release that provides sites subject to the HECT program the opportunity to convert VOC emissions reduction credits (ERCs) that have been properly certified to a yearly allocation of HRVOC allowances. 30 TAC §101.302 defines an eligible ERC as criteria pollutants, excluding lead, or precursors of criteria pollutants for which an area is designated nonattainment. Specific to O₃, eligible ERCs would be any VOC deemed an O₃ precursor. VOC ERCs qualifying for conversion must be generated from sites within the HGB area. ERCs must be generated from a reduction strategy implemented after December 2004, to reduce VOC species other than those defined as an HRVOC. VOC reductions from installation of controls deemed to be best available control technology (BACT), under NSR permit, are not allowed to be

converted to HRVOC allowances. In addition to the emission credit requirements, a qualifying ERC must be real, quantifiable, surplus, and permanent at the time the ERC is converted.

The conversion of qualifying VOC ERCs is calculated based on the ratio of reactivity between the maximum incremental reactivity (MIR) for the speciated VOCs reduced, and the MIR for the HRVOC. The TCEQ uses the MIR values under the table title ***MIR Values for Compounds*** under California's Code of Regulations. Controls on this controversial issue are obtained by requiring the prior approval of the executive director to convert between ERCs and HRVOCs. Further, the amount converted is limited to 5 percent of the site's cap, as a means to control uncertainty attached to this manner of VOC ERC conversion.

The controversy surrounding the issue of trading VOC ERC reductions is due to the uncertainty attached to the MIR scale method of determining the ozone forming potential of VOCs, as discussed in Section 4.3.3. Ambient atmospheric processes occur in a 3-D environment that cannot adequately be explained by a process based on an EKMA model. The uncertainty attached to the MIR scale's determination of the O₃ forming potential of a VOC is magnified in light of 30 TAC §101.399 that allows credit for HRVOC reductions based on the reduction of another type VOC.

5.4 Trading

The trading region essentially consists of one area: Harris County. The second zone, consisting of the remaining seven counties of Brazoria, Chambers, Fort Bend, Galveston, Liberty, Montgomery and Waller, could be subject to the same restrictions as Harris County given public notice. In Harris County, all four HRVOCs are being monitored/traded. The

outlying seven counties are only subject to controls for ethylene and propylene. The differences in the two zones are a result of several reasons: Harris County experiences greater difficulty in obtaining the ozone standard. Additionally, the allowances in the outlying counties are only authorized for ethylene and propylene emissions, while the allowances count for all four HRVOCs within Harris County. Figure 5-1 depicts the trading area.

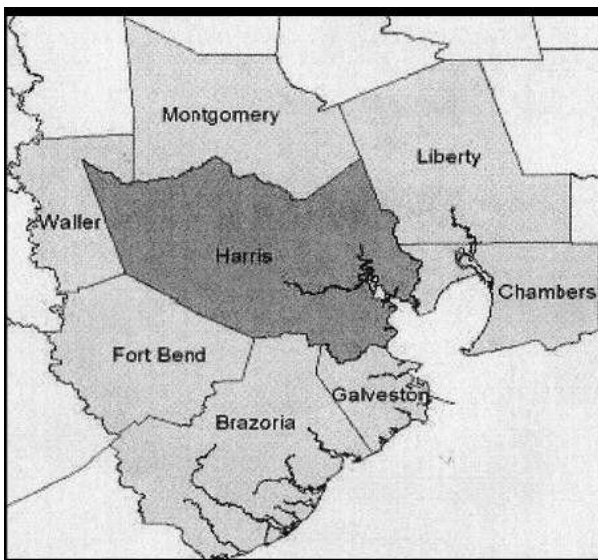


Figure 5-1: HGB Trading Zones

5.5 Administrative Controls

The TCEQ restricts HRVOC allowances to satisfaction of requirements of the HECT program. They are not allowed to be used to meet or exceed the limitations of any annual emission limitation regarding New Source Review (NSR), Nonattainment Review and Prevention of Significant Deterioration (PSD) Review. Allowances may be simultaneously used to offset requirements for new or modified sources subject to federal nonattainment

NSR requirements.

On March 31st of the year following each control period, the program administrator will deduct allowances from the site's compliance account equivalent to the total HRVOC emissions from all covered facilities at the site. Annual HRVOC emissions are to be calculated for each hour of the year and summed to determine total HRVOC emissions. Emissions from scheduled shutdown and startup will be included in total annual HRVOC emissions. The TCEQ has established an hourly emissions limit from emissions events or emissions related to startup, shutdown, or maintenance activities; this short term limit is set at 1200 lb/hr. Alternate methods of calculating HRVOC emissions are allowable, but only after justification for the alternate methods are made.

Allowance deductions for compliance with a control period shall be made first with the most recently allocated allowances before deducting the banked allowances. Any allowances not used for compliance may be banked or traded for use in the following control period only. After this, the allowance expires. Allowances initially allocated to sites located in the seven surrounding counties are restricted from use in Harris County. The same is true for allowances initially allocated to sites in Harris County; they are restricted from use in the seven surrounding counties.

During the reconciliation period, from January through March, account holders complete an annual compliance report, detailing the total amount of HRVOC emissions due by each account holder to the program director. The report also details methods used in determining HRVOC emissions, and a summary of all final trades. The Executive Director must perform an audit within three years of the effective date and every three years thereafter

6. Lessons Learned – The Road to Reactivity-Based Cap and Trade Programs

6.1 Previous Emissions Trading Programs – Lessons Learned

A review of several of the better known emission trading program of the last decade opens up some insights to parameters necessary for an emissions trading program to achieve its target goals. Specific considerations are given to an area's unique characteristics, whether anthropogenic, meteorological and/or geographical. The uncertainties these considerations may impose help to determine how well suited a program is to a specific area, and whether the program considered constituted “good” or ineffective policy.

All of the programs reviewed may be considered part of the “second generation” of emissions trading programs, as defined by Fromm and Hansjurgens (1996). They are far advanced beyond the 1970's “first generation” policies of offset emissions, netting, bubbles, and ERCs. In these aforementioned programs, emissions were tied to activity levels, which are a less efficient method than directly tying emissions with pollution levels (Deweese, 2001). The pinnacle of these “second generation” style programs, the VOC cap and trade, is by far the most complex of its generation.

6.1.1 The National Sulfur Dioxide (Acid Rain) Trading Program

The introduction of the Sulfur Dioxide (SO₂) Allowance Trading program under

Title IV of the 1990 Clean Air Act Amendments was, for its time, a very ambitious application of emissions trading instruments. Emissions trading applications had been used before in the 1980s for the phase-out of leaded gasoline and for stratospheric ozone depleting chlorofluorocarbons, CFCs. But these phase-outs were completed on a much smaller scale than what was planned for the SO₂ trading program. The goal was to decrease SO₂ emissions by 50 percent below 1980 levels by the year 2000.

This first of its kind emission trading program met with overwhelming success, though not without some shortcomings, with emissions reductions that exceeded the target goal. Arguably, it marked a significant event in the timeline of a movement away from the exclusive use of command and control (C²) instruments, and towards a political acceptance of market-based systems. Every successful market-based instrument makes it easier for individuals, firms, and interest groups to accept succeeding ones.

According to Stavins (1998), the idea of market-oriented solutions to social problems had been on the increase since the Carter administration, as noted in the deregulation of various industries such as banking, transportation, and telecommunications. One factor in this acceptance was the tripling of pollution control costs from 1972 to 1990 to \$125 billion annually (U.S. EPA, 1990), thereby creating the need for more cost-effective instruments. Additionally, the C² methodology is a “one size fits all” approach to pollution control. It fails to allow for differences in ages of manufacturing facilities, or variances in manufacturing processes. In the 1980s, the EPA estimated that a well functioning tradable permit program would save up to 50 percent of costs that would exceed \$6 billion annually if directed C² programs were implemented (ICF, 1989). Stavins further indicates that market-

based instruments can also be more acceptable if they can achieve improvements in air quality not otherwise politically or economically achievable. In the case with acid rain, there was no other program or approach that could handle the national problem that acid rain had become.

One key concern of the SO₂ trading program was the formation of “hot spots”, or disproportionate concentrations of pollutants in one area that then violate ambient air quality standards. As a national market with no geographic trading restrictions, the SO₂ trading program allowed trading to take place anywhere within the country. This allowed SO₂ to be deposited in certain areas that had deleterious effects. Such was the case with trades that took place from northeastern polluters to Midwestern firms. Unlike the Atlantic Ocean, which buffered the incoming SO₂ from the northeastern producers, SO₂ formed in the Midwest deposited over fragile lakes in the Northeast. These lakes did not have the buffering capacity of the Atlantic Ocean. Additionally, trades from one region of the country to another were valued at unity. Thus, a polluter in the Midwest, could trade with a firm in the West, where ambient air standards are usually much higher. Pricing the trades at unity would do nothing to discourage this practice.

The U.S. Congress had considered the possibility of instituting multi-trading regions, but decided against it in the conference committee bill that was eventually passed. Kete (1992) indicates that one commentator explained “it was understood that the greater the overall size of the reduction [in overall emissions], the more indifferent society could be to the spatial impact of trades...” (pg. 83). Despite concern expressed by several northeastern states, the U.S. EPA also adopted a single national trading region in its final regulations, with

trading priced at unity.

In 1990, the SO₂ trading program was a unique solution to a distinctive problem that had no traditional approach. It succeeded where it was intended to succeed; it achieved mass emissions reductions of SO₂, a decrease of 8.95 million tons in Phase 1 of the program (Nash and Revesz, 2002). This amounted to over one-half of the 1990 SO₂ levels. The program was well-designed to fulfill the SO₂ emissions reductions. The carefully planned design included simplicity, such as using an absolute baseline against which sources are allocated permits. It demonstrated flexibility by defining trading rules prior to permit allocation. There was no requirement for individual trade approvals. There are conflicting opinions as to whether the program created “hot spots” (Nash and Revesz, 2002). While largely taken for granted in the design of a successful program today, these touches were novel in the late 1980s/early 1990s. Market-based instruments, then and now, are especially suited to problems that are new, with no other realistic approaches to a solution.

6.1.2 OTC NO_x Budget Program

In 1990 under Section 184 of the CAAA, Congress established the Ozone Transport Commission (OTC), a body consisting of representatives from twelve northeastern and Mid-Atlantic states, the District of Columbia and the EPA. In September 1994, this group, with representatives from Maine, New Hampshire, Vermont, Massachusetts, Connecticut, Rhode Island, New York, New Jersey, Pennsylvania, Maryland, Delaware, and the District of Columbia, adopted a memorandum of understanding (MOU) to reduce the regional NO_x emissions in two stages. These states’ collective concern regarding their geographical location “downwind” of numerous NO_x sources in the Midwest, such as coal-fired power

plants, precipitated this action. In Phase I, sources were required to reduce their annual rates of NO_x emissions to meet Reasonably Available Control Technology (RACT) requirements. In Phase II, states participated in a cap and trade program, the OTC NO_x Budget Program, to achieve additional reductions during the ozone season. The program utilized a declining cap as a means of ensuring emission reductions. By 1999, a reduction from 490,000 tons to 219,000 tons was required. By 2003, the reduction would fall to 143,000 tons (Nash and Revesz, 2002).

The MOU divided the area into three regions (Figure 6-1), dependent on geography and by the degree to which the ambient air standards had been exceeded. As a result of these regions, different emission reduction requirements were set. The three regions were the inner, outer and northern regions. The most significant zone was the “inner” zone, which consisted of the contiguous non-attainment counties within the region, from Washington, D.C. up to New Hampshire. The outer zone was the one in which most NO_x emissions were generated. The northern zone, including Vermont and Maine, had sources that were usually in attainment.

The OTC NO_x Budget cap and trade program started in 1999. Largely designed on the successful SO₂ trading program, the OTC, with input from the EPA, created a unique, multi-state cap and trade program to control NO_x emissions. The OTC states, in

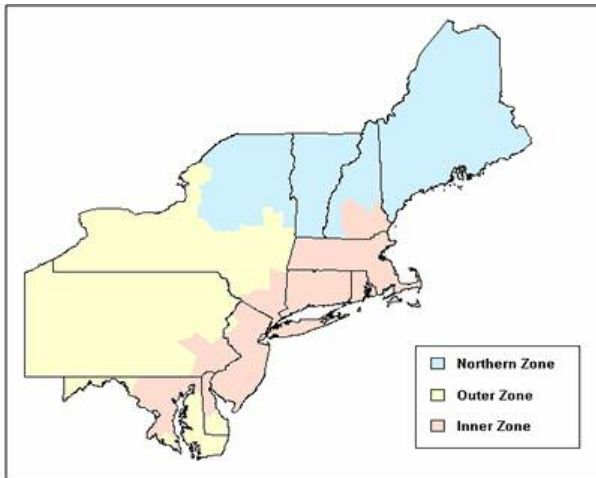


Figure 6-1: NO_x Budget Trading Zones (Source: EPA, 2004)

cooperation with the EPA and stakeholders, identified key elements that should be consistent among the regulations in all participating states so that an integrated interstate emissions trading program could be created. These elements included: program applicability, control period, NO_x emissions rates, emissions monitoring, record keeping of emissions and allowances, and electronic reporting requirements. Each state was then responsible for developing and adopting state rules with these consistent elements. Under this state/federal partnership, the states established the program requirements and emission budgets in accordance with the MOU requirements and then allocated allowances to each affected unit. EPA administered the data systems used to manage the program and provided technical assistance to the OTC states and to affected sources.

The program set a regional budget on NO_x emissions from 1000 large combustion sources in the participating states during “ozone season”, from May 1 through September 30 (EPA, 2003). Each state received an annual emission of allowances that could not be exceeded during “ozone season”. The adherence to the NO_x Budget program reductions

were in addition to the RACT requirements, a concept known as “regulatory tiering” (Tietenberg, 1991). Trading ratios were set at unity. There was no restriction on trading between regions. Remy and Ravesz state that the OTC relied on a simulation that indicated trading between zones or regions would not cause “a discernible difference”, in two trading scenarios, one in which trading was prohibited, and one in which trading was not.

