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ECTOS
Environmental Evaluation of Air Quality
Midterm report

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Introduction

The report at hand deals with the ambient air quality as it was at the onset of the hydrogen project "ECTOS".

The environmental monitoring and pollution modelling is a part of the Socio-Economic & Environmental study in the ECTOS project. A paper on ECTOS Methodology was presented in December 2002 [1]. In this paper it a method was proposed to evaluate the local air quality impact in the project. In this mid-term report the first findings are reported. Final results will be presented at the end of the ECTOS project in year 2005.

The aim of this work package is to evaluate the situation at the start of the hydrogen project and the change that might be expected by a shift to hydrogen vehicles.

The work package is divided in three categories;

- Stationary monitoring
- Pollution modelling
- Bus monitoring

The work conducted includes;

- Stationary air pollution measurements and extraction of data from public air pollution monitoring.
- Direct measurements in buses and comparison of the data with information in literature.
- Calculation for pollution modelling in Reykjavik, based on above and detailed information on traffic in Reykjavik

Air pollution and measurements

Air pollution is regarded as an important source of health problems both related to pollution and due to increasing greenhouse effects. A major part of the pollution is due to increasing traffic. Great resources are invested in research and technological development to reduce the environmental impact of traffic. In this chapter an overview is given over the most problematic results of traffic.

Urban atmosphere may be contaminated with hundreds of different pollutants. Several of these are monitored on a daily basis in all major cities. The traffic in the cities is a major source of air pollution. A number of measures have been taken to reduce urban traffic pollution, one of these being removal of lead in petrol. As a result has the threat of lead toxicity been considerably reduced in most cities. Another action is the introduction of catalysts, which has reduced the emissions of NO_x on a vehicle to a great extent but the increasing number of vehicles has outweighed this positive effect. Traffic emissions are of concern due to both health effects and local or global environmental effects. Environmental effects of traffic are mainly acid rain, greenhouse effect and visual effect.

Health effects

The major health concerns have been related to lung diseases, respiratory irritation and carcinogenic effect but if the earth keeps warming up the resulting problems on health and well being will become an increasing concern. [2, 3] Children, elderly people and individuals suffering from respiratory diseases and cardiovascular diseases are most sensitive to air pollution. The concentration of the pollutants in air is an important factor when considering the magnitude of the impact it can cause. Apart from that the interaction between pollutants can change the effect it has on man and his environment. As an example SO_2 would normally be removed from the upper respiratory system but as it absorbs to particulate matter it is transported deep into the pulmonary system where SO_2 irritation occurs. Carcinogenic effect is considered to be a complicated interaction of many factor. Several well known carcinogenic chemicals have been measured in traffic emission.

One of the most important photochemical oxidant is tropospheric ozone (O_3, abundance and toxicity), forming the so-called "summer smog“ from a number of gases that are present in the troposphere. The smog has been causing respiratory problems (asthma) in the European population for several decades. It can also cause considerable damage to plants. The enormous increase in traffic on account of new licensed vehicles is contrary however, to the effort toward reduction of car emissions. [2, 3]

Acid rain

Sulphur- and nitrogen oxides react with water forming sulphuric-and nitric acid and thereby lowering the pH of rainwater. The phenomenon is called acid rain and it has shown to affect water ecology as well as fauna resulting in death of animals and plants. Acid rain is also known to defect buildings and monuments. Acid rain has pH around 3 - 4 when normal pH value for rain is around 5,7. [2]

Sulphur dioxide, nitrogen oxide and ammonia are the main pollutants causing an acid-deposition. This acidification is damaging acid-sensitive fresh water systems e.g. in Scandinavia, forests (extensive damage to trees in the form of defoliation and discoloration), soils and natural ecosystems in large areas of Europe. Damage is also being caused to important parts of Europe's heritage, such as limestone and marble buildings, monuments and stained glass windows. Geothermal activity is yet another source for sulphur emissions in Iceland. In geothermal steam high concentrations of hydorgen sulfide is found and it is known to partly convert to hydrogen oxides. [4, 5]

Global warming

Green house gasses, including carbon dioxide, in the atmosphere have the property to trap the infrared rays coming from the sun. That means the rays reach the surface of the Earth and only partly reflect back into space while the main part is absorbed by carbon dioxide. This effect is called the "greenhouse effect“. The consequence of increasing atmospheric temperature will be e.g. faster melting of the icecaps and melting of the glaciers resulting in a higher sea level. Global warming is seen as one of the main environmental effects known today. Several pollutants deriving from different sources are known to contribute to global warming. It has proven to be complicated to deal with the emissions of Greenhouse gases as the sources are so many and spread. One of the main sources is emission from diesel and gasoline vehicles. [2]

The greenhouse gas effect is in fact a natural phenomenon as the chemicals causing it serve as an insulation for the earth, keeping the solar heat within the troposphere longer than it would do if no greenhouse gases existed at all. From the start of the industrial revolution anthropogenic emission of greenhouse gases has steadily increased and thereby affecting the natural balance of the greenhouse gas effect. The main greenhouse gases in traffic emission are CO_2, Methane, Ozone and Nitrous oxides.

Visual effects

Traffic emission can as such also result in visual effects. NO_x, SO_x combined with PM (airborn particulate matter) form a yellow or blue smog that is seen especially on still days in cold weather when the concentration of the pollutants rises.

A list of several pollutants giving great concern and the effect they may have is given in Table 1. Health and environmental effects depend on concentration in air and interaction between them [2] and [3].

Table 1. Main traffic related pollutant. Health and environmental effects depend on concentration in air and interaction between them.

Pollutant		Health effects	Environmental effects
NO_x	Nitrogen oxides formed by combustion of fossil fuels	Respiratory diseases	Acid rain Visual effects Global warming
HC (VOC)	Volatile organic chemicals, due to incomplete combustion of fossil fuels	Respiratory irritation Carcinogenic effect	Global warming
PM10	Airborne particulate matter (0-10 μm) from gas exhaust, asphalt and natural sources. Organic chemicals and heavy metals can adsorb to them	Micro particles entering lungs, can cause respiratory problems and diseases. Indications of carcinogenic effect	Visual effects
SO_x	Sulphur oxide formed by combustion of fossil fuels	Respiratory problems and diseases	Acid rain Visual effects
CO_2	Carbon dioxide formed by combustion of fossil fuels		Global warming
CO	Carbon monoxide due to incomplete combustion of fossil fuels	Cardiovascular system	
O_3	Ground level ozone, formed in chemical reactions in urban environment	Eye irritation, affects lung function and immune system	Global warming, plant growth

Pollution measurements in Reykjavik

Air pollution

Air quality monitoring has been practiced in Reykjavik since 1990. Both national and Reykjavik city authorities have an active monitoring program running; Environment and Food Agency of Iceland (EFA) and Reykjavik City Environmental Health and Protection Office (EHPO), see Table 2.

EFA measurements at Miklatorg, Keldnaholt and Alvidra were running all year round and data is available from 1995 for Miklatorg and from 1999 for Keldnaholt and Alvidra. Some older data with other equipment is available for 1986-1992, Miklatorg. Miklatorg station was closed down in June 2002 and a new station opened in Grensasvegur in cooperation with EHPO. Lake Myvatn station was set up in 2000. In 2002 the Alvidra station was closed down. Heavy metals are determined in a collection of dust samples from Miklatorg.

EHPO operates Grensas station measuring NO_2, CO, O_3, SO_2 and PM10. It has been operating since 1990. In 1998 THC measurements (total hydrocarbon) was added. The station is set at Grensas, which is an urban traffic station. For many years the Grensas station was located for 3 months per year at other sites for special projects, usually 2 - 4 weeks at each location. Through the years it has also been located at traffic hot spots, kindergartens, at different suburbs locations. Grensas station serves as the main urban traffic station in Reykjavik from 2003. An urban background station has been running from autumn 2002, in Laugardalur. In addition a portable station is available since 2002, giving data for various locations in the city.

Table 2. Air quality monitoring program in Iceland.

Place	**Type of measuring station**	**Measured components**	**Periode in operation**
Miklatorg in Reykjavik - till early 2003	Urban traffic	Heavy metals, PM10, PM2,5	1995 - June 2002
Keldnaholt in Reykjavik	Urban background (border)	NO_x, ozone	1999 -
Grensas	Urban traffic	NO_x, CO, O_3, SO_2, PM10, PM2,5, THC	1990 -
Laugardalur	Urban background	NO_x, ozone, PM10, PM2,5	2002 -
Portable station	Variable	NO_x, PM10	2002 -
Alvidra - till 2002	Rural background	PM10, NO_x	1999 - 2002
At lake Myvatn	Rural background	PM10	2000 -

Noise

Reykjavik City Environmental Health and Protection Office performs noise measurements. No monitoring programs are running, but individual measurements are carried out upon request, mostly due to complains from citizens. At present 9 reports on such incidents are available.
Reykjavik City Engineers (Umferðardeild Borgarverkfræðings) has carried through a computer analysis, based on traffic flow, for identifying high noise areas. Reports on Environmental Impact Assessment are available for several streets and intersections in Reykjavik. Measurements and calculation on noise is reported.

Traffic

Environmental and Technical Sector of the City of Reykjavik, measure traffic flow in Reykjavik at several transects, see Figure 1. Data are available several years back.

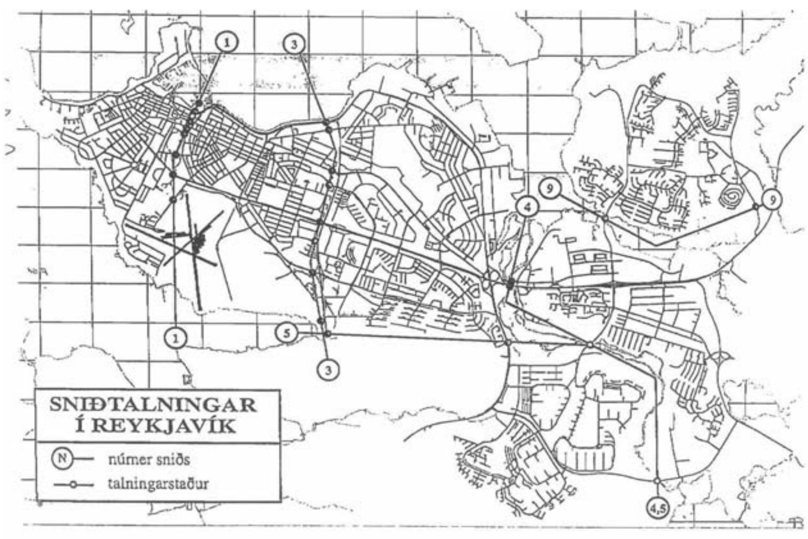

Figure 1. Traffic flow measurements in Reykjavik [6]

The traffic in Reykjavik is highly dependent on private cars. As seen in Figure 2 the number of private cars in Reykjavik has risen dramatically over the last decades and much faster than the population growth. At the same time the use of public transport system has declined. More traffic is therefore not mainly due to population growth, but rather because of a large fleet of privately owned cars. One can assume that by supporting and encouraging the use of the public bus system the local emissions could diminish.

