heat2power

The potential of the CO2 emission reduction with a downsized engine and waste heat regeneration system

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Goal of the presentation

1. Demonstrate the potential of waste heat regeneration on CO2 emissions
2. Demonstrate how the right choice of size of the IC Engine can push the potential further.
3. Give indications of values that can be targeted for
4. Give an update on development of the heat2power concept

Review of the basics

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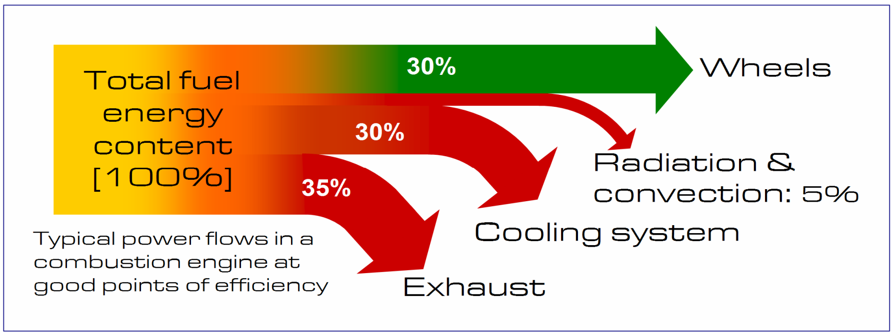
The (near) optimal condition…

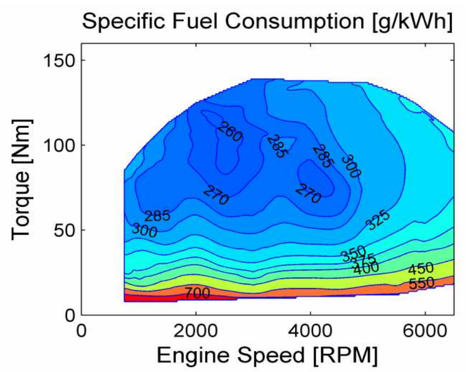


But what about the real life situation ?

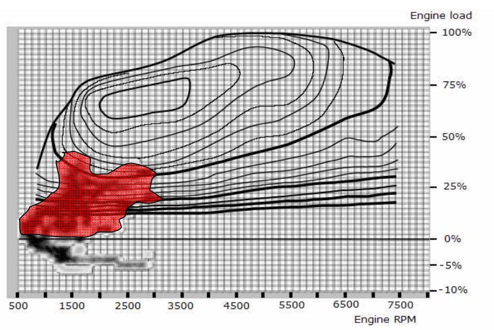
Engine Efficiency…

1

The real life situation is different !!



A typical mainstream European 1.6 liter gasoline engine



Residency plot of an 3.6 l engine on NEDC cycle with 6-speed AT.

(Source: Porsche, 2004 VDI congress)

Engine Efficiency…

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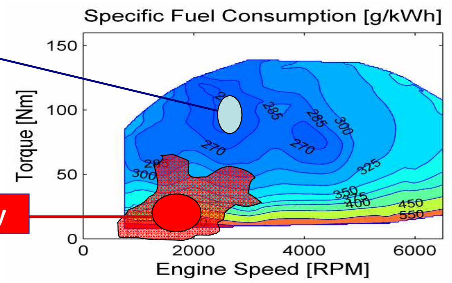
The real life situation is different !!



80 - 90% is LOST

A big part of these 80 - 90% goes to the exhaust → **WHR makes sense**

Targets of WHR on road vehicles

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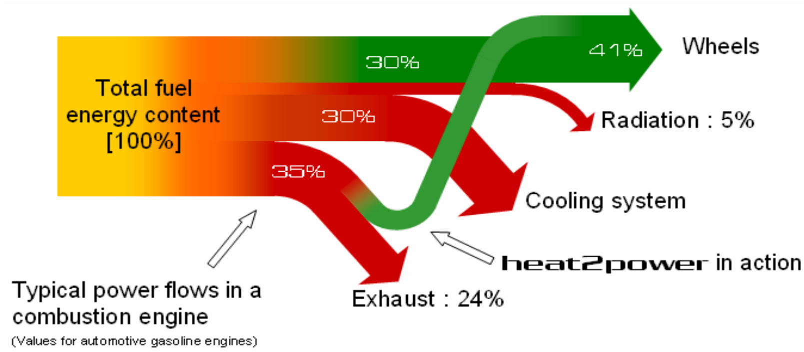

- Ideally we are interested in regenerating about 30-35% of the exhaust thermal power. This kind of ratio is what is generally believed to be the maximum possible. But we can be happy with less. The question is **"How much do we want?"**....
- Under normal motorway driving conditions, a middle class family car needs about 25 kW for maintaining speed. With 35 kW it should also cover above average speeds.
- Bigger engines for high power output are less efficient for the same load.

