



CONSULTING ENGINEERS  
& SCIENTISTS

# ***FINAL REPORT***

## **CMAQ Modelling of Possible Solid Waste Management Scenarios**

**Project Number: #0920063A**

**June 11, 2009**

**SUBMITTED TO: Metro Vancouver  
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**Attention: Roger Quan**  
**Division Manager, Air Quality Policy & Management**

**Subject: CMAQ Modelling of Possible Solid Waste Management Scenarios**

RWDI AIR Inc. is pleased to submit this final report for the CMAQ modelling of possible solid waste management scenarios. This report discusses the methodology adopted for the assessment, the emissions associated with all eight scenarios and one sensitivity case, and provides model results for the 2005 basecase and all scenarios.

We trust this report meets your current requirements. If you have any questions, please do not hesitate to contact the undersigned at (604) 730-5688 ext. 2490.

Sincerely,

**RWDI AIR Inc.**

A handwritten signature in black ink that reads 'Mark C. Milner'. The signature is written in a cursive, flowing style.

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## EXECUTIVE SUMMARY

RWDI AIR Inc. was retained by Metro Vancouver to compare the relative potential regional air quality impacts due to eight solid waste management scenarios in 2020 and one sensitivity case. The most recent version of the Community Multi-scale Air Quality (CMAQ) modelling system that was developed for Environment Canada for the Pacific Northwest was used. CMAQ combines emissions, meteorology and atmospheric chemistry to predict ambient concentrations of air contaminants. CMAQ is a tool used by policy makers to compare the impacts of different air emission related policy options. For this study, results for the 2020 solid waste management scenarios are compared to a 2005 base case, 2005 being the year of the most recent emission inventory for the Lower Fraser Valley (LFV). The focus of this study is to assess the potential impacts of the various scenarios on regional ambient concentrations of ozone and particulate matter (PM), two air contaminants of concern from both a health and a visibility (smog and haze) perspective in the LFV.

The model domain covers most of British Columbia and some of Alberta and Washington State. However, results are presented for a 164 km by 164 km area that encompasses most of the LFV and the Gulf Islands. The period modelled is an ozone-rich portion of the Pacific 2001 summer monitoring campaign from August 9 to 16 that consists of meteorology conducive to ozone formation and has been used by Environment Canada in previous studies. By modelling this period, the worst-case regional summer air quality impacts will be estimated.

Emissions data inputs to the CMAQ model for the 2005 base case were adapted from the 2005 emission inventory developed by Metro Vancouver for the LFV airshed, which includes all of Metro Vancouver, most of the Fraser Valley Regional District (FVRD), and Whatcom County in Washington State. For the 2020 scenarios, emissions from solid waste management are based on the results of the life cycle assessment conducted by the Sheltair Group in support of a study prepared for Metro Vancouver by AECOM Canada Ltd. analysing eight different scenarios for managing the municipal solid waste that remains after all practical efforts to reduce, reuse and recycle waste have been exhausted. Emissions data for all other non-waste management sources are based on the LFV emission inventory forecast for 2020. Results from the life cycle assessment indicate that there will be emissions from solid waste management for the foreseeable future; however, future waste management emissions under any scenario are comparable to 2005 emissions and are very low relative to airshed totals (representing from less than 0.1% to 1.2% of total emissions depending on the air contaminant).

The LFV emission inventory and forecast indicates that total emissions of nitrogen oxides and volatile organic compounds, which are precursors to the secondary formation of ozone and particulate matter, are predicted to decrease in the LFV from 2005 to 2020. By contrast, during the same period, total emissions of ammonia and sulphur dioxide, which are precursors to the secondary formation of particulate matter, are predicted to increase.

Overall, the CMAQ model results show decreases in maximum predicted ozone and PM<sub>2.5</sub> concentrations in most areas of the Lower Fraser Valley between 2005 and 2020. The decreases in ozone tend to be greater than the decreases in PM<sub>2.5</sub>, most likely because of the expected decrease in emissions of both of the major ozone precursors – nitrogen oxides and volatile organic compounds – but in the case of particulate matter some of the precursor emissions are expected to decrease while others are expected to increase.

There is very little difference in the CMAQ model results for the various solid waste management scenarios. The differences between scenarios are well within the error of the model. Also, the differences between scenarios are much less than the overall differences between 2005 and 2020, which indicates that the predicted changes in regional air quality are derived mainly from changes in other emission sources, such as improvements in vehicle emissions.

Although this study is based on an eight-day summer ozone episode, it is expected that the air quality improvements predicted for this episode would translate into overall annual improvements. Annual improvements in ozone and PM<sub>2.5</sub> concentrations can be linked to changes in incidences of various health outcomes, including illness and death.

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## 1.0 INTRODUCTION

Metro Vancouver coordinates the long-range planning process for the recycling and disposal of solid waste in the Lower Mainland. With the Cache Creek Landfill expected to reach capacity soon, Metro Vancouver is considering several options to deal with the region's waste. RWDI AIR Inc. (RWDI) was retained in early 2009 to perform Community Multi-scale Air Quality (CMAQ) modelling to determine the relative potential regional scale air quality impacts of these solid waste management scenarios in metropolitan Vancouver relative to a 2005 base case, 2005 being the year of the most recent emission inventory for the Lower Fraser Valley (LFV). The focus of this study is to assess the potential impacts of the various scenarios on regional ambient concentrations of ozone and particulate matter (PM), two air quality contaminants of concern from a health perspective in the LFV.

The Lower Mainland currently diverts about 55% of the municipal solid waste (MSW) generated in the region from disposal, but Metro Vancouver is considering programs to achieve 70% diversion by 2015. Metro Vancouver has defined eight solid waste management scenarios for the year 2020, assuming the 70% diversion level has been met and the remaining 30% of the generated waste (1,260,000 t/y) must be disposed. In all eight scenarios and one sensitivity case, the existing waste-to-energy (WTE) facility located in Burnaby is assumed to be operating at its future expected capacity of 265,000 t/y. The disposal mechanisms for the remaining 995,000 t/y are as follows:

### **Scenario 1 – Large New WTE**

In this scenario, a new WTE facility will be built in Metro Vancouver and will process 750,000 t/y of waste. The new WTE facility will be optimized for district heating. The remaining waste will be disposed at the Vancouver Landfill.

### **Scenario 2 – Moderate New WTE**

This scenario is the same as Scenario 1 except that the new WTE facility will only process 500,000 t/y of waste.

### **Scenario 3 – In-Region Use of RDF Product from MBT**

In this scenario, a mechanical-biological treatment (MBT) facility will be built to process 500,000 t/y of waste. The MBT product, known as refuse-derived fuel (RDF) will be used as a supplementary fuel in one or more cement kilns located in Metro Vancouver, replacing coal and other fossil fuels.

**Scenario 4 – Out-of-Region Use of RDF Product from MBT**

This scenario is the same as Scenario 3 except that the RDF will be transported by barge to a facility outside the region. This facility will be optimized for electricity generation with no additional use of steam or heat.

**Scenario 5 – Waste Exported Out of Region to WTE**

This scenario is the same as Scenario 2 except that the new WTE facility will be located outside the LFV. Unprocessed waste will be transported by barge to this WTE facility. This WTE facility will be optimized for electricity generation.

**Scenario 6 – Local Landfilling of MBT Product**

In this scenario, a MBT facility will be built to process all 995,000 t/y of the remaining MSW. The stabilized product from the MBT facility will be disposed at the Vancouver Landfill.

**Scenario 7 – Maximize Local Landfilling**

This scenario focuses on the use of the Vancouver Landfill and assumes that it will operate at its current permitted limit of 750,000 t/y. All remaining MSW will be disposed at a new landfill located outside the LFV.

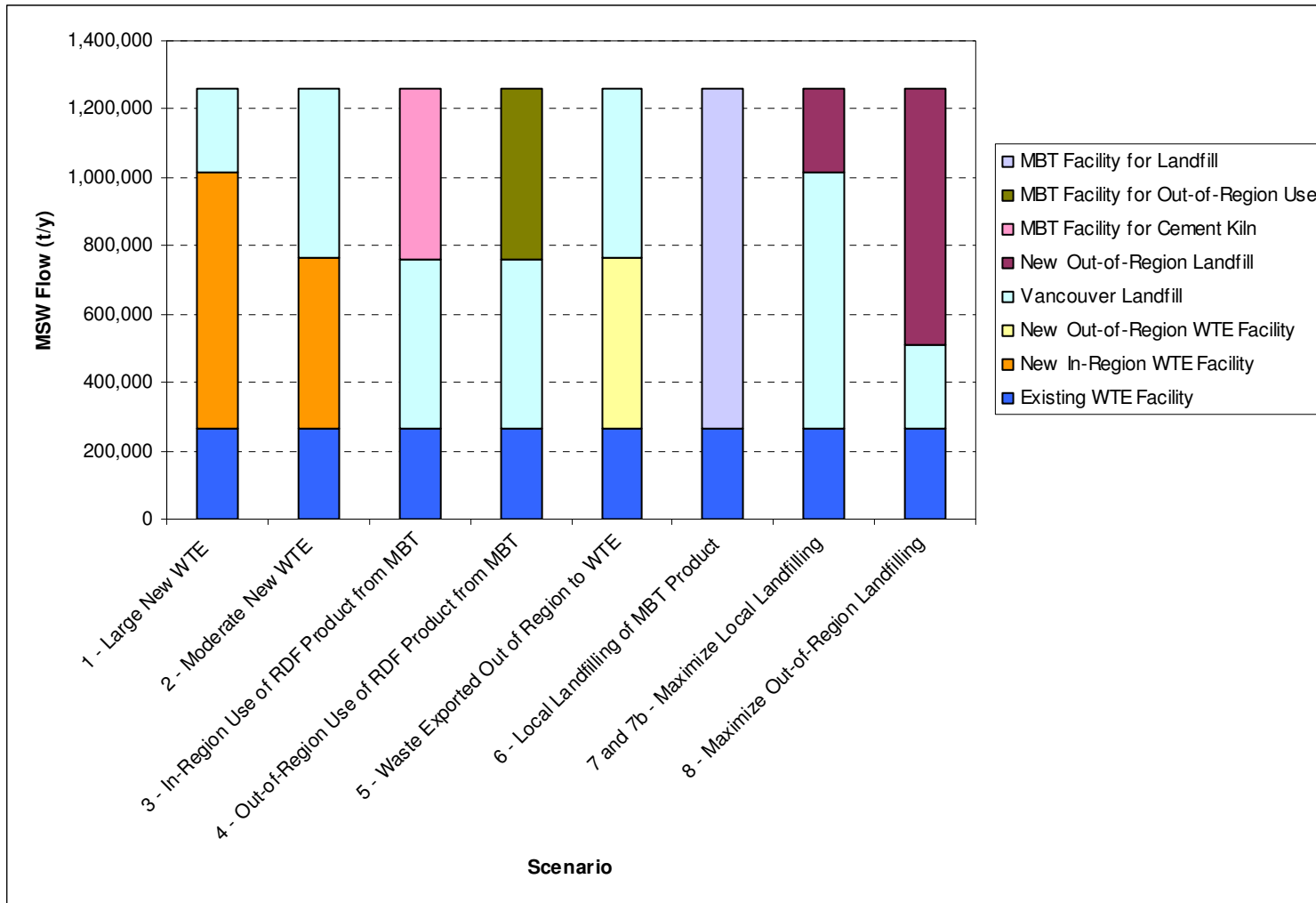
**Scenario 7b – Maximize Local Landfilling with 75% Landfill Gas Capture**

This scenario was added as an alternative to Scenario 7. In this scenario, the Vancouver Landfill is assumed to capture 75% of the generated landfill gas (LFG) as opposed to the 35% assumed for all other scenarios.

**Scenario 8 – Maximize Out-of-Region Landfilling**

This scenario focuses on exporting the bulk of the MSW to a new landfill located outside the LFV. The new landfill is assumed to process 750,000 t/y of waste and the remaining MSW will be disposed at the Vancouver Landfill.

The solid waste management scenarios are illustrated in Figure 1.1.



**Figure 1.1: Depiction of Solid Waste Management Scenarios**

## 2.0 EMISSIONS

### 2.1 CURRENT AND FUTURE EMISSIONS IN THE LOWER FRASER VALLEY

Metro Vancouver develops and publishes an emission inventory to account for total air emissions from all pollution sources within the LFV every five years. The most recently released inventory was for the year 2005 (Metro Vancouver 2007) and is summarized in Table 2.1, which identifies emissions associated with current waste management operations in the LFV (Burnaby WTE facility, Maxim Power and Vancouver Landfill) as well as total emissions for point, area and mobile sources. Also included in the 2005 emission inventory are forecasts of emissions for the years 2010, 2015, 2020, 2025 and 2030. The forecasts are based on projections of variables such as population, economy, employment, vehicle kilometres travelled, and future expansions. Emission forecasts incorporate the federal, provincial and regional regulations that were committed to at the time of preparation of the emission estimates. The forecast was performed under different sets of assumptions depending on the level of uncertainty for three scenarios: the moderate scenario, the high scenario and the low scenario. The 2020 emission inventory forecast for the moderate scenario is shown in Table 2.2 to provide the emissions context for the solid waste management scenarios.

From 2005 to 2020 total emissions of nitrogen oxides ( $\text{NO}_x$ ) and volatile organic compounds (VOCs) are predicted to decrease in the LFV, while total emissions of particulate matter (PM), ammonia ( $\text{NH}_3$ ) and sulphur dioxide ( $\text{SO}_2$ ) are predicted to increase. Since emissions of the key ozone precursors,  $\text{NO}_x$  and VOCs, are both predicted to decrease, it is expected that ozone concentrations will decrease between 2005 and 2020. By contrast, primary PM emissions are expected to increase along with  $\text{SO}_2$  and  $\text{NH}_3$ , two of the secondary PM precursors, while emissions of  $\text{NO}_x$ , another important secondary PM precursor, is expected to decrease. It is therefore difficult to predict whether ambient concentrations of PM would increase or decrease between 2005 and 2020 without running a photochemistry/transport model. Furthermore, there will likely be spatial variation in the changes in predicted concentrations of PM and ozone with increases in some parts of the LFV and decreases in other parts, depending on where the changes in emissions occur.

Both the 2005 and 2020 emission inventories include emissions from the existing WTE facility in Burnaby as well as the Vancouver Landfill. As can be seen from Table 2.1 and Table 2.2, these waste management facilities contribute a very small fraction to total regional air emissions.

In 2005, total emissions from waste management facilities represented up to 1.2% of total regional air emissions.

**Table 2.1: Summary of LFV Emissions in 2005**

Source		CO (t/y)	NH <sub>3</sub> (t/y)	NO <sub>x</sub> (t/y)	PM <sub>10</sub> (t/y)	PM <sub>2.5</sub> (t/y)	SO <sub>x</sub> (t/y)	VOC (t/y)
Point Sources	WTEF in Burnaby	31	1	465	9	7	108	20
	Maxim Power	198	-	41	1	1	11	14
	Total Point Sources	15,783	63	8,664	2,836	1,519	4,361	5,172
Area Sources	Vancouver Landfill	-	51	-	N/A	10	-	46
	Total Area Sources	19,523	17,235	7,015	6,852	3,680	302	70,436
Mobile Sources		404,566	1,247	45,287	2,150	1,835	5,639	32,544
Total		439,872	18,544	60,966	11,838	7,035	10,302	108,153

\* Data excludes estimated road dust emissions generated in the LFV.

**Table 2.2: Summary of Forecasted LFV Emissions for 2020**

Source		CO (t/y)	NH <sub>3</sub> (t/y)	NO <sub>x</sub> (t/y)	PM <sub>10</sub> (t/y)	PM <sub>2.5</sub> (t/y)	SO <sub>x</sub> (t/y)	VOC (t/y)
Point Sources	WTEF in Burnaby	31	1	191	9	8	55	21
	Maxim Power	264	-	55	1	1	14	19
	Total Point Sources	16,118	73	8,454	2,705	1,492	4,343	4,486
Area Sources	Vancouver Landfill	-	86	-	52	14	-	76
	Total Area Sources	20,111	20,111	7,659	7,900	4,044	372	71,247
Mobile Sources		359,699	1,557	29,201	1,996	1,835	7,642	18,788
Total		395,921	21,741	45,287	12,600	7,146	12,356	94,520

\* Data excludes estimated road dust emissions generated in the LFV.

## **2.2 EMISSIONS FOR 2005 BASE CASE CMAQ RUN**

LFV emissions for the 2005 Base Case CMAQ run were adapted from the 2005 emission inventory shown in Table 2.1. Emissions from ocean-going vessels were replaced with a 2002 model-ready dataset developed by RWDI for Environment Canada (RWDI, 2009). This dataset is based on the BC Chamber of Shipping inventory, the Puget Sound inventory and the Corbett inventory. This dataset has been geographically and temporally resolved to represent the individual shipping routes and is considered a state-of-the-science inventory for ocean-going vessels.