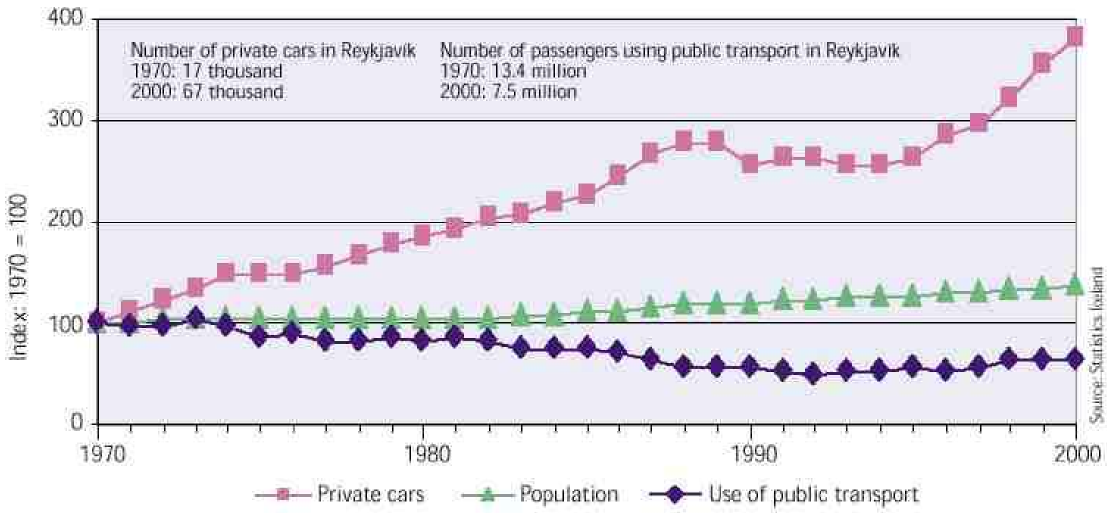

Figure 2. Index of population, number of private cars and the use of public transport in Reykjavik 1970–2000 [7]

Regulatory status

Icelandic regulations on air quality are in accordance with EC legislation. In Table 2 relevant regulations and directives are listed.

Table 1. Icelandic regulation on air quality and corresponding EC directives.

Icelandic regulation	EC directive
Reglugerð 521/2002 um brennisteinsdíoxíð, köfnunarefnisdíoxíð og köfnunarefnisoxíð, bensen, kolsýring, svifryk og blý í andrúmsloftinu og upplýsingar til almennings.	Directive 2000/69/EC of the European Parliament and of the Council of 16 November 2000 relating to limit values for benzene and carbon monoxide in ambient air Council Directive 1999/30/EC of 22 April 1999 relating to limit values for sulphur dioxide, nitrogen dioxide and oxides of nitrogen, particulate matter and lead in ambient air
Reglugerð 791/1999 um um mælingar á syrk ósons við yfirbotð jarðar og viðvaranir til almennings	Council Directive 92/72/EEC of 21 September 1992 on air pollution by ozone
Reglugerð 788/1999 um varnir gegn loftmengun af völdum hreyfanlegra uppsprettna	Council Directive 70/220/EEC of 20 March 1970 on the approximation of the laws of the Member States relating to measures to be taken against air pollution by gases from positive-ignition engines of motor vehicles Council Directive 88/77/EEC of 3 December 1987 on the approximation of the laws of the Member States relating to the measures to be taken against the emission of gaseous pollutants from diesel engines for use in vehicles
Reglugerð 787/1999 um loftgæði	Council Directive 96/62/EC of 27 September 1996 on ambient air quality assessment and management

The general aim of Directive 96/62/EC is to define the basic principles of a common strategy to define and establish objectives for ambient air quality and to assess the ambient air quality in Member States on the basis of common methods and criteria. Also to obtain adequate information on ambient air quality and ensure that it is made available to the public and maintain ambient air quality where it is good and contribute to improvements in other cases.

The objectives of the first daughter directive is to establish limit values for concentrations of sulphur dioxide, nitrogen dioxide and oxides of nitrogen, particulate matter and lead in ambient air intended to avoid, prevent or reduce harmful effects on human health and theenvironment as a whole. Directives 70/220/EEC and 88/77/EEC relate to emissions from vehicles.

In Table 3 the limit values for air quality, stated in the above mentioned directives, are given. In the directives an ambitious plan for this decade is set forward. Some of the values are to be reached in year 2001, others in 2005 or even 2010. In annexes to the regulation a more detailed description is given for the lowering of the limits for e.g. particulate matter.

Table 3. Limit values for air quality.

	Period	**Limit value [µg/m^3]** **(limit values are not to be exceeded more often than indicated in brackets in one calendar year)**
Sulphur dioxide:	1 hour	350 (24)*
	24 hours	125 (3)
	Calendar year and winter	20
Nitrogen dioxides (NO_2)	1 hour	200 (18)*
	Calendar year	40* (protection of human health)
oxides of nitrogen (NO_x)	Calendar year	30 (protection of vegetation)
Particulate matter (PM)	24 hours	50 (35)* in year 2005
		[50 (7) in year 2010]
	Calendar year	40* in year 2005
		[20 * in year 2010]
Lead	Calendar year	0,5*
Ozone	1 hour	110 *(protection of human health)
	1 hour	200 (protection of vegetation)
	24 hour	65 (protection of vegetation)
	1 hour	180 (Population information threshold)
	1 hour	360 (Population warning threshold)

* For margin of tolerance, see directives

General overview on air pollution in Reykjavik

Literature study was made on earlier studies on air quality. A short description of some resent studies and their findings is summarised in this chapter.

Green House Gas effect

Fuel consumption is one factor that has great effects on greenhouse gas emission and CO_2 is about 83% of the exhaust of greenhouse gases in Iceland. Figure 3 shows the origin of total release of CO_2 in Iceland in the year 2000.

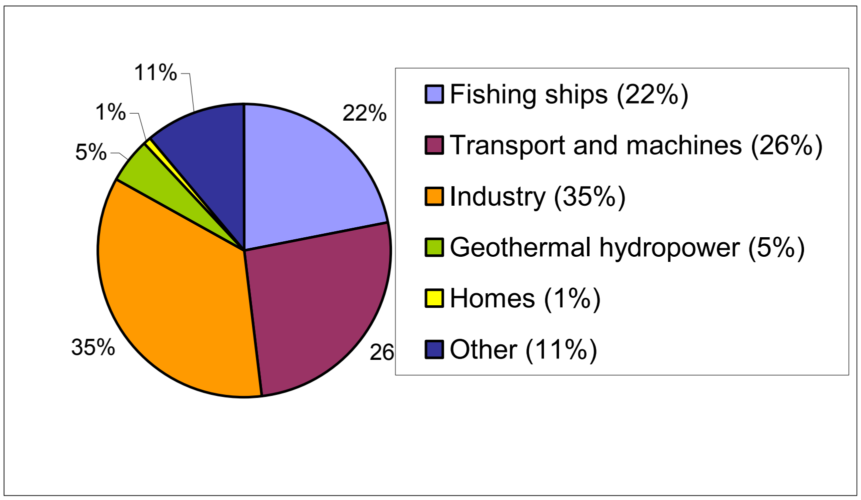

Figure 3. Total release of CO_2 according to source in Iceland in year 2000 [8]

In the year 2000, the total oil consumption in Iceland was about 860.000 tons. A big part of the release of CO_2 in the atmosphere in Iceland can be traced to the oil consumption of vehicles. The fuel consumption in Iceland has increased during the last years. This increase has on the average been 2% per year since 1983 [9]. Figure 4 shows the fuel consumption in Iceland in the year 2000 divided according to trade [10].

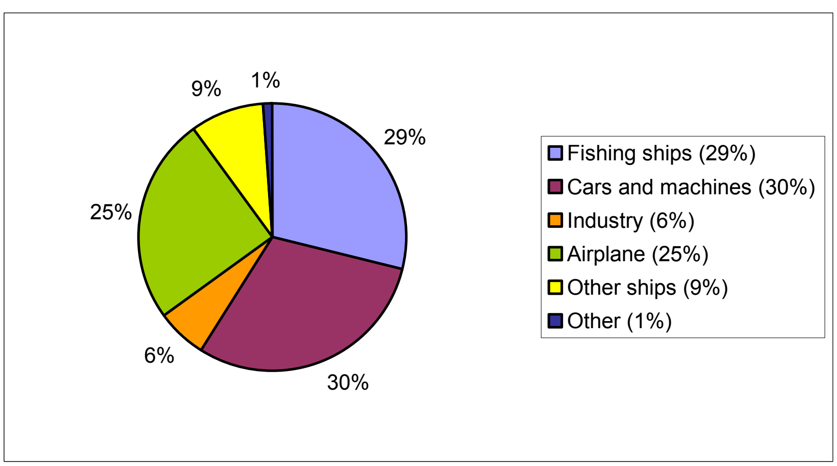

Figure 4. Fuel consumption in Iceland in the year 2000 after trade [10].

During the last years the CO_2 release form traffic has increased steadily from being around 540 thousand tons CO_2 in 1990 to over 600 thousand tons of CO_2 in 1999. [11]. In the same period the number of cars has increased in Iceland. In a report on future scenarios for greenhouse gas emissions in Iceland [11] it is suggested that the total CO_2 release from traffic will reduce in the coming decades as it is likely that the number of cars will reach a limit and that car engines will improve.

Acid rain

Acid rain has not been measured in Iceland to the same extent as in western Europe. Figure 5 indicates that pH in rain fall in Reykjavik and Irafoss (non urban site) is close to the average value for non polluted rain water in the range of pH 5-6. As mentioned above acid rain is often measured with pH 3 - 4. [12]

It is noteworthy that Nesjavellir, a geothermal power plant is sited 13 km from Irafoss and 24 km. from Korpa, a background urban site by Reykjavik. The concentration of H_2S are higher at Irafoss than at Korpa, but the reverse is true for SO_2. [4] The combination of traffic and geothermal effects are not all that clear.

