Cost to benefit ratio of an exhaust heat recovery system on a long haul truck

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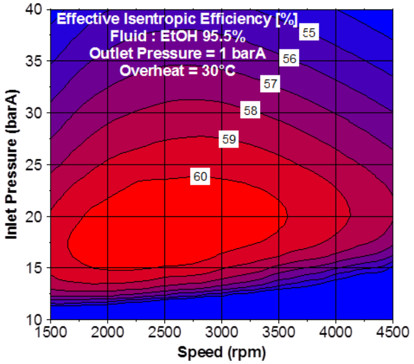
Exoès at a glance

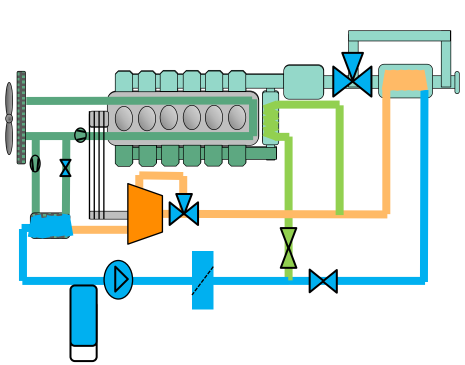
Our skills

EXOES is an engineering company providing its customers with:

Prototypes



Calibrated Simulation



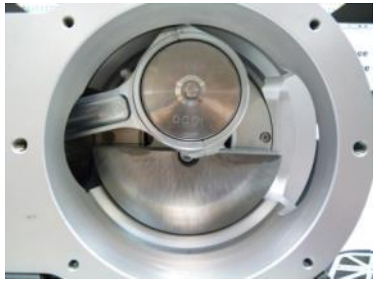
System design

Test rigs

Vehicle integration

Prototype technologies:

Swashplate



Crankshaft

Scroll

Valvetrain

Pump

Experienced in demo-vehicles

References:

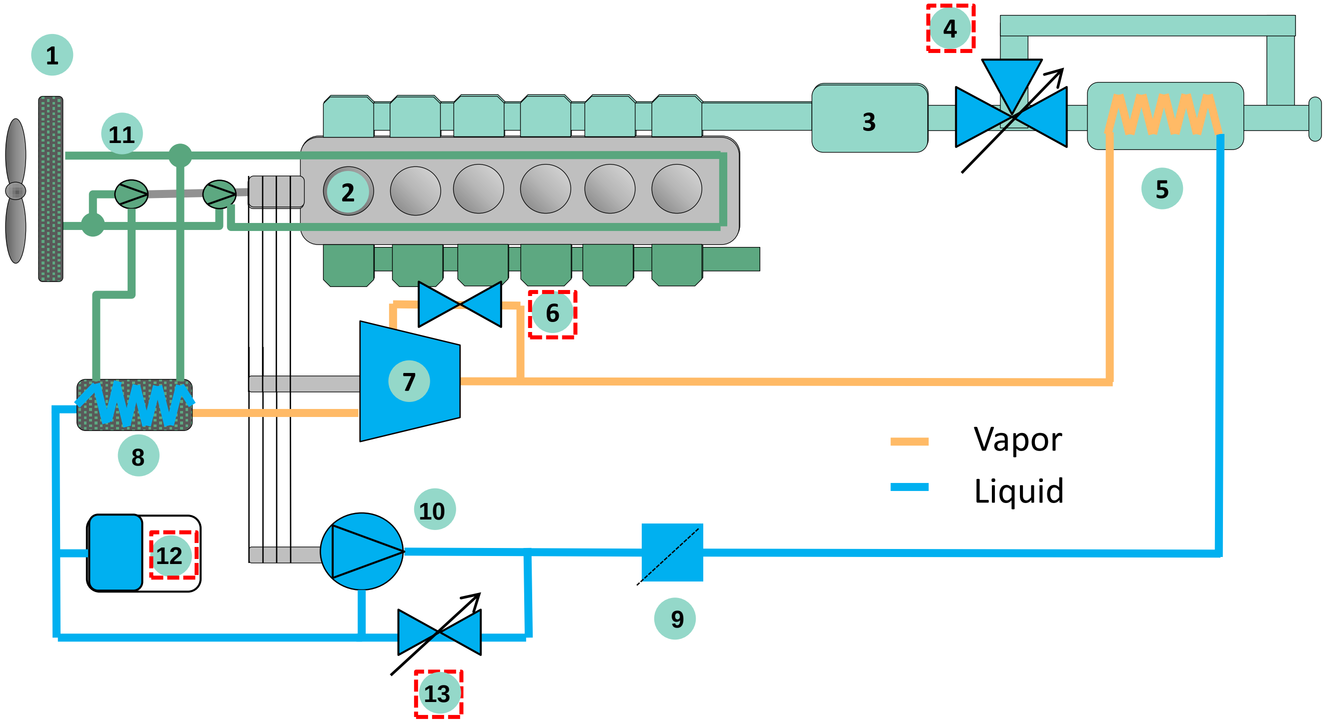
Demotruck:

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

Is there a business case for WHR on long haul trucks ?

Exhaust heat recovery typical layout

- Heavy commercial vehicles – typical class 8 truck
- Focus on exhaust heat recovery only
- Ethanol based working media



1: Main radiator
2: ICE
3: After-treatment
4: Exhaust bypass valve
5: Exhaust evaporator
6: Expander Bypass valve
7: EVE - Expander
8: Condenser
9: Filter
10: Feed pump
11: Cooling pump
12: Expansion vessel
13: Control valve
[dashed box] → to be controlled

