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Ethanol-powered Buses Reduce Vehicle Emissions in Stockholm

Summary

Since 1990, Stockholm Transport (SL) has had 32 Scania ethanol-powered buses serving the city centre. These buses generate far lower emissions of nitrogen oxides and particulates than diesel-powered buses. There is no net carbon dioxide effect as the raw material is based on forestry by-products, a renewable fuel. Although operation and maintenance costs are higher than those for equivalent diesel-powered buses, SL is very pleased with its experience of using ethanol-powered buses, and the predicted risk of increased wear and tear on the engine has proved to be unfounded. As a result, SL has decided to phase out diesel buses in favour of ethanol-powered and hybrid buses. There are now about 130 ethanol-powered buses on the streets of Stockholm.

Highlights

- **Fuel efficiency increased**
- **No greenhouse gas effect**
- **Nitrogen oxides and other emissions reduced by more than 50%**

Ethanol-powered buses in use in Stockholm.

Project Background

The use of ethanol as a substitute for gasoline and diesel results in more energy-efficient engines. Energy efficiency can increase by about 5% when ethanol replaces gasoline in spark-ignition engines. When the entire engine has been optimised for alcohol drive, there is potential for an increase in fuel efficiency of 30%.

The aim of the SL demonstration, which is part of a Swedish national RD&D programme for biofuels, was to reduce emissions from city buses by using ethanol in modified diesel engines. The goal established for the exhaust emissions from the ethanol buses was that they should be appreciably lower than emission levels currently under discussion for heavy-vehicle legislation in Sweden.

The Project

The vehicles used in the demonstration were Scania city buses, model CN113. The engines (11 l DSI11E) were adapted for ethanol operation by measures including:

- increasing the compression ratio from 18:1 to 24:1;
- enlarging the holes of the injectors;
- modifying the injection timing;
- increasing the fuel pump capacity;
- changing gaskets and filters to those resistant to alcohol.

The fuel used was 95% bio-based ethanol from forestry by-products; 2% Avocet ignition improver (later replaced by Beraid) and denaturants were added to the fuel.

Because ethanol has a tendency to dissolve the oil film on greased metal surfaces, the choice of oil was important and castor oil was selected for fuel pump lubrication. The buses were equipped with an extra 115 litre tank, giving a total tank volume of 395 litres. In

Table: Comparison of Exhaust Emissions

	1994 Diesel g/kWh	Emissions ECE-R49 (cycle (1)) g/kWh	Targets of the ethanol project g/kWh	Long-term targets g/kWh	Emissions (Braunschweig cycle (2)) g/km
Oxides of Nitrogen	9.0	3.8	4.5	2-3	6.5
Carbon Monoxide	5.0	0.05	0.1	0.05	0.16
Hydrocarbons	1.2	0.16	0.2	0.1	0.14
Particulates	0.4	–	0.05	–	0.04

(1) The ECE-R49 standard test method based on steady-state engine running.
(2) The Braunschweig cycle based on simulated driving behaviour.

practice, the extra capacity was not needed; the fuel consumption of an ethanol-powered bus never exceeded 150 litres in a 24-hour period.

A special refuelling facility was built with underground cisterns connected to the pumping station. The refuelling system was designed for the feedback of vapourised fuel so that personnel would not inhale ethanol fumes.

Performance

The demonstration – one of the largest tests in the world – involved 32 Scania ethanol-powered urban buses operated by Stockholm Transport (SL). It began in 1990 and during the four-year demonstration the ethanol-powered buses were driven a total of 4 million km.

Meticulous exhaust measurements were carried out on some of the buses. The results of these measurements show very low values for the regulated emissions. They also indicated a potential for further reducing the emissions with newer generations of Scania ethanol-powered engines.

Comparison of the measurements over time (ie the measurements at the start of the test period and those at its conclusion) showed that carbon monoxide emission increased with extended mileage. Emissions of nitrogen oxides were fairly constant, whereas it was difficult to discover any trend in hydrocarbon emissions.

Unregulated emissions were also low, and aldehydes were never higher than for the best quality diesel (city diesel with catalysts). Emissions of polyaromatic hydrocarbons were also low, as were the levels of mutagens found in the exhausts.

The ethanol-powered buses were used in regular traffic in the central part of Stockholm. Drivers and mechanics needed no extra training to operate and service the buses. The drivers found the operational qualities to be the same as ordinary diesel buses and problems that arose were no different from those encountered with diesel buses generally. Dependability was also at the same high level as for conventional diesel buses.

