Air Quality in the Lower Fraser Valley and Waste to Energy Incineration - an Overview

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Executive Summary:

- From an air quality perspective, The Lower Fraser Valley (LFV) has *de facto* "special airshed status" in the scientific community by virtue of its topographic complexity and the nature of its air pollution chemistry. Consequently, it has been the subject of considerable scientific attention, akin to the effort directed at the Los Angeles and Mexico City Basins. Like those places, the LFV has in the past, and has the potential in the future to have severely degraded air quality due to its topographic and meteorological setting.
- The LFV is a rapidly growing region in which the dominant source of air pollution is the transportation sector. To date, improvements in air quality have been attributed to changes in emission sources, technological advances and an aggressive management strategy (Aircare). Improvements in air quality have been hard-won and are by no means secure.
- Within the LFV, the eastern portion is prone to poorest air quality due to the constricted nature of the valley and the warm season tendency for eastward transport of pollutants from sources in the western and central valley.
- At the local scale (less than that currently resolved by computer models) meteorological processes and phenomena operating in the LFV can produce unexpectedly high concentrations. These include gravity wave effects, down-mixing from elevated layers, and recirculation processes.
- Trends occurring at larger scales mean that current air quality is not guaranteed in the future. Recent research shows that background concentrations of some pollutants (e.g ozone and particulate matter) are increasing due to long range transport from burgeoning upwind sources (primarily Asia). Furthermore, Global Climate Change will likely have a negative impact on air quality (e.g. more hot, dry weather patterns that increase the frequency and severity of degraded air quality episodes, and increase the frequency of regional forest fires).
- Addition of any new sources of pollution to this sensitive airshed will likely have a deleterious effect of air quality.

Specific aspects of waste incineration in the Lower Fraser Valley

- **Reduction of ozone precursor emissions in the LFV will not necessarily result in a decrease in ozone in the region. This is because ozone photochemistry is complex and non-linear. Furthermore, hemispheric background concentrations are increasing and may overwhelm local changes.**

- **Emissions from proposed waste incinerators in the Lower Fraser Valley are equivalent to ~1/3 of the emissions from now defunct Sumas 2 gas fired Power station proposal (based on emissions of CO, NO_x, PM_{10}, SO_x, and VOC for scenario 1, new WTEF). This represents a relatively small, but not insignificant, incremental increase in the pollutant burden in the region.**

- **In general terms, European locations of existing waste incinerators (e.g. Britain, France, Belgium, Netherlands, Denmark) do not share the same airshed characteristics as the Lower Fraser Valley (i.e. mountainous coastal valley with restricted dispersion). In Europe, the Po Valley (Italy) may be considered to be one of the few locations having comparable characteristics to the LFV. Elsewhere, more reasonable analogues to the LFV are likely to be found in Japan (where nearly 70 percent of the world's waste incinerators are found and where nearly three-quarters of the nation's waste is burned in such facilities).**

- **In light of rising background pollutants levels, global climate change and local population growth, the addition of new combustion sources in the LFV is not advisable. Furthermore, serious and reasonable concerns elsewhere regarding the impacts of mass incineration on human health would suggest that adoption of the "precautionary principle" is appropriate.**

- **From an air quality perspective, the effects of a "distributed model" (several small incinerators scattered across the region) versus a single source are likely pollutant specific. Careful modeling would be required in order to assess the relative merits of each approach**

- **Health impacts: there remains vigorous debate as to the health risks posed by modern waste incinerators. There is a large body of credible published evidence to suggest that there is indeed sufficient cause for concern, especially from dioxins and nano-particles. In weighing up such evidence, it should be noted that many risk assessments are based on the assumption of efficient and optimal operating conditions at waste incinerators. "Upset" conditions in which non-optimal operating conditions occur require specification.**

