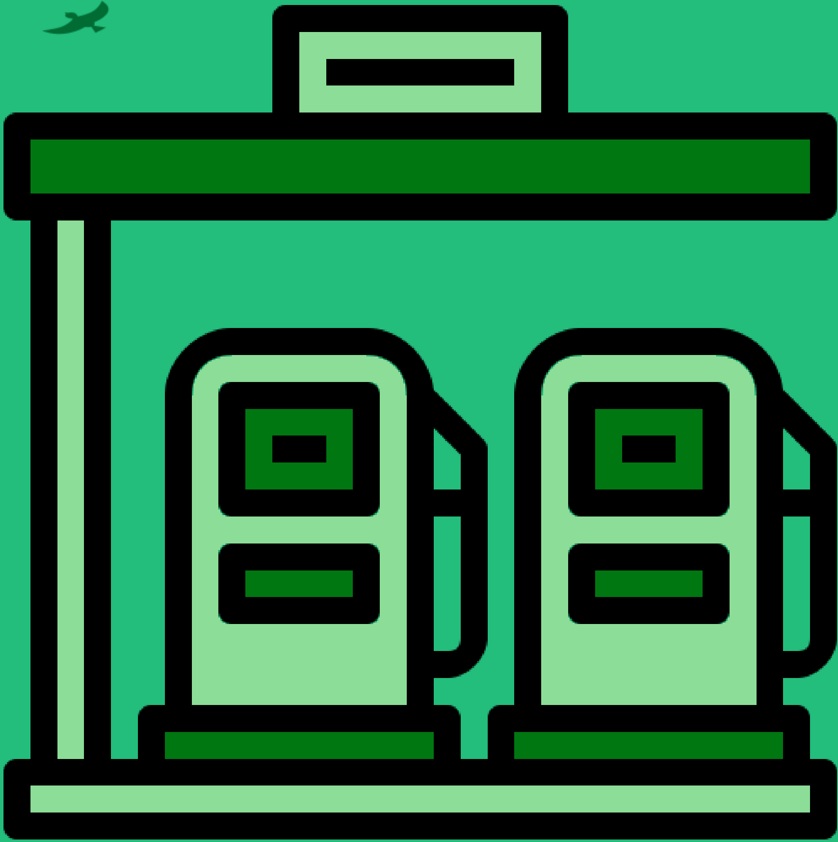

A Review of the Impact of Biofuels on Local, Regional & Global Air Quality

URBAN emissions .info

Sarath Guttikunda

SIM-air working paper series # 15-2009

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(UEinfo) was founded in 2007 with the vision to be a repository of information, research, and analysis related to air pollution. There is a need to scale-up research applications to the secondary and the tertiary cities which are following in the footsteps of the expanding mega-cities. Advances in information technology, open-data resources, and networking, offers a tremendous opportunity to establish such tools, to help city managers, regulators, academia, and citizen groups to develop a coordinated approach for integrated air quality management for a city.

UEinfo has four objectives: (1) sharing knowledge on air pollution (2) science-based air quality analysis (3) advocacy and awareness raising on air quality management and (4) building partnerships among local, national, and international airheads.

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

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A Review of the Impact of Biofuels on Local, Regional, and Global Air Quality

Biofuels in the Mix !

[1]The development of modern biofuels for various energy applications is gaining momentum - both in terms of applications and impacts. Liquid biofuels for transport received special attention in the literature (ESMAP, 2005a; GTZ, 2006; ECN, 2008; Harvard, 2008; IUCN, 2008; NREL, 2000; Pew Climate, 2008; Utria, 2005; USDA, 2007; WRI, 2007; WWI, 2006) and numerous studies on the sustainability (economic and environmental) of large-scale biofuels production continue to be undertaken (Belfer Center, 2008; Climate Group, 2008; EEA, 2008; MIT, 2008; OECD, 2006; Royal Society, 2008; UNDP, 2006; World Bank, 2007). This includes large scale production of the biofuels such as Ethanol and Biodiesel, based on food and non-food crops (FAO, 2008), which are combined with traditional vehicular fuels (gasoline and diesel) in varying proportions. Latin America has the largest transport sector share (GTZ, 2005), owing to the growing sugarcane based ethanol industry (**Figure 1**), and similar trends are expected in the other regions[2].

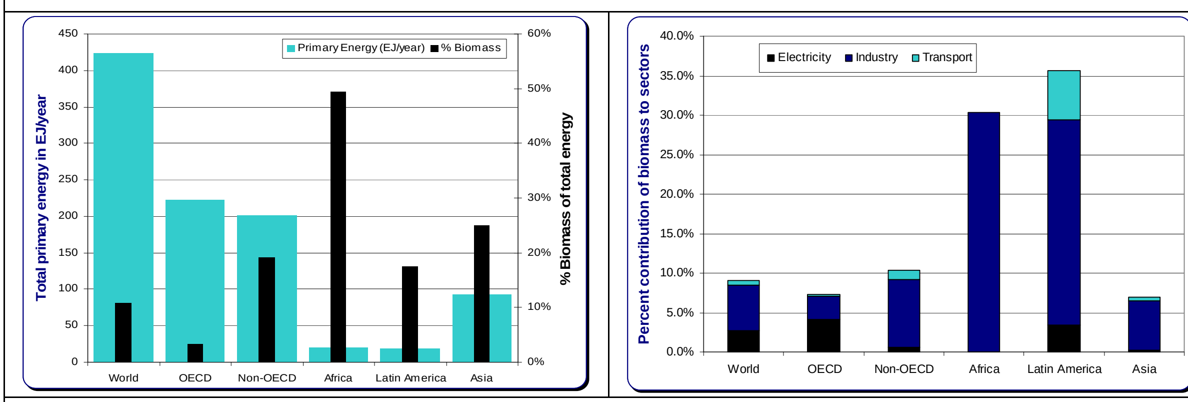


Figure1: Percent contribution of biomass to total energy and sectors (ESMAP, 2005b)