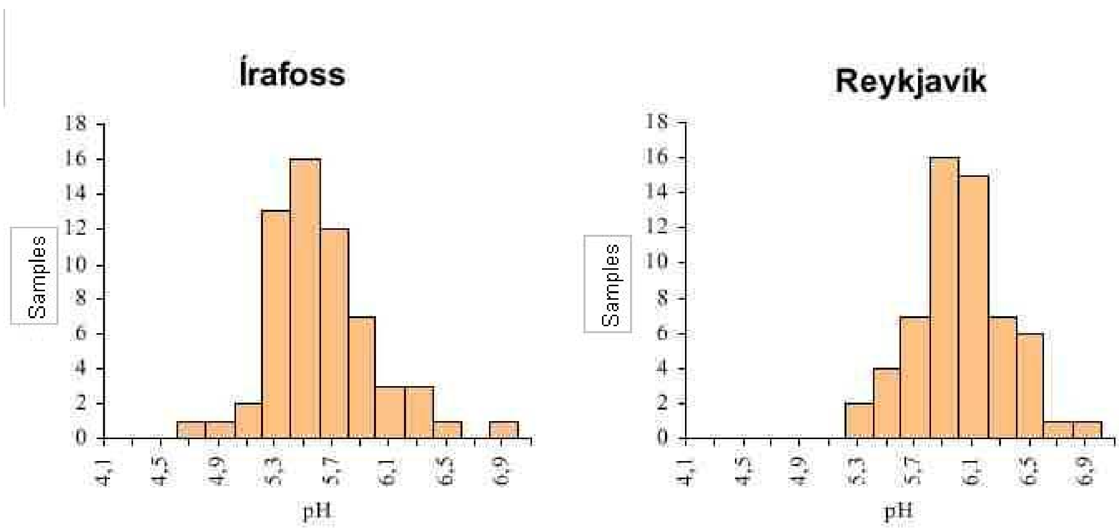

Figure 5. pH in Irafoss and Reykjavik vs number of examples. [10]

Particulate matter

Airborne particulate matter in Reykjavik can only partly be traced to traffic related emissions. There are other known sources, such as soil erosion and sea born salt spraying. Even traffic related emissions have more than one source, the exhaust gas emissions and asphalt particulate matter due to use of studded tires in winter. Studded tires are known to wear off the top layer of asphalt. In a recent study [13] it is suggested that the average combination of particulate matter in Reykjavik is by half deriving from asphalt, or 50%, while soil contributes only half of that, 25%, and soot even less or 15%. Salt is on average 10% and brake lining less than 5%.

In Reykjavik the EU limit values for ambient particle pollution are exceeded on several occasions each year. With regulations becoming gradually more stringent it is foreseen that the in the nearest future the particle concentration in Reykjavik will exceed the limit values set in regulations. In Figure 6 the changes from year to year is shown for 1995 - June 2002. The PM pollution increased steadily from 1995 - 1998 but is there after declining. It is too early to conclude whether the change is only temporary or whether there is a continuing trend towards lower emissions. It should also be noted that in the year 2000 the equipment broke down and few values are behind the average figure. The average values are below the limits as they were at the time, but in regulation 25/2002 more stringent values are set. The yearly value is to be lowered to 20 µg/m^3 in year 2010. It is noteworthy that at an background station, Alvidra, the yearly and average is typically between 6,4 - 9,4 µg/m^3.

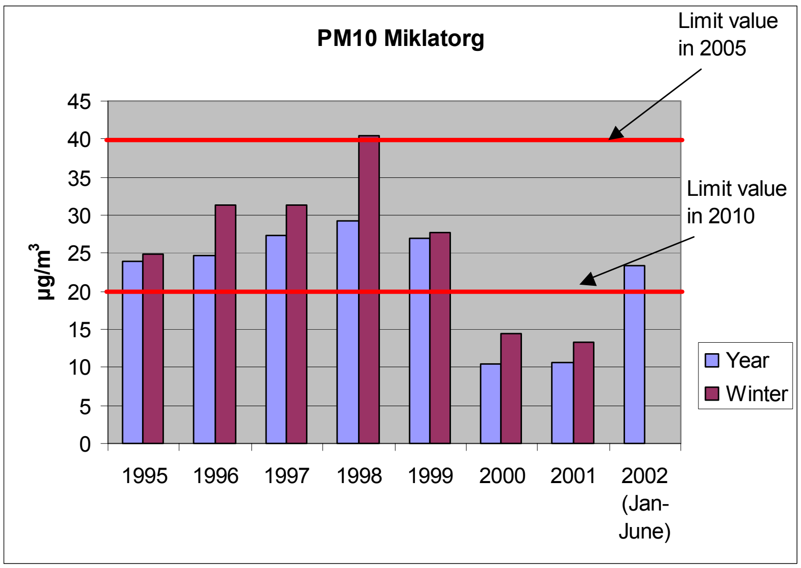

Figure 6. Yearly and winter average for airborne particulate matter at Miklatorg in 1995 - 2001 and the average for Jan - June 2002 [8].

The 24 hour value is to be lowered to 50 µg/m^3 in 2010, allowed to be exceeded 7 times. The number of times exceeding this value in recent years is shown in Figure 7. These are likely to raise problems in Reykjavik in coming years, especially when taking into account the fact that the measuring was only conducted every other day at the time and in e.g. year 2000 the monitoring was stopped for a while due to brake down.

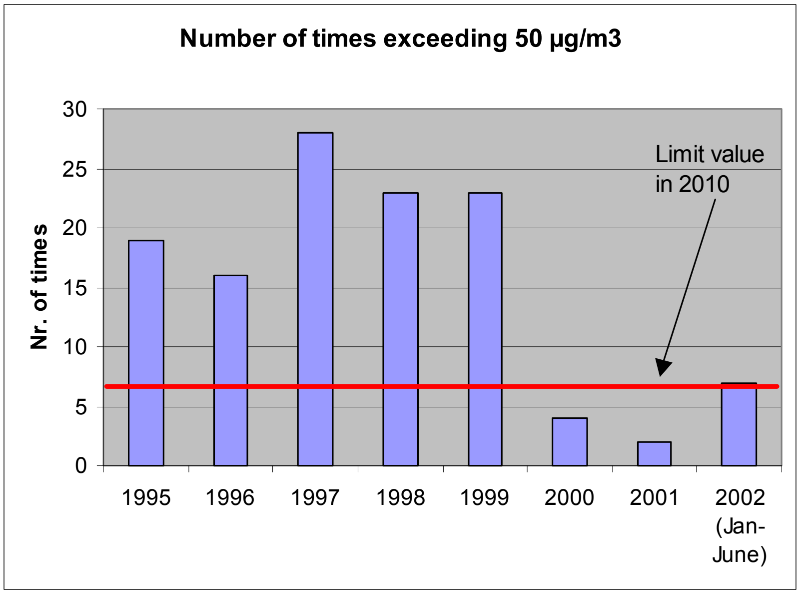

Figure 7. Number of times exceeding the 50 µg/m^3 limit. [8]

Nitrogen oxides, Sulphur dioxide, Ozone

Nitrogen oxieds (NO_2) are measured at an urban background station Keldnaholt and at an urban traffic station, Grensas. The yearly limit is 40 µg/m^3. Results from the urban background station, show early average concentration between 3-5 µg/m^3 which is well below the limit value. At an background station, Alvidra, the concentrations are measured to be 0,4 - 2,0 µg/m^3. At the urban traffic station the values are shown in Figure 8. The limits for sulphur dioxide are low compared to the limit values and usually far below the 24 hour limits as well as the yearly average limit value, see figure 8.

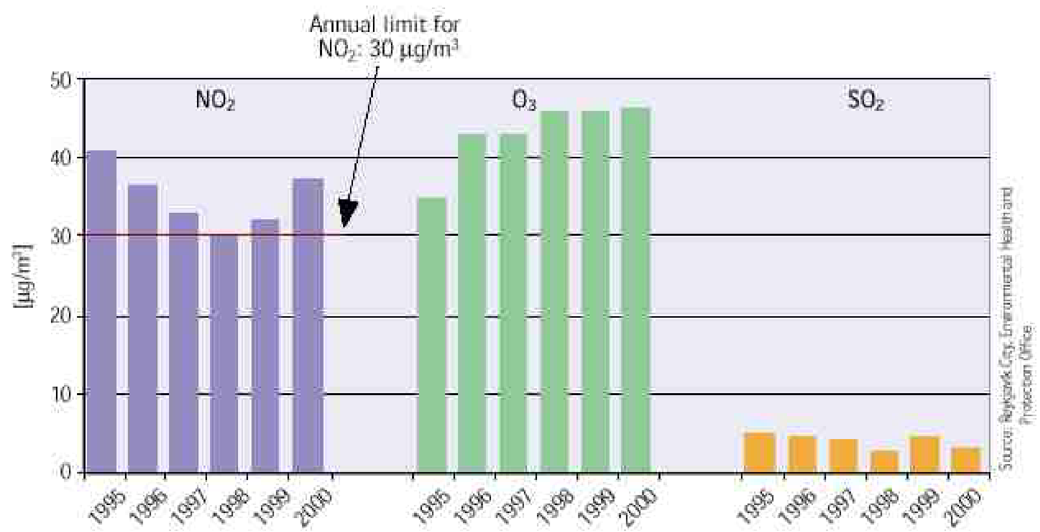

Figure 8. Concentration of NO_2, O_3 and SO_2 in the atmosphere in Reykjavik 1994-2000 [7]

Ozone is measured at Keldnaholt, an urban background station. As an example the measured values for the period 1st of January 2002 til 31st of July 2002 is shown in Figure9. The 24 hour limit value is set to 65 μg/m^3. These limits are frequently exceeded. At an urban traffic station, Grensas, the Ozone limits are frequently exceeded as well, see Figure 8 for early average values. The natural background concentration is unusually high. No explanation is known to why this is so.

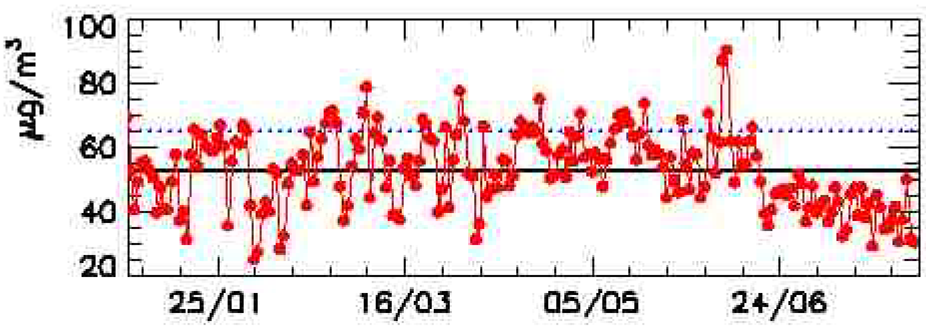

Figure 9. Ozone concentration at Keldnaholt in the first half of year 2002 [8]

PAH

One study on PAH is available, a student project from May 2001 [14]. The project concentrates on the analytical methods but measured values range from 0,2 to 3 ng/m^3 in samples from Reykjavik city and Alvidra, rural background site. Very low values are measured in Vestmanna Islands, a rural background site. The results of the study show that values from Miklatorg are higher than background values but lower than in large cities and that the values are higher for late winter ref [14].

Environmental monitoring and pollution modelling

Stationary Monitoring

In this part of the work, analysis of pollution data is done for the period June 2002 - September 2003. The results are based on both measurements conducted explicitly for this project and data from Reykjavik city EHPO monitoring program.

