iets
Industrial Energy-Related Technologies and Systems
An Implementing Agreement established under the auspices of the International Energy Agency

Industrial Excess Heat – Potentials and Utilization Opportunities

Final Workshop in IEA, IETS, Annex 15, 'Industrial Excess Heat Recovery – Technologies and Applications'

Copenhagen, February 24-25

Venue: Scion DTU, Diplomvej 381, 2800 Kgs. Lyngby

Program

	Tuesday, February 24
12:00 – 13:00	Lunch
13:00 – 15:00	1) What is IEA, IETS? Brief Introduction Thore Berntsson, chair of IETS 2) IEA,IETS, Annex 15, Background and aims Thore Berntsson and Anders Åsblad, Annex Managers 3) Final Report from Phase 1, an overview Thore Berntsson and Anders Åsblad 4) Definition of industrial excess heat Annex Manager (introduction) and experiences in participating countries
15:00 – 15:20	Coffee break
15:20 – 17:20	5) Availability of excess heat and temperature levels in different types of industry Annex Manager (introduction) and experiences in participating countries 6) Experiences of methods and approaches for for identifying industrial excess heat – process integration tools Annex Manager

		Wednesday, February 25
09:00 – 10:00	7)	Experiences of and approaches for inventories of available excess heat in real plants Annex Manager (introduction) and experiences in participating countries
10:00 – 10:20		Coffee break
10:20 – 12:00	8)	Experiences of and R&D on technologies/systems for utilizing exess heat Annex Manager (introduction) and experiences in participating countries
	9)	Economic aspects of using excess heat including possible future policy instruments Annex Manager (introduction) and Annex Participants
12:00 – 13:00		Lunch
13:00 – 15:30	10)	Sustainability aspects of utilizing excess heat including carbon footprint Annex Manager (introduction) and Annex Participants
	11)	Need for further work and discussion on the annex manager suggestion for a Phase 2 Annex Manager (introduction) and Annex Participants
15:30		End of workshop

Weel & Sandvig ENERGI OG PROCESINNOVATION

Reduction of industrial excess heat

A short introduction, status and perspectives in the project:

"Demonstration of industrial high-temperature heat pumping"

IEA IETS Annex 15

Copenhagen 24.-25. February 2015

J. Mikkelsen

Weel & Sandvig
ENERGI OG PROCESINNOVATION

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Agenda

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- Short introduction to a 1.st and 2.nd phase industrial high-temperature heat pump (MVR) demonstration project
- Background
- Short description of technology and technology transfer
- Demonstration site and integration with process plant
- Test run, data and performance
- Conclusion

Background & idea

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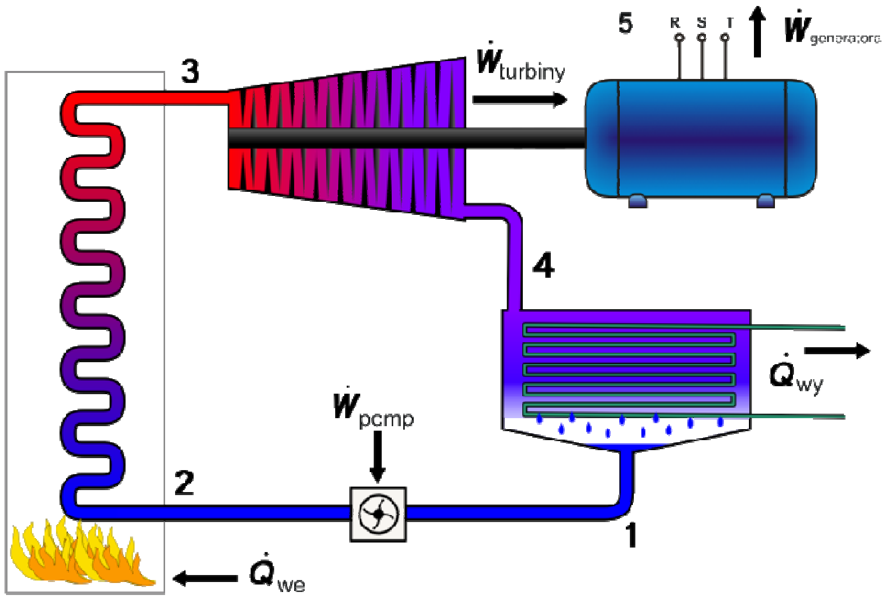
- Future perspective: demand for dramatic reduction of CO2 emission and expected increased power production from non-thermal processes (wind, solar etc).
- Less heat from small scale CHP delivering heat below a modest temperature (up to 200) is expected.
- The so called "CHP advantage" (thermodynamically efficient heat production and no need for large and expensive low pressure equipment (turbine and condenser)) might then be lost. However, also heat pumping can supply heat in a thermodynamically efficient way.
- Almost literally speaking we can extinguish the fire (the CO2 emission source) by reversing the Rankine CHP process (now acting as a heat pump cycle). Some restrictions/drawbacks apply to required temperature level and lift and efficiency of compressor.



High-temperature heat pump –pushing the limits

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- If heat pumps are compact, in many industrial processes internal heat pumping can be arranged and supply (upgrade) heat in a exergy-economic optimal process.
- Water/steam as working fluid.
- Primary operating range (temperature band): 70°C to 180°C.
- Can be integrated with many existing steam supply systems.
  - local upgrade of steam pressure imply possibility for reduced pressure from main supply:
    - facilitates higher boiler efficiency or
    - if steam supplied from CHP increased net power production.

Suitable processes and how to make a process more suitable for heat pumping

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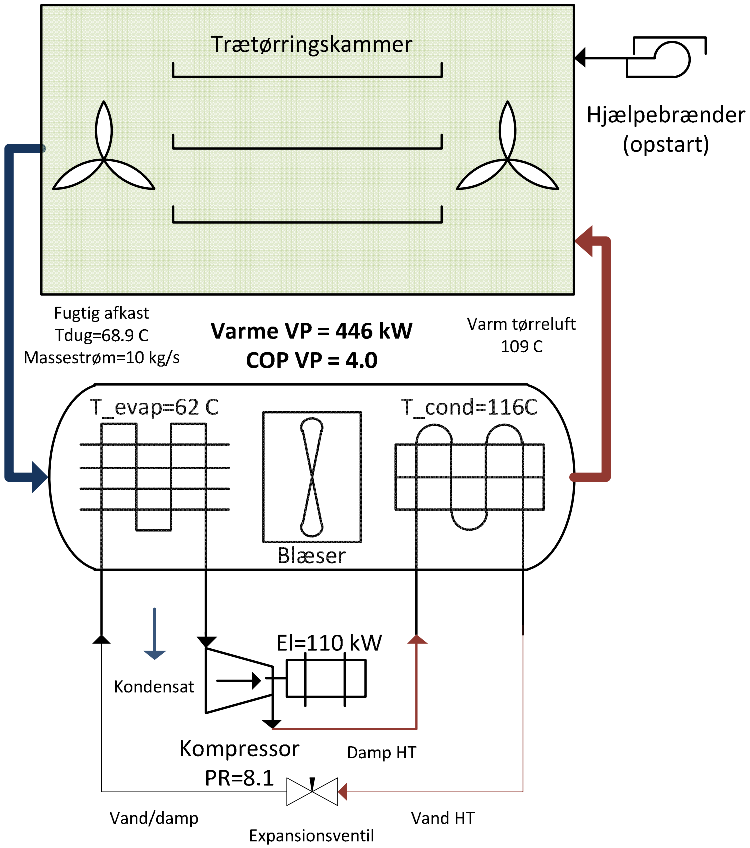
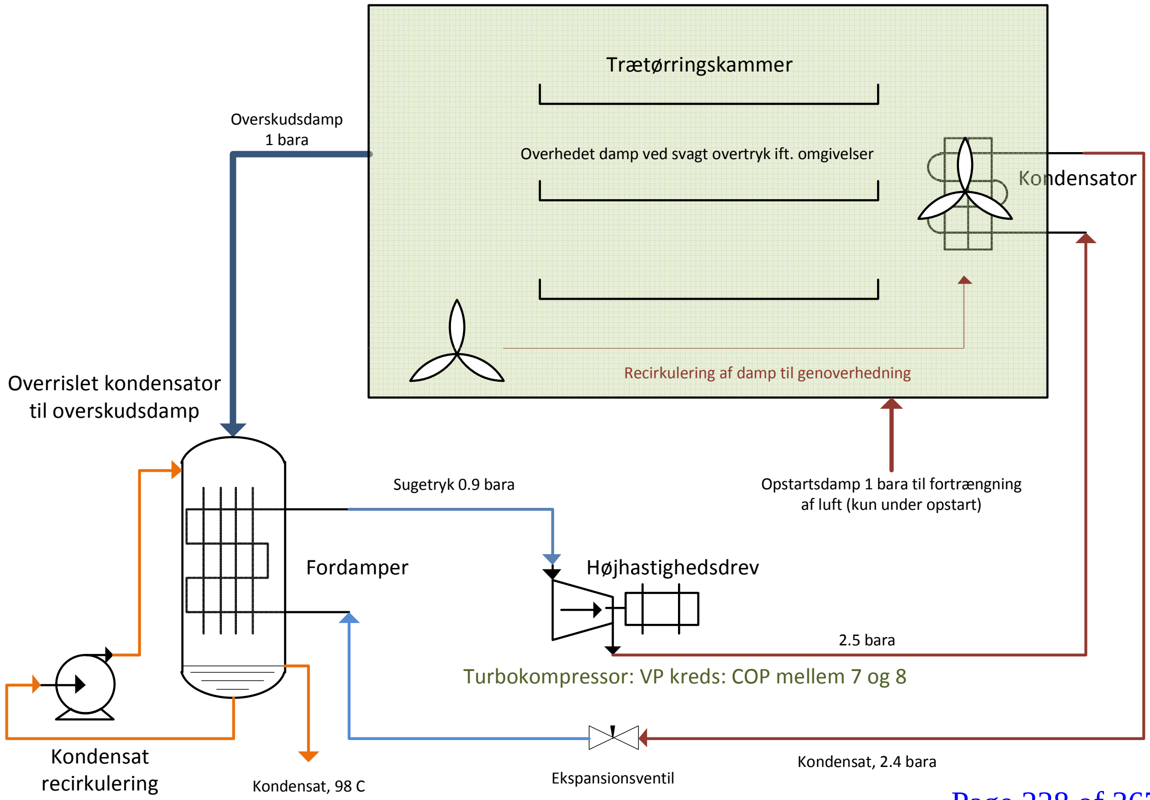
- Breweries and other food industry with boiling processes.
- Distillation processes in general.
- Evaporation plants.
- Drying processes (e.g. wood drying).
- Autoclave, sterilisation.

- Drying in super heated steam instead of moist air can reduce required temperature lift of the heat pump and consequently make a more suitable and efficient drying process for heat pumping.





