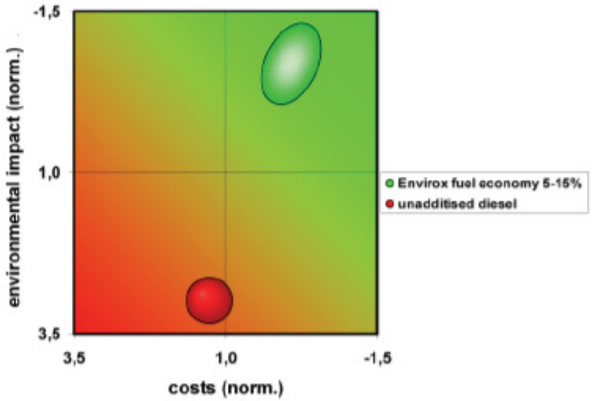
Results of the Eco-Efficiency Analysis

The BASF eco-efficiency analysis considers the economic and environmental impact of various alternatives fulfilling the same customer benefit (CB). In this analysis, the customer benefit involves driving a heavy duty diesel vehicle such as a bus for 1 million km in an urban Asian setting using ULSD diesel. Vehicles are assumed to have no particulate filter or oxidation catalyst. The differential impact is considered*.

Addition of Envirox™ at a cerium oxide concentration of 5 mg per litre of diesel leads to a 11.4% reduction in fuel consumption as well as a reduction in NMVOC (8.0%), carbon monoxide (3.2%) and particulate emissions (10.5%).

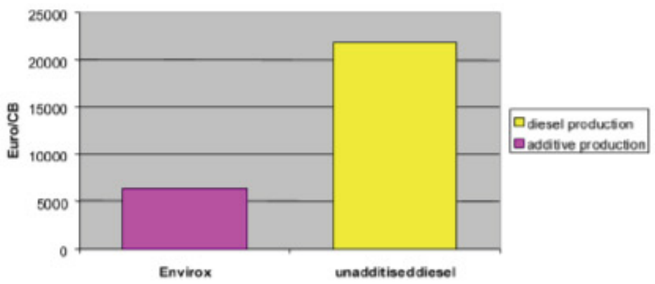


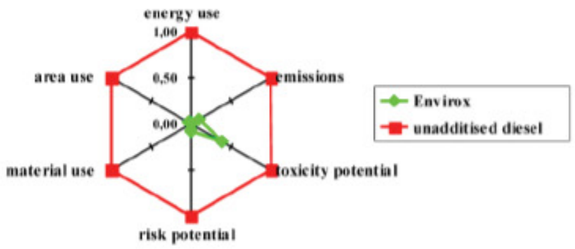
Envirox™ Additised Diesel is Most Eco-Efficient

Enrichment of diesel fuel with the fuel-borne catalyst Envirox™ results in the highest eco-efficiency. The environmental impact of additised diesel is significantly lower than plain diesel. The costs of Envirox™ additised diesel, over the whole life cycle, are also lower than the unadditised alternative. The Envirox™ alternative is shown as an oval to demonstrate savings in fuel consumption ranging from 5 to 15% reflecting different driving conditions. Even at the lowest fuel consumption savings Envirox™ additised diesel remains the most eco-efficient.

Costs

The differential life cycle costs of unadditised diesel are about four times greater than that of additised diesel. The fuel-borne catalyst requires an initial additional expenditure, but this is more than compensated by the savings due to decreased fuel consumption.
In the base case (shown) a diesel price of 0.24 US$/l was assumed as a typical subsidised fuel price for public bus companies. In a scenario, higher diesel fuel values, applicable for example to large trucking companies, were also examined. The cost advantage of Envirox™ additised fuel is even greater in such a scenario.

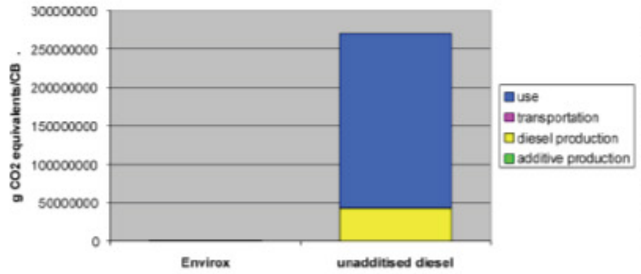




Ecological Fingerprint

The ecological fingerprint shows, in normalized form, the relative impact of additised and unadditised diesel in all the environmental categories examined. A value of one indicates the greatest impact in that specific category. Envirox™ additised diesel demonstrates significantly lower impact in all categories: emissions, energy consumption, resource consumption, toxicity potential, risk potential and area use.

