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Report of the 1st Workshop on the Science of Agriculturally Produced Gas-phase Ammonia

Canada

Report of the 1st Workshop on the Science of Agriculturally Produced Gas-phase Ammonia

- A Preliminary Assessment -

A joint report from:

AGRICULTURE AND AGRI-FOOD CANADA

&

ENVIRONMENT CANADA

March 3rd and 4th, 2003

Meteorological Service of Canada
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FOREWORD

Air quality is a significant environmental concern for Canadians and the government of Canada is committed to providing cleaner air to Canadians. In May 2000, the federal government launched its 'Clean Air Agenda', an overall plan that outlined the main areas of action to improve the quality of the air that we breathe. The plan included federal initiatives, as well as work with provinces, territories and stakeholders. Much of the work has focused on particulate matter because evidence continues to mount regarding its negative impacts on human health. A significant portion of particulate matter is formed by reactions of gases in the atmosphere, including ammonia. As a result, on July 2, 2003, the final Order adding gaseous ammonia to Schedule 1 of the *Canadian Environmental Protection Act, 1999* (CEPA 1999) was published in the *Canada Gazette,* Part II.

Aside from natural sources of ammonia over which we have limited control, agriculture is the largest sources of ammonia to the atmosphere. A range of practices are available to producers to improve production efficiency and reduce impacts on the environment.These practices are being used and research continues to refine them. The chemical reactions linking ammonia to the formation of particulate matter have been studied for many years. However, the transport of ammonia between agricultural sources and environmentally sensitive targets, including humans, is not well understood. Thus, it is not clear if measures are required to manage these emissions, nor what those measures might be.

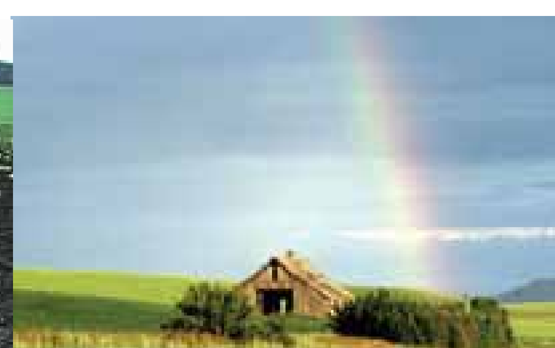
To reduce ambient levels of particulate matter, it is necessary to reduce emissions of precursors since, on average, one-half to two-thirds of fine particulate matter mass can be attributed to formation from precursors. With respect to gaseous ammonia, Environment Canada and Agriculture and Agri-Food Canada are committed to working with Provinces/Territories, industry and stakeholders on the risk management of gaseous ammonia. It will be particularly important to ensure that the agricultural sector is engaged and participates in initiatives under the Agricultural Policy Framework supporting the development of a flexible approach to manage gaseous ammonia. This approach will be based on the best available scientific information and a range of scientific expertise required to address the various aspects and integrate them. Much of this expertise is located within Agriculture and Agri-Food Canada (AAFC) and Environment Canada (EC).

A workshop on the "Science of Agriculturally Produced Ammonia" was held March 3rd and 4th, 2003 in Toronto, Ontario. The workshop was an opportunity to examine the current state of gaseous ammonia science in both departments, identify research gaps, as well as develop possibilities for future collaborative research. The workshop report summarizes the information that was shared during the two-day workshop, additional information brought by invited researchers from Europe and the United States, as well as the results of the discussions of organized break-out groups on several major science questions to be addressed on gaseous ammonia in Canada.

Both EC and AAFC recognize that ammonia use is essential to the production of wholesome food in Canada and the world. This report forms the first step in the discussions with industry and interested stakeholders on the issue of gaseous ammonia science and risk management.

LIST OF ACRONYMS

AAFC	Agriculture and Agri-Food Canada
APF	Agricultural Policy Framework
AMS	Aerosol Mass Spectrometer
BMP	Beneficial Management Practices
CAC	Criteria Air Contaminant
CEPA	Canadian Environmental Protection Act
CWS	Canada Wide Standard
EC	Environment Canada
FEMS	Farm Environmental Management Survey
GEIA	Global Emissions Inventory Activity
LIDAR	Light Detection and Ranging
MOUDI	Micro-Orifice Uniform Deposit Impactor
OC/BC	Organic Carbon/Black Carbon
PM	Particulate Matter
PSL	Priority Substances List
SOA	Secondary Organic Aerosol
TDL	Tunable Diode Laser
WEDD	Wet Effluent Diffusion Denuders



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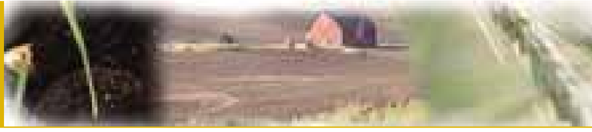


1.0 INTRODUCTION

Atmospheric ammonia is an important air quality issue in Canada. As the only alkaline gas in the atmosphere, ammonia neutralizes acids formed by the oxidation of sulphur dioxide and nitrogen oxides, resulting in the formation of ammonium particles. These particles can deposit, and ammonia and ammonium may act as fertilizers in natural ecosystems (forests, seas), leading to changes in species composition or algal blooms/fish death. Particulate matter is a component of smog, and can have a negative impact on human health, as well as having an influence on the Earth's radiation balance.

Particles are classified in two size ranges: coarse particles having a diameter between 2.5 and 10 μm, referred to as PM_{10}, and fine particles with a diameter less than 2.5 μm, or $PM_{2.5}$. Ammonia has been recognized as one of many precursors to both coarse and fine PM, along with other gaseous precursors such as NO, NO_2, VOCs and SO_2. As a result of the increasing frequency of smog events in many areas of Canada, combined with associated concerns for human health, PM_{10} precursors, including gaseous ammonia, were added to Schedule 1 of the *Canadian Environmental Protection Act, 1999* (CEPA 1999) on July 2, 2003.

Establishing the current state of knowledge on ammonia emissions, atmospheric reactions, and deposition is a necessary step in order to develop future plans to address this issue, both from a scientific point of view and to provide science-based support to the risk management decision-making process.

The "Science of Agriculturally Produced Ammonia Workshop", held March 3rd and 4th, 2003 in Toronto, Ontario, was organized in order to synthesize current knowledge and understanding about ammonia sources, modelling and atmospheric ammonia chemistry in order to plan for future work. The joint participation of Environment Canada's and Agriculture and Agri-Food Canada's scientists was considered essential because the agricultural sector is a major source of atmospheric ammonia in Canada. The workshop was an opportunity to examine the current state of ammonia science in both federal departments, identify research gaps, as well as develop possibilities for future collaborative research.

The impact of ammonia on the formation of particulate matter will be an important area of future research, and thus it is important to understand emissions from agricultural sources, including animal production and manure, fertilizers, as well as atmospheric chemistry and the potential for deposition (due to the secondary effects of particulate matter on human health and the environment).

This document summarizes the scientific information that was shared during the two day workshop, the additional information brought by foreign colleagues, as well as the results of the discussions of breakout groups on the major science questions to be addressed.

2.0 POLICY RELEVANCE

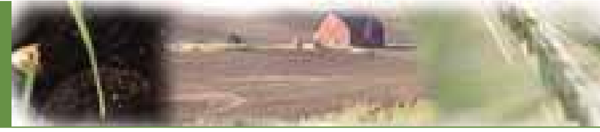
2.1 EC perspective: A Response to CEPA and the Canada-wide Standards

CHRISTIAN PILON discussed the two policy drivers currently in place that extend to both gas-phase ammonia and particle-phase ammonium in the atmosphere. They are the *Canadian Environmental Protection Act, 1999* (CEPA 1999), and the Canada-wide Standards (CWS) for particulate matter.