Technology (transfer of technology)

- Turbochargers (compressors) from the automotive industry are
  - efficient
  - compact
  - light (small amount of material)
  - mass produced
  - cheap

- Requires high speed drives (turbine, high-speed gear or direct high speed electric drive).
- Turbo-compressors have limited stage pressure ratio and turn down ratio of flow.
- Variable speed capacity control is suitable for e.g. evaporation plants (operating on maximum efficiency ridge).

Modular flexible concept

based on few standard compressor units

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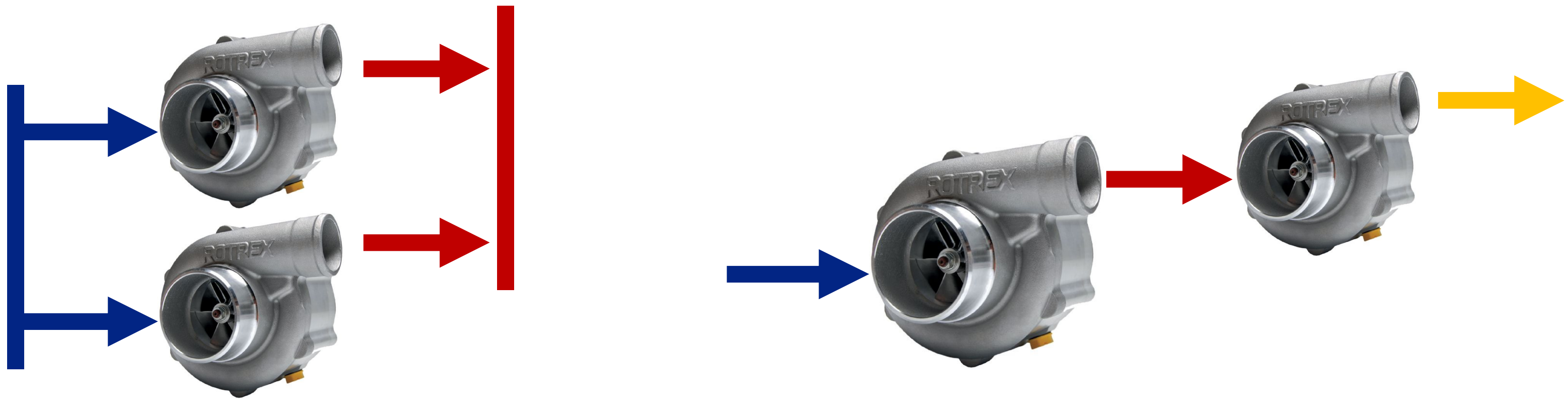
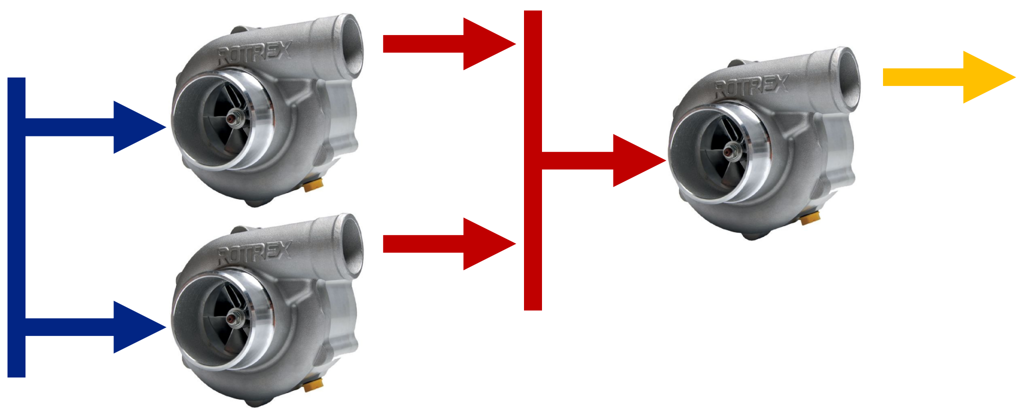
- In parallel (1-stage) or in series (multi-stages)



- Combination of parallel and series (multi-stage)



The solution demonstrated

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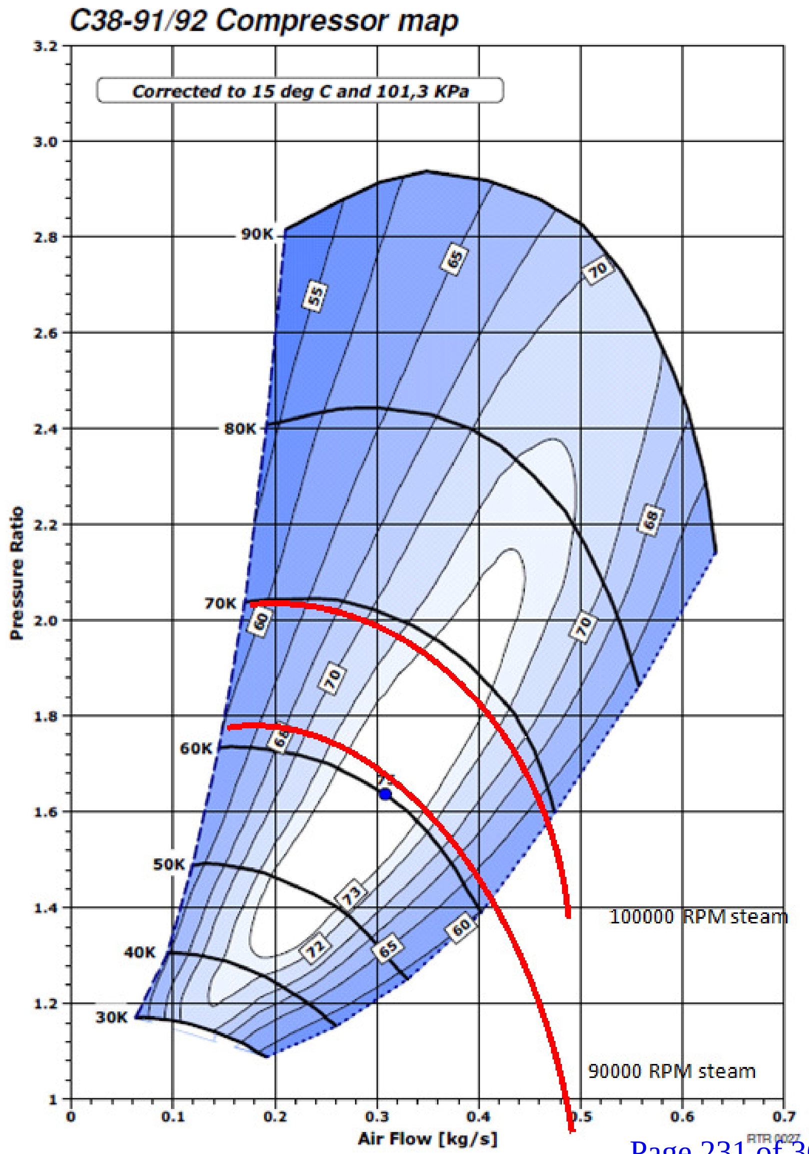
- A centrifugal compressor with integrated high-speed traction gear (Rotrex).
- As compressor is designed for air, performance map is recalculated to steam as working fluid.



Demonstration site:Evaporation plant Haldor Topsøe

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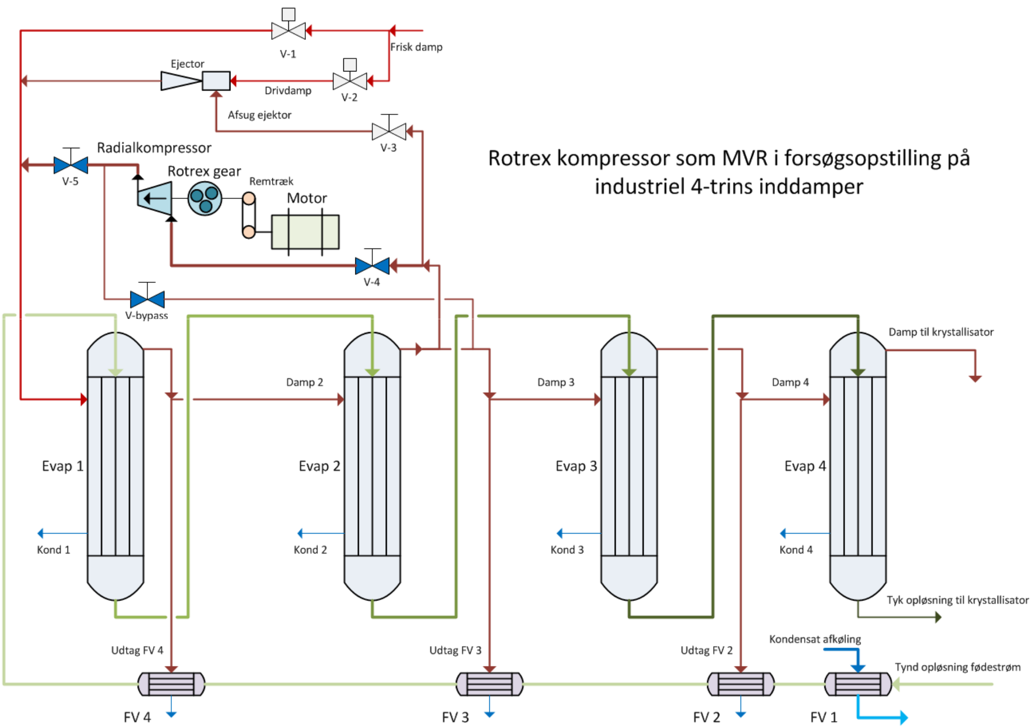

