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|------------------------------------|---|
| <b>Title</b>                       | WHR 2.0 for commercial vehicles   |
| <b>Brief description</b>           | Waste Heat Recovery (WHR): technology transfer of industrial waste heat utilisation to commercial vehicles based on ethanol steam piston engines for space-optimised use in commercial vehicles free of lubricating-oil circuits.   |
| <b>Strategic goal</b>              | Cooperation   |
| <b>Company</b>                     | gian Ingenieurgesellschaft bR, 66620 Nonnweiler   |
| <b>Introduction and motivation</b> | <p>After restructuring in 2018, we are now available as an engineering service provider again. We look back on 22 years' experience in this field combined with more than 17 years' experience in the development of ORC systems. Our focus today lies especially in recovering waste heat from engines and from industrial applications and in returning it to the systems either as mechanical or electrical energy.</p> <p>Our expertise is the result of over 10 years' exclusive development partnership with Volkswagen AG's Group research for the waste heat utilisation of engines, and of an 8-year-long R&amp;D project conducted by the German Federal Ministry for Economic Affairs and Energy (BMWi) as a lead project with the goal of recycling volatile industrial waste heat flows with the greatest benefit.</p> <p>After we have reoriented ourselves, we will re-intensify the business area of mobile application and provide our services on the market freely and independently. Different cooperation models, from traditional order development to integration in existing development teams on site, are possible here.</p> <p>As a basis for further consolidation, we subsequently developed a concept which, in our view, is particularly well suited to recycling waste heat from the engines of commercial vehicles (either on land or water). Especially with regard to tighter emissions standards and impending CO<sub>2</sub> reduction requirements, a significant contribution can be made here by reducing consumption and therefore also emissions. The special feature of the concept is that the majority of the components and systems used have been developed by us and have been tested in the field over many thousands of hours. Development costs up to series production are therefore significantly reduced!</p> |
| <b>Location</b>                    | variable  |
| <b>Start date</b>                  | as of now   |
| <b>Runtime</b>                     | variable  |

# WHR 2.0 for commercial vehicles



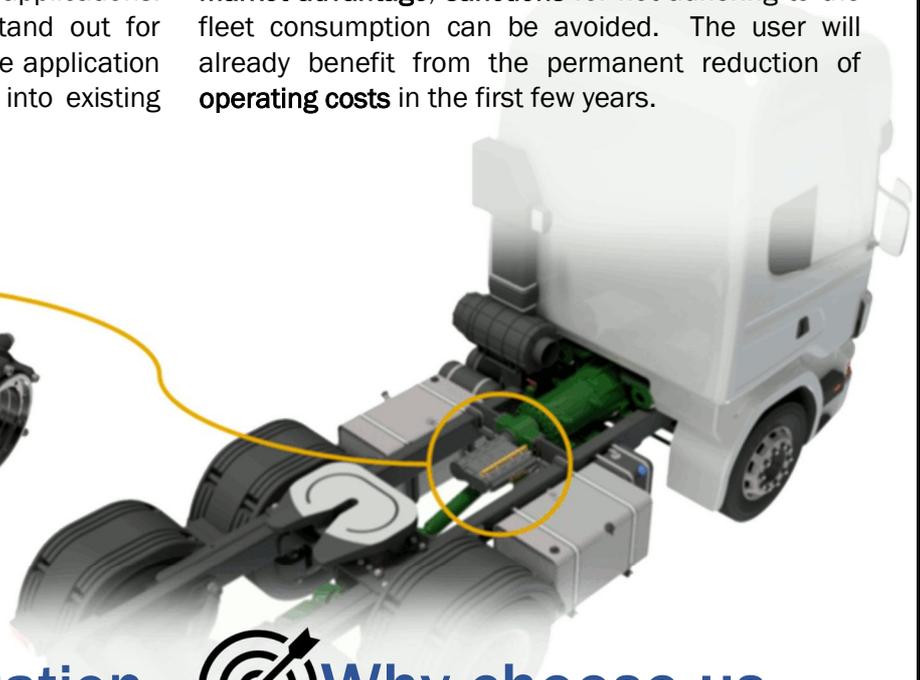
## Solution

Steam cycle processes (CRC/ORC) are already the **state of the art** for stationary waste heat utilisations. In mobile application, there are various approaches which **have not made** the leap into **series application** yet. A **technology transfer** of tested **stationary plant technology** combined with previous knowledge of **mobile technology** forms the solution for **fast market maturity** and high CO<sub>2</sub> saving for mobile applications. Robust and durable **piston engines** stand out for their **high efficiency**, high flexibility in the application area as well as **very good integrability** into existing infrastructures.



