MARKET IMPACT EVALUATION

ERRAC was set up in 2001 and is the single European body with the competence and capability to help revitalise the European rail sector:

- To make it more competitive
- To foster increased innovation
- To guide research efforts at the European level

ERRAC Project Evaluation Working Group (EWG)

Objectives:

- Determine the market impact of previous rail research to improve use of research funding
- Ensure a strategic approach to the prioritisation of rail research

Project Evaluation

- Individual projects are evaluated after they have been completed to ensure successful dissemination of project results
- To ensure that the results of previous rail research can be taken into account for future projects
- To avoid weak market uptake of results by learning the lessons of previous research
- The EWG will provide intelligence based on the project evaluations for input into future European Framework Programmes
ERRAC Project Evaluation Group

GREEN

EVALUATION FROM MAY 2010

Project acronym: GREEN
FP: 6
 Programme acronym: FP6-SUSTDEV-3
Project Reference: FP6-516195
Call identifier: SUSTDEV-2002-3.1.1.1.1
Total Cost: € 21,749,770
EU Contribution: € 12, ???
Timescale: March 2005 - May 2008
Project Coordinator: Edward Jobson,
 replaced then by Johan Engström (Volvo Powertrain AB)
Web references: http://green.uic.asso.fr/
http://www.transport-research.info/web/projects/project_details.cfm?id=28115

Presented by: M. Robinson
Date evaluation: 19.05.2010
Market uptake: Weak
Follow up projects: CleanER-D, internal UIC projects
Other related projects: None
Green Heavy Duty Engine

Premise:
Among surface transport modes, road transport and international waterway navigation produce the largest fraction of the pollutant emissions (O\textsubscript{x}, PM) in this group. Due to an increase in transport by waterway navigation, emissions increased between 1990 and 2001, whilst road transport emissions decreased.

Rail’s share of emissions is comparably small (1-3%), but emissions generated locally by individual diesel vehicles may be highly perceived by the population living nearby. This is to be particularly considered since increasing attention on air quality is paid by the public and authorities, and it seems that often air quality limits are being exceeded in various European hot spots.
Rationale:
The development of heavy-duty (HD) engines is undergoing a rapid step in its evolution. Increased demand for fuel efficiency, emissions and global competition are driving forces. The HD engines operate under constraints much more severe than those of passenger cars, such as:

- higher durability (> 600,000 km) of the engine and of the related after-treatment;
- higher mechanical and thermal stress of the engine (heavier load factor);
- higher pressure on reliability (up-time), investment and fuel economy.

The above constraints characterise the HD engines for their more general applications: not only trucks and urban vehicles but also the rail traction and the inland waterway vessels of the directive 2002/765.

New technologies will help in meeting future emission and fuel consumption targets by:

- a new combustion process enabled by variable components;
- new control strategies;
- considering the engine and the exhaust after-treatment as one system;
- considering sustainable fuels.
Green Heavy Duty Engine

Main Objective:

• The main objective of GREEN is to develop an intelligent flexible HD engine system able to achieve a maximum fuel conversion efficiency of 45%, while complying with a zero-impact emission level.

• As fallout of the achieved knowledge and realised technologies of such an integrated combustion system, innovative HD diesel and gas engines, to be considered as by-products of the GREEN research, are developed. These by-products will allow Europe to maintain the leadership in the production of internal combustion engines in the years 2012 - 2016, while allowing the completion of the integrated combustion system in an innovative powertrain.
**Green Heavy Duty Engine**

**Objectives:**
The future GREEN engine consists of:
- flexible components;
- a new combustion process;
- closed loop emissions control;
- high power density;
- suitability for renewable fuels;
- integrated exhaust after-treatment system.

The project puts emphasis on diesel engines for trucks and rail applications, and on natural gas engines for city transport applications.

The combination of innovation and durability is strongly supported.

The research targets have been chosen to look beyond all legislation known today. Targeting possible sharpening after the year 2010 with a focus on near-zero real-world emissions are set.
## Green: Background