By 2002, the OTC NO_x Budget program achieved reductions of 60 percent below 1990 levels, almost 280,000 tons (EPA, 2003). In 2003, the OTC NO_x Budget Program was replaced by the larger EPA NO_x Budget Trading Program, which extended NO_x reduction goals to a total of 21 states and the District of Columbia. The program was one of several methods that affected states had available to them to reduce NO_x under the auspices of the NO_x SIP Call program, also instituted by the EPA. For each of the four years in which the OTC trading program operated, 1999 until 2002, it achieved reductions below the allocated regional budget (EPA, 2003). These reductions reflect about a 35 percent reduction from estimated RACT levels during the ozone season. Measured by the standards against which the program was instituted, to reduce NO_x emissions in the participating states, the program was a success.

That does not, however, signify that the program did not, and still does not, come under scrutiny for certain aspects of its operation. The design of the OTC NO_x Budget Program also created other issues. Trading was not restricted between the zones. Yet different emission reduction goals were set for the three zones, thus complicating trading results. The Inner Zone, which had the worst air quality, received fewer allocations than the Outer Zone. Yet, the Outer Zone generated most of the emissions. Additionally, the Outer

Zone was upwind of the Inner Zone. The EPA reports that 21 counties in the trading area exceeded allocation allowances by at least 100 tons. Fifteen of these exceedance counties were in the Inner Zone, which had more stringent reduction obligations under the cap and trade program than did the Outer Zone. The difference in the allocation levels produced a higher likelihood of an Inner Zone source having emissions that exceeded allowance allocations.

These results to some degree suggest what the EPA terms "wrong-way trades," as the nonattainment areas in the counties of the eastern OTC region were less likely to have emissions below allowance allocations. In designing the program, the OTC noted the potential for trading between the zones to create such results, but also noted that it was inconclusive whether restricting trades between the zones would influence air quality, while it would clearly complicate the program (Carlson, 1996).

The EPA (2003) puts another facet into consideration of localized increases of air emissions. Its focus was that the NO_x program was instituted to improve air quality in the region concerned. By achieving significant emissions reductions, local air quality is improved across the region. Eliminating "hot spots" was not the goal of the NO_x Budget Program. To achieve it would have required restrictions on trading, and more costs for all involved.

6.1.3 SCAQMD RECLAIM

The South Coast Air Quality Management District of Southern California (SCAQMD) carries the dubious distinction of consistently having the country's smoggiest air in the South Coast Air Basin, which includes the Los Angeles Metropolitan area; the air

quality was rated “extreme” under the EPA’s one-hour ozone standard. As part of its SIP to meet air quality standards, the SCAQMD instituted the federally approved Regional Clean Air Incentives Market (RECLAIM) in October 1993, with implementation in January 1994. The program was established to trade NO_x and SO₂, though the SO₂ program has been considerably less active than the NO_x program (Lejano and Hirose, 2005). This was the first market-based program designed to be applied to a diversified group of sources. It opened to some business and government support, and almost universal disdain from the environmental community.

Sources that emitted at least four tons of NO_x or SO₂ were eligible to participate. The program was designed to achieve a regional 75 percent reduction in NO_x emissions and a 60 percent reduction in SO₂ emissions by 2003 (Nash and Revesz, 2002). Despite being plagued with problems and criticisms, the program was considered a success for reductions made from 1993 – 2003. Incidentally, the SCAQMD had considered a VOC trading program, but scrapped it due to the complexity involved in designing such.

Unlike the NO_x and SO₂ trading programs, the RECLAIM program had two distinctive trading zones – the coastal (zone 1) and inland (zone 2) zones. This was necessary as a direct result of geography. Los Angeles sits in a bowl-shaped geographic depression, with a mountain range to the east. It is bordered on the west by the Pacific Ocean and an industrialized area. Computer modeling argued for trading in only direction, from the coastal area to the inland due to prevailing winds from the West. Having multiple trading zones is generally regarded as one method of decreasing the potential for “hot spots” caused by concentrated air pollutant emissions.

Banking of RTCs was not allowed because of the concern over air quality degradation that could be brought about by the introduction of banked credits into the ambient air. However, participating facilities were divided into two different annual cycles that began six months apart. This ensured that all credits did not expire simultaneously, thus preventing large price distortions and instilling a trading confidence into the system.

RECLAIM was adopted as a cap and trade program with a declining cap as a means of complying with state and federal AQMP. Facilities were given the opportunity to enroll in the program or achieve compliance with strict air quality standards by other means, such as emission control technology, or by using both methods. Approximately 350 facilities of all sizes, including power plants, refineries, cement plants, dye plants and paper mills were affected by this choice. The price for credits, called RECLAIM Trading Credits, or RTCs, was initially set at \$1.00 per pound of NO_x emissions. However, several factors caused the price to spike as high as \$60 per pound from 1998 – 2001. The SCAQMD identified three factors responsible for this price spike: (1) increased demand for power generation related to deregulation, (2) the crossover point in which available RTCs were forecast to be less than what the market required due to the declining cap and (3) delayed installation of controls by power plants and other participants (EPA, 2002).

Facilities were informed of their alternate choices, to include the necessity of installing technological controls to help meet emissions goals, in lieu of expected shortages during the forecasted crossover point. Enforcement was lack at the administrative level. Additionally, lack of belief in the integrity and structure of the system, and an excess of available credits at the start of the program resulted in a delay in installing the necessary

technological controls, thereby resulting in a scramble for available RTCs (Chartier, 2003). This amplified when the California energy crisis hit in 2000 - 2001. Large electricity generators purchased most of the available RTCs. Regardless, in the 2000 compliance year, power producing facilities still exceeded their RTC holdings by forty percent (EPA, 2002).

Reforms adopted in 2001 included removing the power plants and other large generators, those generating more than 50 tons of NO_x per day, from the trading plan until 2007. Other industries that adopted the Best Available Retrofit Technology (BART) could also apply for an exemption from the trading plan. These changes, targeting the large variability in participating facilities, helped to reduce the volatility in NO_x RTC pricing. This was assisted by a price trigger for price exceedances above a certain cost. RECLAIM market participants are currently subject to cumulative reductions of 7.7 tons per day, or a 22.5% percent reduction, of NO_x by 2011, with decreasing adjustment factors per NO_x credit each year until then. Companies may opt for an exemption at any time.

The need for greater regulatory control in the early years of a cap and trade program when credits may be excess, is evident in the unforeseen, but preventable, price spike in 2000 - 2001. The SCAQMD's efforts to relieve market uncertainty following the 2000 incident, by limiting participants, and requiring compliance plans from the largest producers, further alienated stakeholders in the business community. Businesses did not believe they were operating in a stable, long-term program, where the supply and demand of RTCs drive the market price. Further, many businesses were not confident that RECLAIM was driven by economic factors. Rather, they believed that SCAQMD's actions further increased the uncertainty, as attested by the modifications to the RECLAIM program in 2001. This

included the imposition of compliance plans for the largest polluters, such as the electric power industry and other facilities emitting at least 50 tons of NO_x annually.

Under earlier command and control programs in southern California, emissions of NO_x had been cut dramatically. Under RECLAIM, however, the rapid pace of reductions slowed to a crawl. From 1999 – 2001, annual average concentrations of NO_x dropped by only 3 percent, compared to a 13 percent decline in the preceding three-year period of 1996–1998 (SCAQMD, 2001). In 1999, NO_x levels increased, following a decade of consecutive reductions. The many rules established to allow compliance flexibility actually hampered trading. Since the primary purpose of any air emission reduction program is to reduce polluting emissions, by this standard the RECLAIM program must be considered a failure.

6.1.4 Illinois' EPA Emissions Reduction Market System (ERMS)

VOCs can be traded based either on mass or reactivity. A mass-based program is the more simplistic of the two. It assumes a diverse enough spectrum of VOCs such that the varying reactivities could, in effect, cancel each other out. An example of such a program is the Illinois Emission Reduction Market System (ERMS) program. Begun in 1999 and approved by the U.S. EPA in 2001, the much heralded program was the first of its kind in the nation to conduct a cap and trade program for VOCs. The region of control is in northeastern Illinois, specifically, the eight-county area encompassing metropolitan Chicago. Also listed as a moderate non-attainment area for the eight-hour ozone NAAQS, and a “severe-17” area under the old one-hour O₃ attainment standard, attainment is required by 2010 under the eight-hour standard. Like the HGB area, the Chicago Metropolitan area also faced prohibitive costs under the traditional “command and control” scenario of limiting

VOC emissions. VOC emissions from participating sources in the eight-county area originate from a wide variety of industrial operations, including food processing, chemical manufacturing, and paint and printing operations.

The program shares some similarities with the HGB trading program with several significant differences. Similar to the HECT program, the ERMS defines major sources as those facilities which have baseline, or actual, emissions of at least 10 tons of volatile organic material (VOM) during the ozone season, which runs from May through September. Participating sources in both operations received a deduction from their base emissions allowances, which in the ERMS was a 12 percent reduction in emissions allowances from their baseline VOM emissions in the mid-1990s. A source's baseline emissions decreased if it was in non-compliance with the CAAA during the years used for determination of the emissions baseline.

Companies that fail to hold sufficient allotment trading units (ATUs) for purchases during the season are penalized; repeat offenders are penalized at a higher rate than are first time offenders. Following in Table 6.1 is a summation of the ERMS program source categories.

Table 6.1: ERMS Program Source Characterization

Category	Description	Allowance (ATU) Source
Participating Sources	Emissions \geq 10 tpy during O ₃ season, in operation prior to May 1, 1999	IL EPA
New Participating Sources	Emissions \geq 10 tpy during O ₃ season, not in operation prior to May 1, 1999	Must acquire ATUs through trades or long-term transfer agreements

Exempt Sources	Those sources which would otherwise need to be participating sources, but have restricted emissions in one of two ways – 1. limiting seasonal emissions to < 15 tons/season, or 2. already have reduced seasonal emission by ≥ 18 percent of baseline	Not applicable
General Participants	Entities other than participating sources or new participating sources who have obtained account and are allowed to trade (i.e. brokers or companies who have shut down operations but still wish to control own ATUs)	Depends upon original characterization
Special Participants	Entities that register with the IL EPA to purchase and retire ATUs, but not sell ATUs.	Purchase

Unlike the HECT program, ERMS sources were allowed to opt out of the program if they accepted a set percentage of emissions reduction from their baseline level, in this case an 18 percent deduction to ensure an environmental benefit. Finally, the Illinois EPA instituted an annual decreasing cap on emissions to also ensure an environmental benefit, unlike what the HECT program has done.

The year 2005 represented the sixth year of operation for the ERMS program. There are 167 participating sources. According to ERMS records, the program has achieved greater than the 9% base reductions established at the outset for each of the years it has been in operation from 2000 – 2004 (IL EPA, 2005). Participating sources reduced VOC emissions by 38% compared with their allotted emissions in 2000, the first year of the program, and by 47% in 2001 (Tietenberg, 2006). All sources that desired to trade found suitable trading

partners with a sufficient supply of ATUs. Market prices were reported as being conducive to trading with average prices over the 2004 and 2005 season being between \$12.93 and \$16.10 per ATU.

Regarding hazardous air pollutants (HAPs), which are traded, the IL EPA reports no apparent relationship between market activity and hazardous air pollution levels. There is a generally downward trend in HAP emission since the onset of the program, which correlates the downward trend in emission throughout the region since program inception in 2000(IL EPA, 2005). It also reports no geographic concentration of VOMs.

The ERMS program has shown that reductions are possible in a mass-based system. Regardless of program differences between the IL ERMS and the HGB area HECT program, geographic uniqueness and the significant differences in trading considerations of a reactivity, rather than a mass, based trading concept precludes making forecasts about one VOC trading program over the other.

6.2 Measuring the HECT Program against Lessons Learned from Previous Emissions Trading Programs

Key lessons learned from the selected emission trading programs are listed in Table 6-1.

Table 6.2: Applicable Lessons Learned from Selected Emissions Trading Programs

Program	Lesson(s) Learned
The National Sulfur Dioxide (Acid Rain) Trading Program	<ol style="list-style-type: none"> 1. Market-based instruments are especially suited to problems that have no other realistic solutions. 2. Use modeling and monitoring to detect and correct trades that produce localized areas of increased air emissions.
OTC NOx Budget Program	<ol style="list-style-type: none"> 1. For emissions trading program with multiple regions, it is important to maintain similar emissions reduction goals if trading is to take place between the zones. To do otherwise complicates trading results.
	<ol style="list-style-type: none"> 2. Use modeling and monitoring to determine possibility or existence of “wrong-way” trades, which could lead to areas of increased localized emission, or “hot-spots”
SCAQMD RECLAIM	<ol style="list-style-type: none"> 1. Focus on developing a program with similar participants of same size, with similar emissions or missions.
	<ol style="list-style-type: none"> 2. Maintain strong administrative controls and political will throughout a program despite increased costs, as a necessary element in the success of a trading program.
	<ol style="list-style-type: none"> 3. Prohibit trading into overburdened communities.
	<ol style="list-style-type: none"> 4. Ensure the focus is on reducing the pollution itself, not the cost of emissions control.
Illinois’ EPA Emissions Reduction Market System (ERMS)	<ol style="list-style-type: none"> 1. Trading of VOC emissions based on a mass concept can limit emissions without increasing the HAP levels.

7. Measuring the HECT Program against Uncertainties

Farrell (1998) defines seven types of uncertainty against which he models the OTC NO_x Trading program. A modified list is profiled against uncertainties in the HECT program, as indicated in Table 7-1. No attempt is made to rank the uncertainties, only to identify them.