Challenges for the ORC

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

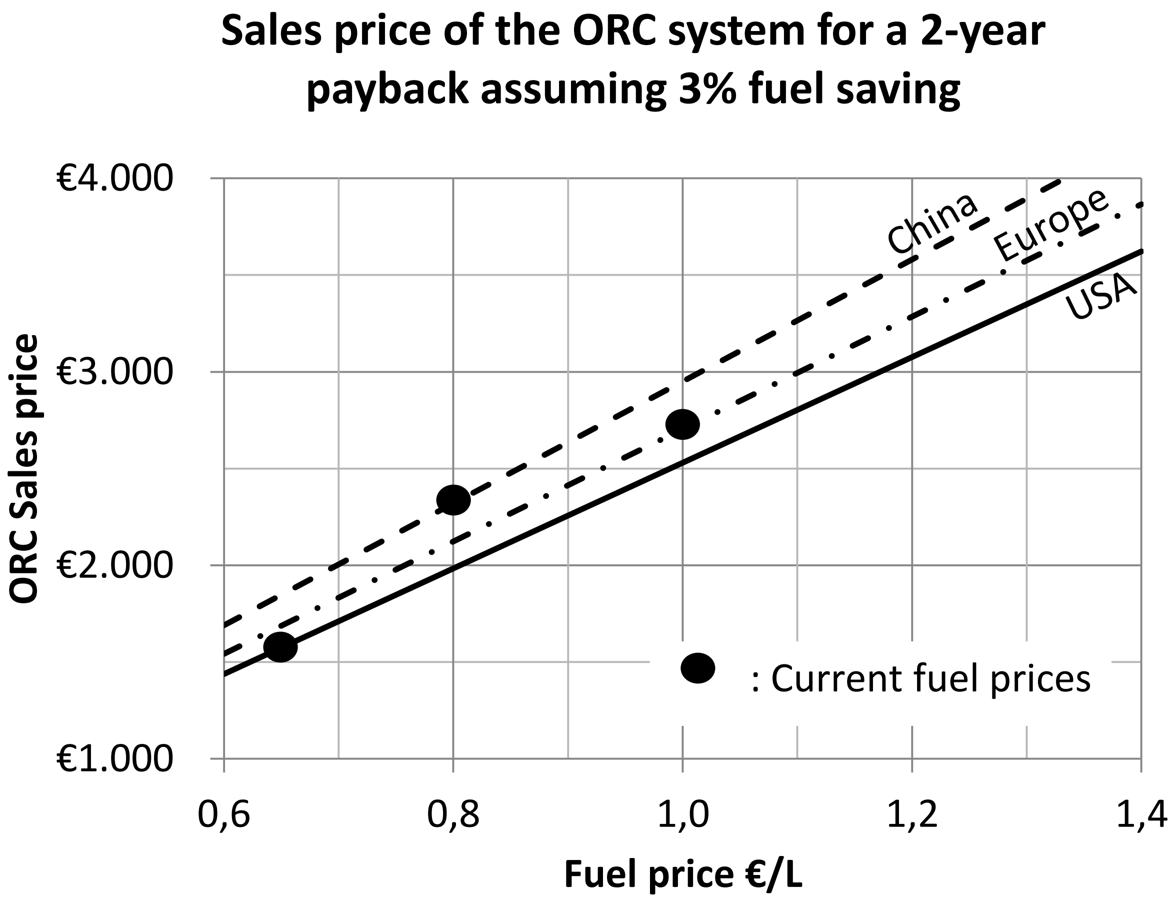
  - **Safety case**
    - Flammable working fluid
    - Extensive risk analysis done by TÜV SÜD / FPT for IVECO
    - System supplier or OEM responsibility

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

  - **Durability case**
    - Prove the component reliability
    - Alcoholate corrosion
    - Fluid ageing: lubricant and ethanol breakdown

Target cost of the system

- Link between payback time, fuel saving and system cost



- Assumptions:

	Europe	USA	China	Unit
Mileage	130,000	110,000	150,000	km/y
Fuel	1	0.65	0.8	€/L
Consumption	35	44	35*	L/100km
ORC Maintenance	100	100	100	€/y

*: projected in 2025 with new regulation implementation

Our costing method

➢Costing method applied by Exoès supported by external cost killers:

Part cost

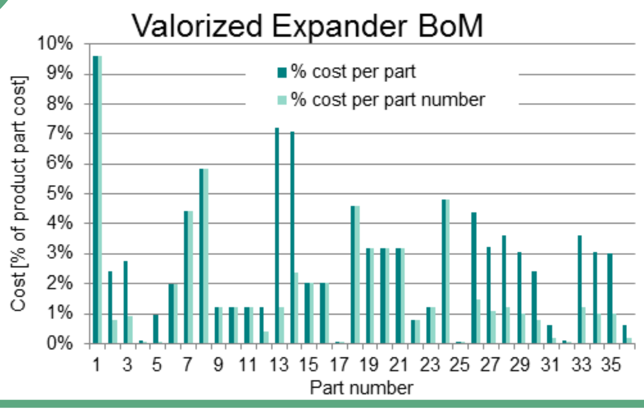
- Bill-of-materials
- Detailed cost on 20% of parts that make 80% of costs
- Simplified estimation of 80% of references
- Make/Buy strategy

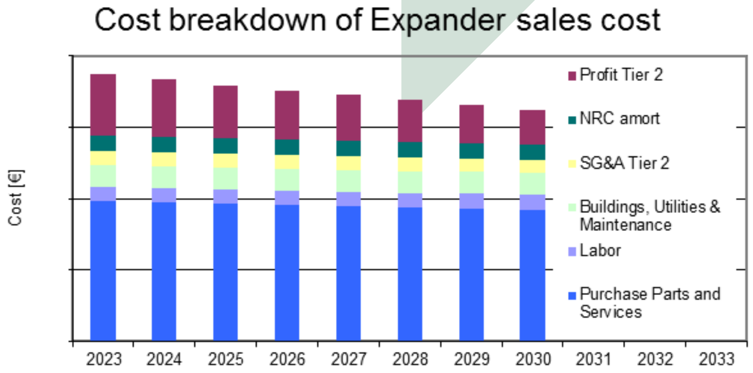
Assembly cost

- Assembly process
- Factory and assembly line

Sales cost

- R&D cost depreciation
- DCF for profit





Manufacturing scheme

- Sales scenario:

	Y1	Y2	Y3	Y4	Y5	Y6	Y7	Y8
Sales per year (unit/y)	5 000	10 000	15 000	25 000	32 500	42 500	52 500	67 500
Cumulated sales (units)	5 000	15 000	30 000	55 000	87 500	130 000	182 500	250 000