In the CMAQ model, landfills were redefined as point sources to accurately model their emissions for comparison to the solid waste management scenarios. Emissions from each individual landfill were provided by Metro Vancouver but were aligned with the total landfill emissions in the 2005 emission inventory.

Emissions for the rest of Canada are based on a 2002 model-ready dataset from Environment Canada. Emissions for the rest of the United States, excluding Whatcom County, are based on a 2002 model-ready dataset grown from the US 2001 National Emission Inventory.

## **2.3 EMISSIONS FOR EIGHT SOLID WASTE MANAGEMENT SCENARIOS AND ONE SENSITIVITY CASE**

Emissions associated with the eight solid waste management scenarios and one sensitivity case were provided by Metro Vancouver in April 2009, based on the life cycle assessment performed by the Sheltair Group in support of a study prepared for Metro Vancouver by AECOM Canada Ltd. analysing eight different scenarios for managing the municipal solid waste that remains after all practical efforts to reduce, reuse and recycle waste have been exhausted. Summaries of these emissions are provided in Table 2.3 to Table 2.11. It should be noted that the emissions shown are not necessarily incremental to the current emissions from waste management in the region. For example, there are presently emissions associated with the existing WTE facility in Burnaby, the Vancouver Landfill, Maxim Power, cement plants and waste hauling activities. For the purposes of modelling, every attempt was made to reconcile the emissions associated with the eight scenarios with existing waste management emissions, to avoid double-counting or omission of emissions.

Metro Vancouver selected one scenario for a sensitivity study. Scenario 7 was selected as it represents the largest quantity of waste being disposed at the Vancouver Landfill, and hence the

largest emission change due to the landfill gas capture rate. Scenario 7b represents the sensitivity case defined for Scenario 7, incorporating the landfill gas capture rate. If the differences between Scenarios 7 and 7b are very small, one would expect the differences for other scenarios to also be very small.

Assumptions for modelling purposes are:

- The new WTE facility in scenarios 1 and 2 was assumed to be located next to the existing WTE facility in Burnaby.
- The use of electricity for solid waste management is associated with indirect emissions. Since the only thermal electricity generation plant in the LFV, Burrard Thermal, has operated as a peaking facility in recent years, these indirect emissions are assumed to occur outside the model domain (see Section 3.1.1) and are not included in this assessment.
- The MBT facility in scenarios 3, 4 and 6 will recover some metals. Metal recovery will result in avoided emissions from steel production. Since there is no steel production in the LFV, these avoided emissions are assumed to occur outside the model domain and are not included in this assessment.
- Each of the scenarios involves avoided district energy emissions from the WTE facilities and the cogeneration occurring at the landfill(s). For modelling purposes, these avoided emissions are subtracted from forecasted 2020 emissions for natural gas combustion in residential heating sources (SCC 2104006000) in the Metro Vancouver census division. Note that a portion of the total avoided district energy emissions for each scenario, from the existing Burnaby WTE facility, is already captured in the forecasted 2020 emissions and are therefore not double-counted in this assessment.
- The RDF in Scenario 3 is assumed to be used at the cement plants in Metro Vancouver. The added emissions due to RDF combustion are allocated to the cement kilns at each facility, as identified by SCC 30500606, 30500622 and 30500623.
- Emissions associated with truck transportation in each of the scenarios are allocated to the road networks in the Metro Vancouver and Fraser Valley Regional District (FVRD) census divisions. Emissions occurring outside the LFV are not significant and are captured as part of the FVRD emissions.

- Barge emissions occurring inside Metro Vancouver in scenarios 4 and 5 are allocated to harbour vessel grid cells within the Metro Vancouver census division as illustrated by green (overlaid on yellow) in Figure 2.1.
- For scenario 4, barge emissions occurring outside the LFV are allocated to ocean-going vessel routes (shown in purple in Figure 2.1) in the Vancouver Island marine county (shown as an orange under-layer).
- No precise location for the new WTE facility in Scenario 5 has been identified but a 100 km barging distance was assumed. Barge emissions occurring outside the LFV were therefore applied to the entire Metro Vancouver marine county (shown as a yellow under-layer in Figure 2.1). The WTE facility was assumed to be located across Howe Sound for modelling purposes.
- The new out-of-region landfill is assumed to be located near the existing Cache Creek landfill in the interior of BC.

**Table 2.3: Summary of Emissions from Solid Waste Management – Scenario 1**

Source	Region	CO (t/y)	NH <sub>3</sub> (t/y)	NO <sub>x</sub> (t/y)	PM <sub>10</sub> (t/y)	PM <sub>2.5</sub> (t/y)	SO <sub>x</sub> (t/y)	VOC (t/y)
WTEF in Burnaby	Metro Vancouver	27.7	4.0	60.0	7.9	6.6	97.2	9.1
New WTEF	Metro Vancouver	37.8	11.3	79.7	8.1	6.8	12.6	25.7
New WTEF	Outside LFV	-	-	-	-	-	-	-
New MBT Facility	Metro Vancouver	-	-	-	-	-	-	-
Cement Plant (Added Emissions)	Metro Vancouver	-	-	-	-	-	-	-
RDF Burning Facility	Outside LFV	-	-	-	-	-	-	-
Maxim Power	Metro Vancouver	114.7	0.0	48.0	1.6	1.5	11.5	29.1
Vancouver Landfill	Metro Vancouver	0.0	71.0	0.0	17.4	4.6	0.0	116.2
Interior Landfill	Outside LFV	-	-	-	-	-	-	-
District Energy (Avoided Emissions*)	Metro Vancouver	-84.2	0.0	-153.8	-12.3	-12.3	-1.0	-8.9
Truck Transportation	Metro Vancouver	0.6	0.05	2.1	0.1	0.1	0.03	0.4
Truck Transportation	FVRD	0.02	0.002	0.08	0.01	0.003	0.001	0.02
Barge Transportation	Metro Vancouver	-	-	-	-	-	-	-
Barge Transportation	Outside LFV	-	-	-	-	-	-	-
<b>Total</b>	-	<b>96.6</b>	<b>86.3</b>	<b>36.0</b>	<b>22.9</b>	<b>7.4</b>	<b>120.4</b>	<b>171.5</b>

\* Avoided emissions are emissions that would have been generated by other types of facilities that burn fossil fuels. These avoided emissions are shown as negative values in the above table because, for modelling purposes, they are subtracted from forecasted 2020 emissions for natural gas combustion in residential heating sources in the Metro Vancouver census division.

**Table 2.4: Summary of Emissions from Solid Waste Management – Scenario 2**

Source	Region	CO (t/y)	NH <sub>3</sub> (t/y)	NO <sub>x</sub> (t/y)	PM <sub>10</sub> (t/y)	PM <sub>2.5</sub> (t/y)	SO <sub>x</sub> (t/y)	VOC (t/y)
WTEF in Burnaby	Metro Vancouver	27.7	4.0	60.0	7.9	6.6	97.2	9.1
New WTEF	Metro Vancouver	25.2	7.5	53.1	5.4	4.6	8.4	17.1
New WTEF	Outside LFV	-	-	-	-	-	-	-
New MBT Facility	Metro Vancouver	-	-	-	-	-	-	-
Cement Plant (Added Emissions)	Metro Vancouver	-	-	-	-	-	-	-
RDF Burning Facility	Outside LFV	-	-	-	-	-	-	-
Maxim Power	Metro Vancouver	227.8	0.0	84.5	2.7	2.5	22.8	58.6
Vancouver Landfill	Metro Vancouver	0.0	143.4	0.0	34.7	9.2	0.0	234.1
Interior Landfill	Outside LFV	-	-	-	-	-	-	-
District Energy (Avoided Emissions*)	Metro Vancouver	-73.1	0.0	-119.0	-9.7	-9.7	-0.8	-7.0
Truck Transportation	Metro Vancouver	0.6	0.05	2.1	0.1	0.08	0.03	0.4
Truck Transportation	FVRD	0.02	0.002	0.08	0.005	0.003	0.001	0.02
Barge Transportation	Metro Vancouver	-	-	-	-	-	-	-
Barge Transportation	Outside LFV	-	-	-	-	-	-	-
<b>Total</b>	-	<b>208.2</b>	<b>154.9</b>	<b>80.8</b>	<b>41.1</b>	<b>13.2</b>	<b>127.7</b>	<b>312.3</b>

\* Avoided emissions are emissions that would have been generated by other types of facilities that burn fossil fuels. These avoided emissions are shown as negative values in the above table because, for modelling purposes, they are subtracted from forecasted 2020 emissions for natural gas combustion in residential heating sources in the Metro Vancouver census division.

**Table 2.5: Summary of Emissions from Solid Waste Management – Scenario 3**

Source	Region	CO (t/y)	NH <sub>3</sub> (t/y)	NO <sub>x</sub> (t/y)	PM <sub>10</sub> (t/y)	PM <sub>2.5</sub> (t/y)	SO <sub>x</sub> (t/y)	VOC (t/y)
WTEF in Burnaby	Metro Vancouver	27.7	4.0	60.0	7.9	6.6	97.2	9.1
New WTEF	Metro Vancouver	-	-	-	-	-	-	-
New WTEF	Outside LFV	-	-	-	-	-	-	-
New MBT Facility	Metro Vancouver	36.2	60.0	36.2	0.0	0.0	14.0	18.0
Cement Plant (Added Emissions)	Metro Vancouver	0.0	0.0	0.7	0.0	0.0	0.0	0.0
RDF Burning Facility	Outside LFV	-	-	-	-	-	-	-
Maxim Power	Metro Vancouver	227.7	0.0	84.5	2.6	2.5	22.8	58.6
Vancouver Landfill	Metro Vancouver	0.0	143.4	0.0	34.7	9.2	0.0	234.1
Interior Landfill	Outside LFV	-	-	-	-	-	-	-
District Energy (Avoided Emissions*)	Metro Vancouver	-41.6	0.0	-45.9	-3.8	-3.8	-0.3	-2.7
Truck Transportation	Metro Vancouver	0.6	0.05	2.2	0.2	0.09	0.03	0.5
Truck Transportation	FVRD	0.01	0.001	0.04	0.003	0.002	0.001	0.008
Barge Transportation	Metro Vancouver	-	-	-	-	-	-	-
Barge Transportation	Outside LFV	-	-	-	-	-	-	-
<b>Total</b>	-	<b>250.6</b>	<b>207.4</b>	<b>137.7</b>	<b>41.6</b>	<b>14.6</b>	<b>133.8</b>	<b>317.5</b>

\* Avoided emissions are emissions that would have been generated by other types of facilities that burn fossil fuels. These avoided emissions are shown as negative values in the above table because, for modelling purposes, they are subtracted from forecasted 2020 emissions for natural gas combustion in residential heating sources in the Metro Vancouver census division.

**Table 2.6: Summary of Emissions from Solid Waste Management – Scenario 4**

Source	Region	CO (t/y)	NH <sub>3</sub> (t/y)	NO <sub>x</sub> (t/y)	PM <sub>10</sub> (t/y)	PM <sub>2.5</sub> (t/y)	SO <sub>x</sub> (t/y)	VOC (t/y)
WTEF in Burnaby	Metro Vancouver	27.7	4.0	60.0	7.9	6.6	97.2	9.1
New WTEF	Metro Vancouver	-	-	-	-	-	-	-
New WTEF	Outside LFV	-	-	-	-	-	-	-
New MBT Facility	Metro Vancouver	36.2	60.0	36.2	0.0	0.0	14.0	18.0
Cement Plant (Added Emissions)	Metro Vancouver	-	-	-	-	-	-	-
RDF Burning Facility	Outside LFV	21.5	6.4	45.3	4.6	3.9	7.2	14.6
Maxim Power	Metro Vancouver	227.7	0.0	84.5	2.6	2.5	22.8	58.6
Vancouver Landfill	Metro Vancouver	0.0	143.4	0.0	34.7	9.2	0.0	234.1
Interior Landfill	Outside LFV	-	-	-	-	-	-	-
District Energy (Avoided Emissions*)	Metro Vancouver	-41.6	0.0	-45.1	-3.8	-3.8	-0.3	-2.7
Truck Transportation	Metro Vancouver	0.6	0.05	2.0	0.1	0.08	0.03	0.4
Truck Transportation	FVRD	0.01	0.001	0.04	0.003	0.002	0.001	0.008
Barge Transportation	Metro Vancouver	0.14	0.001	1.05	0.02	0.02	0.05	0.04
Barge Transportation	Outside LFV	2.19	0.01	16.39	0.27	0.27	0.75	0.68
<b>Total</b>	-	<b>274.3</b>	<b>213.8</b>	<b>200.2</b>	<b>46.5</b>	<b>18.8</b>	<b>141.7</b>	<b>332.8</b>

\* Avoided emissions are emissions that would have been generated by other types of facilities that burn fossil fuels. These avoided emissions are shown as negative values in the above table because, for modelling purposes, they are subtracted from forecasted 2020 emissions for natural gas combustion in residential heating sources in the Metro Vancouver census division.

**Table 2.7: Summary of Emissions from Solid Waste Management – Scenario 5**

Source	Region	CO (t/y)	NH <sub>3</sub> (t/y)	NO <sub>x</sub> (t/y)	PM <sub>10</sub> (t/y)	PM <sub>2.5</sub> (t/y)	SO <sub>x</sub> (t/y)	VOC (t/y)
WTEF in Burnaby	Metro Vancouver	27.7	4.0	60.0	7.9	6.6	97.2	9.1
New WTEF	Metro Vancouver	-	-	-	-	-	-	-
New WTEF	Outside LFV	25.2	7.5	53.1	5.4	4.6	8.4	17.1
New MBT Facility	Metro Vancouver	-	-	-	-	-	-	-
Cement Plant (Added Emissions)	Metro Vancouver	-	-	-	-	-	-	-
RDF Burning Facility	Outside LFV	-	-	-	-	-	-	-
Maxim Power	Metro Vancouver	217.5	0.0	52.1	0.9	0.8	21.7	58.2
Vancouver Landfill	Metro Vancouver	0.0	143.4	0.0	34.7	9.2	0.0	232.5
Interior Landfill	Outside LFV	-	-	-	-	-	-	-
District Energy (Avoided Emissions*)	Metro Vancouver	-41.6	0.0	-45.1	-3.8	-3.8	-0.3	-2.7
Truck Transportation	Metro Vancouver	0.5	0.04	1.9	0.1	0.08	0.03	0.4
Truck Transportation	FVRD	0.01	0.001	0.04	0.003	0.002	0.001	0.008
Barge Transportation	Metro Vancouver	0.36	0.002	2.68	0.04	0.04	0.12	0.11
Barge Transportation	Outside LFV	0.83	0.005	6.24	0.10	0.10	0.29	0.26
<b>Total</b>	-	<b>230.4</b>	<b>154.9</b>	<b>130.9</b>	<b>45.5</b>	<b>17.6</b>	<b>127.5</b>	<b>314.9</b>

\* Avoided emissions are emissions that would have been generated by other types of facilities that burn fossil fuels. These avoided emissions are shown as negative values in the above table because, for modelling purposes, they are subtracted from forecasted 2020 emissions for natural gas combustion in residential heating sources in the Metro Vancouver census division.

**Table 2.8: Summary of Emissions from Solid Waste Management – Scenario 6**

Source	Region	CO (t/y)	NH <sub>3</sub> (t/y)	NO <sub>x</sub> (t/y)	PM <sub>10</sub> (t/y)	PM <sub>2.5</sub> (t/y)	SO <sub>x</sub> (t/y)	VOC (t/y)
WTEF in Burnaby	Metro Vancouver	27.7	4.0	60.0	7.9	6.6	97.2	9.1
New WTEF	Metro Vancouver	-	-	-	-	-	-	-
New WTEF	Outside LFV	-	-	-	-	-	-	-
New MBT Facility	Metro Vancouver	71.9	119.4	71.9	0.0	0.0	27.9	35.8
Cement Plant (Added Emissions)	Metro Vancouver	-	-	-	-	-	-	-
RDF Burning Facility	Outside LFV	-	-	-	-	-	-	-
Maxim Power	Metro Vancouver	38.7	0.0	47.9	2.4	2.3	3.8	10.2
Vancouver Landfill	Metro Vancouver	0.0	31.7	0.0	38.2	10.1	0.0	40.8
Interior Landfill	Outside LFV	-	-	-	-	-	-	-
District Energy (Avoided Emissions*)	Metro Vancouver	-33.5	0.0	-41.4	-3.0	-3.0	-0.2	-2.2
Truck Transportation	Metro Vancouver	0.7	0.06	2.6	0.2	0.1	0.04	0.5
Truck Transportation	FVRD	0.01	0.001	0.04	0.003	0.002	0.001	0.008
Barge Transportation	Metro Vancouver	-	-	-	-	-	-	-
Barge Transportation	Outside LFV	-	-	-	-	-	-	-
<b>Total</b>	-	<b>105.5</b>	<b>155.1</b>	<b>141.1</b>	<b>45.6</b>	<b>16.1</b>	<b>128.7</b>	<b>94.2</b>

\* Avoided emissions are emissions that would have been generated by other types of facilities that burn fossil fuels. These avoided emissions are shown as negative values in the above table because, for modelling purposes, they are subtracted from forecasted 2020 emissions for natural gas combustion in residential heating sources in the Metro Vancouver census division.