## Benefit

Fast and widespread use in trucks **significantly** reduces **energy consumption** up to **10%** and therefore contributes substantially to the adherence to the prescribed **CO<sub>2</sub> fleet consumption** in the next few years. This technology further provides **crucial consumption reduction** also for electric hybridisation or for the use of biogenic fuels. Along with the **market advantage**, **sanctions** for not adhering to the fleet consumption can be avoided. The user will already benefit from the permanent reduction of **operating costs** in the first few years.



## Implementation

**Variable-speed, lubrication-free piston engines** can be integrated **directly** into the **drive train** or also electrically as a super-hybrid version. Precise, clear engine timings with high cross sections and expansion ratios up to **40:1** at max. fluid temperatures of 200 - 300°C can be created thanks to **camshaft-free** gas exchange control. With wet releasing ORC medium **ethanol**, a thermal efficiency of **over 20%** can be achieved at up to **40 bar at a single stage** without a recuperator, and turbines, scroll and screw machines are therefore **markedly superior**. Thanks to the free orientation, the engines can also be placed **horizontally** in the frame. Since **no separation** is required between the ORC and the lubricating medium, seal systems are saved and **compact dimensions** and low weight are achieved.



## Why choose us

As an interdisciplinary team, we rely on **17 years' experience** in the field of research and development of WHR systems, of which **10 years'** exclusive development for **VW's** Group research in the passenger car field. As **pioneers** with **ethanol (since 2004)** as an ORC medium and with over **25,000** operating hours of experience in ORC industrial plants, we have **exclusive practical knowledge**. The **key components** have been **developed**, tested and operated **by us**. The most important one, the **steam engine**, has also been implemented in the versions with a crank or wobble plate drive and are **used** today in the mobile as well as stationary area. We have particular **know-how** in material selection, **tribology** of lubrication-free systems, of gas exchange control and of plant and control technology.

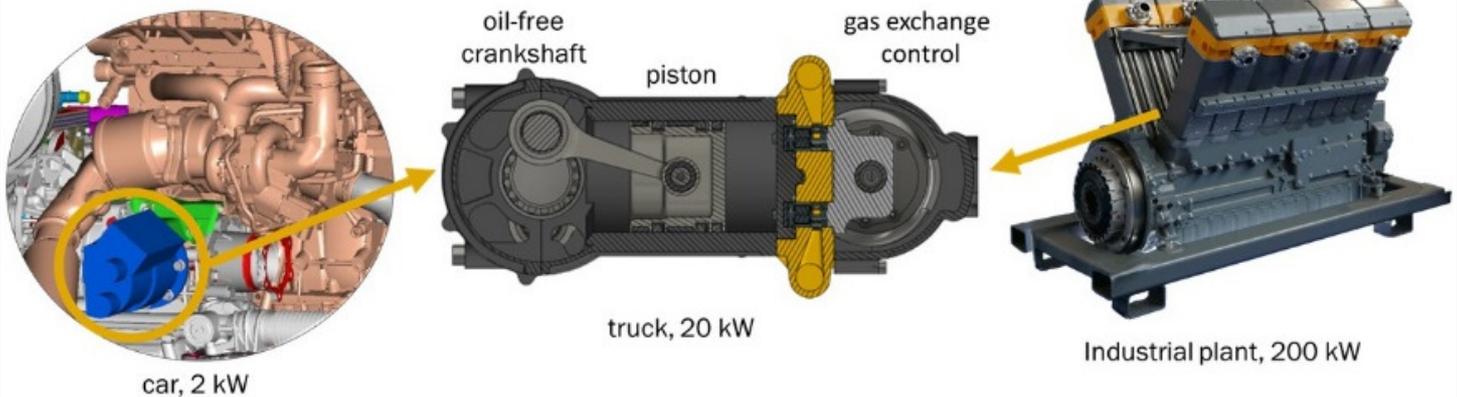
# Technology, combination of car and industry