- Relatively low volumes. It implies as little investment as possible:
  - 100% buy strategy (Tier1s buy parts and “only” assembles them)
  - No fully-automated assembly lines

Built-up of a valorized BoM

➢ A valorized Bill-of-Materials:

Coatings and thermal treatments

- Ex: ~2€/kg surface treatment baths

Manufacturing process

- Casting / Forging / Machining

Labor

- 40€/h +20%overhead, incl. utilities

Raw material cost

- London Stock Exchange rate

Machine rate

- Ex: 30€/h CNC, Lathe, Horizontal

Weight

- According to a design

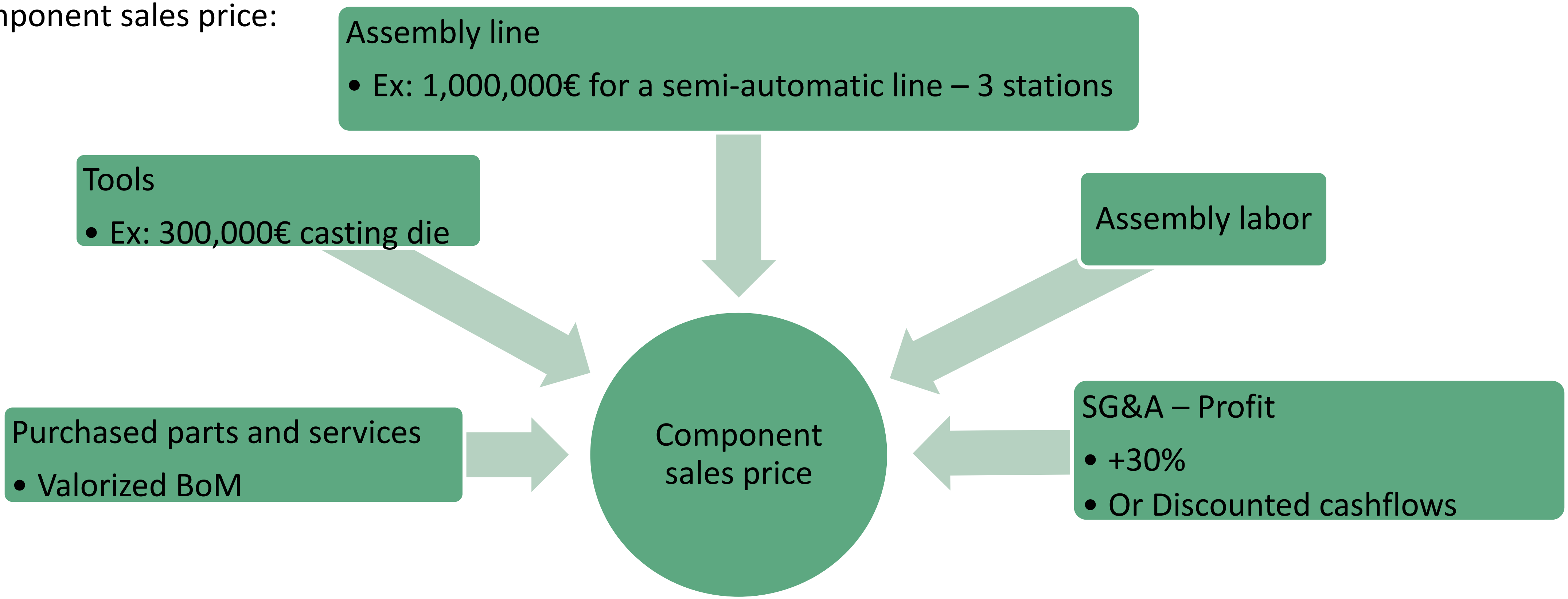
Part

Transport

- 3%

Built-up of the system cost

- Component sales price:

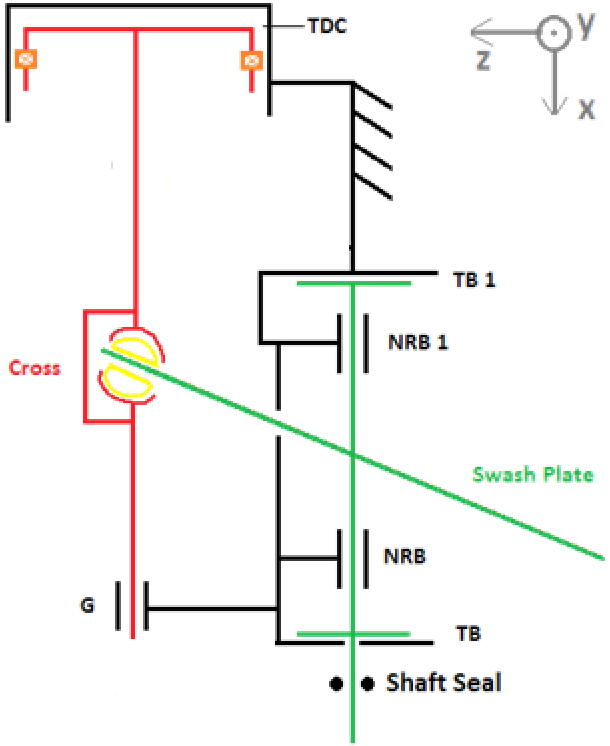


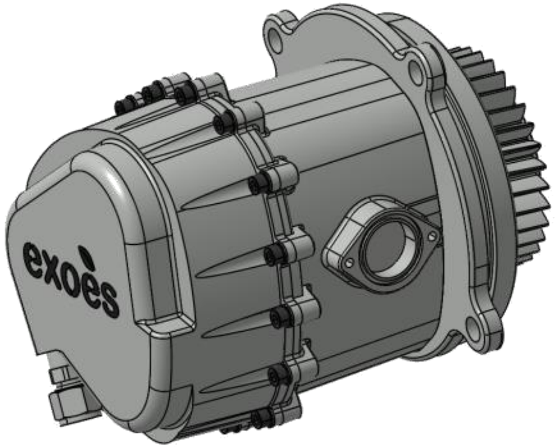
- System sales price:
  - sum of components + OEM margin (+80%)