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Introduction

The Lower Fraser Valley (LFV) is one of three regions in Canada that have experienced repeated exceedances of the Maximum Acceptable National Ambient Air Quality Objective (NAAQO) hourly average ozone (O_3) concentration of 82 ppb. These elevated concentrations generally occur during summertime anti-cyclonic conditions when the combination of local emissions and meteorological factors promote buildup of both primary emissions (e.g. carbon-monoxide, particulate matter, hydro-carbons and nitrogen oxide) and photochemical smog products (including secondary fine particulate matter and ozone). These pollutants not only contribute to degraded visibility, but also (most notably fine particulate matter and ozone) are considered to be deleterious to human health. Given its modest population (~2 million people), transportation dominated emissions, and isolation from long-range sources of pollutants, it is somewhat surprising that photochemical pollutant concentrations in the LFV reach levels comparable to coastal mid-latitude urban centres of twice its size. This has prompted concern and action at the Federal, Provincial and Municipal levels of government, and has stimulated development of Air Quality Management Plans for the region and at least two major international scientific field campaigns (Pacific '93 and Pacific 2001).

In this overview, the physical basis of this problem is described and in particular the challenges associated with the consideration of air quality (including new sources of pollution) are discussed. Implicit in this discussion is the view that any consideration of potential new sources of pollution in the Lower Fraser Valley (LFV) airshed can be neither trivial nor straightforward. Specific questions addressed include:

- Is the LFV in some way "special" or unusual with respect to air quality science? If so, does this imply the need for a more circumspect/precautionary approach to air quality issues?
- What factors are important when considering potential new sources of pollution in the LFV?

2. Geography and Meteorology

The LFV spanning the Canada/USA border at 49^{o}N is a roughly triangular valley with its westward end being the shoreline of the Strait of Georgia. The valley walls consist of the Coast Mountain Ranges in the North and the Cascade Ranges in the south. The valley floor is nearly flat, at an elevation of no more than a few hundred meters above sea level, while valley walls to the North rise to 2000m above sea level within 10km of the floor. Several tributary valleys incorporating long "finger"lakes are present on the northern sides of the valley. Professor Oke (a world reknown climatologist from UBC) has referred to the LFV as being "coffin" shaped (alluding to the negative consequences that has for air quality) with the tributary valleys acting as the "lungs" of the system. In this sense, the LFV has many of the topographic characteristics shared by other air quality "hotspots" such as the Los Angeles Basin, Tokyo, Mexico City, and Rio de Janeiro.

Meteorology

Whilst topography creates the setting for air quality problems it is emission patterns and meteorology that are responsible for the day to day variability and spatial patterns of pollutant concentrations. Although patterns of pollutant emissions vary relatively little from day to day, the ability of the atmosphere to disperse, transport and transform pollutants varies considerably at a range of timescales. Consequently, meteorological variability is the main factor contributing to temporal variations in pollutant concentrations in the LFV.

Weather patterns that produce clear skies, warm air, light winds and reduced mixing layer depths promote photochemical activity and reduced dispersion. In southwestern British Columbia, conditions conducive to the buildup of photochemical smog are generally associated with development of a low level thermal trough in combination with an upper level ridge. This is the typical summertime Fraser Valley "warm spell" known to all inhabitants of the valley. From year to year, annual frequencies of weather conditions that promote development of photochemical episodes are strongly modulated by modes of atmospheric variability present in the North Pacific region. Phenomena such as ENSO (El-Nino Southern Oscillation) and the Pacific Decadal Oscillation (PDO) have a strong impact in the North Eastern Pacific and contribute to year-to year variability in the frequency of weather patterns.

In addition to its variable regional weather patterns, the local meteorology of the LFV is very complex. Below are listed several important phenomena that distinguish the LFV from other regions in terms of air pollution dispersion. It is these factors which make the consideration of new pollutant sources in the LFV far from routine or trivial.

Shallow mixing layers and capping inversions

At the local scale, a major factor controlling the severity of photochemical episodes in the LFV is the very shallow layer through which pollutants can be mixed (or diluted). Under conditions of light onshore winds and clear skies in a coastal environment, the depth of this layer may vary from over-water values of ~60m to a maximum of ~900m at inland sites. These shallow mixed layers are strongly influenced by synoptic scale subsidence, show significant spatial variability and effectively constrain pollutants well below the surrounding ridges.