Table 7.1: Sources of Uncertainty in the HECT Program

Source	Description	Implication for the HECT Program
Temporal	Seasonal production requirements could produce demand peaks which would increase HRVOC emissions; especially troublesome when meteorological conditions are most conducive to ozone formation	The 51 allocated sources in Harris County consists of petrochemical refineries and chemical production facilities. Unlike EGUs, these are not necessarily subject to peak seasonal demands. Unscheduled emission events Emergency venting is source of greatest temporal uncertainty.
Emission events	Unscheduled events accounted for 30 percent of emission events in 2003. Other emission events consisted of start-up, shutdown and maintenance events. Historical emissions from both sources have vented 5,000 lbs in less than one hour, exacerbating already high ozone levels.	Hourly cap of 1200 lbs placed on emissions events. Exceedances in monthly allocations cannot be added to annual cap. Unscheduled events source of significant uncertainty.

Banking	Under a market-based approach, if LDAR and statutory requirements reduced emissions sufficiently, resulting low demand for allowances could allow a reserve of banked allowances to build up, thereby increasing temporal uncertainty.	Allowances may only be banked for one year, due to the problem of a transient, hot weather pollutant like ozone that could be aggravated by spikes caused by aggregate sudden use from build-up of HRVOC allowances. Uncertainty is decreased.
Spatial	Emissions trading may make it possible for “hot spots” to develop, or for “wrong way” trades to occur	VOC trading introduces many uncertainties, especially since one of the traded pollutants is regulated under the NESHAPS. Near stagnant wind conditions, and poor zoning regulations in Houston can make this an area of significant uncertainty
Photochemical Modeling Irregularities	Irregularities produced in MCR of Base Case scenario thus questioning reliability of all modeling results.	The model tends to under-predict on high ozone days and over-predict on low ozone days. This apparent inability of the model to mimic observed conditions decreases confidence in control strategy modeling. This could lead to creation of flawed policy.
OVOC Conversion to HRVOCs	Use of MIR scale to convert OVOC ERCs to HRVOC allowances	The well-known MIR scale has shown to be appropriate for urban low VOC to NO _x ratios. This is opposed by more favorable airshed reactivity scales such as LS-RR; 5% conversion limit decreases uncertainty.
Multiple Trading Regions	The need for several regions, Harris County and surrounding seven counties, is questioned in light of relatively limited number of market participants, perhaps yielding to a thin market with resulting consequences.	Multiple regions are necessary to prevent trades into Harris County where ozone exceedance levels are highest, and regulated facilities are most dense. Additionally, in outlying seven counties only two HRVOCs are regulated via allowances.

Measurement	Uncertainty in baseline emissions inventory and uncertainty due to the estimated magnitude of fugitive emissions, which are not included in the annual or hourly cap.	The TCEQ instituted LDAR requirements, and is continuing to make improvements to base emissions inventory. This results in less uncertainty, but this area still remains a source of great concern.
-------------	---	---

7.1 Temporal

There are 51 accounts in Harris County as of July 2006 (Appendix). The facilities are all petrochemical refineries or chemical production plants that generally do not undergo dramatic shifts in production requirements. In contrast to the electric power industry, the greatest temporal VOC emission is the unscheduled emergency venting of high pressure production facilities and pipelines. These sources have historically released 5,000 – 10,000 lbs of HRVOCs in one hour or less, 2-3 times per month (Murphy and Stoeckinius, 2004). These events, under meteorologically conducive conditions, can lead to the creation of THOEs.

7.2 Emission Events

Emission events are regulated through guidelines in place that require emission events greater than 100 lbs to be reported. Enforcement is at the discretion of the TCEQ Director. Emplacement of the short term, 1200-lb/hour not-to-exceed emission limit should reduce both the frequency and magnitude of the emission events, and help to decrease the potential for THOE formation. Exceedances that do occur cannot be added to the annual cap. To allow such would remove incentive from the possible offenders to enforce monitoring and leak detection procedures. Additionally, the enhanced monitoring requirements the TCEQ

established in chapter 115 of the TAC should serve to prevent undetected HRVOC releases in the future. Finally, penalties apply to those facilities that do not comply with the established limit.

7.3 Banking

Under a market-based approach, if LDAR and statutory requirements reduced emissions sufficiently, a resulting low demand for allowances could allow a reserve of banked allowances to build up, thereby increasing temporal uncertainty. Several facts contradict this occurrence. As a result of the severity of the O₃ pollution in the region, the HGB area has a history of encountering great difficulty in meeting statutory requirements. This is true regardless of the type of program used to meet requirements: C², or market-based programs such as the MECT program for NO_x trading. The one-year life span on allowances allows the more control over the release of the allowances than for those allowances with a multi-year life span. Such control also limits spikes in emissions, possibly resulting in creation of more O₃. This limit on banking thus improves certainty.

7.4 Spatial

The occurrence of localized concentrations of emissions, or “hot spots”, is an area of significant uncertainty in this program. This is a result of the sometime stagnant wind conditions, the co-location of refineries and chemical manufacturing plants with economically deprived communities, and the known toxicity of at least one of the pollutants - 1,3-butadiene. Three of the five programs presented here, the RECLAIM program, the OTC NO_x Budget Program, and the National Sulfur Dioxide Trading Program, have all

experienced documented problems with environmental justice concerns. The HECT program does not officially commence operation until January 2007. Reports of the human health concerns and environmental justice problems in the Houston area, brought on by the proximity of manufacturing facilities and refineries to residential neighborhoods, was the focus of a series in an area paper (Houston Chronicle, 2006). The IL ERMS program has, as of December 2005, no documented issues involving environmental justice concerns.

7.5 Photochemical Modeling Irregularities

All photochemical modeling completed by the UNC team, the TCEQ, or other researchers in regards to the HGB area SIP used the CAMx (Comprehensive Air Quality Model with Extensions) v4.03, unless otherwise noted.

7.5.1 One-Hour Case – H12.8HRB Project

When the EPA required the TCEQ to submit a mid-course review of the 2000 HGB one-hour ozone non-attainment SIP by the end of 2004, the TCEQ chose to develop new ozone modeling databases for a new 2000 episode. The TCEQ commissioners were concerned about modeling uncertainties and some of the new rules for NO_x and VOC emissions. They wanted to better understand the uncertainty associated with the SIP modeling and the previous conclusions. These conclusions were drawn from modeling that indicated that the HGB area would show attainment of the one-hour O₃ standard in 2007.

A special project, named “The Role of Modeling Assumptions in the Houston Mid-Course Review and Impacts on the Sensitivity of 1-Hour/8-Hour Ozone to Emissions Reductions, H012.2004.8HRB, investigated whether the assumptions used in the MCR SIP

modeling introduced bias into predicted 2007 ozone concentrations. The project involved research groups from University of Texas at Austin/Environ Corporation, University of Houston and the University of North Carolina at Chapel Hill. The groups also attempted to answer whether the model's potential biases would impact the effectiveness of the proposed control strategies. Answers to these two questions were needed to provide support for "weight of evidence" (WOE) arguments in support of the modeling.

7.5.1.1 UNC-CH

The UNC group used 26 multi-day simulations that investigated nine VOC inventories, two grid resolutions and four meteorological variations (Jeffries and Arunachalam, 2005). The conclusions are listed in Table 7-2:

Table 7.2: Conclusions Obtained in Project H12.8HRB by UNC Research Group

1. Base case is biased high for precursors, low for ozone; likely inhibited O ₃ production
2. Future case is biased high for precursors, unknown for O ₃
3. Future case biases impacts effectiveness of controls
4. Future efforts are needed to reduce uncertainty

Source: Jeffries and Arunachalam, 2005

In the UNC case, the findings were not conclusive as WOE arguments needed for the SIP MCR. One of the reported problems was a poor history matching for wind fields used within the model. The UNC team observed several serious flaws in the wind speed and direction fields provided to the model. The TCEQ replaced a middle portion of the study period, from August 25 – August 31, 2000 with corrected meteorological simulation data. To be able to have meteorological data for the extended period, August 18 - September 6,

2000, the TCEQ attempted repairs by devising a “hybrid” meteorology that combined simulation data from two sources, one which tended to predict wind speeds much higher than observations, and the other which predicted daytime wind speeds less than observations.

Regardless of these efforts by the TCEQ, the UNC team judged that some of the model’s meteorological data was distorted to the point of yielding results which could not reliably be used to develop policies. The UNC team only conducted sensitivity testing of the middle period, August 25 – August 31, 2000, though this period also offered some mismatches between predicted and observed wind field data.

A second problem discovered with the meteorological input fields was the model’s low predicted nighttime mixing depth. The model’s large overpredictions of nighttime observed chemical species suggested an actual nighttime mixing depth of almost seven times larger than what the model calculated. Corrections to the meteorological input field in the model could not be made without distorting other data. Among other species, this included erroneous predictions for NO_x, HRVOC, biogenic VOCs, HCHO and O₃, as well as large differences in predicted and observed nighttime surface layer wind speeds.

Still another problem was the low vertical mixing rates used in the model. Sensitivity tests of this parameter showed that O₃ could be predicted 20 ppb higher or lower at different locations in the model.

Results of UNC sensitivity testing further distorted future case predictions. Sensitivity testing yielded such results as future case NO₂ concentrations at 14 of 16 sites that were being predicted at higher concentrations than the base case. This was true even after mobile source and industrial reductions of 80 percent were included. The opposite

occurrence would be the expected outcome, given the application of control strategy reductions to the base case. The goal of the model is to predict ozone concentrations. Given the distinctions between the observed and actual occurrences, the model predicted very low ozone concentrations. The model overpredicted NO_x concentrations when the opposite was true.

The amount of ozone predicted as a result of NO_x inhibition was statistically similar enough to the TCEQ's ozone prediction to allow it to pass application of the EPA statistical testing standards. However, the TCEQ imputed more than 16 times as much HRVOCs to its modeling runs for the same periods as did UNC. As a result the observed loss in ozone yields an unreliable outcome for policy predictions. Uncertainty is increased.

7.5.1.2 UTA/Environ

Table 7-3 lists the key findings by the research teams at the University of Texas at Austin and Environ Corporation.

Table 7.3: Synthesis of Findings in Project H12/HRB by the UTA/Environ Corporation Research Group

1. Impact of Fires	Future O ₃ concentrations are biased high by assuming that fires occur at a higher than normal intensity than occurred in 2000.
2. Uncertainties in Biogenic Emissions	The TCEQ's attainment demonstration model used land cover data that was current in the 1990s and the most comprehensive data available at the time. The changing land cover of the HGB area introduces uncertainties in predicted ozone concentrations. The current SIP model over predicts isoprene concentration by 2-5 times over observations. As k _v in model is increased, ground level concentration of all O ₃ precursors is decreased, as is O ₃ concentrations.

3. Uncertainties Due to Choice of Chemical Mechanisms	When modeling 1-hr O ₃ NAAQS attainment scenario, SAPRC99 and all versions of CB-IV mechanism predict similar absolute O ₃ concentrations. Averaged over 8-hr, relative O ₃ reduction factors are used. SAPRC99 predicts larger relative ozone reductions than CB-IV. SAPRC99 is also more responsive to NO _x emissions than CB-IV. Cause for difference in mechanism predictions is not identified.
4. High Resolution Grids	Model predictions of O ₃ are sensitive to the horizontal and vertical resolution used in the model, especially in areas with high densities of point source emissions. Predicted O ₃ concentrations generally increase as horizontal and vertical resolution is increased; however, the validity of current meteorological models at fine scale (<4 km) horizontal resolution introduces poorly understood uncertainties into the air quality modeling.

Source: Allen and Yarwood, 2005

Comments on work completed by the UTA/Environ group are restricted to their fourth finding of O₃ sensitivity to horizontal and vertical resolutions. This is done to limit the discussion of the numerous variables that impact photochemical modeling to several that the author believes exhibits the greatest impact on modeling THOE formation. The UTA team found photochemical modeling better able to replicate the event emissions at a 1-km, rather than a 4-km, horizontal grid resolution. The team compared results of using a 200 m very high resolution grid against a Lagrangian puff model embedded in a 4-km grid. It found an advantage of using the puff model to be its ability to demonstrate slower dispersion than the grid model. This resulted from the grid's inability to properly resolve the plume because of "excess artificial dispersion on the grid" (Allen and Yarwood, 2005). The reverse, however, was true when the plume spanned the intermediate scale from 200m to 4 km. The puff model dispersed more quickly than did the 200m grid model as result of intermediate level spatial and temporal dispersion characteristics that were missed when moving from

between the two scales.

The team indicated the advantage of using the 1-km grid driven with 4-km meteorology to facilitate the portrayal rapid ozone formation near HRVOC emission points. However, such a grid resolution cannot properly resolve the dispersion characteristics of the “larger scale ozone features such as the urban plume” (Allen and Yarwood, 2005).

In its attainment demonstration modeling, the TCEQ used a 4-km horizontal grid resolution with a 1-km inventory (Jeffries, 2006). The 4-km grid acts to “smooth” and dilute the effect of localized concentrations, such as event emissions. The H12 UNC project clearly showed that the model needed a grid resolution of 1-km or smaller to give chemistry a competitive chance against artificial dilution. Regardless, the TCEQ maintains the results of its model runs at the 4 km horizontal resolution, instead of at the necessary 1 km. Additionally, the TCEQ computed the emissions inventory at 1 km and aggregated it to 4 km (Jeffries, 2006), which also can result in the dilution of the effects of localized concentrations. Uncertainty is again increased.

