Waste Heat Recovery for Hybrid trucks
Exoès at a glance
Our skills

EXOES is an engineering company providing its customers with:

- Prototypes
- Calibrated Simulation
- System design
- Test rigs
- Vehicle integration

Prototype technologies:

- Swashplate
- Scroll
- Pump
- Fast charging batteries
- Fuel cells
Experienced in demo-vehicles

References:

Demotruck:

- EXOES, Renault-Trucks and Faurecia
- a 2-year program
- Waste heat recovery
- Integration of an EXOES expander
- Real life driving and roller test bench
Saving fuel on long haul trucks?
Drivers for fuel efficiency in HCVs: TCO

High fuel costs drive competition within the truck industry

Everywhere in the world, fuel efficiency for HCVs is key factor for the end customer

Source: Daimler – June 2015
Drivers for fuel efficiency in HCVs: CO₂ regulations

Source: Roland Berger

Countries where CO₂ emission targets for HCVs are expected to be voted by 2020
Tackle to the waste heat

A third of fuel is lost as heat in the exhaust...

...we do believe that Waste Heat Recovery Systems will become a standard as soon as 2024+

We engineer robust and versatile ORC technologies
E-ORC system general architecture

- Heavy commercial vehicles – typical class 8 truck
- Torque assisted by an electric motor
- “Free” electricity production with an E-ORC
- 4 major components that can be packaged into 1 box
Detailed ORC layout

- Focus on exhaust heat recovery only
- 2.5 to 5% fuel cuts are expected on real trucks

1: Front radiator
2: ICE + E-Motor
3: EATS
4: Exhaust bypass valve
5: Exhaust evaporator
8: Bypass valve
9: Expander + Generator
10: Condenser
11: Filter
12: Charge pump
13: Cooling pump
14: Expansion vessel
Demonstration truck

- System simulation and sizing
- Components supply (except expander)
- Integration and control
- Test

EXOES, Renault-Trucks and Faurecia
- a 2-year program
- Waste heat recovery
- Integration of an EXOES expander
- Real life driving and roller test bench

Source: Faurecia, Heavy-Duty, On- and Off-Highway Engines 2017
Challenges for the ORC

- Ethanol bottoming Rankine cycles are facing the following challenges to enter OEM development programs:

  - **Safety case**
    - Flammable working fluid
    - Extensive risk analysis already done by TÜV SÜD / FPT for IVECO
    - System supplier or OEM responsibility

  - **Business case**
    - Ratio cost / benefit
    - Prove the fuel savings
    - Reduce the components and integration costs

  - **Durability case**
    - Prove the components reliability
    - Alcoholate corrosion
    - Fluid ageing: lubricant and ethanol breakdown
Target cost of the system

- Link between payback time, fuel saving and system cost

Sales price of the ORC system for a 2-year payback assuming 3% fuel saving

Assumptions:

<table>
<thead>
<tr>
<th></th>
<th>Europe</th>
<th>USA</th>
<th>China</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mileage</td>
<td>130,000</td>
<td>110,000</td>
<td>150,000</td>
<td>km/y</td>
</tr>
<tr>
<td>Fuel</td>
<td>1</td>
<td>0.65</td>
<td>0.8</td>
<td>€/L</td>
</tr>
<tr>
<td>Consumption</td>
<td>35</td>
<td>44</td>
<td>35*</td>
<td>L/100km</td>
</tr>
<tr>
<td>ORC Maintenance</td>
<td>100</td>
<td>100</td>
<td>100</td>
<td>€/y</td>
</tr>
</tbody>
</table>

*: projected in 2025 with new regulation implementation
Expander design
Exoès piston expander technology

- EVE-T2: Single acting swashplate technology – 3 pistons
- Inlet poppet valves, and exhaust ports and valves
### Expander Datasheet

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Specification</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>EVE-T2</strong></td>
<td></td>
</tr>
<tr>
<td><strong>Speed range</strong></td>
<td>1,000 - 4,530 RPM</td>
</tr>
<tr>
<td><strong>Shaft power range</strong></td>
<td>&lt;12 kW</td>
</tr>
<tr>
<td><strong>Eff. Is. efficiency range</strong></td>
<td>Typ. 55 - 65%</td>
</tr>
<tr>
<td><strong>Size</strong></td>
<td>&lt; D200xL200mm</td>
</tr>
<tr>
<td><strong>Weight without coupling</strong></td>
<td>15kg</td>
</tr>
<tr>
<td><strong>Oil circulation rate</strong></td>
<td>Typ. 10%</td>
</tr>
<tr>
<td><strong>Outlet pressures</strong></td>
<td>1 - 4barA</td>
</tr>
<tr>
<td><strong>Inlet pressures</strong></td>
<td>&lt;40 barA</td>
</tr>
<tr>
<td><strong>Nominal pressure ratio</strong></td>
<td>15 – 20 for ethanol</td>
</tr>
<tr>
<td><strong>Nominal gear ratio</strong></td>
<td>1.5 – 2.5 for trucks</td>
</tr>
<tr>
<td><strong>Transmission</strong></td>
<td>Freewheel</td>
</tr>
<tr>
<td><strong>Bypass valve</strong></td>
<td>Integrated</td>
</tr>
</tbody>
</table>