Siting of stations

The best available source for assessment of average air quality in heavy traffic areas in Reykjavik is the Grensas station. Grensas is a major measuring station in Reykjavik at a large traffic crossing, ideally sited for measuring overall traffic pollution impact. It is also situated at one of the major bus route connection point. For comparison measurements from two other stations are available, in Reykjavik municipal park in Laugardalur on one hand, which can be classified as an urban background area, and from a portable station on the other hand, which has been stationed at both urban traffic sites and in less polluted urban background areas. To start with the data form the portable station will be treated in one package but later on the data is split up in urban traffic and urban background measurements.

Monitored factors

Measured parameters at Grensas station are particulates (PM2,5 and PM10), carbon monoxide, nitric oxides, methane, non-methane HC's and total HC's, SO_2, ozone, benzene, toluene and xylene, as well as weather. These pollution parameters are all affected by traffic. Not all these parameters are available for comparison at the other sites, but at all stations there are measurements of particulates, carbon monoxide, nitric oxides, carbon dioxide and methane. Comparison is also affected by the fact that the methods and equipment varies between the stations.

Monitoring period

The number of days measured at each site and station is given in Annex I. The measurements are for the most part continuous, with some exemptions due to maintenance and unforeseeable disturbances. The measurements at Grensas and Laugardalur span a year while the portable station is used more periodic. The definition of the seasons is: summer June-Aug., autumn Sept.-Nov., winter Dec.-Feb., spring March-May.

Seasonal and yearly averages

The parameters that are available from both permanent stations are for particulates, NOx and O_3 measurements. The average values for these different sites are illustrated in Figure 10.

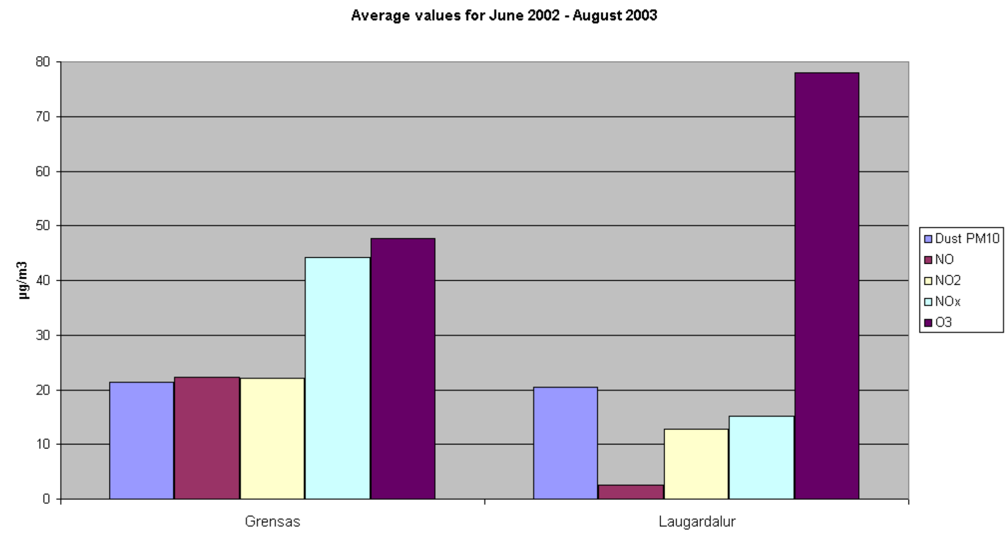

Figure 10. Average values for June 2002 - August 2003 for urban traffic station Grensas and urban background station Laugardalur.

The yearly averages are not that different for PM_{10} for the urban station (Grensas) and the background station (Laugardalur) The difference is on the other hand clear for the NO_x values and traffic related influence is clearly seen. Ozone concentration rises when moving away from traffic, as would be expected based on the nature of the ozone chemistry. Ozone is not an exhaust gas but is formed in traffic polluted air during decomposition of Nitrogen oxides. As nitrogen oxides concentration falls in traffic background areas the ozone concentration rises.

Looking at the seasonal changes in Figure 11, the pattern seen is that the particulates concentration rises during winter and spring whereas the NOx is highest in autumn and winter. I ti interesting to see that the pattern is not the same for all pollutants and further collection of data will be interesting. The pattern is similar for both stations, though the curve is flatter for the background station.

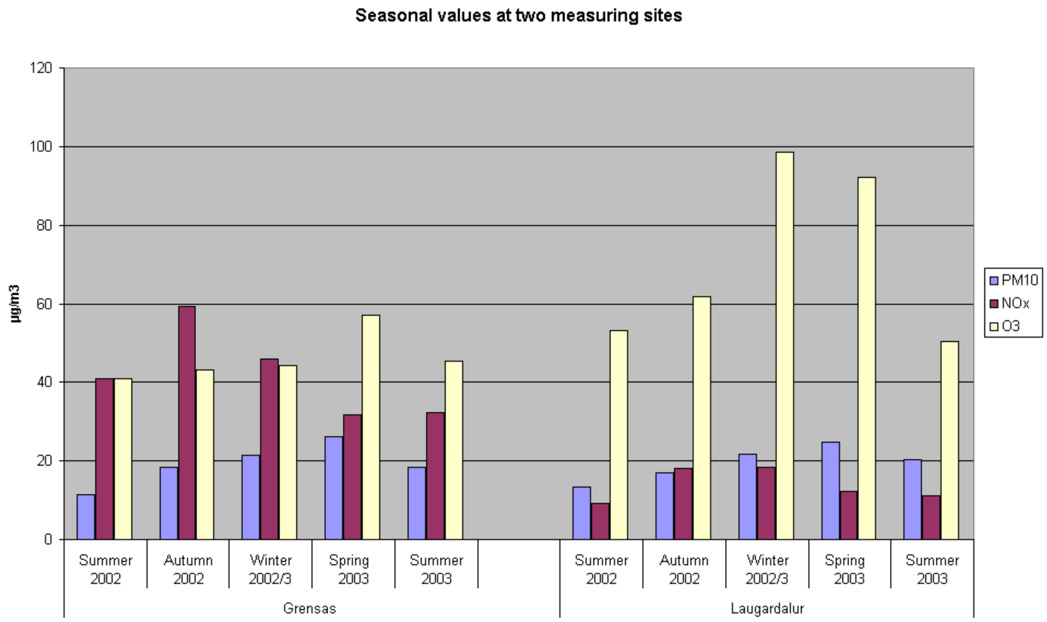

Figure 11. Average values for five seasons between June 2002 - August 2003 for urban traffic station Grensas and urban background station Laugardalur.

As other parameters than mentioned above, are not available for all sites these are therefore treated separately. Other measurements for Grensas are shown in Figure 12. Comparison between station is not possible but for some factors seasonal pattern is seen as for particulates and NOx above, but for other parameters, such as CO and CO2 the seasonal average is stable through the year.

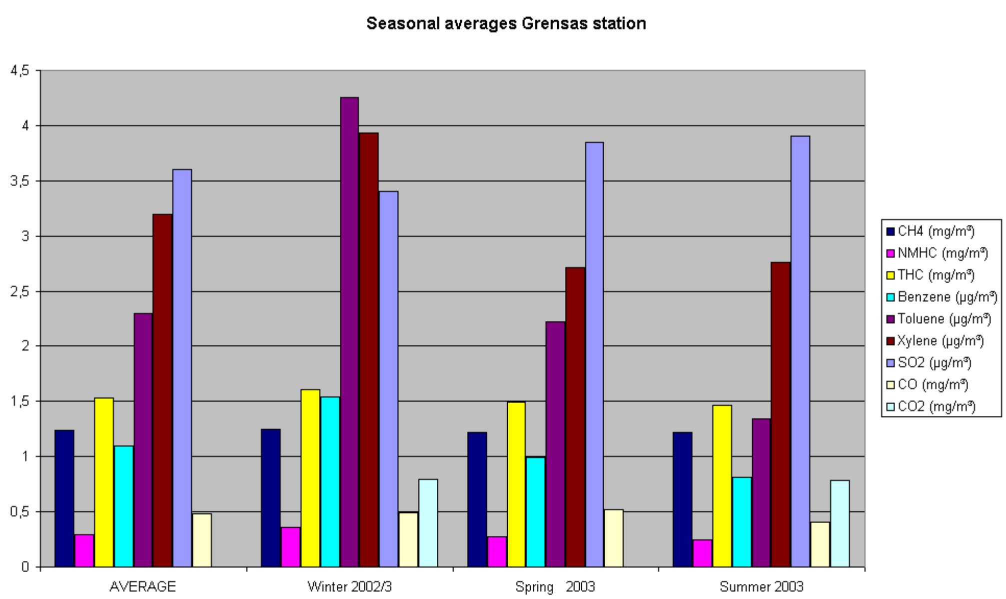

Figure 12. Seasonal averages for Grensas station.

Analysis of the measurements at Grensas show that air quality is very much affected by traffic and not so much by weather or any specific other sources of pollution. The variation in pollution levels are much more affected by time of day rather than wind direction or other variables. In annex I a wind rose for the Grenas station is shown and in Figure 13 the pollution level in different wind directions. The pollution levels are slightly higher in westerly winds which is probably due to topography, to the west of the station there is a hill providing shelter and lower wind speeds in westerly wind with slightly higher levels as result.

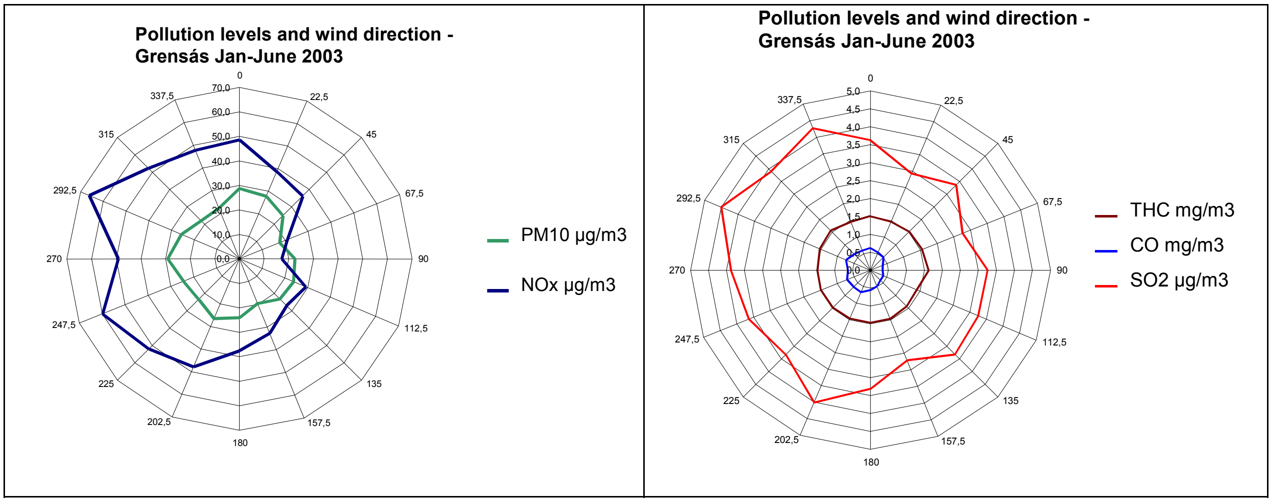

Figure 13. Pollution level for particulates, NOx, THC, CO and SO2 in different wind direction at Grenas station

In Figures 14 and 15 the daily pattern for several measured parameters is shown. Very roughly, it can be said that in this area the pollution level at day is double the level of night time levels for pollutants such as particulates, carbon monoxide, sulphur dioxide and NOx, which are mainly contributed by traffic. This supports the suggestion above that the air quality in the region is affected by traffic rather than anything else. In figure 14 both THC and THC variation is shown, which is THC (concentration minus lowest value)*10, in order to make the variations in concentration visible.