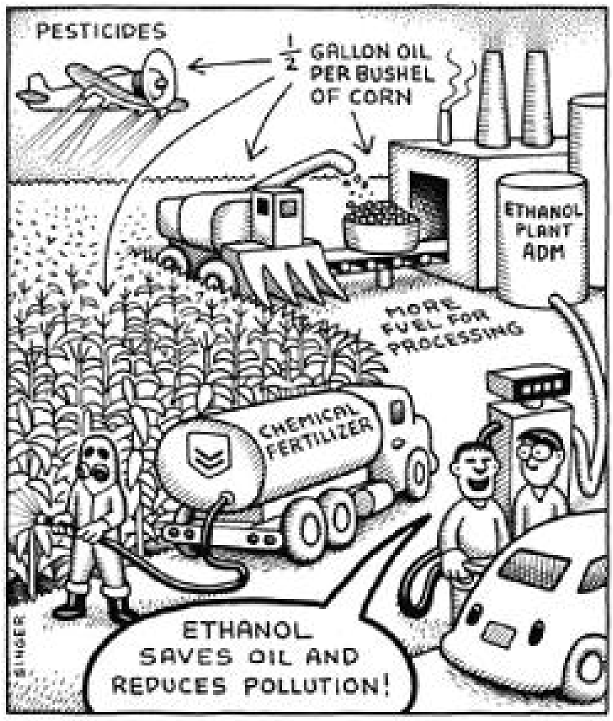
Is Yellow the new Green?[3] The reported environmental benefits upon replacing the use of fossil fuels may be substantial but are also controversial. A large amount of literature already exists, discussing the usefulness and benefits of biofuels and constraints associated with their production and distribution. For example, the ESMAP (2005a) report - says that

[1] Sections of this working paper will appear in a Biofuels review report by IRG Consultants, USA.

[2] The sustainability of the ethanol production is argumentative. For example, as much as the US government is pushing the ethanol production mandates (e;g., forcing a 10 percent mix in the gasoline, http://www.worldwatch.org/node/6017), the farmers in the Midwest are already witnessing a downturn in the demand (http://www.nytimes.com/2009/02/12/business/12ethanol.html). One reason being the fall in the oil prices from $140 per barrel in 2008.

[3] Some argue that the Biofuels are the new generation of fuel, but it is important that this issue is scrutinized from both the sides - Energy and Environment (see Daniel Sperling @ http://pubs.its.ucdavis.edu/publication_detail.php?id=1056). The Biofuels might reduce our dependence on the oil, on a short term basis, but with the increasing inter-linkages with the food supply and the environment (air & water pollution), this gets complicated. According to Mark Jacobson of Stanford University, when it comes to energy sustainability (http://www.newscientist.com/article/dn16419-top-7-alternative-energies-listed.html), the other alternatives such as solar and wind, rank higher than the biofuels.

the use of biofuels can result in significant reduction in the emissions of certain pollutants – criteria pollutants such as particulates (PM) and GHG's such as carbon dioxide (CO_2) while other pollutants such as nitrogen dioxides (NO_x) may be increased. Similar studies and results are presented in Deluchhi, 2006 and IEA, 2004. On the other hand, large-scale production of biofuels from agricultural crops can put pressure on food supply and the local environment (FAO, 2005; FAO, 2008; OECD, 2006).



Though the potential for scale up exists, it is important to view this issue in a holistic framework, beyond the production and consumption of biofuels[4].

In addition to transportation fuels, there is growing evidence of the bioenergy usage for the small-scale rural applications, such as running irrigation pumps and rice mills (APEC, 2005). Also at the household level, biofuels are being developed as substitutes to highly polluting traditional biofuels (e.g. wood, dung, and field residue), kerosene, and charcoal for cooking and heating. The later application is gaining momentum, especially in the rural settings of Asia and Africa [5]. For example, Jatropha and Pongamia, are often cited as energy crops with large potential for small-scale rural applications (Winrock, 2004; Parsons, 2005; Rajvanshi, 2006). However, there is little information on the costs and benefits (air quality, climate change, economic, social) of production for such rural applications.

The sustainability question aside, this review will focus on the environmental externalities (air quality) – positive and negative, due to the introduction of biofuels on a large scale.

[4] BBC, 2006, "Biofuels: Green energy or grim reaper". http://news.bbc.co.uk/2/hi/science/nature/5369284.stm.

[5] Jatropha in Africa @ http://www.ecoworld.com/home/articles2.cfm?tid=367
Seeds of Change: Jatropha in India @ http://www.new-ag.info/07/06/develop/dev3.php
Oil, toil and trouble bubbling - India's jatropha tussle @ http://www.new-ag.info/08/06/focuson/focuson2.php

Transport & Air Quality

Transport, the fastest growing air pollutant emitting sector, is one of the main culprits (if not the primary) causing air pollution in the urban centers of the developed and developing countries. **Figure 2** presents a summary of the estimated share of transport sector to the local air pollution, based on a series of source apportionment studies across the world. The numbers represent the direct vehicular emissions and do not include the fugitive dust from paved and unpaved roads due to the vehicular activity, which is a major part of the measured PM pollution, especially in the developing countries.