### Partners

<table>
<thead>
<tr>
<th>Country</th>
<th>Partners</th>
</tr>
</thead>
<tbody>
<tr>
<td>Austria</td>
<td>AVL List GmbH</td>
</tr>
<tr>
<td>Belgium</td>
<td>Union of European Railway Industries</td>
</tr>
<tr>
<td>Czech Republic</td>
<td>Czech Technical University in Prague</td>
</tr>
<tr>
<td>France</td>
<td>Union Internationale des Chemin de Fer; Institut Français du Pétrole</td>
</tr>
<tr>
<td>Germany</td>
<td>Advanced Combustion GmbH (ACDE); Robert Bosch GmbH; DaimlerChrysler AG; Deutz AG; FEV Motoren technik GmbH; MTU Friedrichshafen GmbH; Rheinisch-Westfälische Technische Hochschule Aachen</td>
</tr>
<tr>
<td>Greece</td>
<td>National Technical University of Athens</td>
</tr>
<tr>
<td>Italy</td>
<td>C.R.F. Società Consortile per Azioni; Iveco S.p.A.; Politecnico di Torino – Dipartimento di Energetica; Metatron s.p.l.</td>
</tr>
<tr>
<td>Spain</td>
<td>Universidad Politécnica de Valencia</td>
</tr>
<tr>
<td>Sweden</td>
<td>Chalmers University of Technology; Volvo Powertrain Aktiebolag</td>
</tr>
<tr>
<td>Switzerland</td>
<td>Swiss Federal Institute of Technology Zurich; Paul Scherrer Institut; Iveco Motorenforschung Ltd</td>
</tr>
<tr>
<td>The Netherlands</td>
<td>NONOX B.V.</td>
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<tr>
<td>Turkey</td>
<td>Ford Otomotiv Sanayi A.S.</td>
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<tr>
<td>United Kingdom</td>
<td>Holset Engineering Co. Ltd; Johnson Matthey plc; Ricardo UK Ltd; Delphi Diesel Systems Ltd</td>
</tr>
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</table>
The work in GREEN is divided into sub-project and crossover activities:

- **Sub-project 1:** HD gas engine for urban areas, with the objective to reach low gaseous emissions and diesel-engine equivalent fuel consumption by variable valve management, cooled EGR (Exhaust Gas Recirculation) for gas engines and close-to-valve multipoint port-gas injection, and comparing this with direct injection (DI).

- **Sub-project 2:** Enhanced flexible engine, with the objective to find the best combination and concept to reach emission limits beyond Euro 5, flexible engine components/sub-systems and exhaust after-treatment systems.

- **Sub-project 3:** Innovative control and air utilisation, with the specific objective to develop the sub-systems for a new combustion process with complete air utilisation and to develop the models for a model-based closed-loop emission control, to regard engine and after-treatment as one system in the future.

- **Sub-project 4:** High BMEP (Brake Mean Effective Pressure) engine, with the specific objective to investigate the advantages and possibilities of a very high BMEP to reduce fuel consumption as much as possible.

The crossover activities link the subprojects further:

- future HD technology adaptation to rail diesel engines and to develop the rail diesel engine in 2012+;
- basic investigations and comparison on fuels: diesel - bio fuels - GTL;
- further development of a comparable injection system for gas engines - electromagnetic operated control valve (EOCV) system.
Green : Background

Achievements Subproject A1: HD Gas engine

- Optimised near-to-valves port-fuel injection electronically controlled (including an advanced Pressure Regulator)
- Improved cylinder head cooling
- Flexible Electro-Hydraulic Valve Management system for gas engines (EVMG)
- Low-pressure Cooled EGR (and Uncooled EGR)
- Integrated control system

<table>
<thead>
<tr>
<th>Technology</th>
<th>Results versus today EEV engines</th>
<th>Expected</th>
<th>Achieved</th>
</tr>
</thead>
<tbody>
<tr>
<td>EVMG</td>
<td>Fuel consumption reduction of BMEP increasing of</td>
<td>4 ÷ 5%</td>
<td>4 ÷ 5%</td>
</tr>
<tr>
<td>Cooled EGR</td>
<td>Power density increasing of</td>
<td>10%</td>
<td>10%</td>
</tr>
<tr>
<td>Enhanced cylinder head cooling</td>
<td>Power density increasing of</td>
<td>5% ÷ 6%</td>
<td>up to 20%</td>
</tr>
<tr>
<td>Turbocharging Ignition delay + Exhaust EVMG</td>
<td>Improved load response (turbo lag reduction)</td>
<td>15%</td>
<td>20-25%</td>
</tr>
<tr>
<td>Related to power density increase</td>
<td>Fuel consumption reduction of</td>
<td>2% ÷ 3%</td>
<td>3% ÷ 4%</td>
</tr>
<tr>
<td>DI injection</td>
<td>Turbo lag reduction (reduction of boost pressure)</td>
<td>5%</td>
<td>10%</td>
</tr>
<tr>
<td>Combined Technologies</td>
<td>NOx: – 50%; CO₂: – 7%; GWE: – 7%</td>
<td>(even higher reduction)</td>
<td></td>
</tr>
</tbody>
</table>
Green : Background

Achievements Subproject A2: Enhanced flexible engine

- The prototype parts were all designed, procured and tested in engine test rig showing good functionality.
- The Green emission targets are reached.
- The Green fuel consumption targets are partly reached with improvement of 3% compared to the Euro III reference in ESC (Green target 5%).
- The LNA after-treatment system, although well designed, did not reach the NOx conversion ratio of a state of the art SCR system.
Green : Background

Achievements Subproject A3: Innovative Control and Air Utilisation

- An innovative highly flexible prototype fuel injection system has been developed and operated.
- The Green targets have a realistic chance to be fulfilled using just one exhaust gas after-treatment system (SCR system).
- Thermodynamic and raw emission models applicable for the complete engine map range have been derived, positively tested, and form the foundation of a model based closed-loop emission control system.
Green : Background