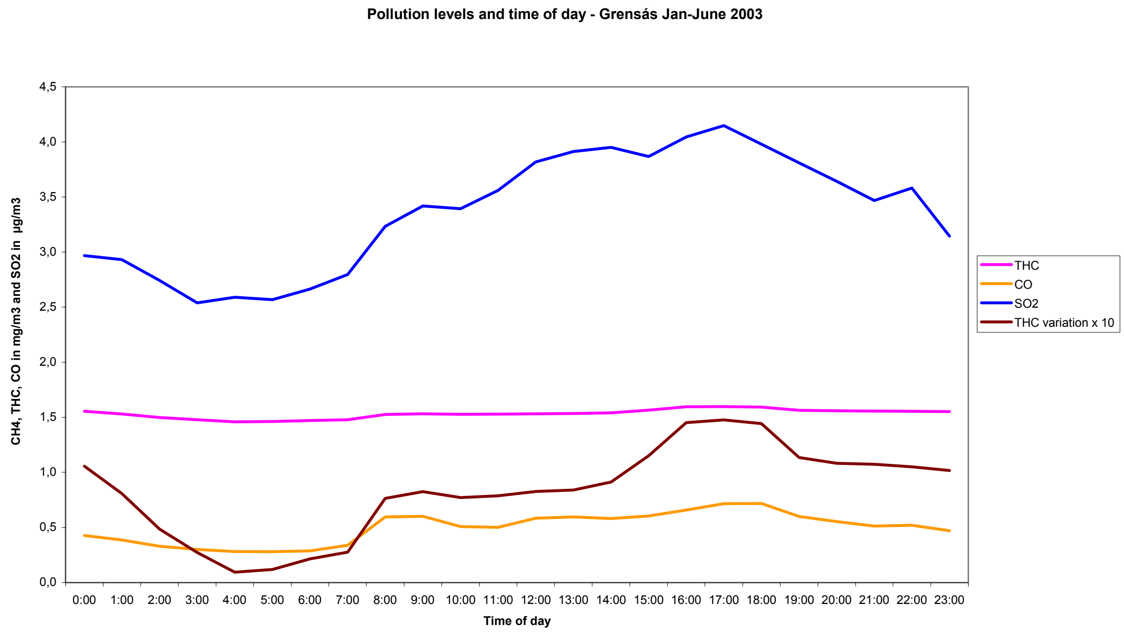

Figure 14. Pollution level at different time of day at Grenas station. Average values for each hour for January - June 2003, THC, CO, SO2 and THC variation .

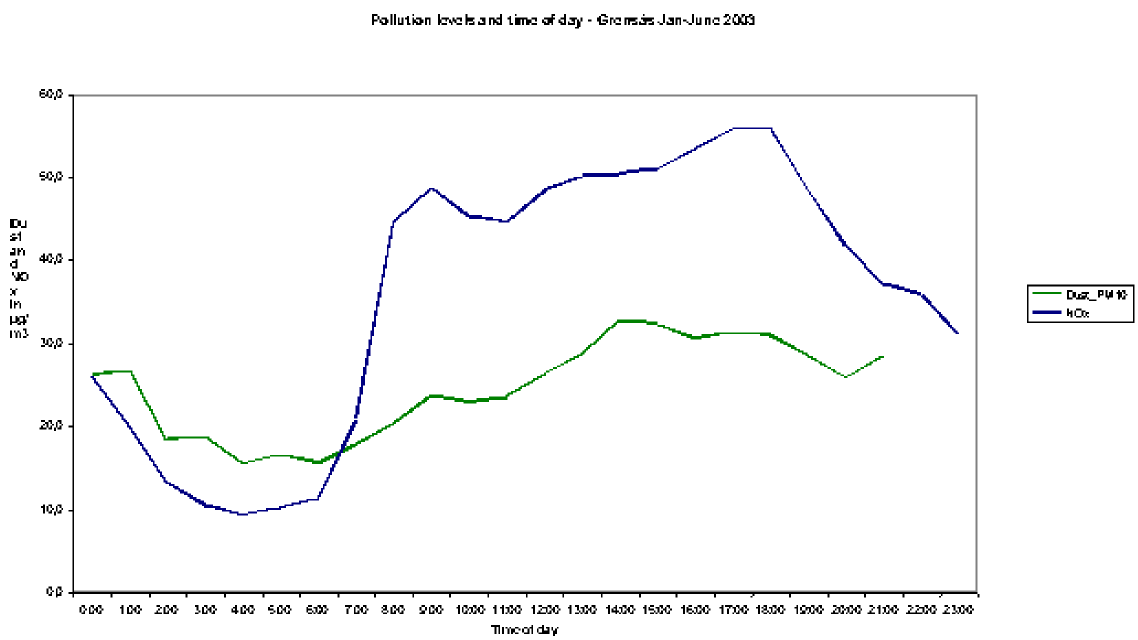

Figure 15. Pollution level at different time of day at Grensas station. Average values for each hour for January - June 2003, PM10 and NOx.

In Figure 16 the seasonal averages for all measured parameters in Laugardalur is given. Analysis of the measurements at Laugardalur, which is a municipal park area, show that air quality is less affected by traffic but the variation in pollution levels is as in the urban traffic station Grensas more affected by time of day and traffic rather than wind direction or other variables.

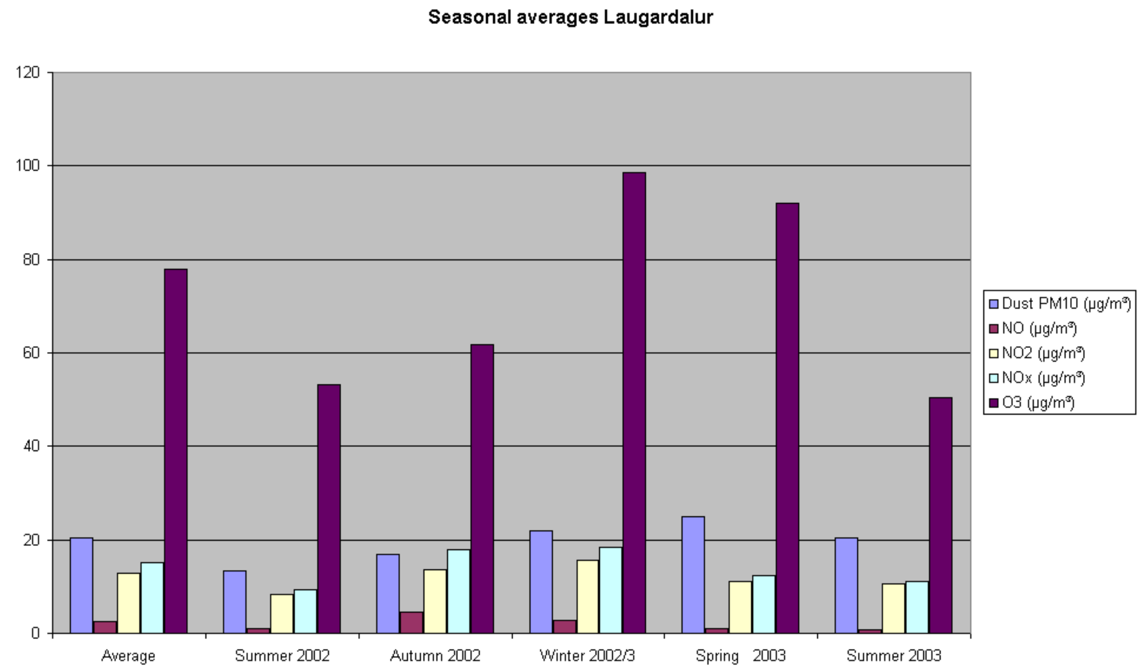

Figure 16. Seasonal averages for Laugardalur municipal park area.

These results are depicted in the following graphs, Figures 17 and 18. For direct comparison the axis values are the same as in the corresponding graphs for Grensas. As may be seen the values are generally lower, although particulates is not so much reduced as other factors.

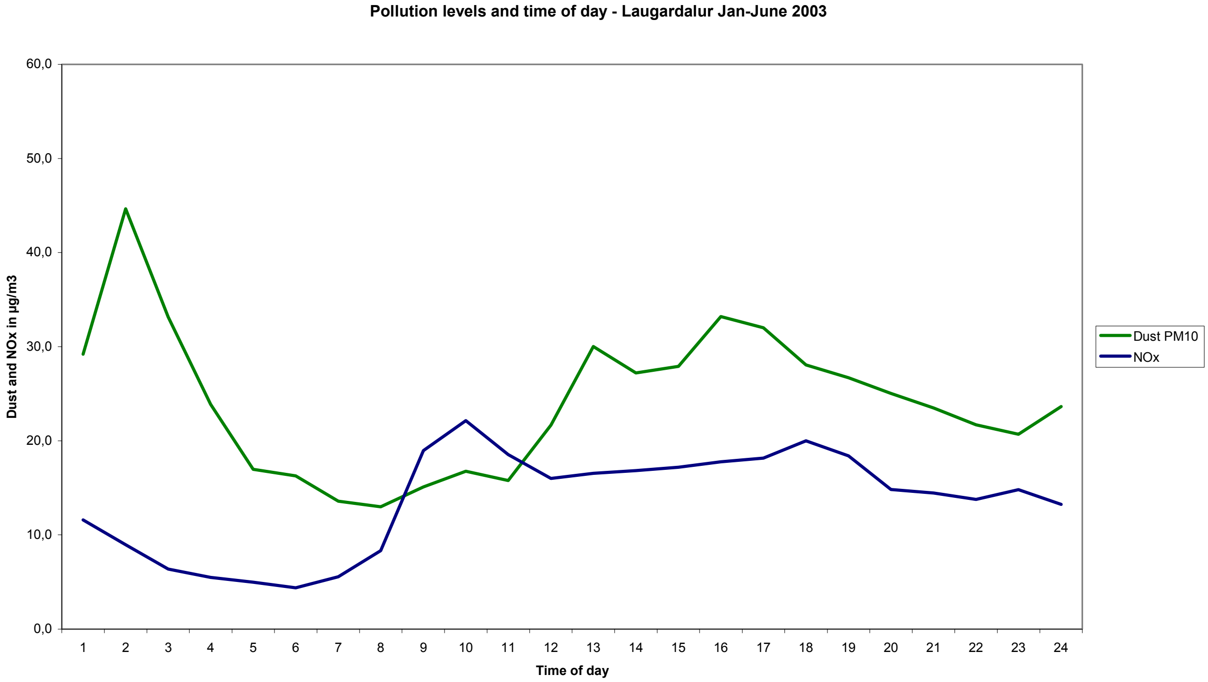

Figure 17. Pollution level at different time of day at Laugardalur station. Average values for each hour for January - June 2003, PM10 and NOx.