Local breezes

Combined sea breeze and valley/slope wind regimes also strongly influence the distribution and potential recirculation of LFV pollutants during summertime anti-cyclonic conditions. Observations and modelling studies show that daytime onshore sea breezes and upslope/valley flows develop simultaneously across the basin as a result of interaction between terrain and coastal effects. Adjoining tributary valleys such as the pitt Valley and Harrison Lake are now also known to play an important role in air pollution meteorology of the region. Trajectory modelling studies show significant daytime pollutant transport into valleys along the north side of the LFV. This pollutant pathway has been confirmed by observational studies that show some of the highest concentrations of O_3 in the entire region may be found in these unmonitored mountainous areas.

Recirculation of Pollution

At night, local thermo-topographic flows in the region reverse, creating the potential for horizontal recirculation of pollutants. Simply put, pollutants emitted into the LFV during the day may be carried out over Georgia Strait at nighttime, and then reintroduced to the LFV the following day by sea breezes. This process leads to a day-to-day buildup of pollutants and has recently been well documented by modeling studies and *lidar* observations.

Vertical Mixing of Pollutants and Complex Layered Structures

It is now known that important processes vent pollutants from the valley and also potentially mix pollutants from aloft to ground. These processes are most effective along mountain slopes which when heated during the day create an upward flow of air that carries pollutants aloft and creates deep pollutant layers that persist over mountainous regions. These processes are not well handled by standard air quality modeling approaches. The mountain venting or "chimney effect" associated with slope flows is thought to be the principal mechanism of planetary boundary layer- free troposphere exchange (an important means of dispersing pollutants vertically) in the region and is likely responsible for the elevated layers and "deep haze" observed during photochemical smog episodes. If such layers are sufficiently low, or brought ground-ward by subsidence, there is also potential for elevated layers to be mixed to ground when intercepted by the growing mixed layer the following day.

3. Rising "Background" Concentrations

Until recently, air pollution in the LFV was considered to be exclusively of local or regional origin. However, despite being relatively remote from continental pollutant sources, and with a prevailing exposure to North Pacific air masses, British Columbia is subject to significant medium- and long-range transport of pollutants, including crustal dust. Notable sources include:

- Crustal dust (aerosol) emanating from large desert sources in Asia and North Africa. This dust is often chemically mixed with sulphate material generated by human activities.

- Pollutants generated by human activities. (notably carbon monoxide (CO), ozone (O_3), nitrogen oxides (NO_x), radon (Rn), mercury (Hg), peroxyacetylnitrate (PAN), non-methane hydrocarbon (NMHC), particulate matter, including sulphate aerosol, and persistent organic pollutants) The nearest primary upwind source of these pollutants is Asia although background contributions originate from the entire hemisphere.

- Biomass burning in Eurasia (including Siberia), and western North America. Recent research suggests that forest fires along the west coast of North America (e.g., California/Oregon/Washington State) may contribute significantly to summertime pollutant concentrations in BC.

From summary table 1-1 it is evident that for important pollutants such as particulate matter less than 2.5 microns in diameter ($PM_{2.5}$) and O_3, long-range transport from Eurasian sources may contribute significantly to local BC ground-level concentrations. Episodically, the impact of background concentrations may be sufficient, when combined with local sources, to exceed local air quality standards. Of the two criteria pollutants listed in table 1-1, O_3 shows a significant upward trend of 0.5 to 2.0% per year. Such increases are set against a background of burgeoning emissions in Asia where, not only have sulphur dioxide (SO_2) emissions increased by 119% between 1980 and 2003, but also Asian sulphate influx to North America has increased 72 to 85% between 1985 and 2006. Asian SO_2 emissions are projected to increase from 25.2 Mt in 1995 to 30.6 Mt in 2020 (assuming emission controls are implemented on large power plants) and possibly to 60.7 Mt without emission controls. East Asian enhancements of sulphate aerosol episodically degrade western Canadian surface $PM_{2.5}$ air quality by as much as 1.5 ug m^{-3} . Emissions of nitrogen oxides (NO_x) are projected to increase from 12.0 Mt in 1995 to 26.6 to 29.7 Mt by 2020, with little in the way of pollution controls or other emission reduction measures in place. Emissions of CO are projected to decline from 115 Mt in 1995 to 96.8 Mt in 2020, due to more efficient combustion techniques, especially in the transportation sector; if these measures are not realized, carbon monoxide emissions could increase to 130 Mt by 2020.