## Piston engine:

The piston engine is the expansion machine with the highest, almost isentropic efficiency, as the potential energy, in the form of pressure, is directly converted into mechanical energy. In order to create the required expansion ratios of up to 40:1, short engine timings (20° crank shaft) and the lowest dead volumes are achieved thanks to camshaft-free gas exchange control. Intake actuation only takes place on the inside, so that high-pressure sealing of control elements or shafts moved outwards and therefore risk of leakage are prevented. Moderate variable speeds (50- 2000 1/min) guarantee excellent mechanical coupling in the drive train, high partial load efficiencies and durability.

## No lubricating-oil circuit

Since neither the crank shaft, piston guide, piston rings or the complete gas exchange control are lubricated with an oil, the usual lubricating-oil circuit for piston engines, including the peripherals such as a pump and cooler, is omitted. There is no risk of the ORC and the lubricating medium mixing. This is achieved through suitable material pairings made of steel and high-performance plastics, which remain stable in shape and wear-resistant also under ethanol high-pressure steam up to 300°C. We proved its durability in industrial plants over more than 25,000 hours. The installation position can be selected freely (vertical or horizontal).



## Ethanol as ORC medium

As first-time users of ethanol (2004) in ORC applications, we know and control the high process advantages just as well as the challenges regarding the material, (light metals and seals) as well as safety requirements (fire and explosion protection). Especially in the application with piston engines, this can be released in the wet steam area, which makes a recuperator redundant. Temperature differences between inlet and outlet of 170°C demonstrate the high thermal efficiency of over 20%. The condensation heat can be discharged via the existing water circuit without any issue. Since ethanol does not have a risk of freezing, increased safety or authorisation requirements, it is the ideal material for the mobile application. Plant components such as the ORC pump, heat exchangers, valves and MSR technology are provided for use with ethanol by our experienced supplier network.

## 25,000 operating hours / 15% net efficiency

25,000 operating hours and demonstrated 15% net efficiency demonstrate our know-how in process technology, tribology, construction material and material pairings as well as plant and MSR technology. Since 2004, we have almost exclusively developed ORC plants for mobile and stationary applications by order or independently. 10 years of exclusive development with the aggregate research of the Volkswagen group formed a large part of it. With our development partner Evonik, we have analysed over 1,000 ORC materials and material mixtures for different fields of application, created them for niche applications and examined them for efficiency and durability in real operation at our own test facilities. Our own system and component test facilities reduced costly field test examinations.

# Shareholders' history

Schmidt, Schnur and Horbach

## Project excerpts

- 2004 - 2014** Waste heat utilisation for medium-sized diesel and direct petrol injector car as booster and hybrid with piston and vane motor, working fluid ethanol, water and other organic materials | Exclusive development for the Group research Volkswagen AG
- 2005 - 2014** System test facilities for car waste heat utilisation technologies for 2.0 TFSI or TDI engines
- 2007 - 2009** Waste heat utilisation of a 3.0 MW mine gas engine with a newly developed 200 kW ethanol steam engine as ORC release aggregate.
- 2007 - 2018** Test facilities for steam engine components (gas exchange element, seals, ducts,...)  
Self-learning "Early damage detection and predictive maintenance" system with the aid of
- 2009 - 2018** structure-borne and airborne sound for continuous operation without supervision of periodically running machines and plants over 100kW
- 2009 - 2014** Field test for industrial waste heat power plants in the fields of steel, glass, chemistry and biogas Badische Stahlwerke, Noelle und von Campe, Evonik Industries and STEAG New Energies
- 2009 - 2015** Development of marketable waste heat power plants for industrial processes with a performance between 100 and 270 kW
- 2010 - 2016** Test facility for ORC media development (pure materials and material mixtures): Practical evidence of thermal efficiency and stress tests of developed fluids in real operation.