CEPA 1999 is an Act "respecting pollution prevention and the protection of the environment and human health in order to contribute to sustainable development". CEPA 1999 came into force on March 31, 2000 and under section 76, the Ministers of the Environment and of Health are required to establish a Priority Substances List (PSL) that identifies substances to be assessed on a priority basis to determine whether they are toxic (as defined under Section 64 of the Act). It is also a requirement to assess whether the substances pose a significant risk to the health of Canadians or the environment. Assessments of substances placed on the PSL are the shared responsibility of Environment Canada and Health Canada.

On May 27, 2000, the Ministers of the Environment and Health declared in the *Canada Gazette* that PM_{10} is considered to be "toxic" under section 64 of CEPA 1999, due to its impact on human health. PM_{10} was added to the List of Toxic Substances (Schedule 1) of CEPA 1999 in May 2001. The PM_{10} PSL Assessment Report specifies that PM_{10} can be released directly into the atmosphere or formed secondarily in the atmosphere from precursors as a result of physical or chemical transformations. The report identifies the principal precursors to PM_{10} to be SO_2, NO_x (NO and NO_2), gaseous ammonia (NH_3) and VOCs. Since up to two-thirds of fine particulate matter is formed from these gaseous precursors, any actions aimed at controlling PM must also consider the precursor substances. As a result, on July 2, 2003, the precursors to PM_{10} were added to Schedule 1 of CEPA 1999. By adding PM_{10} precursors and ozone and its precursors to Schedule 1 of CEPA 1999, the federal government is putting in place the authority it needs to take action to meet its domestic commitments on clean air. In order to deliver on these commitments, the federal government needs access to all "CEPA tools", which are only available if a substance is listed on Schedule 1.

Canada-wide Standards can include qualitative or quantitative standards, guidelines, objectives, and criteria for protecting the environment and reducing the risk to human health. CWSs will include a numeric limit (for example, ambient, discharge, or product standard), a commitment and timetable for attainment, a list of preliminary actions to attain the standard, and a framework for reporting to the public. The standard for $PM_{2.5}$ is 30 $\mu g/m^3$ averaged



over 24 hours, to be achieved by 2010. Achievement of the standard will be measured based on the 98th percentile value, averaged over three consecutive years. CEPA 1999 and the CWS process work together to minimize the risks posed to our environment and human health, where CEPA is the federal instrument to deliver part of the CWS. In terms of gaseous NH_3, Environment Canada plans to take a long-term management approach. Over the next five years, Environment Canada will move forward with reductions of the other precursors (NO_x, SO_x and VOCs), monitor and track information on ammonia, work with its federal partners on science and risk management measures and support Provincial/Territorial efforts on ammonia where appropriate.

2.2 AAFC perspective: The APF and Increased Environmental Sustainability

ISABELLE PROULX discussed the Agricultural Policy Framework (APF), which resulted from extensive consultations between federal and provincial governments. The APF is proposing new approaches to achieve the sustainability of the agri-food sector. Through this framework, it is expected that there will be a stronger co-operation among all partners. This will reduce the need for regulations imposed upon farmers and producers, and improve risk management. The three facets of sustainability (i.e. social, environmental, and economical) will be addressed in various ways through the Framework's components. Environmental and social facets of the APF are of interest for the workshop participants.

Environmental issues are becoming increasingly important, considering their impact on human health and the concerns expressed in many areas (e.g. water and air quality). Environmental issues cannot be dissociated from the economical facet: it is expected that more environmentally-friendly practices will help brand Canada as a country where food is produced with a strong respect for the environment. Internally, environmental stewardship will also contribute to gain better support from Canadians for the agricultural sector's activities.

Several approaches will be taken to achieve this vision. In particular, environmental issues will be addressed through the environmental farm plans that, linked with the nutrient management plans, will contribute to improving air and water quality. Beneficial management practices (BMPs), will be re-evaluated to take into account the most recent developments in animal production systems and in crop production, particularly fertilizer application.

The long-term goals of the APF will also serve the objectives of other departments and sectors (e.g. Environment Canada and Health Canada) that are striving to improve air quality and reduce human health effects, as well as improve the quality of the Canadian environment.

3.0 CURRENT SCIENTIFIC KNOWLEDGE

This section will summarize the presentations made by Canadian (EC and AAFC) and visiting scientists.

3.1 Atmospheric Chemistry

PAUL MAKAR described the role of gaseous ammonia in the formation of particulate matter. He used a "simple" example, involving the following four compounds; $NH_{3(g)}$, $NO_{(g)}$, $SO_{2(g)}$, and $NaCl_{(s)}$ to illustrate the complex processes that occur between precursors and the formation of particulate matter in the atmosphere.

Emissions of gaseous ammonia can exist in equilibrium with aqueous ammonia, while nitrogen and sulphur oxides, through oxidation processes and in the presence of water, can form acids (HNO_3 and H_2SO_4). There are many reactions that can occur which are highly dependent on temperature and relative humidity, and will result in the formation of small solid particles. Other inorganic constituents that are present in the atmosphere may further react with these four compounds and their reaction products, resulting in highly complex chemistry. The relative concentrations of all compounds are important to determine the end products. Such reactions are typical in the atmosphere and illustrate the complex nature of particulate matter formation in smog. The equilibrium constants for such reactions are non-linear functions of concentrations, and include activity coefficients, and terms needed for nonideal concentrations.

From these considerations, it is clear that the impact of NH_3 on particle formation will be highly dependent on:

- Location in space - (the proximity to primary emissions of NH_3 and other precursors) and transport time (determines the time for oxidation and other chemical reactions)
- Local meteorology - the equilibrium constants are dependent upon relative humidity and temperature

If the understanding of the chemical processes is based only on a limited number of meteorological conditions, then predictions may be inaccurate.

The current understanding of how ammonia containing particles form in the atmosphere are biased by uncertainties related to:

(a) The behaviour of gases at low temperature with an effect on inorganic particle formation:

- The dependence of K constants upon temperature are estimated theoretically, but have not been confirmed experimentally in the laboratory;
- The amount of water in the particles is estimated from measurements at 25°C (ZSR relationship). Water content at other temperatures and how it is affected by temperature change has not been determined in the laboratory;
- States of particles (e.g. do particles freeze? If yes, what is the effect on the composition of the particles?) Some inorganic impurities could be emitted;

- The assumptions made at 25ºC about the components that are present are almost certainly not correct at other temperatures.

(b) Mass exchange between particles of differing compositions and sizes:

- Exchange between gaseous components – Will gas leave particles of one size and be adsorbed into particles of another size? Is it possible to model such exchanges or reactions and to verify them in the laboratory?

(c) Relationship to organics:

- Many secondary organic aerosol compounds resulting from gas-phase oxidation of a volatile organic compound precursor, are at least weakly polar, and may dissociate and react with inorganic particle components. Knowledge about these reactions is very limited;
- Some organic compounds contain molecular groups that may function in a manner similar to ammonia, e.g. amines. Very preliminary laboratory evidence suggests that these compounds may have a significant ability to form aerosols, due to their ammonia-like properties. If verified at a large scale, this would have an impact on the understanding of the role of ammonia in the atmosphere.

SHAO-MENG LI provided additional information on atmospheric chemistry from an intensive air quality study conducted in 2001 in the Lower Fraser River Valley. There were several scientific objectives in the study:

- To characterize the chemical and physical properties of the fine particulate matter in the smog
- To determine the horizontal and vertical distribution of fine particulate matter and ozone in smog in the area under study
- To characterize the transition zone between emissions and the particulate matter formation zone
- To study the fractions of fine particulate matter in road dust
- To elucidate the processes in SOA and O_3 formation as well as the relative role of biogenic vs. anthropogenic emissions for SOA and O_3.