Table 1-1: Background $PM_{2.5}$ and O_3 Concentrations and Trends in BC (McKendry, 2006; Vingarzan, 2005)

$PM_{2.5}$	O_3
• On an annual basis, average background $PM_{2.5}$ concentrations of 2 μg m^{-3} along the west coast of the United States are comprised of approximately 40% organic aerosol, 20% sulfate, and 15 to 20% mineral dust. Concentrations vary seasonally with a summer peak and winter minimum. It is likely that precipitation variability is a major control on background concentrations across the Province. • Episodic trans-Pacific dust transport during spring is infrequent but has the potential to elevate hourly concentrations by ~20 μg m^{-3} • Mean monthly background concentrations in air masses arriving in BC with north Pacific trajectories are of the order of 1.5 to 2 μg m^{-3}. This represents a significant proportion of the overall background concentration in BC. • East Asian enhancements of sulphate aerosol episodically degrade western Canadian surface air quality by as much as 1.5 μg m^{-3} (McKendry et al. 2008) • There is little evidence of an upward trend in background concentrations. It is likely that background concentrations associated with regional or continental scale transport are decreasing due to abatement strategies in urbanised areas.	• The mean background is estimated to be in the range of 20 to 35 ppb and varies seasonally with a spring maximum. This level represents approximately 50% of the CWS. • There is little evidence that stratospheric intrusions of O_3-rich air contribute to exceedances of the CWS at ground level in BC (Bovis, 2001). However, this source may contribute 20 to 40 ppb to short-term peak concentrations (but generally in meteorological conditions not conducive to elevated concentrations associated with local anthropogenic activities). • Episodic trans-Pacific ozone transport (arising from either biomass burning or the anthropogenic combustion sources in Eurasia) may episodically increase short-term, ground-level concentrations by 5 to 15 ppb. In one case this has been shown to lead to exceedance of an 82 ppb 8-hour standard. • Mean background concentrations show an upward trend of 0.5 to 2.0% per year. • Using five of the less conservative IPCC emission scenarios, the average global surface ozone concentration is expected to be in the range of 35 to 48 ppb by 2040, 38 to 71 ppb by 2060, 41 to 87 ppb by 2080 and 42 to 84 ppb by 2100.

4. CHEMISTRY

Recent research in the LFV has identified three important site-specific aspects of photochemistry that have pollution management implications. These stem from the isolated, transport-dominated setting, local meteorology and the character of local anthropogenic and biogenic emissions.

(1) biogenic isoprene (a natural hydrocarbon produced by vegetation) has been found to play a significant role in local photochemistry. Based on detailed chemical analysis during Pacific '93, up to 13% of the observed O_3 at the mouth of the Pitt Lake Valley during a period of elevated O_3 concentrations could be attributed to chemistry involving primarily the isoprene.

(2) There is a poor correlation observed between elevated O_3 concentrations and fine particulate matter concentrations. Low correlations between O_3 and fine particulate matter concentrations in the LFV imply that episodes of poor visibility and elevated O_3 concentrations do not occur simultaneously and are therefore controlled by different meteorological process and chemistry. Clearly, this too has important implications for air quality forecasting and the implementation of abatement strategies in the region.

(3) abundance of ammonia in the central LFV (primarily from livestock emissions) is thought to play an important role in local particulate chemistry and observed spatial patterns of degraded visibility. Visibility has emerged as a primary air quality issue in the LFV due to a perception than the aesthetic and economic (i.e. tourism) value of spectacular local vistas is becoming significantly degraded.