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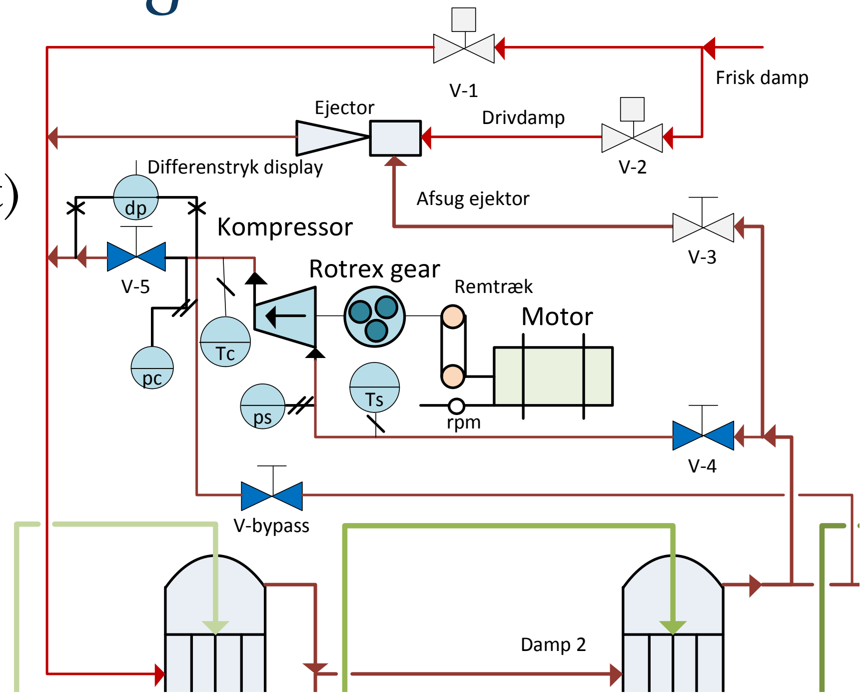
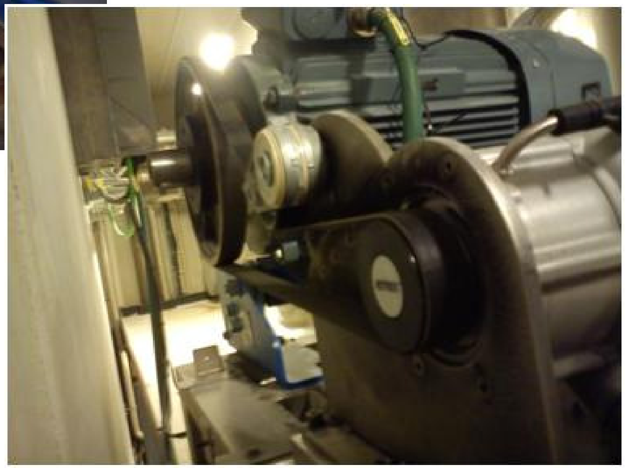
- 4-stage evaporation plant (KNO3) with TVR (over the first 2 stages).
- Turbo-compressor integrated as MVR in parallel with the TVR.
- Bypass system for test runs (and start-up and shot-down procedures) while evaporation continues.
- Manuel control system only.

Industrial test rig

- Main components:
  - Rotrex compressor: C38-91 (largest) integrated with traction gear 7.5:1.
  - Electric motor (VEM, 37 kW).
  - Variable speed drive (Danfoss, 55kW).
  - Belt drive 1:3.75





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Instrumentation and control

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- Suction line after 2.nd stage.
- Pressure line to 1.st stage with bypass line back to downstream of suction line
- Manual butterfly-valves in suction, bypass and pressure lines.
- Differential pressure sensor over butterfly-valve in pressure line.
- Pressure and temperature sensors in suction and pressure lines.
- Accelerometer on gear house.
- Manual speed control (Danfoss)

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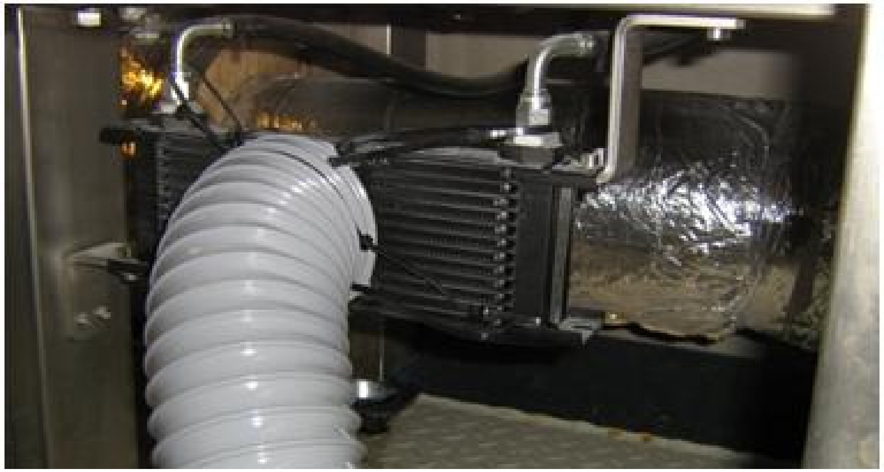
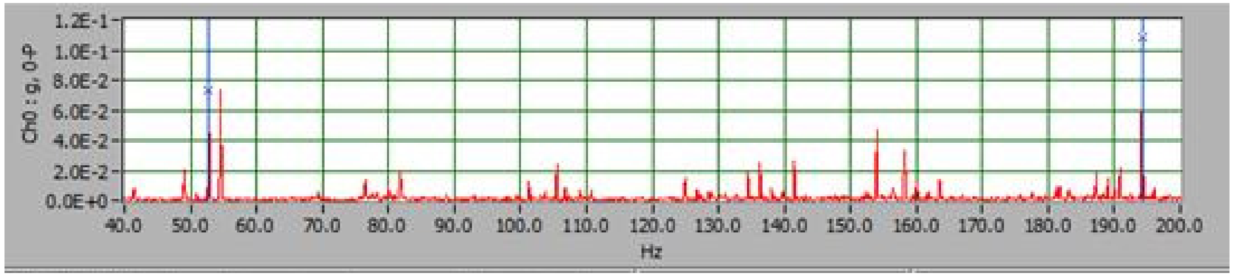
Oil cooling system

- Traction oil in gear is circulated with internal pump mechanism to external cooler supplied with cooling air from blower.
- Small oil canister (0.5 l).
- Magnetic oil filter.
- Oil flow approx. 0.7 l/min.



Vibration measurements



- Primarily for detection of increased vibration levels at certain speeds and in case of surge.
- Secondly for measurements of impeller speed, pulley speed and motor speed and calculation of slip in gear and belt drive.
- Equipment from Colding A/S.

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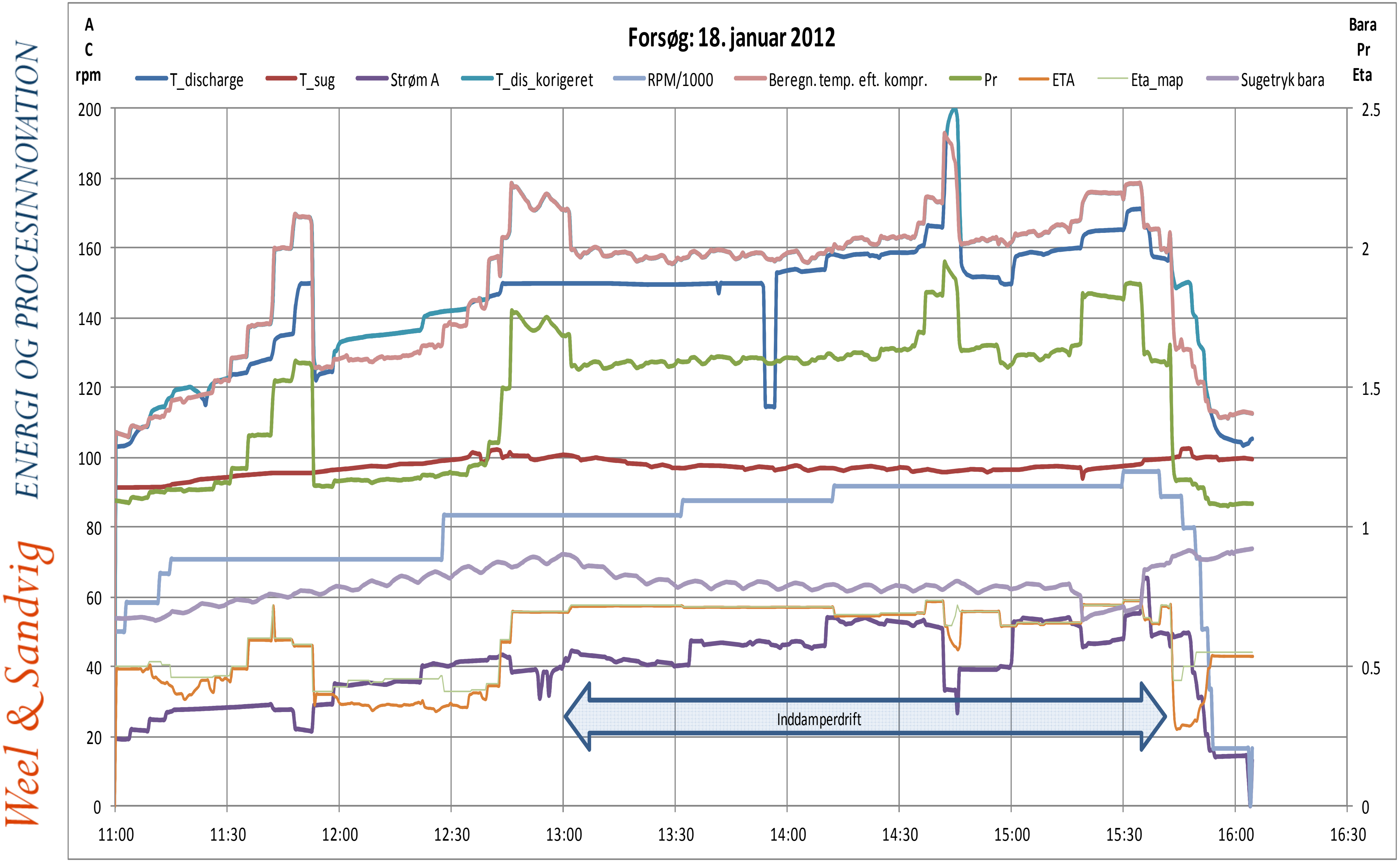

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Forsøg: 18. januar 2012
A
C
rpm
Bara
Pr
Eta
T_discharge
T_sug
Strøm A
T_dis_korigeret
RPM/1000
Beregn. temp. eft. kompr.
Pr
ETA
Eta_map
Sugetryk bara
200
180
160
140
120
100
80
60
40
20
0
2.5
2
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Inddamperdrift