The objectives were designed to identify the significance of NH_3 to fine particulate matter formation and determine its sources in the Lower Fraser River Valley. In addition, the study aimed to understand the NH_3, sulphur or nitrogen limitations with respect to SOA formation, the effect of NH_3 reductions on visibility, and how increases in particle acidity affect formation processes. In order to achieve the objectives, the following measurements were made at five air quality-monitoring sites:

(a) Ground measurements:

- *Gaseous measurements:* NO_x/NO_y, O_3, VOCs, OVOCs, SO_2, CO, NH_3
- *Chemical characterization of particles:* identification of inorganic and organic species, OC/BC, size distribution of some constituents, S- and C-isotopes, metals, aerosol mass spectrometric measurements
- *Physical characterization of the particles:* total mass, total condensation nuclei, mass and number size distribution, and absorption

(b) Meteorological measurements:

- *Meteorological measurements:* tethered balloons, and LIDAR remote sensing provided horizontal and vertical distribution of aerosol backscattering in the Lower Fraser Valley.

Measurement techniques including WEDD, tunable diode laser (TDL), denuder tube, MOUDI, and AMS determined:

- The spatial-temporal variability of NH_3 at the study sites
- That the relationship between the hourly mean NH_3 concentration and relative humidity and temperature was not significant
- Measurements at sites such as the Burnaby South High School where the average monthly NH_3 concentrations for the year 2000 and 2001 ranged between 0.2 and 2.3 ppb.

The author investigated the phase partitioning between NO_3 and NH_4 at one site, as well as the temporal variation of NH_4 concentrations as a function of particle diameter. Generally, large diameter particles had a smaller concentration of NH_4. There were considerable differences in the content of organics, sulfate, nitrate and ammonium in the samples from three different sites. NH_4 amounted to between 11% and 31% in the particles.

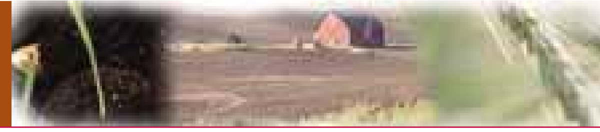
The study found high levels of NH_3 in the Lower Fraser River Valley with $NH_{3(g)}$ generally in excess of particle-gas equilibrium, regardless of the particulate composition. Therefore, NH_3 is not a limiting factor in terms of particulate matter formation in the area. It is therefore reasonable to assume that particulate ammonium has significant implications for visibility impairment in this region.

ROBERT VET presented an overview of atmospheric ammonia and ammonium, and NH_3 emissions in Canada. He presented results from measurements made at 7 sites across Canada for the years 1991-1997. Although data was not collected for the same time period at all sites, a trend of decreasing average atmospheric concentrations was found from west (Abbotsford) to east (Kejimkujik). Concentrations ranged between 0.01 and 50 $\mu g/m^3$. NH_3 concentrations vary considerably from day-to-day and are generally higher in the summer than the winter. A more detailed comparison of concentrations over the period February 2001 - October 2002 showed values about 100 times higher in southwestern Ontario than in Nova Scotia. Measurements made in schoolyards in downtown Toronto ranged between 0.5 and 8 $\mu g/m^3$ in August 2000. Values in a residential area of Vancouver were lower, less than 2.5 $\mu g/m^3$, in August 2001. Since data was not obtained during the same calendar year, it is difficult to draw conclusions, as other conditions may have been different.

The composition of $PM_{2.5}$ across Canada is variable in both time and space. Particles moving over areas with higher ammonia emissions pick up additional mass in the form of ammonium. Ammonium is a measurable fraction of the fine particle mass across Canada (10-20%). The presence of sulphur and nitrogen compounds is required for the formation of particulate ammonium. A reduction in NH_3 concentrations in ambient air will lead to a decrease in fine particle mass, particularly in winter. Nitrate and sulfate concentrations are location and season dependent.

Information about NH_3 is still very limited. To date, the following is known about the spatial distribution of ammonia:

- Ammonia emissions and wet deposition of ammonium are more important in agricultural areas;
- There is little information available about the large-scale spatial pattern of ambient NH_3 (*Figure 1*) but it is expected to roughly mimic the pattern of ammonia emissions;



- There is strong evidence that p-NH_4^+ is transported from the ammonia-rich areas of the U.S. into Canada;
- There is a need to improve data on emissions and deposition.

3.2 Emissions inventory and available models

SUSAN CHARLES presented an overview of the 1995 National Emissions Inventory of atmospheric ammonia, compiled by the Criteria Air Contaminant (CAC) Division of the Pollution Data Branch. It provides a summary of emission estimates of ammonia and is broken down by major pollution sources at the national, provincial and territorial levels. This report fulfills one of Canada's commitments under the Canada-US Air Quality Agreement. Inventories of total particulate matter, PM_{10} and $PM_{2.5}$ are included. The report presents emission information for 5000 facilities as well as mobile and open source emissions.

Sources of ammonia (*Figure 2*) captured (18 kt) represent only 3% of the ammonia inventory (553 kt). Emissions occur mainly in the Quebec-Windsor corridor, southern Manitoba and the Edmonton-Calgary corridor.

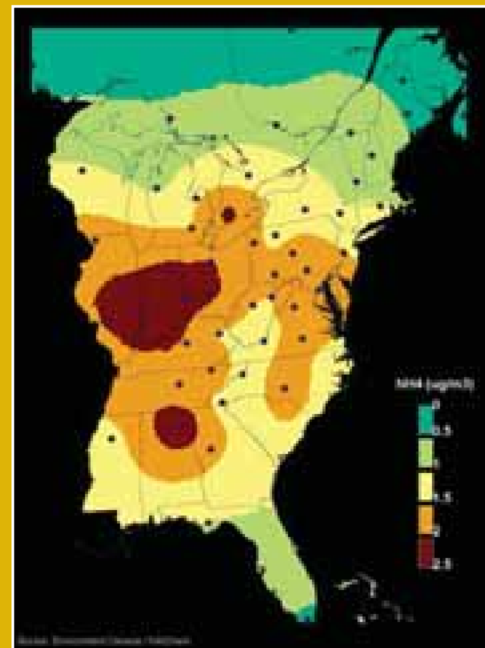


Figure 1: NH_4^+ concentrations across Eastern North America – 1997-98 average.

For the livestock sector, emission estimates were calculated from the numbers of animals and emission factors specific to animal husbandry (grazing, housing, storage, manure etc.) using the UK inventory and Canadian manure management practices. For the crop production sector, emissions were estimated from the amounts of fertilizers sold in each province and a volatilization percentage.

There is a large uncertainty linked to these estimates (on average ± 25% accurate). Estimates are an annual average, not seasonal, adding to the uncertainty. Future plans include a more accurate determination of emissions from feedlots and higher precision on emission estimates.

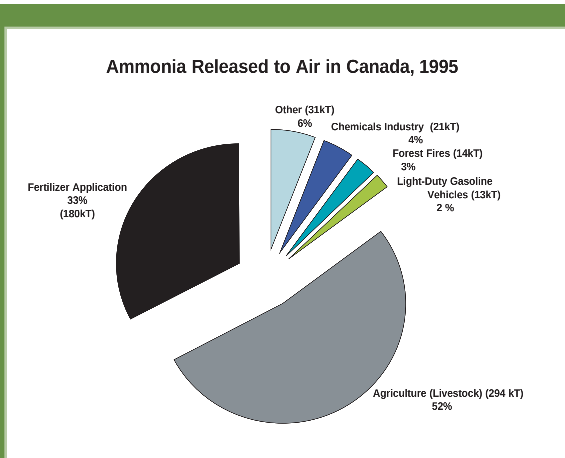


Figure 2: Canadian atmospheric ammonia sources in 1995.