![Exander Diagram]
Expander tests and model calibration

Effective Isentropic Efficiency measured* vs calculated

- $y=+5\%$
- $y=-5\%$
- $y=x$

Effective Isentropic Efficiency
@ 2000rpm, 1barA outlet, 30°C superheat

Effective isentropic efficiency:
\[
\eta_{eff,is} = \frac{\dot{W}_{shaft}}{\dot{M}(h_{in} - h_{out,is})}
\]

*Measured = calculated based on measured values
Exoès scroll expander technology

- Compliant Scroll – Volume ratio 4.6 – Capacity 139cm³

<table>
<thead>
<tr>
<th></th>
<th>EVE-T2 - piston</th>
<th>EVE-T3 - scroll</th>
</tr>
</thead>
<tbody>
<tr>
<td>Speed range (RPM)</td>
<td>1,000 - 4,530</td>
<td>1,000 – 6,000</td>
</tr>
<tr>
<td>Shaft power range</td>
<td>&lt;12 kW</td>
<td>&lt;15 kW</td>
</tr>
<tr>
<td>Eff. Is. efficiency range</td>
<td>Typ. 55 - 65%</td>
<td>Typ. 60 - 75%</td>
</tr>
<tr>
<td>Size</td>
<td>&lt; D200xL200mm</td>
<td>&lt; D200xL130mm</td>
</tr>
<tr>
<td>Weight w/o coupling</td>
<td>15kg</td>
<td>16kg</td>
</tr>
<tr>
<td>Oil circulation rate</td>
<td>Typ. 10%</td>
<td>Typ. 5%</td>
</tr>
</tbody>
</table>
Efficiency forecast

Higher efficiency expected

Efficiency comparison with Ethanol 95.5%mass
@ 2000rpm, 1bar outlet, 30°C superheat (EVE-T1 and T2)
@ 3600rpm, 1bar outlet, 20°C superheat (EVE-T3)
Pump design
Exoès gear pump technology

- A unique design for low flow, high pressure, with no lubricant
- A one-stop product for several required functions

<table>
<thead>
<tr>
<th>Feature</th>
<th>Specification</th>
</tr>
</thead>
<tbody>
<tr>
<td>Flow</td>
<td>0.75 – 6 L/min</td>
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<tr>
<td>Elec. power range</td>
<td>&lt;1.2 kW</td>
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<tr>
<td>Pump size</td>
<td>&lt;D180xL210mm</td>
</tr>
<tr>
<td>Weight</td>
<td>&lt;4kg</td>
</tr>
<tr>
<td>NPSHr</td>
<td>~300mbar</td>
</tr>
<tr>
<td>Inlet pressures</td>
<td>1 - 4barA</td>
</tr>
<tr>
<td>Outlet pressures</td>
<td>1 - 40 barA</td>
</tr>
<tr>
<td>Additional functions</td>
<td>100 µm inlet filter</td>
</tr>
<tr>
<td></td>
<td>10 µm outlet filter</td>
</tr>
<tr>
<td></td>
<td>Relief valve 43 barG</td>
</tr>
<tr>
<td></td>
<td>Expansion tank w/ pressure regulator</td>
</tr>
<tr>
<td>Sensors</td>
<td>In &amp; Out pressures</td>
</tr>
<tr>
<td></td>
<td>Temperature</td>
</tr>
<tr>
<td>Motor</td>
<td>24 Vdc – CAN bus</td>
</tr>
</tbody>
</table>
Electrical vs Mechanical
Micro-hybrid favors E-ORC

Electrical energy recovery vs Mechanical energy recovery

• Easier integration
• Better control
• Recovery when engine brakes

• Coupling efficiency
• Cost

Source: Volvo Trucks – November 2017 - EORCC
Dynamics favors E-ORC

- In steady state, the additional degree of freedom offered by the expansion machine speed control is not compensating the decrease in coupling efficiency.

- In dynamic, recovery is enabled during a longer period giving a relative advantage to the electrical coupling.

Source: from Tenneco – November 2017 - EORCC
Conclusion
Conclusions

- Electric waste heat recovery may reach the market in 2024+
- >4% fuel economy are expected
- 48V – 12kW Electric expander & 48V – 500W Electric pump are 2 key products of the system
Thank you for your attention