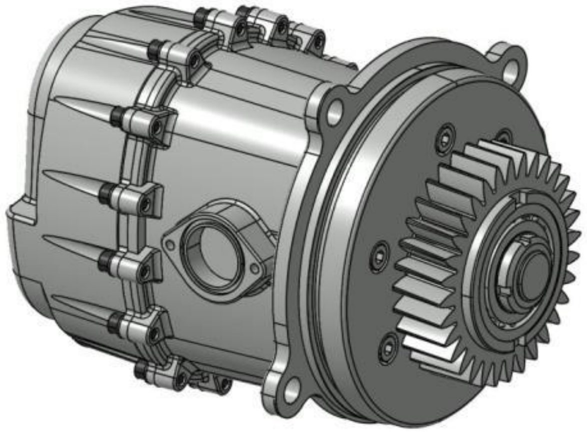
Expander design and cost

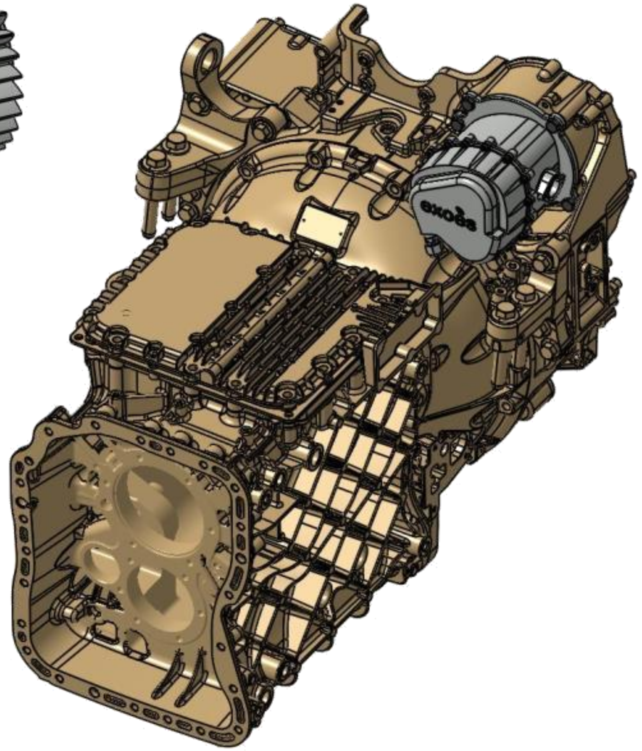
Exoès piston expander technology

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



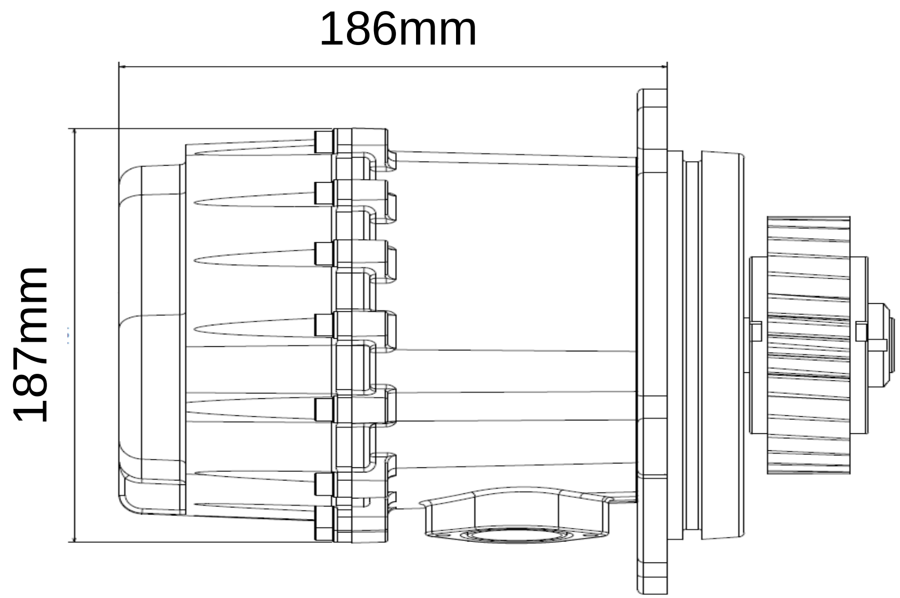




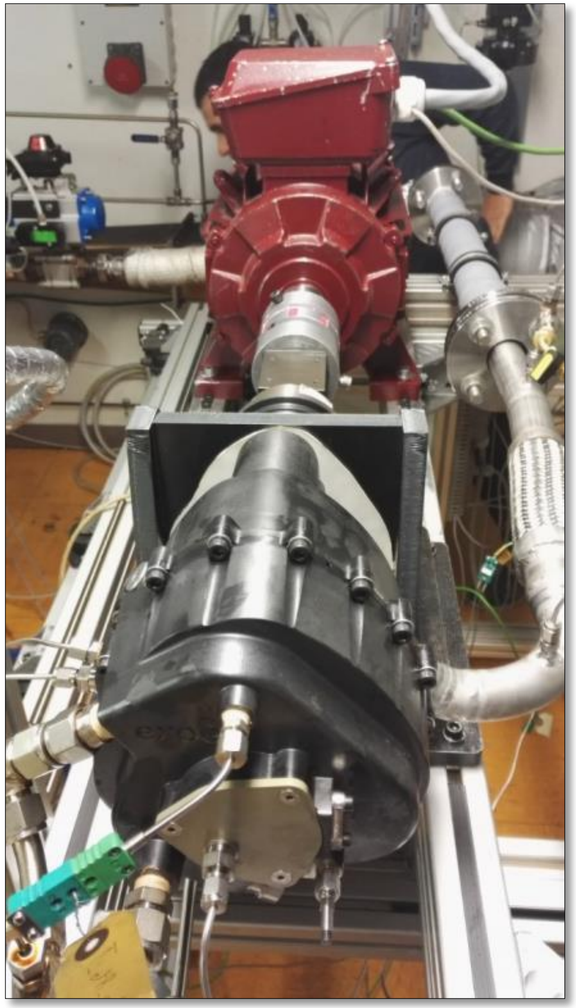


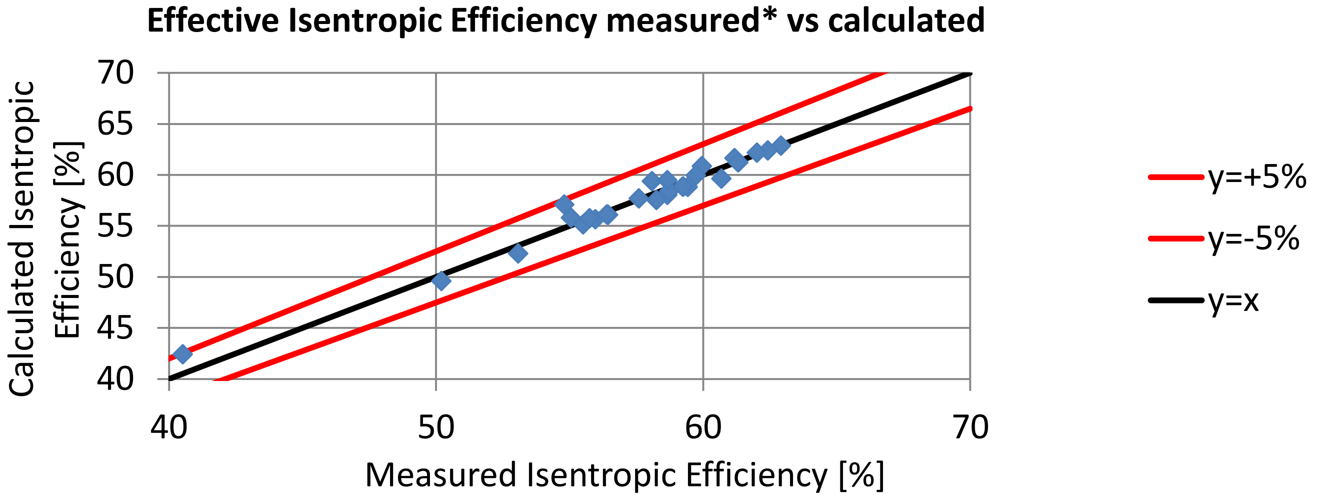
Expander Datasheet

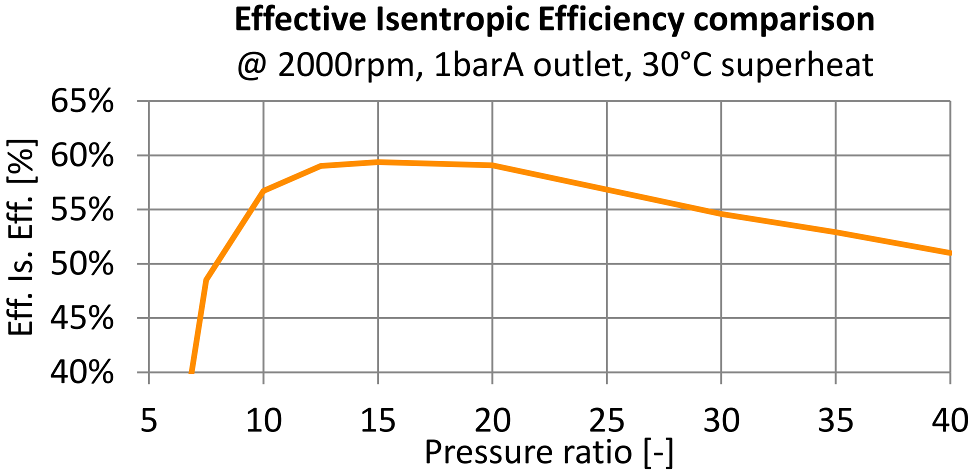
	EVE-T2
Speed range	1,000 - 4,530 RPM
Shaft power range	<12 kW
Eff. Is. efficiency range	Typ. 55 - 65%