MIKE MORAN addressed emissions processing for air quality models. Regional air quality models are based upon information related to the nature of atmospheric pollutants, and the processes taking place in the atmosphere.

a) Current regional air quality issues in Canada are:

- Acid deposition: SO_x, NO_x, NH_3
- Ground-level ozone: NO_x, VOCs
- Particulate matter: SO_x, NO_x, VOCs, NH_3
- Air toxics: Hg, Pb, Cd, As, POPs

b) Air quality models include calculations for emissions, dispersion, transport, atmospheric transformation, and dry and wet deposition. The development of models requires the following information:

- Spatially-, temporally-, and chemically-resolved emissions
  - Gridded surface (area) emissions
  - Elevated sources
  - Time resolution
  - Speciation
  - Size-resolution
- Source types (anthropogenic, biogenic, geogenic)
- Geographical coverage (Canada, U.S.A., Mexico)
- Meteorological data

The Canadian Emissions Processing System converts the annual emissions of CAC species reported for political jurisdictions in the Canadian and U.S. national emission inventories into a set of gridded, speciated, time-varying, and air quality-model-useable emissions files. It can also model emissions from some source types as influenced by meteorological conditions (e.g. biogenic and onroad mobile sources).

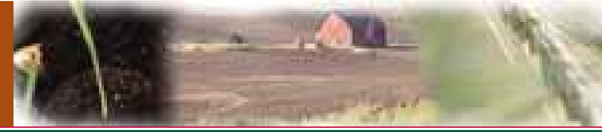
Source category codes are then assigned to processes and activities of concern:

- Agriculture, 34 source category codes describe processes and activities in crop and animal production.
- Temporal (79 temporal profiles)
- Spatial (15 spatial allocation factors on a 20 x 20 km grid showing population, number of households, fraction of province area)
- 12 land-use categories to disaggregate all agricultural emissions
- Disaggregation factors – to develop maps of anthropogenic NH_3 emissions that display various types of emissions with their spatial distribution.

The NH_3 emissions (tonnes) by major source sector were as follows for Canada and the US:

SOURCE TYPE/ COUNTRY	ANIMAL HUSBANDRY	FERTILIZER APPLICATION	OTHER	TOTAL
Canada	295	180	79	554
U.S.	3109	500	623	4232
Total	**3404**	**680**	**702**	**4786**

These emissions were mostly consistant throughout the year. *Figure 3* illustrates that the spatial distribution of NH_3 emissions is very different from other "criteria" pollutants. The relative contribution of fertilizer is more important in Canada than in the U.S.



The estimation of monthly variations of NH_3 emissions by the Emission Processing Systems requires improvement, especially for temporal profiles linked to geographic location, and in accounting for temperature dependence.

SEAN McGINN presented information on emissions from the agri-food sector, and discussed the methodology used to reduce emissions. He communicated new approaches being undertaken by Agriculture and Agri-Food Canada (AAFC) and how AAFC's new structure is expected to facilitate further interdepartmental co-operation.

One of the themes of the Environmental Health National Program is air quality, which includes air contaminants, in particular, reducing the exchanges of airborne contaminants (ammonia, odour, particulate matter) between the farming system and the atmosphere.

Gaseous ammonia research is presently conducted at 7 sites: Agassiz, Lethbridge, Brandon, Ottawa, Lennoxville, Sainte-Foy, and Charlottetown. Research projects address fertilizer (urea and other inorganic fertilizers) and animal (dairy, hog, and feedlots) production, feed, housing, odours, and manure storage and use.

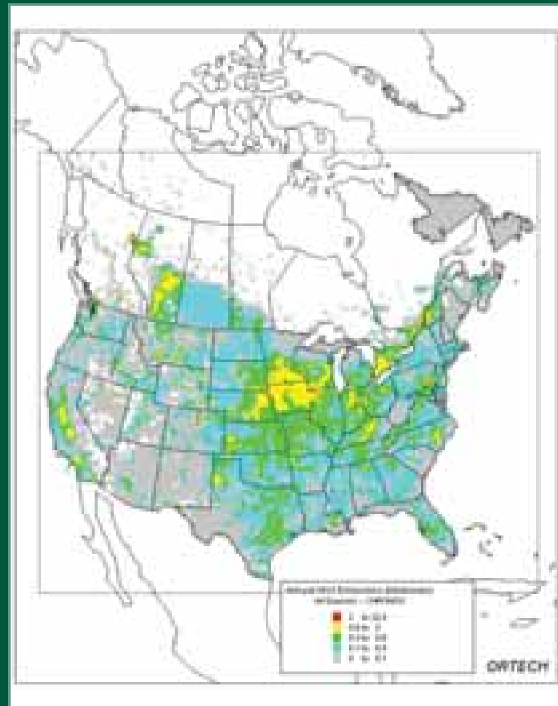


Figure 3 : 1990 North American anthropogenic NH_3 emissions

Manure:

- Preference would be to use it as a source of nutrients
- Regulations limit the period for land application - manure has to be stored for several months before use, creating problems
- Research covers barn manure management and application techniques. For example, ammonia losses were evaluated for several application techniques, e.g. broad banding (with 50% loss NH_4^+), surface banding with no aeration, banding with aeration (25% loss). Work was also performed on N balance and ammonia emissions from livestock slurry as a function of different operating systems.

Fertilizer:

- Urea is largely used in Canada because it releases N more slowly. However, it is prone to release ammonia
- Agrotain is a urease inhibitor that, through binding to urease enzyme, slows the conversion of urea to NH_3. Although its effect dissipates within 5-14 days, it increases the window in which rain events can act to increase urea infiltration into the soil
- In Charlottetown, work was done on urea and ammonium nitrate application on forages with an assessment of losses through volatilization. The relationship between soil aeration and ammonia volatilization was also investigated.

Animal production (barns and feedlots):

- Work is carried out on odour emissions, adsorption/desorption from wells, and on NH_3 deposition from feedlots.
- Research addresses
  - manure management, including the use of additives to limit ammonia emissions
  - NH_3 volatilization and soil nitrogen dynamics following fall application of pig slurry on canola crop residues
  - The focus of NH_3 research at AAFC is on odour nuisance, conservation of nitrogen, and environmental impacts, but there is no activity on emissions inventory or air quality modelling.

3.3 Development of indicators

SHABTAI BITMANN discussed the development of an ammonia indicator among the agri-environmental indicators project. The general objectives of the indicator project are to:

- Inform decision makers on environmental performance to guide their responses
- Demonstrate the progress of the agri-food sector towards sustainability
- Support the strategies targeted at areas posing environmental risk

Potential indicators would be sensitive to farm management practices, changes in land use/land use management, and changes in technology. Also, they would reflect the state of the agricultural sector, and the risk for particulate formation in sensitive airsheds.

In order to develop a useful NH_3 indicator, there is a need for:

- Emission sources inventory (Census Canada 2001, Farm Environmental Management Survey 2002 (FEMS), but there is a need for validation by provincial and industry experts)
- Emission factors (adapt the emission factors from other regions and or other countries for Canada, considering the diversified environment and activities, such as wide ranging and generally cold climate, short growing season, freeze/thaw, range in moisture, animal confinement; no housing for beef industry)

Ammonia sources from the agri-food sector include fertilizers (urea and anhydrous ammonia), manure spreading, grazing (mainly cow-calves), feedlots, swine, poultry layers and broilers, manure processing, and possibly other residues on farmland.

The NH_3 indicator will help in identifying high-risk environmental conditions (with a detailed assessment of ammonia emissions) and appropriate risk reduction measures.

