# Urban Air Pollution Analysis in Ulaanbaatar Mongolia

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This report was conceptualized, drafted, and designed by the members of UEinfo.

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# Urban Air Pollution Analysis in Ulaanbaatar, Mongolia

Urbanization has resulted in increasing air pollution due to rapidly expanding vehicular population, growing industrial sector, higher electricity demand, and bludgeoning demand for domestic heating and cooking in the densely packed city (~1600 people per square km) of Ulaanbaatar. Ulaanbaatar is the coldest national capital in the world, with an average annual temperature of -1.3°C (29.7°F).


Ger Area


Smoke from a Ger


Coal and fuelwood sacs


Flyash from power plants


Fugitive dust


Old trucks


Road dust


Industrial boilers


Garbage burning

Fossil fuel, mostly coal is the primary source of energy and consequently air pollution. In addition, the burning of biomass such as firewood, agricultural and animal waste contributes in the household sector. In early 2007, total urban population crossed 1 million and at the current growth rate of 4 percent, constant over the last five years, total urban population is expected to reach the 2 million in 2020. Major cause for urban population rise is in-migration fueled by 1) higher incomes in towns compared to villages; and 2) increased employment opportunities, especially in the construction and mining sectors. Also, a combination of the city's' relative isolation and government policy preventing in-migration to cities have spurred the growth in the Ger (residential) areas of Ulaanbaatar.

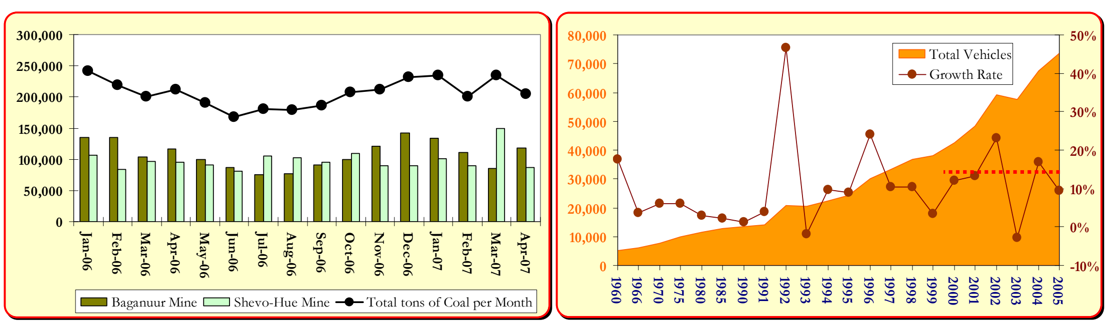
Rapidly growing urban areas are ill equipped to absorb such a fast growing population. The lack of infrastructure has brought on severe problems such as waste management, lack of clean water and sanitation, and high levels of air pollution due to increased and inefficient combustion of coal. Also, the natural constraints in the layout of the city, as a linear city surrounded by mountains limits the dispersion of pollutants and enhancing their ground level concentrations. Preliminary findings of a study conducted on indoor air pollution[1] indicate that particulate matter (PM) and carbon monoxide are above WHO standards. For example, the Mongolian standard for 24 hour total suspended particulates is 150 $\mu g/m^3$. This standard is high considering the standard set by US-EPA for $PM_{2.5}$ is 65 $\mu g/m^3$. Yet the mean PM measurements in homes with individual heat stoves measured at 750 $\mu g/m^3$ during the study period.

This report summarizes[2] an **application of SIM-air** for the city of Ulaanbaatar, to underpin discussions on air quality in Ulaanbaatar and possible short- and long- term strategies for reducing air pollution via clean coal technologies. Analysis and results presented in this study are based on data collected (from various ministries, academic, and non-governmental agencies) and discussions during workshops in Ulaanbaatar with the city environmental authorities.

## Energy & Emissions

Air quality has become a prime concern and a priority problem for the city of Ulaanbaatar and informed early action could avert this growing crisis. Amassing an accurate air pollution management knowledge base is critical and often a constraint. Developing a good knowledge base and feel for the critical pollutants is a necessary step.

