Technical perfection, automotive passion

faurecia

Emissions Control Technologies

EHRS Impact on Engine Warm up and Fuel Economy

Edouard Barrieu

Why Consider Exhaust Heat Recovery?

Industry Challenges

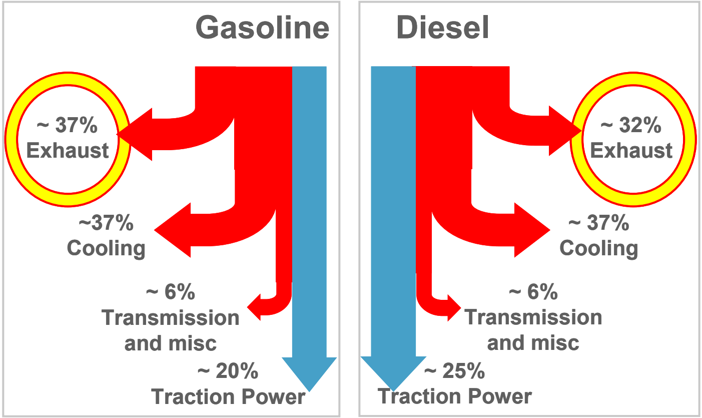
Fuel Economy/CO_2

- Regulations
- Real life use
- Labeling

Passenger Comfort

Cold Start

Opportunity

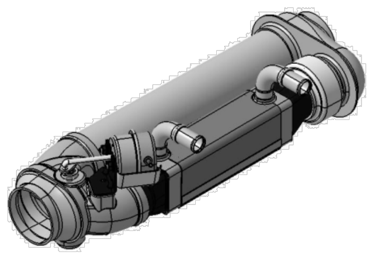


About 1/3 of the energy stored in the fuel is lost through the exhaust

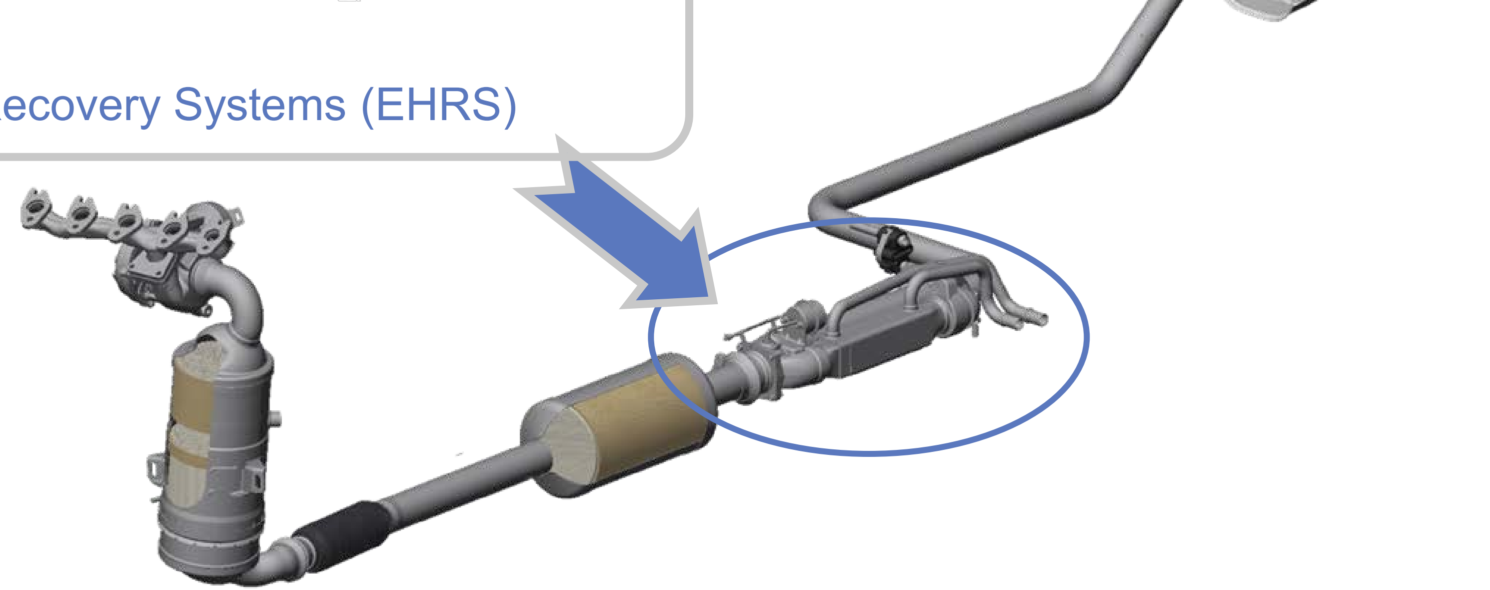
Faurecia Exhaust Heat Recovery Technologies

Gen 0 for diesel applications

Gen 1 for gasoline & diesel applications



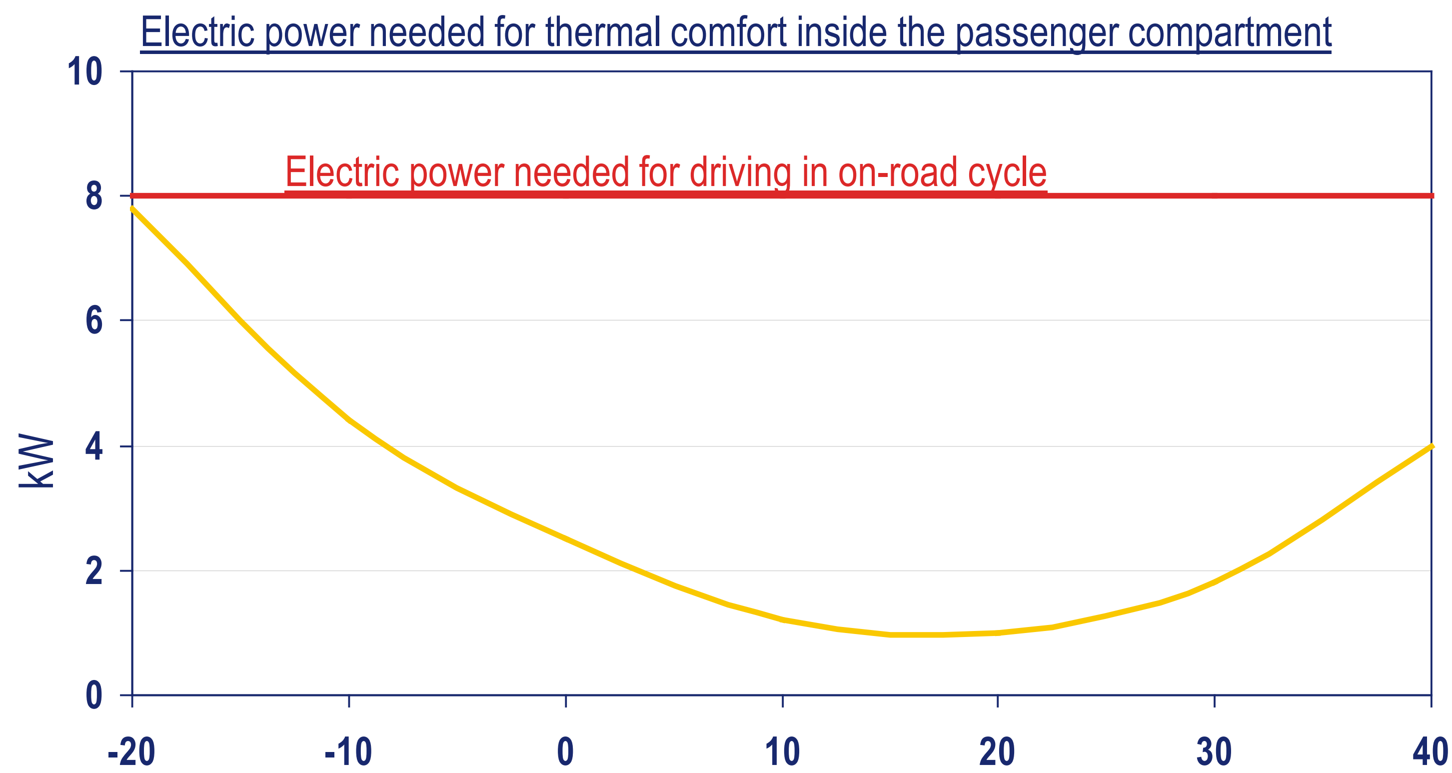
Exhaust Heat Recovery Systems (EHRS)