7.5.1.3 University of Houston

The research team at the University of Houston assessed the impact of land covers and choice of mechanisms on model performance. Table 7-4 lists the most important modeling improvements they found:

Table 7.4: Key Modeling Improvements Needed in Project H12/HRB as Obtained by University of Houston Research Team

1. Vertical diffusivity formulation
2. Planetary boundary layer (PBL) and land surface physics and/or data assimilation schemes affecting model horizontal winds
3. HRVOC event emissions and stack parameters for stack and flare emissions
4. Urban radical sources downwind of the Houston Ship Channel
5. Cloud cover and photolysis rates
6. Chemical mechanism speciation and reaction schemes

Source: Byun, 2005

Comments regarding the findings by the University of Houston team are restricted to HRVOC event emissions and stack parameters for stack and flare emissions. The model under predicted for HRVOC species compared to canister measurements in the upper layers. The imputed emissions inventory, used in the model, included 1,092 tons of VOCs, composed primarily of OLE and ETH. This inventory was added to the model as low-level emissions. UH researchers surmise that use of this inventory resulted in over predictions of the surface concentrations of these species, especially at night. Further, the researchers believe that additional HRVOC required to increase ozone formation came from flares and stacks having release velocities sufficient to move the emissions above the height of the lowest model layer. The TCEQ model assumed that the emissions came from low level emissions. Doubling and quadrupling the exit velocities were not sufficient to raise emissions above the lowest model layer. Similar to the UNC team, the UH team found

strong doubts about the validity of the inventory that was used as the basis for all of the SIP modeling. Uncertainty is increased.

7.5.2 Eight-Hour Case

The TCEQ implemented improvements in inputs to the model's HGB area August/September 2000 episode to improve areas of concern from the H12/HRB project. Changes were instituted to the meteorology, the chemical mechanisms, and the emissions inventory, in the attempt to correct irregularities from the unreliable one-hour base and future case model runs. Nevertheless, similar irregularities showed up in the eight-hour case runs.

Jeffries and Kim (2006) evaluated the corrected one-hour attainment demonstration model against the eight-hour model, using the Python-based Performance Analysis Support System (PyPASS) in four regions of the HGB area: Aldine (North), Clinton (East), Bayland Park (West), and Deer Park (South). Results indicate no more than a marginal improvement in the eight-hour case over the one-hour model run. Using Process Analysis tools, Jeffries and Kim indicate that all sites have the same limited new $\text{OH}\bullet$ production problem as did the one-hour case. Thus, only 125 to 150 ppb NO is ever oxidized to NO_2 regardless of the ready availability of VOCs, including HRVOCs.

Any increases in NO_x should signal an eventual increase in O_3 production, whereas the opposite is occurring with the model predictions. Ozone production is limited. This is a further indication of model irregularities, which makes any predictions based on this model unreliable, thereby increasing uncertainty.

7.6 OVOC Conversion to HRVOCs

In 2004, the TCEQ added a provision allowing VOC ERCs to be converted to HRVOCs using the well-known MIR scale. The MIR scale has shown to be appropriate for urban situations that demonstrate low VOC to NO_x ratios. The cap for such trades is set at five percent of the facility's cap. Uncertainty over the outcome of such trades limits the quantity proposed for trade. As part of the study entitled "Survey of Technological and Other Measures to Control HRVOC Event Emissions", Murphy and Stoeckinius (2004) simulated MIR-based trading of HRVOC and OVOC annual emissions. They indicate that the replacement of the MIR-equivalent weight C7 – C9 aromatics, xylene was used in the study, for HRVOCs produced more O₃. Conversely, substituting the MIR-equivalent weight of C3 – C7 alkanes, in the study n-pentane was used, for the MIR-equivalent weight of HRVOCs produced more ozone. However, the HECT allowed substitutions do not discriminate between alkanes and aromatics.

A recent study by Thompson et al (2006) addresses the issue of the effects of reactivity-weighted trading on HGB area air quality. It appears to be premature in its assessment of the lack of impact that trading reactivity weighted compounds have on one another. Specifically, according to the authors, when 100% of the OVOC emissions, whose inventory consists mainly of the highly reactive toluene and xylene, were converted to HRVOC allocations (ethylene and propylene), and these allocations were all traded into one region, daily maximum one-hour averaged and eight-hour averaged ozone concentrations increased. The maximum increases were 0.3%; the maximum decreases were limited to 1%. Both these values were dependent on the region into which emissions were traded. However,

4 km grid resolution used to model trading scenarios, leading to the given conclusion, diminishes the impact of localized increases. Additionally, the study used the same emission inventory as the TCEQ, which was compiled at 1 km, and is $\text{OH}\bullet$ limited. Lack of input consistency at a given resolution results in unreliable outcomes. More research is needed on the issue before trading is increased above five percent of a facility's cap. The five percent limit helps to decrease uncertainty.

7.7 Trading Regions

The TCEQ has divided the HGB area into two regions - Harris County, and the outlying seven counties. The allowances in Harris County are used for all four designated HRVOCs. Trading is restricted to account holders within this county since Harris County is where most of the emissions are generated, and where the exceedances are most numerous. The outlying seven counties are not subject to the mandates of the trading program, though that can change in the future, given public notice. These seven counties are only required to control for ethylene and propylene. TCEQ modeling studies indicate that reductions in these seven counties are unnecessary to attain the one-hour O_3 standard (TCEQ, 2004). Industry representatives in these counties indicate that HRVOC emissions in their individual air permits are well below the emission limits likely to be put in place through the HECT annual cap.

7.8 Measurement

7.8.1 Emissions Inventory Errors

A central premise to the cap and trade program is the accuracy of the emissions

inventory. It drives the establishment of the baseline and the cap. Additionally, the measurement techniques used in establishing the cap are likely used to maintain measurement of emissions throughout the program. Cantu (2004) indicates that 46 percent of the year 2000 emissions in Harris County were from fugitives. VOC measurement techniques, principally CEMS, continuous emissions monitoring system, do not account for the large percentage of fugitive emissions. The errors in the inventory were most likely from errors in the estimates of emissions from cooling towers, flares, fugitive emissions and start-up, shutdown and malfunction events.

7.8.2 Flare Efficiency

The TCEQ assumes that flares have combustion efficiencies of 99 percent for ethylene and propylene, and of 98 percent for 1,3 –butadiene and the isomers of butene (Industry Professionals for Clean Air, 2005). These assumptions have come under greater scrutiny because of the parameters under which such high combustion efficiencies were determined. In the EPA’s 1983 Flare Study EPA, optimal conditions of wind speeds less than five mph and high efficiency flares burning simple hydrocarbons determined such parameters. The same parameters fail to adequately describe the operating conditions in effect in the HGB area refinery and petrochemical operations. Levy et al (2006) lists the “unrealistic assumptions” in effect as follows:

- Plants are consistently operated according to the parameters necessary to optimize flame efficiency.
- Crosswinds have minimal effect on combustion efficiency.
- Flares perpetually operate at high destruction efficiency.

Real world conditions in refineries or petrochemical facilities usually call for plant operators to inject steam or propane, an assist gas, into the flare stream to help achieve more complete combustion. Improper additions of excess steam or assist gas, however, serves to reduce the combustion efficiency by reducing the flame below optimum operating conditions (Industry Professionals for Clean Air, 2005).

Another factor affecting flame efficiency is the presence of crosswinds. Proper conditions for high combustion efficiency require that the combustible material be present in the flame for a set amount of time. The presence of crosswinds in excess of eight kph reduce this time by separating the flame from the burner tip, resulting in significant drops in efficiency. The coastal location of many facilities, and what Levy calls the “routine, yet less than ideal weather conditions” along the Gulf Coast makes this of concern.

Given this information, it is not unreasonable to conclude that flares are one, if not the principal, cause of excess and incompletely combusted, hydrocarbons in the waste stream. As depicted in Figure 7-1, flares account for a large portion of the VOC emissions. Specifically in the sample period depicted, 19 flares account for 50 percent of the total VOC emissions. Cantu (2004) indicates that in the 2000 HGB area EI, fugitive emissions were responsible for 46 percent of total emissions.

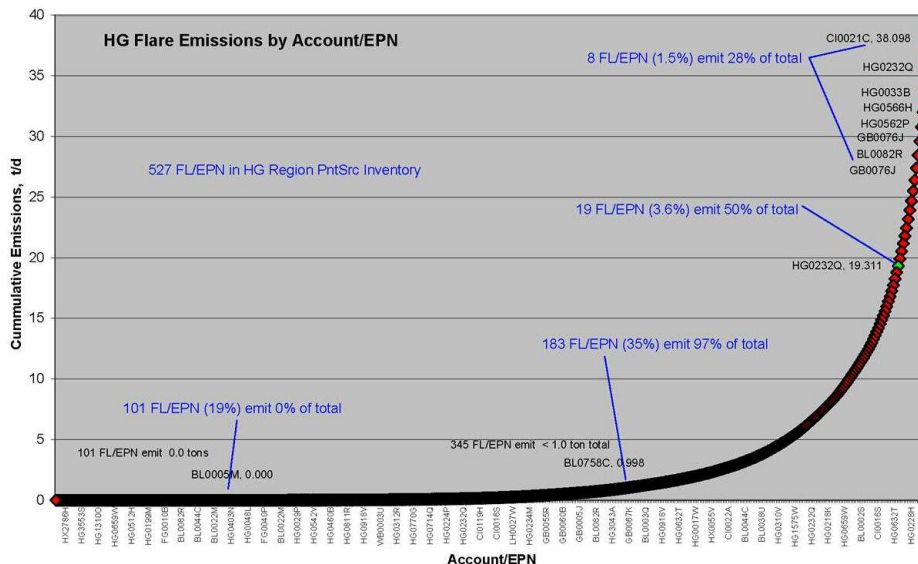


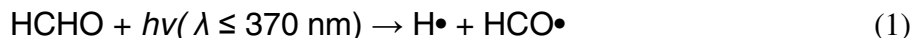
Figure 7-1: Flares as a VOC Source, 19 flares (approximately 4% of all flares) account for 50% of total VOC emissions from flares (Source: Jeffries, 2003)

7.8.3 The Role of HCHO in O₃ Formation

Jeffries (2006) indicates that flares could be a major source of fugitive formaldehyde (HCHO) emissions, a recognized by-product of incomplete combustion in petrochemical facilities. HCHO is not easily measured by techniques in current use throughout refineries and other industrial facilities. It is not accurately accounted for in the emission inventories. However, ambient measurements of VOC/NO_x ratios consistently yield ratios that are larger than what would be expected, given known inputs from emissions inventories (Jeffries, 2006). Further, HCHO is a major factor in O₃ formation.

The absence of HCHO in the emissions inventories can also explain the under- and over- predictions of ozone formation in the model. In the December 2004 SIP Revision, the TCEQ imputed 1,092 tons of HRVOCs to the emissions inventory. The UNC team later added 67 tons of HRVOCs to the same inventory and achieved similar results as the TCEQ did, though for different reasons. HCHO photolysis generates radicals, which in turn

generates the OH•, a major oxidant for organics, according to the following reactions (1 – 4):



Larger aldehydes can also make the OH•, but not as quickly as can HCHO due to the shorter wavelengths involved in their photolysis. Reactions (1) – (4) play a crucial role in “turning the crank” on the photochemical model. The absence, or shortage, of the OH• in a model limits the amount of radicals formed, which in turn will limit O₃ formation.

The TCEQ model is “OH-limited”. In summarizing the H12 project, the UNC team indicated that on exceedance days, when observed O₃ concentrations exceeded the one-hour O₃ standard, the model under predicted for O₃ (Jeffries and Arunachalam, 2005). Likewise, on non-exceedance days, the model overpredicted for ozone. Ozone exceedance days during the study period are matched with emission events. Flares or some other type of process upset are affiliated with these emission events. Even with an efficient burner, which should result in CO₂ and H₂O as the products, the flares still discharged one to two percent of its mass as incompletely combusted hydrocarbons. The otherwise unaccounted for sources for the larger than expected ambient measurements of HCHO, could be the flare combustion process (Jeffries, 2006).

From January 31 through December 31, 2003, emission events with a total mass of over four million pounds contributed 4% to the 45,000 tons of VOC emitted over a single

year from point sources in four counties in the HGB area (Allen and Jeffries, 2004).

Therefore, incomplete combustion from flare releases has the potential to discharge significant quantities of unaccounted for VOCs into the atmosphere. Adding large quantities of HRVOCs will not have the desired effect of “jumpstarting” the model. The model is no longer sensitive to VOCs. It requires a source of OH•, which HCHO supplies. Therefore, the addition of large quantities of HRVOCs will not have the desired effect of producing similar concentrations of O₃ to that observed in the base case.

7.8.4 Projected/Current Emissions Inventory Development.

The TCEQ has decided to improve the inventory of HRVOCs in the listed areas by requiring monitoring of cooling towers, flares, pressure relief devices and process vents that are in HRVOC service. The guiding rules for this are contained in 30 TAC §115. This source monitoring, expected to be in place by end of 2006, should significantly reduce the amount of error in the HRVOC inventory. The improvements will directly measure both continuous emissions and emission events. Two more recent additions will help to decrease the mass of fugitive emissions, and the amount of error in estimates of the same. The TCEQ is now requiring that more accurate correlation equations be used to estimate VOC fugitive emissions, instead of the AP-42 emissions factors. Additionally, affected industries are beginning to take advantage of the new infrared (IR) imaging camera technology for fugitive emission detection.

8. Future NAAQS Attainment?

In spite of the HECT program uncertainties, research conducted by other than TCEQ personnel indicates HGB attainment of the eight-hour O₃ NAAQS standard by 2015. Tesche (2006b) quantified the success of existing federal VOC and NO_x control programs on attainment of the 8-hour NAAQS O₃ standard in the HGB area. The research entailed use of CMAQ (Community Multi-scale Air Quality) modeling developed over a nested 36/12 km VISTAS (Visibility Improvement State and Tribal Association of the Southeast) grid for the continental United States. The CMAQ modeling base case consisted of modeling results from CY 2002 and future year modeling for 2009 and 2018. Tesche interpolated between the 2009 and 2018 model years' O₃ DV (daily value) projections at each 8-hour monitor in the HGB area to determine the yearly reduction rate in DVs brought about by federal and regional controls. Modeling results from the 36-km grid suggest achievement of the 8-hr attainment standard as early as 2013.

