# Thermoacoustic technology for energy saving and emission reduction

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ECN
Your energy. Our passion.

# Thermoacoustic technology for energy saving and emission reduction

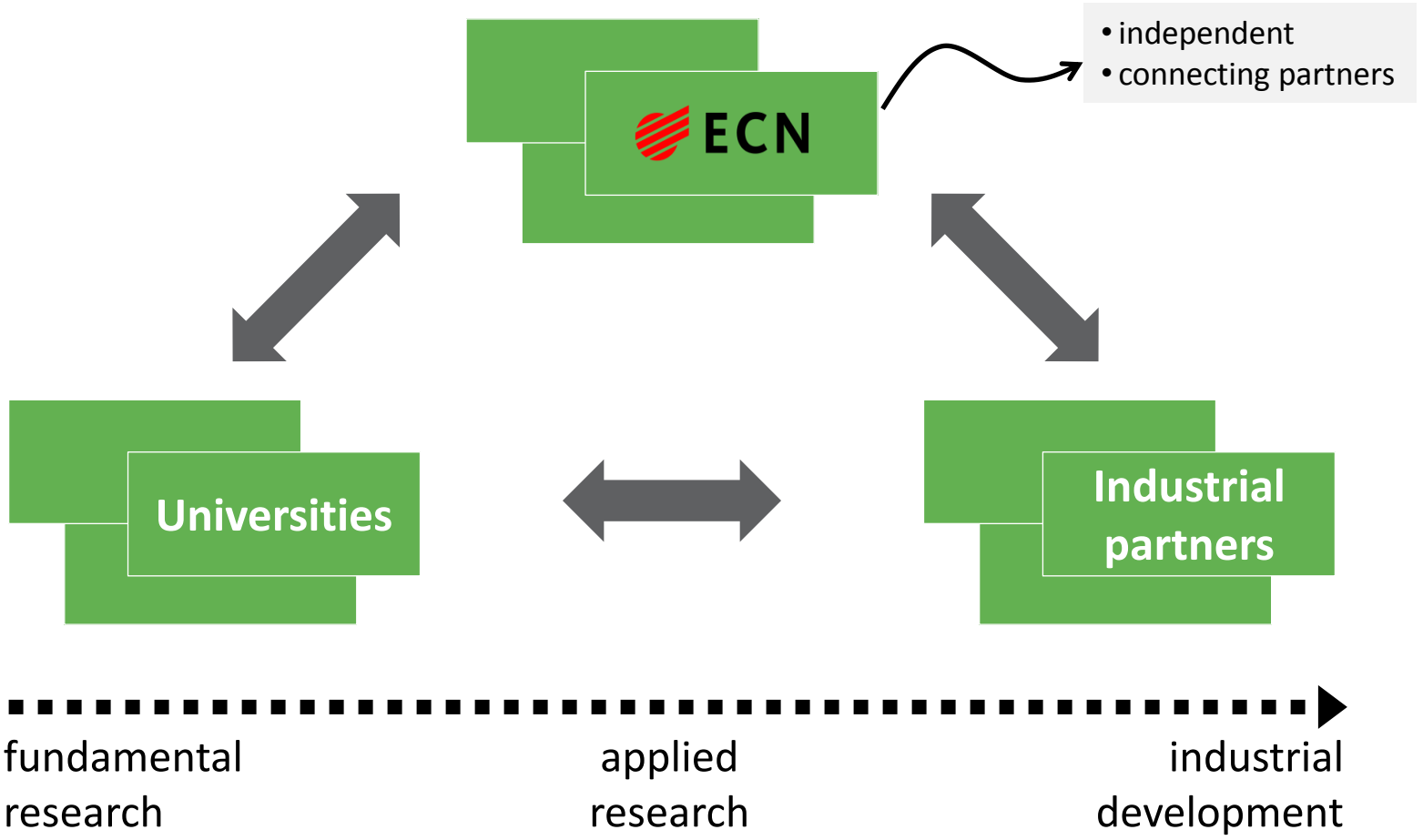
**Hassan Tijani**

2nd International Workshop on Thermoacoustics
Sendai, Japan
23-25 May 2014

# Content

- Introduction to ECN
- Overview activities Thermal systems group
- Thermoacoustic activities at ECN
- Industrial applications
- R&D thermoacoustics
- Examples of developed TA-systems
- conclusions

# Position


• independent
• connecting partners
ECN
Universities
Industrial partners
fundamental research
applied research
industrial development

# Locations

**ECN Petten**
(head office)

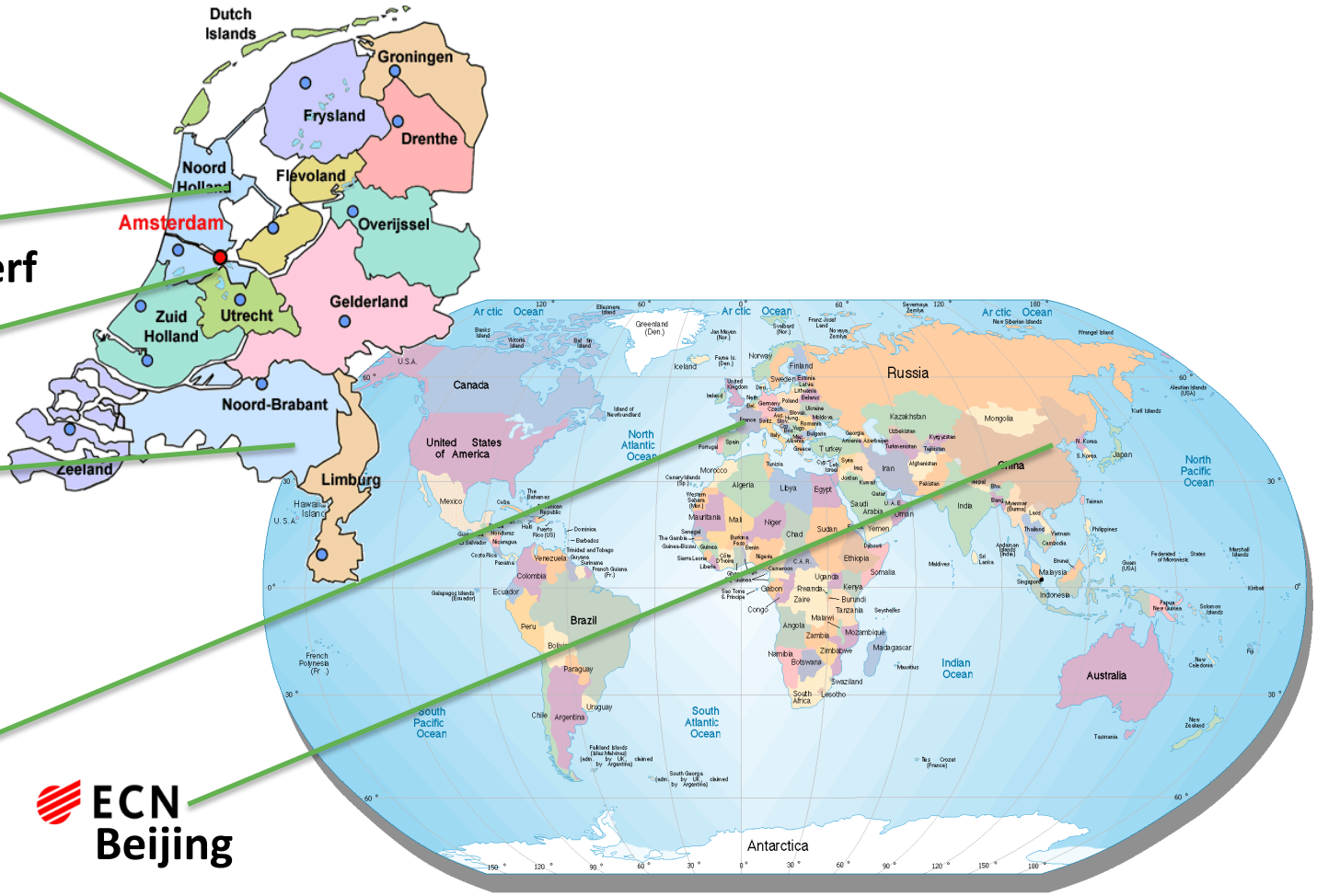
**ECN Wieringerwerf**

**ECN Amsterdam**

**ECN Eindhoven**

**ECN Brussels**

**ECN Beijing**



# ECN

- Number of employees : 500
- Turn over: 140 M€
  - Governmental subsidy 36 M€
  - Contract research 108 M€
- Publications (2011):
  - Reports 180
  - Articles 70
  - Conference contributions 230
  - Books/chapters 20

# What we do

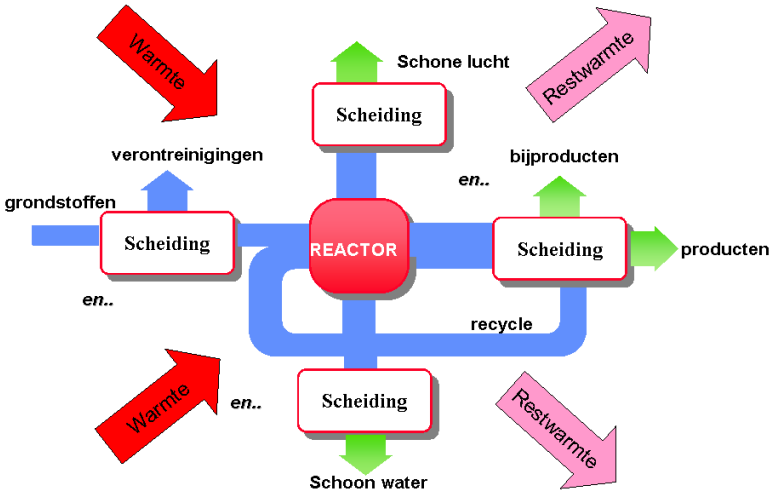
- Technology development
  Developing technology into prototypes and industrial application
- Strategic & Technological studies
  Creating insights in energy technology and policy
- Problem solving
  Using our knowledge, technology, and facilities to solve our clients' issues

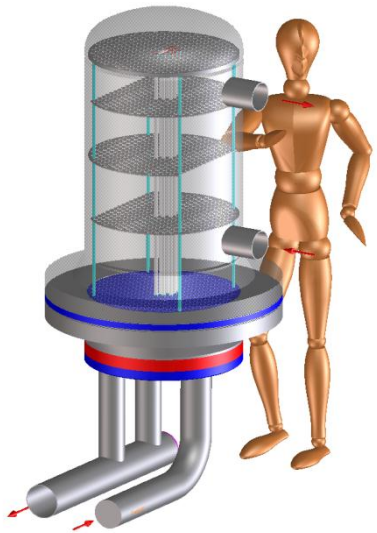
# ECN Program units

- Strategically **Policy Studies**
- Energy savings **Biomass & Energy Efficiency**
- Renewable energy
  **Solar Energy**
  **Wind Energy**
- Support **Engineering & Services**