Size	< D200xL200mm
Weight without coupling	15kg
Oil circulation rate	Typ. 10%
Outlet pressures	1 - 4barA
Inlet pressures	<40 barA
Nominal pressure ratio	15 – 20 for ethanol
Nominal gear ratio	1.5 – 2.5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



Expander tests and model calibration







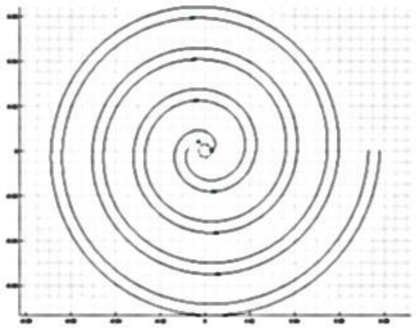
Effective isentropic efficiency:

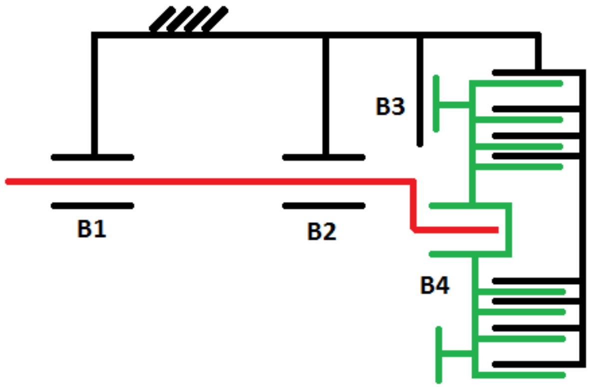
$$\eta_{eff,is} = \frac{\dot{W}_{shaft}}{\dot{M}(h_{in} - h_{out,is})}$$