**Table 2.9: Summary of Emissions from Solid Waste Management – Scenario 7**

Source	Region	CO (t/y)	NH <sub>3</sub> (t/y)	NO <sub>x</sub> (t/y)	PM <sub>10</sub> (t/y)	PM <sub>2.5</sub> (t/y)	SO <sub>x</sub> (t/y)	VOC (t/y)
WTEF in Burnaby	Metro Vancouver	27.7	4.0	60.0	7.9	6.6	97.2	9.1
New WTEF	Metro Vancouver	-	-	-	-	-	-	-
New WTEF	Outside LFV	-	-	-	-	-	-	-
New MBT Facility	Metro Vancouver	-	-	-	-	-	-	-
Cement Plant (Added Emissions)	Metro Vancouver	-	-	-	-	-	-	-
RDF Burning Facility	Outside LFV	-	-	-	-	-	-	-
Maxim Power	Metro Vancouver	342.4	0.0	119.5	3.6	3.3	34.3	88.7
Vancouver Landfill	Metro Vancouver	0.0	217.3	0.0	52.1	13.8	0.0	354.3
Interior Landfill	Outside LFV	224.5	27.3	66.8	1.6	1.4	23.4	181.1
District Energy (Avoided Emissions*)	Metro Vancouver	-46.4	0.0	-47.3	-4.2	-4.2	-0.3	-3.0
Truck Transportation	Metro Vancouver	0.5	0.04	1.6	0.1	0.07	0.02	0.3
Truck Transportation	FVRD	0.5	0.04	1.6	0.1	0.07	0.02	0.3
Barge Transportation	Metro Vancouver	-	-	-	-	-	-	-
Barge Transportation	Outside LFV	-	-	-	-	-	-	-
<b>Total</b>	-	<b>549.1</b>	<b>248.6</b>	<b>202.2</b>	<b>61.2</b>	<b>21.0</b>	<b>154.6</b>	<b>630.8</b>

\* Avoided emissions are emissions that would have been generated by other types of facilities that burn fossil fuels. These avoided emissions are shown as negative values in the above table because, for modelling purposes, they are subtracted from forecasted 2020 emissions for natural gas combustion in residential heating sources in the Metro Vancouver census division.

**Table 2.10: Summary of Emissions from Solid Waste Management – Scenario 8**

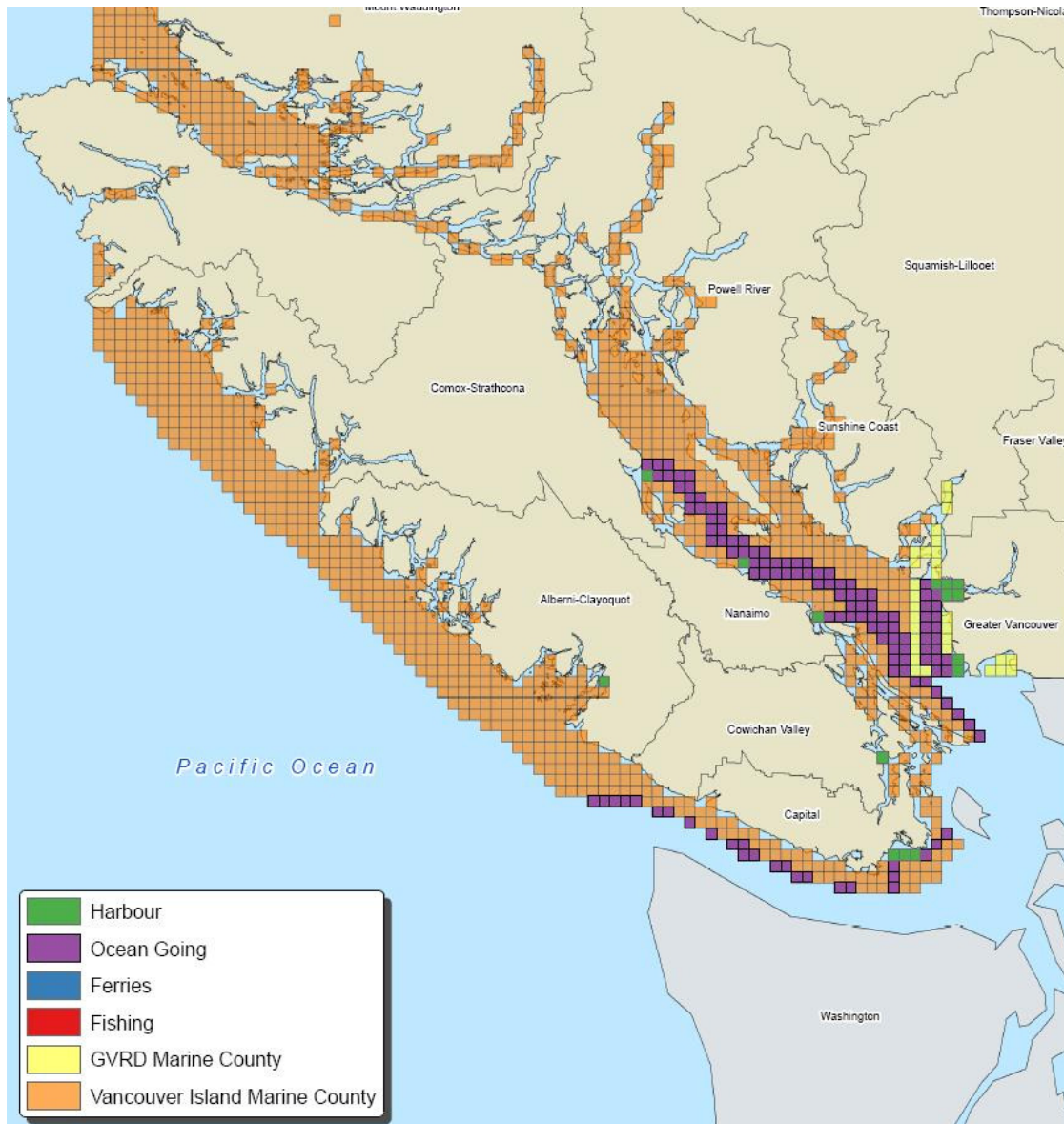
Source	Region	CO (t/y)	NH <sub>3</sub> (t/y)	NO <sub>x</sub> (t/y)	PM <sub>10</sub> (t/y)	PM <sub>2.5</sub> (t/y)	SO <sub>x</sub> (t/y)	VOC (t/y)
WTEF in Burnaby	Metro Vancouver	27.7	4.0	60.0	7.9	6.6	97.2	9.1
New WTEF	Metro Vancouver	-	-	-	-	-	-	-
New WTEF	Outside LFV	-	-	-	-	-	-	-
New MBT Facility	Metro Vancouver	-	-	-	-	-	-	-
Cement Plant (Added Emissions)	Metro Vancouver	-	-	-	-	-	-	-
RDF Burning Facility	Outside LFV	-	-	-	-	-	-	-
Maxim Power	Metro Vancouver	112.4	0.0	40.7	1.3	1.2	11.3	29.0
Vancouver Landfill	Metro Vancouver	0.0	71.0	0.0	17.4	4.6	0.0	115.8
Interior Landfill	Outside LFV	687.0	83.6	203.3	4.8	4.3	71.6	554.3
District Energy (Avoided Emissions*)	Metro Vancouver	-37.0	0.0	-43.0	-3.3	-3.3	-0.3	-2.4
Truck Transportation	Metro Vancouver	0.4	0.03	1.3	0.09	0.06	0.02	0.3
Truck Transportation	FVRD	1.4	0.1	4.7	0.3	0.2	0.06	1.0
Barge Transportation	Metro Vancouver	-	-	-	-	-	-	-
Barge Transportation	Outside LFV	-	-	-	-	-	-	-
<b>Total</b>	-	<b>791.7</b>	<b>158.7</b>	<b>267.1</b>	<b>28.4</b>	<b>13.6</b>	<b>179.9</b>	<b>707.0</b>

\* Avoided emissions are emissions that would have been generated by other types of facilities that burn fossil fuels. These avoided emissions are shown as negative values in the above table because, for modelling purposes, they are subtracted from forecasted 2020 emissions for natural gas combustion in residential heating sources in the Metro Vancouver census division.

**Table 2.11: Summary of Emissions from Solid Waste Management – Scenario 7b**

Source	Region	CO (t/y)	NH <sub>3</sub> (t/y)	NO <sub>x</sub> (t/y)	PM <sub>10</sub> (t/y)	PM <sub>2.5</sub> (t/y)	SO <sub>x</sub> (t/y)	VOC (t/y)
WTEF in Burnaby	Metro Vancouver	27.7	4.0	60.0	7.9	6.6	97.2	9.1
New WTEF	Metro Vancouver	-	-	-	-	-	-	-
New WTEF	Outside LFV	-	-	-	-	-	-	-
New MBT Facility	Metro Vancouver	-	-	-	-	-	-	-
Cement Plant (Added Emissions)	Metro Vancouver	-	-	-	-	-	-	-
RDF Burning Facility	Outside LFV	-	-	-	-	-	-	-
Maxim Power	Metro Vancouver	827.3	0.0	203.5	4.9	4.4	49.0	29.5
Vancouver Landfill	Metro Vancouver	0.0	83.6	0.0	52.1	13.8	0.0	118.0
Interior Landfill	Outside LFV	224.5	27.3	66.8	1.6	1.4	23.4	181.1
District Energy (Avoided Emissions*)	Metro Vancouver	-46.4	0.0	-47.3	-4.2	-4.2	-0.3	-3.0
Truck Transportation	Metro Vancouver	0.5	0.04	1.6	0.1	0.07	0.02	0.3
Truck Transportation	FVRD	0.5	0.04	1.6	0.1	0.07	0.02	0.3
Barge Transportation	Metro Vancouver	-	-	-	-	-	-	-
Barge Transportation	Outside LFV	-	-	-	-	-	-	-
<b>Total</b>	-	<b>1034.1</b>	<b>114.9</b>	<b>286.3</b>	<b>62.5</b>	<b>22.2</b>	<b>169.4</b>	<b>335.4</b>

\* Avoided emissions are emissions that would have been generated by other types of facilities that burn fossil fuels. These avoided emissions are shown as negative values in the above table because, for modelling purposes, they are subtracted from forecasted 2020 emissions for natural gas combustion in residential heating sources in the Metro Vancouver census division.



**Figure 2.1: Allocation of Barge Emissions for CMAQ Modelling**

### **3.0 MODELLING APPROACH**

The locations of potential future waste management facilities are not known and therefore the local scale impacts of these potential facilities cannot be assessed. In addition, the standard local scale plume dispersion models are not suitable for estimating the secondary formation of PM and ozone. Therefore a modelling system capable of simulating the regional atmospheric photochemistry was used. Specifically, Environment Canada's Pacific Northwest CMAQ (PNW-CMAQ) modelling system was selected for this study as it has been used to assess air quality in the LFV and the Pacific Northwest since 2003 (RWDI 2003a, 2003b, 2003c, 2005a, 2006, 2009). The most recent version of this modelling system, developed to model the effect of emission controls on ocean-going vessels in the Pacific Northwest in 2020 (RWDI 2009), was selected. Since the marine emissions of greatest concern are SO<sub>x</sub>, NO<sub>x</sub>, PM and the secondary formation of PM, the chemistry mechanism selected for the latest version of PNW-CMAQ is optimized for PM chemistry.

The PNW-CMAQ modelling system is comprised of a meteorological model and pre-processor, an emission processing system, and a photochemistry/transport model. Because they are computationally intensive, CMAQ modelling systems are used to simulate episodes of high ozone and PM concentrations rather than full years of typical conditions. For this study, the ozone-rich portion of the Pacific 2001 summer field monitoring campaign spanning from August 9 to 16, 2001 was modelled. This episode has been used for several previous studies for Environment Canada (RWDI 2003a, 2003b, 2003c, 2005a, 2006, 2009).

Regional-scale models such as CMAQ are often used by policy makers to compare different emission reduction scenarios. The focus of such comparisons is the relative difference in predicted concentrations, rather than the absolute values, between the emission scenarios and a base case. In this assessment, the eight solid waste management scenarios and one sensitivity case are compared to a 2005 base case.

#### **3.1 METEOROLOGICAL MODEL**

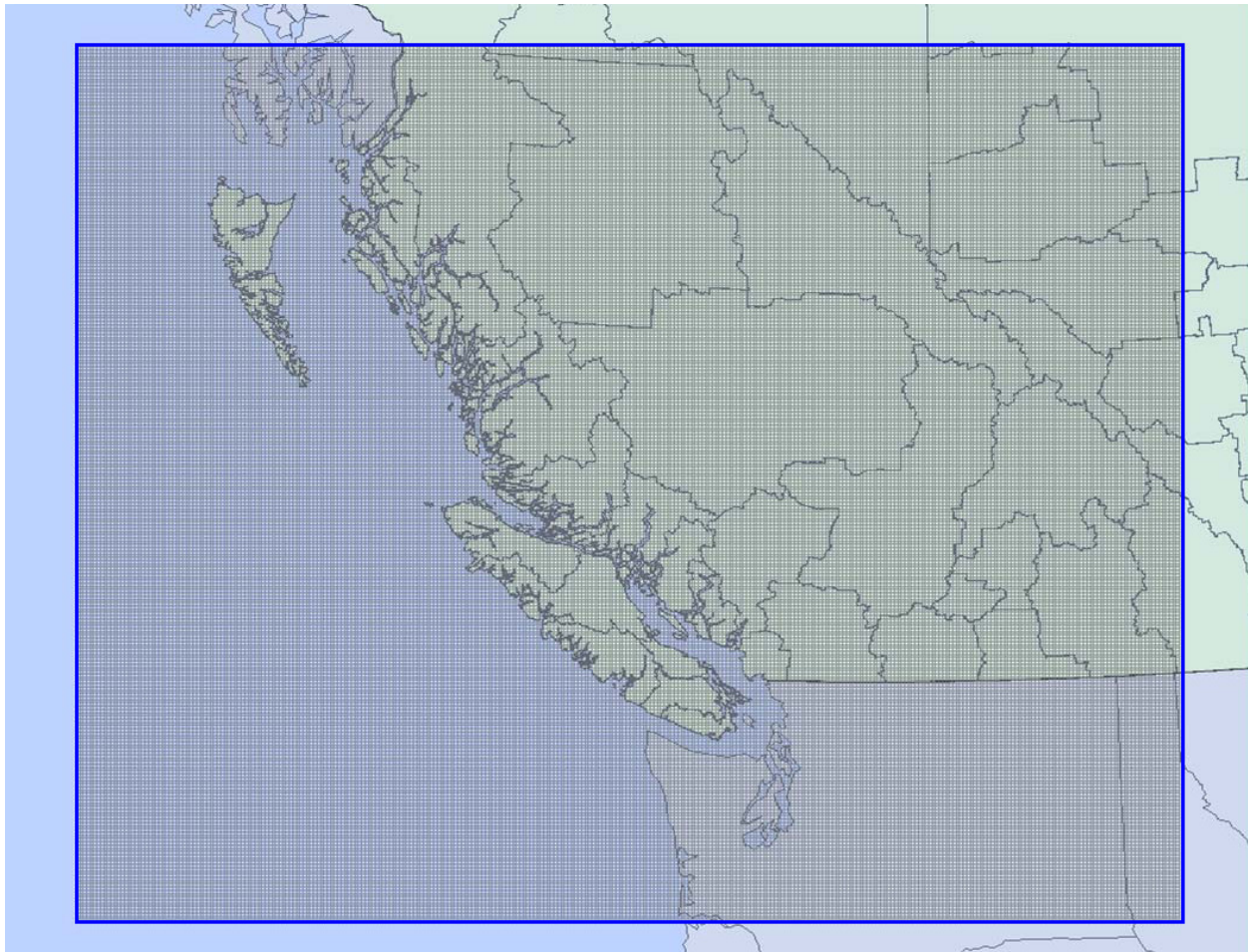
##### **3.1.1 Model Domain**

The pre-existing expanded PNW-CMAQ model domain developed by RWDI and Environment Canada was used for this assessment. This domain covers a large part of British Columbia as defined by the coordinates in Table 3.1 and shown in Figure 3.1. Meteorological fields for the