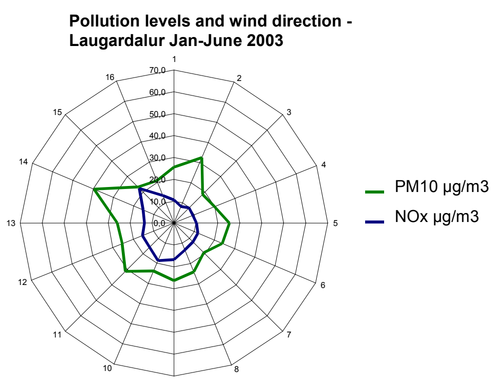

Figure 18. Pollution level for Particulates and NOx in different wind direction at Laugardalur station

Finally measurements from the portable station, which has been located at various sites during the year, are similarly depicted. The locations and dates can be seen in Annex I. The same overall period has been selected for comparison as in Grensas and Laugardalur, but the results are classified between urban traffic and urban background locations, see Figure 19. In Figure 20 the pollution level at different time of day is showed for the portable station. Average values for each hour for January - June 2003 are given and for direct comparison the axis values are the same as in the corresponding graph for Grensas. The results for the urban traffic sites are very similar to the Grensás results. The results are interesting, as the difference in particulates between the urban traffic and urban background sites is not very great, but much more pronounced in NO_x.

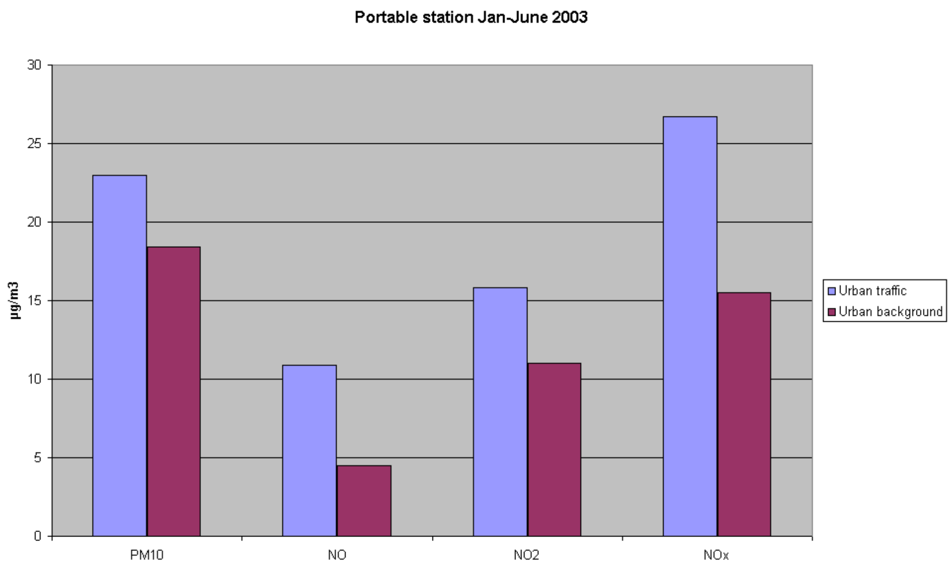

Figure 19. Average values for measured components for portable station divided in urban traffic and urban background locations

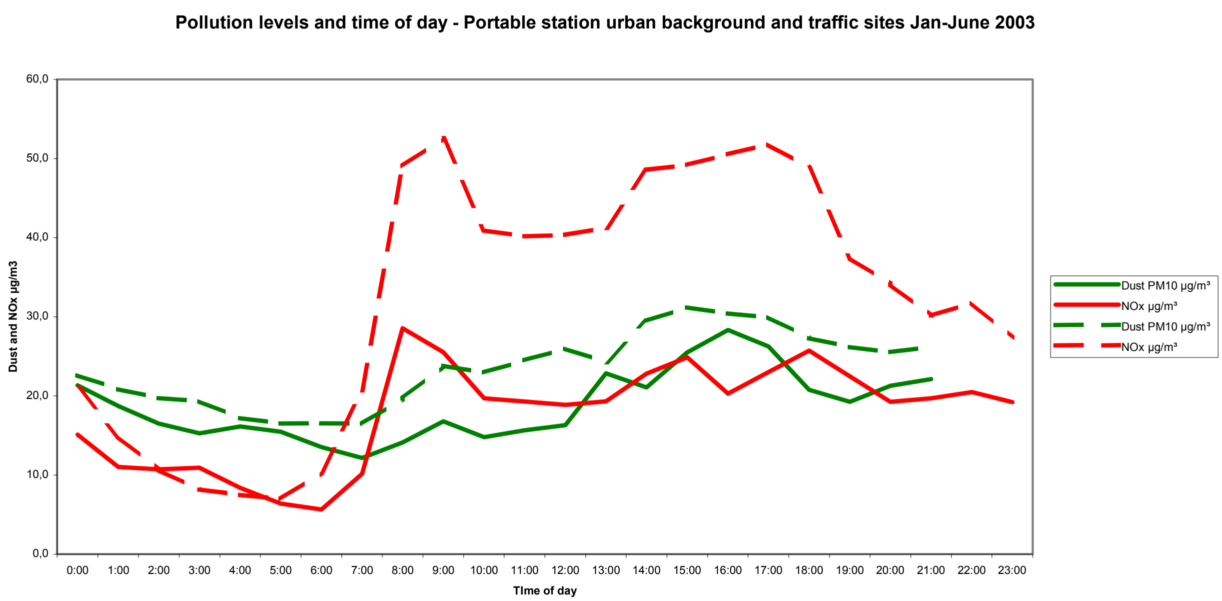

Figure 20. Pollution level at different time of day for portable station. Broken line shows values for traffic locations and whole line values for background locations. Average values for each hour for January - June 2003, PM10 and NOx.

Air pollution modeling

In this chapter a simple model of the urban traffic air pollution is made. The model is made to evaluate the expected changes in pollution levels due to changes from current situation to partial hydrogenisatin. The calculations are based on the following figures, see annex II for further description of the background data:

a) Actual number of vehicles in five categories
b) Actual use of petrol fuel and estimated use of diesel fuel in Iceland
c) Estimates of total driven distances in Iceland and Reykjavik area and figures from Straeto bs. for km driven by busses in Reykjavik
d) Various measured and reported pollution factors per driven km by different types of vehicles
e) Measured pollution factors of a bus from Straeto bs. Reykjavik, see results in next chapter, "Measurement of individual bus pollution contribution".

Actual number of cars in five categories

The figures used are based on the Icelandic vehicle registration database [16] and the they are the published data at the end of the year 2001. From this we have made the grouping illustarated in figure 21. The exact number of diesel powered vs. petrol powered trucks is not available in the published data, but we have assumed that all trucks and buses and heavy trucks are diesel powered.

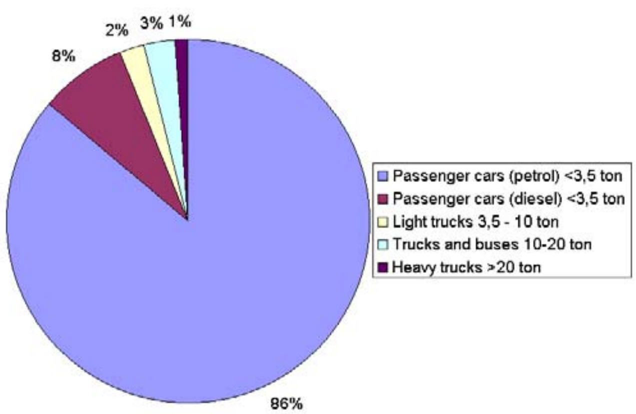

Figure 21. Estimation of number of cars in Reykjavik

Fuel use and driven distance

Figures on the use of petrol by vehicles in Iceland are available from the oil and petrol companies, and the figures used are the actual sales figures for the year 2001. The sold amount of petrol was 189,3 M ltrs in 2001. The figure for sold diesel fuel for vehicle transport is not available, only the total sold amount of diesel fuel, including air and marine use. An estimate is available from an Icelandic source [11], giving the estimated use of diesel fuel for vehicle transport as 50500 tons/yr or 71,1 M ltrs in 1999 and an average fuel economy of 18,7 L/100 km and total driven distance as 380 M km. We have made our own estimate from figures on the number of diesel cars in the various categories, estimated driving range and average fuel economy for different categories and reached an almost identical result from these simple premises, and also made estimates of fuel use and distance driven by vehicles in Reykjavik, see annex II.

Pollution factors per driven km by different types of cars

We have searched the literature for these and made our own measurement onboard a Reykjavik bus for comparison, see annex II. It is fairly difficult to do an accurate assessment of these pollution factors, as very many variables affect the emission profile. It can be temperature and weather, driving behaviour and driving range, topology (hilly or flat), urban or rural environment, the age of the car and whether it has an catalysator or not. As a result, reported pollution factors for different pollutants vary considerably between sources, up to a factor of two or more in some instances. In the following table the factors we chose to use in our calculation are shown. They are mostly from four sources, the US BTS (2002 report)[17], KFB in Sweden (1999) [3], Vito in Holland, a study of bus emissions (2001) [15] and Dublin [18] and finally our own measurement of a Reykjavik bus, see next chapter.

Estimated changes in traffic related pollution in Reykjavík
- with increased use of hydrogen powered vehicles

The modelling is ued to estimate the possible changes in traffic related pollution in Reykjavík that would follow the changes from petrol or diesel to hydrogen powered vehicles. Four scenarios of increasing use of hydrogen are set up, first, all buses are hydrogen powered, second, additionally 50% of light trucks are hydrogen powered and 15% of petrol cars, third, increasing to 30% of petrol cars and finally fourth, increasing to 50% of petrol passenger cars;

Scenario 1	Buses all hydrogen driven
Scenario 2	100% buses, 50% light trucks, 15% petrol pass.cars hydrogen power
Scenario 3	100% buses, 50% light trucks, 30% petrol pass.cars hydrogen power
Scenario 4	100% buses, 50% light trucks, 50% petrol pass.cars hydrogen power

The calculations yield the results shown in Figure 22 . The results may be regarded as not revealing any great truths, as it is highly likely that when ca. half of the traffic is switched to almost pollution free power, the traffic related pollution will be reduced in half. But it may be also pointed out that pollution of CO, NO_x and increased levels of CO_2 and HC's in Reykjavík are almost entirely due to traffic and transport activities. The city is heated by geothermal energy and is not an industry intensive area. So it is likely that a 36% reduction in traffic-generated NO_x-release will result in approximately one-third reduction of NO_x levels in ambient air.