*Measured = calculated based on measured values

Future expander generation

- Compliant Scroll – Volume ratio 4.6 – Capacity 139cm^3



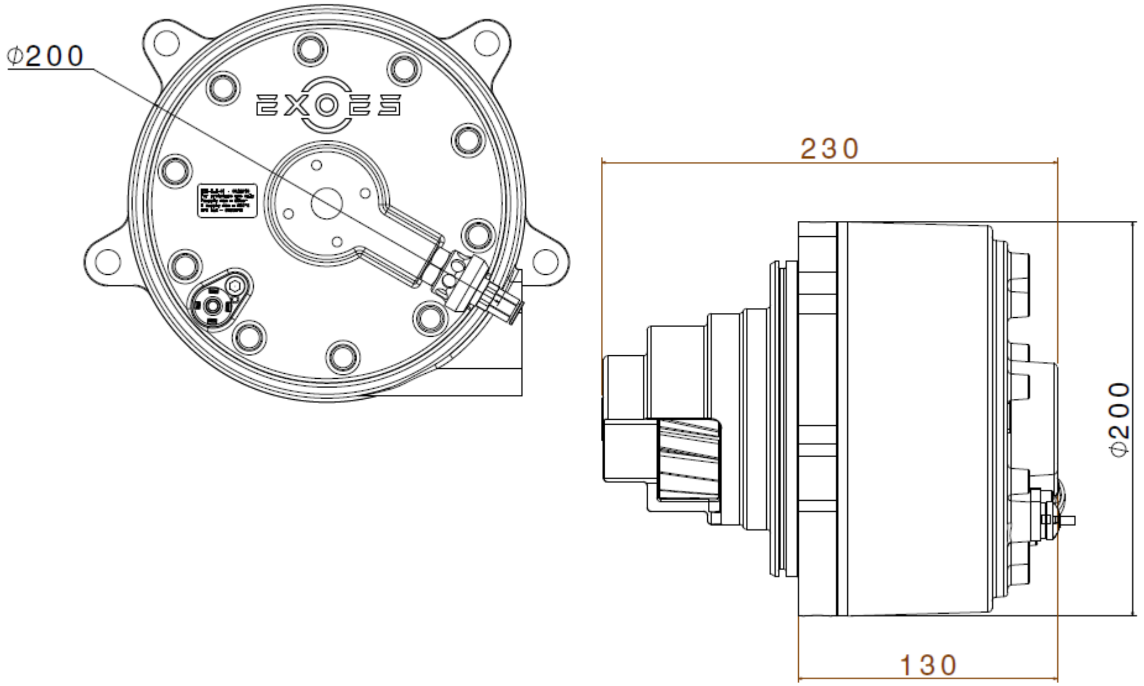


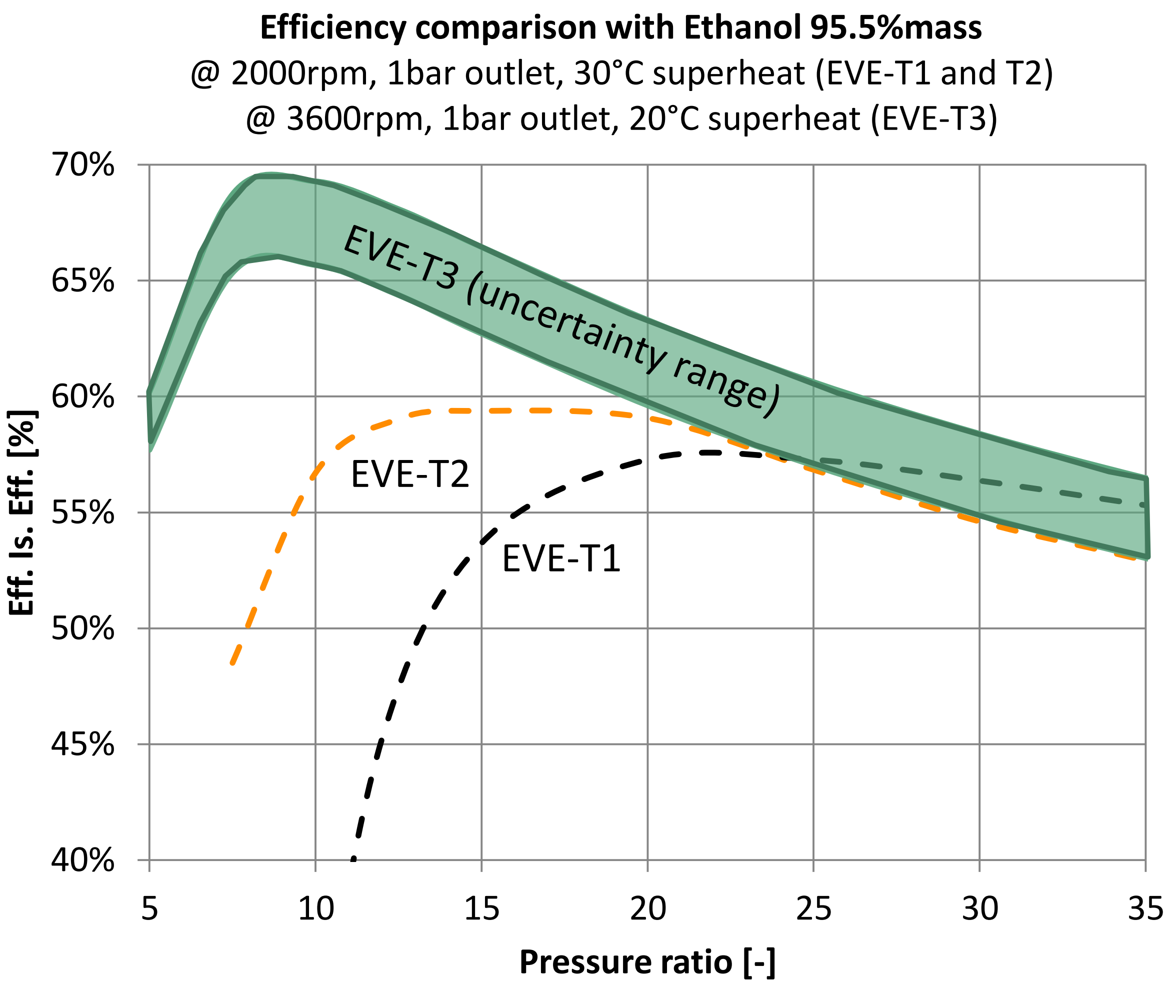
	EVE-T2 - piston	EVE-T3 - scroll
Speed range (RPM)	1,000 - 4,530	1,000 – 6,000
Shaft power range	<12 kW	<15 kW
Eff. Is. efficiency range	Typ. 55 - 65%	Typ. 60 - 75%
Size	< D200xL200mm	< D200xL130mm
Weight w/o coupling	15kg	16kg
Oil circulation rate	Typ. 10%	Typ. 5%