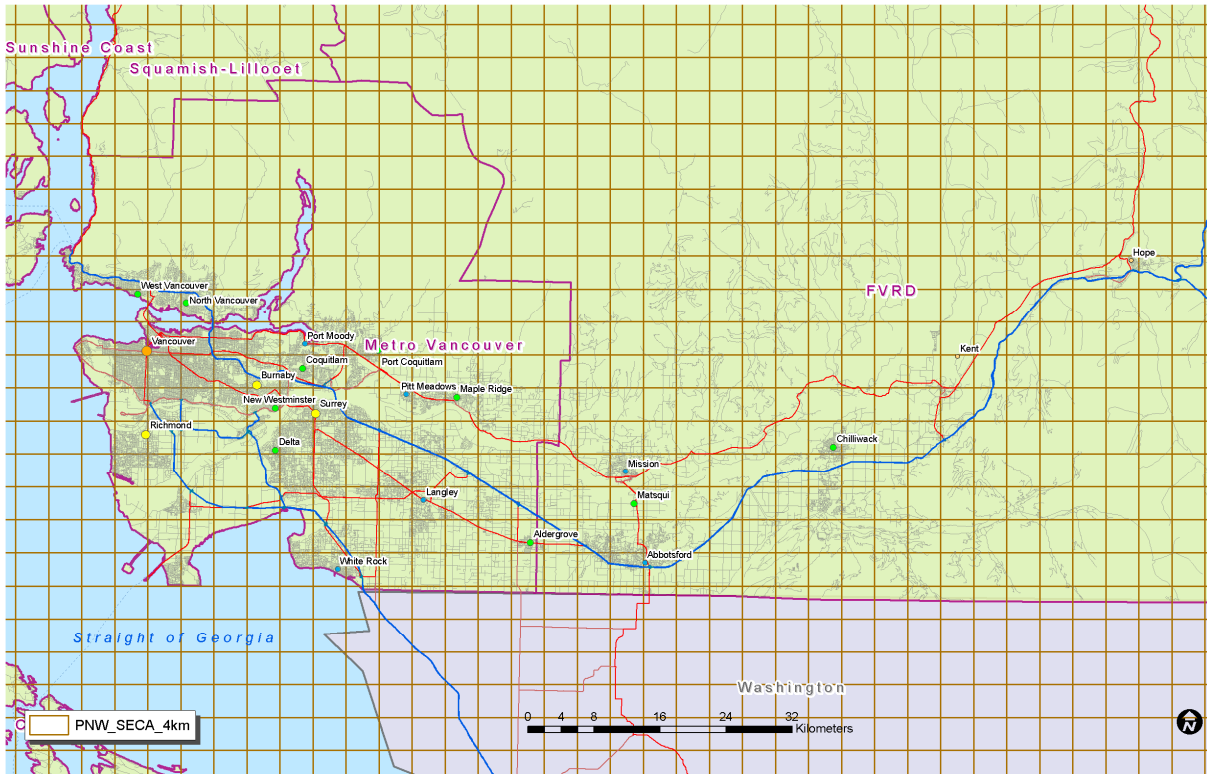
domain were processed at a 4-km grid resolution based on 2.5-km resolution Global Environmental Model Limited Area Model (GEM-LAM) outputs generated by Environment Canada. A close-up of the grid cells over the LFV is shown in Figure 3.2.

**Table 3.1: Model Domain Coordinates**

	<b>Latitude</b>	<b>Longitude</b>
Southwest Corner	45° 35' 25.259"	-133° 25' 36.529"
Southeast Corner	46° 09' 56.580"	-116° 14' 13.457"
Northwest Corner	55° 29' 15.132"	-136° 08' 19.280"
Northeast Corner	56° 10' 37.615"	-115° 10' 41.354"



**Figure 3.1: Location and Extent of Model Domain (4 km grid spacing)**



**Figure 3.2: Model Grid Cells Over the Lower Fraser Valley (4 km grid spacing)**

### 3.1.2 Model Period

CMAQ was initialized for a one-week period from August 9 to 16, 2001. This represents the ozone-rich portion of the Pacific 2001 summer monitoring campaign. During this period, a high amplitude ridge anchored over the eastern Pacific resulted in a period of elevated levels of pollutants over the LFV. Moreover, summer temperature inversions suppressed mixing heights throughout the day, trapping pollutants within the valley. Synoptic patterns during this period were typical of ozone episodes. The meteorology that drives the transport, dispersion, and deposition of airborne pollutants during this ozone episodes is described in greater detail elsewhere (e.g., Snyder and Qiu 2007; Snyder 2002). By modelling this period, the worst-case regional summer air quality impacts will be estimated.

For previous studies in the LFV and the Pacific Northwest, a winter episode from December 1 to 13, 2002 was also modelled. During this period, a high amplitude ridge aloft occurred over the majority of the Pacific Northwest, causing a stagnant period with weak easterly flows. This period was modelled in previous studies to provide a representation of a typical trans-boundary

winter episode. This period was not modelled in this study because photochemistry in the winter months at this latitude is not conducive to ozone formation. In addition, previous model results for PM during this period were similar to those for the summer episode over most of the model domain, with limited trans-boundary effects observed over Vancouver Island.

## **3.2 EMISSION PROCESSING SYSTEM**

The emission processing system is required to prepare specialized inputs for CMAQ modelling. This system can distribute an annual emission inventory of criteria air contaminants, as typically prepared by government agencies such as Metro Vancouver, into hourly emissions of partitioned model species.

### **3.2.1 SMOKE**

Anthropogenic point, area and mobile source emissions were processed for CMAQ using the Sparse Matrix Operating Kernel Emissions (SMOKE) processing system, which was originally developed by the MCNC Supercomputing Center in North Carolina. SMOKE is used to create hourly, gridded, and speciated emissions data for use in the photo-chemical/transport models, using annual, county-based emissions data as inputs. Annual, county-based emissions data are produced by both the US EPA and Environment Canada. SMOKE version 2.3 was adopted for this assessment.

### **3.2.2 MEGAN**

Biogenic emissions were computed on an hourly, gridded basis using the Model of Emissions of Gases and Aerosols from Nature (MEGAN) version 2.04. Gridded inputs (leaf area index, plant functional type, and emission factors) were prepared from gridded land use data using ArcGIS and then integrated with the CMAQ Meteorology Chemistry Interface Processor as input to MEGAN.

## **3.3 PHOTOCHEMICAL GRID MODEL**

CMAQ version 4.6 was applied for this assessment. Modelling was performed using the SAPRC-99 chemical mechanism, leveraging the ISOROPIA solver in combination with the ae4\_aq aerosol module with sea salt. SAPRC-99 is generally considered to be a superior chemical mechanism for the replication of PM<sub>2.5</sub>, and in particular secondary organic aerosols but it has been shown by others to over predict ozone concentrations (e.g., Pan et al. 2008).

SAPRC-99 was selected for the most recent Environment Canada study, which evaluated emission control strategies for ocean-going vessels, because of its level of sophistication for handling more species and more advanced secondary organic aerosol modules. Based on the model results for the most recent Environment Canada study, the prediction of PM<sub>2.5</sub> is quite good but the model over-predicts ozone particularly in the western part of the LFV (RWDI 2009).

## 4.0 MODEL RESULTS

CMAQ modelling was used to estimate maximum ground-level concentrations of ozone and fine particulate matter (PM<sub>2.5</sub>), including sulphate, nitrate and secondary organic aerosols, for the 2005 base case, the eight 2020 solid waste management scenarios and the one 2020 sensitivity case. Results were extracted for a 164 km by 164 km area that encompasses most of the LFV and the Gulf Islands.

### 4.1 CHANGES TO MAXIMUM PREDICTED CONCENTRATIONS

Table 4.1 compares maximum modelled ozone and PM<sub>2.5</sub> concentrations for the eight solid waste management scenarios and one sensitivity case to maximum modelled concentrations for the 2005 base case in the entire 164 km by 164 km area. Figure 4.1 and Figure 4.2 illustrate the maximum eight-hour ozone and 24-hour PM<sub>2.5</sub> concentrations as a percentage of the 2005 base case. Maximum predicted one-hour ozone and PM<sub>2.5</sub> concentrations in the entire area decrease by up to 15% and 17%, respectively, relative to the 2005 base case. Maximum predicted eight-hour ozone concentrations are expected to decrease by about 14% and maximum predicted 24-hour PM<sub>2.5</sub> concentrations are expected to decrease by about 3%.

There is very little difference in the CMAQ model results for the various solid waste management scenarios. The differences between scenarios are well within the error of the model. Also, the differences between scenarios are much less than the overall differences between 2005 and 2020, which indicates that the predicted changes in regional air quality are mainly due changes in other emission sources, such as improvements in vehicle emissions. These model results demonstrate that regional air quality is not sensitive to emissions from waste management given their small contribution to overall airshed loading (ranging from <0.1% to 1.2% depending on the contaminant). Other emission sources and trends are driving the predicted changes in ambient air quality from 2005 to 2020.

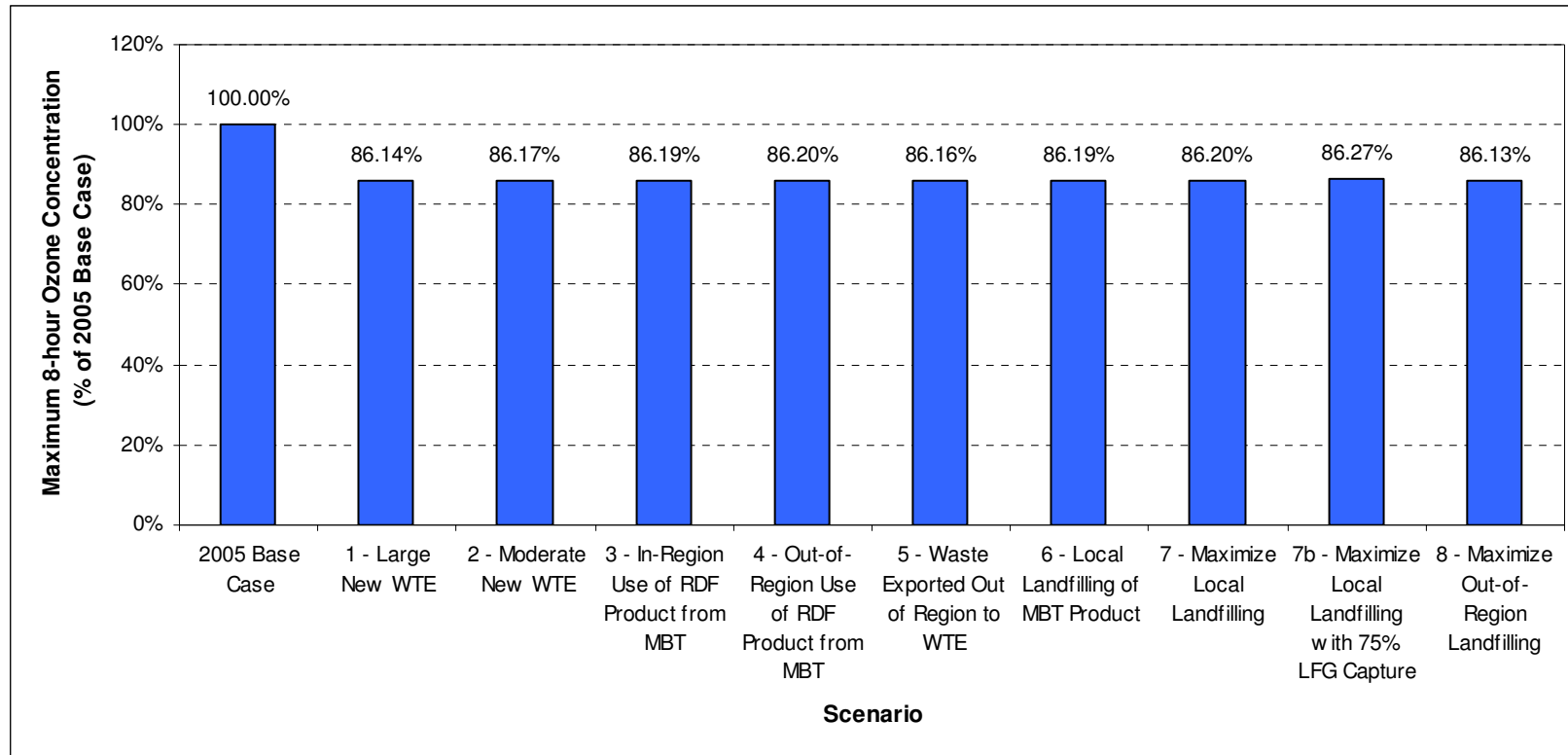
Results for several select municipalities (Abbotsford, Chilliwack, Hope, Burnaby, Surrey and North Shore) are summarized in Appendix A. The results for these municipalities illustrate the regional differences in changes in predicted ambient concentrations. For example, ozone decreases from 2005 to 2020 are predicted for all municipalities, but at Chilliwack, Hope and North Shore the decreases are less than the decreases in overall maximum predicted concentrations shown in Table 4.1. By contrast, greater decreases are predicted in Burnaby and Surrey. Of note, the differences in ambient concentrations between municipalities are much

greater than the differences between scenarios. The predicted decreases in ozone concentrations from 2005 to 2020 are expected given the decrease in expected total emissions of the ozone precursors NO<sub>x</sub> and VOCs during this period. The differences in decreases between municipalities reflect spatial differences in NO<sub>x</sub> and VOC emission decreases.

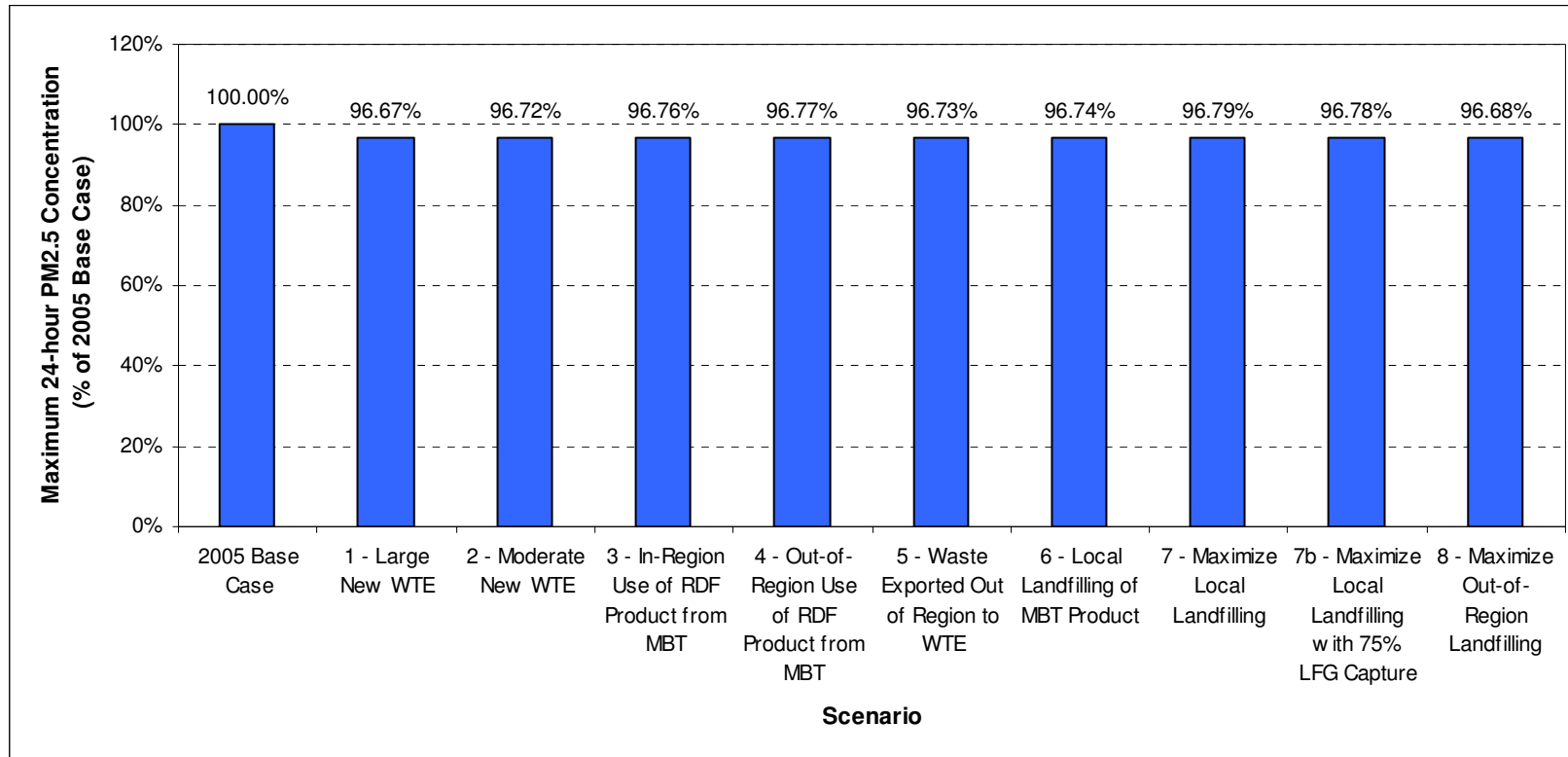
**Table 4.1: Change in Maximum Predicted Concentrations Relative to 2005 Base Case – Entire 164 km by 164 km Extracted Area**