Targets of WHR on road vehicles

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Should the WHR device regenerate with the maximum efficiency up to maximum Power of the ICE ?

For road cars : NO

- The engine is seldom used at high power
- Higher regeneration power means bigger WHR equipment (tougher packaging)
- Bigger WHR takes longer to heat up and become effective (less effect on NEDC)
- Bigger WHR equipment involves higher cost
- When fully operational a big WHR and an adapted WHR device can regenerate the same amount of power under given conditions.

- **It would be logic to have a system adapted to maximize regeneration on motorway speeds up to about 150 km/h.**
- **Above that speed the WHR power may remain constant**

Some maths

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The high end of the scale

- If we can count on a regeneration efficiency of 33%
- If we count on equal power in exhaust and crankshaft then
- $P_{ICE} * (1 + \eta_{regen}) = 35$ kW → $P_{ICE} =$ 26 kw and $P_{regen} = 9$ kW
- The attained fuel economy by WHR only $1 – 1 / (1 + \eta_{regen}) = 25\%$

The low end of the scale

- If we can count on a regeneration efficiency of 25%
- If we count on equal power in exhaust and crankshaft then
- $P_{ICE} * (1 + \eta_{regen}) = 25$ kW → $P_{ICE} =$ 20 kw and $P_{regen} = 5$ kW
- The attained fuel economy by WHR only $1 – 1 / (1 + \eta_{regen}) = 20\%$

To make significant fuel economy the waste heat regeneration unit should be able to deliver 5-9 kW

Where the waste heat goes

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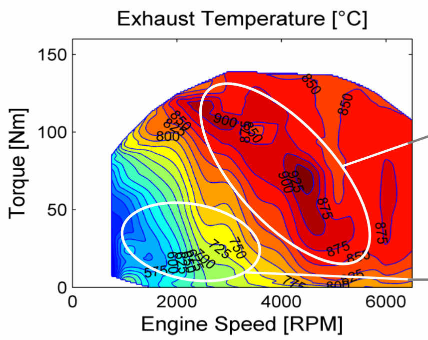
The first target is to choose the ICE in a way that for sustained driving periods, like motorway or national road is already very optimized.



Measured after catalyst, values including +50°C for potential with thermal insulation.

Area of WHR on a downsized engine,
With high WHR potential due to high temperatures

Area of WHR on a big sized engine
With good potential of WHR effect due to bad power ratio crankshaft/exhaust.

The focus should not be on WHR alone.
Good efficiency starts with putting the right ICE in the first place.

The right engine size

1

A large variety of WHR systems exist.

Technology depends on what power flows in and ICE's exhaust is tapped into.

1. **Thermal power flow**
2. **Kinetic power flow**
3. **Chemical power flow (non-combusted HC, CO, Soot)**
4. **Upper latent heat flow**

The heat flow to the cooling system is outside of the scope of this presentation

How to regenerate the power?

(1) **Converting the thermal power flow into another but desired power flow**

Thermo-dynamics (to obtain mechanical power)

- Stirling engine
- Rankine cycle (steam or organic)
- Ericsson cycle
- Proe Afterburning cycle

Thermo-electric (to obtain electrical power)

- Seebeck effect
- Lithium-hydride cycle
- Thermo-photo-voltaic
- Thermo-ionic emission
- Thermo-tunneling

Thermo-chemical (to obtain chemical power)

- Endothermic vapo-cracking (H_2 generator)
- Autothermic fuel reforming (H_2 generator)
- MIT – Plasmatron (H_2 generator)

Thermo-acoustics (to obtain mechanical power)

Thermo-storage (to have heat available when needed)

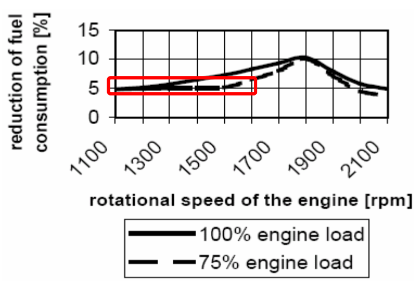
- Phase Transition (keep Catalyst hot longer)

How to regenerate the power?