Benefit of Exhaust Energy Recovery for Hybrid Vehicles

DEER 2011 — Directions in Engine-Efficiency and Emissions Research Conference — U.S. Department of Energy — Detroit, MI ■ October 3 - 6, 2011

The vehicle cabin can be heated more rapidly and fuel can be saved by using more pure electric traction motor

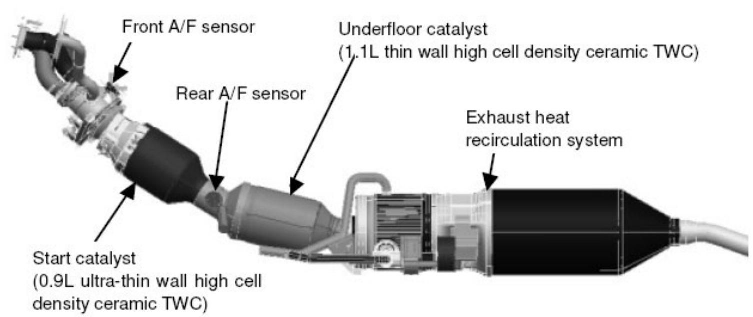


External Temperature °C

Benefit of Exhaust Energy Recovery for Hybrid Vehicles

- EHRS usage rational
  - Engine losses to coolant are normally used to heat the cabin
  - In modern efficient engines, especially hybrids, this may lead to a deficit of energy from coolant to heat the cabin
  - On a hybrid vehicle, thermal engine starts immediately when cabin heater is ON and stops when coolant reaches ca. 60°C to enable pure electric traction
  - The supplement of energy given by the EHRS can shorten this warm up time and save fuel

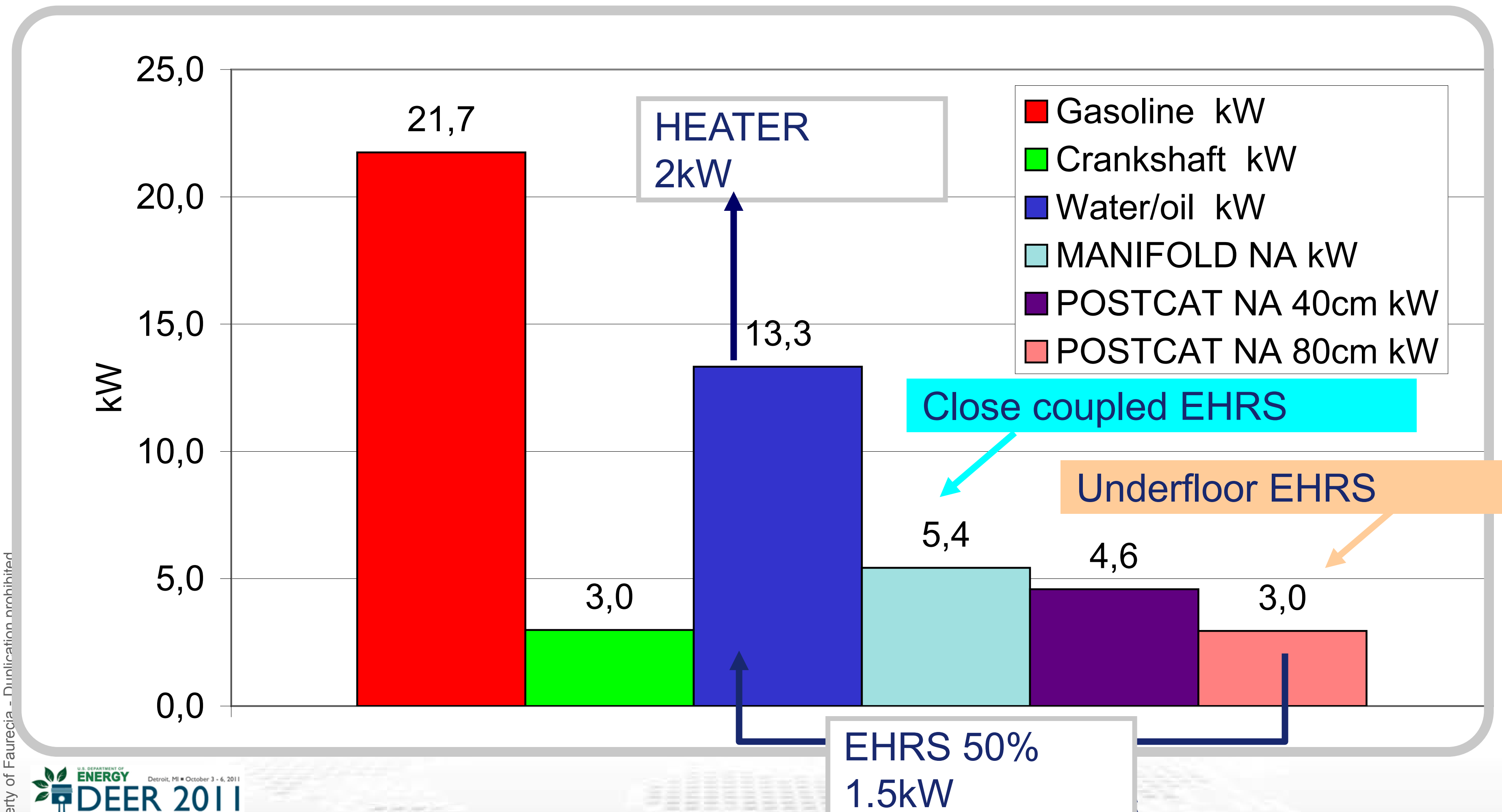
Toyota Prius Hybrid Drive



Energy Flow at 20C Cold Start Average on ECE

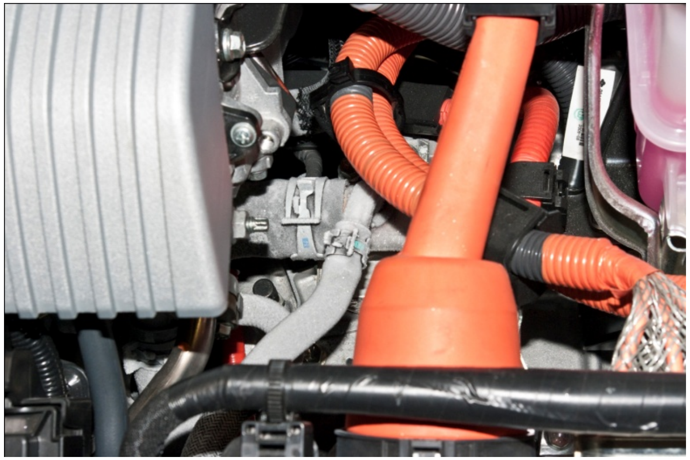
U.S. DEPARTMENT OF ENERGY DEER 2011 DIRECTIONS IN ENGINE-EFFICIENCY AND EMISSIONS RESEARCH CONFERENCE Detroit, MI ■ October 3 - 6, 2011