# Biomass & Energy Efficiency

- Process Technology
- Bio-refinery & processing
- Bio-energy
- Thermal systems
  - Heat pumps for heat and cold production
  - Heat storage



# Thermal systems

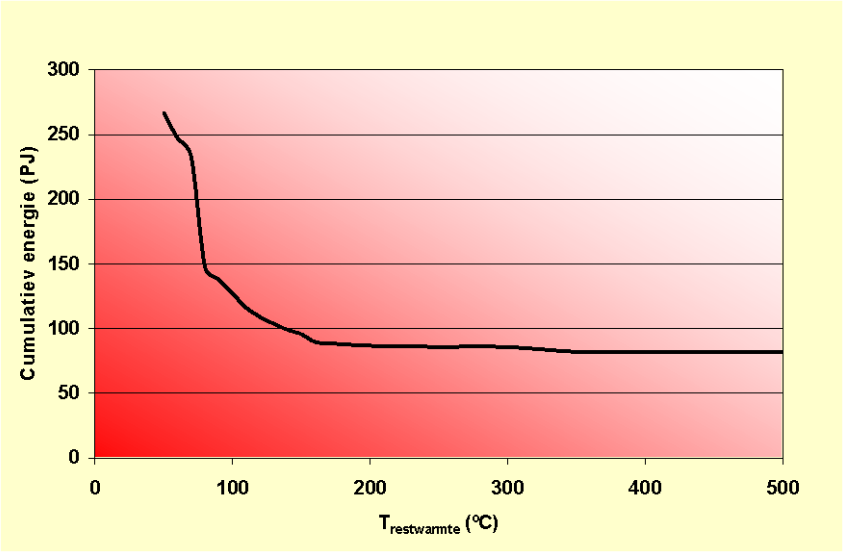
**Inventory**

250 PJ waste heat in NL T> 50°C

**Problem**

Mismatch in

- **–Temperature**
- –Time
- –Place




**Possible technological solution**

Industrial heatpumps for upgrading waste heat to process heat or cold

- – high operating temperature (130-230°C )
- – large temperature lift (> 50°C)
- – across the pinch

# Thermal systems activities

Increase energy efficiency with innovative technologies

- Upgrading of (waste) heat

  Application of innovative heat pump technologies

  Thermoacoustic heat pumps

  Thermochemical heat pumps

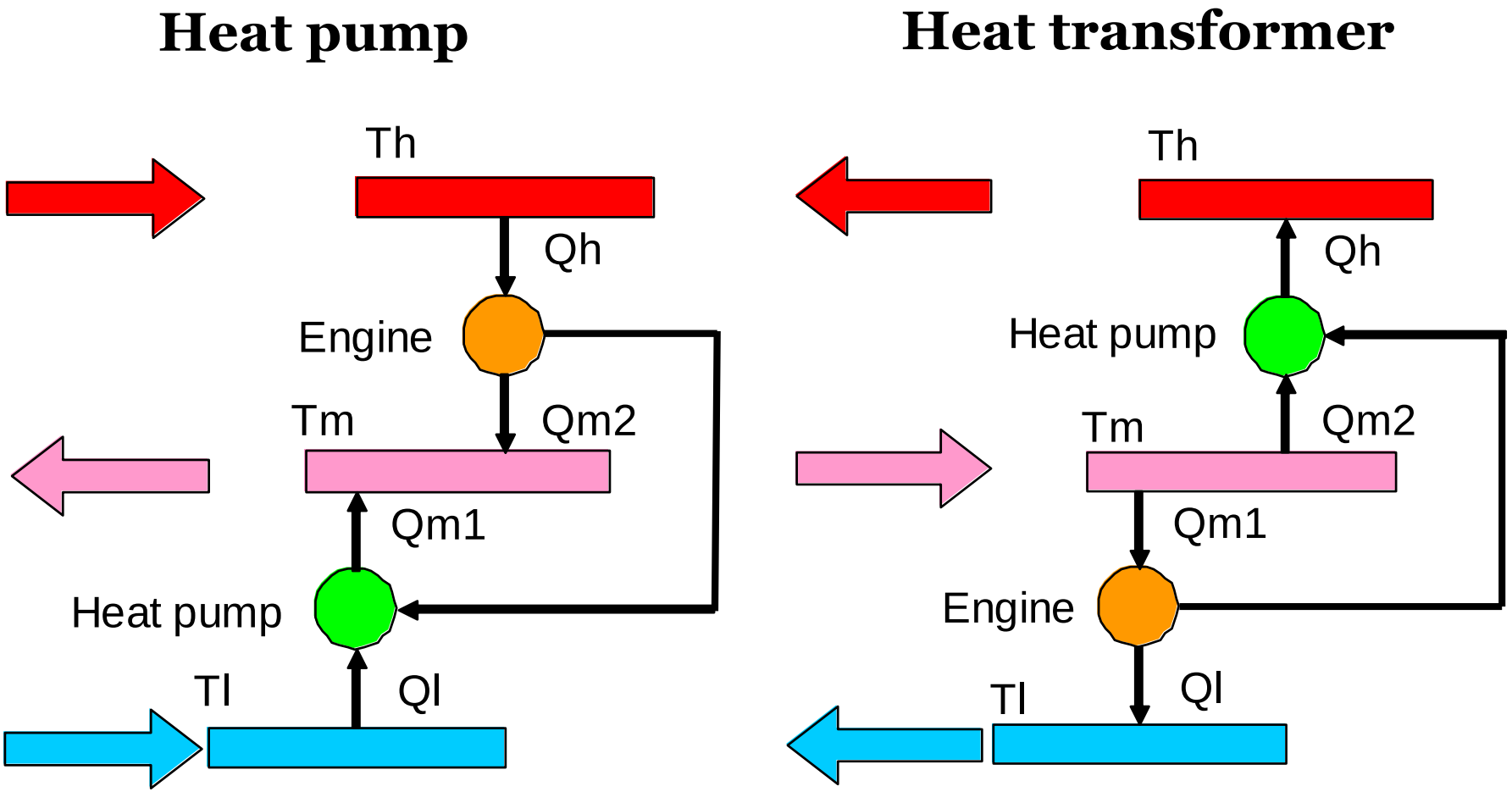
- Storage of (waste) heat

  Development of knowledge and experience concerning all types of heat storage (sensible, latent, thermochemical) and their specific field of application (industry, transport, buildings).

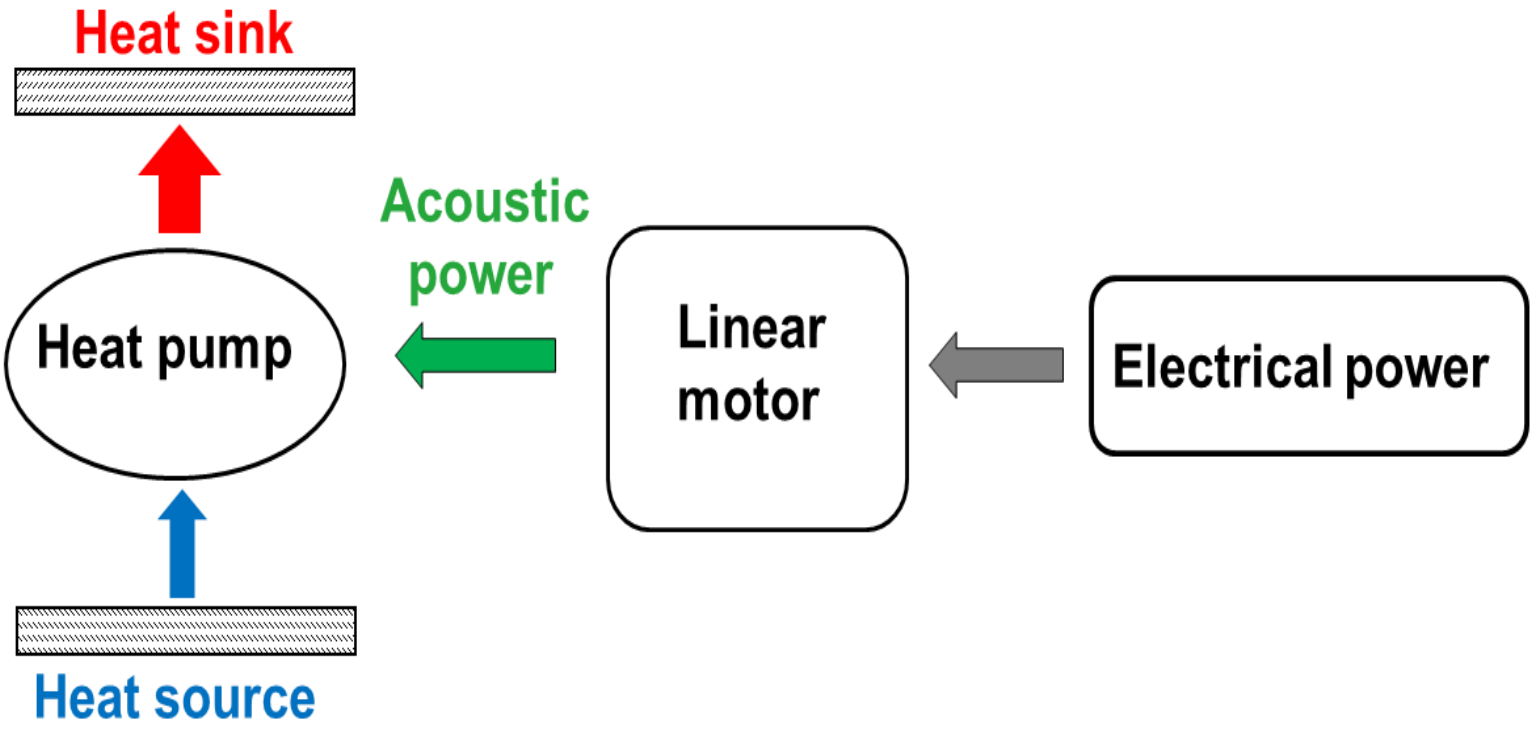
# Thermoacosutic applications

- Upgrading waste heat (80-150°C) to process heat (180-230°C )
  - Thermoacoustic heat pump
    - Thermally driven heat pump
    - Electrically driven heat pump
  - Thermoacoustic heat transformer
- Upgrade (waste) heat to cold
  - Thermoacoustic cooler
- Power generation