Scenario	Max Ozone		Max PM <sub>2.5</sub>	
	1-Hour	8-Hour	1-Hour	24-Hour
Scenario 1 – Large New WTE	-16.761%	-13.855%	-14.687%	-3.335%
Scenario 2 – Moderate New WTE	-16.760%	-13.826%	-14.647%	-3.277%
Scenario 3 – In-Region Use of RDF Product from MBT	-16.777%	-13.807%	-14.589%	-3.239%
Scenario 4 – Out-of-Region Use of RDF Product from MBT	-16.772%	-13.801%	-14.584%	-3.234%
Scenario 5 – Waste Exported Out of Region to WTE	-16.784%	-13.842%	-14.642%	-3.273%
Scenario 6 – Local Landfilling of MBT Product	-16.779%	-13.814%	-14.584%	-3.258%
Scenario 7 – Maximize Local Landfilling	-16.776%	-13.803%	-14.591%	-3.215%
Scenario 7b – Maximize Local Landfilling with 75% LFG Capture	-16.732%	-13.726%	-14.589%	-3.220%
Scenario 8 – Maximize Out-of-Region Landfilling	-16.806%	-13.870%	-14.667%	-3.321%

While ozone concentrations are predicted to decrease from 2005 to 2020 in all municipalities that were examined, the same cannot be said of PM<sub>2.5</sub>. In Burnaby, Surrey, and the North Shore the PM<sub>2.5</sub> concentrations are predicted to decrease more than the decreases in overall maximum predicted concentrations shown in Table 4.1. In Abbotsford and Hope increases in ambient PM<sub>2.5</sub> concentrations are predicted, and in Chilliwack the predicted decreases in PM<sub>2.5</sub> are very small. The increases are likely due to the expected increases in regional emissions of SO<sub>2</sub> and NH<sub>3</sub>, largely driven by changes in marine vessel and agricultural emissions, respectively. In addition, the difference in PM<sub>2.5</sub> changes between the more eastern and more western municipalities could be due to smaller decreases in NO<sub>x</sub> emissions in the eastern part of the LFV airshed.



**Figure 4.1: Change in Maximum Predicted Eight-Hour Ozone Concentrations Relative to 2005 Base Case – Entire 164 km by 164 km Extracted Area**



**Figure 4.2: Change in Maximum Predicted 24-Hour PM<sub>2.5</sub> Concentrations Relative to 2005 Base Case – Entire 164 km by 164 km Extracted Area**

## 4.2 SENSITIVITY STUDIES

As discussed in Section 2.3, Scenario 7b was modelled as a sensitivity case to determine the effects of varying the landfill gas capture rate. As indicated in Table 4.1, the difference in model results between Scenario 7 and Scenario 7b is very small. Given that the other scenarios would have a smaller emission change due to a change in the landfill gas capture rate, the difference in predicted ambient concentrations would be even smaller than the differences between Scenarios 7 and 7b.

The Sheltair Group also conducted a number of other sensitivity studies to consider changes in emissions with respect to (1) the greenhouse gas intensity of electricity production, (2) the uptake of district energy associated with the new in-region WTE facilities, and (3) the type of energy output from the new in-region WTE facilities (i.e., electricity versus heat). These studies showed that changes in emissions would be small, up to a maximum of 100 t/y of NO<sub>x</sub> for Scenario 1 with the new in-region WTE facility maximized for electricity production. The difference in NO<sub>x</sub> emissions between some scenarios is greater than 100 t/y and yet there is very little difference between predicted ambient concentrations. Therefore, it is expected that the changes in ambient concentrations due to changes in emissions resulting from the additional life cycle assessment sensitivity studies would be very small.

## 5.0 HEALTH VALUATION

Since the 1970s, studies have consistently shown that air pollution has a negative impact on human health and the environment. Based on such studies, changes in ambient air quality can be linked to changes in incidences of various health outcomes, including morbidity (illness) and mortality. In 2005, on behalf of a consortium of funding partners and other interested agencies, the British Columbia Lung Association (BCLA) commissioned a study to provide estimates of health benefits and costs related to specified changes in ambient concentrations of PM and ozone in the LFV. This study evaluated the changes in health outcomes due to changes in regionally averaged annual PM<sub>2.5</sub> concentrations and mean-daily one-hour maximum ozone concentrations, based on linear mathematical functions (RWDI 2005b). The changes were assessed on a regional level and do not address potential health impacts associated with local air quality. These changes in health outcomes can also be assigned a monetary value, based on the value individuals place on avoiding the health outcomes.

It was found that a 1% improvement in annual ozone and PM<sub>2.5</sub> concentrations between 2000 and 2010 in the LFV can produce health-related benefits on the order of CDN\$ 17 million annually. It was also found that potential benefits associated with reducing ambient PM<sub>2.5</sub> concentrations are an order of magnitude greater than the benefits associated with reducing ambient ozone concentrations. Furthermore, a 1% improvement in annual ozone by 2010 was found to result in 0.4 fewer deaths, 6 fewer emergency hospital visits, 6,000 fewer minor restricted activity days, 2 fewer respiratory hospital admissions, and 2,250 fewer asthma symptom days. A 1% improvement in annual PM<sub>2.5</sub> concentration is expected to result in 4.5 fewer deaths, 2 fewer emergency room visits, 9,200 fewer restricted activity days and 1,000 fewer asthma symptom days.

These estimates are based on changes to annual average ambient concentrations, in comparison to the results of this study, which are for an eight-day episode. However, it is expected that summertime improvements would lead to overall annual improvements and associated health-related benefits.

## 6.0 REFERENCES

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**APPENDIX A: CMAQ MODEL RESULTS FOR SELECT MUNICIPALITIES**

In addition to the results for the 164 km by 164 km area (most of the LFV and the Gulf Islands), results were also extracted for a single 4 km by 4 km grid cell that encompasses the “city centre” of select municipalities as defined by the coordinates in Table A-1.

**Table A- 1: Coordinates for Extraction of Model Results at Select Municipalities**

<b>City/Municipality</b>	<b>Latitude</b>	<b>Longitude</b>
Abbotsford	49° 02' 39"	-122° 16' 00"
Chilliwack	49° 10' 20"	-121° 56' 45"
Hope	49° 22' 56"	-121° 26' 22"
Burnaby	49° 14' 56"	-122° 57' 43"
Surrey	49° 11' 30"	-121° 50' 44"
North Shore (North Vancouver)	49° 19' 45"	-123° 04' 19"

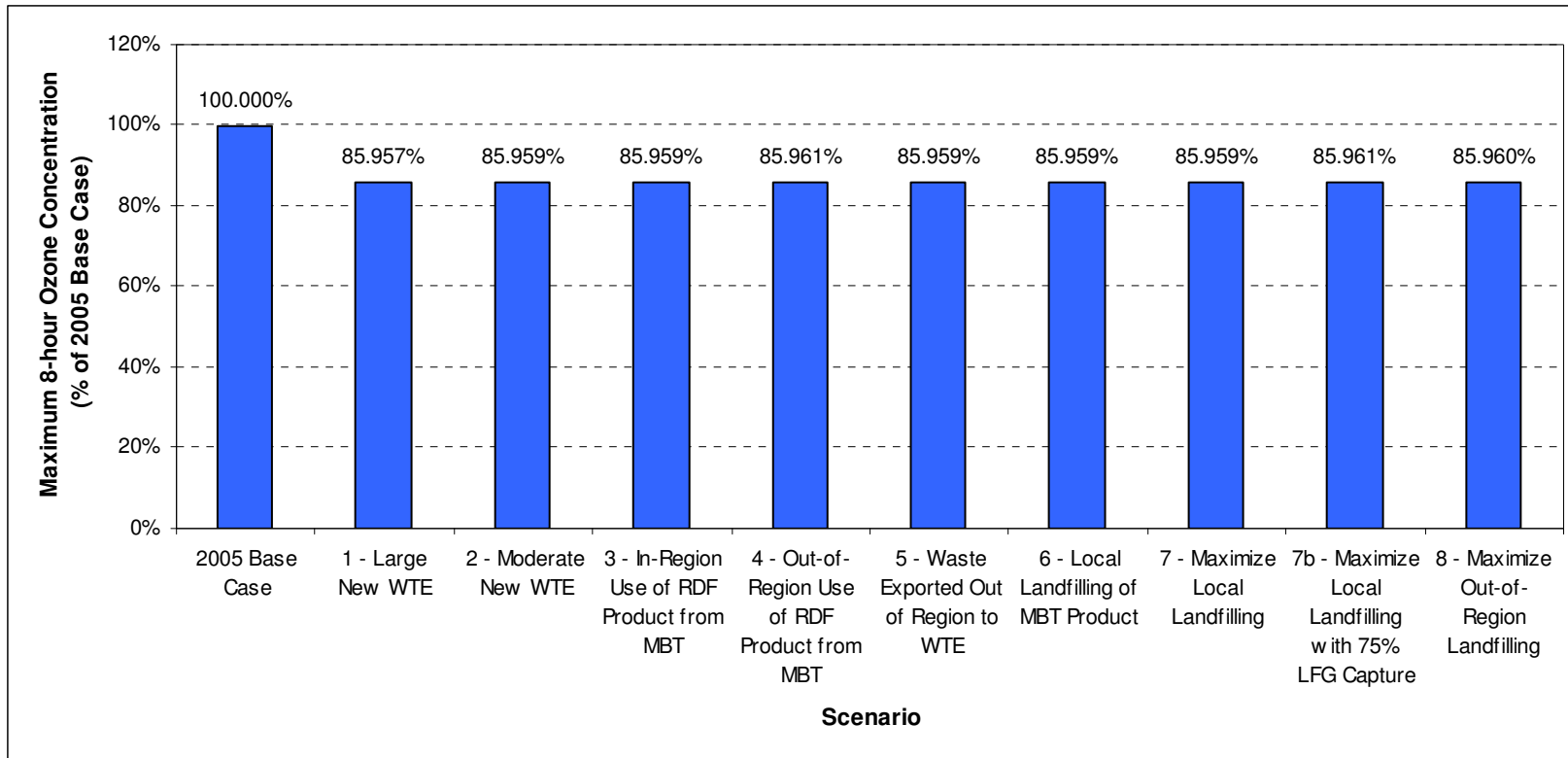
## **A.1 ABBOTSFORD**

Table A-2 compares results for the eight solid waste management scenarios and one sensitivity case to the 2005 base case in Abbotsford. Changes in eight-hour ozone and 24-hour PM<sub>2.5</sub> are illustrated in Figure A-1 and Figure A-2. Maximum ozone concentrations decrease by 14% for the eight-hour period. While the maximum one-hour PM<sub>2.5</sub> concentrations are expected to show little change between 2005 and 2020, the maximum 24-hour PM<sub>2.5</sub> concentrations are predicted to increase by about 7%.

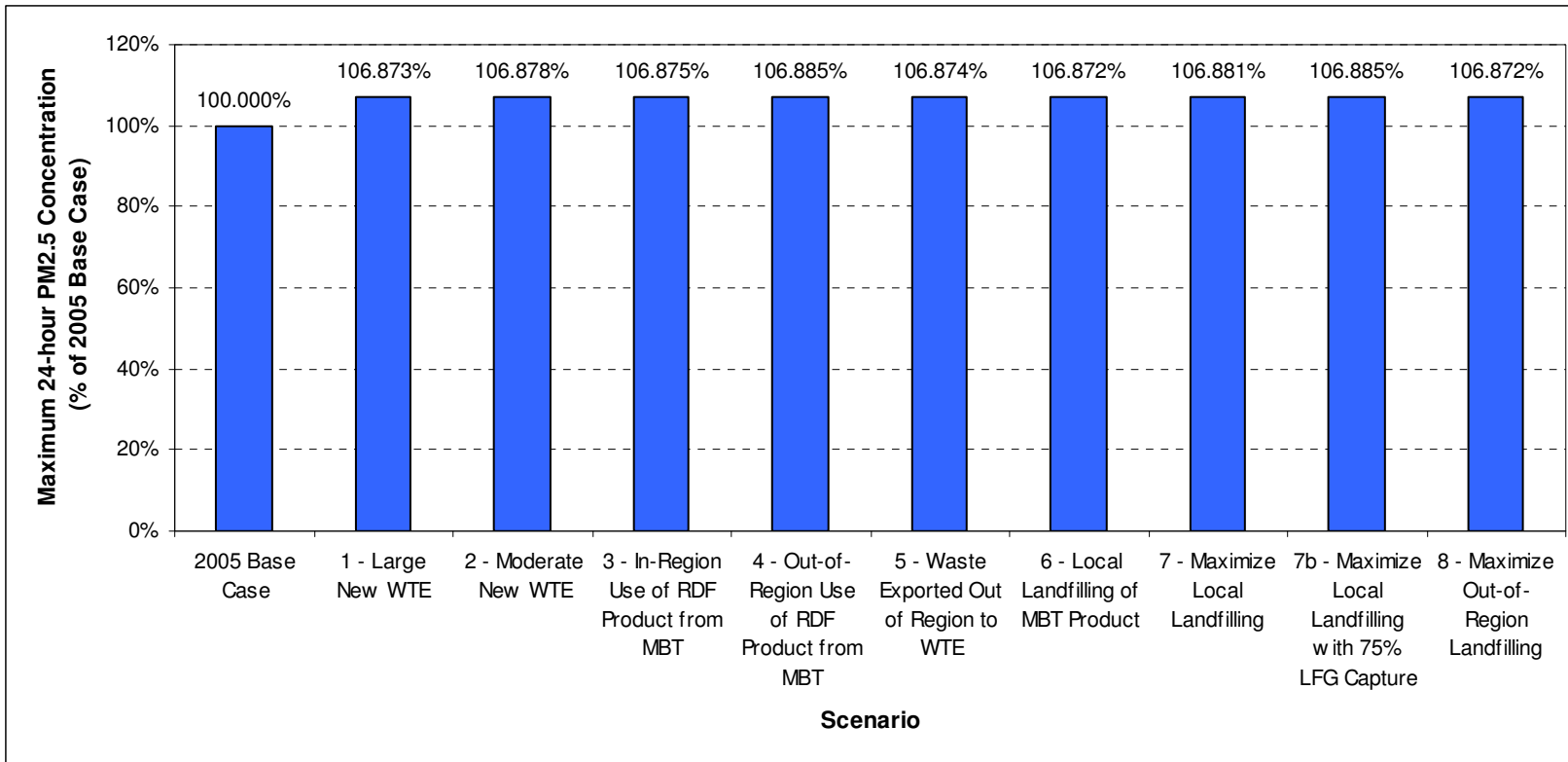
Increases in particulate concentrations at Abbotsford may be due to expected increases in point source emissions of primary PM and agricultural emissions of NH<sub>3</sub>, a precursor to secondary PM. Point source emissions of primary PM in the municipality are predicted to increase by more than 30% between 2005 and 2020.