When recast onto a 4-km grid, the attainment dates slip to as long as 2015 at several key monitors, such as Deer Park (DRPK) and Bayland Park (BAYP). Uncertainty associated with recasting the grid mesh from 36-km to 4-km results in DV results that run 1-3 ppb higher on the 4-km domain than on the 36-km domain. As a result of this uncertainty, as per results reported by Arunachalam (2005), upper and lower attainment date boundaries are calculated. Figure 8-1 indicates the upper bound, or worst case, attainment dates. Thus,

according to this model prediction, without the addition of further statewide or local controls the HGB area can achieve attainment by 2015.

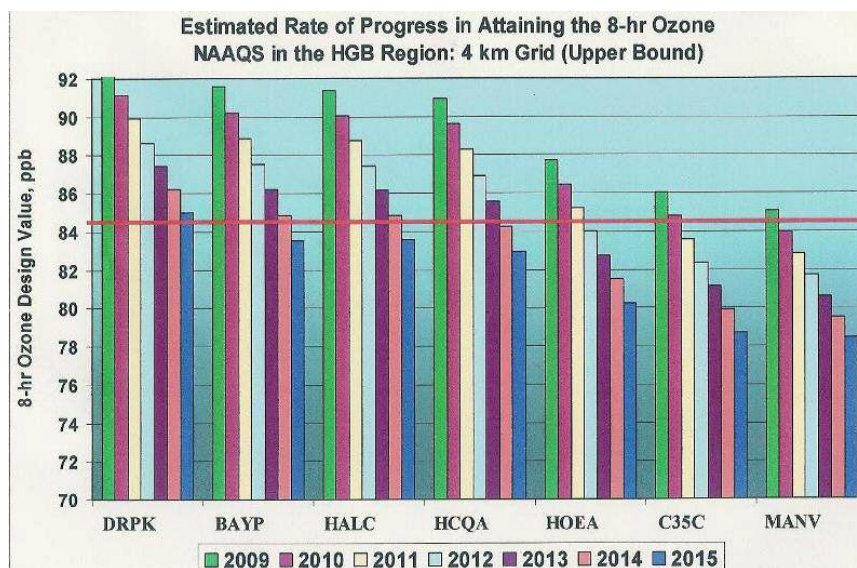


Figure 8-1: Estimating Rate of Progress in Obtaining the 8-hr O₃ NAAQS in the HGB Region 4km Grid - Upper Bound, (Source: Tesche, 2006b)

The TCEQ has achieved a level of success in stricter monitoring of VOC emissions and reporting standards. Since results of the TexAQS 2000 study indicated underreporting of VOC emissions, the TCEQ has sought to properly estimate VOC emissions from point sources in the HGB area. The addition of five new auto-GCs (automated Gas-Chromatographs) since 2003 in the Ship Channel area, located in southeastern Harris County, has allowed the TCEQ to better estimate point source emissions locations using what the TCEQ deems a potential source contribution function (PSCF). Figure 8-2 graphically depicts the decrease in Ship Channel emissions from point sources over a three year period, as determined from auto-GC measurements at area monitors. The decreased emissions were mapped over a three-year period, from 2002 – 2004 or 2003 – 2005 depending on the monitor. These decreases demonstrate the effectiveness of the HRVOC controls already

underway, such as the LDAR program and the enforced permitting requirements.

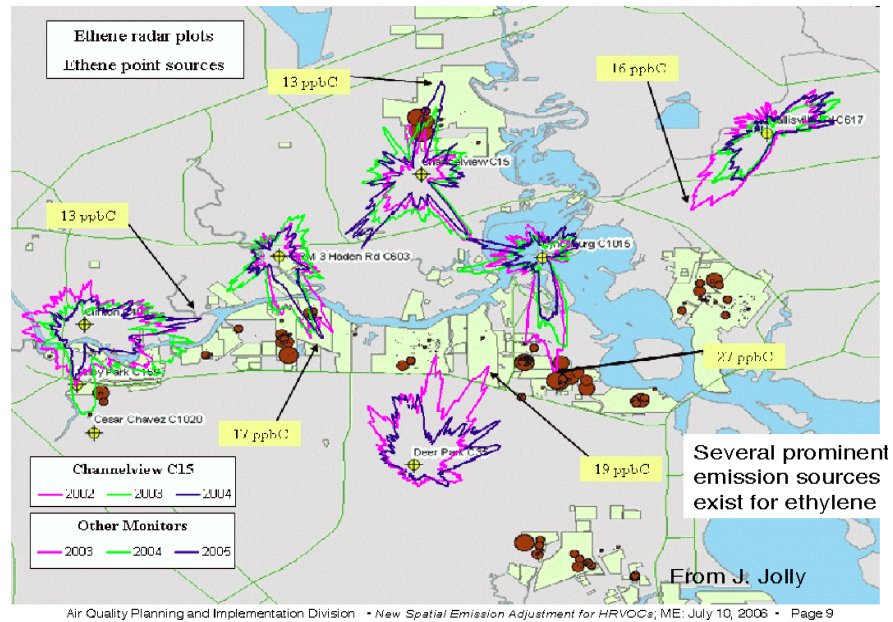


Figure 8-2: Radar plots depicting effect of increased VOC controls on ethylene concentrations over three-year period, as measured at auto-GC monitors in the vicinity of the Houston Ship Channel. Highlighted numbers indicate concentration of C emissions in latest year of measurement. Brown dots indicate ethylene point sources. Dots are sized according to magnitude of facilities' emissions (Source: TCEQ, 2006).

9. Discussion

VOC reactivity-based trading arguably makes the HGB HECT cap and trade program the most complex of the “second generation” of emissions trading programs. Questions are raised about the validity and strength of this untried program in a number of areas, and include the reliability of the photochemical modeling results and emissions data. The TCEQ must also complete attainment demonstration modeling for the new eight-hour ozone standard by 2007. The challenges that the program must ameliorate are daunting. These include a geographical area with ozone exceedances that are caused by chemistry and meteorological conditions unique in the U.S. Regardless of the difficulties faced, however, the central premise is whether this program will be an effective enough instrument to help the HGB area achieve the NAAQS eight-hour O₃ standard by 2010, without increasing the risk to public health.

The purpose of the HECT program is to reduce HRVOC emissions. In a cap and trade program accurate emissions data is crucial for program success. Regarding photochemical modeling, consideration must be made of whether the uncertainty surrounding the one-hour modeling has led to the formation of ineffective or “bad” policy.

9.1 Photochemical Modeling

In October 2005, the EPA proposed approval of the revisions to Texas’ revised SIP

attainment demonstration, submitted in December 2004, to achieve the one-hour O₃ standard by 2007. In proposing approval, the EPA deemed the TCEQ's model performance adequate as a control strategy to address routine emissions (EPA, 2005c). However, the EPA also indicates concern in that the model under predicts O₃ during days of observed high O₃ concentrations. Conversely, the model tends to over predict O₃ on days when observed ozone concentrations are low.

Several failures in the modeling explain this occurrence. An obvious failure is in the lack of modeling conducted at the 1-km grid resolution level. A coarser 4-km grid resolution was used by the TCEQ for the one-hour base and future control case attainment demonstrations. However, the TCEQ computed the emissions inventory at 1-km and aggregated it to 4-km (Jeffries, 2006). This effectively diluted any consequences of local concentrations, such as what might be found in the immediate vicinity, and downwind, of industrial point source complexes.

The 4-km grid resolution was also used by researchers to investigate the effects of HGB area trading on O₃ "hot spot" formation (Wang et al, 2006), the effects of reactivity-weighted trading on HGB area air quality (Thompson et al, 2006), and the air quality impact of allowing facilities to trade chlorine emission reductions for HRVOC allocations on a reactivity-weighted basis (Wang et al, 2006). Results of the aforementioned studies and the attainment demonstrations should be discounted to the extent that no proof is offered of the model's ability to correctly describe the effects of changes in VOC emissions.

Another disturbing concern regarding the proposed approval of the HECT program and the 2004 SIP Revisions is the TCEQ's lack of certainty over what is causing the model to

over- and under- predict O_3 concentrations in the HGB area. The December 2004 revised SIP, of which the HECT program is an essential part of, has already received a “proposed approval” from the EPA without definitive proof that its model can explain exceedance and non-exceedance days. The model does not exhibit this problem on “routine” emission days, an indicator that there is no inherent problem with the model used. Rather, an external factor is the likely cause of the disagreement between modeled and observed conditions and outcomes.

Model underpredictions were reported by Jeffries and Arunachalam (2005) for several days in latter August 2000. This report also stated that the TCEQ added 1,092 tons of HRVOC over the course of the modeled period in 2000 as a means of helping to achieve compliance. The EPA, in its proposed approval, uses this as evidence that the emission inventory did not adequately provide for the actual quantity of HRVOCs (EPA, 2005c). However, this fails to explain model discrepancies as UNC added only 67 tons of HRVOCs during the same period, yet achieved statistically similar results as the TCEQ. That similar ozone concentrations can be achieved in photochemical modeling does not necessarily mean that the reasons for such happening are the same. Different input combinations for precursor conditions and meteorology can achieve the same result (Kim, 2006). Such results, however, might well be meaningless and thus, useless as a basis for policy decision without some other collaboration.

It is concerning that the TCEQ will use its base case modeling as the foundation of the eight-hour O_3 SIP. The eight-hour attainment SIP is due to the EPA in 2010. The TCEQ claims that this does not allow adequate time to complete a new “base case” for modeling, as

well as the necessary future case. Yet the Houston 8-Hr Coalition Group, via Alpine Geophysics and the University of Houston, has completed four new additional 8-hour photochemical modeling cases (Tesche, 2006a).

The VOC composition used in the model results in very little new organic radicals. The radicals present are primarily a result of HCHO photolysis (Jeffries, 2006). Compared to modeling conducted in other urban areas, aircraft and monitor data suggests that this model underpredicts HCHO aloft and in the eastern side of the HGB area. Incomplete flare combustion is a source of HCHO. However, HCHO is not currently measured. Its presence is inferred from modeled results and observations, as well as knowledge of flare inefficiency in the HGB area.

Jeffries and Kim (2006) raise several questions regarding discrepancies in the meteorology, chemistry and emissions differences between the one-hour and eight-hour modeling cases. These are brought about as a result of SIP modeling input changes. This Process Analysis, which focused only on low level emissions, indicates decreases in NO_x and CO that should help the model better fit to observations. New spatial distribution and improved meteorological inputs completed prior to the eight-hour modeling simulations indicate similar trends in OH•, NO₂ and O₃ production with the one-hour simulations, which did not fit with observations.

Despite decreases in modeled NO_x and CO, NO₂ and CO are still overpredicted, consuming approximately 50 percent of the available OH•, thereby limiting the VOCs consumed. The OH• is not replenished since there is not a modeled source of new radical sources, like HCHO. VOCs are rich in this model. Adding much more VOCs to the model

to initiate photochemistry, as has been done by the TCEQ as well as several other researchers does not yield reliable results. An example of this is the already described situation of the TCEQ imputing 1,092 tons and achieving results that could pass the EPA's battery of statistical results as did the UNC H12 team. In reality the $\text{OH}\bullet$ should react with the VOCs to produce peroxy radicals, which in turn form more NO_2 , thereby allowing more O_3 to be formed during daylight hours. This inhibition of modeled O_3 formation, increases differences between modeled and observed values. This limitation is true at virtually all of the monitored sites in the HGB area.

9.1.1 The Use of Modeling to Test a Trading Program

Just because a model can produce a desired result does not mean the results are worthy of creating policy with it. The model used to meet the HGB area SIP attainment objectives is $\text{OH}\bullet$ -limited. A question that must be asked is how can a model that exhibits such characteristics be used to judge the effects of VOC changes in the future case? Indeed, in its proposed approval of the HGB area SIP, the EPA places more emphasis on WOE than on the model's ability to demonstrate attainment (EPA, 2005d). Kim (2006) argues the need for rational criteria to be used in judgment of whether an attainment demonstration is met. The description of how to do a WOE determination needs clarification. It has come under scrutiny by stakeholders in comments regarding SIPs suggested for approval.

9.1.2 Emissions Inventory/Program Cap

Several issues remain unresolved with the HECT program's emission inventory. One matter that continues to stand out is the 2000 emissions inventory upon which the program's baseline is established. Researchers (Murphy and Stoeckinius (2004), Jeffries and

Arunachalam (2005)) continue to state that the EI is flawed and does not, especially, account for what has collectively been deemed as the OVOCs. OVOCs are dominated by alkanes up to C6 and substituted aromatics, especially xylenes and toluene. Reductions in OVOCs, which are emitted in larger quantities than the HRVOCs, were not modeled in the MCR SIP.

In addition to not modeling the OVOCs, the flawed MCR modeling led to a future case scenario in which more HRVOCs were produced in the future controlled case, as a result of the imputation by the TCEQ of 1,092 tons of additional VOCs, than was modeled in the unadjusted inventory for the base case (see Table 3.2). This should not be since the future case should depict the impact of controls and restrictions on the emissions, thereby yielding a smaller magnitude of emissions than the base.

Of further concern is the lack of a declining cap in the HECT program that can hamper the goal of the SIP, which is to reduce ozone concentrations. The declining cap was included in the other trading programs modeled, specifically to ensure an environmental benefit.

9.2 Program Rules/Environmental Justice

Another looming concern with the trading program involves the conversion of VOC ERCs to HRVOCs. The EPA proposed approval of the HECT program after limiting emissions to five percent of a facility's HECT cap; this was done to decrease the uncertainty related to reactivity-weighted trading. A previously mentioned simulation study completed by Thompson et al (2006) tested the conversion theory by converting 100% of the OVOC emissions to HRVOC allocations. These allocations were all traded into one region. Daily

maximum one-hour and eight-hour averaged ozone concentrations increased by a maximum of 0.3% and decreased by a maximum of 1%, depending on the region into which emissions were traded. The results are discounted as a result of the lack of proof of VOC sensitivity at the 4-km grid resolution level.