Achievements Subproject A4: High BMEP Engine

- Engine efficiency has been improved even beyond target emission limits and higher BMEP.
- A VCR is feasible also for heavy duty HBMEP engines and may increase the power of existing engines without extending the engine outer dimensions.
- An improved single stage turbocharger (axi/radial compressor) was realised and tested. It met the requirements for this engine.
- Simulations of exhaust heat recuperation systems showed the potential of further BSFC reduction.
- Experience was gained with different EGR- systems and related problems of condensation, corrosion and engine.
- Tribological and friction behaviour of a high PFP engine were evaluated.
Green : Background

Achievements work package 0.2: Advanced EOCV, Fuel tests

- Support to A1 concerning the impact of varying natural gas.
- Further development of Electromagnetic Operated Control Valve (EOCV) engine.
- Fuel tests for Homogeneous Charge Compression Ignition (HCCI).
- Fuel tests for diesel combustion.

Achievements work package 0.3: Rail specifications and engine development

- The specific rail sector’s requirements have been identified and evaluated.
- Possible in-cylinder measures for reduction of NOx emissions in locomotive applications have been described and evaluated.
- A new combined combustion process (EGR+HCCI) has been tested on a one cylinder engine.
- The new EGR-concept has been examined on a multi-cylinder demonstration engine.
- The Green HD engine fulfils the rail sector’s requirements and can be transferred with slight modifications only.
GREEN: Evaluation

Partners interviewed:

<table>
<thead>
<tr>
<th>Organisation</th>
<th>Name of interviewee</th>
<th>Country</th>
</tr>
</thead>
<tbody>
<tr>
<td>UIC</td>
<td>☑ Enno Wiebe</td>
<td>France</td>
</tr>
<tr>
<td>UNIFE</td>
<td>☑ Judit Sandor</td>
<td>EU</td>
</tr>
</tbody>
</table>
Green : Evaluation

1. Were the results implemented in the design of the new products and services? Were these new products/services put into commercial operation?
   - No, not for the rail sector. Some new products and services have been implemented and put in commercial operation in automotive sector (i.e. Deutz has patented a burner/vaporiser unit for exhaust after-treatment).

2. Is new legislation and standardization based on findings from this research project?
   - No rail standardisation is based on the EU project GREEN. The EU legislation process (Stage IIIb) has been independent of these research results.

3. Are the results of the project implemented across Europe or only in a small number of Member States?
   - No.

4. Are the results of the project implemented outside Europe before being accepted in Europe?
   - No, this topic was specifically European.
Green : Evaluation

5. Did the projects increase competitiveness of the European railway sector abroad with regard to products, services, standards and system design?
   - No.

6. Did the project increase competitiveness of the railway transportation compared to other transport modes?
   - No.

7. Are the results of the project taken into consideration when preparing public tenders?
   - No, this would require standardisation for the rail sector first - either in a UIC leaflet or a joint UIC/UNIFE TecRec.

8. Does the implementation of the project results help facilitate cross-border operations by problem-solving in the domain of interoperability?
   - No
9. Does the implementation of the project results help facilitate inter-modal operations by problem-solving in the domain of inter-modality?
   - No

10. Can benefits be assessed in financial terms?
    - No, there was not performed any specific analysis for the rail sector.

11. Applicability of results to future scenarios.
    - Yes, possible in the near future. Volvo does not develop any engine for the railway market, but MTU confirmed that some results of Green are being currently implemented in a EU stage-IIIb compliant diesel engine for the rail sector.

12. Usefulness of research procedures for future projects (incl. modelling).
    - Yes, the results provided some input to the CleanER-D project.
Green : Reasons for outcome

✓ The project objectives were addressed from the beginning mainly to the automotive industry. Therefore, the project focussed on the exploitation and implementation of the results just in this specific area.

✓ The specificity of the engines used in the rail sector (fitment space, power, weight, life cycle costs, etc.) was a hindrance to the implementation of the project results in commercial applications.

✓ The partnership of the project was well balanced. This offered the partners from the rail sector (MTU, UIC, UNIFE) the possibility to analyse the results from the automotive sector and to evaluate a possible transfer of the results, accordingly to the rail sector requirements. Even so, as their participation was quite limited (compared to the partners from the automotive sector) the market uptake was rather weak in the rail sector.
GREEN : Lessons learnt

✓ The aim of the project was to implement a new engine compliant to stage IIIb. However, the impact and the efficiency of the EC funding could have been mitigated because the industrial companies were required by EU regulations to make efforts in this direction anyway.

✓ Taking into account the intersectorial character of the project, the participants from the rail sector should have targeted more ambitious objectives and a bigger share of participation (in terms of efforts and funding).

✓ A follow on project was needed to ensure that the GREEN HD engine will meet the rail requirements and is transferable to the railway sector.