Efficiency & cost forecast

- Higher efficiency expected

- Projected cost for 50,000 pcs/year
  - 350€ ±50€ sold to OEM

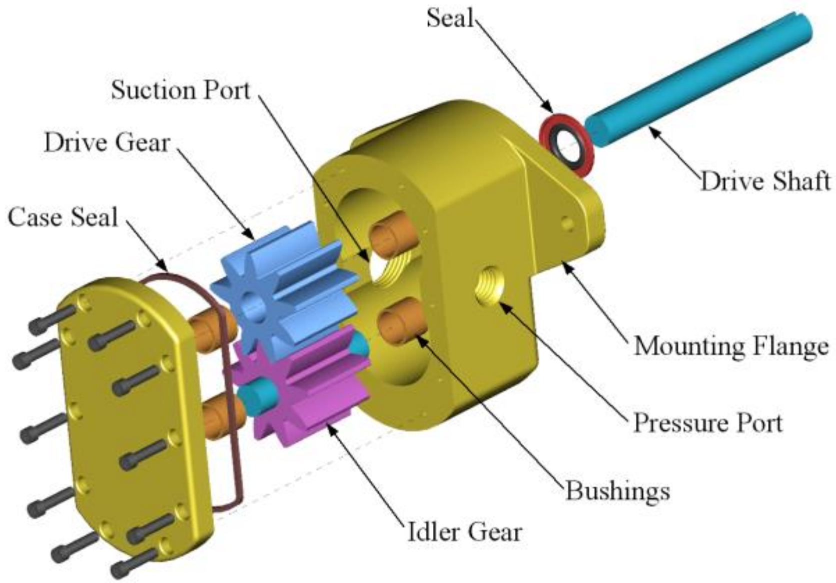




Pump design and cost

Pump Datasheet

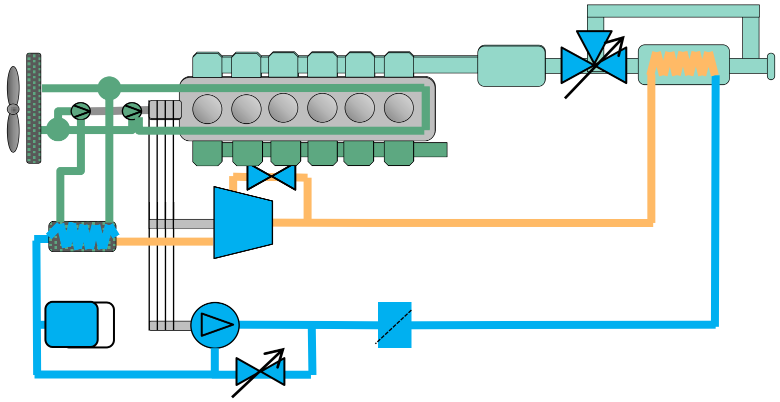
	PHP-T1
Speed range	750 – 6,000 RPM
Max flow	7 L/min
Fluid	Ethanol – Water mixtures
Size	D100mm x L200mm
Weight	<5kg
Required subcooling	~5°C
Inlet pressure	1 – 4 barA
Outlet pressure	<40 barA
Optional : motor	24Vdc Electric motor integrated Communication: CAN
Other options:	Filter Relief valve Pressure & Temperature sensors