The HECT program's rules compare favorably with other emissions trading programs modeled, and against those that are not modeled here. The TCEQ has incorporated some of these lessons learned from previous programs into its own. Three programs - the SO₂ Trading Program, the OTC NO_x Budget program and the RECLAIM illustrate what can happen when sufficient work is not done to prevent or ameliorate the possibility of "hot spots". In the Acid Rain and the OTC NO_x Budget programs, because of the prevailing winds from the west, "wrong way" trades should not have been allowed. But, in both programs they were, with the resulting consequences of higher levels of acid precipitation and/or NAAQS exceedances in eastern areas. The RECLAIM program was sued by a concerned citizens group because it allowed the conversion of area source credits to stationary point credits, with a resulting increase in minority area emissions (Kosobud, 2000). From a different standpoint, just because a market does not directly focus on a yet, non-existent problem, such as the potential for "hot spots", does not necessarily indicate that the program will fail. It is very difficult to design a program that deals with all contingencies.

Regardless, as part of the SIP approval process, the EPA reviews such for adherence to environmental justice concerns as indicated in Chapter 16.2 of its Economic Incentive Program (EIP) Guidance. In its October 5, 2005 proposed approval of the EPA listed several

actions that the TCEQ is taking to adhere to environmental justice principals. They include the triennial program audit, as called for in Chapter 101.403 of the TAC. The guiding regulations place emphasis on the impact on attainment and compliance by the participants. The audit results must be available for public inspection.

Additional actions taken by the TCEQ to conform to environmental justice guidelines is the TCEQ's establishment of the Toxicological Risk Assessment (TARA) Effects Evaluation Procedure. This process, authorized under section 382.0518(b)(2) of the Texas Health and Safety Code, states that the TCEQ may not grant a permit to a facility, nor may a facility begin operating, unless it can demonstrate that emissions will not have an adverse impact on public health and welfare. This demonstration is accomplished by establishing off-property ground level-air concentrations of species resulting from the proposed emissions. Further these concentrations are evaluated for the potential to cause adverse health effects. Data on these findings are to be available for public release. The last method that the EPA allows as a means to ensure compliance to environmental justice issues is the requirement that all information be released. Regardless of what measures are addressed to reduce concern over environmental justice, reactivity-based trading will remain under heavy scrutiny because of the concerns regarding human health in economically deprived areas. This is especially true in Houston, resulting from the lack of zoning restrictions and the preponderance of low income and minority neighborhoods near the Houston Ship Channel.

9.3 Operational Efficiency

The TCEQ has taken steps toward ensuring a program whose structure would appear to suggest a measure of operational efficiency via the reduction of transaction costs. The

program has, like the successful Lead Permits program of the 1980s, narrowed its focus on the petrochemical and chemical manufacturing industry. The HECT program has further narrowed its trading focus by setting the entrance level for required participation as the potential to emit greater than 10 tons of HRVOCs. If not for the similarities among the industries, the 51 Harris County participants might constitute a thin market. The Lead Permits program also developed a narrowly focused program, with a resulting decrease in transactions costs incurred by facilities when trying to find suitable trading partners. All participants were refineries, and they participated in the same markets. Gangadharan (2000) indicates that efficiency losses from transactions costs were limited to 10 percent in the Lead Permits program.

The TCEQ has designed other areas that lend themselves to minimize the cost of participating in this program. Simplicity of design and establishing effective regulations is a proven way to maintain such. In addition to the prohibition of trading between the two regions, the TCEQ has limited banking to only one year, thereby decreasing intertemporal trading and decreasing the uncertainty associated with a buildup of bankable credits.

Failure to establish design simplicity and maintain effective regulations is what caused the problems that the SCAQMD experienced in managing the RECLAIM program. As a result of its lax enforcement of regulations regarding emplacement of necessary control technologies, businesses continued to rely principally on the RTC as a means of meeting compliance standards. The looming shortage of RTCs as a result of declining cap levels was supposed to have been offset by emplacement of control technologies at impacted facilities. However, because of the lack of administrative controls, especially at a time of a crisis in

electric power generation, participatory rules were changed, and the business community lost faith in the SCAQMD.

Other issues concerning the HECT program remains unanswered. Approval of the HECT program does include a number of questions that come to mind for situations in which the governing rules do not cover. For example, rules do not cover the situation encountered when a barge, which is not covered under the LDAR rules of Ch 115 to the Texas Administrative Code, utilizes a site where the Chapter 115 rules are covered. What of the extra leaks that are likely to be found? New technologies such as emerging remote sensing techniques should be considered for such areas as barge hatches, where VOCs can leak from undetected since there are currently no governing regulations for such.

Regardless, these measures of operational efficiency, which could culminate in lower transaction costs, and the LDAR plan concerns are not what will decide the fate of this program. The measures of improved operational efficiency from the program's infrastructure are, when compared to the dearth of adequate photochemical modeling, akin to the TCEQ "majoring" on the minor and "minoring" on the major. Just because a modeled attainment demonstration can pass the EPA's statistical muster, as the MCR of the SIP attainment demonstration showed, does not indicate that the model's outcome is a reliable basis for policy decisions, unless it is understood how the model achieved its results. For a policy based on air quality modeling to be institutionalized and effectively implemented, it needs legitimacy (Lejano and Hirose, 2005). To achieve legitimacy, and realize effective policy, certain conditions must hold both from observations and the model.

9.4 Before Implementation

The TCEQ air quality modeling scenario and the policy based upon it offer several teaching points of what is necessary to know about the results of photochemical air quality modeling before the policy is broadly applied. As already mentioned, the TCEQ's SIP attainment demonstration has passed statistical muster and "lightweight" weight of evidence scenarios. However, lack of supporting evidence, such as modeling outcomes that accurately describe historical episodes, render such WOE scenarios without merit. What is at stake in this process is, ultimately, the health of the region's population. Monetary losses could include the loss of federal highway dollars and the dilution of economic strength as some businesses relocate, or choose not to locate there. If the eight-hour SIP is not submitted to the EPA by 2007 and operational by 2010, the sanctions or situations discussed are a possibility. Based on lessons learned from the HECT program thus far, and the four other emissions trading programs discussed, there are some areas that should be addressed prior to model engagement.

1. Knowledge of what is at stake. It is essential to know the possible consequences of not achieving SIP approval and implementation in sufficient time.
 - a. Consider the cost to the taxpayer of not achieving the federal attainment standards in sufficient time. What are the alternatives to not being able to reach O₃ NAAQS standard on time?
 - b. What are the consequences of requesting a "bump up" to the next higher eight-hour non-attainment category, which in the HGB area would give it a "severe" status? Doing so would allow necessary time to develop a workable attainment demonstration that

can stand on the merits of something other than lightweight WOE factors, and unsupportable assumptions of future attainment when attainment cannot reasonably be achieved in the base case.

c. Can the area/region “live” with the consequences of being placed under a more severe rating as the price of spending the extra time it takes to come up with an effective model whose inputs were not tweaked to achieve a certain result?

d. Consider the health benefits of obtaining the O_3 standard. Consider the health benefits of obtaining the ozone standard. Hubbell et al (2005) estimates that attaining the 8-hr O_3 standard could decrease the average number of nationwide premature deaths by up to 1300. Meeting the same O_3 standard could reduce the number of children admitted to the hospital for respiratory concerns by up to 3600. In a case study in Houston Levy et al (2001) estimates the monetary value of health benefits from reducing O_3 concentrations at approximately \$10/person/ $\mu\text{g}/\text{m}^3$ reduced. The majority of this cost savings, 90%, would be that brought about by decreases in premature mortality. The study considered an at-risk population of 345 million people.

2. How was the model output achieved? Can similar studies obtain the same results with similar inputs?

3. Does the model effectively compensate for region specific peculiarities, such as a sufficiently fine grid resolution to accommodate local O_3 formation phenomena or steeply varying terrain? Without fine resolution, apparent ozone formation can be minimized.

4. Are there any local impacts from trading this pollutant, such as “hot spots”? If so,

what are they and how likely is the potential for formation?

a. How does the model account for these?

b. Does the trading include the use of HAPS? If so, local impacts from trading can be particularly egregious. This is particularly important in neighborhoods composed principally of minority or low income occupants, not unusually neighborhoods in the vicinity of pollution generating facilities.

5. How reliable are the results of the model? How much uncertainty is there in the results? The results of too many SIP attainment demonstrations have often fallen short of predicted goals (Fine and Owen, 2005) leading to the conclusion that there is either an inherent model bias, or an overoptimistic attitude when reading the results.

6. How representative of the region's air quality is the event selected as the basis for the model attainment scenario? Similarly, what of the emissions inventory? How complete is it, and what assumptions are being made in the prediction of attainment?

9.5 Gauging Effective Policy

Given what is known about the HECT program, we revisit the questions presented at the beginning:

a. What constitutes "good" policy?

b. How "bad" can various facets of a program be before it yields "wrong" policy?

c. Is "terrible" policy better than a "perfect" one that cannot be instituted?

“Good”, or effective, policy achieves a desired outcome with acceptable uncertainty, since all uncertainty cannot be eliminated. The National Sulfur Dioxide Trading Program exhibits acceptable uncertainty in that the program was deemed an overwhelming success despite the existence of “hot spots” caused by SO₂ emissions. Preventing “hot spot” formation was not the program’s focus; rather, the focus was to reduce SO₂ emissions at an acceptable cost, which it did. That auto-GC measurements graphically depict decrease in air emissions over a period of time indicates progress toward the goal of maintaining the air standard.

The consequences to achieving a policy “wrong” for the HECT area could be the loss of federal dollars, and an increased risk to public health. Because the HECT program is without precedent, unintended consequences could occur, especially given an essential program weakness: aspects of the MCR SIP photochemical modeling. An important concern for public health is that of trading a known carcinogen, 1,3-butadiene, in light of the flawed modeling in which the program is based. There is also some exposure potential from many possible secondary and tertiary products of a set of specified reactants, given the “soup” of industrial by-products that can exist in any urban area. Economically, should the program prove ineffective at decreasing HRVOCs, the loss of federal highway dollars is a possibility. Such a scenario, however, stands in doubt given the effectiveness of the HRVOC reductions already in force.

In a 3-dimensional modeling environment too many uncertainties exist that make creating a “perfect” program difficult. Additionally, different stakeholders may define “program perfection” with a multiplicity of diverse standards and from varying backgrounds.

If the HECT program were ever considered “terrible” as a result of the unintended consequences that might occur at some future point, it is still better than the “perfect” program that cannot be created. There is insufficient information to determine all of the consequences of trading HRVOCs. There are elements of this program that need careful monitoring, such as better matching of emissions observations to the inventories, the health impacts of trading the known carcinogen 1, 3-butadiene, and the effectiveness of a non-declining program cap determined via debatable modeling practices. Nevertheless, this program is one of several, or many, steps in the right direction to reduce the elevated HGB area O₃ levels.

10. Conclusion

Emissions trading markets have moved a long way from the early 1990s, when the SO₂ allowance trading program raised great consternation among environmentalists, and some politicians. Market-based instruments have moved to center stage. It is economically infeasible to continue with O₃ precursor reductions, such as the one-time proposed 90% NO_x reductions in the Houston area's industrial facilities, as the predominant method to arrest tropospheric ozone production. Such challenges point to a need to think outside the "business as usual" comfort zone. The HECT program is forward thinking in its intentions, and very daring in its proposals, to reduce O₃ production through reactivity-based trading.

Regardless, the program invites many concerns and questions, one of the most important being the reliability of the modeled attainment demonstrations. This includes limitations inherent in the chemistry and meteorological mechanisms of the photochemical model. Other concerns, such as the need for an improved emissions inventory, can be responded to and needs to be corrected before other facets of the HECT program are expanded. Certain components of the program, for example the conversion of EBTP VOCs for HRVOCs, are more dependent upon having an accurate emissions inventory. Other questions must be answered, such as were the right questions asked when seeking to model air quality in Houston? Examining previous emissions programs can teach us what mistakes should be avoided and show what worked well in the past. Yet, each trading program is

distinctive, and must be evaluated on its own merits, given the uniqueness of every geographical location. Every area of uncertainty must be examined, though every area will not be completely resolved.

The SIP process ought not to be rushed. To do so creates pressures for modelers and planners to be less diligent in the scrutiny of input files, such as emissions inventories, and overly optimistic in the interpretation of the output. It also allows planners and policy makers to be overly optimistic in the selection and implementation of the best emission reduction program for a region. A politically unpopular, but necessary, alternative to rushing the SIP process to meet established deadlines, is for the governor to request a downgrade to either one of the next two lower air quality ratings. This would likely prove a politically unpopular move. Additionally, it creates quality of life and economic disincentives for families and for businesses trying to attract potential employees.

Under the eight-hour O₃ standard of 0.08 ppm a downgrade in air quality rating would be to a “serious” in the HGB area, requiring attainment by 2012. Likewise, if the lowest category rating, of “extreme” is requested, attainment would be required by 2018. Jeffries (2006b) indicates that motor vehicle controls, which modeling indicates will govern future attainment scenarios, cannot achieve compliance until after 2012. This would require a double “bump-up” to 2018, though factors indicate compliance can be achieved possibly as early as 2015. Requesting, and receiving, approval to get a “bump-up” rating would allow some very necessary time to properly implement the SIP process.

In the case of the HGB program, as with any other program, the ultimate judge of how “good” the program policy was will not come from how well the program resembled

past trading programs, or how well the attainment demonstrations met EPA requirements. Rather, real and quantifiable emissions reductions leading to improved air quality, and improved health indicators, such as fewer emergency room visits due to asthma attacks, will determine program success. One example can be found with the SO₂ Allowance Trading Program, which has been able to demonstrate improved air quality with higher pH rain and decreased fish kills in the Northeast.