**Table A-2: Change in Maximum Predicted Concentrations Relative to 2005 Base Case -  
Abbotsford**

Scenario	Max Ozone		Max PM <sub>2.5</sub>	
	1-Hour	8-Hour	1-Hour	24-Hour
Scenario 1 – Large New WTE	-9.819%	-14.043%	-0.806%	+6.873%
Scenario 2 – Moderate New WTE	-9.817%	-14.041%	-0.800%	+6.878%
Scenario 3 – In-Region Use of RDF Product from MBT	-9.817%	-14.041%	-0.804%	+6.875%
Scenario 4 – Out-of-Region Use of RDF Product from MBT	-9.705%	-14.039%	-0.790%	+6.885%
Scenario 5 –Waste Exported Out of Region to WTE	-9.817%	-14.041%	-0.806%	+6.874%
Scenario 6 – Local Landfilling of MBT Product	-9.817%	-14.041%	-0.808%	+6.872%
Scenario 7 – Maximize Local Landfilling	-9.817%	-14.041%	-0.796%	+6.881%
Scenario 7b – Maximize Local Landfilling with 75% LFG Capture	-9.816%	-14.039%	-0.790%	+6.885%
Scenario 8 – Maximize Out-of-Region Landfilling	-9.817%	-14.040%	-0.811%	+6.872%



**Figure A- 1: Change in Maximum Predicted Eight-Hour Ozone Concentrations Relative to 2005 Base Case – Abbotsford**



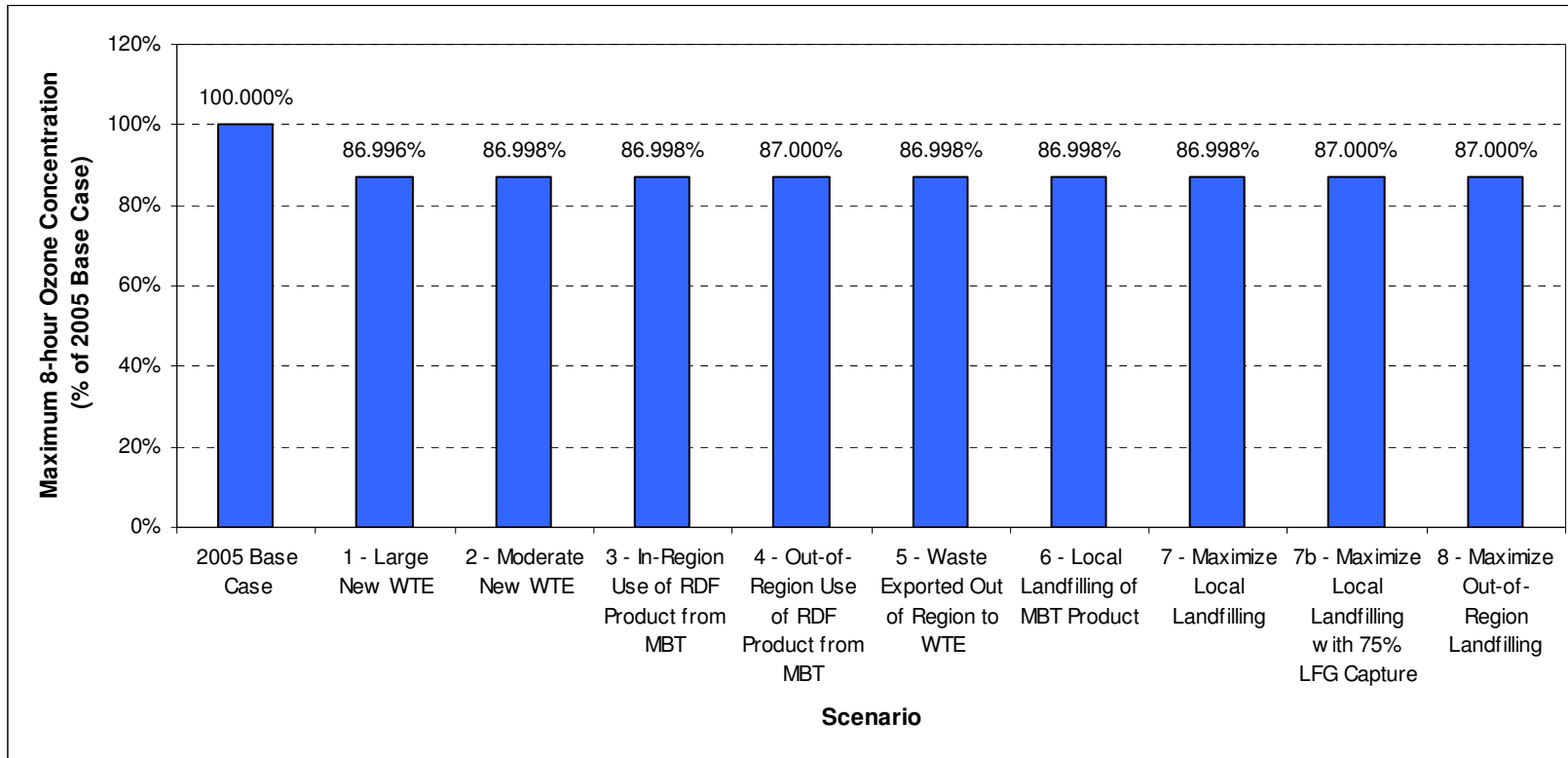
**Figure A- 2: Change in Maximum Predicted 24-Hour PM<sub>2.5</sub> Concentrations Relative to 2005 Base Case – Abbotsford**

## A.2 CHILLIWACK

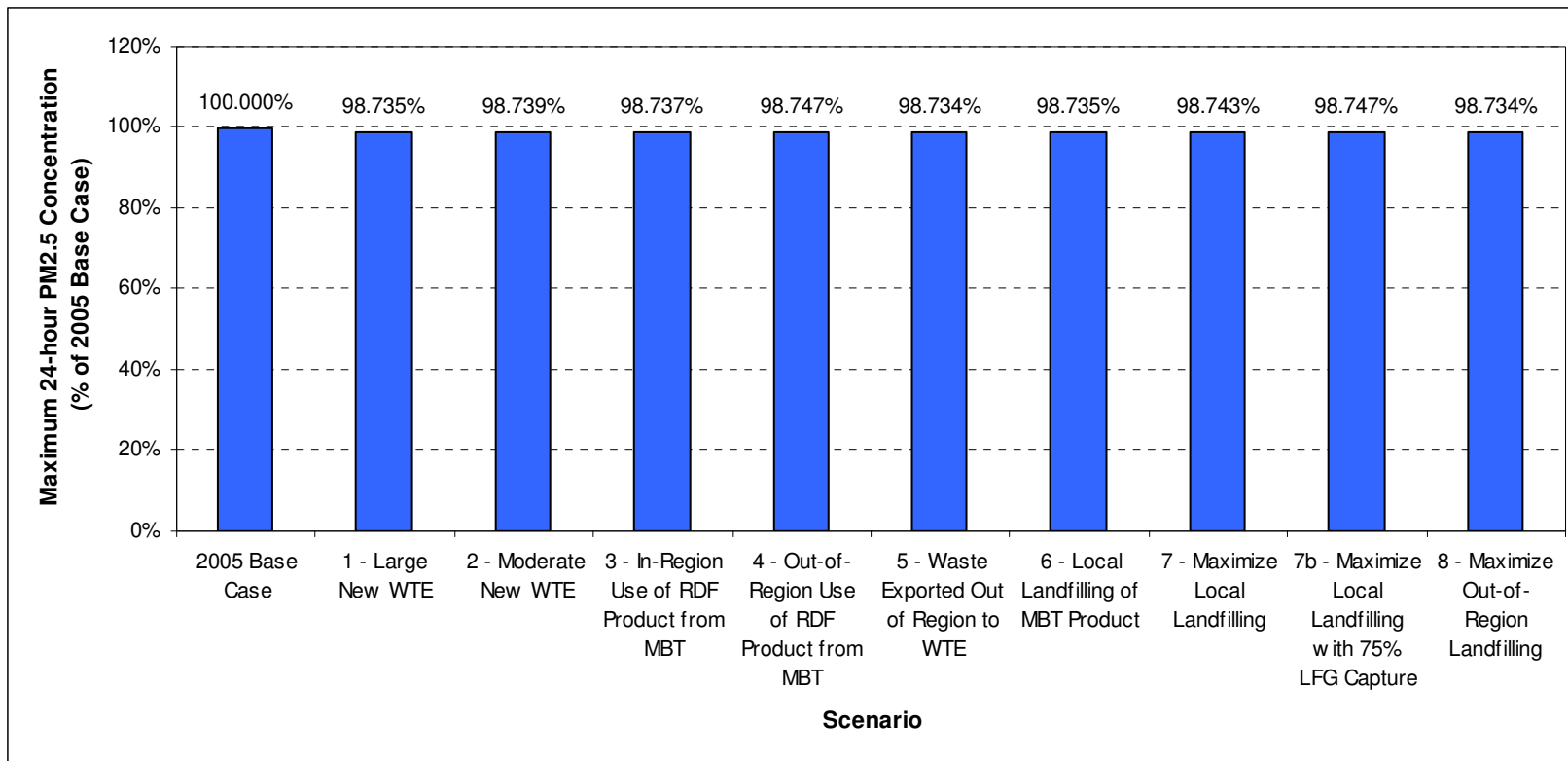
Table A-3 compares results for the eight solid waste management scenarios and one sensitivity case to the 2005 base case in Chilliwack. Figure A-3 and Figure A-4 illustrate these results for eight-hour ozone and 24-hour PM<sub>2.5</sub>. In Chilliwack, maximum eight-hour ozone concentrations decrease by 13%, which is a bit less than the decrease at Abbotsford. Maximum 24-hour PM<sub>2.5</sub> concentrations are predicted to decrease by 1.3%. By contrast, increases in 24-hour PM are predicted in Abbotsford and Hope. This difference between municipalities could be due to a forecasted decrease in mobile emissions, due to stricter vehicle standards, which may have a larger relative effect in Chilliwack than in Abbotsford and Hope, or it may be possible that increases in NH<sub>3</sub> emissions do not have as large an effect in Chilliwack as they do in Abbotsford and Hope.

**Table A-3: Change in Maximum Predicted Concentrations Relative to 2005 Base Case - Chilliwack**

Scenario	Max Ozone		Max PM <sub>2.5</sub>	
	1-Hour	8-Hour	1-Hour	24-Hour
Scenario 1 – Large New WTE	-10.182%	-13.004%	-4.190%	-1.265%
Scenario 2 – Moderate New WTE	-10.181%	-13.002%	-4.184%	-1.261%
Scenario 3 – In-Region Use of RDF Product from MBT	-10.181%	-13.002%	-4.187%	-1.263%
Scenario 4 – Out-of-Region Use of RDF Product from MBT	-10.075%	-13.000%	-4.174%	-1.253%
Scenario 5 –Waste Exported Out of Region to WTE	-10.181%	-13.002%	-4.190%	-1.266%
Scenario 6 – Local Landfilling of MBT Product	-10.181%	-13.002%	-4.191%	-1.265%
Scenario 7 – Maximize Local Landfilling	-10.180%	-13.002%	-4.178%	-1.257%
Scenario 7b – Maximize Local Landfilling with 75% LFG Capture	-10.180%	-13.000%	-4.174%	-1.253%
Scenario 8 – Maximize Out-of-Region Landfilling	-10.179%	-13.000%	-4.192%	-1.266%



**Figure A- 3: Change in Maximum Predicted Eight-Hour Ozone Concentrations Relative to 2005 Base Case - Chilliwack**



**Figure A- 4: Change in Maximum Predicted 24-Hour PM<sub>2.5</sub> Concentrations Relative to 2005 Base Case - Chilliwack**

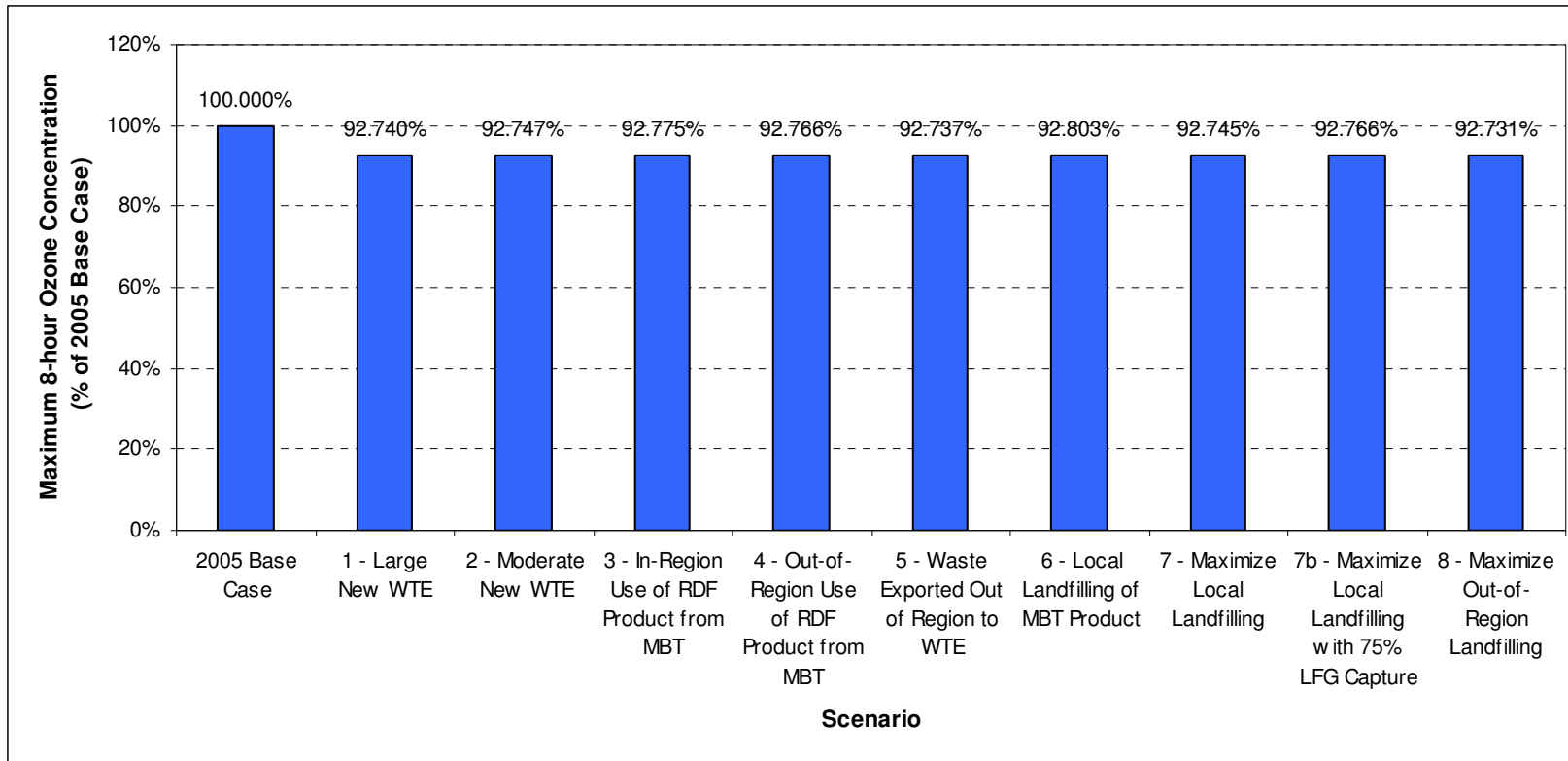
### A.3 HOPE

Table A-4 compares results for the eight solid waste management scenarios and one sensitivity case to the 2005 base case in Hope. Figure A-5 and Figure A-6 illustrate these results for eight-hour ozone and 24-hour PM<sub>2.5</sub>. Maximum eight-hour ozone concentrations are predicted to decrease by 7.2%. Maximum 24-hour PM<sub>2.5</sub> concentrations are predicted to increase by 8.4%.