3.4 Presentations from international colleagues

WILLEM ASMAN, from the Danish Institute of Agricultural Sciences, discussed sources and emissions, transport and dry and wet deposition. Agricultural emissions are the major sources of ammonia, but emissions data are scattered. Because emissions are close to the ground, and partly influenced by meteorological conditions, they are not easy to measure. Furthermore, all ammonium in the atmosphere originated from ammonia, i.e. there are not primary particulate ammonium emissions.

The reaction between NH_3 and atmospheric acids (HCl, H_2SO_4, HNO_3) results in particulate matter formation. In contrast to other types of particles, ammonium chloride particles are susceptible to evaporation depending upon temperature, humidity and concentration conditions. The dry deposition rate of these particles is rather high: uptake by plants takes place through deposition on wet leaves. Dry deposition velocity depends on particle size, wind speed, atmospheric stability, humidity and surface wetness. Dry deposition of ammonia is high (about 20% within 500m from the source) and fast close to sources, because the source height is low and the plume is not diluted. Once NH_3 is vertically diluted (no large vertical gradient), removal rate is of the order of 1% h^{-1}. A high vertical resolution is needed to model dry deposition of NH_3 close to sources. Deposition velocity depends also on the "roughness" of the vegetation, i.e. forest > wheat > grass. Once NH_3 is converted to NH_4^+ it can travel over long distances: only removal by precipitation is efficient.

Wet deposition takes place in the form of ammonium as clouds and raindrops. Models are essential to calculate the contributions of different processes to the ammonium concentration in the precipitation. Most ammonium in precipitation originates from in-cloud scavenging of ammonium particles, and the process is fast (in the order of 75% h^{-1}).

A model for deposition requires high spatial resolution (>1x1 km^2) in areas with high ammonia emission densities to adequately model the large horizontal gradients. A model for particle formation does not require high resolution, but an accurate model of dry deposition of ammonia near the source is still needed.

NH_3 emission inventories are used in atmospheric transport models (on a regular grid and with temporal variations), and for policy development (abatement measures). A high spatial resolution is required only in areas with high emission density. Emission factors are defined as emission/animal/year, and per kg of fertilizer applied/year. They vary with manure handling systems and give only an annual average emission, not the emission as a function of time.

NH_3 emissions from housing depend upon the housing system and management practices, and animal behaviour. NH_3 emission during storage depends upon the type of storage, the type of cover and wind speed. It is generally small during manure application. However, following application, it depends upon meteorological conditions (solar radiation, temperature, wind speed, humidity, precipitation), dilution factor (this ensures less emission), soil properties (pH, calcium content, cation exchange capacity, water content, buffer capacity, porosity etc.), amount applied per ha, application method, time elapsed between application and incorporation into the soil.

NH_3 emissions from fertilizers depend on the same factors as for manure but also on the chemical composition of the fertilizer (loss from urea > other types).

Measurements of NH_3 emissions are usually made for different steps (housing, storage, application, grazing etc.), not on a total per farm basis. Therefore, information from different studies must be combined to calculate global emissions. Calculating emissions from different steps may result in overestimates of NH_3 emissions. Results could show more than 100% emission of ammoniacal nitrogen when combining independent experiments. A solution to this is to use the mass

balance method and express the amount of N emitted in % of N input for each step. Proceeding stepwise would allow for corrections to be made.

There are still many unknowns regarding emission processes. Temporal variations over the year are well modeled, but average annual values are used. Emissions can be generated as a function of time and space once the number of animals and other conditions are known. Annual variations in meteorological conditions make it difficult for decision-makers to have an accurate overall picture.

Global Emissions Inventory Activity (GEIA): The objective is to make an emission inventory that can be used in atmospheric chemistry and transport models. Emissions are calculated per animal/year, keeping track of the N-balance in each step, from feeding to excretion and manure utilization. Emissions in one step are influenced by the emissions from the previous step, so it is important to proceed stepwise. Conditions may vary from region to region. Much more is known for Europe than for developing countries. Besides animal emissions, other NH_3 sources must be considered:

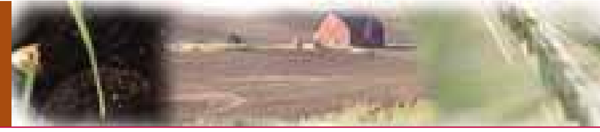
- Fertilizer: Emissions depend on chemical composition, crop type and temperature
- Agricultural crops: Emission due to high NH_3 concentration in plants, and is a function of growth stage and meteorological conditions
- Biomass burning: Deforestation, savanna burning, agricultural residues, and other biofuels
- Seas
- Other sources: Fossil fuel combustion, industry, human excrements, wild animals, and natural ecosystems

Overall, uncertainty for global emissions is at least 25%. NH_3 emissions (53.7×10^6 tonnes N yr^{-1}) are of the same order of magnitude as other N oxide emissions (41.8×10^6 tonnes yr^{-1}) but a larger fraction of ammonia comes from anthropogenic sources.

LOWRY HARPER, from the U.S. Department of Agriculture, discussed the measurements of NH_3 emissions. He summarized properties of ammonia: 1) most abundant alkaline constituent in the atmosphere; 2) it is highly soluble and reactive; 3) neutralizes acid gases and; 4) it is a precursor to particulate matter.

Among the anthropogenic sources, agriculture is the largest source of NH_3. Natural sources amount to about a third. NH_3 up to 50 ppm, has various negative effects on humans and beyond 50 ppm, it can be dangerous, even lethal. At concentrations of 25 ppm, it can have negative effects on animal performance (weight-gain/loss, reduced resistance to infections and eye damage).

Several methods are available to measure NH_3, including chambers, wind tunnels (verification difficulties with some techniques), micrometeorological methods (eddy covariance, gradient techniques, mass balance techniques), Lagrangian methods (inversion dispersion analysis), other micrometeorological methods (relaxed eddy accumulation, gaussian plume/puff dispersion), isotopes and other tracer techniques (nutrient isotopes, tracer gases). These techniques were evaluated and results suggest discrepancies between methods, pointing to potential inadequacies of current technologies.



Instruments were evaluated: generally insufficient sensitivity, equipment may be expensive and procedures labor-intensive. There is a need for economically feasible and easy-to-use instruments. Examples were given for ammonia measurements under forced and natural ventilation. There is a need for instruments for integrated and long-term research projects.

DAVID CHADWICK, from the United Kingdom's Institute of Grassland and Environmental Research, discussed the issue of animal production in buildings. In the United Kingdom, the major sources of NH_3 are the land spreading of manure and emissions from barns, which account for more than 30%, followed by fertilizer and hard-standing, accounting for about 10%. Cattle contribute to 57% of the emissions and are the largest source of NH_3. Absorption flasks and passive samplers were used to determine the impact of housing on NH_3 emissions. The key findings were:

- Liquid manure releases more NH_3 than solid manure
- Increasing the amount of straw for bedding use reduces the NH_3 emissions from animal houses
- There is an increase in ammonia emissions when animals stay longer in the buildings; therefore, reducing the time cattle spend in buildings will likely lead to a reduction of NH_3 emissions, but the reduction may not be proportional to the decrease in housing period since cattle also produce NH_3 in the pastures.
- Emission factors were determined for different housing systems and management practices:
    - Hosing and scraping manure reduces emissions from hard standing
    - Slurry: emissions increase linearly with time until there is crust formation
    - Farmyard manure: most of the emissions occur soon after the heap is established

Ammonia abatement options exist for slurry storage systems and lagoons at the farm-scale, e.g. by covering storage tanks and manure heaps, or using material forming a crust.

SVEN SOMMER, from the Department of Agricultural Engineering Research Centre in Bygholm, Denmark, discussed NH_3 from livestock manure and available abatement techniques. NH_3 emissions are not only related to environmental problems (i.e. eutrophication), but they also reduce the value of livestock manure for crop nutrients. In Denmark, 80% of the NH_3 emissions originate from animal production and 8% from mineral fertilizers. Since the 1980's, a reduction in the use of fertilizers has led to a decrease of NH_3 emissions.