# Heat driven heat pump



# Electrically driven heat pump



# Thermoacoustic activities

- R&D
  - Materials, Components, Systems (labscale, benchscale)
  - Modelling for design & interpretation of results
- Market studies
  - In cooperation with end-users and consultants
- Business cases
  - Calculations carried out in cooperation with several end-users show promising results
- Cooperation with equipment manufacturers
  - Scale up, production technology, costs engineering, commercialisation

# R&D

- Design of  TA-systems (DeltaEC, CFD)
- Components development
  - Regenerator
  - Heat exchangers,
  - Resonator
  - Acoustic circuit
  - Configuration
- Systems (labscale, benchscale)

# Design and analysis of TA-system

- DeltaEC is used for the design of the TA-systems.
- CFD is used for the analysis of the complex flows in TA-systems and for design.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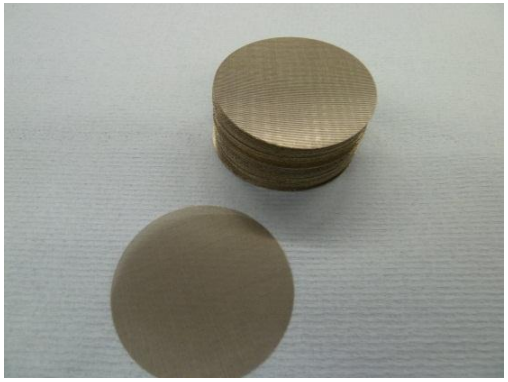
# Components development

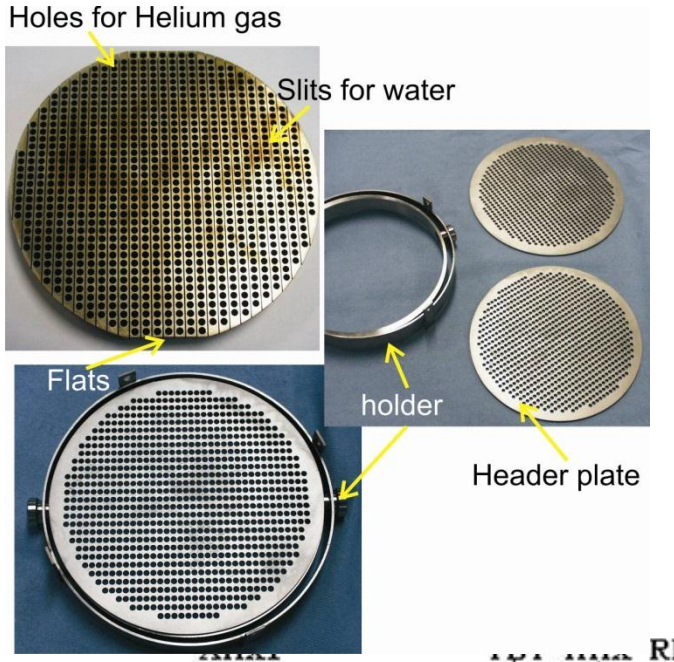
Component study

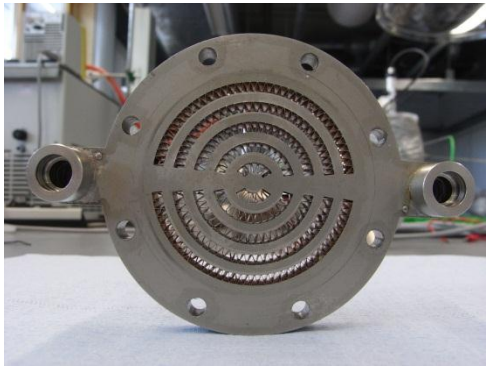
- Heat exchangers (fin-fin, shell and tubes, etc…)
- Regenerator (stack of screen sheets, sinter screen sheets, sintered fibres, etc)
- Resonator (acoustic, mechanical, etc..)
- Acoustic circuit configuration
- Acoustic driver

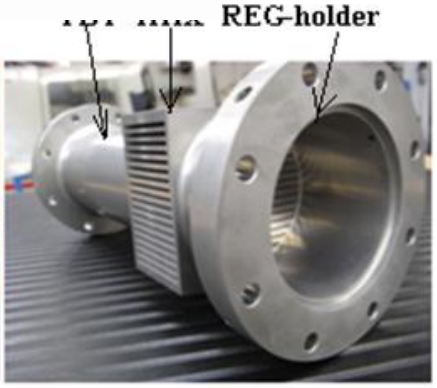
# Regenerator

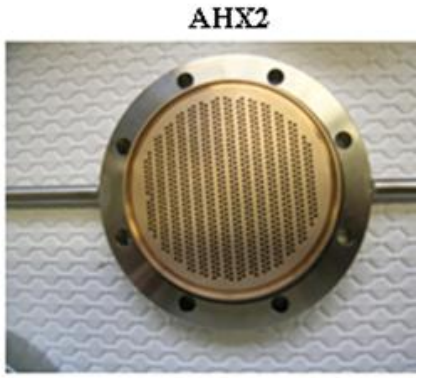


# Heat exchangers

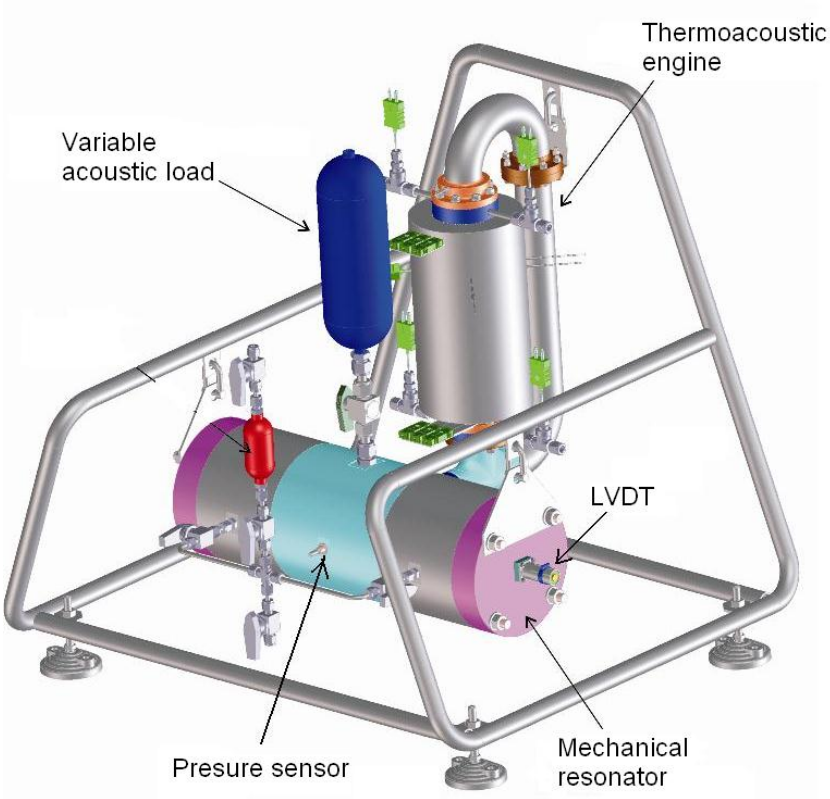


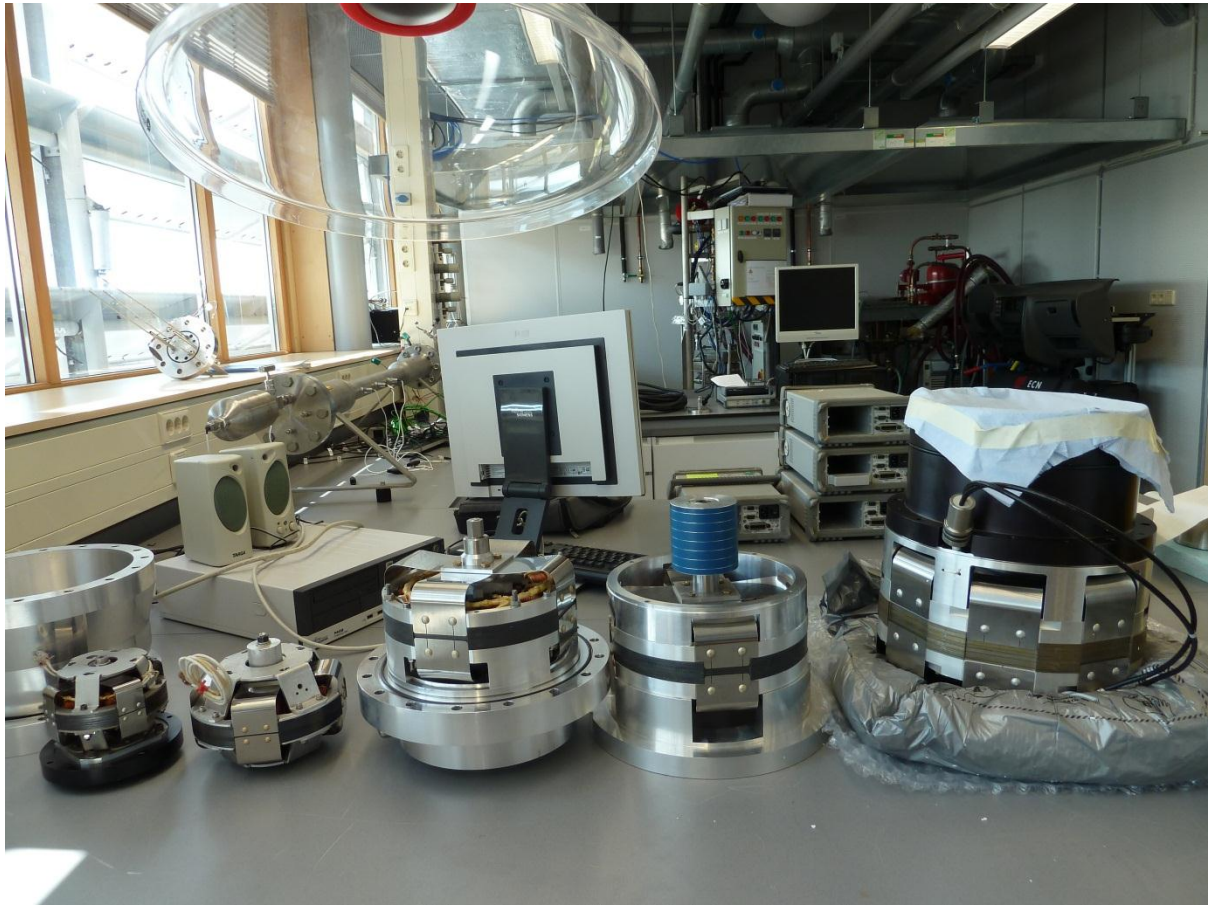


# Resonator


Thermoacoustic engine
Variable acoustic load
LVDT
Presure sensor
Mechanical resonator