For sulphur there is a braking point in Figure 22. The reason is that in scenario 3 and 4 all the change is expected in gasoline powered passenger cars and the sulphur content is lower in gasoline than in diesel. It is possible that sulphur concentrations in Reykjavik are to some extend due to geothermal activity in Reykjavik area and surroundings. Sulphur emissions tend to increase when geothermal areas are activated for power production [4]. As it is highly likely that geothermal power production will increase close to Reykjavik in near future the reduction in ambient air concentrations might be overestimated.
Regarding particulates it is likely that a switch to hydrogen powered vehicles will change fairly little. As mentioned before a study on the sources for particulate matter suggests that only 15% of the particulate matter derives from exhaust gases [11]. The largest source for PM in Reykjavik is suggested to be wearing of asphalt.

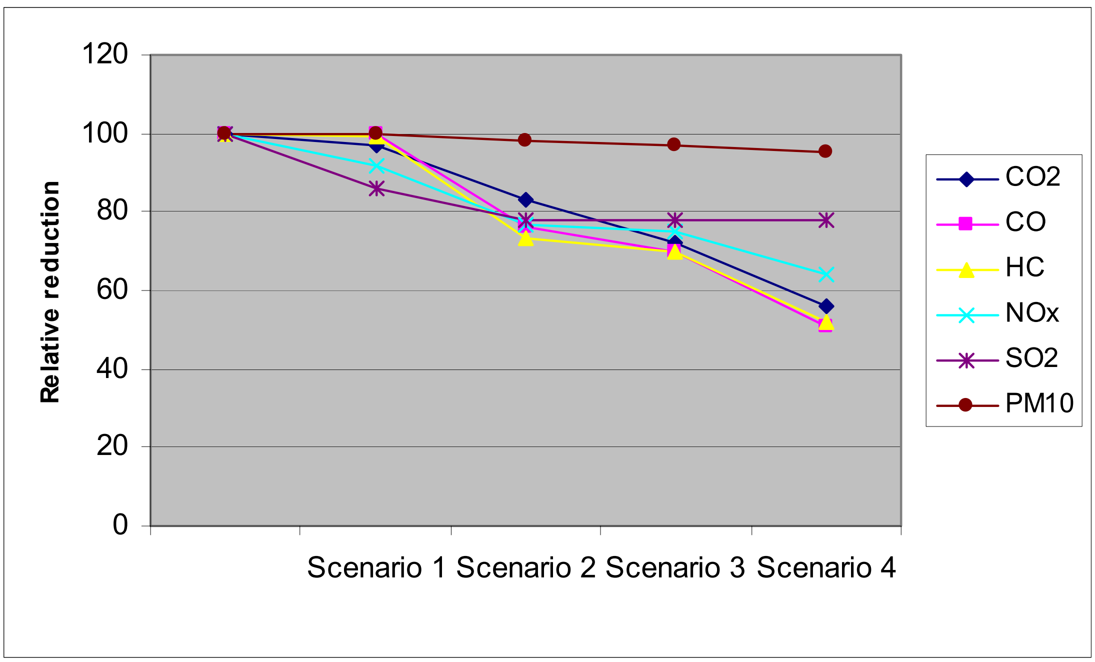

Figure 22. Air pollution modelling

Measurement of individual bus pollution contribution

A method for estimating individual bus pollution has been tested in this project. A direct measurement of gas composition from the rear of the bus very near the bus exhaust outlet is compared to the measured gas composition of city air at the front end of the bus. This can be seen schematically in Figure 23.

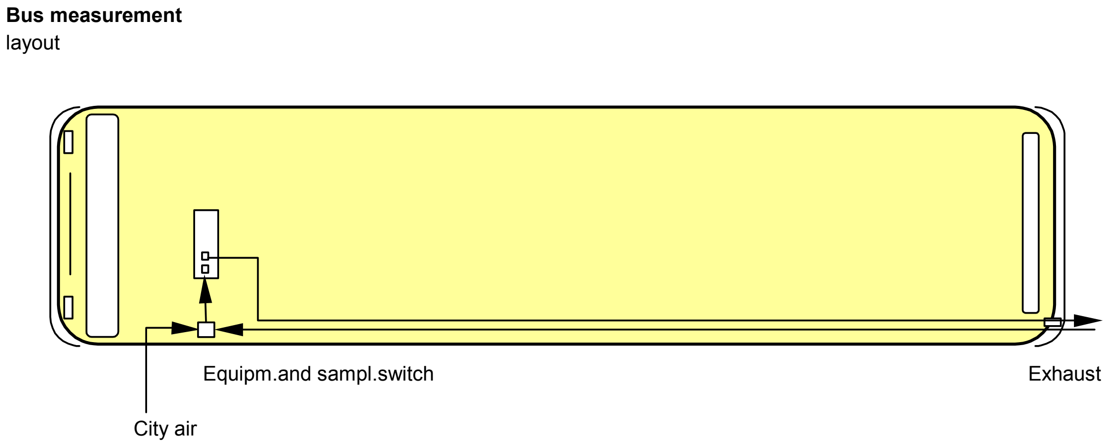

Figure 23. Placing of measuring equipment in bus.

The gases are CO_2, CO and CH and they are measured by infrared photo-acoustic gas analysis. As well as measuring the CO_2 the amount of gasoline used on the bus tour is monitored and used to calculate the CO_2 emission from the bus and this is used as a basis of a mass balance for estimating the total CO and CH emission of the bus. A measurement of SO_2 was also intended as an internal reference as the amount of S in the gasoline is well known and regularly monitored but the accuracy of the gas monitoring equipment does not allow this.

Measurements have been made in winter 2002 and spring, summer and autumn 2003. There have only been resources for making measurements in one bus on the selected route. The bus type is Scania CL94, year model 2002 and it has been driven 157.000 km at present.

The measurements alternate between the bus exhaust and city air, starting on exhaust for 15 minutes and then city air for 15 minutes etc. The starting of the bus initializes the equipment and no measurement is made when the bus engine is not running. As the bus is enroute for approximately 45-50 minutes, the measurement of the bus exhaust are almost two times longer than the city air. The layout of the equipment and timer control may be seen in Figure 24.

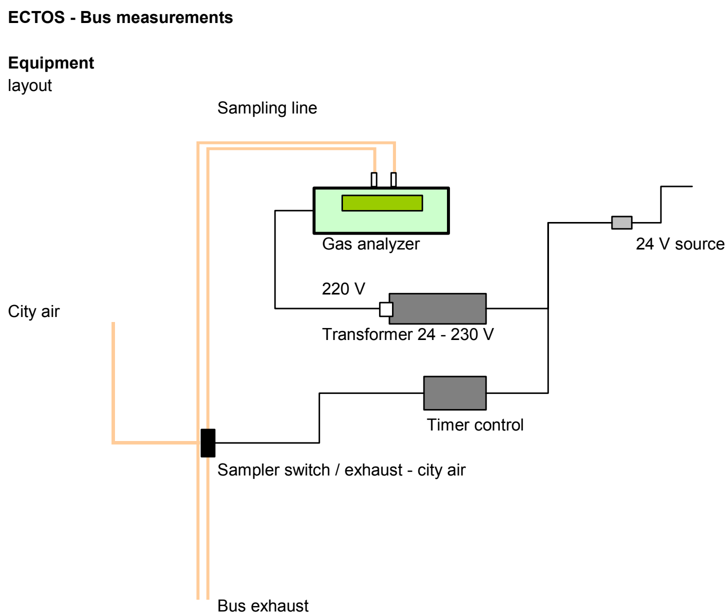

Figure 24. The layout of the equipment and timer control

There have been some problems with the timer control and the initializing of the equipment so quite some days of measuring have not returned useful data, especially as it is necessary to have whole days of measurement, as the gasoline use is only measured for whole days. The installation of the equipment was done in a good cooperation with STRAETO bs, the staff at the garage and the bus drivers. The drivers received an information leaflet, see Annex III.. The results can be seen in the Table 4.

Table 4. Results from bus pollution measurements

	CO2 mg/m3		**HC mg/m3**		**CO mg/m3**		**Fuel consumption l/100 km**
Season	*Bus exhaust*	*City air*	*Bus exhaust*	*City air*	*Bus exhaust*	*City air*	
winter	5447	918	8,992	3,970	12,55	0,64	47,75
spring	5345	817	3,533	1,640	14,30	0,68	47,04
summer	5780	815	4,489	1,936	18,00	1,06	47,20
autumn	4783	874	3,383	1,549	12,98	0,82	48,4

The air concentration figures are averages of 200-300 point measurements for the bus exhaust and 100-150 points for city air each day of measurement. From this the pollution factors in Table 5 can be calculated.

Table 5. Pollution factors for different seasons

Season	CO_2 g/km	HC g/km	CO g/km
winter	1264	1,40	3,3
spring	1246	0,52	3,7
summer	1250	0,64	4,3
autumn	1282	0,60	4,0
Average	**1261**	**0,79**	**3,8**

The average result seems plausible in comparison with other measurements, see annex II, such as the VITO studies of bus pollution [ref], but the variation in the results is greater than we would like to see. One would expect the CO in the bus exhaust in wintertime to be higher than in summer, and the HC's in the exhaust in the summertime is lower than expected. Also, the level of HC's in city air in the winter measurement is higher than expected. All in all, these variations reduce the reliability of the measurements in spite of an effort to make an accurate calibration of the gas monitor. Two point span calibrations have been made of the monitor for each gas and the span range of the calibration gases proved to be sufficient to cover the low and high individual measurements within a linear range, except in the case of CO_2. As the measurement of CO_2 is crucial to the whole calculation of the pollution factors a second degree correction to the CO_2 measurements has been calculated and applied based on a span gas of 150000 ppm in addition to our original calibration of 0 and 1000 ppm calibration. This results in the pollution factors being 13-16% lower than without the correction.

Future work

In this report the first results form the environmental evaluation in ECTOS are presented. In the nest two years this work will continue with ongoing watch and measurements of ambient air pollution and direct measuring of bus pollution, including hydrogen buses. Apart form that the air pollution modelling will be refined by looking at the local effects for certain streets in Reykjavik.