- Several techniques for reducing ammonia emissions during manure application were assessed, using the splash plate application as a reference
- Splash plate: on crops and soil, wide coverage, reduced "infiltration" in the experiment, 17% of the total applied N was lost as NH_3
- Trail hose application: manure is applied on the soil below crop canopy. NH_3 is taken up by the crop (up to 25% of emitted NH_3), infiltration in the soil is improved
- Surface application and incorporation: reduces the width of application
- Injection: infiltration is improved, and there is better contact with the soil
- Change slurry characteristic: decreasing pH will shift the equilibrium of NH_4/NH_3 to NH_4 but large amounts of acid are needed
- Timing: during the night, there is less wind, less turbulence and the temperature is lower, all these factors reduce NH_3 emissions

4.0 ISSUES AND CONCERNS FOR SCIENTIFIC RESEARCH

During the second day of the "Science of Agriculturally Produced Ammonia Workshop", the participants were divided into four groups with representatives from each of AAFC, EC-MSC and EC-EPS, as well as an international scientist, in order to facilitate discussion on issues related to gaseous ammonia. These issues were divided into four sub-categories: emissions, modelling, atmospheric processes and monitoring and policy/economics. The list of abbreviated questions considered by the groups and a summary of the responses received are outlined below. The complete set of questions is attached in *Appendix A*.

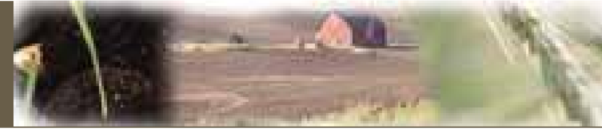
4.1 Emissions

Do we know how much NH_3 is released from various agricultural systems and their relative significance with respect to other sources?

- There are some significant information gaps with respect to the relative importance of emissions and data completeness. It would be highly beneficial to determine the areas most at risk for impacts on human health, crop health, nutrient cycling and visibility, then determine the practices that could be changed based on a cost-benefit analysis.
- There are different knowledge levels depending on the aspect of the system, whether it be livestock buildings, manure storage, or land application of manure/fertilizer.
- Background levels (both natural and ambient) of ammonia are needed to identify emissions hot spots across the country.
- Nitrogen balance is needed on facility measurements to validate emission rates. Currently, European emission factors are used and applied to Canadian data, however there needs to be validation that this strategy is sufficient as well as identification of where these emission factors can be improved.

Do we know how to reduce NH_3 emissions from these sources? Do we know how to implement abatement practices?

- There is little information on the impact of management practices on ammonia emissions (i.e. dietary differences)
- Mitigation strategies that have been applied elsewhere (i.e. Europe) should be evaluated for the Canadian situation (both economical and practical considerations) before they are implemented. In addition, other source sectors should be considered (i.e. transportation) as abatement techniques will more than likely differ between sectors.
- Implementation is also region specific and requires collaboration between the regulators and implementors.



4.2 Modelling

Do we know enough about the fate of NH_3 to understand the scale of influence of NH_3 source emissions? And as a result, are we able to build reliable models?

- There are modelling efforts underway that capture ammonia, however while the chemistry of the summer season is relatively well understood, the chemistry of ammonia during the winter needs to be refined, as does regional and seasonal variability in ammonia behaviour.
- Long and short-range transport of ammonia is also reasonably well known.
- Chemistry of the atmosphere/soil interface is not well understood, and will require another set of modelling activities.
- A significant question is: how effective will abatement practices be in reducing particulate production and what is the relative cost-effectiveness across the country? Where will abatement have the biggest impact?
- We do not currently have the capability to link air quality models to agricultural systems.

Can we verify the reliability of models?

- The spatial and temporal resolution of emissions information needs to be improved, as well as the available data that can be used for air quality model validation (long-term routine as well as short-term intensive). The methodologies used for verification also need work.
- Ammonia sources and sinks can be verified with available technology (flux measurements), but overall, expanded monitoring networks may be required for accurate model validation.

Can we generate national inventories that reliably reflect farm practices nation-wide?

- Current emission factors may not accurately reflect actual farm practices; there is a need for substantial data collection to develop a more exact inventory. The most uncertain emissions database is that for animal housing systems, feeding practices and animal distribution.
- Emissions again can be quite different between Canada and Europe as a result of many factors; the applicability of these emission factors in Canada should be tested and verified.

4.3 Atmospheric Processes and Monitoring

Do we know enough about how NH_3 impacts ambient PM formation and how NH_3 reduction scenarios may impact aerosol and precipitation acidities across the country?

- We do have significant knowledge on the formation of PM and where there are knowledge gaps, good ideas exist on how to fill in the gaps. The most uncertain processes appear to be in seasonal trends and ammonia behaviour in sub-zero temperatures.
- It is difficult to say how NH_3 reduction scenarios will affect acidity since the emissions inventory and ambient monitoring data is relatively weak in comparison to the air quality models.
- Dry deposition of NH_3 is less well developed and requires work.

Is there adequate monitoring in place to effectively measure NH_3 and determine the impact of risk management measures on NH_3 levels in specific regions of the country?

- There is a high degree of spatial variability in the monitoring network such that fixed stations may not be the best approach. Stations will need to be near sources as well as downwind in order to evaluate long range effects (i.e. sulphate vs. nitrate limited); may need a re-evaluation of network design principles.
- Monitoring should be scale-dependent in order to measure the major gradients in concentration, including an emphasis on populated areas in order to understand exposure. The vertical as well as horizontal gradient could be important.
- Building on improved emissions inventory data in the future may help to guide monitoring network decisions. In addition, the impact of local-scale versus long-range transport of ammonia may direct the monitoring site specifics.

4.4 Policy and Economics

What are the health impacts of ammonia emissions?

- Particulate ammonium is a more significant health issue as a result of PM – we are fairly sure of the effects of gaseous ammonia, but we do not have quantitative information on the health effects of particulate ammonium.
- Direct health research can be considered to be slightly outside of the mandates of both EC and AAFC, however this work should be kept on the radar in order to influence long-term research decisions; (requires linkages with Health Canada)

What are the off-site environmental effects of NH_3 emissions?

- Acid gases play an important role in off-site effects, as does the eutrophication of water bodies, biodiversity, greenhouse gas emissions, effects on both vegetation and visibility.

What are the economic costs (or benefits) of abatement techniques?

- There has really been no research on the economics of NH_3 abatement, thus there is a large knowledge gap here, particularly with respect to benefits.

4.5 Prioritization of Potential Research Projects

This section discusses areas where additional research has been identified as a requirement to more completely answer the science questions posed at the March workshop. Research into atmospheric ammonia will require long-term attention in order to understand the extent of the problem and to address it appropriately. In the meantime, there are several research priorities that are considered by scientists to support the immediate action required on the policy side. These priorities include research on the emissions inventory, atmospheric processes and monitoring, modelling and policy/economic considerations. Short-term and long-term research priorities are listed with the exception of atmospheric modelling, where the research goals are expected to take a significantly longer time frame.

1. Emissions Inventory

Ammonia emissions are related essentially to the use and transformation of N-containing substances; therefore, the agriculture sector is identified as a major source of NH_3 emissions. Once a better understanding of NH_3 as a precursor to PM is obtained with specific focus on the agri-food sector, the next logical step will be to extrapolate the information to any additional sources of ammonia. It is well recognized that information on emissions is available from several countries, but there is a need to validate the findings for Canadian climatic conditions.