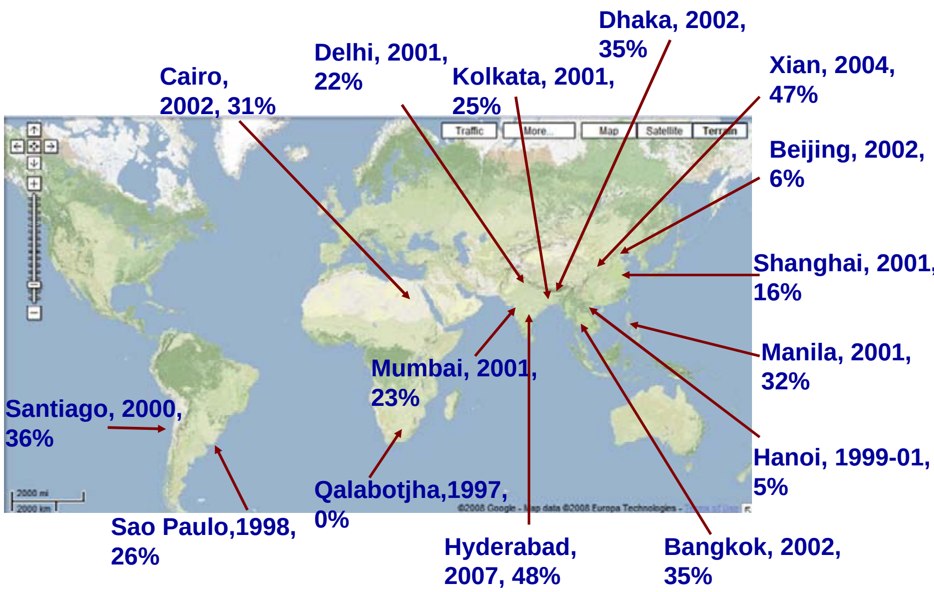


Figure 2: Summary of source apportionment results, presenting the year of study and share of transport to measured ambient air quality (Guttikunda, 2008a)

The cities (most) presented in **Figure 2** are megacities, cities with population more than 10 million. In Asia, the secondary cities, with population more than 2 million are increasing (Demographia, 2008) and given the economic and industrial growth, demand for personal cars is growing and these cities are increasingly facing the air pollution problems, especially from the transport sector. It is important to note that the results presented in **Figure 2** are based on monitoring data (operated at limited capacity), and in reality, the exposure levels (and times) of transport related pollution is expected to be higher.

In the transport sector, especially for the PM pollution, the diesel combustion dominates – in number and quantity, especially from the buses and the goods vehicles. Among the personal transport, the gasoline is the traditional fuel, but due to subsidy programs for diesel and the emerging engine technologies, the diesel component is increasing (GSI, 2006). **Table 1** presents average emission factors for a vehicle fleet in the developing countries.

Table 1: Average Emission Factors for Vehicular Fleet in Developing Countries[6]

	Gasoline			Diesel				CNG			
	2Ws	3Ws	Cars	Cars	LDV	HDT	Bus	3Ws	Cars	LDV	Bus
PM_{10}	0.10	0.20	0.10	1.00	1.25	2.00	1.50	0.10	0.05	0.02	0.02
$PM_{2.5}$	0.05	0.08	0.03	0.60	0.50	1.00	0.80	0.05	0.02	0.01	0.01
SO_2	0.02	0.02	0.07	0.40	0.30	1.00	1.00	0.00	0.00	0.00	0.00
NO_x	0.15	0.10	0.20	1.25	2.00	10.0	10.0	0.35	0.20	3.50	2.50
CO	2.50	8.00	5.00	2.00	2.50	3.50	3.50	3.50	1.00	3.50	3.50
CO_2	40	80	200	250	500	850	850	70	100	450	450
HC	1.50	5.00	1.00	0.40	0.20	1.00	1.00	0.15	0.02	0.10	0.10

In Asia, current trends suggest that the transport fleet will grow in the coming decades. **Figure 3** presents the speculated trends in the vehicular population and related PM emissions (local indicator) and CO_2 (global indicator), calculated by Fabian et al., 2008, indicating a larger role for management options in the transport sectors – including stringent emission standards, emission control technologies, fuel substitution, and traffic management.