Management strategies designed to reduce ambient pollutant concentrations necessarily imply understanding of local details of emissions, meteorology, and chemistry as well as a sound assessment of impacts. By virtue of its complex coastal setting, rapid growth, and the local nature of sources, air pollution in the LFV might be expected to have different meteorological and chemical controls than other Canadian regions afflicted by photochemical smog (i.e. the Windsor-Quebec corridor or the Maritime region of Eastern Canada). There are still numerous gaps in understanding of the LFV problem.

Furthermore, it is important to note that any discussion of air quality trends in the LFV must be considered against a background of quite rapid demographic and technological change as well as meteorological variability. The first two factors in particular are responsible for complex and linked spatial and temporal trends which make it difficult to identify temporal trends in air quality alone. For example, between 1985 and 1990 total VOC emissions in the region decreased by 1% while NOx emissions increased by 6% . Superimposed on this has been a shift in emissions eastward over time with population growth. This appears to have resulted in an eastward shift in the urban ozone plume, which, when combined with the western bias of the monitoring network, likely gives an overly optimistic impression of air quality trends in the region.

5. IMPACTS:

Although, the impact of air pollution on human respiratory and cardiac health is the primary concern in the LFV, photochemical smog likely has wide-ranging impacts that extend beyond the aesthetic and economic impacts associated with degraded visibility or the local economic ramifications of reduced crop/forest productivity. As yet the ecological or hydrological impacts of poor quality are poorly understood while the impact of emissions from regions such as the LFV on global tropospheric chemistry (and hence climate) are only beginning to be addressed.

In the LFV, robust links between ambient concentrations of O_3 and the lung function in segments of the population (i.e. adult farmworkers) have only recently been established These studies show that even with relatively low ambient O_3 concentrations, specific population groups conducting intense work outdoors are subject to high O_3 dosages resulting in acute decreases in lung function that persist into the following day.

With respect to fine particulate pollution, it is estimated that PM_{10} pollution in the GVRD is responsible for 10.2 extra deaths, 34 extra respiratory, cardiac and asthma extra hospitalisations , 46 extra emergency room visits and 18,308 extra school absences per year. With both O_3 and fine particulate pollution, the available epidemiological evidence suggests that even at the relatively low concentrations (by international standards) experienced in the LFV, significant health impacts are likely. Clearly, there is an urgent need for further focussed research related to the chemistry, meteorology and epidemiology of both O_3 and fine particulate pollution in the region.

With a rich agricultural base surrounded by forested mountainous watersheds (with recreational, aesthetic and economic value), there is concern that air pollution may have an impact on vegetation (including economically important crops) and the general ecological health of remote sites in the region. The ecological impact of air pollution at remote sites surrounding the LFV is as yet completely unknown. Observations of seriously degraded air quality in tributary valleys (e.g Pitt Lake) and indirect evidence of nocturnal deposition of O_3 and other chemical species along slopes in the tributary valleys however suggest that significant ecological impacts of air pollution are likely.

6. WASTE INCINERATION IN THE LOWER FRASER VALLEY

The following is based on consideration of the AECOM report (Management of Municipal Solid Waste in Metro Vancouver) and the RWDI report (CMAQ Modelling of Possible Solid Waste Management Scenarios – June 11, 2009). In particular, I have chosen to comment on:

1. Assertion that reducing ozone precursor emissions in the LFV airshed will reduce ozone levels in the eastern Fraser Valley.

The history of the attempts to control photochemical smog in urban settings has been plagued by frustration and failure. This has been particularly the case in the Los Angeles basin and arises as a result of the strong non-linearity in the chemistry associated with ozone production. This is encapsulated in the well known Empirical Kinetic Modelling Approach (EKMA) diagram below. The EKMA diagram plots the ozone concentration (blue isopleths) that arise from particular combinations of precursor species. Of relevance here is the observation that reductions in one precursor (NOx) can actually result in increases in ozone. Control of ozone therefore requires very careful manipulation of the combination of precursor species and even this may be unsuccessful.