14

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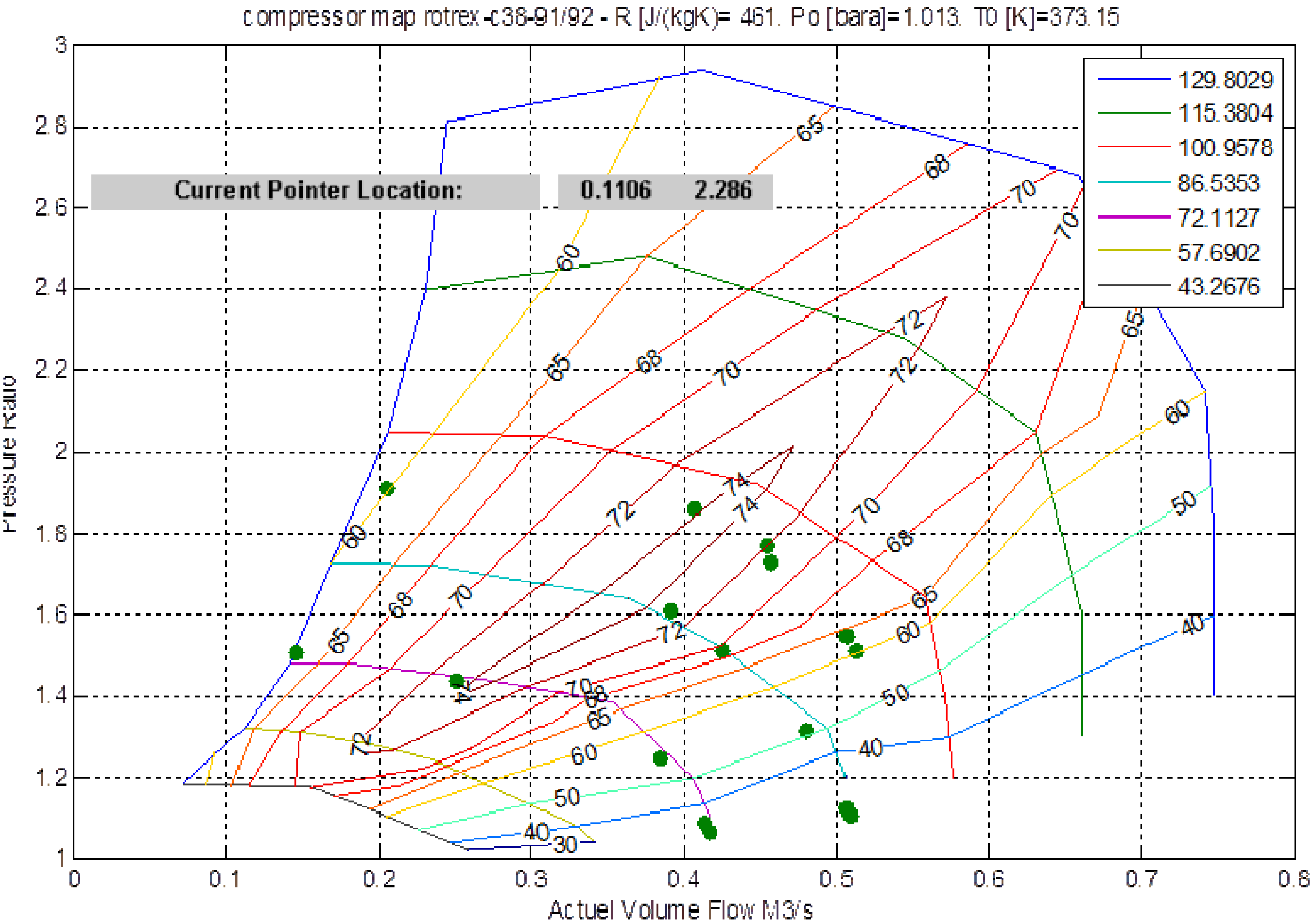

- Operating points (PR, rpm) for 70700, 83300, 87500, 91650 og 95800 rpm.

Temperature with IR kamera

Test run 18.th of January 2012

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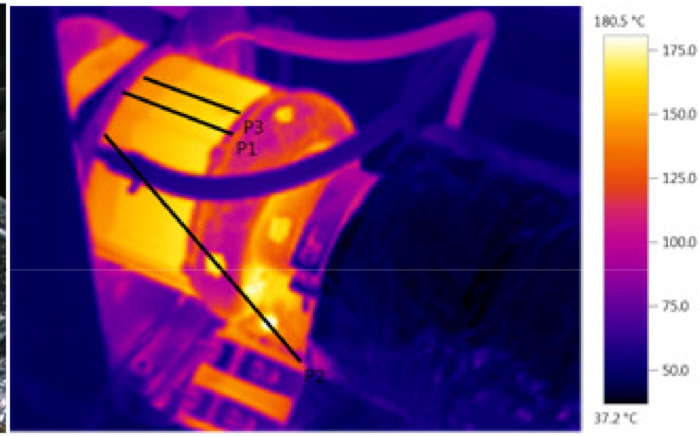
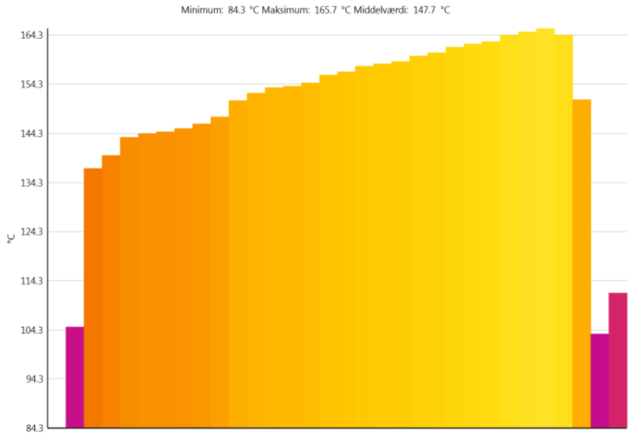
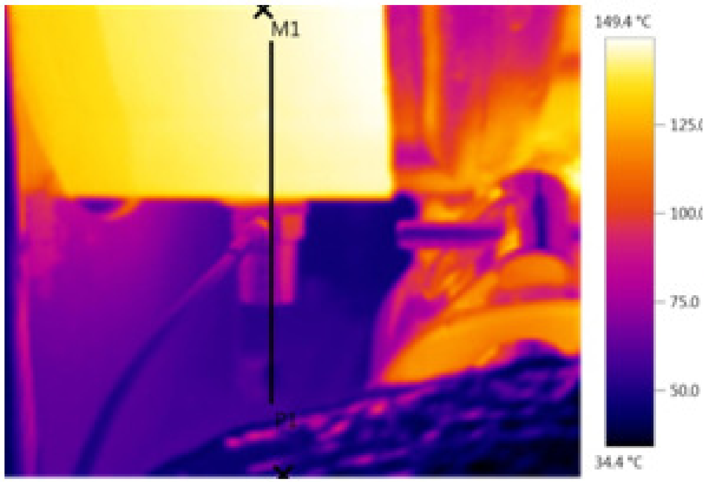
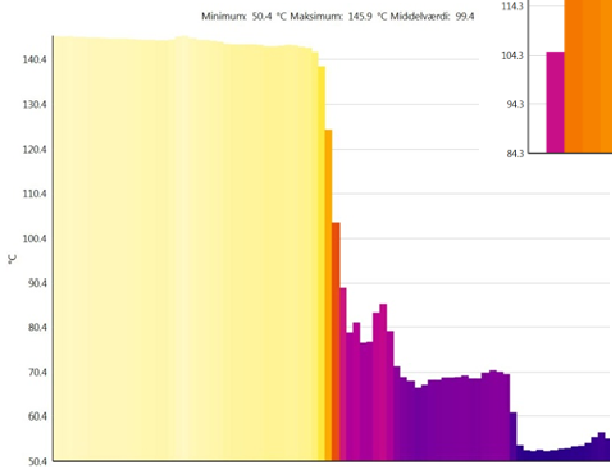
- Vibration measurements from buttom of Rotrex-gear and temperature measurement with IR-kamera.
- Accelerometer (max 120°C).









Analysis of vibrations frequencies

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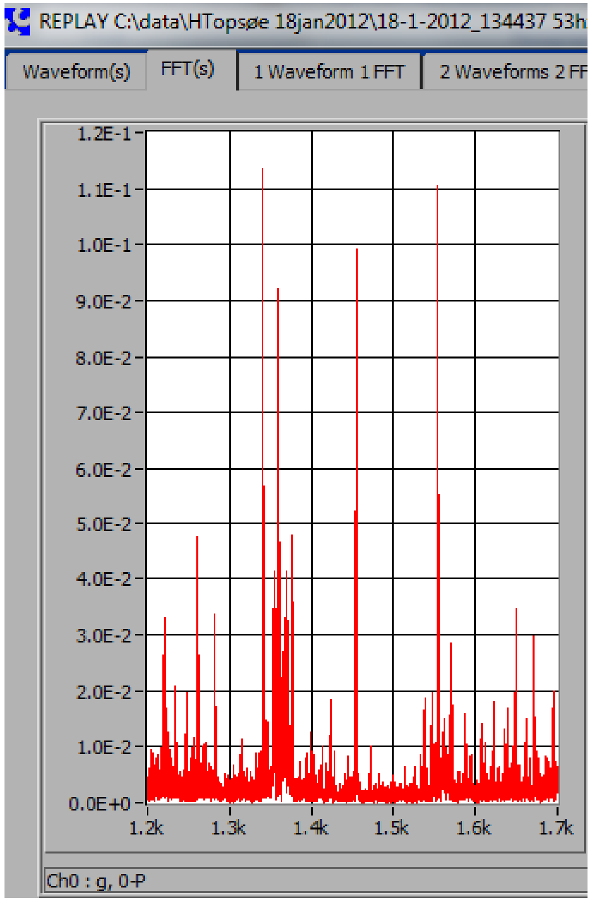
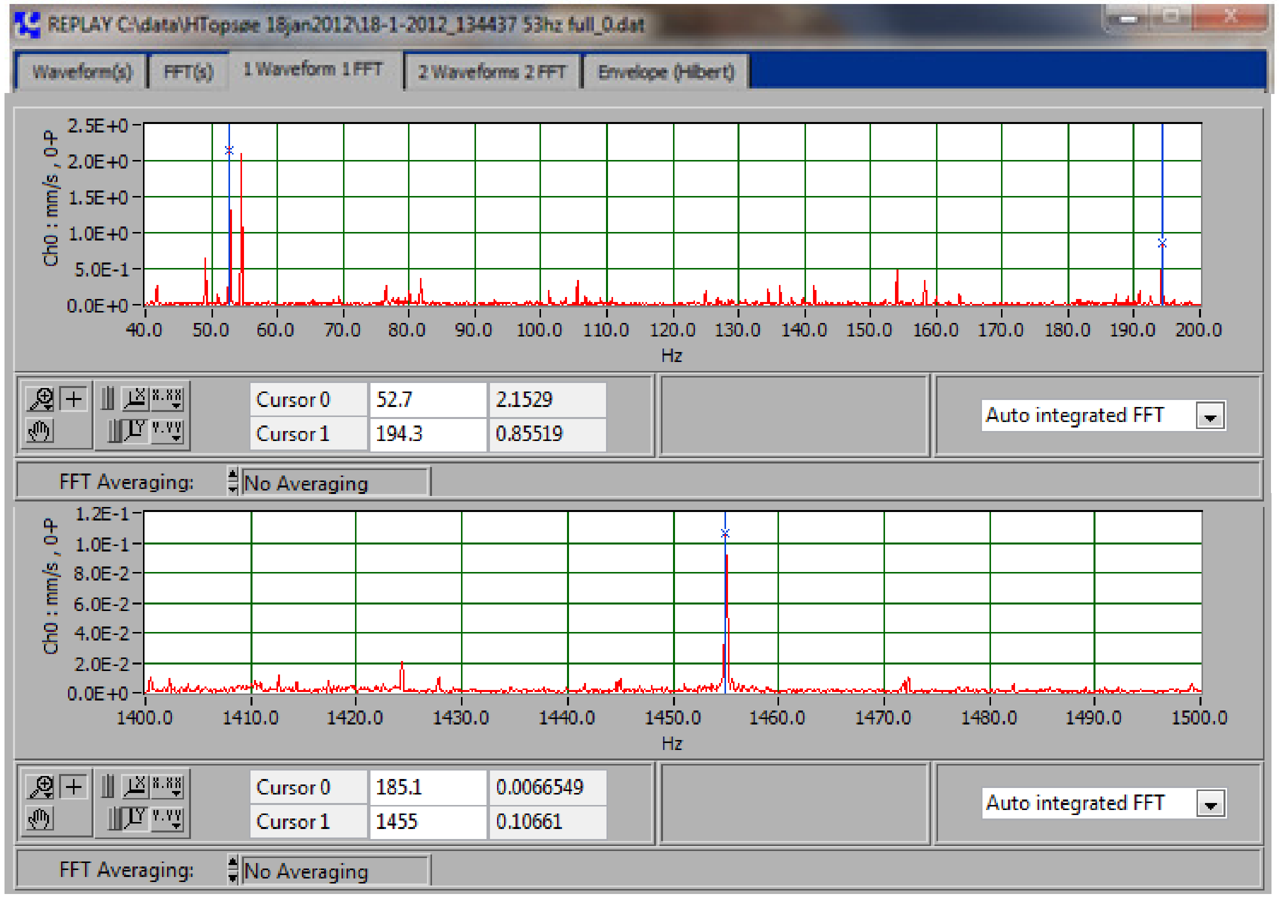
- Motor frequency 52.7 Hz
- Pulley speed 194.3 Hz (11658 rpm)
- Gear ratio 7.5: Compressor impeller 1457.3 Hz (87435 rpm)