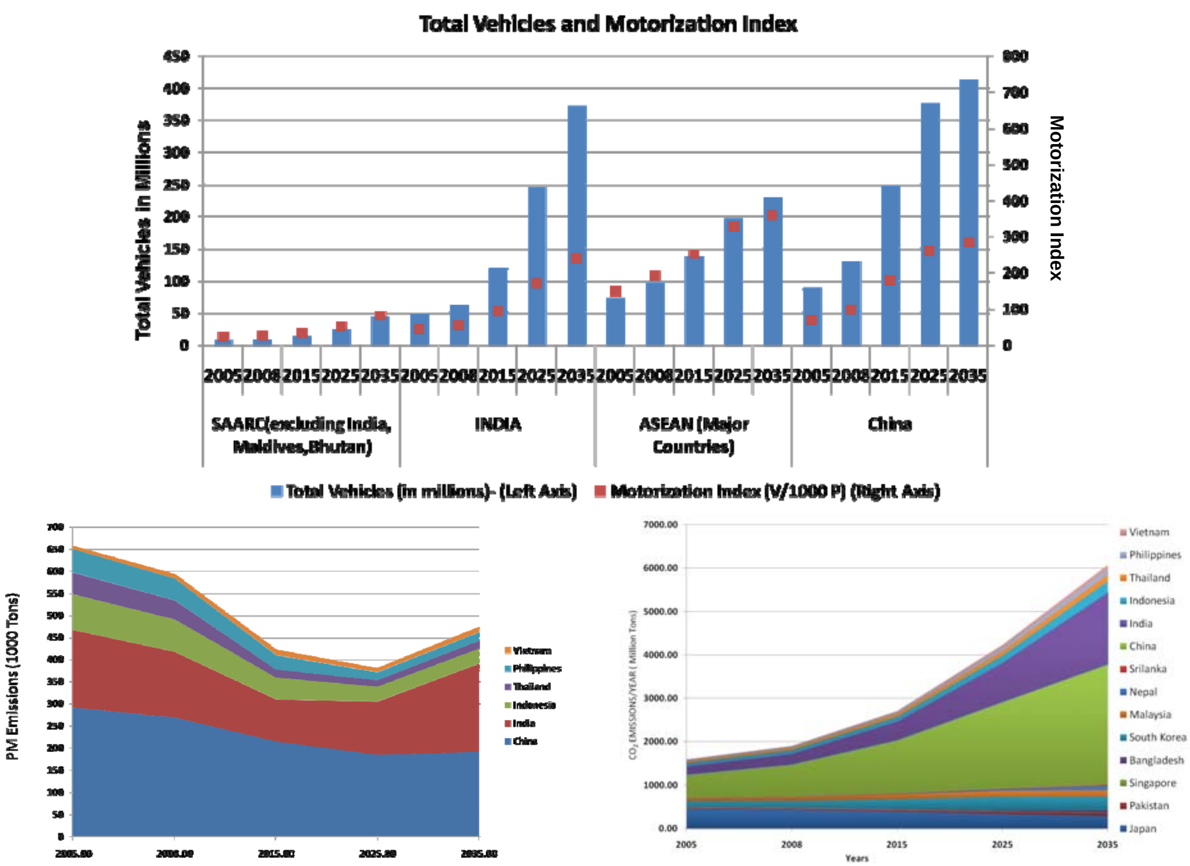


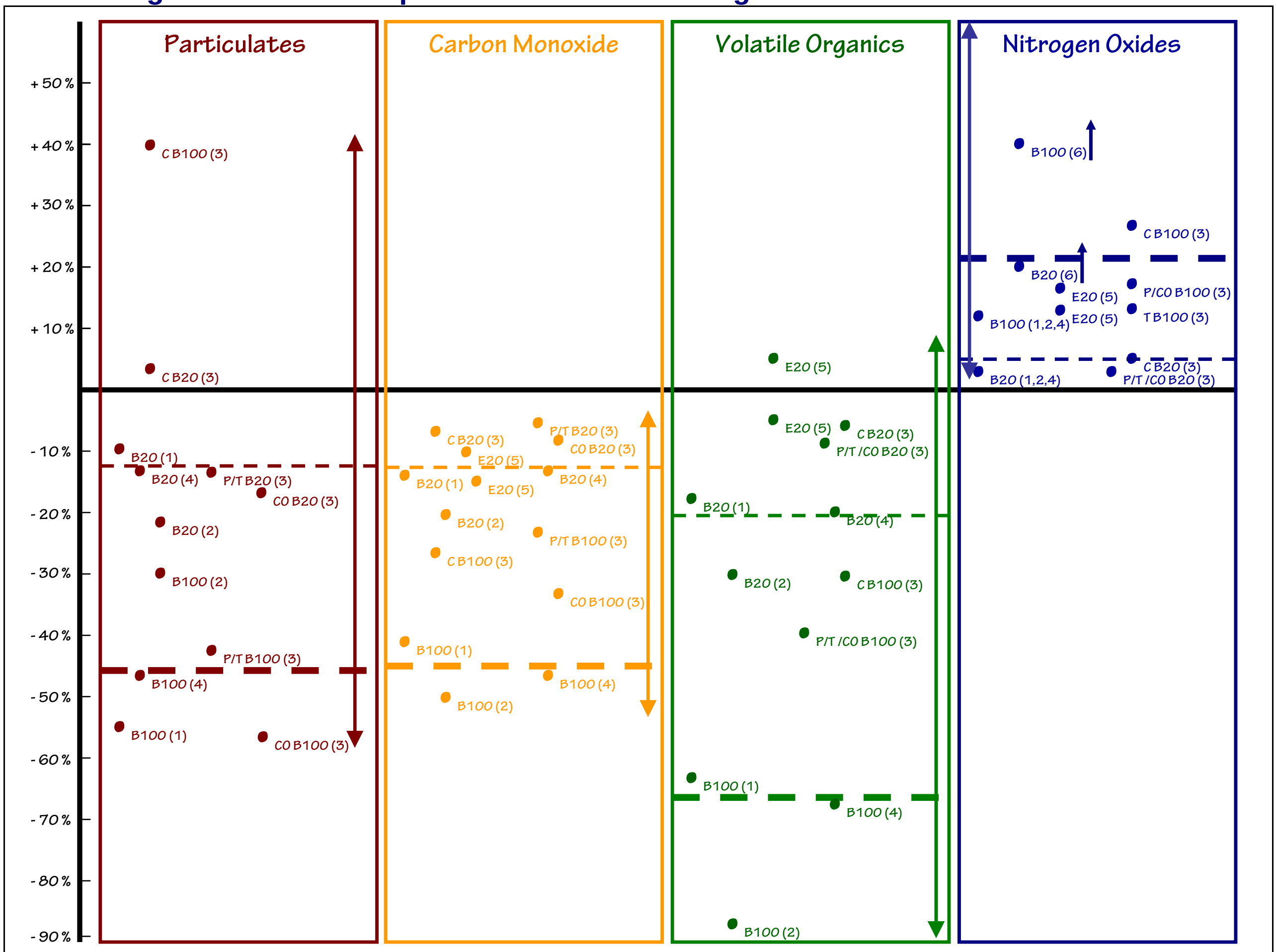
Figure 3: Total Vehicles in Asian Countries, Total PM Emissions, and CO2 Emissions (Fabian, 2008)