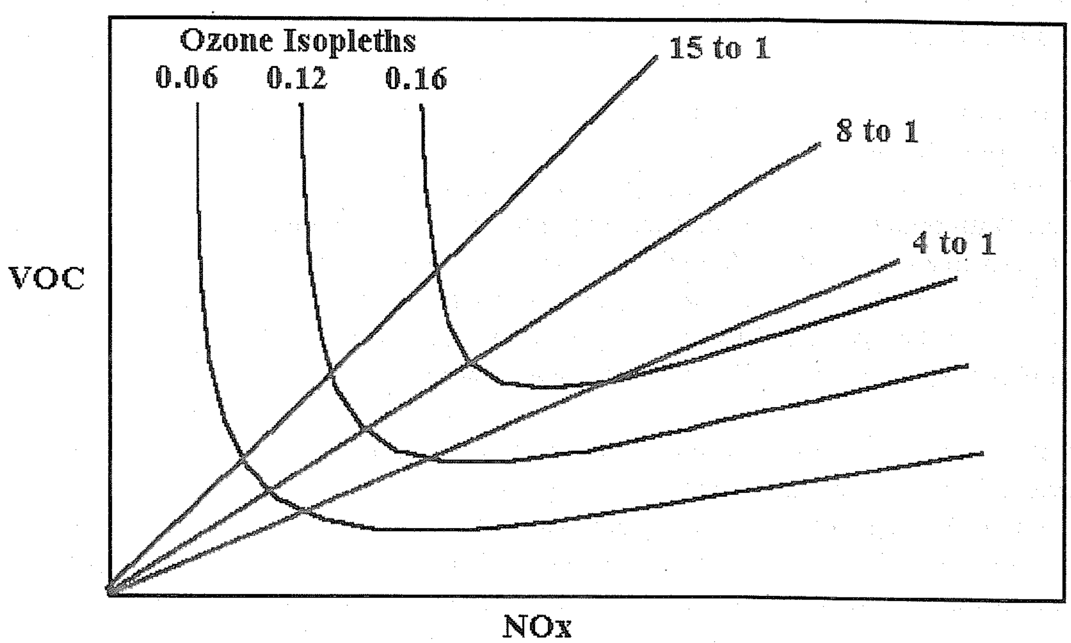

Figure 1: the EKMA diagram illustrating the complex relationship between Ozone and its precursor species.

In respect to this assertion, it should also be noted that statements of projected trends in ozone and precursor species the region neglect evidence of rising background concentrations of ozone in the northern hemisphere as well as the potential deleterious impacts of global climate change. As emphasized earlier, this is no longer simply a local issue in which consideration of local sources and processes can be used to estimate future pollutant concentrations.

2. Estimates of the amount and characteristics of air pollutants in the AECOM report and the significance for the airshed.

The types of pollutants and the emission rates proposed in the AECOM report are reasonable assuming optimal operating conditions (see below). The AECOM report notes that the proposed emission sources are equivalent to the emissions for $PM_{2.5}$, NO_x, and dioxins and furans from 1500 – 5600 heavy duty vehicles (depending on pollutant). It should also be noted that this is equivalent to ~1/3 of the emissions proposed from the now defunct Sumas Energy 2 Gas fired power station proposal (based on emissions of CO, NO_x, PM_{10}, SO_x, and VOC for scenario 1, new WTEF).

This represents a relatively small increase in total emissions of criteria pollutants and greenhouse gases in the LFV airshed. However, the near field impacts of dioxins and furans etc. may well be a more important issue, and is a problem for which there are few baseline measurements made in the region..

3. Topographical and meteorological similarities between the LFV airshed and any other airsheds in the world in which waste-to-energy incinerators are located.