Results from first test runs - conclusion

- Operation of Rotrex-compressor in steam for 12 hours.
- 3 hours operation on industrial evaporation plant.
- Promising operation – no significant problems observed.
- Loss in drive (electric motor, belt drive and gear) slightly larger than expected. However measurement accuracy was not high.
- Eta compressor measured to 0.68 at 0.21 kg/s.
- COP: 15.8 (500 kW heat delivered. Temperature lift 13.4 C. Electricity consumption 31.6 kW).
- Weight of compressor and gear 6 kg.
- Long time testing (automatic test rig) is still required!

Optimal compressor design as func. of inlet conditions

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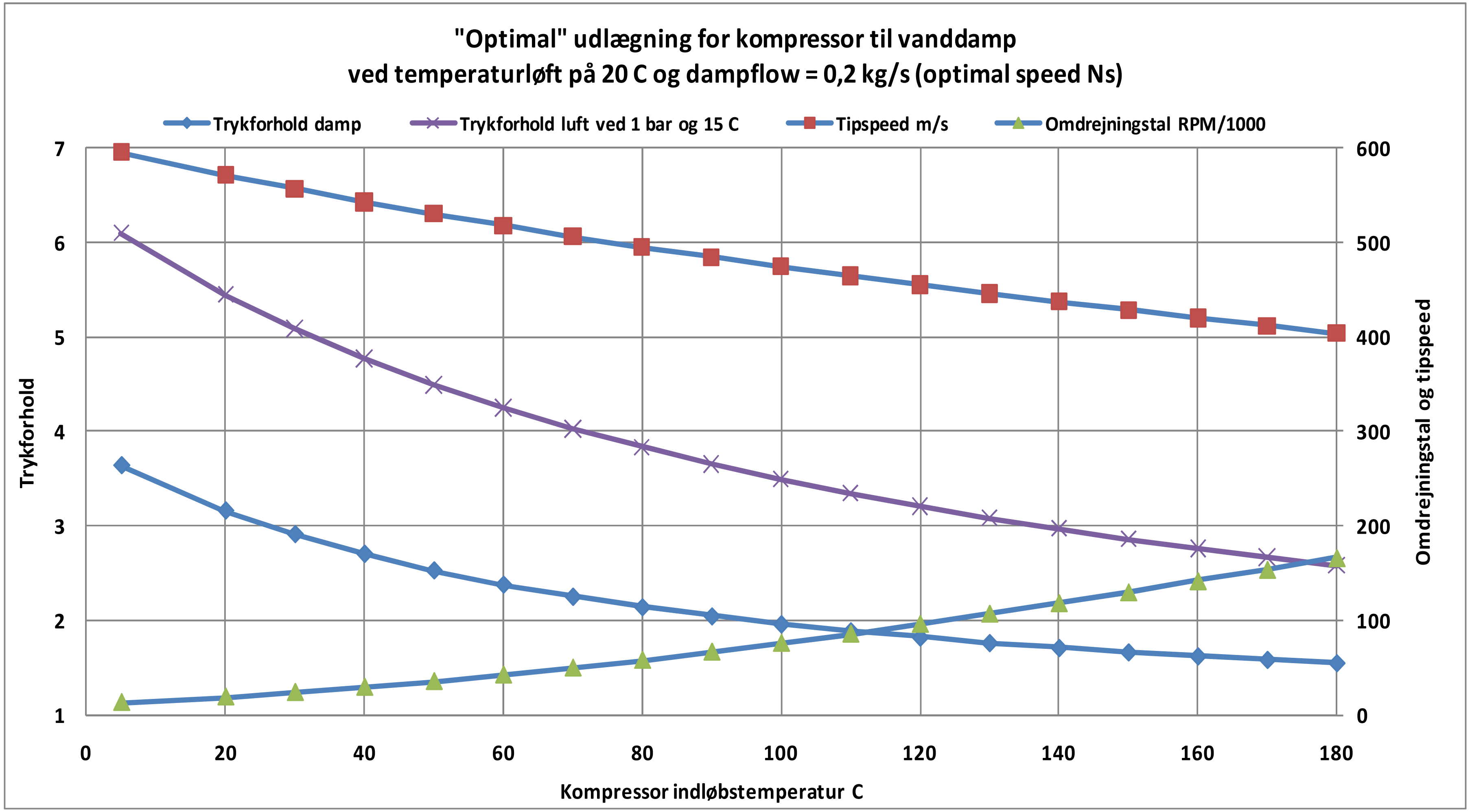

2.nd phase: 2012:

Development of Rotrex turbo compressor for steam compression

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Project manager: Danish Technological Institute

Participants:

- Weel & Sandvig
- Rotrex A/S
- Spirax-Sarco
- Xvaporator
- Enervision
- Union Engineering A/S
- Johnson Controls Danmark Aps

Pressure ratio up to 2.8, Titanium impeller

Tested on air: Rotrex test rig (DK)

Tested on steam:

- H. Topsøe evaporation plant (Weel & Sandvig)
- Spirax Sarco (test facility in UK).

Steam compressor measured at evaporation plant

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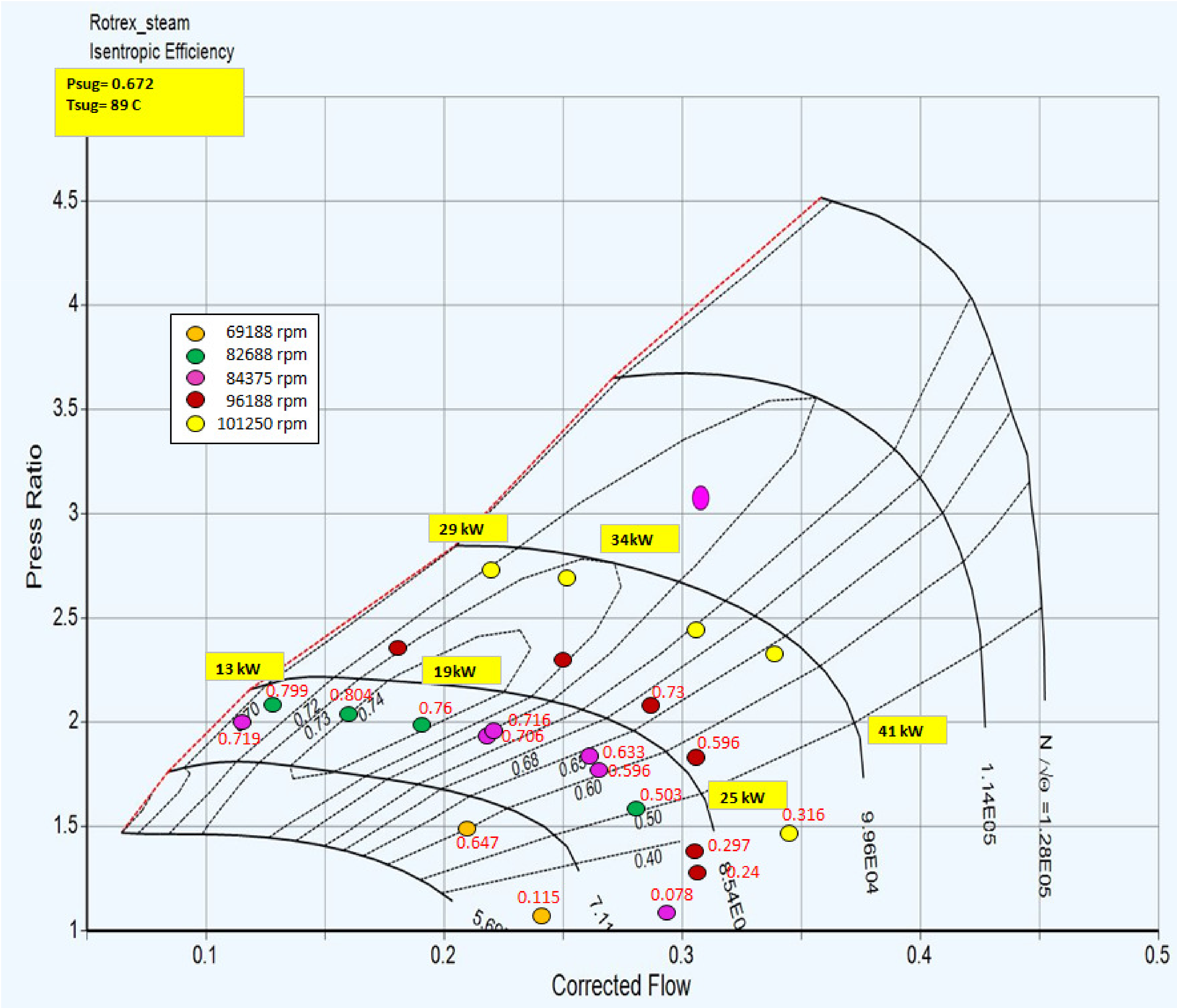
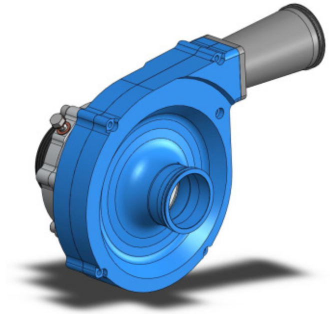
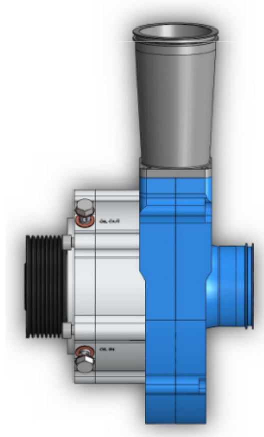
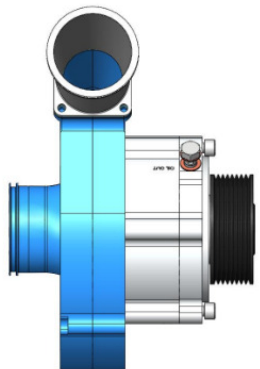