Energy Split at Cold start on a 2.0L NA gasoline engine



Roller Bench Procedure and Cooler

- Testing procedure for negative temperature
  - A climatic chamber was not available
  - To simulate negative cold start temperature, the Prius engine is “over-cooled” with an external -20°C 5kW chiller
  - The engine, the EHRS, the cabin heater and the complete cooling circuit are flowed with -20°C coolant during 2 hours
  - The cold start occurs at ambient temperature



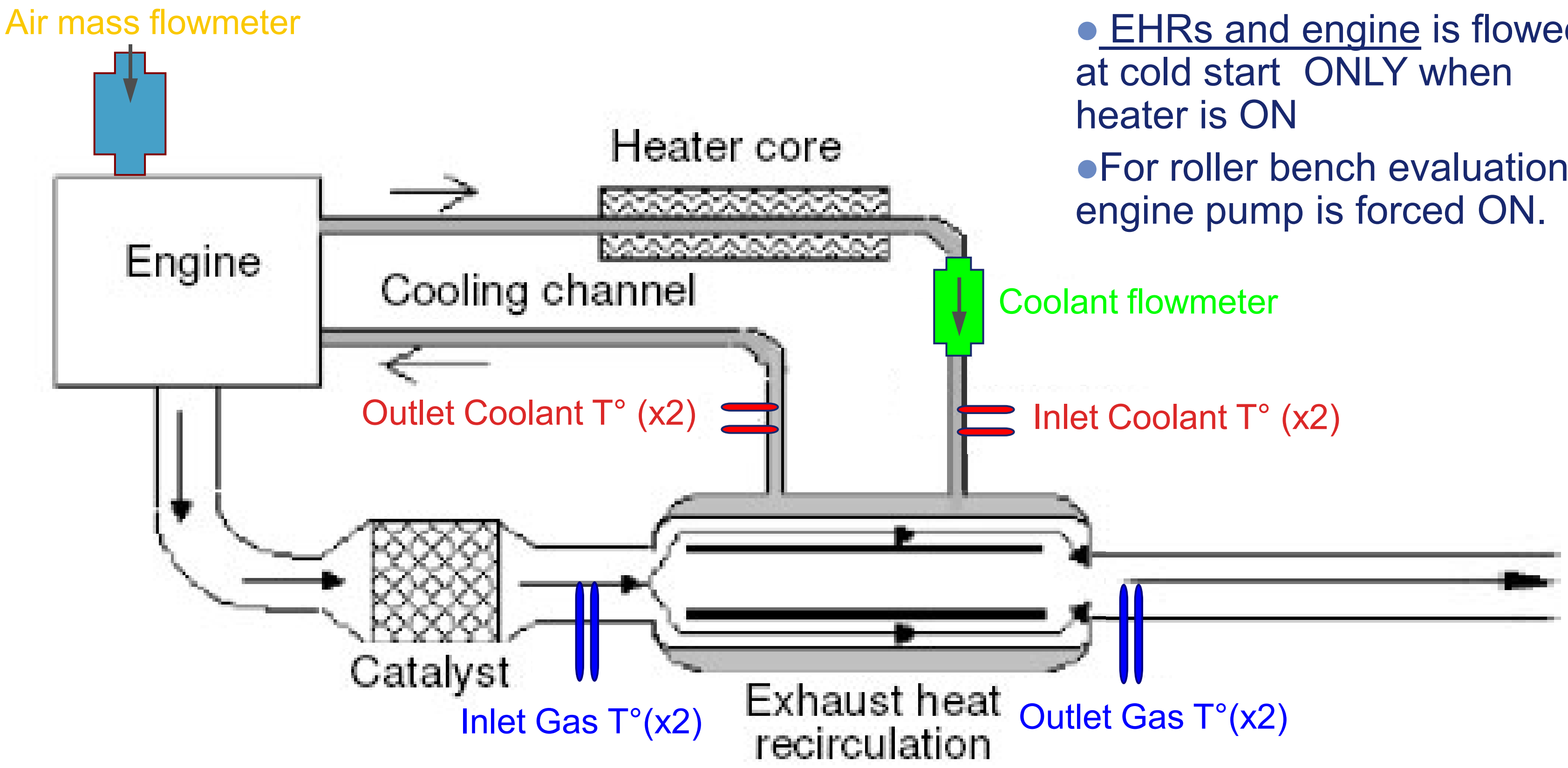
Calculation Method & Testing Procedure

Cabin heater is OFF	Battery SOF sufficient	Vehicle maximizes electrification. ICE is ON until coolant reaches 40°C.
Cabin heater is ON	Battery SOF sufficient	The vehicle forces thermal engine ON, with reduced electric assist until the coolant reaches 55- 65°C depending heater demand.

Test procedure

- To evaluate EHRS efficiencies, cabin heater is forced ON (heater full load).
- Energy balance (output in coolant / input from exhaust) is integrated from 0 to 300sec.
  - At this time, thermal engine may stop, and EHRS is no longer used.
- NEDC cycle is performed up to 800s (ECE part only).
- Two start temperatures are performed : 20°C and -15°C.

Exhaust & Energy Recovery Configuration



- EHRs and engine is flowed at cold start ONLY when heater is ON
- For roller bench evaluation, engine pump is forced ON.