[6] Details on the methodology, use, and constraints of these emission factors is presented in the SIM working paper 02-2008, "Four Simple Equations for Vehicular Emissions Inventory" @ http://www.urbanemissions.info. The average emission factors presented in this table are author's interpretation from a wide literature; discretion is advised when in use.

Biofuels & Air Pollutant Emissions

In the urban centers, given the economic and industrial growth and increased motorization, these cities are increasingly facing the air pollution problems. The biofuels have the potential to leap-frog the developments for the alternative fuel and a number of tests in laboratory and on road were undertaken to estimate the potential benefits or otherwise. Some low and high blends of ethanol are already in use in United States, Brazil, and Europe (ATSE, 2008; ECN, 2008; GTZ, 2005; GTZ, 2006; Rajvanshi, 2007; UNCTAD, 2006; USDA, 2007). In Asia, the India and China announced their plan to scale up production and use of biofuels for transport (Biofuels Digest, 2008, and CEnet, 2007).

Figure 4: Estimated pollutant emission changes for various biofuel blends[7]



References in parenthesis: (1) NREl, 2003; (2) PCI, India, 2003; (3) CSIRO, 2007 **; (4) EPA, www.biodiesel.org; (5) PCD, Thailand, 2008; (6) Verbeek, et al., 2008

** The results are compared to use of ultra low sulfur diesel in the heavy duty trucks in Australia.

[7] Acronyms: B20 is 20% of biodiesel in diesel; B100 is 100% of biodiesel in diesel; E20 is 20% of ethanol in gasoline; C BD= canola based biodiesel; P BD = Palm oil based biodiesel; T BD = Tallow based biodiesel; CO BD = cooking oil based biodiesel.

Figure 4 presents a summary of possible changes in the emission levels by introducing biofuels. This summary represents averages from various studies; the thin dotted line represents average for B20 and the thick dotted line represents average for B100.

In general, the substitution of the regular fuels (gasoline and diesel) with the biofuels is expected to reduce most of the air pollutant emissions and thus reducing the health risks due to exposure. Depending on the level of penetration of the biofuels, they are expected to provide significant benefits to local air pollution.

In Asia, among the criteria pollutants, the particulates dominate. The biofuels are tested to reduce on average the PM & carbon monoxide (CO) emissions by ~12 percent and ~45 percent for B20 and B100 respectively, for most of the feed stocks. For canola based biodiesel, the net PM emissions are expected to increase.

For the volatile organics (VOCs), depending on the end use, the emissions are expected to reduce up to ~60 percent. However, when used in motorcycles, the VOC emissions are expected to marginally increase (PCD, Thailand, 2008).

At individual pollutant level, the sulfur pollution is reduced the most by replacing the regular diesel. For B20 and B100, a reduction of 20 percent and 100 percent of the sulfur emissions is expected respectively (not presented in **Figure 4**). However, the NO_x emissions from the biofuels usage are expected to increase for all blends, ranging as high as 700 percent.

To better understand the possible role of biofuels for cleaner air, the complex interdependencies and better data on the externalities, such as weighing potential benefits (e.g. emission reductions) against potential costs (e.g. biodiversity losses) should be developed.

Impact of Biofuels on Air Quality

At the local level, the air quality is a key environmental indicator and this is significantly correlated with **PM pollution**, both from the primary emissions and secondary pollution. The secondary pollution forms a major part of the fine particulates (PM less than 2.5 micron meter in aerodynamic diameter and critical for health impacts due to exposure) and includes sulfates from SO_2, nitrates from NO_x, and secondary organic aerosols (SOA) from VOCs.

Among the VOCs, the formation of SOA is neither simple nor straight forward. This also depends on the chemical composition of the pollutants in the atmosphere and local meteorological conditions, such as humidity levels to support the relevant chemical interactions and transformations (also known as the photochemistry)[8].

[8] For details on the photochemistry (NOx-VOC-Ozone interactions) see "Introduction to Atmospheric Chemistry" by Dr. Daniel Jacob - http://www.as.harvard.edu/people/faculty/djj/book; NARSTO's reports on air pollution transport and chemistry @ http://www.narsto.org/section.src?SID=74

Never the less, the introduction of biofuels is expected make a significant dent in the direct and the indirect sources to PM pollution. On a short term, the biofuels are considered a good fit for immediate reduction of local pollution, improve the air quality index[9]; this is not always positive, as it depends not only on the end-use benefits of the biofuels, but also on the life cycle assessment of the biofuels, including production and processing..