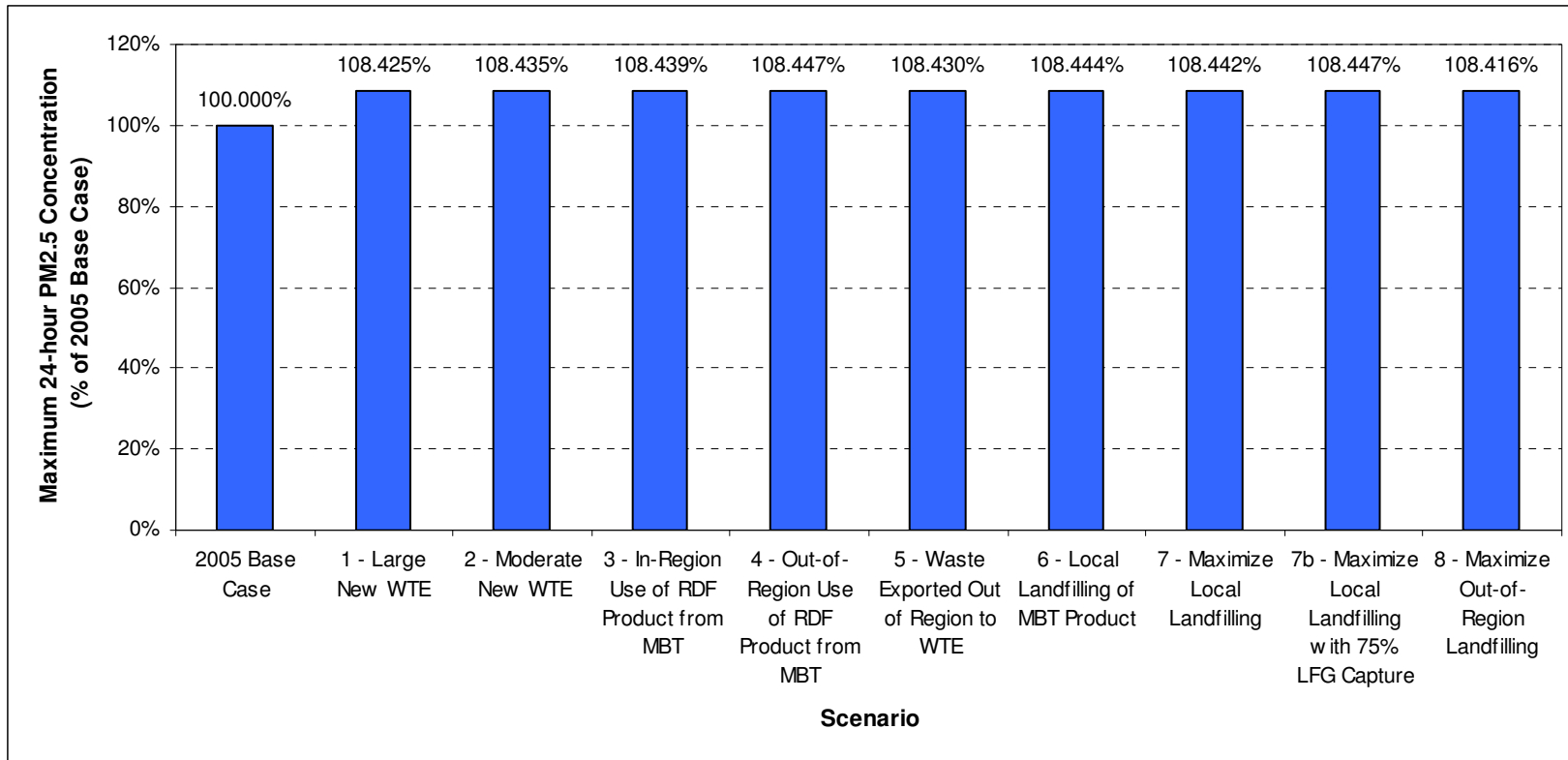
The increases in PM concentrations are most likely due to expected increases in agricultural emissions of NH<sub>3</sub>. Point source emissions at Hope are insignificant and are not predicted to change considerably between 2005 and 2020.

**Table A-4: Change in Maximum Predicted Concentrations Relative to 2005 Base Case - Hope**

Scenario	Max Ozone		Max PM <sub>2.5</sub>	
	1-Hour	8-Hour	1-Hour	24-Hour
Scenario 1 – Large New WTE	-8.772%	-7.260%	+6.486%	+8.425%
Scenario 2 – Moderate New WTE	-8.765%	-7.253%	+6.488%	+8.435%
Scenario 3 – In-Region Use of RDF Product from MBT	-8.737%	-7.225%	+6.490%	+8.439%
Scenario 4 – Out-of-Region Use of RDF Product from MBT	-8.743%	-7.234%	+6.489%	+8.447%
Scenario 5 –Waste Exported Out of Region to WTE	-8.780%	-7.263%	+6.486%	+8.430%
Scenario 6 – Local Landfilling of MBT Product	-8.708%	-7.197%	+6.493%	+8.444%
Scenario 7 – Maximize Local Landfilling	-8.768%	-7.255%	+6.487%	+8.442%
Scenario 7b – Maximize Local Landfilling with 75% LFG Capture	-8.743%	-7.234%	+6.489%	+8.447%
Scenario 8 – Maximize Out-of-Region Landfilling	-8.785%	-7.269%	+6.481%	+8.416%



**Figure A- 5: Change in Maximum Predicted Eight-Hour Ozone Concentrations Relative to 2005 Base Case – Hope**



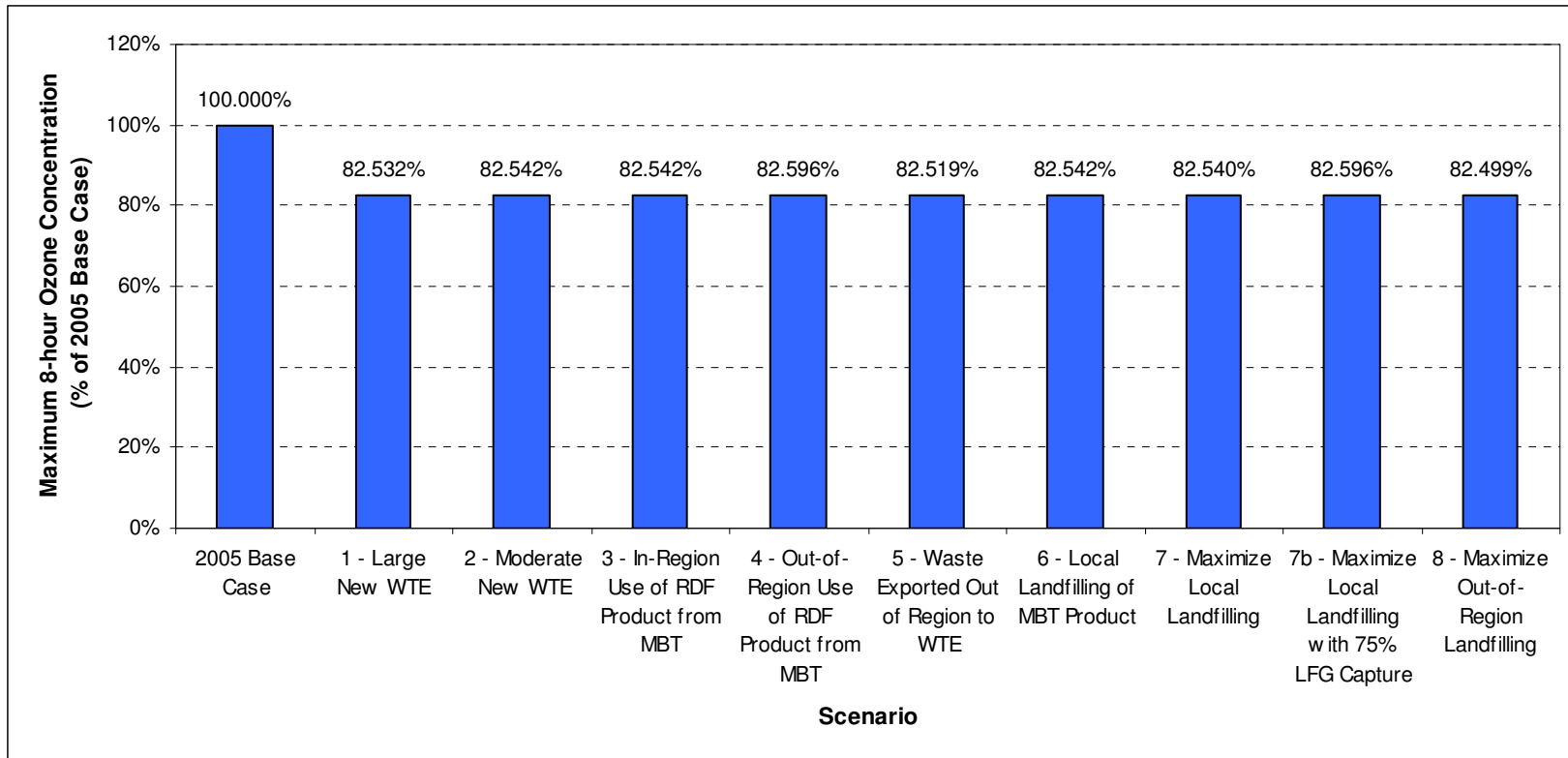
**Figure A- 6: Change in Maximum Predicted 24-Hour PM<sub>2.5</sub> Concentrations Relative to 2005 Base Case – Hope**

#### A.4 BURNABY

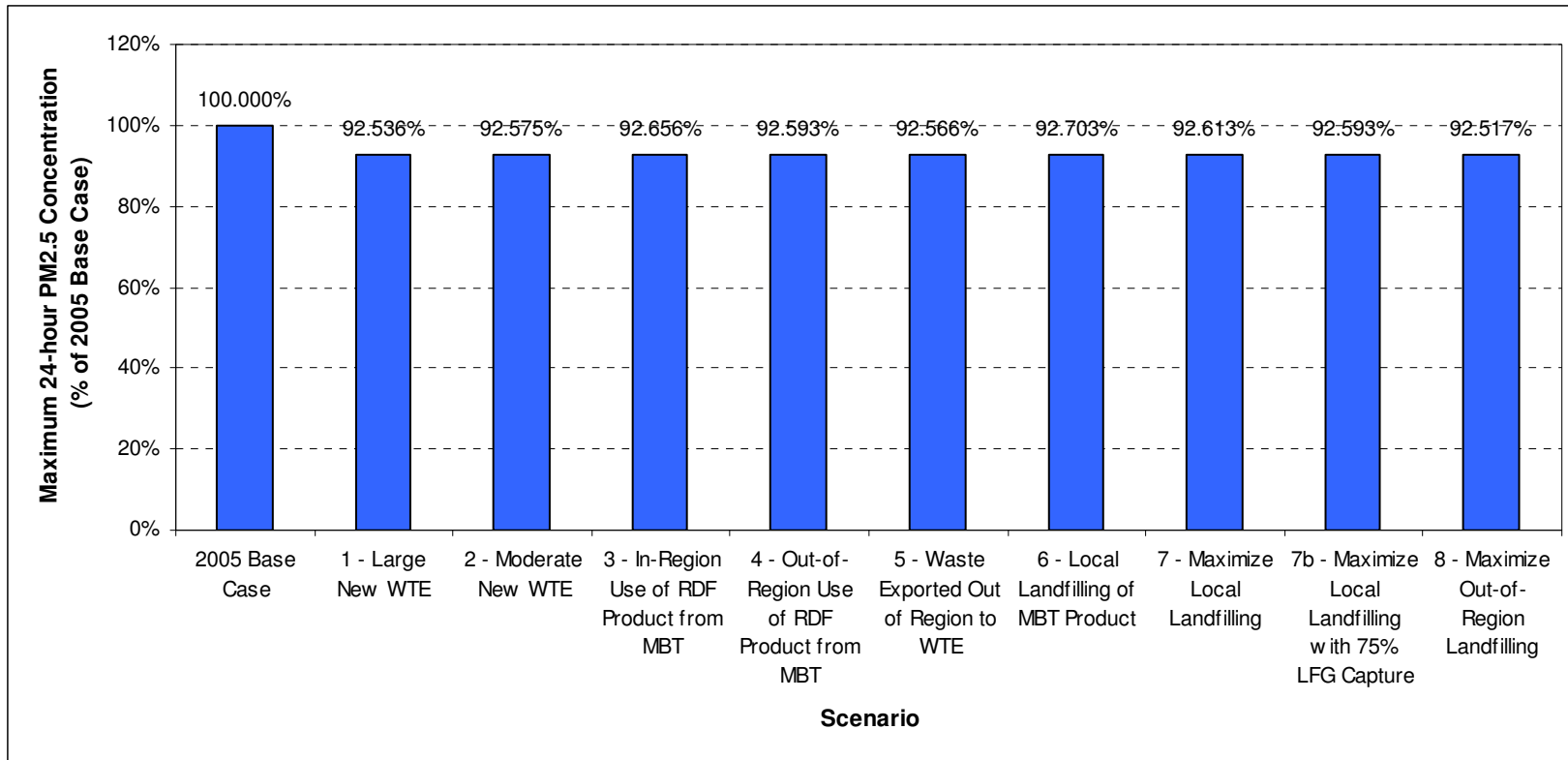
Table A-5 compares results for the eight solid waste management scenarios and one sensitivity case to the 2005 base case in Burnaby. Changes in eight-hour ozone and 24-hour PM<sub>2.5</sub> are illustrated in Figure A-7 and Figure A-8. Maximum eight-hour ozone concentrations decrease by 17.5% and maximum 24-hour PM<sub>2.5</sub> concentrations decrease by 7.3 to 7.4%.

**Table A-5: Change in Maximum Predicted Concentrations Relative to 2005 Base Case - Burnaby**

Scenario	Max Ozone		Max PM <sub>2.5</sub>	
	1-Hour	8-Hour	1-Hour	24-Hour
Scenario 1 – Large New WTE	-15.127%	-17.468%	-12.767%	-7.464%
Scenario 2 – Moderate New WTE	-15.125%	-17.458%	-12.695%	-7.425%
Scenario 3 – In-Region Use of RDF Product from MBT	-15.161%	-17.458%	-12.595%	-7.344%
Scenario 4 – Out-of-Region Use of RDF Product from MBT	-15.070%	-17.404%	-12.655%	-7.407%
Scenario 5 –Waste Exported Out of Region to WTE	-15.179%	-17.481%	-12.677%	-7.434%
Scenario 6 – Local Landfilling of MBT Product	-15.173%	-17.458%	-12.575%	-7.297%
Scenario 7 – Maximize Local Landfilling	-15.149%	-17.460%	-12.612%	-7.387%
Scenario 7b – Maximize Local Landfilling with 75% LFG Capture	-15.070%	-17.404%	-12.656%	-7.407%
Scenario 8 – Maximize Out-of-Region Landfilling	-15.203%	-17.501%	-12.742%	-7.483%



**Figure A- 7: Change in Maximum Predicted Eight-Hour Ozone Concentrations Relative to 2005 Base Case – Burnaby**



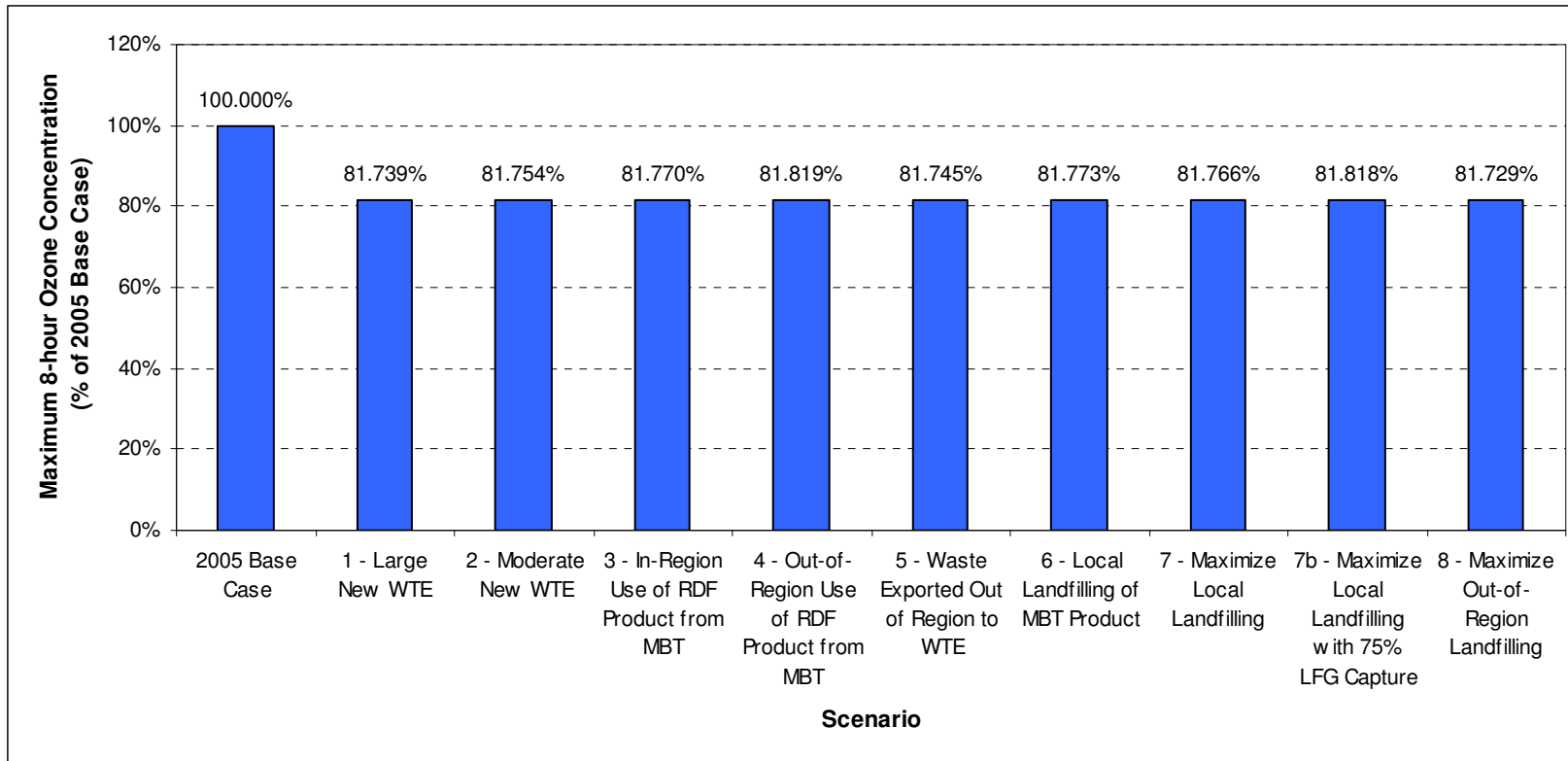
**Figure A- 8: Change in Maximum Predicted 24-Hour PM<sub>2.5</sub> Concentrations Relative to 2005 Base Case – Burnaby**