In general terms, locations in Europe (e.g Paris) do not share the same airshed characteristics as the Lower Fraser Valley (i.e. mountainous coastal valley with restricted dispersion). However, some locations such as the Po Valley airshed will provide reasonable analogues. Others are more likely found in Japan (where nearly 70 percent of the world's waste incinerators are found and where nearly three-quarters of the nation's waste is burned in such facilities). It is worth noting that the impacts of dioxins in Japan have been significant, and is a major issue associated with the incineration industry there.

4. Advisability of new combustion sources in the airshed.
Improvements in air quality in the "sensitive" and complex Lower Fraser Valley airshed have been won on the basis of aggressive management policies. However, these gains are threatened by:

- population growth in the region
- indications of increasing background concentrations beyond the control of local stakeholders (e.g. trans-boundary and trans-Pacific air pollution)
- A likelihood that global climate change will increase the frequency of episodes of degraded air quality

Furthermore, epidemiological evidence that the pollutants arising from combustion processes have deleterious impacts on human morbidity and mortality (especially ultrafine particles, dioxins and furans, and mercury) is mounting. Given the risks of harm to human health and the remaining uncertainties associated with the magnitude of health impacts, adoption of the "precautionary principle" would seem a desirable course to follow. Based on these considerations, the deliberate addition of further significant combustion sources to the Lower Fraser Valley airshed poses potential risks to human health and threatens to establish an incremental trend which at its worst implies a move away from a focus on reducing emissions toward a model of "polluting to the regulatory limit".

5. The significance of the precise location of new sources of pollution in the airshed (whether 1 large or 6 small incinerators).

From an air quality and human health perspective there are likely important tradeoffs associated with exact location (s) of proposed incinerators. Factors such as the impacts of transportation of materials to the facilities will come into play. From an air quality perspective, the effects of a "distributed model" (several small incinerators scattered across the region) versus a single source are also likely to be pollutant specific. For example, where significant near-field effects are of concern (say for dioxins and furans), it may be preferable to have single large facility remote from population sources as opposed to smaller facilities which may affect several localities. For long-lived and relatively inert species of global concern (e.g. GHGs) there may be relatively little difference between the distributed and single source approaches. For reactive and precursor species (e.g. NO_x) the exact position and magnitude of the facility will influence concentrations of secondary species (e.g. Ozone) downwind. In this case, careful modeling would be required in order to assess the relative merits of each approach.

6. Claims in AECOM report that toxics such as dioxins and nanoparticles are not an issue for modern incineration.

This statement is at odds with research and assessments by highly reputable scientists (e.g Professor Vyvyan Howard and the Paris Appeal signed by the International Society of Doctors of the Environment). There is a large body of credible published evidence to suggest that there is indeed sufficient cause for concern. However, it is important to acknowledge a diversity of expert opinion. Dr Roy Harrison (UK, University of Birmingham), a leading UK expert on air pollution notes:

"...that epidemiological studies had not demonstrated significant health problems (including additional cancer cases) due to incinerators, even when some studies examined older installations. Current levels of dioxins emissions from incinerators are unlikely to increase the human body burden and indirect estimates of health effects have shown that waste incineration contributes a very small health impact".
From: *"IPPC: Incineration Sector; Managing the Implications for the Health Consultee"*
4th March 2005, Birmingham

Suffice it to say, there remains vigorous debate as to the health risks posed by modern waste incinerators. In weighing up such evidence, it should also be noted that many risk assessments are based on the assumption of efficient and optimal operating conditions at waste incinerators. The National Academy of Science observes:

"..for all types of incinerators, there is a need to be alert to off-normal (upset) conditions that might result in short-term emissions greater than those usually represented by typical operating conditions or by annual national averages. Such upset conditions usually occur during incinerator startup or shutdown or when the composition of the waste being burned changes sharply. Upset conditions can also be caused by malfunctioning equipment, operator error, poor management of the incineration process, or inadequate maintenance". (P3, executive summary). Furthermore, "more information is needed, especially for dioxins and furans, heavy metals, and particulate matter"

Waste Incineration and Public Health (National Academy of Sciences)
http:/books.nap.edu/catalog/5803.html