Figure 1




Coal consumption @ CHP 4 — Vehicular growth in city

With the bludgeoning population in the city, comes the energy demand - for electricity, cooking, heating, industrial use, and for running vehicles. Heating is required for almost nine months of the year and is generated primarily through

[1] ESMAP, 2004. "*Impact of Improved Stoves on Indoor Air Quality in Ulaanbaatar, Mongolia.*" The World Bank, Washington DC, USA

[2] This study was conducted as part of the World Bank consultations with the City of Ulaanbaatar. Full report and the analysis details are available @ http://www.urbanemissions.info/ulaanbaatar

combustion of coal. Electricity and heating is provided to apartments and commercial buildings from 3 large combined heat and power plants[3] (CHP 2, 3, & 4) and around 910 heat only boilers burning 6.0 million tons of domestically produced lignite per year.

In the domestic sector, heating in Gers (the traditional Mongolian dwellings consisting of a wooden frame beneath several layers of wool felt) is provided by stoves using an estimated 0.6 million tons of coal in 2005. An unofficial survey estimates this number to be much higher because of growing kiosks and food shops that use smaller stoves, if not similar size as Gers, for heating purposes. In the last five years, the number of kiosks is on the rise along with Ger population. On average, Gers are estimated to consume 5 tons of coal and 3.0 $m^3$ of fuel wood per year. Most of the coal is consumed during the heating season and fuel wood during the spring and summer months for cooking and minor heating needs.

**Table 1: Vehicle split in the Ulaanbaatar**

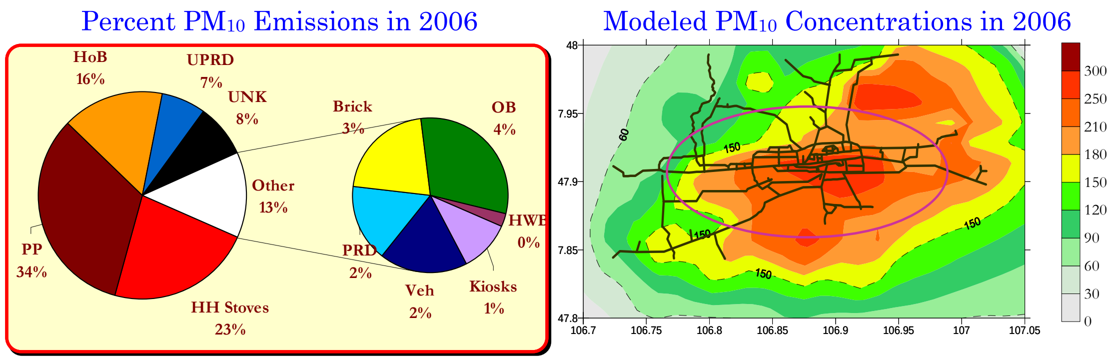
| Category | 2004 | 2005 | 2006 | 2010 | 2015 | 2020 |
|---|---|---|---|---|---|---|
| Passenger vehicles | 49,123 | 54,316 | 58,541 | | | |
| Trucks | 9,658 | 10,954 | 12,001 | | | |
| Buses | 6,553 | 6,130 | 6,303 | | | |
| Tank Cars | 702 | 587 | 448 | | | |
| Special Vehicles | 1,325 | 1,753 | 2,247 | | | |
| Sub Total | 67,361 | 73,740 | 79,540 | **104,993** | **146,990** | **205,786** |
| Motorcycles | 333 | 370 | 368 | | | |
| Tractors | 730 | 656 | 708 | | | |
| Trailers | 1,190 | 1,384 | 1,490 | | | |
| **Grand total** | **69,614** | **76,150** | **82,106** | **108,380** | **151,732** | **212,424** |

*Source: Dr. Sereether, Director, Department of Transport, Ulaanbaatar, Mongolia*

The transport sector is the fastest expanding sector (see Figure 1), with an estimated 15 percent annual growth rate in the last five years, especially private passenger vehicles. In 2006, total in-use vehicular population was estimated at 82,000 inclusive of public transport system. This number is based on the statistical report, although unofficial numbers put it 50 percent higher, with 60% of the fleet of age more than 11 years. Currently, most of the heavy duty fleet, especially diesel trucks are old and tend to produce higher emissions compared to the permissible levels. The current growth is expected to continue in the coming decade (Table 1), more than doubling the vehicular population by 2020 to a grand total of ~212,500. A large portion of this increase is expected among passenger vehicles – car and vans.