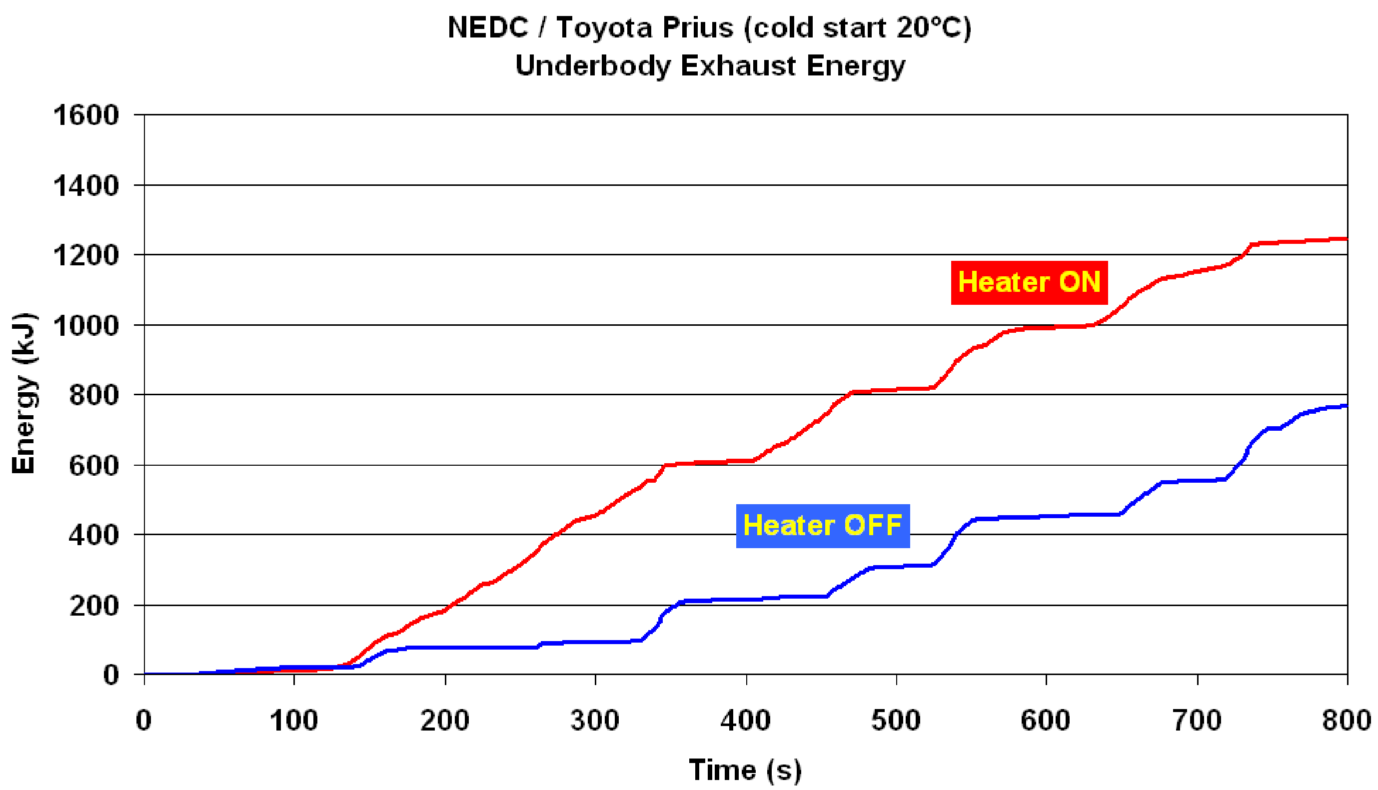
Benchmark Systems

Faurecia underfloor (serial PSA) EHRS1	Faurecia compact close coupled (Innovation) EHRS2	Competitor 2 (Serial production) EHRS3	Competitor 1 (serial production) EHRS4
• Pneumatic	• Pneumatic actuation	• Wax actuation	• Wax actuation

- The benchmark heat recovery systems have not been designed with the same performance requirements :
  - Bypass size is adapted to engine size
  - Heat exchanger size and technology is a trade off between cost and performance
  - Actuation may be wax or pneumatic

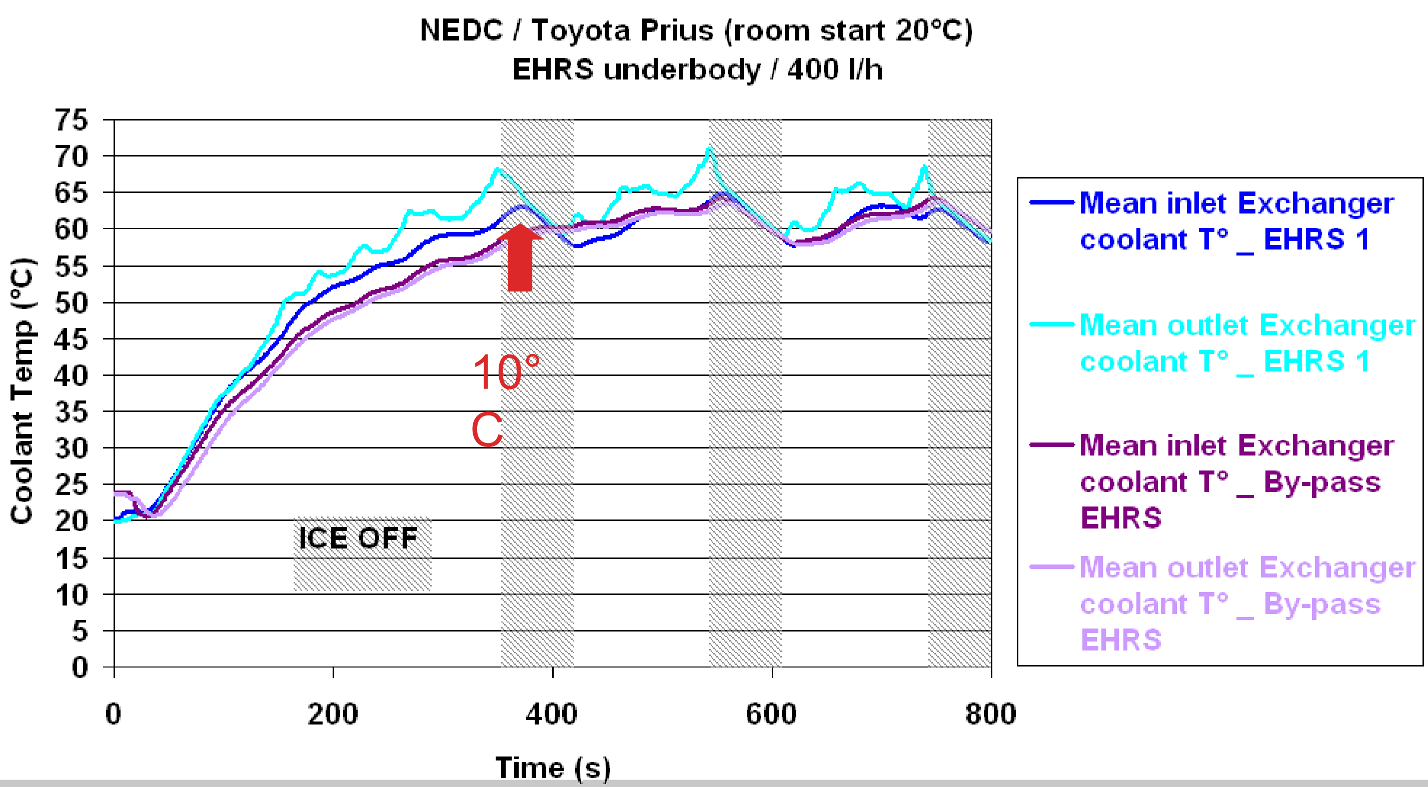
- This leads to very different performance levels, size and weight