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Annex I - Data from Stationary Monitoring

Measured data for the location Grensas station

Grensas station	Particulates PM_{10}	NO	NO_2	NO_x	CH_4	NMHC	THC
Period	µg/m³	µg/m³	µg/m³	µg/m³	mg/m³	mg/m³	mg/m³
Average 2002-2003	21,3	22,2	22,1	44,2	1,24	0,29	1,53
Summer 2002	11,31	23,11	17,71	40,92	1,26	0,14	1,40
Autumn 2002	18,43	33,35	26,02	59,18	1,26	0,27	1,54
Winter 2002/3	21,35	23,43	22,48	45,92	1,25	0,36	1,61
Spring 2003	26,12	12,11	19,63	31,74	1,22	0,27	1,49
Summer 2003	18,49	14,70	17,71	32,41	1,22	0,25	1,47

Grensas station	Benzene	Toluene	Xylene	SO_2	O_3	CO	CO_2
Period	µg/m³	µg/m³	µg/m³	µg/m³	µg/m³	mg/m³	mg/m³
Average 2002-2003	1,1	2,3	3,2	3,6	47,6	0,48	
Summer 2002	0,29	0,02			40,82	0,38	
Autumn 2002	0,48	0,03		3,52	43,12	0,50	
Winter 2002/3	1,54	4,25	3,93	3,40	44,15	0,49	792
Spring 2003	0,99	2,22	2,71	3,85	57,01	0,52	
Summer 2003	0,81	1,34	2,76	3,90	45,45	0,41	787

Measured data for the location Laugardalur

Laugardalur station	Particulates PM10	NO	NO_2	NO_x	O_3
Period	µg/m³	µg/m³	µg/m³	µg/m³	µg/m³
Average 2002-2003	20,5	2,5	12,8	15,2	78,0
Summer 2002	13,47	1,01	8,23	9,24	53,15
Autumn 2002	16,95	4,51	13,65	17,97	61,87
Winter 2002/3	21,81	2,71	15,75	18,46	98,58
Spring 2003	24,84	1,08	11,18	12,26	92,10
Summer 2003	20,41	0,65	10,47	11,05	50,33

Average values for measured components for portable station divided in urban traffic and urban background locations

Period 2003 (Jan-Jun)*	**Particulates PM_{10}**	**NO**	**NO_2**	**NO_x**
Site class	**µg/m³**	**µg/m³**	**µg/m³**	**µg/m³**
Urban traffic	23,0	10,9	15,8	26,7
Urban background	18,4	4,5	11,0	15,5

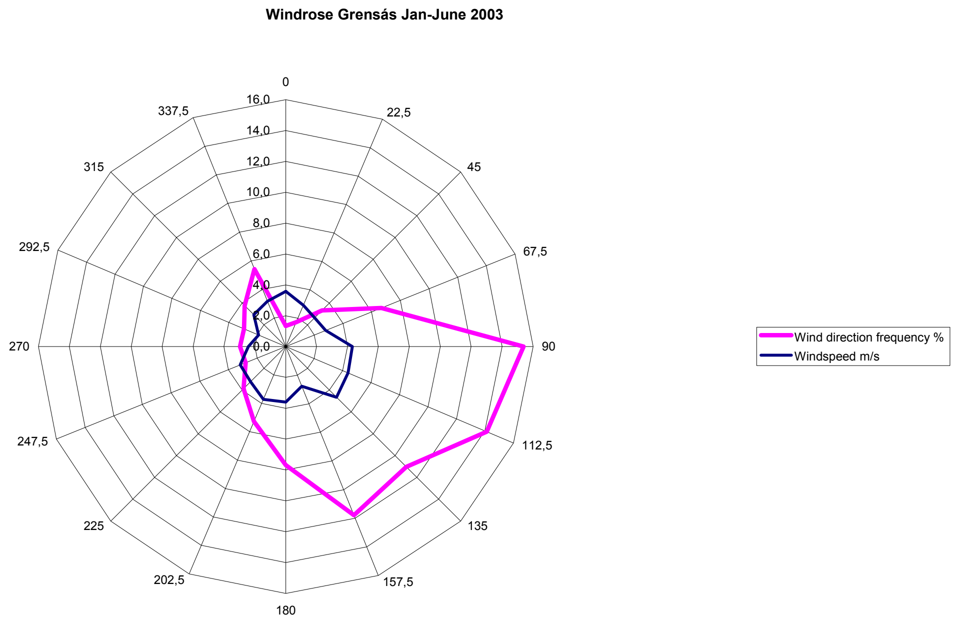
Location of portable station.

Location	**Period**	**Classification of site**
Flókagata, hverfisbækist.gmstj.	25.10.2002 - 6.11.2002	Urban background
Reykjavíkurflugvöllur	6.11.2002 - 13.12.2002	Urban background
Keldnaholt	13.12.2002 – 8.1.2003	Urban background
Austurstræti	8.1.2003 – 4.2.2003	Urban traffic
Örfirisey, Olíubryggja	4.2.2003 – 27.2.2003	Urban background
Miklatorg	27.2.2003 – 9.4.2003	Urban traffic
Gufunes, bryggja Ábv.	9.4.2003 – 30.4.2003	Urban background
Jafnasel, hverfisbækistöð gmstj.	30.4.2003 – 25.6.2003	Urban background
Fossvogur, Brautarland	25.6.2003 – 30.9.2003	Urban background

Number of days measured at each site and station

Year		***Grensas***	***Laugardalur***	***Portable station***
2002		Days meas.	Days meas.	Days meas.
Summer		10	60	
Autumn		90	90	35
Winter		30	30	30
	Total	**130**	**180**	**65**
2003				
Winter		60	60	60
Spring		90	90	90
Summer		30	30	30
Autumn				
Winter				
	Total	**180**	**180**	**180**

Wind-rose for Grensas station:



Annex II - Data for calculation of air pollution modelling

Actual number of cars in five categories

Vehicle classification	**Reykjavik**	**Iceland**
Petrol powered vehicles	97381	151131
Diesel powered vehicles	15243	28880
Total number of vehicles	**112624**	**180011**

Vehicle classification	**Size tons**	**Number Percentage %**
Passenger cars (petrol)	<3,5 ton	87
Passenger cars (diesel)	<3,5 ton	8
Light trucks	3,5 - 10,0 ton	2
Trucks and buses	10,0-20,0 ton	3
Heavy trucks	>20,0 ton	< 1

Fuel use and driven distance

Vehicles, fuel type	**Number of cars**	**Fuel use M L/yr**	**Driven distance M km/yr**
Petrol vehicles	151131	189,3	1721
Diesel vehicles	28880	72,8	389
Total	180011	262,1	2110
Petrol vehicles Reykjavik	97381	101,2	920
Diesel vehicles Reykjavik	15243	28,4	152
Total vehicles Reykjavik	112624	129,7	1072
Stræto bs. Rvík	50	3,9	7,8

Pollution factors per driven km by different types of cars

	CO_2 g/km	CO g/km	HC g/km	NO_x g/km	SO_2 g/km	Particulates mg/km
US BTS						
Pass.cars petrol		11,2	1,1	0,78		
Light trucks petrol		15,9	1,42	0,95		
Pass.cars diesel		1,09	0,47	1,07		
Light trucks diesel		0,96	0,55	1,02		
Trucks diesel		2,37	0,46	10,37		
KFB, Sweden						
Pass.cars petrol		7,3	0,67	0,36		14
Pass.cars diesel		0,46	0,09	0,69		89
VITO, Holland						
City bus average	1405	4,1	1,55	13,0		
Rural bus	937	2,1	1,0	8,9		
Dublin bus	1423	2,39	0,85	15,7		
IceTec						
Reykjavik bus	1250	3,8	0,9			
Estimates IceTec						
Pass.cars petrol	270					
Light trucks petrol	619					
Pass.cars diesel	248				0,06	
Light trucks diesel	545				0,13	
Trucks diesel	792				0,19	

Percentage reduction of exhaust gases

	CO_2	**CO**	**HC**	**NO_x**	**SO_2**	**PM10**
	%	**%**	**%**	**%**	**%**	**%**
Sc.1	**3**	**0,3**	**1**	**8**	**14**	**0,5**
Sc.2	**17**	**24**	**27**	**23**	**22**	**2**
Sc.3	**28**	**30**	**30**	**25**	**22**	**3**
Sc.4	**44**	**49**	**48**	**36**	**22**	**5**

Annex III - Information leaflet

Information leaflet to drivers regarding air pollution measurements. Translation of the text in the information leaflet is presented to the right

<table>
<tr>
<td>
Iðntæknistofnun — Strætó bs — efnagreiningar KELDNAHOLTI

VETNISVAGNAVERKEFNIÐ
MENGUNARMÆLINGAR Í ÞESSUM STRÆTISVAGNI

Í þessum vagni hefur verið komið fyrir búnaði til mælinga á mengun frá útblæstri vagnsins.

Þetta er gert vegna vetnisvagnaverkefnisins, sem Strætó bs. er þátttakandi í. Gerðar verða mengunarmælingar frá strætisvögnum í Reykjavík á árunum 2003 – 2004. Einungis verður mælt nokkrum sinnum á hverju ári og mælt í 1-3 daga í hvert sinn.

Búnaðurinn felur í sér eitt mælitæki, tímastýringu og spennubreyti og er mælitækinu komið fyrir við hlið sætis bílstjóra. Við vonumst eftir góðri samvinnu við bílstjóra um þessar mælingar og vonumst til að þær valdi sem minnstri röskun við starf þeirra. Við biðjumst velvirðingar á því að vera kann að snúningshreyfing sætis sé takmörkuð og biðjum bílstjóra að taka tillit til þess.

Tækið ræsist sjálfkrafa þegar vagninn er ræstur. Á 2-3 mínútna fresti heyrist lágt suð frá tækinu í um 15 sek í hvert sinn. Tækið tekur þá inn á sig lítið loftsýni til mælinga, en sýninu er síðan skilað aftur út í útblástur frá bílnum.

Sé frekari upplýsinga um þessar mælingar óskað eru þær góðfúslega veittar og ef einhverjar spurningar koma upp varðandi þennan búnað hafið samband við Hermann Þórðarson hjá Efnagreiningum Keldnaholti, sími 570 7100 (Iðntæknistofnun) eða síma 699 6874. Einnig má senda fyrirspurnir áherth@iti.is

efnagreiningar KELDNAHOLTI
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<td>
Hydrogenbus project
POLLUTION MEASUREMENTS IN THIS BUS

Equipment for measuring exhaust gases has been installed in this bus.

This is done as a part of the hydrogen bus project which STRAETO bs. participates in. Measurements will be performed in busses in Reykjavik during the years 2003 - 2004. Several measurements will be done each year for 1 - 3 days at a time.

The equipment consists of a measuring unit, time control and a transformer and the measuring unit is placed aside the drivers seat. We wish for a good cooperation with the drivers and hope that this will not cause disturbance in their work. The turning of the seat might be inhibited a little, we apologise for that and ask the driver to show consideration regarding this.

The equipment is started automatically when the bus is started. Every 2 - 3 minutes the equipment makes a low buzz lasting for around 15 seconds each time. A small air samples is then taken into the equipment for measuring and the sample is returned to the car´s exhaust.

Do not hesitate to ask for further information on these measurements and if any questions arise regarding the equipment please contact Hermann Þórðarson at Efnagreiningar Keldnaholti, tel: 5707100 (Iðntæknistofnun) or 699 6874. Questions can also be sent to herth@iti.is.
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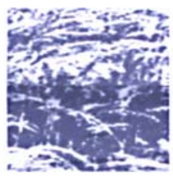

The primary function of IceTec is to forward innovation, productivity and competitiveness in Icelandic enterprises.

Acting in close relationship with industry the Institute focuses on research & development, technology transfer, education and consulting.

Entrepreneurs and SMEs are provided with qualified information and guidance.

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