## Publicly funded projects

- 2009** German Federal Ministry for Economic Affairs and Energy (*BMWi*); EnEff:Industry ORC pilot plant: Research and demonstration project of a stationary steam engine
- 2014** *BMWi*; EnEff:Heat - ORCent - Steam engine for the utilisation of low-temperature heat flows : Stage 2: Field test
- 2014** *BMWi*:Development of new working fluids for the "ORCent steam expansion engine" for the utilisation of industrial exhaust gases. Joint project: Field test "ORCent steam expansion engine" and heat exchanger development for the utilisation of highly corrosive industrial exhaust gases for energy recovery
- 2018** German Federal Ministry of Education and Research (*BMBF*): Power generation with ORC technology combined with a street collector system

## Patents

Below is a list of patents we have developed and written by order or independently

- 2016** DE102016102650 Sealing between working fluid and lubricating medium in a steam engine
- 2016** DE102016102649 Easy disassembly of the crosshead piston without dismantling the duct in a steam engine
- 2011** DE102011076157 Steam engine with rotary valve control
- 2009** DE102009048479 Vane motor as ORC engine
- 2009** DE102009038140 Piston engine with different working fluids and pressures
- 2009** DE102009024436 Steam engine with innovative inlet valve control
- 2008** DE102008058558 Axial piston steam engine with wobble plate as ORC engine
- 2007** DE102007017357 Gas exchange control in piston engines and vane motors
- 2002** DE000010233763 Auxiliary unit for the utilisation of exhaust gas energy for motor vehicles
- 2001** DE000010141402 Electric engine as wheel hub unit for electrically powered cars
- 2001** DE000010132610 Vehicle drive with an electric engine integrated into a wheel of the vehicle

## Other projects

- Foundation and development of a start-up company for the recognised technology company with its own highly automated product manufacture.
- Foundation and setup of a joint venture with a Chinese partner in Jieyang/China for the production and sale of waste heat power plants in the Asian region
- Technology transfer to China
- Fully automatic fail-safe control of waste heat power plants in higher-level process control systems
- Steering & suspension study: Determination of steering feel and steering behaviour through the analysis of kinematic and elastokinematic behaviour | Hyundai Motor Company
- Vegavo I+II: Weight optimisation of a powered front axle by approx. 30% with consistent cost neutrality compared to equivalent series application | Ford Research Centre Aachen

## Our experience at a glance:

- 20 years' experience as engineering service provider
- 20 years' experience in the area of construction and manufacture of prototypes and complex parts
- 15 years' experience in the area of tenders, project controlling
- 15 years' experience in product development
- 15 years' specialisation in the area of waste heat utilisation
- 10 years' product development - waste heat power plants for the industry
- 10 years' sponsoring experience with project promoters, *BMWI*, *BMU* (German Federal Ministry of the Environment, Nature Conservation and Nuclear Safety), *UBA* (German Environment Agency) and *KfW*
- 10 years' experience in the field of *EEG* (German Renewable Energy Sources Act), efficiency directive, ISO 50001
- 10 years' experience in planning waste heat power plants as a general contractor

## Prizes/awards:

- Finalist of the German Industry Innovation Award 2016 and Top 100 award
- 2 x 2nd place for the Innovation Award for Climate and Environment awarded by the German Federal Ministry of the Environment (*BMU*) and the Federation of German Industries (*BDI*)

## Qualifications

- Certified lead auditor ISO 50001 | IRCA
- Fire and explosion protection | ZPT
- Explosion protection document according to the Industrial Safety Regulation (*BetrSichV*) | ZPT
- CAD/CAM: Siemens NX; Autodesk Inventor, Solidworks, ADEM, MasterCAM; iTNC530, iTNC640; Sinumerik 840D, Mach3
- SPS / MSR: Siemens Logo/S5/S7 (TIA); NI Labview Full Dev.; Moeller easySoft
- Languages: German / English

## Memberships / licences

- Bundesverband Kraft-Wärme- Kopplung e.V. (B.KWK)
- Energy auditor acc. to sec. 7 para. 3 combined with sec. 8b *EDL-G* (Law on Energy Services and other Energy Efficiency Measures) of the *BAFA* (German Federal Office of Economics and Export Control)
- Energy efficiency experts for funding programmes of the federation
- Certified (IRCA) lead auditor ISO 50001 (Energy management systems; EnMs)
- EffCheck / EffNet consultant: Energy efficiency programme of Rhineland-Palatinate
- Association of German Chambers of Industry and Commerce (*DIHK*) Committee on Industry and Research

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