[3] CHP4, 2006. Central Heating Power plant No. 4, Ulaanbaatar, Mongolia. http://tpp4.energy.mn

Figure 2




Annual Total $PM_{10}$ = 98.5 ktons
Annual Total $PM_{2.5}$ = 43.5 ktons
Annual Total $SO_2$ = 23.3 ktons
Annual Total $NO_x$ = 53.2 ktons

Daily Standard = 150 μg/m³
Annual average = 200 μg/m³
Winter average = 265 μg/m³
Summer average = 125 μg/m³

PP = power plants; HH = household; HoB = heat only boilers; PRD = paved road dust; UPRD = unpaved road dust; Veh = vehicular exhaust; HWB = hospital waste burning; OB = open burning; UNK = miscellaneous

A survey of sources and emissions of primary air pollutants was conducted in the SIM-air framework. Figure 2 presents an estimated emissions inventory of $PM_{10}$, $SO_2$, and $NO_x$, for base year of 2006. For PM emissions, single largest emitters are the power plants (36 percent) followed by domestic stoves (25 percent) and industrial boilers (17 percent). The direct vehicular contribution to PM is less but is increasing more rapidly than the household and industrial sectors. It is important to note that although the large point sources dominate the overall emissions, the impact of low lying sources such as cooking stoves, small boilers for heating, vehicular emissions, and road dust (an indirect vehicular source) is the most to the ambient ground level concentrations – for details on the methodology and the inputs, please refer to the full report.

## Mapping of PM Pollution & Impacts

For dispersion modeling of emissions, the ATMOS model[4] (Calori, et al., 1999, and Guttikunda, et al., 2003) was utilized. The SIM-air model was setup for a 30 x 20 grid at a resolution of ~1 km. Gridding process included geographical maps from the city council – Ger areas and road maps, and industrial location information (for power plants and 350+ HoBs) from local experts. Note that the distribution to the grids is subjective where real location information is not available.

Figure 2 also presents modeled annual average total $PM_{10}$ concentrations for year 2006. This includes the primary PM contribution and secondary contributions from $SO_2$ and $NO_x$ emissions. For the formation of secondary concentrations, a simplified chemical conversion is assumed. Lines in black represent major road networks in Ulaanbaatar.

[4] ATMOS, Dispersion model. http://www.cgrer.uiowa.edu/ATMOS/atmos-urbat-linux/; **Calori, et al., 1999**. "*An urban trajectory model for sulfur in Asian megacities: model concepts and preliminary application.*" Atmospheric Environment 33, 3109–3117; **Guttikunda, et al, 2003**, "*The Contribution of Megacities to Sulfur Pollution in Asia. Atmospheric Environment.*" Atmospheric Environment 37, pp. 11-22.

The total $PM_{10}$ concentrations exceed health guidelines set by WHO and Mongolian standard for 24 hours of 150 μg/m$^3$. Currently, there is only one nephlometer in operation since March, 2007 with the air quality division, located in the center of the city. During May, 2007, $PM_{10}$ concentrations averaged 170 μg/m$^3$. In general, winter concentrations are at least double that of the summer months, measured at the National University of Mongolia (Dr. Lodoysamba). In 2006, summer $PM_{10}$ concentrations averaged 39 - 180 μg/m$^3$ compared to 118 - 330 μg/m$^3$ in the winter months. For the city center, model calculations simulated annual average peaks of 250 μg/m$^3$ and average for the domain circled in the Figure 2 is 200 μg/m$^3$, with winter average of 265 μg/m$^3$ (November to March) and summer average of 125 μg/m$^3$ (May to August). Of the total $PM_{10}$, secondary pollution averaged 15%.