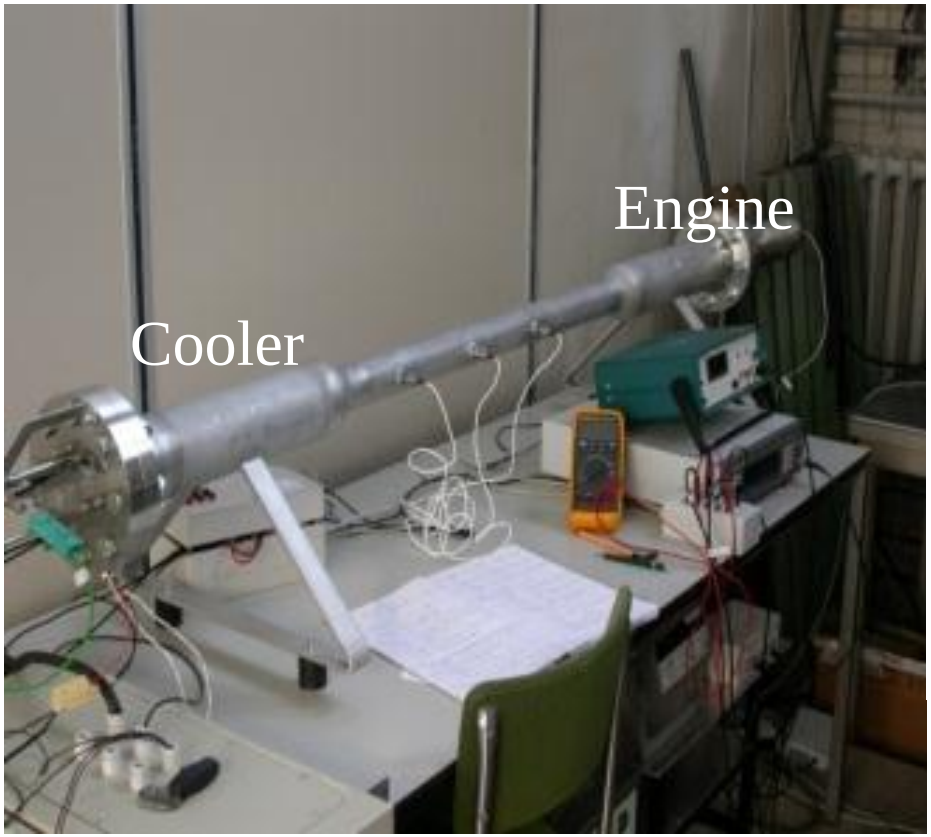
# Acoustic driver

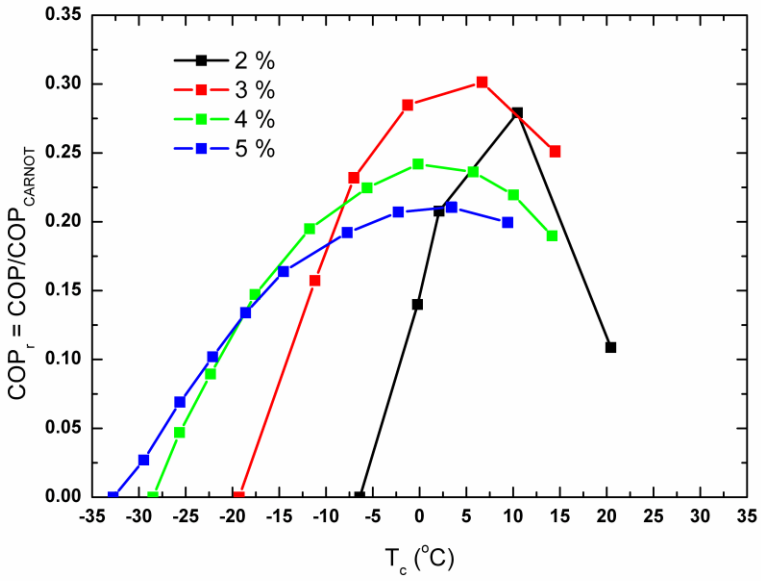


# Lab scale TA-systems

- Design, construction, and test of lab scale TA-systems to demonstrate the operation for a given application
- Demonstrate performance
- Parameter and components test etc..

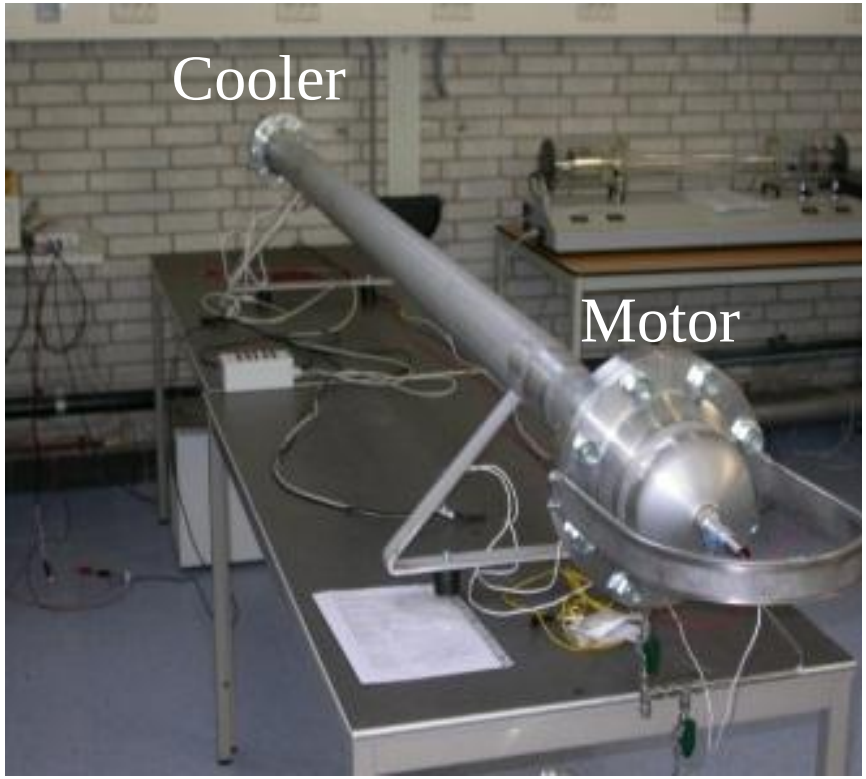
# TA-cooler driven by TA-engine

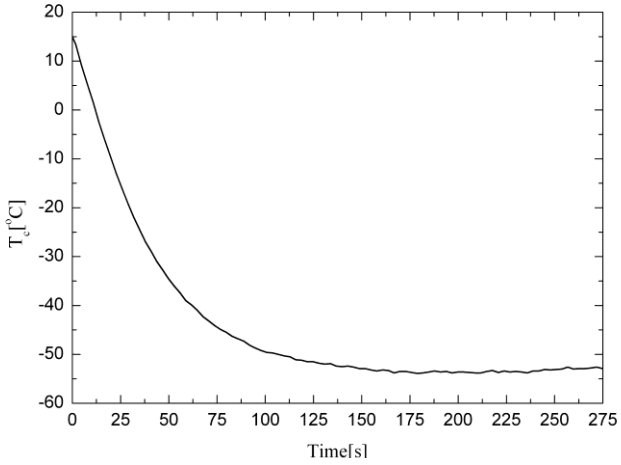


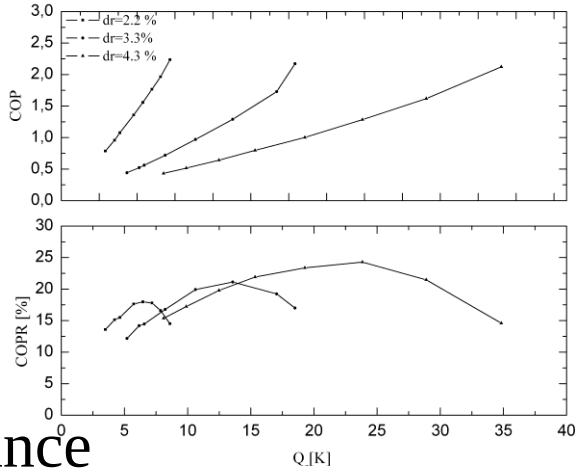




- Engine performance is 21 % of Carnot at $T_h$ = 390°C and dr = 5 %.
- The cooler achieves a performance of 30 % of Carnot and a low temperature of -40°C.