Impact of Heater on ICE Exhaust Energy



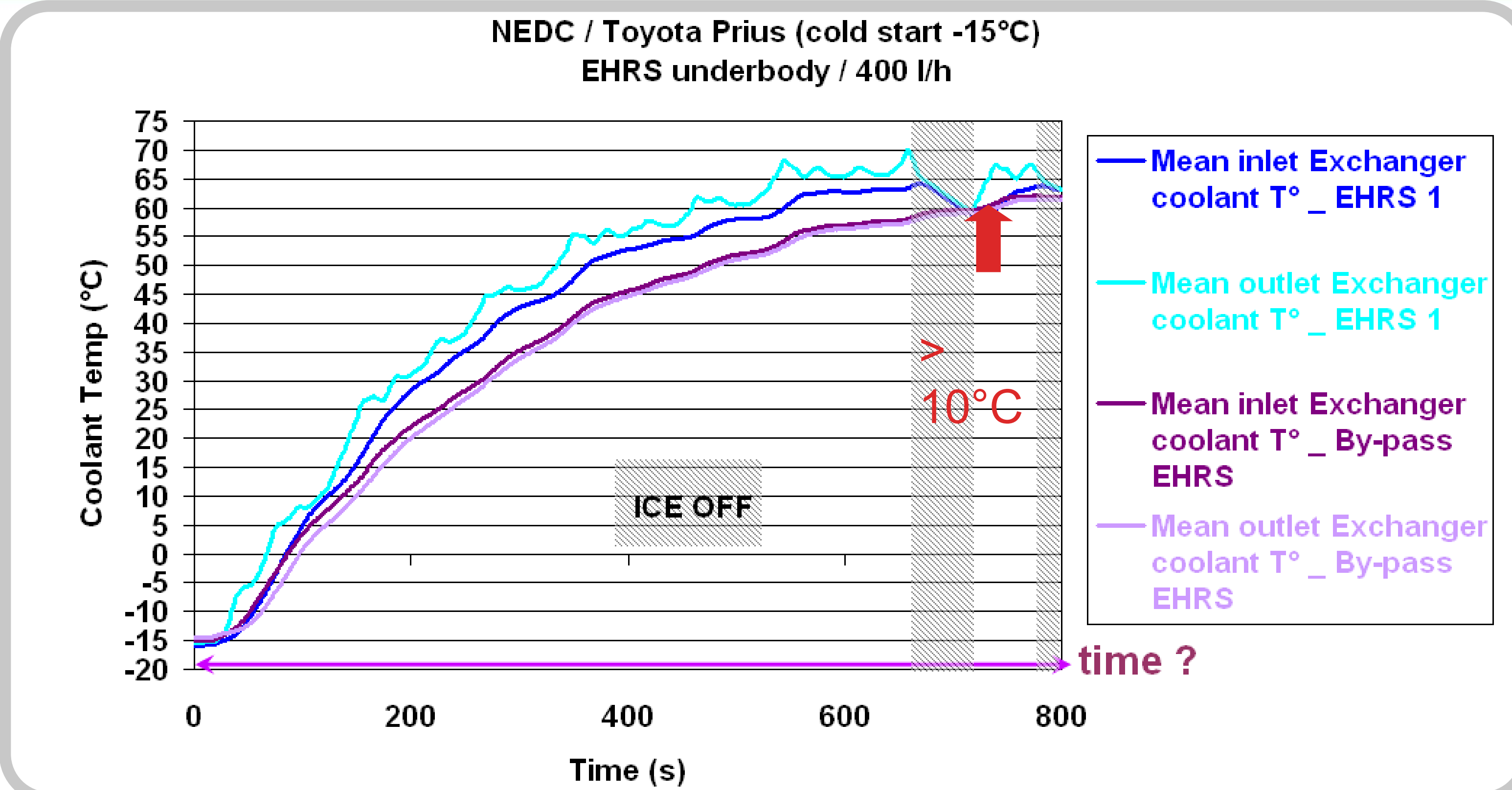
The Heater need the Prius ICE to be a water heater.

Engine Warm up 20C with Heater ON



An efficient underbody EHRS can increase of about 10°C the coolant temperature => BETTER comfort plus frequent engine shut off

Engine Warm up -15C with Heater ON



An efficient underbody EHRS can increase of about 10°C coolant temperature and enable rapid engine shut off.

EHRS Summary Table

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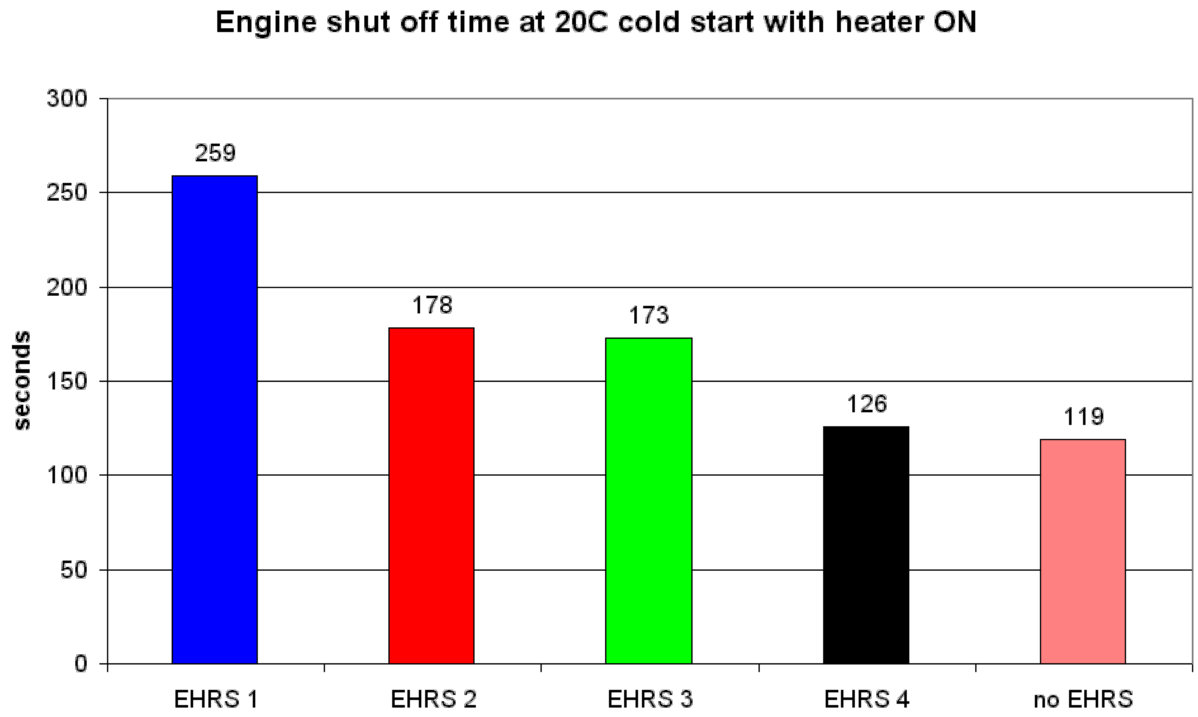
	Start temperature condition	Source exhaust energy (kJ)	Sent to coolant energy (kJ)	Counter effect* (kJ)	corrected energy* (kJ)	Efficiency (%)	Engine shut off time (sec)	kW exhaust average	kw coolant average
EHRS 1	ambient 20°C	480	204	47	157	42	259	1,4	0,583
EHRS 2	ambient 20°C	486	184	24	161	38	178	1,4	0,527
EHRS 3	ambient 20°C	482	95	32	63	20	173	1,4	0,270
EHRS 4	ambient 20°C	486	44	79	-35	9	126	1,4	0,127
no EHRS	ambient 20°C	443	-79			-18	119	1,3	-0,227
EHRS 1	cold -15°C	468	250	38	213	53	74	1,3	0,715
EHRS 2	cold -15°C	467	224	19	205	48	55	1,3	0,640
EHRS 3	cold -15°C	460	113	25	88	25	0	1,3	0,324
EHRS 4	cold -15°C	470	62	63	-1	13	0	1,3	0,176
no EHRS	cold -15°C	450	-63			-14	0	1,3	-0,179

* Estimated

- Test "no EHRS" shows negative impact of EHRS on the coolant circuit : due to additionnal coolant volume and self thermal inertia that has a counter effect on engine warm up.
- EHRS2 is the a super compact EHRS and show minimal counter effect.