(1) **Converting the kinetic power flow**

The turbine, in which not only kinetic energy but also some thermal energy is regenerated, is the basic element that serves in a variety of applications:

- Turbocharger (widely used on cars and trucks)
- Mechanical Turbo-Compound (Napier Nomad, Cummins-Scania, Volvo)
- Electrical Turbo-Compound (John Deere, Caterpillar)
- Exhaust turbine generator (Visteon TIGERS)



Fuel economy of about 3 to 5% on cycle

Up to 10% for the peak values.

A few reminders of last year

1

The most interesting technologies that are already in use in other domains or in development

- (Organic-) Rankine cycle
- Stirling cycle
- Turbo-compounding
- Thermo-electrics, thermo-ionic emission, thermo-tunneling
- Endothermic vapo-cracking
- Thermo-chemical (Lithium-hydride cycle)

Most technologies have Inconveniences :

- Too big or too heavy
- Efficiency only good in small powerband
- Too expensive (at least for the coming 10 years)
- Uses additional liquids, some with strong greenhouse effect
- Requires expensive additional equipment (power electronics)
- Lacks robustness or durability
- Safety issues (flamability of liquids), regulations
- Maintenance rather difficult

A few reminders of last year

1

We identified the requirements on an automotive waste heat regeneration system

WHR should give SIGNIFICANT FUEL ECONOMY AT REASONABLE COST

- To fit in the vehicle, it needs to be compact and have packaging flexibility
- Operate in range of exhaust temperatures
- Have a high level of efficiency over whole range of operation
- No use of exotic materials
- No use of additional liquids
- Easy or no specific maintenance
- System built with conventional components and technologies
- It "may not cost much" (this is the automotive industry)

That is why heat2power developed its own WHR technology

Heat2power concept

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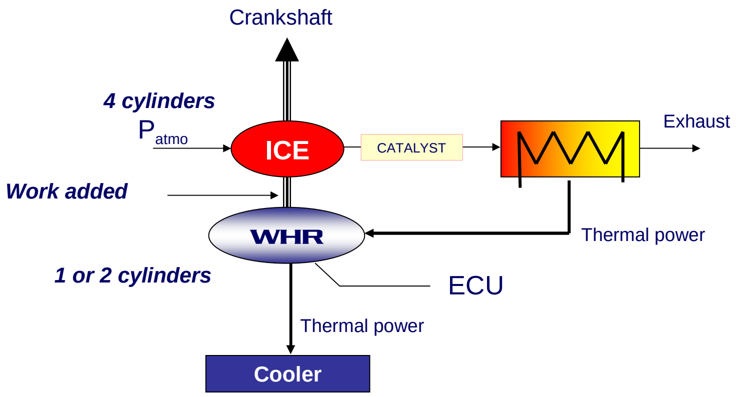


Details and mode of operation can be discussed in face to face meetings

The heat2power principle

We have come up with a WHR concept that combines all requirements for application in series production of cars and trucks :

- Thermodynamic principle called **heat2power** (patented Sept 2006)
- Heat regeneration efficiency of 18 - 31 %
- Combining this with high specific power (up to 1,2 kW/kg for high speed racing engines)
- Cost effective (less than 25 € per % fuel economy)
- Compact
- Uses conventional technology
- Low counter pressure in the exhaust leaves ICE function unaffected
- Startup cost for industrialization similar to a variant of an existing engine
- Novel thermodynamic cycle using air as working medium
- Various configurations possible (add-in or add-on) (simple or optimized)
- Compatible with all fuel types (Diesel, gasoline, ethanol, methanol, CNG, LPG, etc.)