Typical air pollution picture in Winter months (Jan'07) by *Dr. Myagmarjav, MNE*

The difference between the seasons is very prominent. For winter months, wind speeds are generally low, westerly direction dominating for most of the season, which pushes emissions from Gers in the West and power plant emissions in the south towards the city center. It is also important to note that the coal consumption in the winter months is higher than the spring and summer months. For household stoves, it is approximately 7:1 ratio for winter to summer months. The power plants which operate at a higher load in the winter and the HoBs operating mostly in the winter months, show similar trend. Also due to lower mixing heights during the winter season, the dispersion of the low lying sources is very limited, increasing the severity of exposure to high PM pollution levels.

**Table 2: Average modeled contribution range to city center**

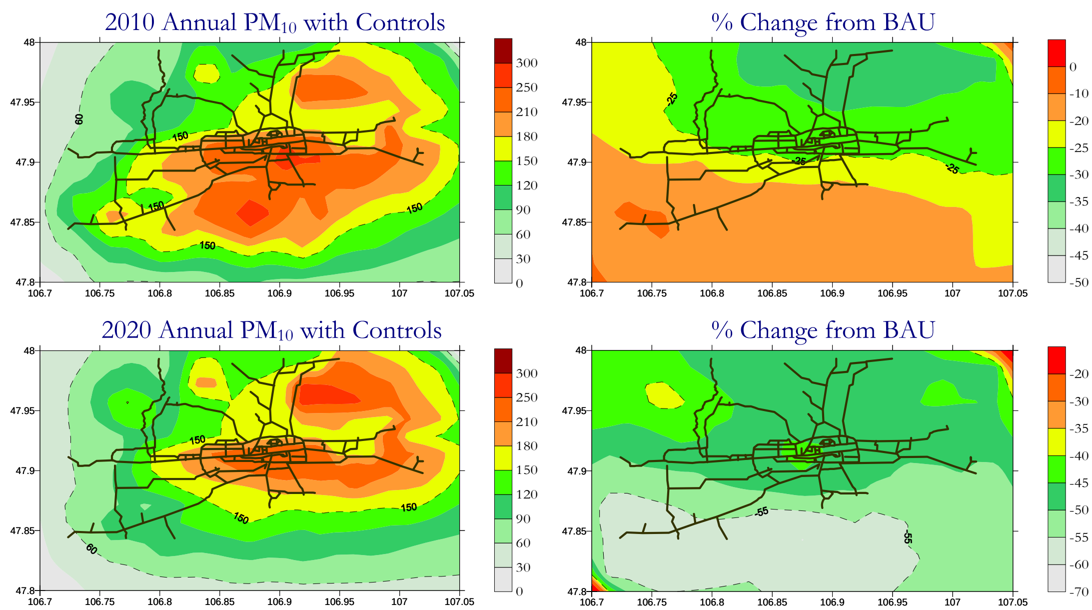
| Source Type | Percentage Range |
|---|---|
| Household stoves | 25-40 |
| Heat only boilers | 15-25 |
| Power plants | 15-30 |
| Vehicles | 6-8 |
| Vehicles + Road dust | 18-21 |
| Brick industry | - |
| Open waste burning | 4-6 |

The ground level sources contribute significantly more than the elevated sources (see Table 2). In general, the low lying sources, cooking stoves and HoBs, contribute to an estimated 40-60 percent. Road dust is the most uncertain and is more prominent in the dry seasons. Contribution of brick industry is small in the east (10 factories) and west (11 factories), but at the current rate of demand for construction material, this contribution is expected to grow in the coming years. Open waste burning, which is distributed along the Ger locations, shows 3-6 percent, but contribution is high in absolute numbers. Similar to the coal consumption, waste generated is more in the winter months and most of it is locally burnt. In winter months, these contributions are much higher than the annual averages, given increased coal consumption for heating in the households and power sector.

## Opportunities for Pollution Management

Ways in which air pollution can be addressed along with expected level of impact is presented in Table 3 (end of the report). The interventions listed include institutional, policy, economic, and technical options which vary from the traditional command-and-control to more innovative, flexible, and market-oriented types.

**Figure 3**




Of the interventions listed, two scenarios were simulated for years 2010 and 2020 (see Figure 3).