# Electrically driven TA-cooler

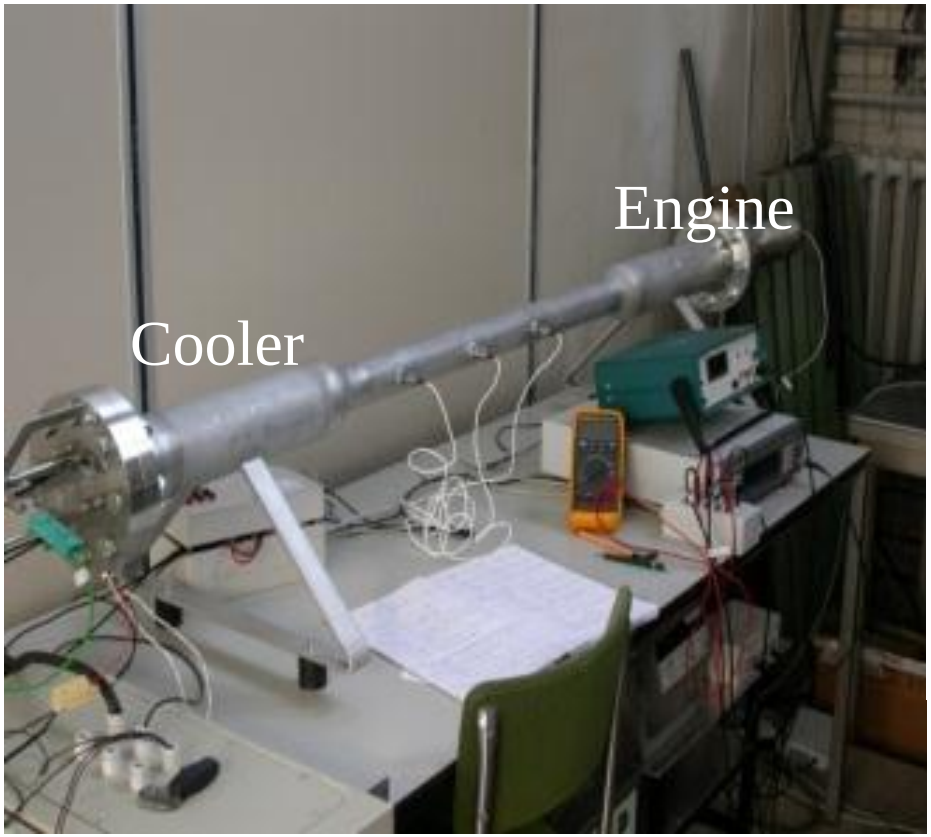


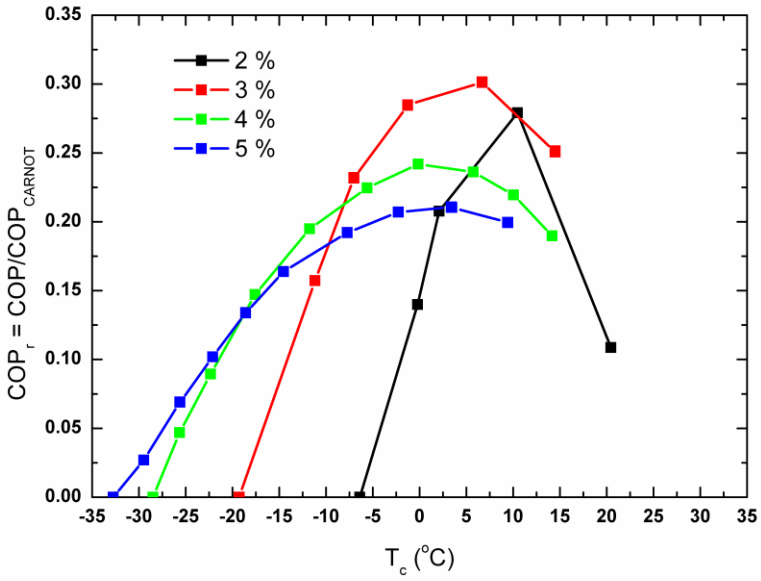




The cooler achieves coefficient of performance relative to Carnot of 25 % and a low temperature of -54°C

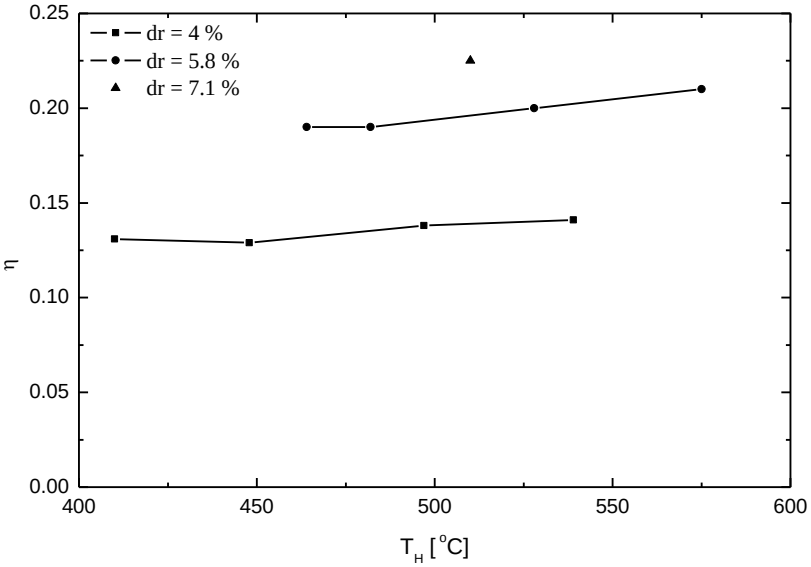
# TA-cooler driven by TA-engine



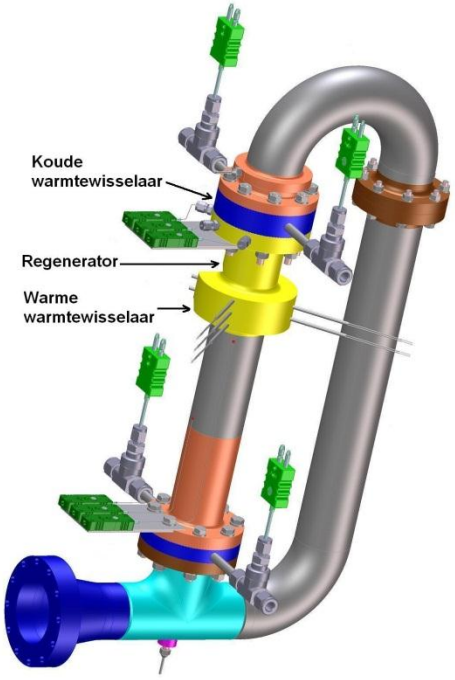

- Engine performance is 21 % of Carnot at $T_h$ = 390°C and dr = 5 %.
- The cooler achieves a performance of 30 % of Carnot and a low temperature of -40°C.

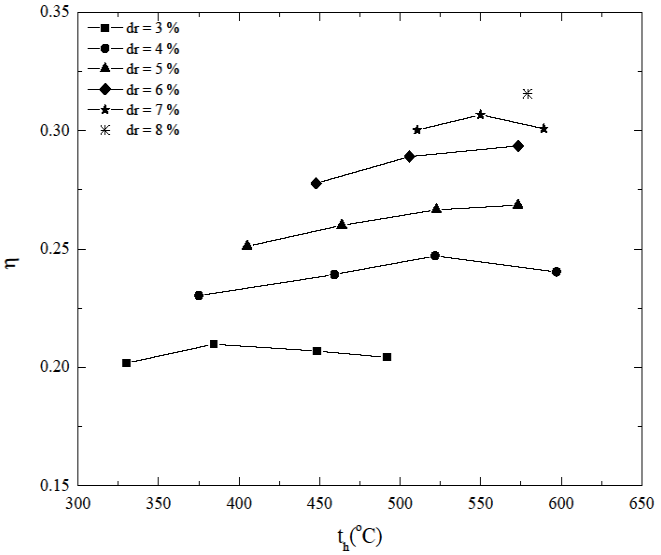
# High temperature heat engine




Thermal efficiency of 23 % corresponding to 36 % of Carnot performance

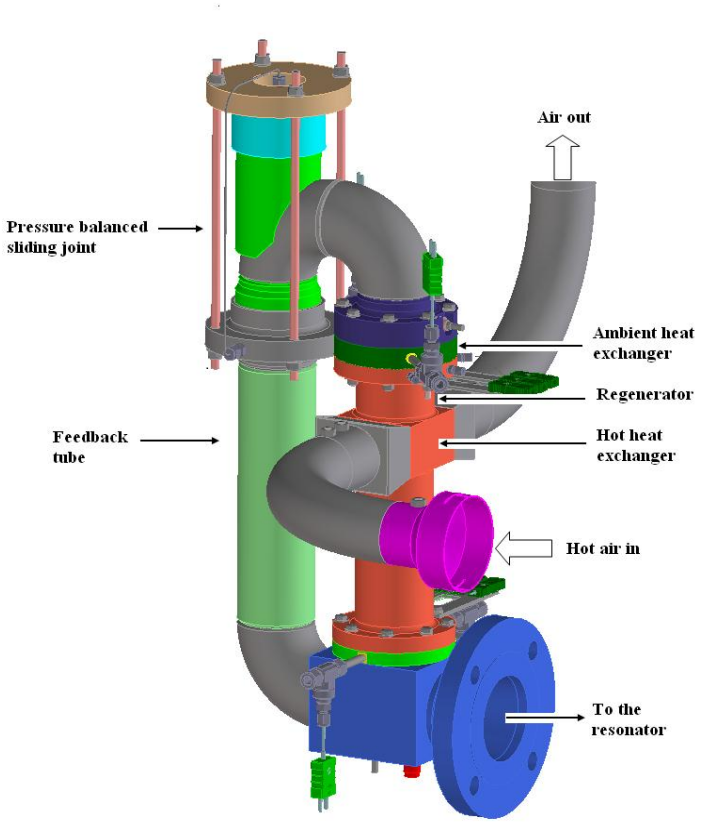
# High temperature heat engine

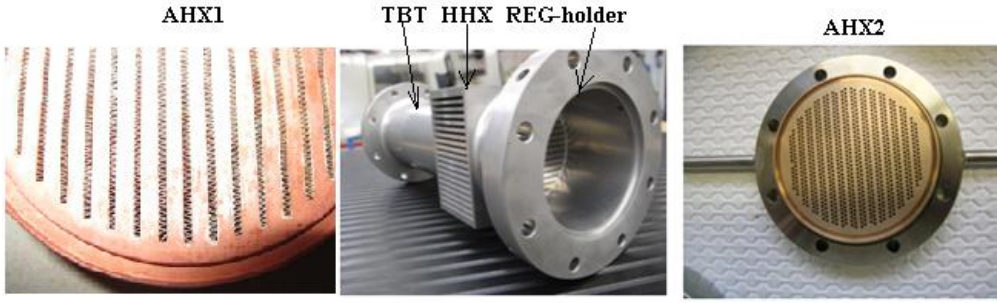


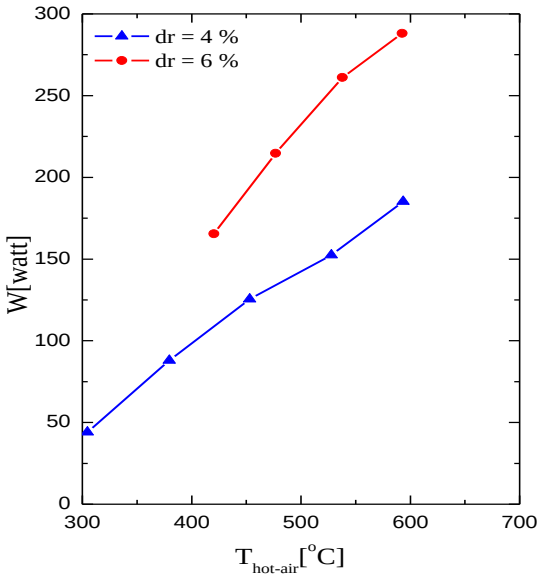



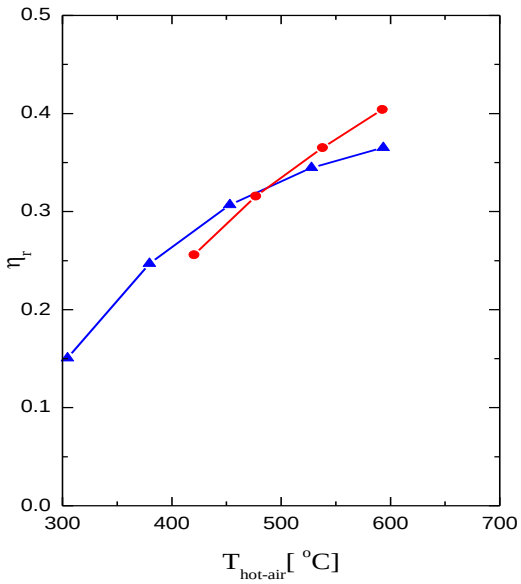

Thermal efficiency of 32 % corresponding to 49 % of Carnot efficiency.