In the developing countries, among the many pollutants linked to health risks, the PM pollution dominates the policy dialogue and decision making process. Unlike in the developed countries of North America and Europe, where other pollutants such as **Ozone** share a substantial role[10], ozone is not yet considered a criteria pollutant in Asian cities, nor measured on a regular basis.

The share of transport sector to air pollution is growing, in spite of the efforts to introduce stringent emission standards among new vehicles, better inspection and maintenance for the older vehicles and providing alternative fuels and modes of transport[11]. Among these emissions, NO_x is a growing pollutant and introduction of biofuels is expected to further increase its contribution to ambient PM levels (in the form of nitrates), as well as contribute to the ozone pollution levels, especially along the transport corridors; resulting in local and regional (transboundary) impacts on health and agriculture (BAQ, 2008).

The NO_x emissions play a critical role in the formation of ozone, in combination with VOCs and other pollutants (NARSTO, 2004). In an urban environment, the photochemical reaction sequence initiated by the NO_x, VOCs, and CO, can alter the ozone pollution levels in either way. Jacobson, 2007 (**Box 1**) predicts that, in the United States, the substitution of gasoline or diesel with ethanol by 2020 will lead to ozone formation. Given the stringent regulations on the ground level ozone pollution, this will violate the ambient standards and adding to the environmental costs. Jacobson also estimates that other energy alternatives such as wind and solar, rank higher than the biofuels, in terms of cost effectiveness and sustainability.

[9] See links to AQI across the global cities @ http://urbanemissions.blogspot.com/2009/02/air-quality-index-aqi-in-urban-centers.html

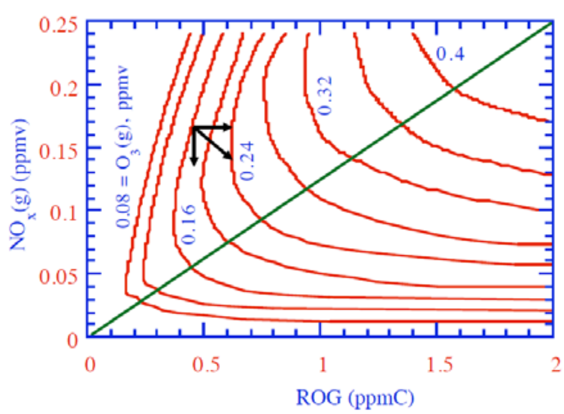
[10] See US EPA's "Ozone Transport Assessment Group" (OTAG) @ http://www.epa.gov/ttn/naaqs/ozone/rto/otag; Ozone pollution across Europe @ http://www.eea.europa.eu/maps/ozone/welcome (presents monitored ozone maps).

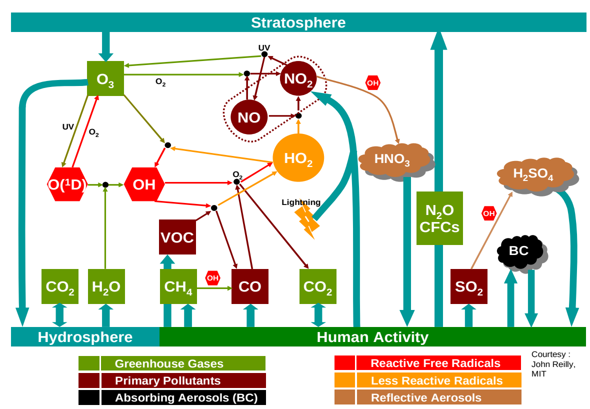
[11] "Reducing air pollution from urban transport" @ http://www.cleanairnet.org/cai/1403/article-60384.html; Energy efficiency and climate change considerations of on-road transport in Asia @ http://www.cleanairnet.org/caiasia/1412/articles-70656_finalreport.pdf

Box 1: Impact of Biofuels on Ozone Pollution

Jacobson, 2007, suggests that the impact of the growing emissions is enhanced for ozone, when gasoline is substituted with ethanol. This study analyzed the introduction of E85 (85 percent of ethanol in gasoline) in Los Angles (USA) for 2020, its impact on the ozone production levels, and corresponding impact on cancer cases and premature mortality. In one of the scenarios, introduction of E85 is estimated to result in an additional 120 deaths per year. The presence of enhanced NO_x and reduced VOCs, led to reduction in the presence of oxidizing agents and further photolysis led to production of ozone.

The chemical transformation resulting in ozone production cannot be explained in one equation; which is also interlinked with local chemical and meteorological conditions. A vital indicator in this scenario is the NO_x to VOCs ratio. Sensitivity of the ozone pollution due to the NO_x and VOC concentrations is depicted in the form of ozone isopleths (**left panel**) Figure represents ozone production and destruction potential (in ppm) depending on the local NO_x and ROG concentrations. ROG's are reactive organic gases, intermediates formed from VOCs during photochemistry.





In NO_x rich conditions, as predicted in case of biofuels substitution, the net production of NO_2 is higher, reaching higher steady state ozone concentrations during the day time. Reducing the VOC emissions (moving right to left on x-axis) and increasing the NO_x emissions (moving bottom to top on y-axis) results in net production of ozone and related health impacts, as summarized by Jacobson, 2007. In a less polluted area, with lower VOC and NO_x concentrations, the change in ozone production could be marginally low.