Currently, the HGB HECT program appears to benefit from lessons learned in previously instituted programs; many of these lessons have been applied in the rules of the HGB HECT program. However, the definitive response as to whether the program is successful will be in a program that can affirm it has the necessary components to produce the results expected from a best policy option. In the vast eight-county HGB area, this would be a program that can reduce both “background” O₃ levels and the unique THOEs sufficiently to comply with current O₃ standards. This is made more difficult in an area densely populated with refineries, petrochemical facilities, and residential areas. To do so in an economically acceptable manner will require options in addition to the command and control option, a situation known as regulatory tiering. Previous emissions trading programs, such as the SO₂ trading program, the OTC NO_x Budget program, RECLAIM and the IL ERMS program, each began as a solution to a unique and very difficult challenge. Simplifying the complexity of an air quality challenge can be achieved via harnessing the power of self-interest inherent in market forces. But, the process cannot be rushed. Specific goals must be established, and modeling must be instituted with those goals in mind.

11. Recommendations for Future Studies

Investigations into the following scenarios might help to better understand the policy or modeling issues raised by the HGB program.

a. Model the HGB area airshed at 1 km grid resolution and 1 km EI with events, for multiple episodes.

b. Once the model works for the right reason, evaluate the ca and trade program for “hot spots” and “effectiveness” and OVOC to HRVOC trades using new EPA 3-D reactivities.

c. Conduct cost (including to public health) - benefit analysis

APPENDIX – Final HRVOC Allocations for the HECT Program (tons)

Final Allocations for the Highly Reactive Volatile Organic Compound Emissions Cap and Trade (HECT) Program

Last updated March 20, 2006

The following tables show the final allocation of allowances in the HECT program for sites within Harris County. This allocation is based on data submitted by the following companies on their Form ECT-3H, Highly Reactive Volatile Organic Compound Emissions Cap and Trade Level of Activity Certification, and has been verified by the TCEQ. This allocation assumes that 1.65% of the total allowances for Harris County will be used for storage and loading terminals.

Production/Use Sites in Harris County:

Company Name	Customer Number	Site Name	Regulated Entity Number	Preliminary Allocation (tons)
Albemarle Corporation	CN600129589	Albemarle Houston Plant	RN100218247	5.0
American Acryl, L.P.	CN600731756	American Acryl Pasadena	RN101379287	5.9
Basell USA Inc	CN600623326	Basell USA Bayport Plant	RN100216761	75.2
BASF Corporation	CN600124895	Pasadena Plant	RN100225689	8.6
BP Amoco Chemical Company	CN600126775	BP Amoco Chemical Pasadena Plant	RN102528197	40.6
Celanese, LTD	CN600130850	Celanese Clear Lake Plant	RN100227016	26.2
Chevron Phillips Chemical, L.P.	CN600303614	Chevron Phillip Chemical Cedar Bayou Plant	RN103919817	246.3
Chevron Phillips Chemical, L.P.	CN600303614	Chevron Phillips Chemical Pasadena Plastics Complex	RN102018322	91.0

Company Name	Customer Number	Site Name	Regulated Entity Number	Preliminary Allocation (tons)
Dow Chemical Company	CN600356976	Clear Lake Plant	RN104150123	24.1
E.I. Du Pont de Nemours and Company	CN600128284	E.I. Dupont de Nemours La Porte Plant	RN100225085	9.7
Enterprise Products Operating L.P.	CN600131478	Morgan's Point Plant	RN100210665	34.7
Equistar Chemicals, L.P.	CN600124705	Equistar Chemicals Bayport Complex	RN102926920	18.8
Equistar Chemicals, L.P.	CN600124705	Channelview Chemical Complex	RN100542281	441.9
Equistar Chemicals, L.P.	CN600124705	Equistar Chemicals La Porte Complex	RN100210319	101.7
ExxonMobil Chemical	CN601549660	Baytown Chemical and Baytown Technology and Engineering Complex	RN102574803	194.3
ExxonMobil Chemical	CN601549660	Houston Olefins Plant	RN102576063	25.9
ExxonMobil Chemical	CN601549660	Baytown Olefins Plant	RN102212925	289.9
ExxonMobil Corporation	CN600123939	Baytown Refinery	RN102579307	429.7
Georgia Gulf Chemicals & Vinyls, LLC	CN600753966	Pasadena Division	RN100213958	18.5
Goodyear Tire & Rubber	CN600616049	Houston Chemical Plant	RN100870898	13.2
Goodyear Tire & Rubber	CN600616049	Bayport Chemical Plant	RN102608932	5.0
Innovene Polymers Inc.	CN601551427	Innovene Polymers	RN102537289	37.9

Company Name	Customer Number	Site Name	Regulated Entity Number	Preliminary Allocation (tons)
Innovene Polyethylene North America	CN602882201	Innovene Polyethylene North America	RN100229905	60.7
Johann Haltermann, LTD	CN601181282	Haltermann Plant I	RN100219237	5.0
Johann Haltermann, LTD	CN601181282	Haltermann Plant II - Channelview	RN102610912	5.0
Kaneka Texas	CN600129928	Kaneka Texas	RN100218841	5.0
Lubrizol Corporation	CN600269617	Deer Park Facility	RN100221589	9.6
Lubrizol Corporation	CN600269617	Bayport Facility	RN101058410	5.0
Lyondell Chemicals	CN600344402	Channelview Chemical Complex	RN100633650	117.2
Lyondell Chemicals	CN600344402	Bayport Choate Plant	RN102523107	39.6
Lyondell Citgo Refining	CN601313083	Houston Refinery	RN100218130	111.3
Millennium Petrochemicals	CN602625402	La Porte Site	RN100224450	10.5
Natural Gas Odorizing	CN600132047	Mercaptans Plant	RN100683952	5.0
Nisseki Chemicals	CN600569701	Bayport Plant	RN102887270	5.0
Noltex LLC	CN600127229	La Porte EVOH Facility	RN101049518	5.0
Nova Chemicals	CN600253975	Bayport Facility	RN100542224	11.7
Shell	CN601542012	Deer Park Plant	RN100211879	351.0
Sunoco, Inc (R&M)	CN601179914	Sunoco R&M La Porte Plant	RN102888328	26.6
Sunoco, Inc (R&M)	CN601179914	Sunoco R&M Bayport Propylene	RN100524008	12.2

Company Name	Customer Number	Site Name	Regulated Entity Number	Preliminary Allocation (tons)
Sunoco, Inc (R&M)	CN601179914	Bayport PE Site	RN103773206	5.0
Texas Petrochemicals, L.P.	CN600130322	Houston Plant	RN100219526	193.3.
Total Petrochemicals USA Inc.	CN600582399	Total Petrochemicals Bayport	RN100909373	29.4
Total Petrochemicals USA Inc.	CN600582399	Total Petrochemicals La Porte Plant	RN100212109	117.9
Valero Refining Texas L.P.	CN600127468	Houston Refinery	RN100219310	119.4

Storage/Loading Terminals in Harris County:

Company Name	Customer Number	Site Name	Regulated Entity Number	Preliminary Allocation (tons)
Dynegy Midstream	CN601301559	Galena Park Marine Terminal	RN100214212	15.6
Enterprise Products	CN602765703	Oil Tanking Terminal	RN102580834	5.0
Enterprise Products	CN602765703	Alameda LPG Facility	RN102940103	5.0
Intercontinental Terminals	CN601470222	Deer Park Terminal	RN100210806	13.1
Kirby Inland Marine	CN600611206	Degassing Plant	RN102204211	8.3
LBC Houston	CN601179849	Bayport Terminal	RN101041598	5.0
Odfjell Terminals (Houston) L.P.	CN601651607	Seabrook Marine Terminal	RN100218411	5.0

REFERENCES

- Allen, D., 2006, Phone conversation with author on February 15.
- Allen, D., Durrenberger, G, McGaughey, C., and J. Nielson-Gammon, 2002, Accelerated Science Evaluation of Ozone Formation in the Houston-Galveston Area: Meteorology, accessed at <http://www.utexas.edu/research/ceer/texasarchive/pdfs/Meteorology-version2.0final.PDF>
- Allen, D. and H. Jeffries, 2004, Variable Industrial VOC Emissions and Their Impact on Ozone Formation in the Houston Galveston Area, Presentation at the 13th Emissions Inventory Conference, accessed at http://airchem.sph.unc.edu/Research/Projects/Texas/UT_UNC/
- Allen, D. and H. Jeffries, 2004, Variable Industrial VOC Emissions and Their Impact on Ozone Formation in the Houston Galveston Area, Final Report to the Texas Environmental Research Consortium on Project H13, accessed at http://www.tceq.state.tx.us/assets/public/implementation/air/sip/sipdocs/2004-05-HGB/04042sipapi_pro.pdf
- Allen D. and E. Olaguer, 2004, State of the Science of Air Quality in Eastern Texas: Major Scientific Findings and Recommendations, accessed at <http://files.harc.edu/Projects/AirQuality/Projects/H030.2004/H30FinalReport.pdf>.
- Arunachalam, S., Holland, A., Do, B., and M. Abraczinskas, 2006, A quantitative assessment of the influence of grid resolution on predictions of future-year air quality in North Carolina, USA, *Atmospheric Environment*, (in press).
- Atkinson, R., 2000, Atmospheric Chemistry of VOCs and NO_x, *Atmospheric Environment*, 34, 2063 – 2101,.
- Bergen, M., Russell, A., and J. Milford, 1995, Quantification of Individual VOC Reactivity Using a Chemically Detailed, Three-Dimensional Photochemical Model, *Environ Sci Tech*, 29, 3029 – 3037.
- Berkowitz, C.M., et al, 2004, Chemical and Meteorological Characteristics Associated with Rapid Increases of O₃ in Houston, Texas, *J. Geophys. Res.* 109D10307, doi:10.1029/2003J004171.
- Byun, D., 2005, Role of Modeling Assumptions in the Houston Mid-Course Review, HARC Project H12/HRB (University of Houston), accessed at <http://files.harc.edu/Projects/AirQuality/Projects/H012.2004/8HRB/H128HRBUHExecutiveSummary.pdf>

- Cantu, G., 2003, Speciation of Texas Point Source VOC Emissions for Ambient Air Quality Modeling, , accessed at ftp://ftp.tnrc.state.tx.us/pub/OEPAA/TAD/Modeling/HGAQSE/Modeling/EI/PointEI_VOC_Speciation_Report-GabrielCantu.pdf
- Carlson, L., 1996, NESCAUM/MARAMA NO_x Budget Model Rule, prepared for the NESCAUM/MARAMA NO_x Budget Task Force.
- Carter, W.P.L. and R. Atkinson, 1987, An experimental study of incremental hydrocarbon reactivity, *Environ. Sci. Technol.*, 21, 670-679.
- Carter, W.P.L., 1994, Development of Ozone Reactivity Scales for Volatile Organic Compounds, *J. Air & Waste Manage. Assoc.*, 44, 881-899.
- Chang et al, 2002, Sensitivity of Urban Ozone Formation to Chlorine Emissions Estimates, *Atmos. Environ.*, 36, 4991-5003,.
- Chartier, D., 2002, RECLAIM Wins Positive Report from EPA, *Environmental Finance*, 31, http://www.emissions.org/publications/member_articles/ef12ema31.pdf.
- Croes, B.E., et al, Reactivity-Based Hydrocarbon Controls: Scientific Issues and Potential Regulatory Applications, *J. Air Waste Manage Assoc.*, 42, No. 5, 657-661, 1992.
- Darby, L.S. et al, 2002, Relationship between Mean Wind Direction and O₃ Trends at LaPorte, Texas, paper presented at Fourth Conference on Atmospheric Chemistry: Urban, Regional and Global Scale Impacts of Air Pollution, Natl. Ocean. and Atmos. Admin. Orlando, FL.
- Daum, P.H., et al, Origin and Properties of High Ozone Observed During the Texas 2000 Air Quality Study (TexAQS), *J. Geophys. Res.* 109, D17306, doi:10.1029/2003JD004311.
- Deweese, D., Emissions Trading: ERCs or Allowances?, *Land Economics* 77(4), 513- 526.
- Dimitriadis, B., 1999, Scientific Basis of an Improved EPA Policy on Control of Organic Emissions for Ambient Ozone Reduction, *J. Air Waste Manage Assoc.*, 49, 831-838,.
- Doyle, M. et al, 2005, Effects of 1,3-Butadiene, Isoprene, and their Photochemical Products on Human Lung Cells, *Environmental Health Perspectives*, 112, No. 15, 1488-1495.
- Drury, R.T. et al, 1999, Pollution trading and Environmental Injustice: Los Angeles' Failed Experiment in Air Quality Policy, *Duke Environmental Law and Policy Forum*, 9, 231-289.
- Environ Corporation, 2005, Survey and Demonstration of Monitoring Technology for Houston Industrial Emissions, Project H31.2004, for Houston Advanced Research Center, <http://files.harc.edu/Projects/AirQuality/Projects/H031.2004/Phase1A/H311AProjectSummary.pdf>

- Environmental Law Institute, 1997, *The U.S. Experience with Economic Incentives in Environmental Pollution Control Policy*.
- Fine, J.S., and D. Owen, 2005. Technocracy and Democracy: Conflicts between Models and Participation in Environmental Law and Planning, *Hastings Law Journal* 56, 901 -
- Finlayson-Pitts, B.J. and J. Pitts, 2000, *Chemistry of the Upper and Lower Atmosphere*, Academic Press.
- FLIR Systems, online brochure, ThermaCAM[®] GasFindIR, <http://www.flirthermography.com/media/GasFindIR%20Brochure.pdf>
- Forswall, C. and K. Higgins, Clean Air Act Implementation in Houston: An Historical Perspective, 1970 - 2005, http://cohesion.rice.edu/CentersandInst/ShellCenter/emplibrary/SIP_2.pdf.
- Fromm, O. and B. Hansjorgen, 1996, 'Emission Trading in Theory and Practice: An Analysis of RECLAIM in Southern California, *Environment and Planning C: Government and Policy*, 14, 367-384.
- Hakami, A. et al, 2004, Ozone Formation Potential of Organic Compounds in the Eastern United States: A Comparison of Episodes, Inventories and Domains, *Environ. Sci. Technol.*, 38, 6748-6759.
- Hakami, A. et al, 2004, Regional Three-Dimensional Assessment of the Ozone Formation Potential of Organic Compounds, *Atmos. Environ.*, 38, 121 – 134.
- Houston Chronicle, 2006, "In Harm's Way", <http://130.80.24.5:8081/content/chronicle/special/04/toxic/index.html> ,.
- Hubbell, B., Hallberg, B., McCubbin, D., and E. Post, 2005, Health-Related Benefits of Attaining the 8-Hr Ozone Standard, *Environmental Health Perspectives*, 113, No. 15, 73-82.
- ICF, Inc., 1989, Economic Analysis of Title V (Acid Rain Provisions) of the Administration's Proposed Clean Air Act Amendments (H.S. 3030/S. 1490). Prepared for the U.S. EPA, Washington, D.C.
- IL EPA, Annual Performance Review Report – 2005: Emissions Reduction Market System, <http://www.epa.state.il.us/air/erms/apr/2005/aprr-2005-full.pdf>
- Industry Professionals for Clean Air, 2005, Reducing Flare Emissions from Chemical Plants and Refineries: An analysis of industrial flares' contribution to the Gulf Coast region's air pollution problem, http://www.refineryreform.org/downloads/reducing_flare_emissions.pdf
- Jeffries, H., 2006, e-mail correspondence with author.