In the short-term (< 3 years):

- derive emissions factors for each farm practice and activity as well as animal populations
- identify areas that may result in practices that change NH_3 emissions
- joint research projects on N life cycle and mass balance
- scoping paper to compare existing foreign emissions inventories to Canadian procedures
- emissions from cropping systems in comparison to European systems

In the longer-term (3-10 years):

- understand the relative importance of other NH_3 sources (i.e. transportation)
- determine the potential changes in NH_3 emissions and the effects on air quality
- study ways to improve the efficiency of nitrogen fertilizers to reduce emissions of NH_3 and greenhouse gases
- concentrated research into areas identified through the initial scoping study
- integrated studies to look at whole picture, not just the sum of the parts

2. Atmospheric Processes and Monitoring

When N-containing pollutants are released, they interact with other atmospheric components. Such reactions are responsible for the transport, transformation and production of particulate matter. The occurrence, extent and distribution of PM in space and time are beginning to be more thoroughly understood in Canada. It is essential to determine both emissions and ambient 'hot spots' to provide support to policy-makers.

In the short-term (< 3 years):

- more monitoring in a strategic fashion with consideration of upwind sources
- assessment of impact of seasonality and temperature on potential ammonia impacts on PM formation
- improve ammonia monitoring network (location and number of sites)
- PM speciation monitoring to understand the impacts of NH_3 emissions on PM composition in 'hot spots' and surrounding areas; also important to monitor co-pollutants and their interactions with NH_3 emissions
- would like to understand the role of NH_3 as a precursor to N_2O
- research into the climate effects of NH_3 to PM conversion in the atmosphere
- relationship to visibility: how does NH_4 composition in PM relate to changes in visibility
- how is NH_3 incorporated into clouds and/or precipitation?
- how do reductions in other precursor gas emissions (NO_x, SO_x) interact with reductions in NH_3 emissions in the atmosphere

In the longer-term (3-10 years):

- understand the relative gains in reducing NH_3 emissions to reduced PM levels as compared to reducing other emissions (i.e. primary PM)
- understand transboundary transport
- need to understand deposition rates to correctly model air quality and to understand changes in biodiversity

3. Policy and Economics

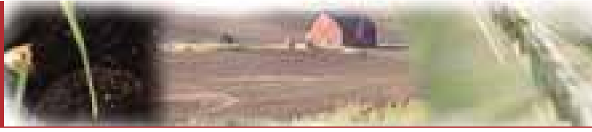
The lack of scientific information regarding the extent of emissions, reactions and distribution of ammonia and PM in the atmosphere limits the extent to which scientists are able to support policy elements. Making a link between economics and ecosystem management will contribute to the development of better management practices.

In the short-term (< 3 years):

- education and communication programs should be developed

In the longer-term (3-10 years):

- Promote the use of environmental farm planning and promote the use of beneficial management practices targeted at reducing agricultural risks and providing benefits to the health of air and the atmosphere, particularly in areas where air quality has been identified as an issue.
- Develop beneficial management practices targeted at reducing air emissions from agricultural sources including particulate matter, and gaseous ammonia.
- Develop and use agri-environmental indicators to monitor the performance of the agriculture sector in environmental stewardship in the area of air emissions.
- Develop measures to allow the agricultural sector to obtain recognition and market benefits for environmental stewardship efforts, including an environmental certification program.



5.0 CONCLUSIONS AND RECOMMENDATIONS

The Workshop on Agriculturally Produced Gas-Phase Ammonia addressed CEPA risk management requirements and Canada-wide Standards regarding gaseous ammonia and PM. The need to better understand ammonia emissions and the processes and transformation in the atmosphere to form particulate matter was highlighted. International co-operation and networking of colleagues at the Workshop on Agriculturally Produced Gas-Phase Ammonia provided useful knowledge sharing opportunities and built the potential for future relationships. Collaborative work between EC and AAFC will continue and support a coordinated federal approach to addressing emissions from agriculture. EC and AAFC are committed to working with stakeholders on the risk management of gaseous ammonia.

The most important next step is to expand this discussion to other levels of government (provincial and municipal), academia and stakeholders to provide a well-balanced and scientifically sound process. It is important that all interested stakeholders be engaged early in the process to help guide effective science-based risk management of gaseous ammonia that will be beneficial to stakeholders and Canadians.

APPENDIX A

ISSUES	STATUS (1-5, OR OM)*	RESEARCH NEEDED TO ADDRESS ISSUES (INCLUDING POSSIBLE DESIGN, RESOURCES, EXPERTISE, LOCATIONS)	
		SHORT TERM (<3 YEARS)	MEDIUM/LONG TERM (3-10 YEARS)
1. Emissions: • Do we know how much NH_3 is released from various agricultural systems (livestock buildings, manure storage, land application of manure, land application of fertilizer) and their significance with respect to other sources? • Do we know how to reduce NH_3 emissions from these sources? • Do we know how to implement abatement practices?		1. 2. 3.	1. 2. 3.
2. Modelling: • Do we know enough about the fate of NH_3 (various processes related to transport and deposition) to understand the scale of influence of NH_3 source emissions (e.g., local, regional and/or long-range transport)? • Do we know enough to build reliable models and appropriate emissions inputs that predict NH_3 emissions and abatement potential? • Can we verify the reliability of models (e.g., using atmospheric measurements)? • Can we generate national inventories that reliably reflect farm practices, nation-wide?		1. 2. 3.	1. 2. 3.
3. Atmospheric Processes and Monitoring: • Do we know enough about how NH_3 impacts ambient PM formation (e.g. particle growth, particle mass and its interrelationship with other PM precursors) and how NH_3 reduction scenarios may impact aerosol and precipitation acidities across the country? • Is there adequate monitoring in place to effectively measure NH_3 and determine the impact of risk management measures on NH_3 levels (and PM formation) in specific regions of the country?		1. 2. 3.	1. 2. 3.
4. Policy and Economic: • What are the health impacts of ammonia emissions? • What are the off-site environmental effects of NH_3 emissions? • What are the economic costs (or benefits) of abatement techniques?		1. 2. 3.	1. 2. 3.

* 1 = we know so little that this objective is not achievable, even with extensive further research; 5 = we know so much that no further research is necessary; OM = outside our mandate

APPENDIX B

GASEOUS AMMONIA SCIENCE WORKSHOP
MARCH 3-4, 2003 • DOWNSVIEW, ONTARIO
LIST OF PARTICIPANTS

ENVIRONMENT CANADA

NAME	LOCATION
Keith Puckett	MSC-Downsview
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Dave MacTavish	MSC-Downsview
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Cristian Mihele	MSC-Downsview
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Jason O'Brien	MSC-Downsview
All Wiebe	MSC-Downsview
Chul-Un Ro	MSC-Downsview
Kurt Anlauf	MSC-Downsview
Amy Leithead	MSC-Downsview
Katherine Hayden	MSC-Downsview
Jan Bottenheim	MSC-Downsview
Maris Lusis	MSC-Downsview
Fred Conway	MSC-Downsview
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Heather Morrison	MSC-Downsview
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Cindy Grant	Brandon
Henry Janzen	Lethbridge
Karen Koenig	Lethbridge
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INTERNATIONAL

NAME	LOCATION
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Lowry Harper	USDA
Sven Sommer	Dept. of Agricultural Engineering, Research Centre Bygholm, Denmark
David Chadwick	Institute of Grassland and Environmental Research, UK