# Hot air driven TA-engine



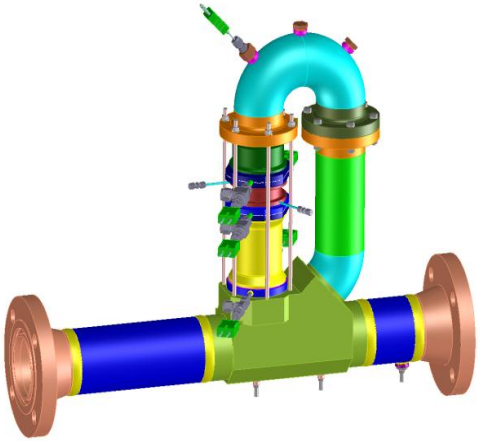



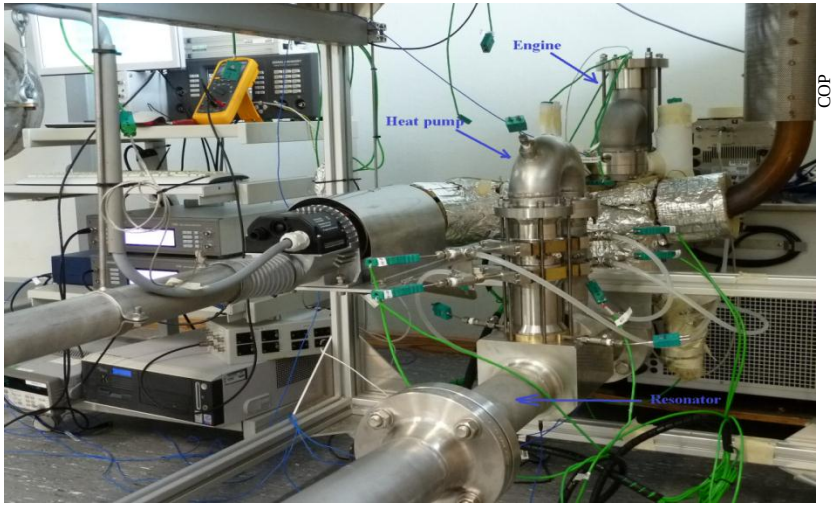



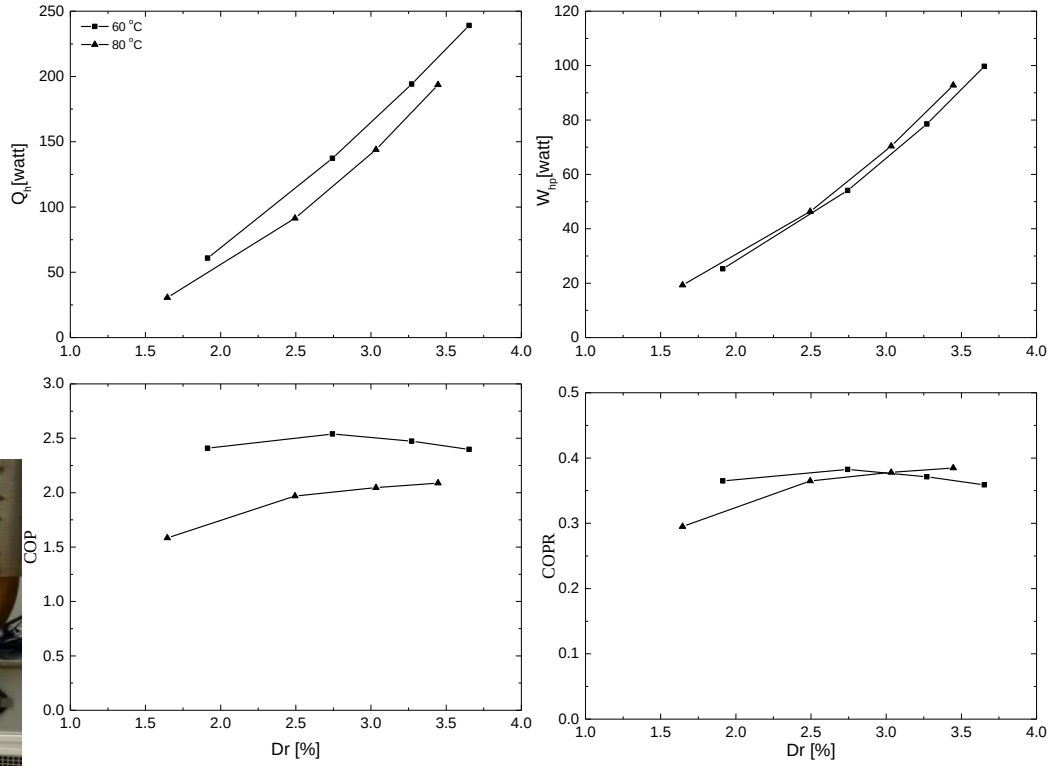




Efficiency of 41 % of Carnot efficiency.

# Heat pump driven by TA-engine





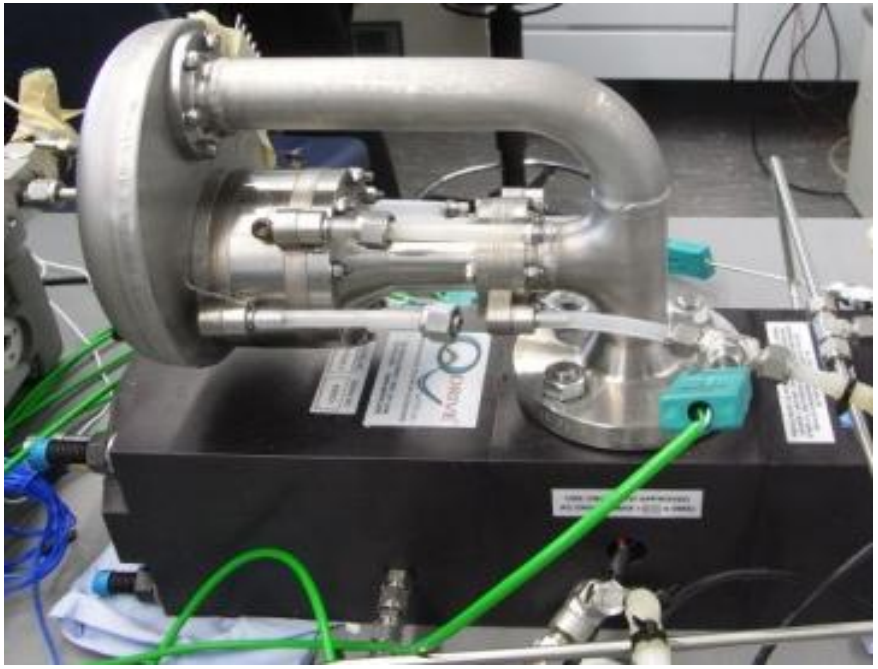



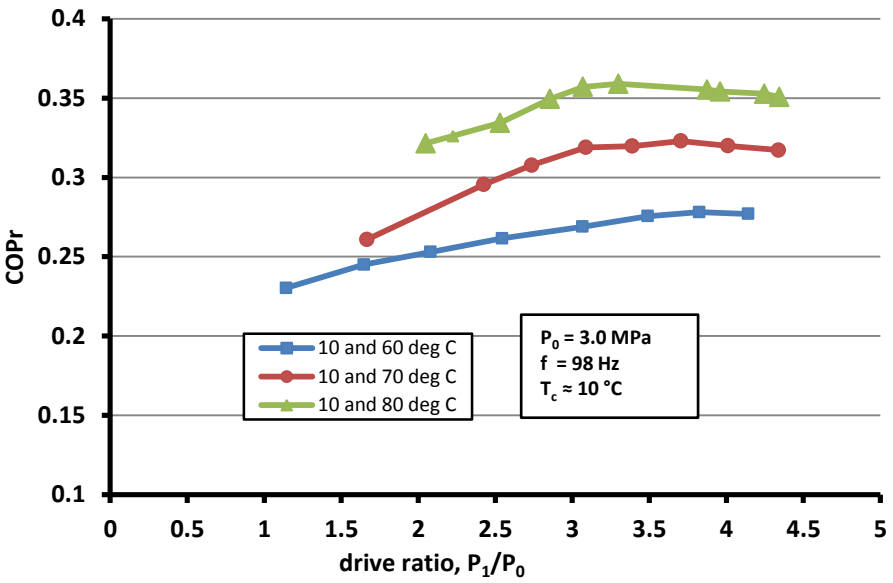

Heat pump operates between 10 and 80 °C

200 W at 80 °C at dr = 3.5 %

COPR= 40 %

# Electrically driven heat pump






The heat pump achieved a COPR = 36 % for a hot temperature of 80 °C and a drive ratio at the piston of about 3 %.