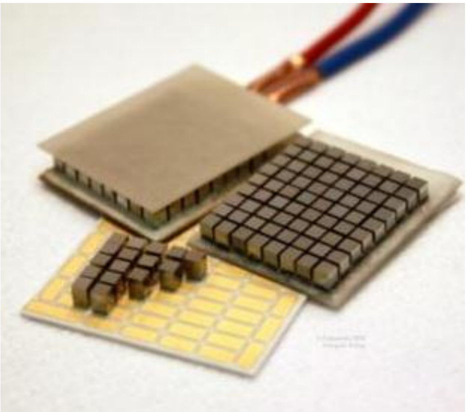


Est. of potential for HP in Danish industry 2013: DEA (Dansk Energianalyse) and Weel & Sandvig

- *Large potential in food industry. Processes like boiling, drying, evaporation, distillation and hot water for CIP are suitable for HP.*
- *Potential:*
  - *4.5 PJ/year with temp. lift of 20 C*
  - *7 PJ/year with temp. lift of 40 C*
  - *15-20 PJ/year with temp. lift of 70 C (approx. one third of total process heat demand)*
- *Main heat delivered close to 100 C*
- *Additional 5.5 PJ/year heat demand can be supplied if HP up to 180 C.*

Thermoelectric modules built with new high-temperature materials

4th Thermoelectrics Conference, 10.-12.12.14, Berlin
K. Bartholomé
J. Heuer, J. Horzella, M. Jägle, J. König, K. Tarantik
Fraunhofer IPM, Freiburg, Germany



Fraunhofer IPM

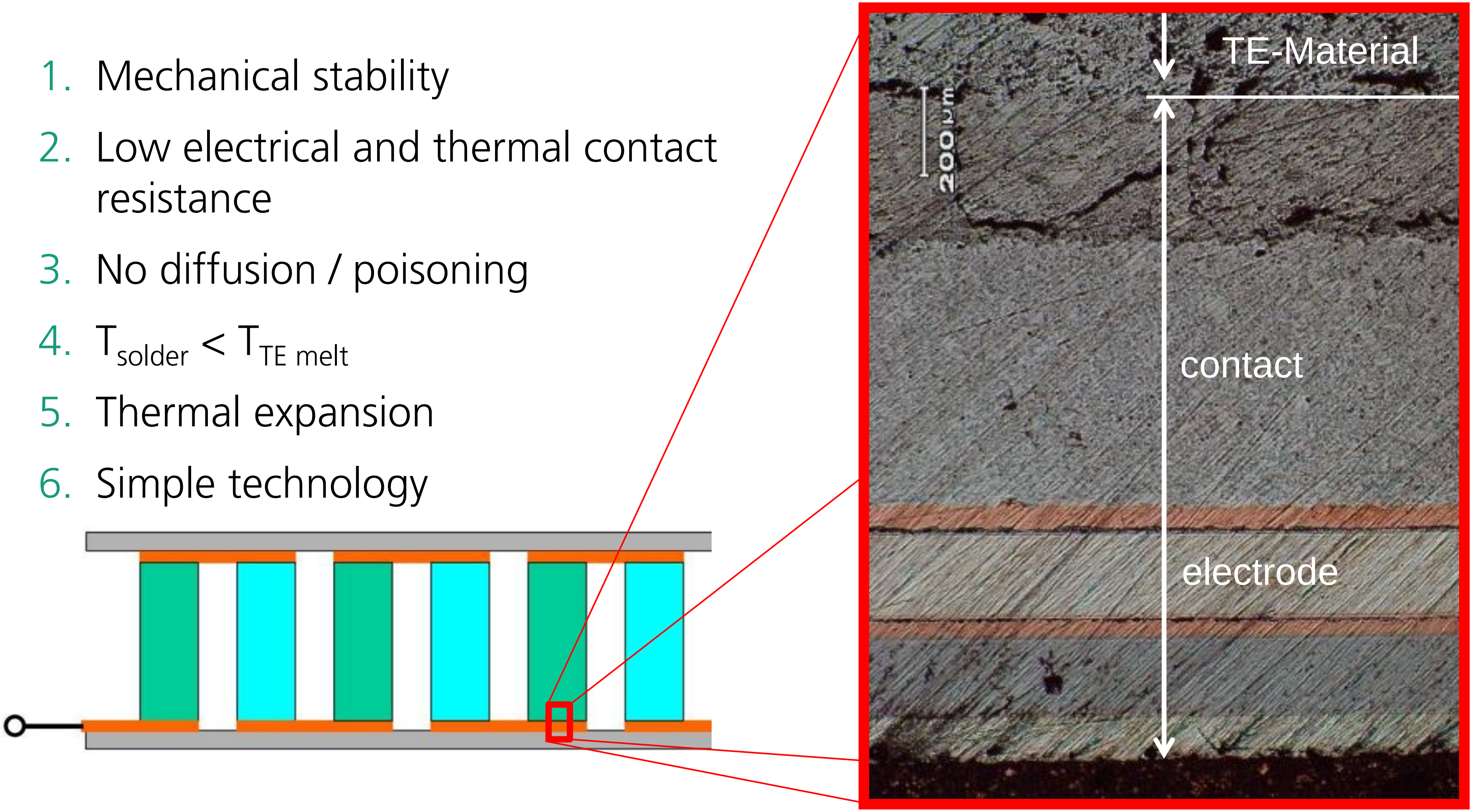
Thermoelectric modules built with new high-temperature materials

Content

- Introduction:
  Module production process
- High-Temperature Modules
- Cost considerations
- Summary

Electrical Contacts
Requirements

1. Mechanical stability
2. Low electrical and thermal contact resistance
3. No diffusion / poisoning
4. $T_{solder} < T_{TE\ melt}$
5. Thermal expansion
6. Simple technology

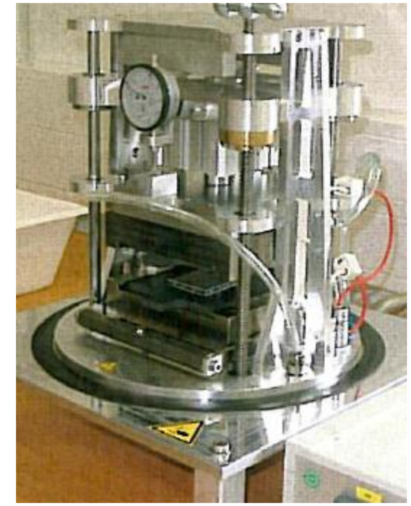


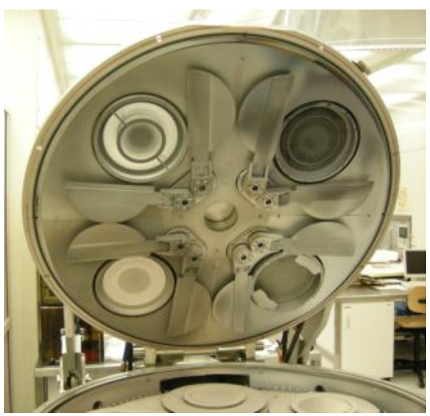
Electrical Contacts

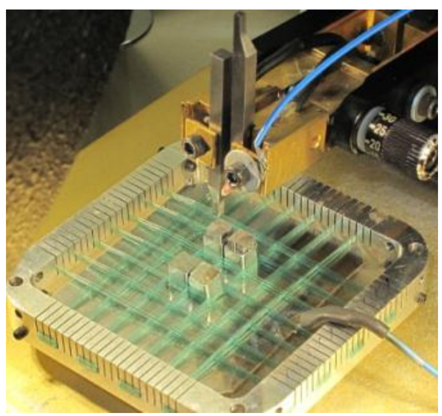
Formation

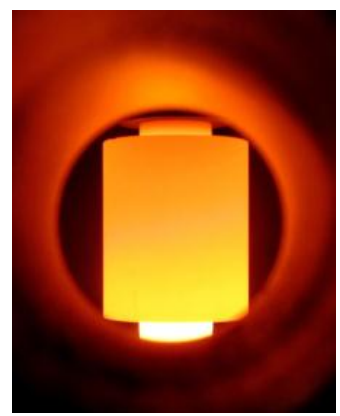
Different methods:

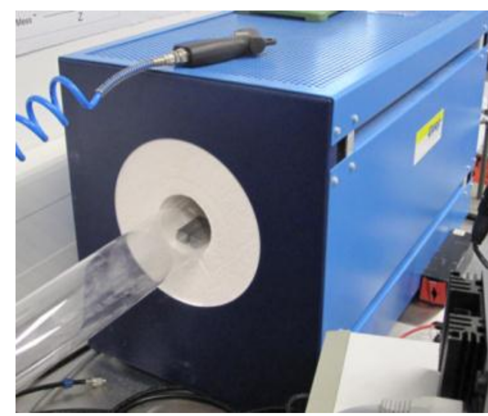
SPS, sputtering, PVD, electroplating, soldering, brazing, welding ...