- For 2010, assumed improvements from business as usual (BAU) include 50 percent shift to improved stoves in Gers; 50 percent shift from coal to briquettes for stoves and HOBs; 50 percent abolishment of small heat only boilers operating in the city; 50 percent improvement in the garbage collection and reduction of in-situ burning; and use of fly ash from power plants for making bricks.
- For 2020, assumed improvements from BAU: 100 percent shift to improved stoves in the households; 100 percent shift from coal to briquettes in the household stoves; 50 percent abolishment of small heat only boilers operating in the city; halving the growth of small and big heat only boilers and promotion of district heating and solar water heating; 50 percent

improvement in the garbage collection and reduction of in-situ burning; introduction of ESPs for all the power plants without (2 & 3) and improving the efficiency of ESPs for CHP-4; introduction of FGD systems reducing SO2 and NOx emissions by 75 percent; use of fly ash from power plants for making bricks; mechanical sweeping of the paved roads and reducing the silt loading on roads for the spring and summer and conversion of a fraction of roads from unpaved to paved in Gers.

Initiatives aimed at reducing emissions from local sources should be based on assessments of their relative contributions to the pollution load. Interventions listed are tailor made for the city of Ulaanbaatar, based on existing practices and institutional setup; and based on discussions with local experts in May, 2007 in Ulaanbaatar and on-going programs described in Table 3; however they provide a direction to policy makers and allow them to evaluate the relative benefits and impacts of different policy strategies.

The two scenarios (see Figure 3), upon full implementation, are expected to achieve reductions of 20-30 percent in 2010 and 30-40 percent in 2020 compared to their respective business as usual estimates for annual average $PM_{10}$ pollution. Possible reduction in incurred health costs due to PM pollution was estimated using methodologies[5] and dose response functions. For 2010 and 2020, control scenarios estimated avoided health costs of US$148 and US$690 million respectively.

## In Conclusion

The problem of air pollution is complex for there are no *cookie cutter* solutions. Local authorities need to develop a well defined process for action planning, coupled with activities such as – establishing a baseline, analyzing the source categories, developing set of options, considering the necessary indicators (air quality improvements, perceptions and practicability); preferably based on existing institutional capacity, to build an informed decision support system.

**Acknowledgments**: The views expressed in this report are entirely those of the authors and not necessarily of the organizations or the countries listed. Analysis presented is based on discussions with local bodies in Mongolia, following the formation of Air Quality Management Bureau and a series of workshops. This analysis was financially supported by the World Bank, between May-June, 2007.

[5] HEI, 2004. "*Health Effects of Outdoor Air Pollution in Developing Countries of Asia: A Literature Review*." Health Effects Institute, Boston, USA; Li, et al., 2004. "*Curbing Air Pollution in Megacity: Human Health Benefits of Air Pollution Control in Shanghai*." Journal of Environment Management, 70, pp 49-62.