Engine Shut off Time 20° C



- Of course heater is not used at 20°C but these savings can be extrapolated for 0-15°C cold start
- Cumulated shutt off time are correlated with EHRS efficiencies and fuel savings

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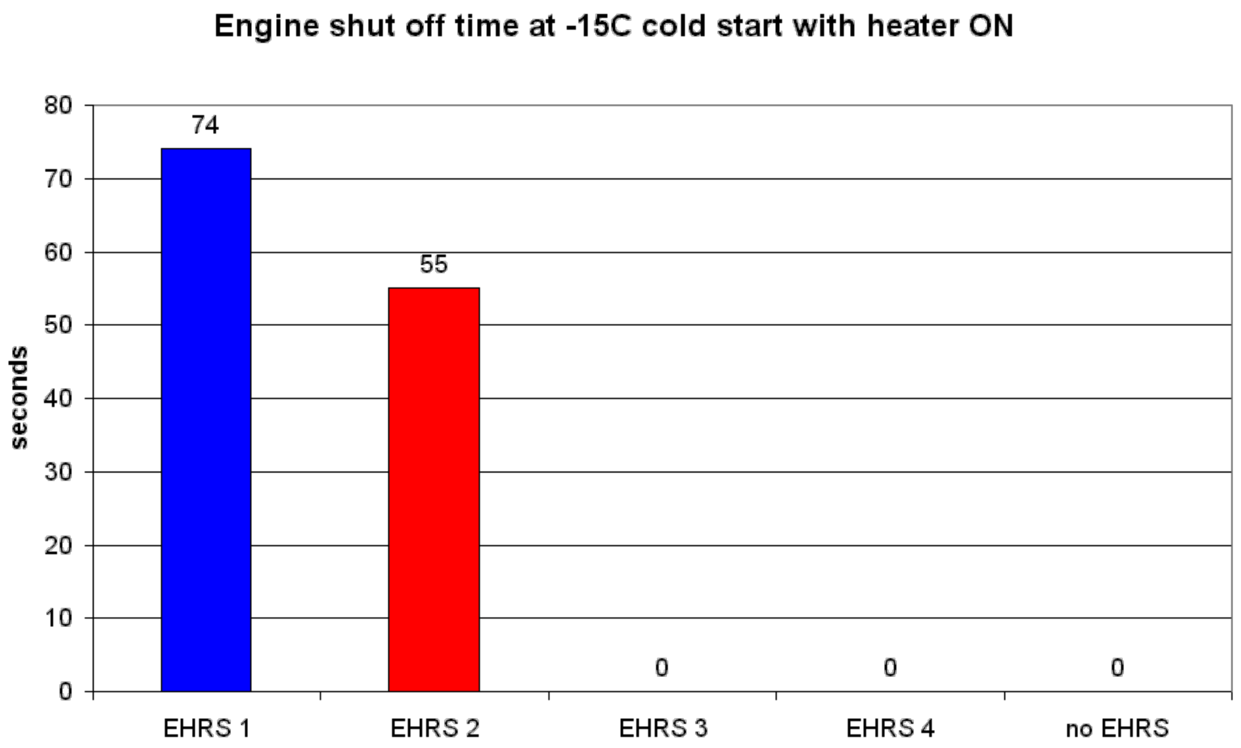
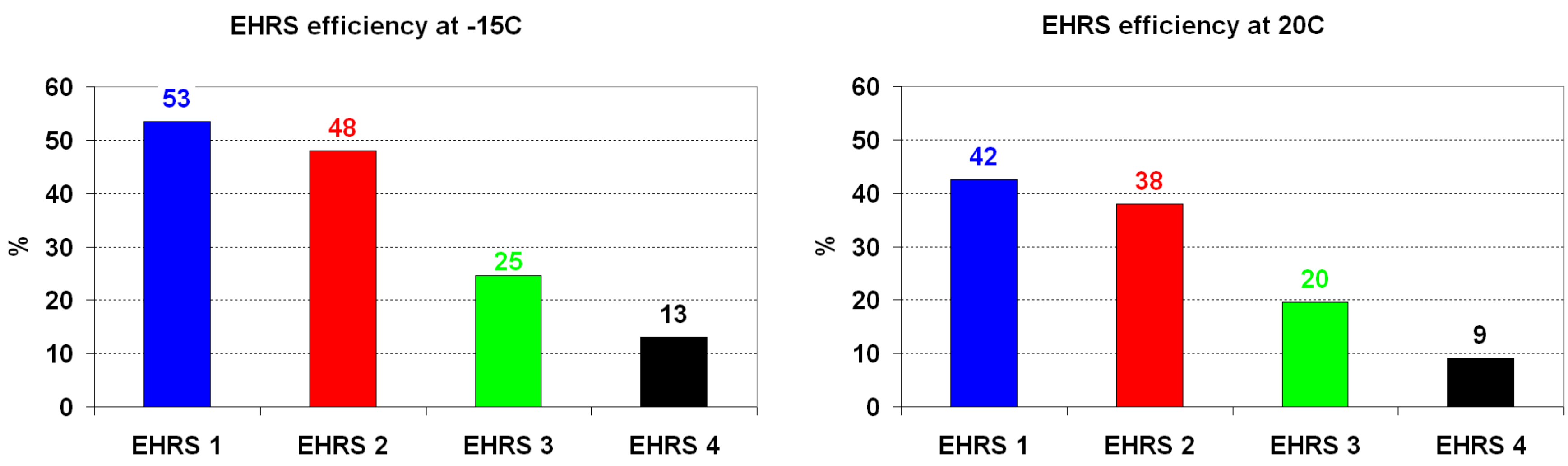
Engine Shut off Time -15° C