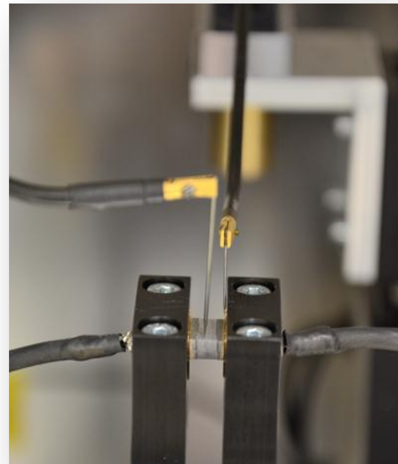


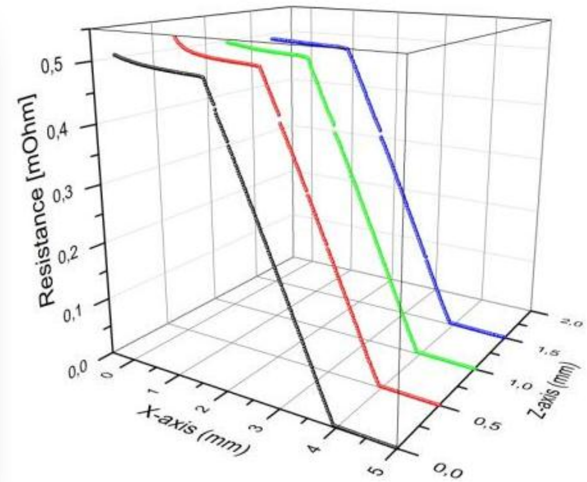


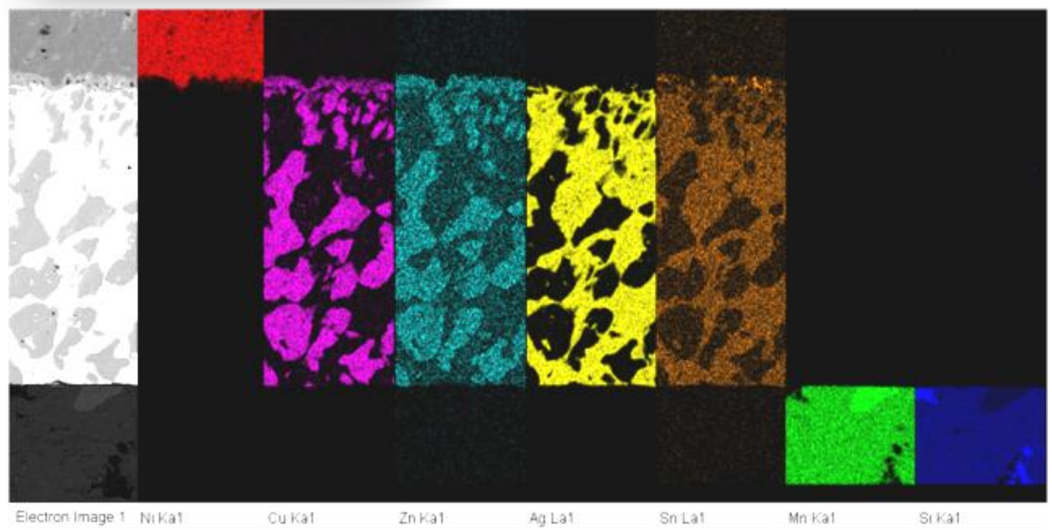


Electrical Contacts
Analysis

- (Contact) resistance measurement setup
- Contact analysis under working conditions by thermography
- Chemical, mechanical and thermal stability characterization …



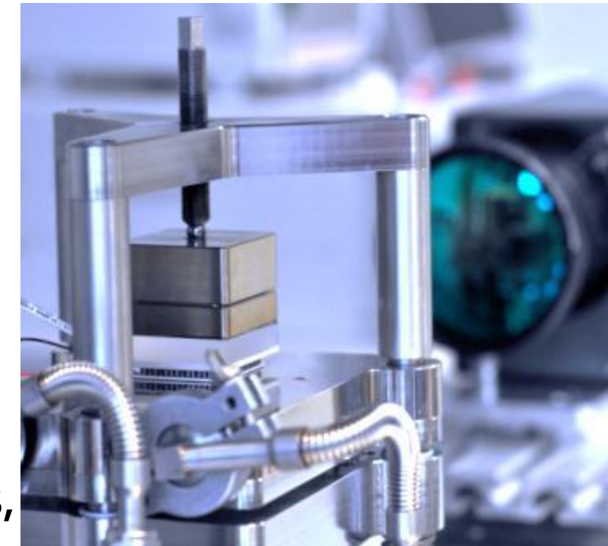


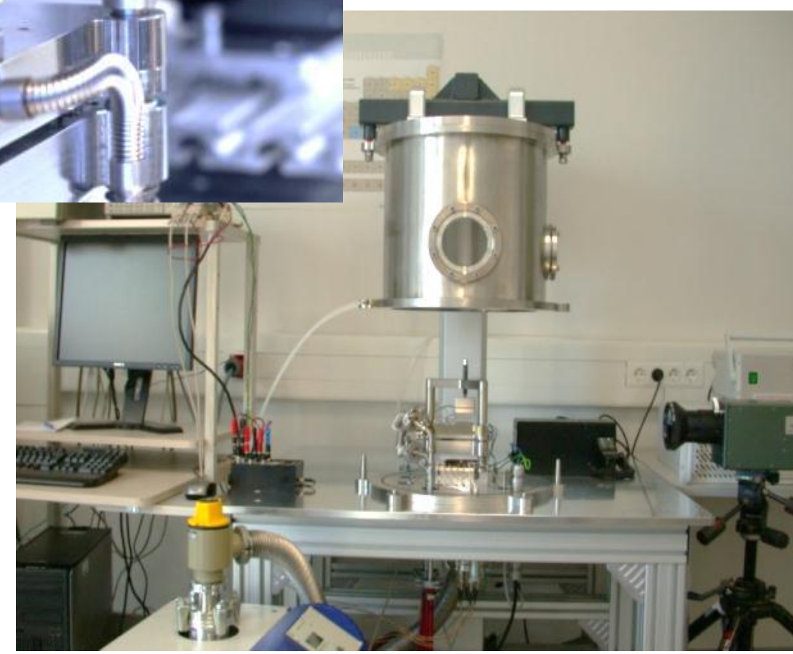


Electrical Contacts

Module testing

- Complete electric module characterization
- *U*, *I*, *P* in dependence on temperature
- Load tests, lifetime assessment, failure analysis, cycling, …
- Tests in different environments (N_2, Air..)





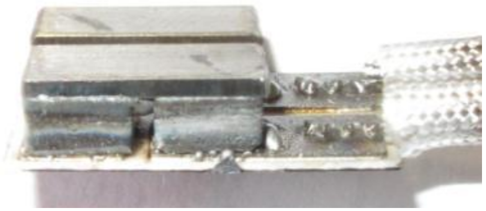
Electrical Contacts

PbTe contact development

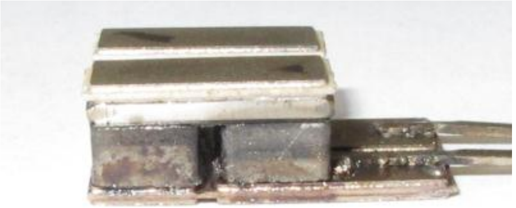
Federal Ministry of Education and Research

solder + 0.25mm Ni

1mm Ni



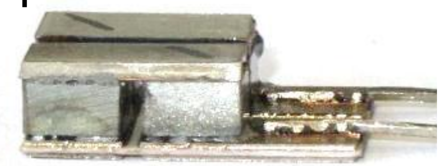
0.1mm Fe +1mm Ni + $Ni/Cu/Al_2O_3/Cu/Ni$



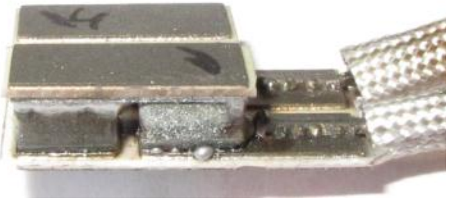
solder +1mm Ni

$Ni/Cu/Al_2O_3/Cu/Ni$

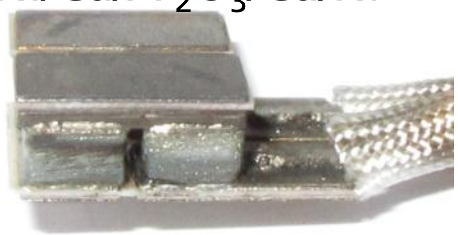
2µm Fe / 1mm Ni



solder + $Ni/Cu/Al_2O_3/Cu/Ni$



1mm Ni + $Ni/Cu/Al_2O_3/Cu/Ni$



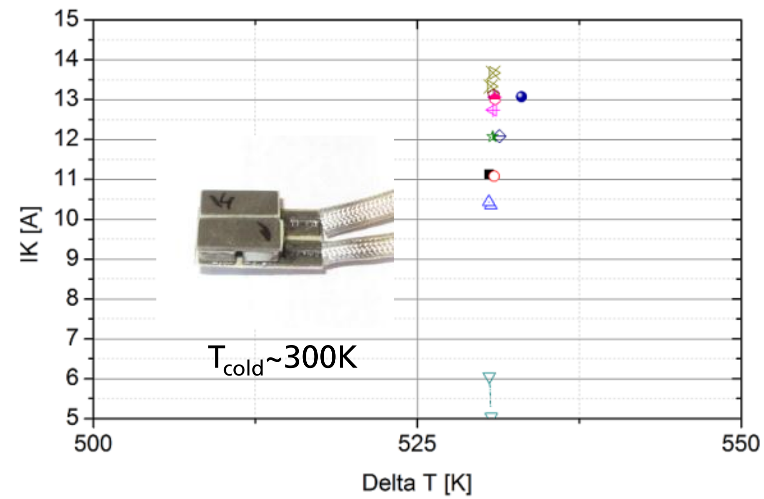
2µm Fe / 1mm Ni
Rough surface

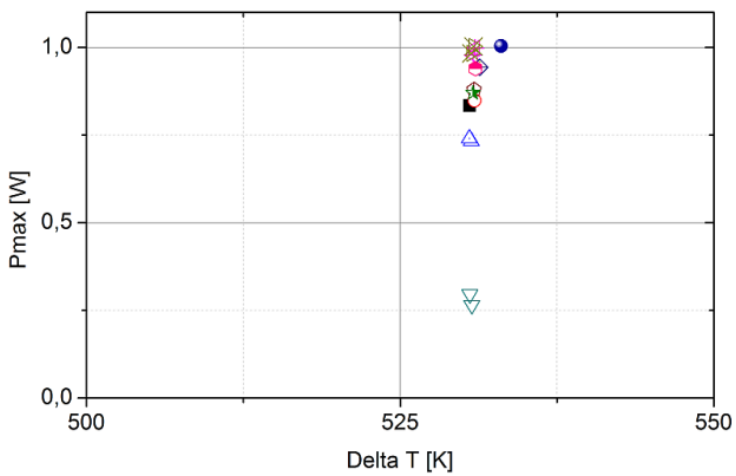
Thermoelectric leg size 5 x 5 x 3 mm^3

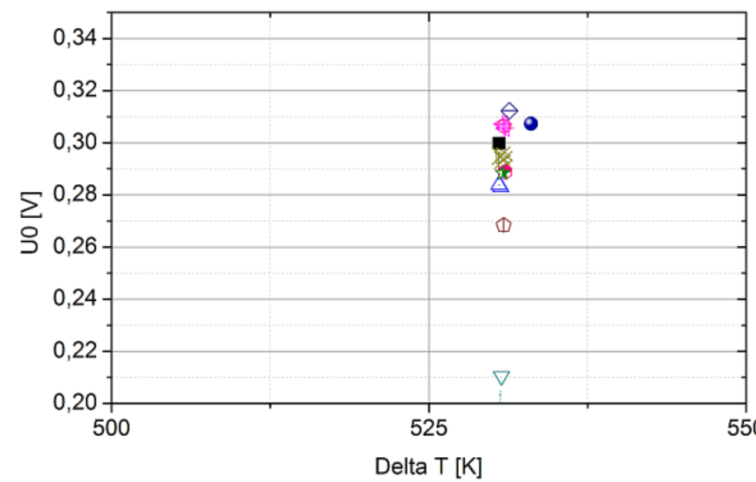
Electrical Contacts

PbTe contact development

- PbTe+solder+Ni 0.25mm
- PbTe+Solder+Ni 1mm
- PbTe+Ni 1mm
- PbTe+Ni/Cu/Al2O3/Cu/Ni
- PbTe+Solder+Ni 1mm+Ni/Cu/Al2O3/Cu/N
- PbTe+Fe 0.1mm+Ni 1mm
- PbTe+Fe 0.1mm+Ni 1mm+Ni/Cu/Al2O3/Cu/Ni
- PbTe 2µFe+Ni 1mm rough surface
- PbTe+Fe 2µm +Ni 1mm
- PbTe+2µm Fe/Ni 1mm rough
- PbTe+solder+Ni 1mm+Ni/Cu/Al2O3/Cu/Ni