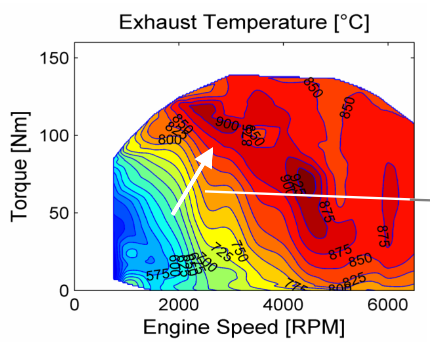
Optimizing the engine size

(2)

The WHR system adds torque to ICE engine torque

A powertrain equipped with WHR can benefit from a smaller engine to generate the same total torque.

In case of application in a hybrid-electric vehicle the ICE operation can be chosen to operate even more in the high efficiency and high temperature area.



Load point shifting through downsizing is a major tool for fuel economy. Both for the ICE itself but also for the performance of the waste heat regeneration system.

Shift of load point with downsizing.

Load point shifting

(2)

What has to be retained :

1. The WHR system already improves the total fuel economy by using the waste heat of the ICE
2. Load point shift improves fuel economy of the ICE itself
3. Load point shift improves thermal conditions for optimized WHR

Performance predictions

3

Key results from simulations on cars with gasoline engines :

Adding a WHR system on a base engine can reduce fuel consumption on NEDC by around 12-15%
However the total power of the power train increases by maximum of 31% dependent of size of WHR system. We were not looking for power increase…

Adding a WHR system on a downsized engine can reduce fuel consumption on NEDC by around 15-22%.

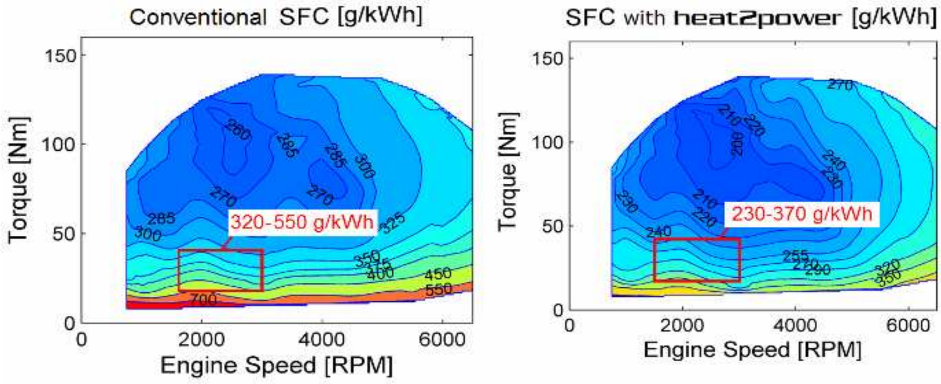
On a downsized engine with WHR the heat regeneration and the effects of load point shift improves fuel economy by about 30% on extra urban driving.

The WHR systems remains compatible with all developments inside the ICE itself (Combustion enhancement, Variable stroke, Overexpansion …)

The heat2power principle

3

The potential of WHR with a regeneration simulated efficiency on typical NEDC cycle points of operation :



Diagrams based on a gasoline engine

Improvement for torques < 30% interesting for bigger engines (US market)

Performance predictions

(3) (4)

Key results from simulations on other engines :

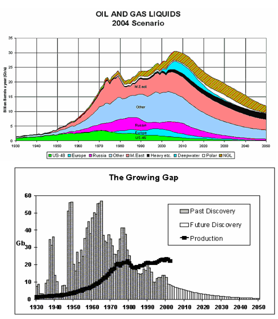
Large diesel generator sets for combined power, heat and cold generation are already very efficient. In many cases there is still too much heat and we would like to set the pointer more on the power generation side. We currently running a study that shows about 10% fuel economy on 480 kW engines.

Adding a WHR system on a race engine is very interesting. Running at full power all the time, thermal conditions are perfect for WHR. And the ratio of thermal power over crankshaft power can be as high as 1.8 on the 8000-11000 RPM range….
Some vehicles carry ballast so the power added by heat2power at 1.2 kW/kg is only a minor drawback.

Why WHR is to be introduced

Because the World is changing…

Peak Oil

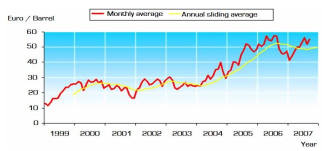


We need to reduce fuel consumption

Changing Climate

We need to reduce CO_2 emissions

Oil price is going up



We want to reduce fuel consumption

Contact us

Thank you for attending the presentation

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