**Table 3: List of interventions planned for 2010-2020 for IAQM and expected level of impact in Ulaanbaatar**

| Intervention | Status | Impact on Air Quality | Comments |
|---|---|---|---|
| Particulate pollution monitoring | Current capacity to monitor PM pollution in the city is low. Programs in place to setup seven new stations and to conduct source apportionment study for further analysis by National University of Mongolia. | Enhances the Institutional capacity of air quality division in identifying the pollution hot spots. | Air quality monitoring is essential to evaluate the impact of air pollution reduction measures. |
| Public awareness | Media, public, and political demands. There is increased awareness in the local media for air pollution | Enhances institutional capacity for regulation and enforcement. | An essential part of the campaign to promote energy efficiency at the household and industrial level. |
| Improved cookstoves | Pilot program to promote improved stoves is under implementation. A total of 20,000 improved stoves were distributed with 50 percent subsidy (GEF project). Programs are in place for scaling up and introducing new and improved stoves. | This intervention is expected to have an immediate impact on ground level concentrations. Full conversion is estimated to reduce ~11,000 tons of total $PM_{10}$ emissions or ~9 percent from business as usual in 2010. | Cooking stoves are a low lying source and contribute significantly to indoor and outdoor air pollution, especially in the winter months. Also impact of black carbon or soot due to inefficient coal combustion in stoves and efforts are underway to received financial support under clean development mechanism. |
| Fuel substitution - briquettes | Private and small scale projects are in place producing charcoal briquettes using sawdust. Among the scale-up programs, three programs are in place for production of 300,000 tons a year coal fired briquettes. | Upon full implementation, clean coal technology briquettes for cooking stoves and industrial HoBs is expected to have high impact on ambient PM. Full conversion is estimated to reduce ~12,500 tons of total $PM_{10}$ emissions or ~10 percent from business as usual in 2010. | This intervention has the largest impact among the cookstoves and HoBs, for not only emissions are reduced from scattered low-lying sources, but also a single point source offering better control options. |
| Pollution control at power plants | Only CHP-4 is using ESP at 95 percent PM capture efficiency. One of the clean coal briquette manufacturing plant is planned at the power plants for efficient production and pollution control. | Although this is an elevated source and doesn't contribute as much as low-lying sources to ambient levels, it is still the largest emitter in the vicinity. Implementation of ESP for other and new power plants will result in 10-20 percent of ambient PM concentrations. Estimated reductions are ~21,500 tons or ~20% of the 2010 BAU. | Technology for ESPs and FGDs is mature and available internationally at efficiencies higher than 95 percent. |
| Garbage collection | Limited program in place with substantial amount being burnt in-situ | Impact of this intervention on air quality is immediate, but small in proportion. | This requires institutional set-up for garbage collection and landfill management. |
| Liquefied petroleum gas | Half of official taxis are converted to LPG. | Conversion of a larger fleet in the next decade will have significant impact on air quality. | This intervention needs pricing and supply reforms, to make it more widely available. Can be |

| | | | |
|---|---|---|---|
| | | | costly to low-income households and high-volume commercial users. Most readily option to replace coal in cooking in the housing sector. |
| Controlling fugitive dust on paved and unpaved roads | Manual sweeping on the main corridors in the center of the city are in place. | A larger intervention for capture of fugitive dust via wet sweeping and conversion of a large section of unpaved roads to paved roads will have the largest impact in the Ger areas. | This intervention is expected to reduce spring and summer time on-road fugitive source. Heavy-duty vehicles for this purpose are available internationally. |
| Going to unleaded gasoline | There is no testing facility for lead in gasoline. | Reduction in lead content in ambient air. | Gasoline is imported and city lacks testing facilities to check lead content in gasoline. This intervention requires a strong resolution to import unleaded gasoline only. |
| Energy efficiency at heat only boilers | A large of old technology boilers are in use operating at 40-50 percent efficiency. | Improving efficiency of existing boilers, replacement of old heating boilers or connecting to new centralized district heating facilities, will have an immediate 30-40 percent reduction in HoBs contribution to ambient air pollution. | Nearly 800 small boilers are operated in the city for heating purposes. This intervention can reduce dispersed pollution by abolishing small scale boilers and upgrading them to district heating system. Increased demand for district heating is expected increase the coal consumption at power plants. |
| Solar water heating systems for new housing complexes | No activity in place. | Impact on air quality will be immediate due to reduction in demand of district heating when possible. Since Ulaanbaatar experiences on average 250 days of sunlight, this is a likely intervention for new housing complexes. | This is an expensive and a possible short term intervention. With the new 40,000 housing system in plan, the solar water heating can reduce the load on district heating system and power plants. Technology is available internationally. |
| Gasification of urban solid waste | Small scale projects in place using livestock waste. | Impact on air quality is small compared to other sources in place, but a good in-situ source of energy, improving household and industrial efficiency. | In combination with garbage and solid waste management, can supply for small scale energy needs and heating. Technology is well documented and available internationally. |
| Ash ponds at power plants | No activity in place. | This intervention is expected to reduce spring and summer time fugitive source out of power plants ash ponds. This is a very uncertain source dependant on meteorological conditions. | Technology for using fly ash to make bricks and construction material is well studied and available internationally. |
| Bus rapid transport | A feasibility study of allowing bus rapid transport is underway. | Fleet is small and their effect may be counteracted by growth in the passenger vehicles and barriers. | This intervention needs further institutional setup and lacks policy frameworks for inspection and maintenance for buses. |

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