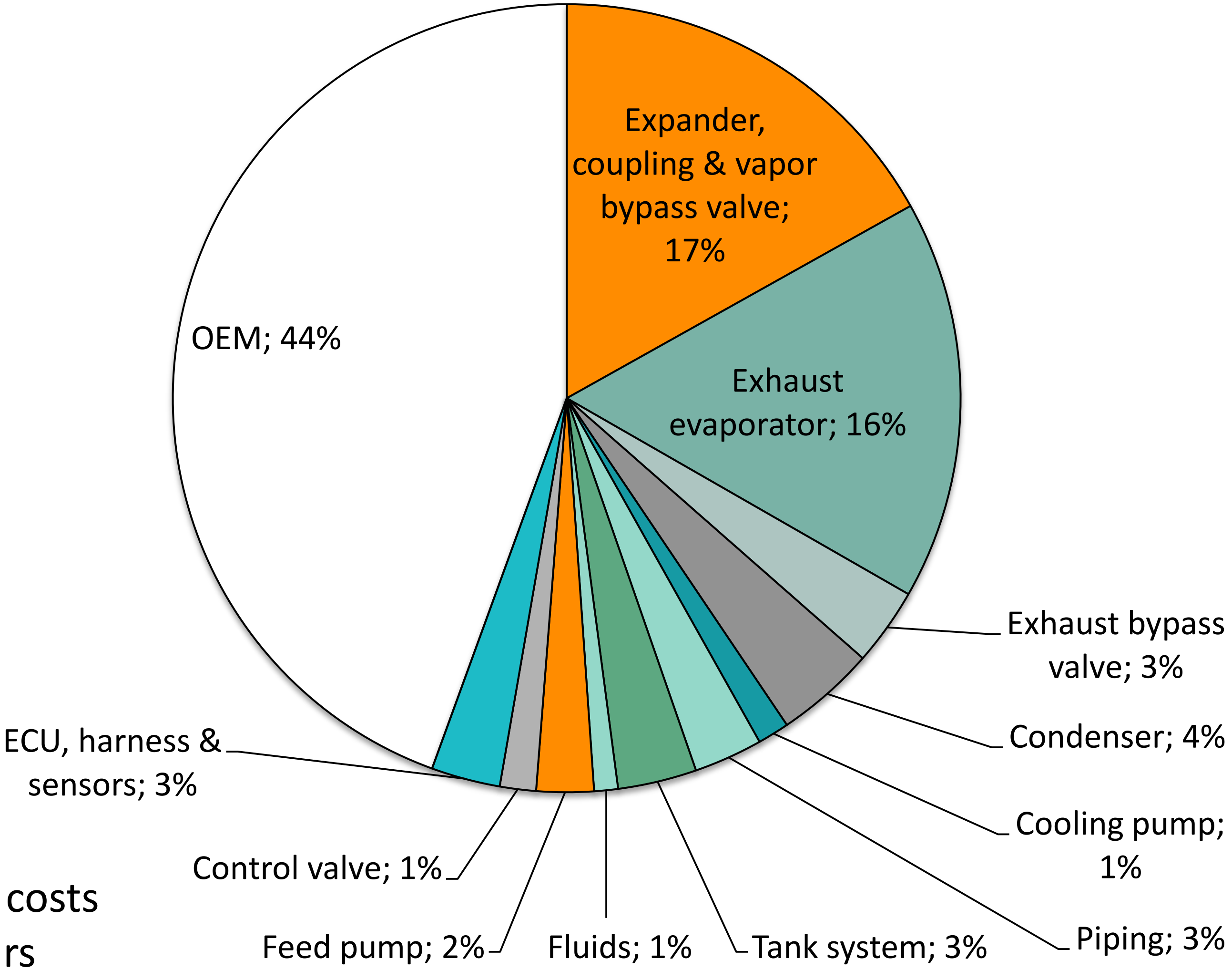


Conclusion

Estimated system price

- **Estimated sales price: 2,700€ (± 300€)**

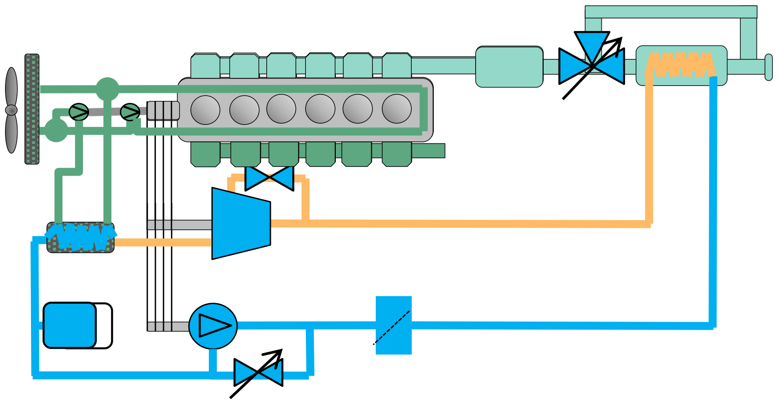




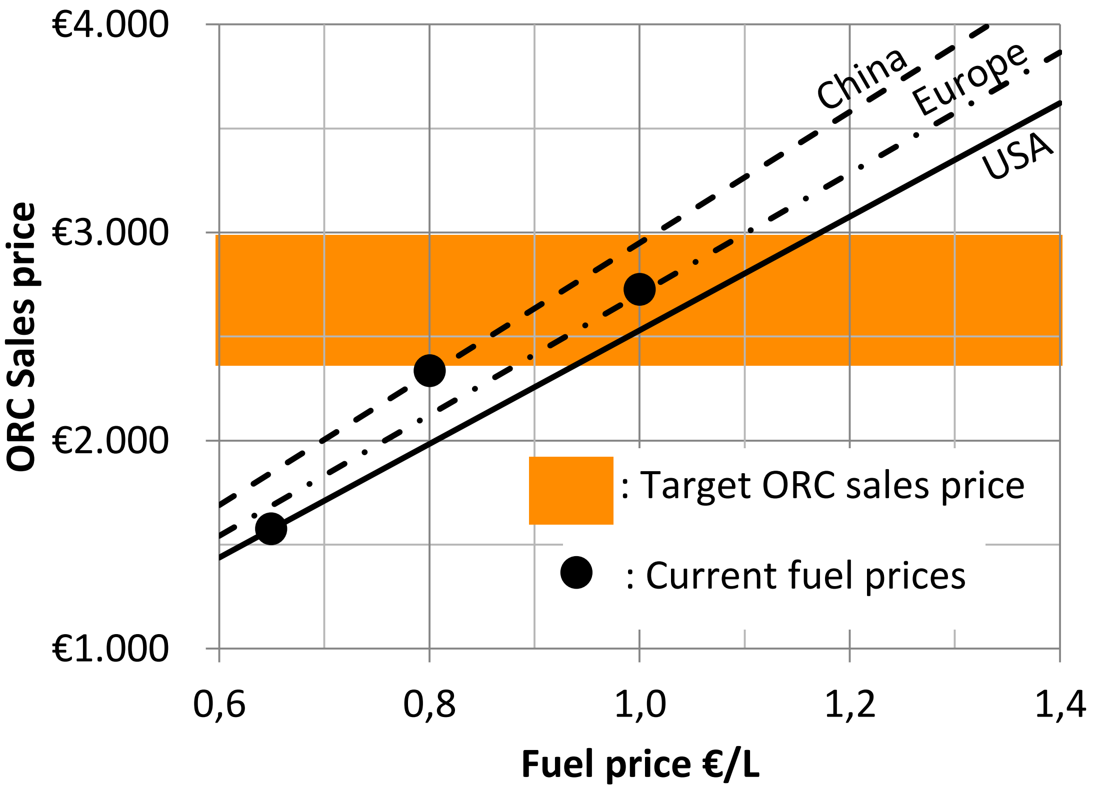
- Some assumptions:
  - Exhaust WHR (No EGR recovery)
  - Radiator carried over
  - Mechanical feed pump
  - Mechanical coupling of expander
  - OEM costs and profit = 80% of components costs
  - ~50,000 unit/year; 250,000 units over 8 years

Business case

- Fuel savings:
  - measured on demovehicle – 11L SCR only engine – 40-ton truck
  - between 2.75 to 3% according to driving cycle
  - Paper to come with detailed results



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



- **Valid business case (at least in Europe)**

Thank you for your attention