Given the complex photochemistry involving 100's of equations (**right panel**), the increase in NO_x emissions and reduction in others due to introduction of biofuels will be vital in the developing countries of Asia, altering the chemical balance towards ozone production or destruction. However, it is important to note that the changes are entirely dependent on the initial mix of emissions and level of photochemistry.

Average VOC/NO_x ratios and role of these ratios on ozone production and destruction in the urban environments is presented in Guttikunda et al., 2005. Table **below** presents the ratios from emissions inventory for year 2000 (in the units of g C per g NO_2)

City	Ratio	City	Ratio	City	Ratio
Dhaka	5.0	Tokyo	1.4	Seoul	0.7
New Delhi	2.5	Beijing	2.0	Manila	5.0
Calcutta	3.3	Shanghai	1.6	Singapore	0.7
Mumbai	2.5	Chongqing	2.5	Jakarta	10.0
Karachi	1.6	Hong Kong	1.2	Bangkok	5.0

The VOC to NO_x emission ratios (mass based) range from ~10 in Jakarta to ~0.7 in Seoul. The highly motorized cities like Seoul, Tokyo, Singapore and cities in the emerging markets of China and India have a lower VOC to NO_x ratios (high NO_x emissions) and prone to secondary pollution, depending on their position on the ozone isopleths.

The estimates, presented in **Table 2**, are based on GHG emissions life cycle assessments for the various feed stocks. On an average, a reduction of 35 percent in the GHG emissions is considered a modest estimate. The emissions exist at every stage from the biofuels production to the transportation of the product to the final destination (Delucchi, 2006). Hence, in situ applications (in the rural sector for domestic usage or at the industrial level for generator sectors) are expected to provide higher benefits, with the later transportation components nullified. **Figure 5** presents an overview of the stages involved in the life cycle assessments.

Table 2: Estimated range of GHG reductions and yields for various biofuels (SEI, 2008)

Fuel	Feedstock	Location	GHG reduction (relative to petrol or diesel)	Yield (liters per hectare)
Ethanol	Corn	USA	15-35 %	3000-4000
Ethanol	Sugar beet	Europe	45-65 %	4000-5000
Ethanol	Sugar cane	Brazil	80-90%	6000-7000
Ethanol	Cellulosic	USA	70-90%	4500-5500
Biodiesel	Soya	Brazil	30-50%	500-600
Biodiesel	Rape seed	Germany	40-60%	1000-1400
Biodiesel	Oil Palm	Indonesia	75-85%	4000-6000
Biodiesel	Various	Various	50-100%	Various

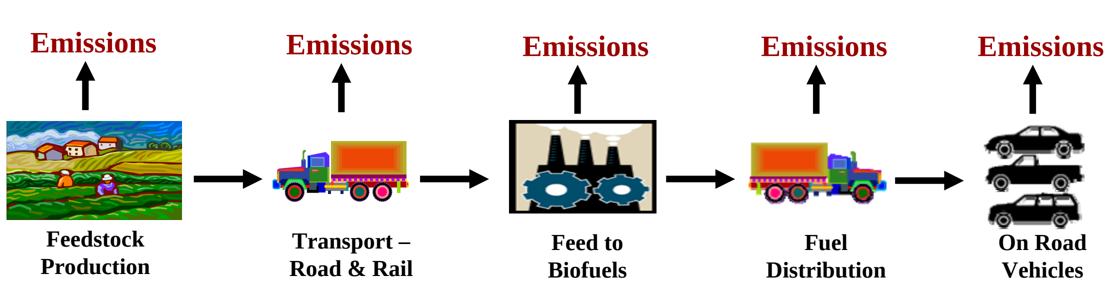
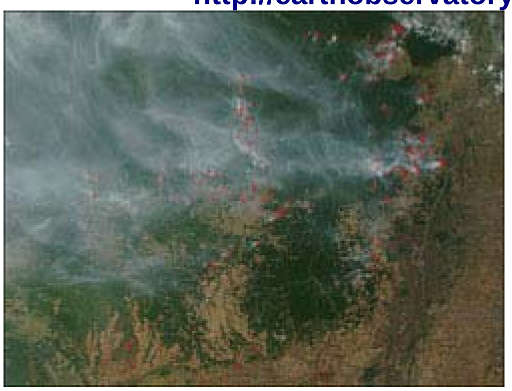


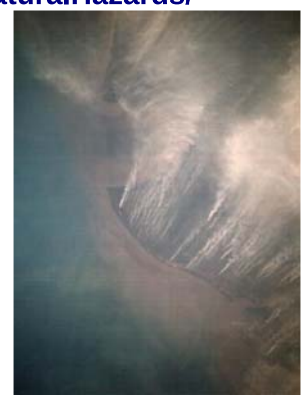
Figure 5: Life Cycle of Emissions from the Biofuels Production

Fugitive Emissions: Combustion of the biofuels as an alternative fuel to gasoline and diesel in the transport sector and in some applications in the domestic and industrial sector is expected to benefit the local pollution and GHG emissions. However, the fugitive PM such as wind erosion due to deforestation and burning of the landscapes for feedstock cultivation is a very uncertain source of emissions and should be taken into account (NASDI, 2006, presents an analysis of Amazon forest clearing for sugarcane production). This clearing of rain forests for biofuels is happening in Brazil[12], Indonesia, and Malaysia (**Figure 6**), and will probably continue in the other parts of the developing world. Economics favors production of these biofuels, since they are cheaper than petroleum - even though they may be worse for local pollution and climate[13].