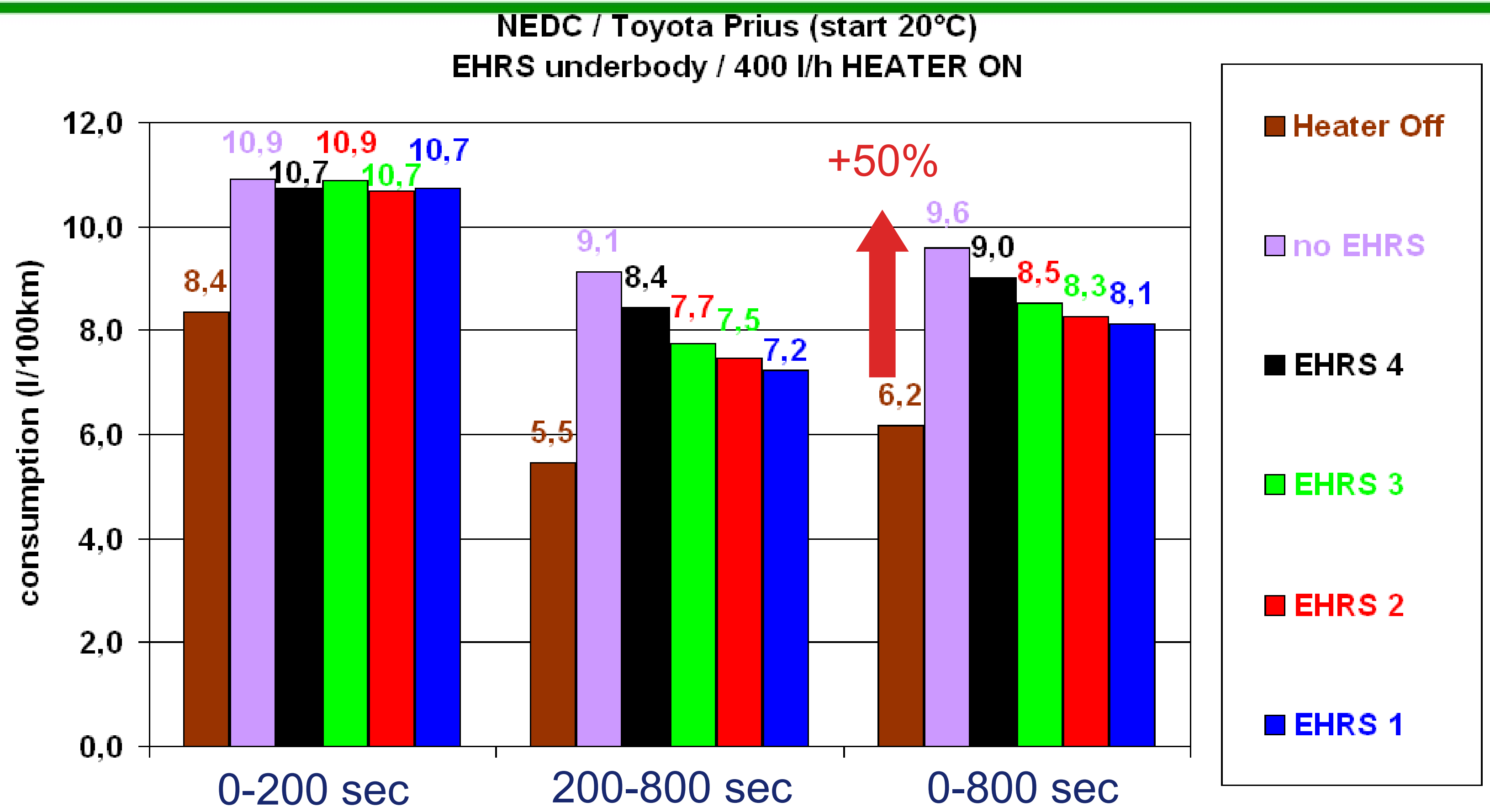
Shutt off times at -15°C occurs mainly on NEDC where torque demand is too high to enable pure electric mode…

EHRS Efficiency on NEDC 20C / -15C



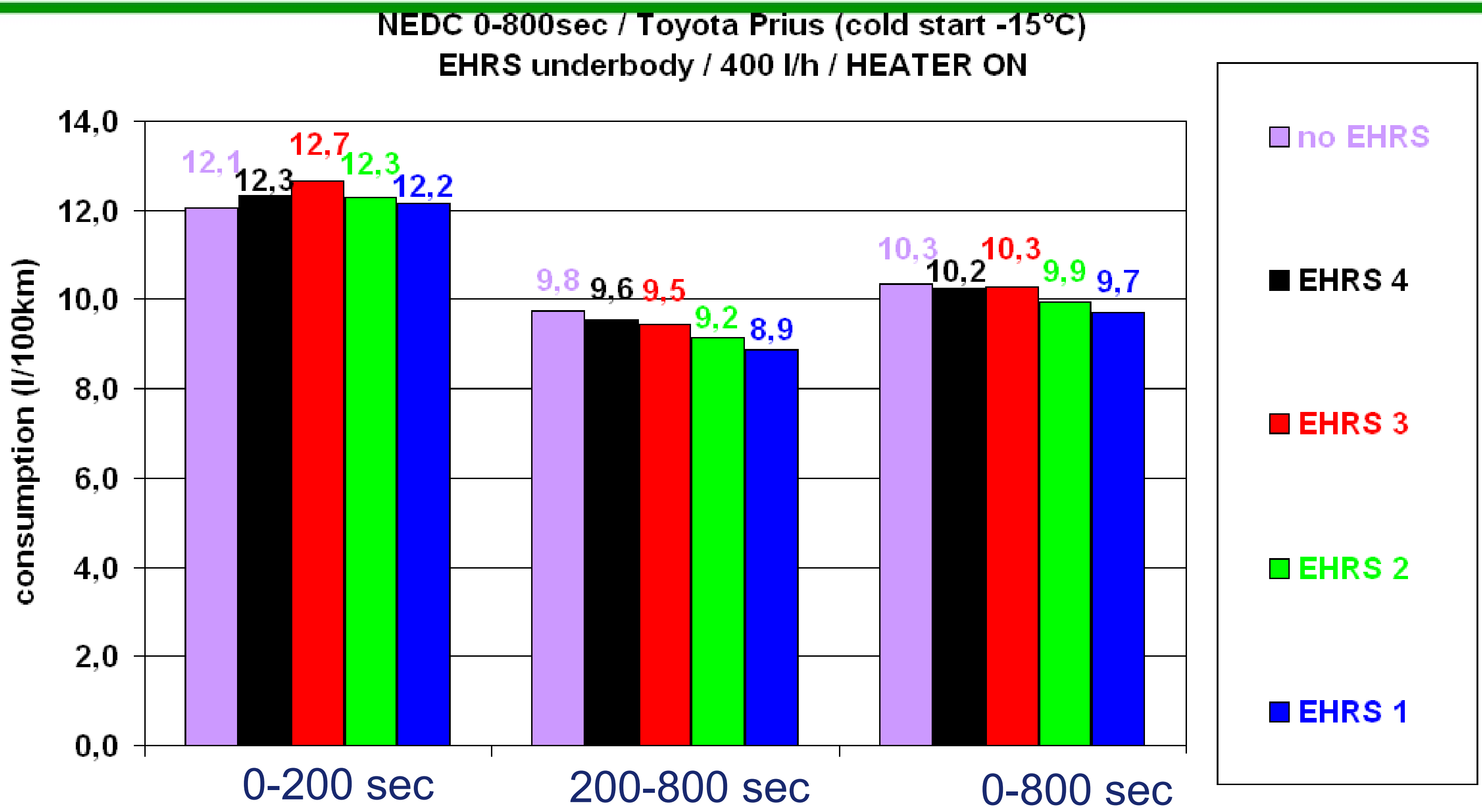
Colder = more efficient the EHRS
The EHRS design may drastically increase its performance (heater core size and EHRS thermal inertia)