APPENDIX B (Cont...) EC and AAFC Ammonia-Related Work

ELEMENT	PROJECT	STATUS
Knowledge and information:	Priority Substances List (PSL) Assessment Report: Respirable Particulate Matter Less Than or Equal to 10 Microns, Environment Canada, Health Canada	**Completed** (2000)
Process understanding (emissions, chemistry, dispersion and transport, deposition)	National Ambient Air Quality Objectives for Particulate Matter: Science Assessment Document (SAD), Health Canada, Environment Canada Precursor Contributions to Ambient Fine Particulate Matter in Canada, A Report by the Meteorological Service of Canada (MSC), Environment Canada Nutrients and their Impact on the Canadian Environment, Government of Canada, January 2001	**Completed** (1999) **Completed** (2001) **Completed** (2001)
Modeling & Inventories	Regional Visibility Experimental Assessment (REVEAL) REVEAL II Lower Fraser Valley Ammonia Study Georgia Basin Ecosystem Initiative Pacific 2001 Ammonia Released to Air in Canada from All Sources, 1995, Pollution Data Branch, Environment Canada Environment Canada Atmospheric Ammonia Inventories 1999 Ammonia Emission Inventory in the Lower Fraser Valley National Pollutant Release Inventory	**Completed** (1993) **Completed** (1994) **Completed** (1997) **On-Going** **Completed** (2003) **Completed** (2001) **Completed** (1980, 1993, 1995) **Completed** (1999) **On-going**
Performance measurement: Monitoring, indicators	Canadian Air and Precipitation Monitoring (CAPMoN) network data National Air Pollution Surveillance (NAPS) network Canadian Acid Aerosol Monitoring Program Guelph Aerosols and Visibility Monitoring Program Nutrient Levels in the Atmosphere of the Elk Creek Watershed Toxic Substances Research Initiative Nitrogen Scoping Study	**On-going** **On-going** **Completed** (1996) **Completed** **Completed** (2000) **Completed** (2001) **On-going**
Knowledge and information: Process understanding (emissions, chemistry, dispersion and transport, deposition)	Development of a prototype denuder-filter-REA conditional sampler to measure particulate and gas phase Development of field techniques to monitor ammonia emissions	**Pending** (Elizabeth Pattey) **Completed** (Sean McGinn) Reference: McGinn S. M. H. H. Janzen. 1998. *Ammonia sources in agriculture and their measurements.* Can. J. Soil Sci. **78:** 139-148.
Modeling & Inventories	PERD Study B Ammonia emissions from manure-amended soils	**Completed** (Sean McGinn) Reference: McGinn, S. M. and R. Pradhan. 1997. *Ammonia emissions from manure-amended soils.*

APPENDIX B (Cont...) EC and AAFC Ammonia-Related Work

ELEMENT	PROJECT	STATUS
	Measurement of ammonia emissions from intensive livestock facilities by open path tunable diode laser	*Final Report to Energy Research and Development Program.* Completed (Sean McGinn) Reference: Bertram, T. Flesch, S. M. McGinn, H., T. Coates, P Dzikowski and P. Llewellyn. 2001. *Measurement of ammonia emissions from intensive livestock facilities by open path tunable diode laser.* Final report to Alberta Environment. pp 62.
	Ammonia Volatilization and Soil Nitrogen Dynamics Following Fall Application of Pig Slurry on Canola Crop Residues	Completed (Philippe Rochette & al.) Reference: Rochette, P. M. H. Chantigny, D. A. Angers, N. Bertrand and D. Côté. 2001. *Ammonia Volatilization and Soil Nitrogen Dynamics Following Fall Application of Pig Slurry on Canola Crop Residues.* Can. J. Soil Sci. **81**: 515-523.
	Ammonia volatilization following application of raw and anaerobically digested pig slurry on a loamy soil	Completed (Martin Champigny & al.) Reference: Chantigny, M. H., P. Rochette, D. A. Angers, D. Massé and D. Côté. 2003. *Ammonia Volatilization and Selected Soil Characteristics Following Application of Anaerobically Digested Pig Slurry.* Submitted to Soil Sci. Soc. Am. J.
	Ammonia volatilization following application of various pig slurries on a loamy and a sandy soil cropped to timothy (Phleum pratense L.)	On going (Martin Champigny)

APPENDIX B (Cont...) EC and AAFC Ammonia-Related Work

ELEMENT	PROJECT	STATUS
	Agronomic and environmental fate of spring applied pig slurry 15N in a clay and a sandy soil cropped to maize	**Pending** (Martin Champigny)
	Measurement of ammonia level in a hog production facility with liquid and solid bedding systems	**Completed** (John MacLeod)
	Measurement of ammonia levels in liquid manure storage with and without manure additive treatments	**On-going** (Dan Hurnik and Allan Campbell)
	Ammonia deposition rates and its controlling factors to soil and surface water in an area with concentrated CLOs	**Completed** (Chi Chang & Xiying Hao)
	Mechanisms of NH_3 input to agro-ecosystems near livestock operations	**Pending** (Chi Chang & Xiying Hao)
Abatement strategies	Development of a scientific protocol for the evaluation of manure additives, including effect on ammonia emission level	**On-going** (Daniel Massé)
	CABIDF Study B Strategies for reducing odour of beef manure from feedlots and during land application	**Completed** (Sean McGinn) Reference: McGinn S. M. and H. H. Janzen. 1998. *Ammonia sources in agriculture and their measurements.* Can. J. Soil Sci. **78:** 139-148.
	Model Farm Project (2002-2006) : Mitigation of methane emissions related to livestock, including an ammonia component	**Completed** (Sean McGinn) Reference: McGinn, S. M. and R. Pradhan. 1997. *Ammonia emissions from manure-amended soils. Final Report to Energy Research and Development Program.* pp 29.
	Quantification of Greenhouse Gas and ammonia Emissions produced by a dairy cattle herd and recommendation of mitigation techniques	**On-going** (Daniel Massé)
	Evaluation of technologies to oxydise or capture methane, ammonia and other gas from livestock buildings and manure storages	**On-going** (Daniel Massé)
	New farrowing pen design adapted for high ambient temperatures	**On-going** (Daniel Massé)
	Effect of the Urease Inhibitor NBPT (n-(n-butyl)thiophosphoric triamide or Agrotain) on Volatile losses of Ammonia From Surface Applications of Urea or Urea Ammonium Nitrate	**Completed** (Cindy Grant & al.) References: Grant, C. A., Jia, S., Brown, K. R. and Bailey, L. D. 1996. *Volatile losses of NH_3 from*

APPENDIX B (Cont...) EC and AAFC Ammonia-Related Work

ELEMENT	PROJECT	STATUS
		surface applied urea and urea ammonium nitrate with and without the urease inhibitor NBPT. Can. J. Soil Sci. **76:** 417-419. Rawluk, C. D. L., Grant, C. A. and Racz, G. J. 2001. *Ammonia volatilization from soils fertilized with urea and varying rates of urease inhibitor NBPT.* Can. J. Soil Sci. **81:** 239-246. Rawluk, C. D. L., 2000. *Effect of soil texture, temperature and irrigation on the performance of urea fertilizers amended with the urease inhibitor n-(n-butyl thiosphoaric triamide).* MSc. Thesis. University of Manitoba. 127 pp.
Performance measurement	Innovative methods for reducing ammonia emissions from dairy manure applied on a grass sward	Completed (L. Van Vliet and S. Bittman)
Monitoring and Indicator	Development of a gaseous ammonia agro-indicator	On-going (Shabtai Bittman)

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Ackermann, I.J., Hass, H., Memmesheimer, M., Ziegenbein, C., and Ebel, A., *Parameterization of the sulfate-nitrate-ammonia aerosol system in the long-range transport model EURAD*, Meteorol. Atmos. Phys., **57**, 101-114, 1995.

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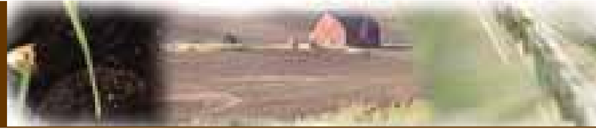

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