- Jeffries, H., 2006, written correspondence with author.
- Jeffries, H. and Kim, B., 2006, HGA SIP-Relevant Research, Presentation to the TERC Advisory Committee,
http://files.harc.edu/Sites/TERC/About/Events/SAC200605/SIP_HGBRelevantResearch.pdf
- Jeffries, H., and S. Arunachalam, 2005, Role of Modeling Assumptions in the Houston Mid-Course Review, HARC Project H12.8HRB (UNC),
<ftp://airchem@sph.unc.edu/research/H12/unc/report>.
- Jolly, J., F. Mercado, and D. Sullivan., 2004, Comparing the Emission Inventory to Ambient Data in Houston. Appendix HH of Chapter 4, May 2004 SIP revision, and accompanying presentation, Houston EI: Ambient Comparison–VOC/NOX ratios by quadrant.
- Kete, N., 1992, “The U.S. Acid Rain Control Allowance Trading System”, In: OECD, *“Climate Change: Designing a Tradable Permit System”*.
- Khan, M. et al, 1999, Photochemical Reactivities of Common Solvents: Comparison between Urban and Regional Domains, *Atmos. Environ.*, 33, 1085-1092,.
- Kim, B., 2006, Development, Implementation and application of an improved protocol for the performance evaluation of regulatory photochemical air quality modeling, PhD Dissertation, University of North Carolina at Chapel Hill
- Kleinman, L.I. et al, 2002, Ozone Production Rates and Hydrocarbon Reactivity in 5 Urban Areas: A Cause of High Ozone Concentration in Houston, *Geophys. Res. Lett.* 29, No. 10, 1467, 101029/2001GL014569.
- Krupnick, A. J. et al, 1983, On Marketable Air-Pollution Permits: The Case for a System of Pollution Offsets. *Journal of Environmental Economics and Management*, 10, 233 – 247.
- Lei, W. et al, 2004, Chemical Characterization of Ozone Formation in the Houston-Galveston Area: A Chemical Transport Model Study, *J. Geophys. Res.* 109, D12301, doi:10.1029/2003JD004219.
- Lejano, R. and R. Hirose, 2005, Testing the Assumptions Behind Emissions Trading in Non-Market Goods: the RECLAIM Program in Southern California, *Enviro. Sci. & Pol.*, 8, 367 – 377.
- Levy, R. et al, 2006, Reducing Emissions from Plant Flares, Paper #61, Industry Professionals for Clean Air, http://www.h-gac.com/NR/rdonlyres/ejedvvdnzgw7vyg7usvcaqgz74m4n7m5x45apfk4z3kxkqlx356qhk_n3hodqpoxabg4p6nf^{c2}wo5pltwzzpbtzkante/AWMAPaper61ReducingEmissionsFromPlantFlares.pdf

- Martien, P.T. et al, 2003, Evaluation of Incremental Reactivity and its Uncertainty in Southern California, *Environ. Sci. Technol.*, 37, 1598-1608.
- McDaniel, M., 1983, EPA-600/2-83/052, Flare Efficiency Study. (EPA 1983 Flare Study) Engineering Science, Inc.
- McNair, L. et al, 1992, Airshed Calculations of the Sensitivity of Pollutant Formation to Organic Compound Classes and Oxygenates Associated with Alternative Fuels, *J. Air Waste Manage. Assoc.*, 42:174-178.
- Murphy, C. and T. Stoeckinius, 2004, Survey of Technological and Other Measures to Control HRVOC Emission events, Final Report to the Texas Environmental Research Consortium on Project H12EE, <http://files.harc.edu/Projects/AirQuality/Projects/H012.2004/EE/H12EEFinalReport.pdf>
- Murphy, C. and D. Allen, 2005, Hydrocarbon Emissions from Industrial Release Events in the Houston-Galveston Area and their Impact on Ozone Formation, *Atmos. Environ.*, 39, 3785 – 3798.
- NAPA, 2000, Cross-cutting Analysis of Trading Programs., National Academy of Public Administration, http://www.napawash.org/pc_economy_environment/epafile06.pdf
- NARSTO, 2005, Improving Emissions Inventories for Effective Management Across North America, NARSTO 05-001, Pasco, Washington, U.S.A.
- Nash, J. and R. Revesz, 2002, The Design of Marketable Permit Schemes to Control Local and Regional Pollutants, *An Introduction to the Law and Economics of Environmental Policy: Issues in Institutional Design*, 20, 331 – 377.
- Russell, A., et al, 1995, Urban Ozone Control and Atmospheric Reactivity of Organic Gases, *Science*, 269, 491-495.
- Ryerson, T.B., et al, 2001, Observations for Ozone Formation in Power Plant Plumes and Implications for Ozone Control Strategies, *Science*, 292, i5517.
- Ryerson, T.B. et al, 2003, Effect of Petrochemical Industrial Emissions of Reactive Alkenes and NO_x on Tropospheric Ozone Formation in Houston, Texas, *J. Geophys. Res.* 108(D8), 4249, doi:10.1029/2002JD003070.
- South Coast Air Quality Management District (SCAQMD), 2001, Air Quality, SCWMD, Emission Trend.
- Sexton, K. and H. Westberg, 1983, Photochemical Ozone Formation from Petroleum Refinery Emissions, *J. Atmos. Environ.*, 17, 467-475.
- Solomon, B. J. and R. Lee, 2000, Emissions Trading Systems and Environmental Justice, *Environment*, 42, 32-45.

- Soward, L., 2004, "Houston Air Quality: Meeting the Ozone Standards", Speech delivered at Rice University Shell Center for Sustainability Conference on Houston Air Quality: Meeting the Ozone Standards, October 6. <http://www.ruf.rice.edu/~eesi/scs/Soward.pdf>
- Stavins, Robert N., 1998, What Can We Learn from the Grand Policy Trading Experiment? Lessons from SO₂ Allowance Trading", *Journal of Economic Perspectives*, Vol. 12, No. 3, 69-88.
- Tanaka, P. et al, 2000, Anthropogenic Sources of Chlorine and Ozone Formation in Urban Atmospheres, *Environ. Sci Technol.*, 34, No. 3, 4470-4473.
- Tanaka, P. et al, 2003, Direct Evidence for Chlorine-Enhanced Urban Ozone Formation in Houston, Texas, *Atmos. Environ.*, 37, 1493-1400.
- TCEQ, 2002, Post-1999 Rate-of-Progress and Attainment Demonstration Follow-up SIP for the Houston/Galveston Ozone Nonattainment Area, Rule Log No. 2002-046a-SIP-AI, http://www.tceq.state.tx.us/assets/public/implementation/air/sip/sipdocs/2002-12-HGB/02046sip_ado.pdf
- TCEQ, 2003, Randy Wood presentation at Rice University, "How Will Current Regulations be Revised to Improve Air Quality". [http://www.ruf.rice.edu/~eesi/scs/Wood.ppt#268,3,Houston/Galveston Emissions \(tons per day\)](http://www.ruf.rice.edu/~eesi/scs/Wood.ppt#268,3,Houston/Galveston Emissions (tons per day))
- TCEQ, 2004a, Rule Project No. 2004-058-101-AI, Texas Commission on Environmental Quality, http://www.tnrc.state.tx.us/oprd/rule_lib/proposals/04058101_pro.pdf
- TCEQ, 2004b, 2002 SIP Base Case Model Performance Evaluation, <http://www.tceq.state.tx.us/assets/public/policy/epi/sip/sipdocs/2004-05-HGB/Ch3Part2.pdf>
- TCEQ, 2004c, HGB Mid-Course Review SIP Narrative (2004-042-SIP-NR), http://www.tceq.state.tx.us/implementation/air/sip/dec2004hgb_mcr.html
- TCEQ, 2006, A New Spatial Emissions Adjustment for HRVOCs, http://www.tceq.state.tx.us/implementation/air/airmod/committee/pmtc_set.html
- Tesche, T.W. et al, 2005, Meeting the 8-hr Ozone NAAQS in Houston, Alpine Geophysics. http://www.tceq.state.tx.us/assets/public/implementation/air/am/workshop/20051011-12/TCEQ_air_quality_planning_relevant_questions.pdf
- Tesche, T.W., 2006a, 8-hr Ozone Attainment Scenario Modeling for Houston: Residual Nonattainment and Sensitivity to Precursor Emissions Reductions. http://www.tceq.state.tx.us/assets/public/implementation/air/am/committees/pmt_set/20060215/20060215-tesche-8hr_hgb_o3_modeling.pdf

- Tesche, T.W., 2006b, Estimated Rate of Progress in Attaining the 8-hr Ozone NAAQS in the HGB Region Using CMAQ Simulations of the Full Summer 2002 National Modeling Episode,
- Thompson, T. et al, 2005, 8 Hour Ozone Standard – Briefing on Air Quality Research Pertaining to Monitors in HGB Perimeter Counties, University of Texas at Austin.
http://www.tceq.state.tx.us/assets/public/implementation/air/am/committees/pmt_set/20051214/20051214-perimeter_county_aq_research-ut.pdf
- Tietenberg, T., 1991, Tradable Permits for Pollution Control When Location Matters. *Environmental and Resource Economics*, 5, 95-113.
- U.S. EPA, 1990, Environmental Investments: The Cost of a Clean Environment, Washington, D.C., U.S. Environmental Protection Agency.
- U.S. EPA, 2000, AP-42 Compilation of Air Pollution Emission Factors,
<http://www.epa.gov/ttn/chief/ap42/>
- U.S. EPA et al, 2001, The Episodic Release Reduction Initiative,
<http://www.epa.gov/region6/6en/a/erri07-5fin.pdf>
- U.S. EPA, 2002, An Evaluation of the South Coast Air Quality Management District's Regional Clean Air Incentives Market - Lessons in Environmental Markets and Innovation, <http://www.epa.gov/region09/air/reclaim/report.pdf>
- U.S. EPA, 2005a, Guidance on the Use of Models and Other Analyses in Attainment Demonstrations for the 8-hour Ozone NAAQS.
- U.S. EPA, 2005b, Interim Guidance on Control of Volatile Organic Compounds in Ozone State Implementation Plans, 40 CFR Part 51,
<http://www.epa.gov/ttncaaa1/t1/memoranda/27601interimguidvoc.pdf>
- U.S. EPA, 2005c, Approval and Promulgation of Air Quality Implementation Plans; Texas; Highly Reactive Volatile Organic Compound Emissions Cap and Trade Program for the Houston/Galveston/Brazoria Ozone Nonattainment Area, Federal Register / Vol. 70, No. 192,
<http://a257.g.akamaitech.net/7/257/2422/01jan20051800/edocket.access.gpo.gov/2005/pdf/05-19996.pdf>
- U.S. EPA, 2005d, Approval and Promulgation of Air Quality Implementation Plans; Texas; Revisions to the Ozone Attainment Plan for the Houston/Galveston/Brazoria Nonattainment Area, Federal Register / Vol. 70, No. 192,
<http://a257.g.akamaitech.net/7/257/2422/01jan20051800/edocket.access.gpo.gov/2005/pdf/05-19996.pdf>
- U.S. EPA, OTC NOx Budget Program 1999-2002 Progress Report, Office of Air and Radiation – Clean Air Market Programs, <http://www.epa.gov/airmarkets/otc/otcreport.pdf>

- U.S. EPA, 2004, The OTC NO_x Budget Program (1999-2002): Emissions Trading and Impacts on Local Emission Patterns, Office of Air and Radiation Discussion Paper, <http://www.epa.gov/airmarkets/otc/papers/localtrends.pdf>
- Wenfang, L. et al, 2004, Chemical Characterization of Ozone Formation in the Houston-Galveston Area: A Chemical Transport Model Study, *J. Geophys. Res.* 109, D12301, doi:10.1029/2003JD004219.
- Wilson, J., 2004, GHASP President, Letter to TCEQ regarding HRVOC control strategies, <http://www.ghasp.org/publications/sipcomments/ghaspTCEQ080904sip.pdf>
- Yang Y.-J. et al, 1995, Uncertainties in Incremental Reactivities of Volatile Organic Compounds, *Environ. Sci. Technol.*, 29, 1336-1345.
- Zhang, R. et al, 2004, Chemical Characterization of Ozone Formation in the Houston-Galveston Area: A Chemical Transport Model Study, *J. Geophys. Res.* 109.