Fuel Economy on NEDC 20C



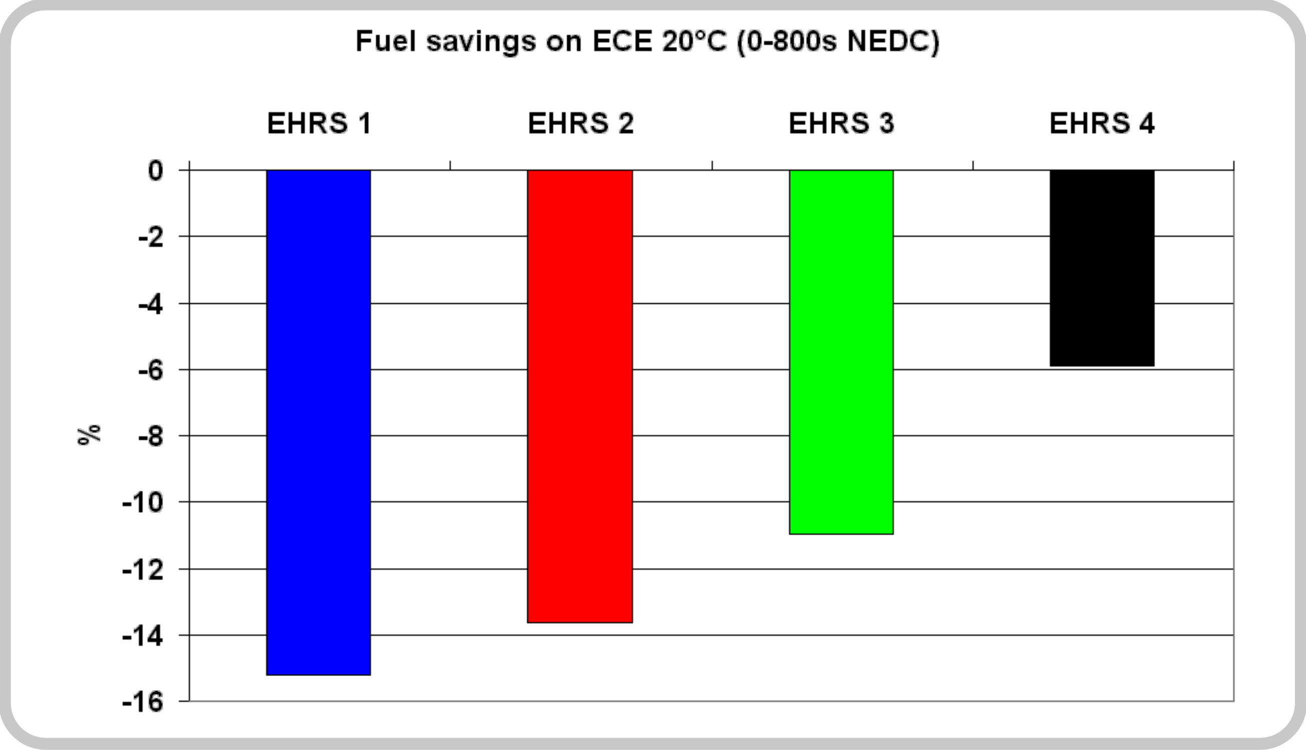
The heater increases about 50% the fuel consumption of an hybrid!
EHRS sizing is of first importance on fuel savings

Fuel Economy on NEDC -15C



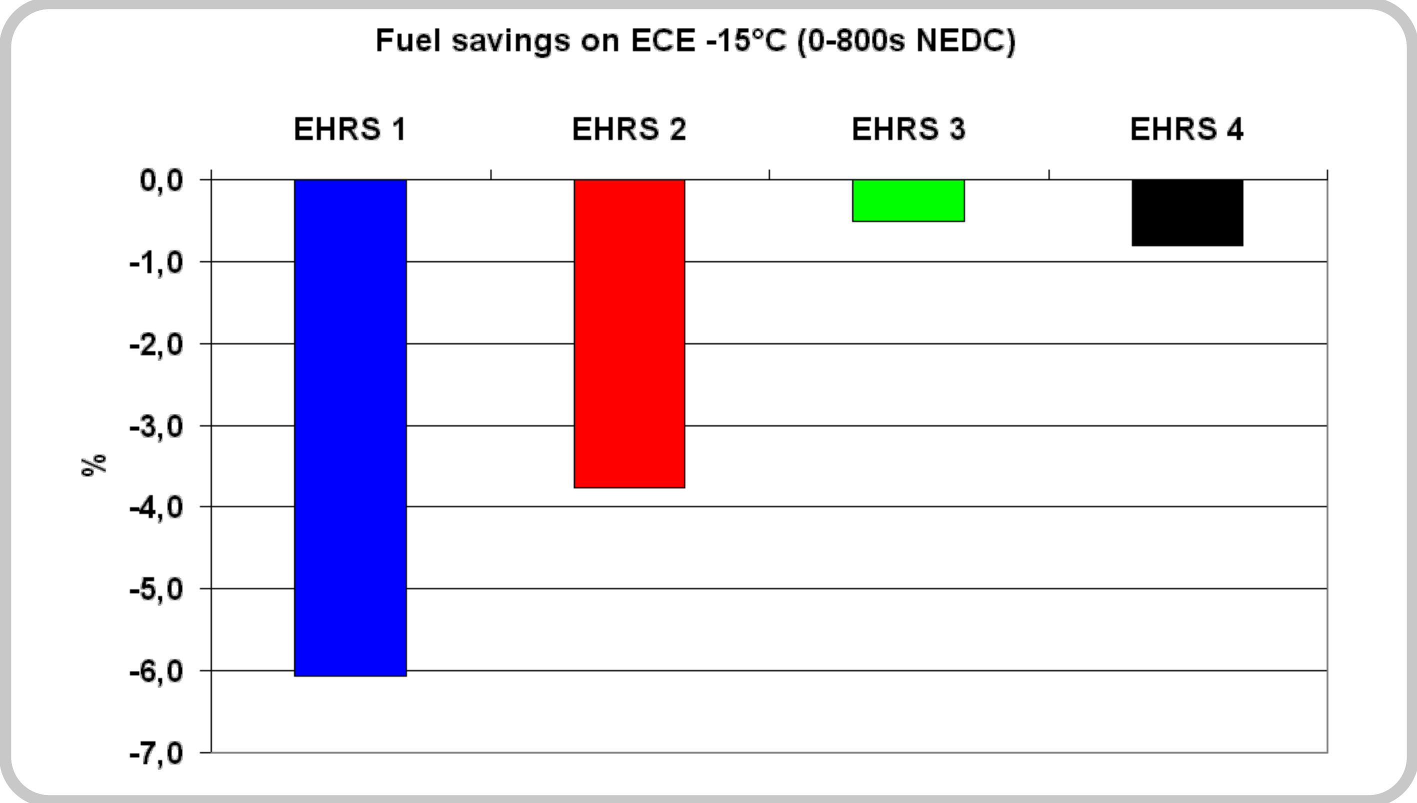
Impact of the EHRS sizing is of first order on fuel savings

Fuel Savings at 20C Cold Start on ECE with Heater ON



EHRS fuel saving at 0-10°C cold start are estimated at about 10% on ECE

Fuel Savings at -15C
Cold Start on ECE with Heater on



Savings do not occur in the 0-800s time interval but rather in the EUCD -800-1200s : these test are not available at the time of writing.

Conclusions

- The exhaust energy recovery technology is an enabler for improving fuel consumption in hybrid vehicles
  - EHRS can increase cabin heating (+10°C coolant side) with a positive impact on fuel economy.
  - The fuel savings on a hybrid with the heater ON can reach 10% on NEDC depending cold start temperature and heating strategy.
  - Fuel economy with the heater OFF has not been shown because the engine pump is OFF during cold start. This would require deeper vehicle modifications. A carbon heater-EHRS special branch should be created.
  - We were not able to evaluate fuel savings while keeping energy constant from the heater to cabin, however these savings may be greater than discussed in this presentation.

Scheduled tests end 2011

- Test with EHRS branch canceled
- Test on EUDC to check savings at higher speed
- Test a close coupled EHRS