## A.5 SURREY

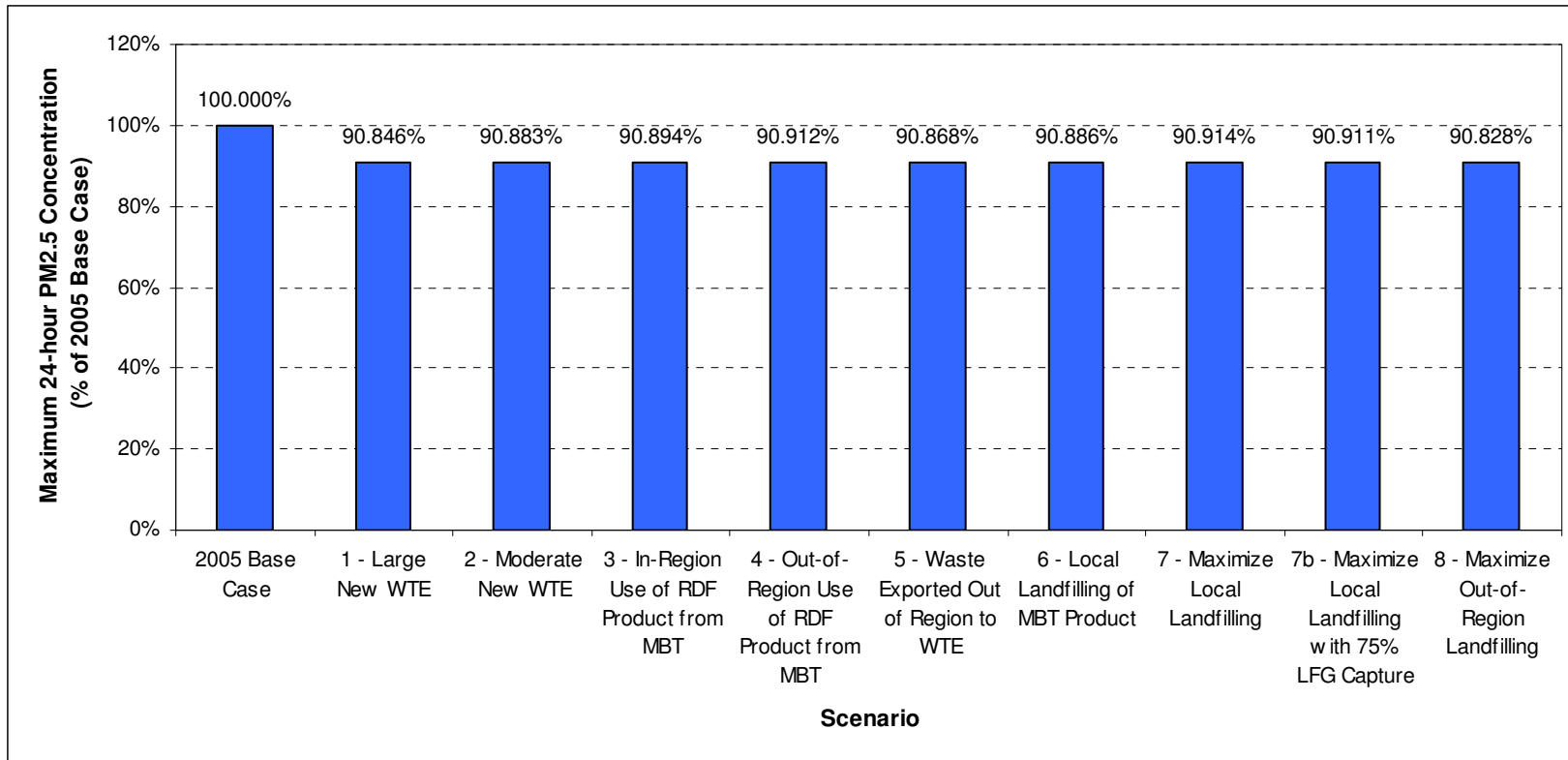
Table A-6 compares results for the eight solid waste management scenarios and one sensitivity case to the 2005 base case in Surrey. Figure A-9 and Figure A-10 illustrate these results for eight-hour ozone and 24-hour PM<sub>2.5</sub>. Maximum ozone and particulate concentrations in Surrey are also predicted to decrease considerably between 2005 and 2020, by about 18% for eight-hour ozone and about 9% for 24-hour PM<sub>2.5</sub>.

**Table A-6: Change in Maximum Predicted Concentrations Relative to 2005 Base Case – Surrey**

Scenario	Max Ozone		Max PM <sub>2.5</sub>	
	1-Hour	8-Hour	1-Hour	24-Hour
Scenario 1 – Large New WTE	-15.730%	-18.261%	-19.088%	-9.154%
Scenario 2 – Moderate New WTE	-15.729%	-18.246%	-19.023%	-9.117%
Scenario 3 – In-Region Use of RDF Product from MBT	-15.743%	-18.230%	-19.190%	-9.106%
Scenario 4 – Out-of-Region Use of RDF Product from MBT	-15.699%	-18.181%	-19.074%	-9.088%
Scenario 5 – Waste Exported Out of Region to WTE	-15.751%	-18.255%	-19.242%	-9.132%
Scenario 6 – Local Landfilling of MBT Product	-15.743%	-18.227%	-19.299%	-9.114%
Scenario 7 – Maximize Local Landfilling	-15.742%	-18.234%	-19.062%	-9.086%
Scenario 7b – Maximize Local Landfilling with 75% LFG Capture	-15.699%	-18.182%	-19.077%	-9.089%
Scenario 8 – Maximize Out-of-Region Landfilling	-15.771%	-18.271%	-19.373%	-9.172%



**Figure A- 9: Change in Maximum Predicted Eight-Hour Ozone Concentrations Relative to 2005 Base Case – Surrey**



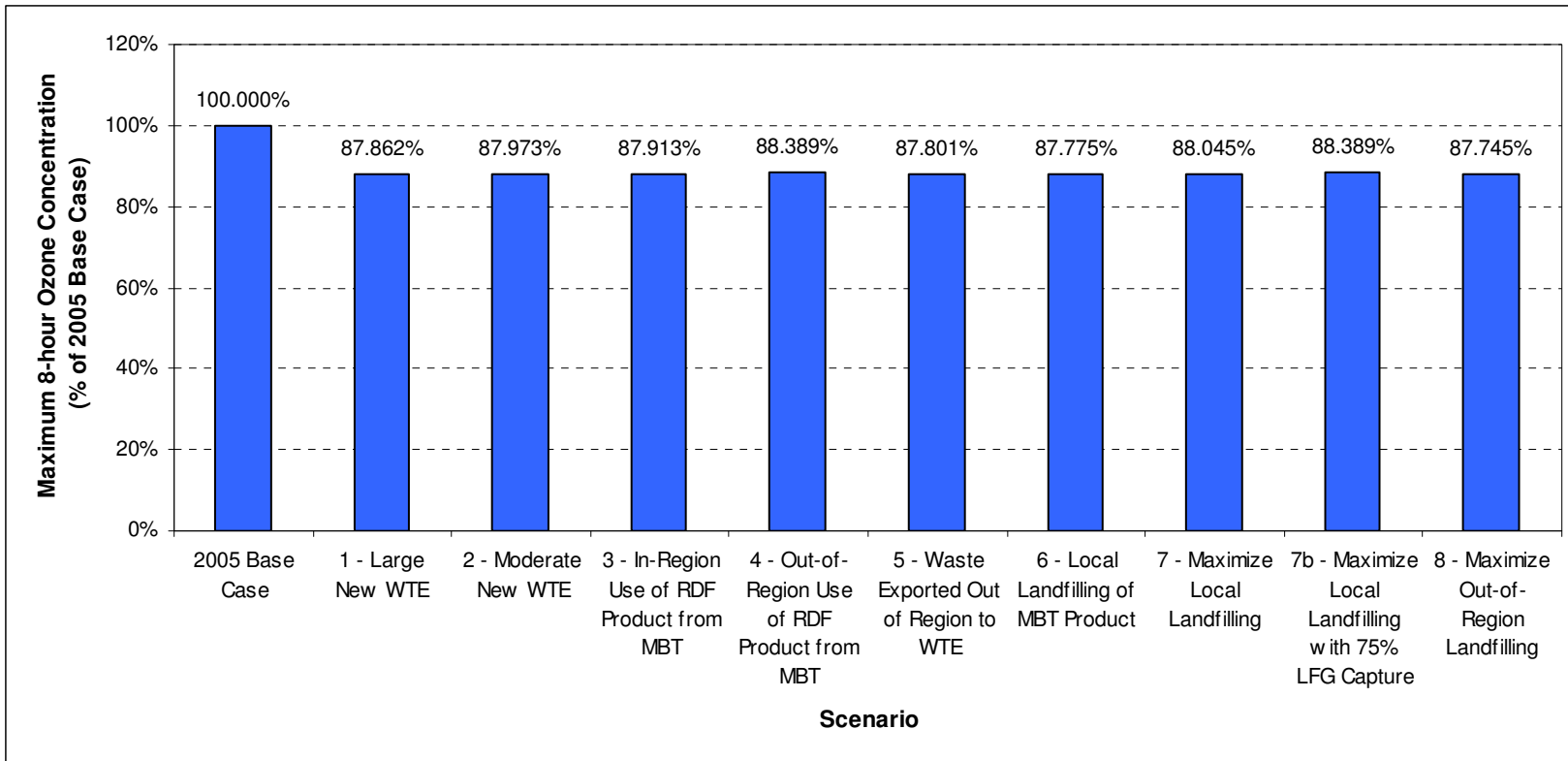
**Figure A- 10: Change in Maximum Predicted 24-Hour PM<sub>2.5</sub> Concentrations Relative to 2005 Base Case – Surrey**

## A.6 NORTH SHORE

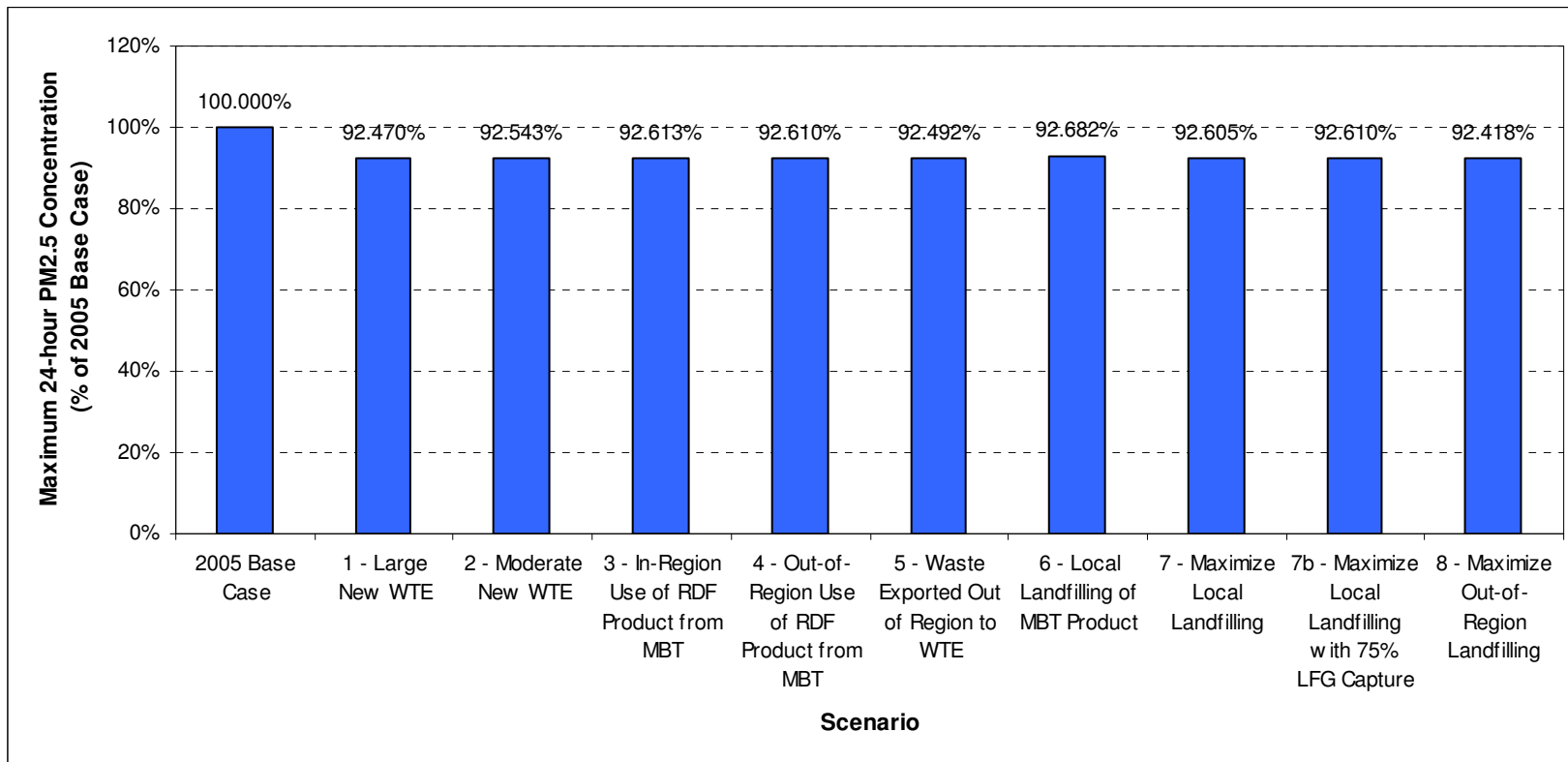
Table A-7 compares results for the eight solid waste management scenarios and one sensitivity case to the 2005 base case in the North Shore (North Vancouver). Figure A-11 and Figure A-12 illustrate these results for eight-hour ozone and 24-hour PM<sub>2.5</sub>. Maximum eight-hour ozone concentrations are predicted to decrease by about 11%. Maximum 24-hour PM<sub>2.5</sub> concentrations are predicted to decrease by 7.4 to 7.6%.

**Table A-7: Change in Maximum Predicted Concentrations Relative to 2005 Base Case – North Shore**

Scenario	Max Ozone		Max PM <sub>2.5</sub>	
	1-Hour	8-Hour	1-Hour	24-Hour
Scenario 1 – Large New WTE	-13.278%	-12.138%	-6.946%	-7.530%
Scenario 2 – Moderate New WTE	-13.213%	-12.027%	-6.859%	-7.457%
Scenario 3 – In-Region Use of RDF Product from MBT	-13.279%	-12.087%	-6.962%	-7.387%
Scenario 4 – Out-of-Region Use of RDF Product from MBT	-12.955%	-11.611%	-6.773%	-7.390%
Scenario 5 – Waste Exported Out of Region to WTE	-13.350%	-12.199%	-6.898%	-7.508%
Scenario 6 – Local Landfilling of MBT Product	-13.374%	-12.225%	-7.067%	-7.318%
Scenario 7 – Maximize Local Landfilling	-13.190%	-11.955%	-6.771%	-7.395%
Scenario 7b – Maximize Local Landfilling with 75% LFG Capture	-12.956%	-11.611%	-6.774%	-7.390%
Scenario 8 – Maximize Out-of-Region Landfilling	-13.395%	-12.255%	-6.982%	-7.582%



**Figure A- 11: Change in Maximum Predicted Eight-Hour Ozone Concentrations Relative to 2005 Base Case – North Shore**



**Figure A- 12: Change in Maximum Predicted 24-Hour PM<sub>2.5</sub> Concentrations Relative to 2005 Base Case – North Shore**