Figure 6: Satellite Imagery from NASA Representing Agricultural Burning
http://earthobservatory.nasa.gov/NaturalHazards/



Smoke blankets the tropical Amazon forests, west-central Brazil, as fires and deforestation continue to encroach along the margins of the disappearing forests
(NASA, August 11th 2002)



Smoke from the Indonesian Borneo forest fires is an indication of the transmigration from densely populated Java and the preparation of land for new agriculture
(NASA, November 22nd, 2004)

The fires and haze form a significant part of the long range transport of the pollutants, and due to the large scale burning (as witnessed in **Figure 6**), the emission plumes are expected to reach far distances, effecting the local and regional pollution patterns (including human health and biodiversity) and precipitation patterns (WMO, 2009). These unintended consequences – though not all unanticipated – highlight the need for updated, comprehensive tools to analyze the true net impacts of policies that increase biofuels use[14].

Depending on the feedstock choice, good farming methods can achieve increases in productivity (without clearing the forest lands) with neutral or even positive impacts on the local and regional environment (MIT, 2008; FAO, 2008). Alternatives include cellulosic biofuels[15] made from switchgrass and prairie grasses[16], waste materials from forests, and

[12] Brazil Amazon destruction rises after 3-year fall @ http://www.reuters.com/article/environmentNews/idUSTRE4AR5W420081128
[13] FAIR trade report of 2006, "Sustainability of Brazilian Bioethanol", presents an analysis of Amazon forest clearing for sugarcane production @ http://www.bioenergytrade.org/t40reportspapers/otherreportspublications/00000098c10cd1202;
Indonesia's fires and haze – the cost of catastrophe @ http://www.idrc.ca/openebooks/332-1;
The Cost of the Biofuel Boom: Destroying Indonesia's Forests @ http://e360.yale.edu/content/feature.msp?id=2112
[14] Science Daily – Aerosols may have high impact on rainfall @ http://www.sciencedaily.com/releases/2009/02/090212093653.htm
[15] Science Daily - Cellulosic Ethanol May Benefit Human Health And Help Slow Climate Change @ http://www.sciencedaily.com/releases/2009/02/090202174934.htm

algae grown in vats[17]. More research is needed to better understand which crops and practices can best minimize the negative impacts (land clearing and emissions) and maximize the positive benefits (health and climate)[18].

Key Issues to Analysis

Among the plethora of management options, there is no single solution for reducing all pollutant emissions and improve air quality at all levels. Hence, an informed decision making process considering the holistic scenario with maximum benefits at local level (health impacts due to PM) and global level (GHG emissions) is advised.

Overall, the potential for biofuels as an alternative fuel in Asia is significant and given the supply, the benefits of reductions in the local air pollutants (like PM) will be substantial, along with co-benefits of GHG emission reductions. Since the parameters involved and effecting the air pollution (like ozone) are many and mixed, these impacts should be evaluated on a case by case basis. Key messages to address the impacts of biofuels in a holistic manner include,

- The interaction of policies (introduction of biofuels at larger scale) and knowledge base (analysis of possible impacts) have not been sufficiently investigated. Policy research aimed at clarifying the synergies and trade-offs in this field could help to develop the instruments that work both ways – local and global[19].
- Local circumstances, both physical and socio-economic, should be taken into account when addressing problems. The level of technical development, possibilities for financing, and the energy intensity of the economy are important factors determining the effectiveness of measures.
- Policy harmonization could be maximized by choosing a combination of options to address the negative impacts – like land clearing and increase in ozone formation.
- With the growing awareness, inclusion of all possible synergies with interchangeable credit system for air quality and climate mitigation will be beneficial at local and global level[20].
- Given the possible reductions in the GHG emissions and growing interest in the "low carbon strategies" for the urban centers, the strategy is not an obstacle to economic development, especially if it is combined with air quality policy.

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[16] Cellulose is the fiber contained in leaves, stems, and stalks of plants and trees. Unlike corn and sugar – the plants can now used to make ethanol and it can be grown in all parts of the world; and it does not effect the food production cycle. Cellulosic ethanol is expected to be less expensive and more energy-efficient than today's ethanol because it can be made from low-cost feedstocks, including sawdust, forest thinnings, waste paper, grasses, and farm residues (e.g., corn stalks, wheat straw, and rice straw). Switchgrass and other perennial grasses, in particular, are considered to be promising sources of cellulosic ethanol. Fast-growing woody crops, such as poplar and willow, are also attractive options because of harvesting and storage advantages.

[17] Science Daily - Biofuel Development Shifting From Soil To Sea, Specifically To Marine Algae @ http://www.sciencedaily.com/releases/2008/12/081220084424.htm

[18] Science Daily - Some Biofuels Risk Biodiversity And Could End Up Harming Environment @ http://www.sciencedaily.com/releases/2008/03/080331130255.htm

[19] See the SIM working paper 08-2008, "Co-benefits of management options for AQM" @ http://www.urbanemissions.info.

[20] Science Daily – What Does Future Hold for Biofuels @ http://www.sciencedaily.com/releases/2008/02/080216142159.htm

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