# Industrial applications

- Distillation
- Drying (Dairy, paper, etc)
- Metal industry

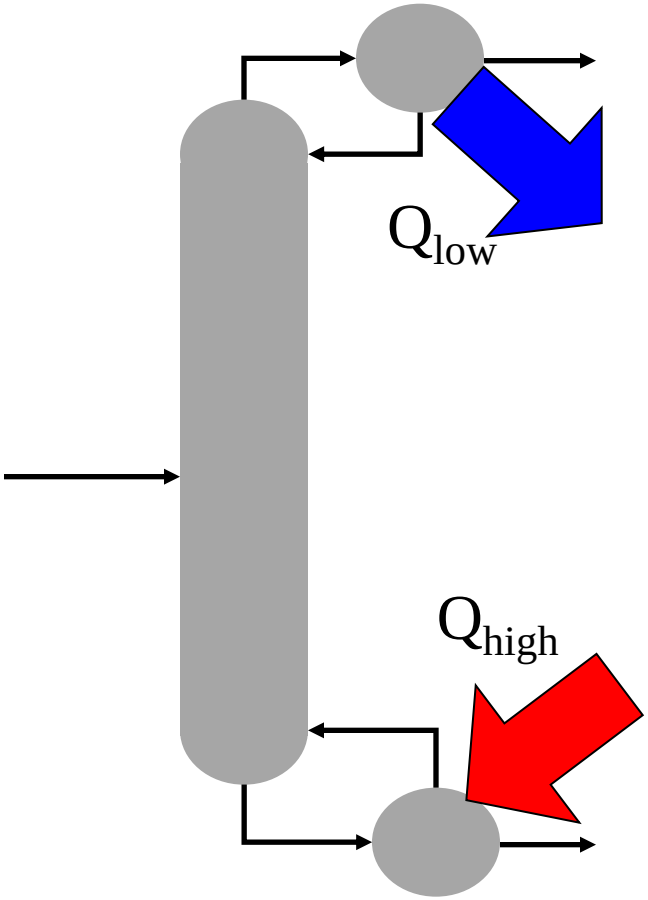
# Industrial applications

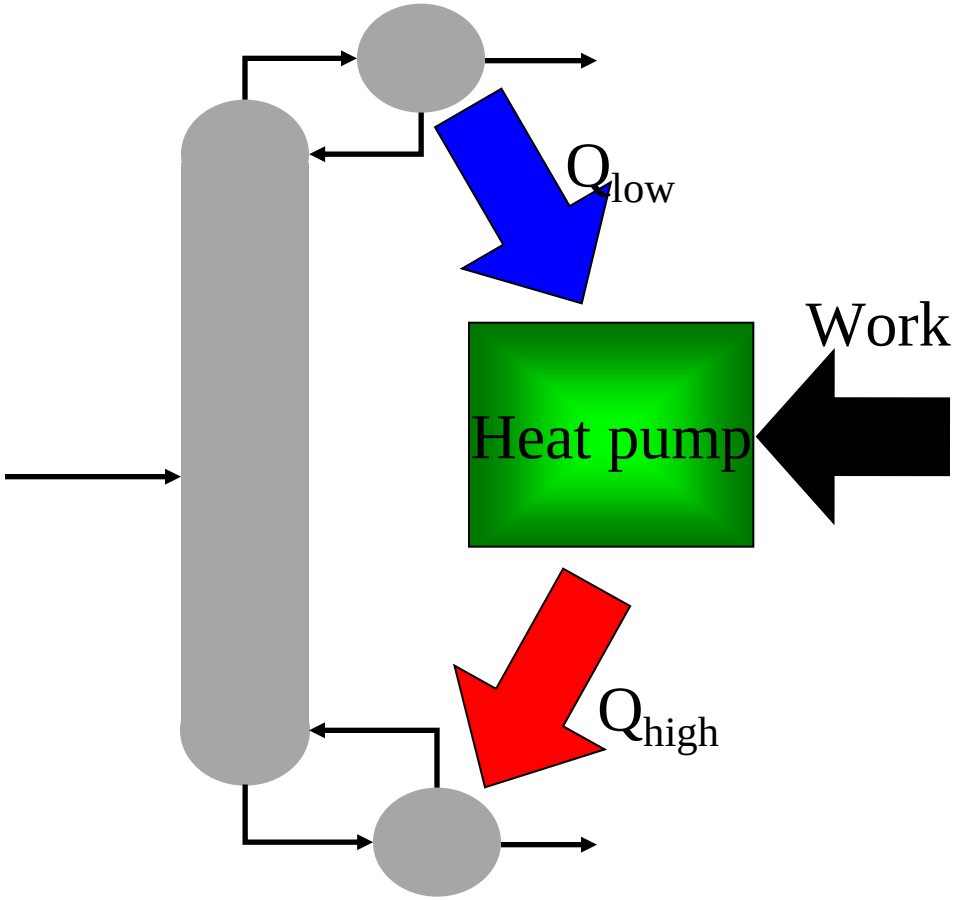
| | Thermoacoustic |
|---|---|
| Advantages | Use of waste heat<br>No moving parts<br>No noise<br>Low maintenance costs<br>High temperature lift<br>Broad application range<br>Environmentally friendly working medium<br>Commercially available materials<br>Intrinsic heat storage capacity |
| Disadvantages | Volume/low power density<br>Efficiency/reliability yet to be proven |

# Distillation

- Distillation requires high temperature heat as input (reboiler) and delivers low temperature heat as output (condenser); the column itself is adiabatic in principle
- A heat pump can upgrade low temperature heat to high temperature heat
- Process integration rule
  *A heat pump should always be applied across the pinch temperature*
- Needed are:
  - Heat pumps that operate in the temperature range of 50 - 150°C
  - Heat pumps that can generate a temperature lift of 10 - 60°C