*Envirox production compared to additional fuel and emissions by the unadditised fuel alternative

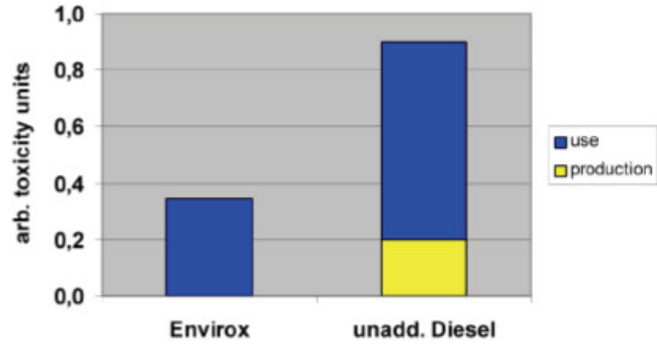


Global Warming Potential

The total warming global emissions are greatest for the unadditised fuel alternative. The reason for the greater emissions is the fact that the fuel consumption is greater. Thus, not only do additional global warming emissions occur during the production of the extra diesel, but, more importantly, more diesel is combusted (and emitted as CO_2) by the vehicle.

Toxicity Potential

The determination of the toxicity potential is based on the Risk Phrases of all substances produced during the life cycle of the alternatives as well as the emissions occurring during driving. The health risks are coupled with fixed numerical values which are multiplied by the concentration, exposure and persistence factor of each substance to obtain the overall toxicity potential. In this analysis, it was assumed that all nanoparticulate emissions, independent of type, exhibit pulmonary persistence as well as carcinogenicity. This is a worst-case scenario for Envirox™ since there is no experimental data suggesting toxicity risks of emitted cerium residues. Even considering such a worst-case scenario, Envirox™ additised diesel outperforms unadditised fuel. The latter, due to the significantly higher fuel consumption, results in greater particulate emissions (soot) as well as NMVOC (non-methane volatile organic carbons) and carbon monoxide.

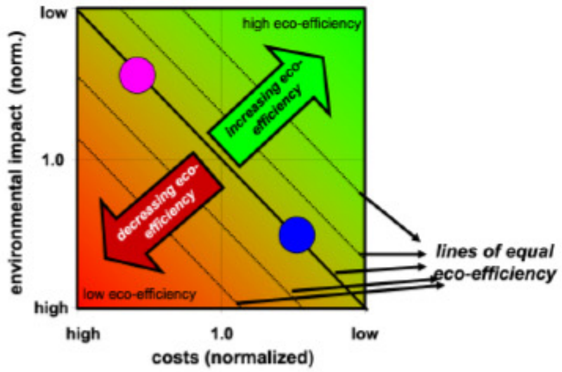


SUMMARY

- **The eco-efficiency of Envirox™-additised diesel is much higher than that of unadditised diesel for use with heavy duty vehicles. The overall environmental impact is significantly lower for the additised fuel since very small amounts of Envirox™ result in large fuel consumption reductions.**
- **The overall life cycle costs for Envirox™-additised diesel are lower than the costs for unadditised diesel. The additional costs for the fuel-borne catalyst are more than compensated for by the savings in fuel use.**
- **The greater eco-efficiency of Envirox™-additised diesel is greater at all fuel consumption values tested.**

BASF Eco-Efficiency Analysis

The BASF eco-efficiency analysis is a tool for quantifying sustainability of products and processes. It provides an assessment of the total costs and environmental impact that a product or process creates over its complete life cycle, starting with raw material extraction and continuing on to post-use disposal or recycling. The analysis includes an in-depth comparison of the pros and cons of various product alternatives, all of which fulfill the same customer need. Also included in the analysis is an examination of potential scenarios to check future developments and to assess uncertainties.



Method

The BASF eco-efficiency analysis is based on DIN EN ISO 14040 et seq for ecological audits. Besides the commonly used life cycle analysis inventory data — energy consumption, material consumption, air emissions, water emissions, and wastes — the BASF eco-efficiency analysis also incorporates the toxicity potential, risk potential, and land use that are associated with the life cycle of a product. A detailed description of the method is available in the following publication:

Saling et al., **INT J LCA 7** (4) 203-218 (2002)

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Eco-Efficiency Analysis:

Envirox™ Diesel Fuel Additive

BASF
The Chemical Company

Envirox™ is the trade name for Energenics's formulated diesel additive with demonstrated benefits of improved fuel consumption and reduced emissions. **Envirox™** lowers the combustion temperature of soot residues in the engine and helps promote the optimum amount of oxygen within the combustion chamber, leading to a cleaner burn and increased power. **Envirox™** consists of cerium oxide dispersed in aliphatic and cycloaliphatic carriers.

An eco-efficiency analysis comparing heavy-duty vehicles running on unadditised diesel and **Envirox™** additised fuel was performed. The complete life cycle was considered, including production of fuel and additive components as well as the actual driving. The eco-efficiency of the additised fuel was significantly higher than that of the unadditised diesel. The additional environmental impact and costs due to the **Envirox™** were more than compensated by the large reduction in fuel consumption. Moreover, the more efficient combustion of fuel in the presence of **Envirox™** resulted in lower vehicle emissions. Over the complete life cycle use of **Envirox™** additised diesel results in lower overall costs than plain diesel due to the decreased fuel use.

This analysis was based on the validated BASF eco-efficiency methodology, which fulfills the requirements of the life cycle analysis norms DIN EN ISO 14040 et seq.