One “ethanol-specific” problem did arise, however. Sometimes the exhausts from the buses smelled like acetic acid. Although this was not a health problem it was a source of annoyance. The cause was unburned fuel converted into acetic acid in the catalyst and emitted along with the other exhausts. The smell was strongest during acceleration from bus stops. Apart from these occasions the ethanol buses have been almost odourless.

Today about 130 of Stockholm’s buses run on ethanol. Stockholm Transport has pledged to achieve three targets by the year 2000:

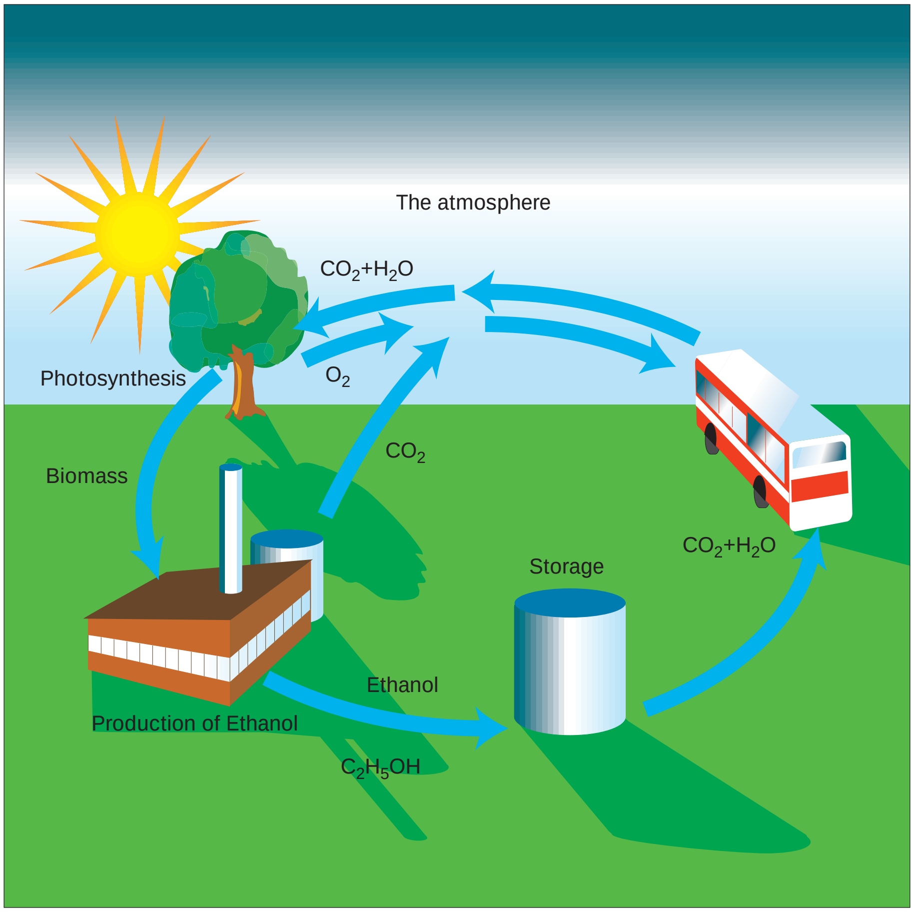
- emissions of nitrogen oxides to be halved compared with those in 1980;
- carbon dioxide emissions to be no greater than their 1988 level;
- the average noise level not to exceed 77 dB(A).

To achieve these targets, SL intends to have 300 ethanol-powered buses in operation by the turn of the century.

Economics

Today’s fuel prices, taxes and tariffs taken together mean that using biofuels involves increased costs for vehicle operators. The costs for ethanol fuel in the SL project were higher than those for diesel fuel. On average, an ethanol bus in Stockholm during 1996 had an extra annual cost of SEK 95,000 (where SEK is the Swedish krona) compared with a diesel bus. This extra cost is almost entirely related to the more expensive fuel. However, the price today does not reflect the true environmental costs. Socio-economically correct pricing would require that the costs for all environmental effects be included in the price of fuel. This is not yet being done and the situation favours fuels which are more harmful to the environment.

During the test period, operation and maintenance costs for the ethanol-powered buses were slightly higher than those for equivalent diesel buses. This was due to more frequent cleaning of the fuel injectors, replacement of the high-pressure fuel pipes and fuel filters and lubricating oil for the fuel pump. The excess maintenance costs amounted to about SEK 3,500/bus each year. Many of these problems have been solved resulting in longer periods between services and lower operation and maintenance costs.



The ethanol ecocycle.

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