# Heat pump concept

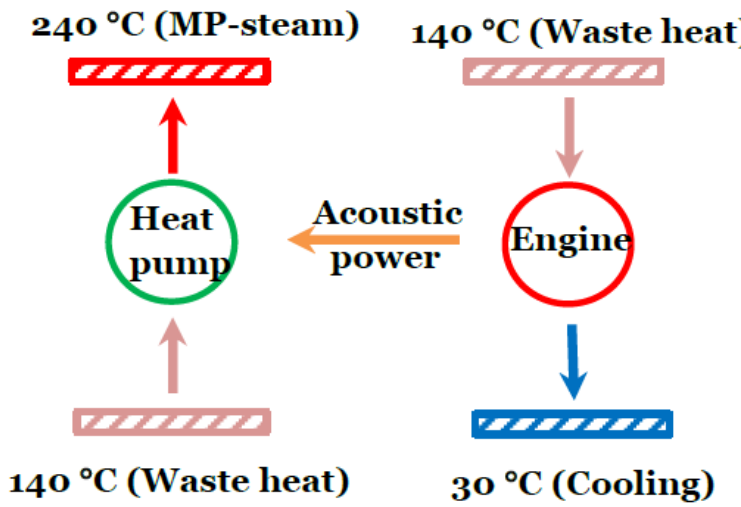


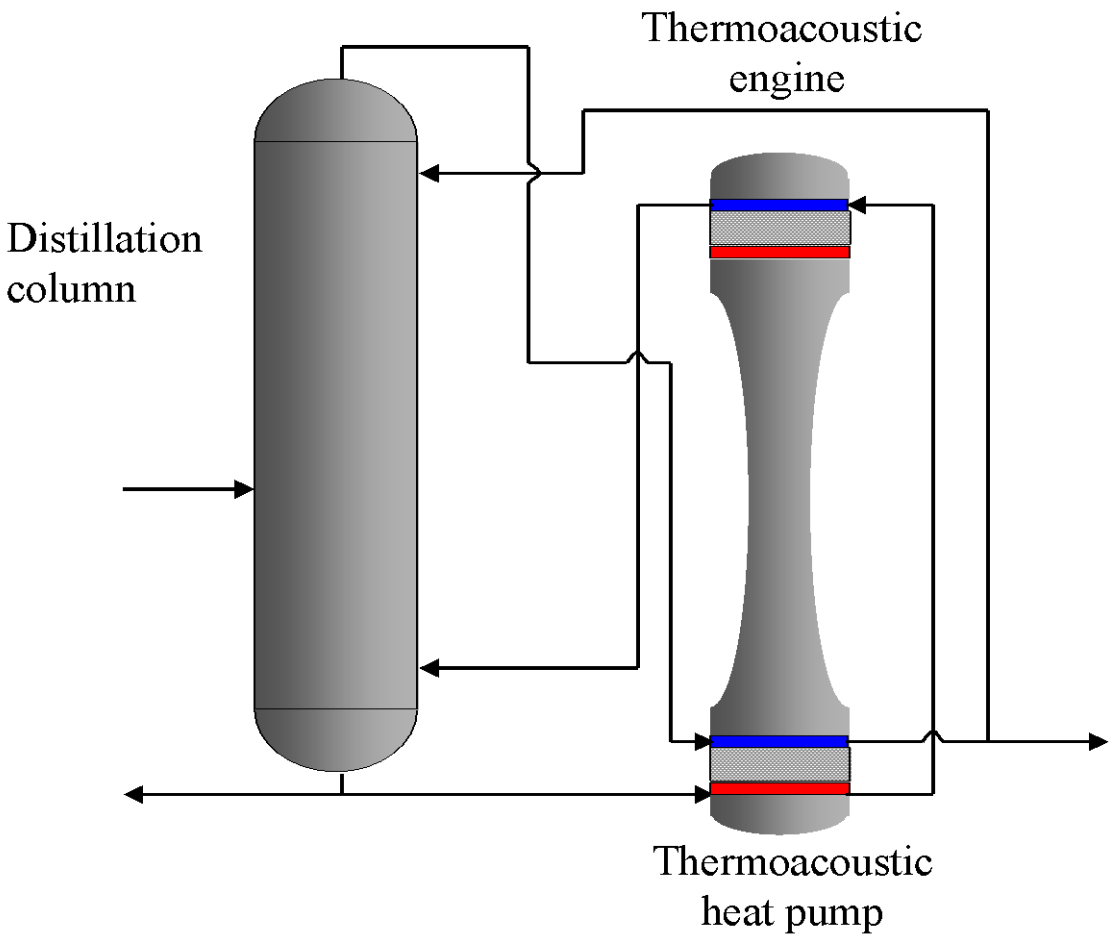
# Upgrading of waste heat

Heat pump

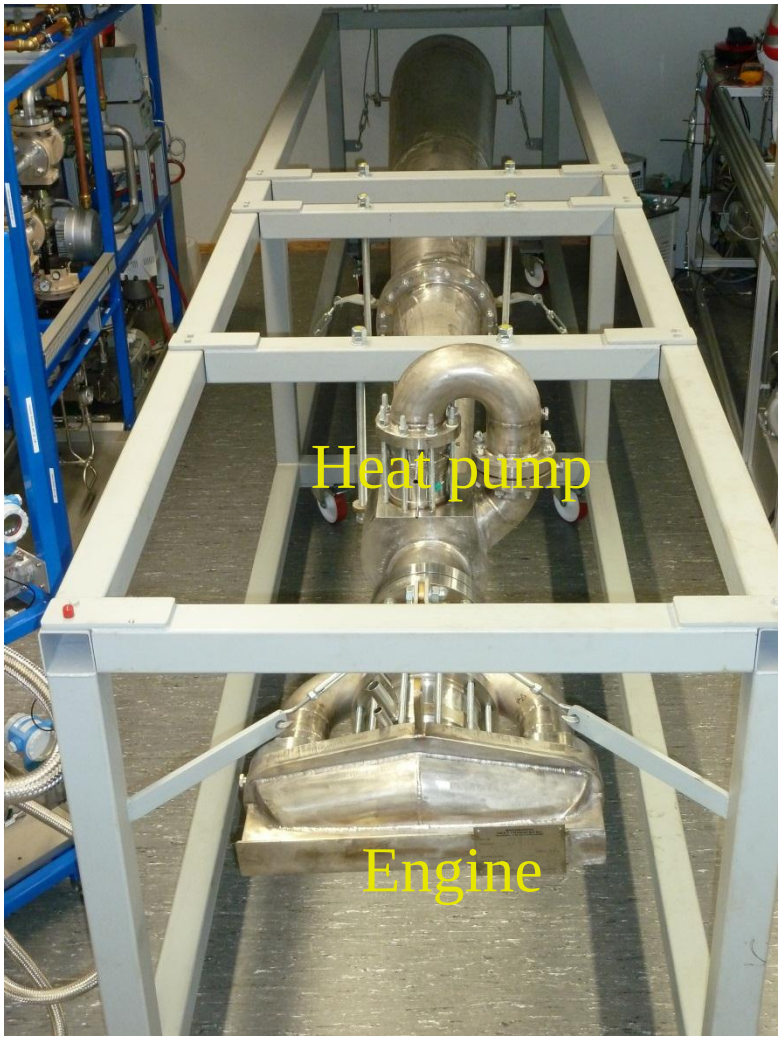
Multi-stage engine

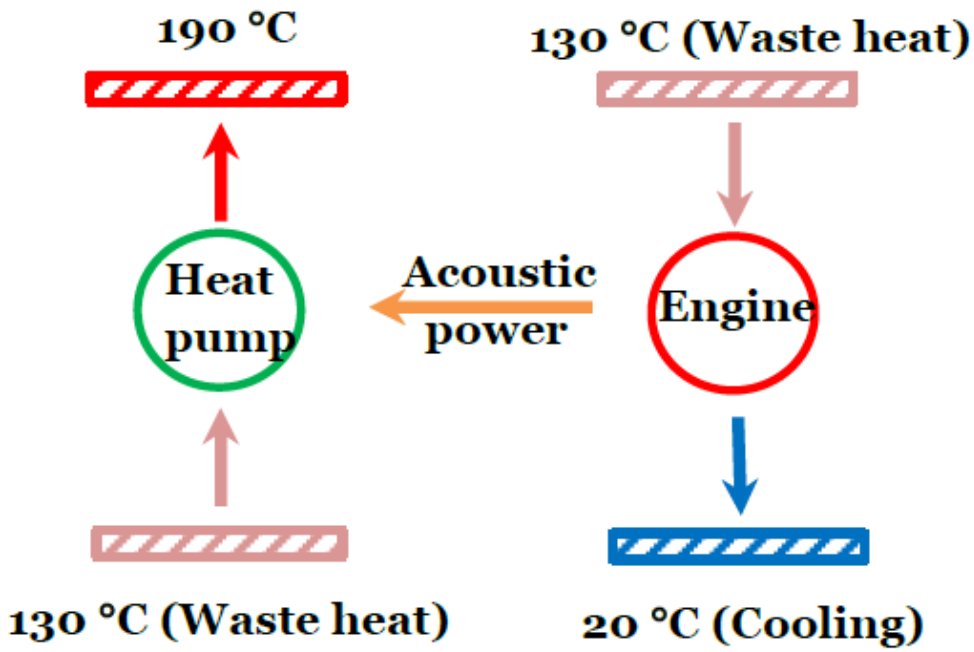


# Gas powered heat pump

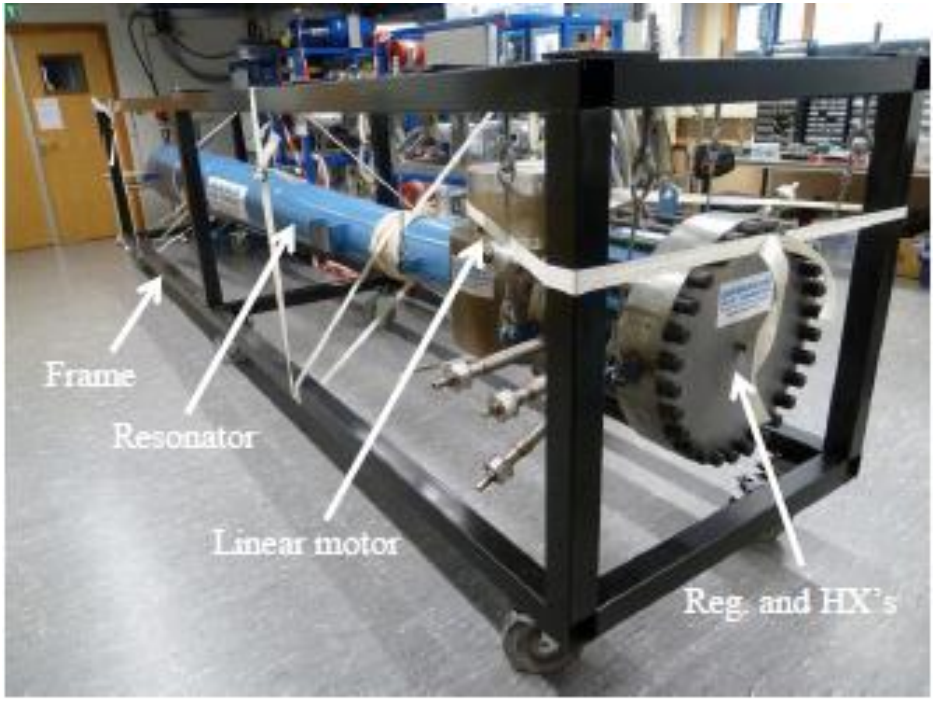


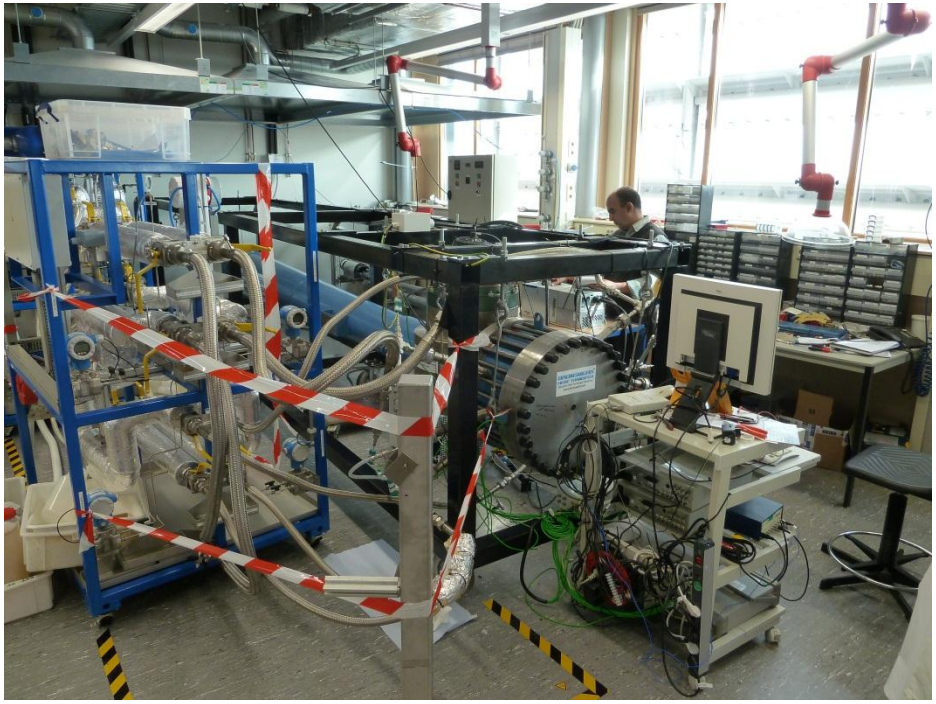

# Benchscale heat transformer



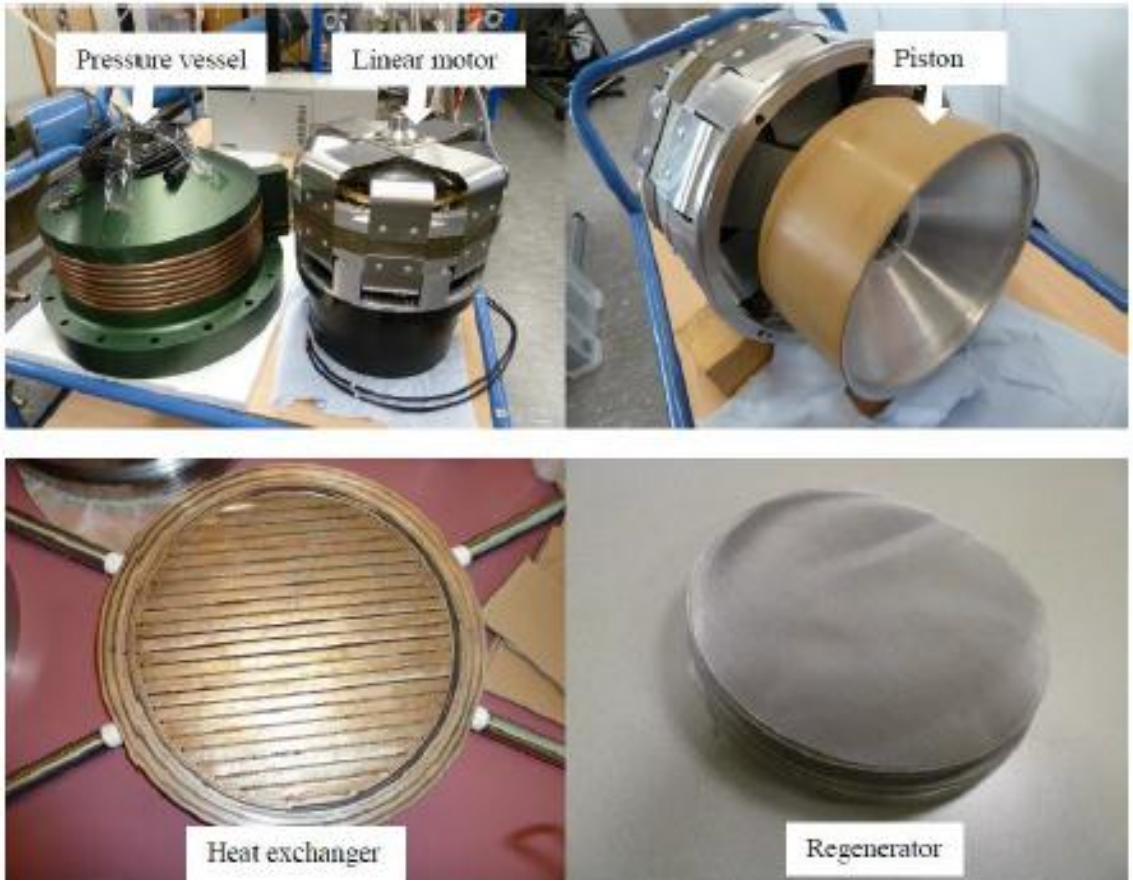



# Benchscale Electrically driven TAHP



# Benchscale Electrically driven TAHP



# Summary

- An overview of the thermoacoustics R&D activities at ECN is given
- The lab scale TA-systems demonstrate a promising performance which is of interest for industry and it is expected that higher efficiencies for bench- and full-scale systems can be achieved.
- Efficiencies of about 50 % of Carnot for engines and 40 % for heat pumps are demonstrated.
- Bench scale system are built and are under test
- The scaling study and economic feasibility show a good perspective for the application of TA-systems in the industry

Questions ?

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