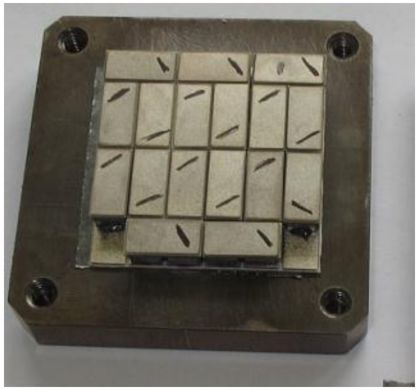


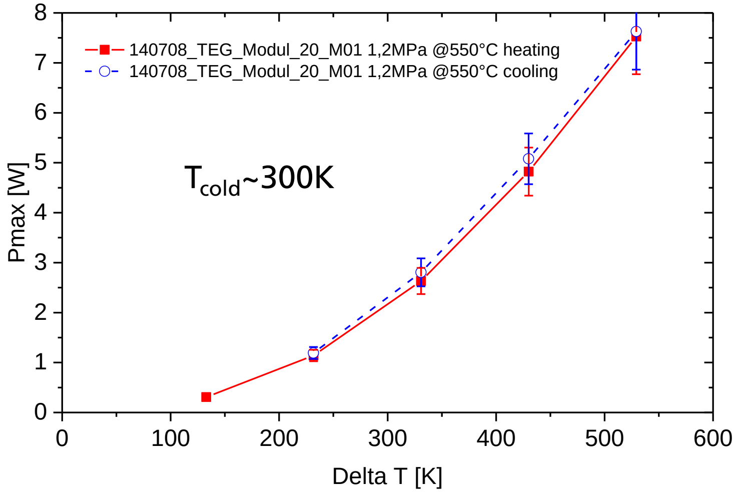


Fraunhofer IPM

Electrical Contacts

PbTe contact development





Thermoelectric modules built with new high-temperature materials

Content

- Introduction:
  Module production process
- **High-Temperature Modules**
- Cost considerations
- Summary

Fraunhofer IPM

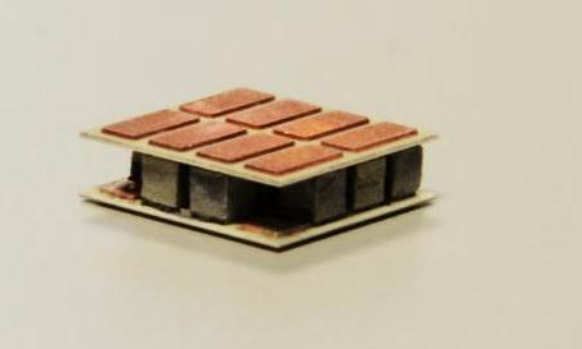
Thermoelectric at Fraunhofer IPM

High temperature modules

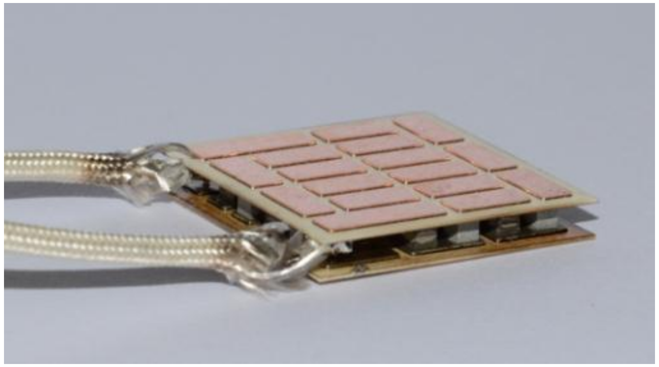
Chalcogenides

Silicide

Half-Heusler



Skutterudite



Thermoelectric at Fraunhofer IPM

High temperature modules

Chalcogenides

Silicide

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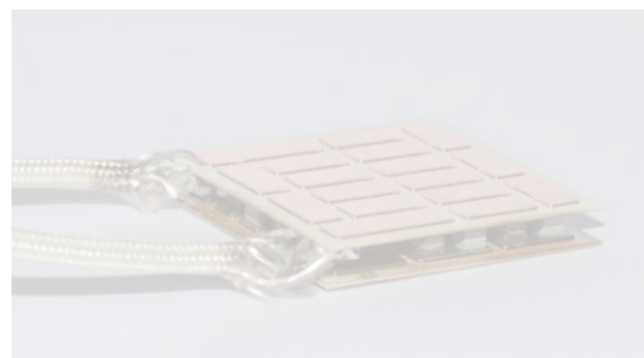
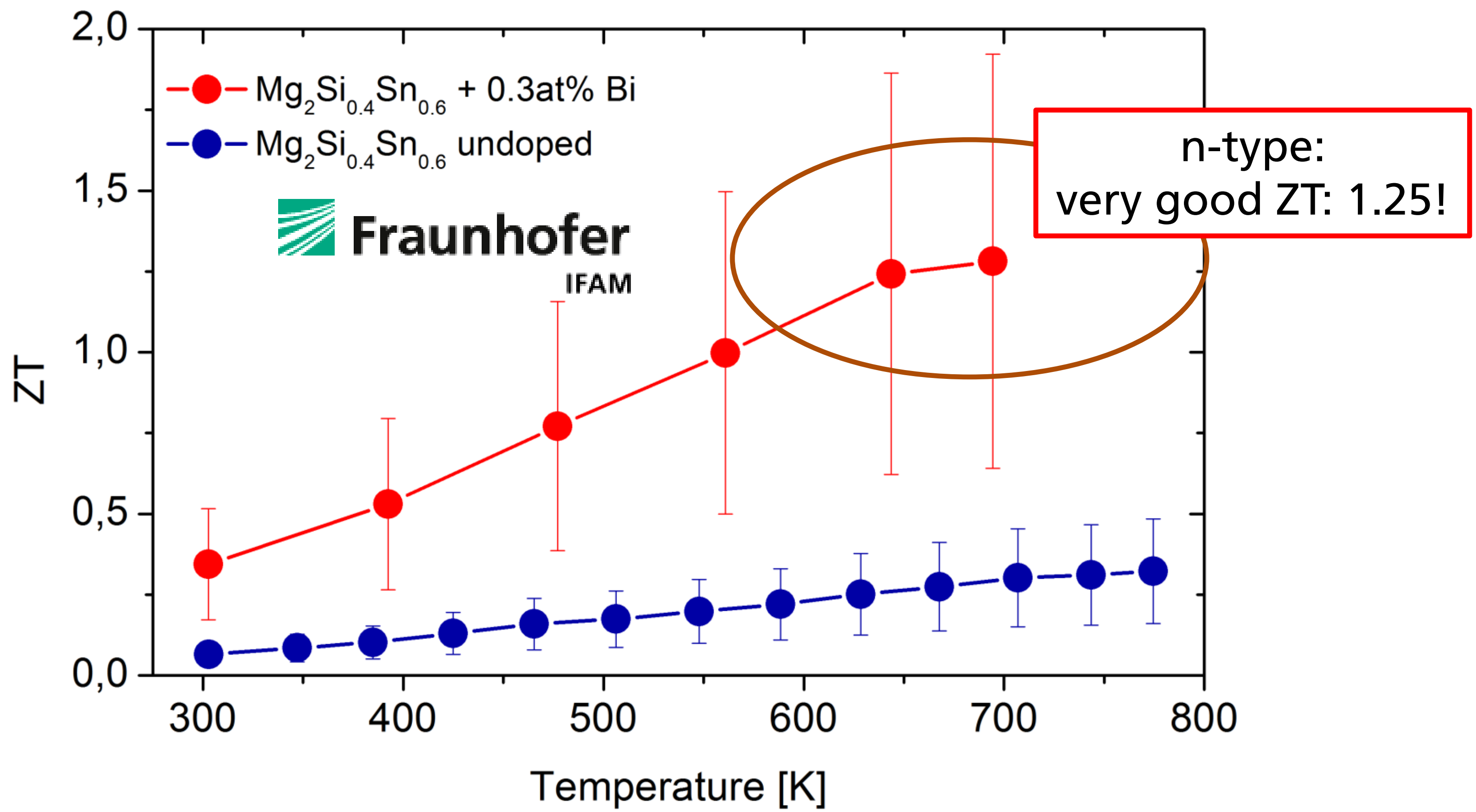
Skutterudite



Silicide modules

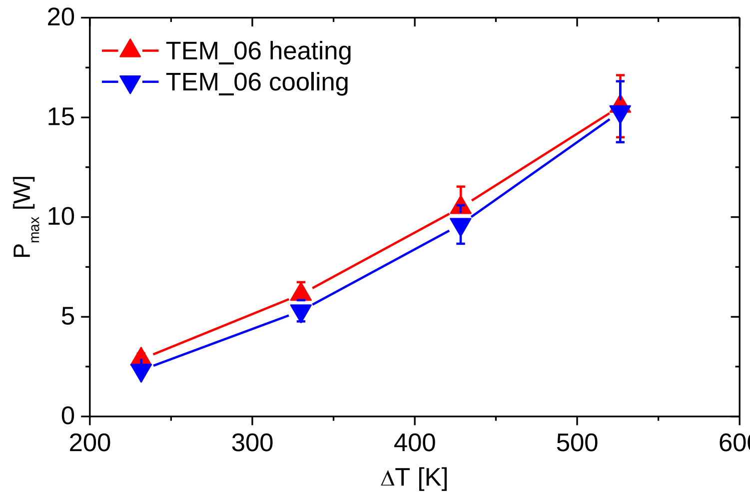
Material properties

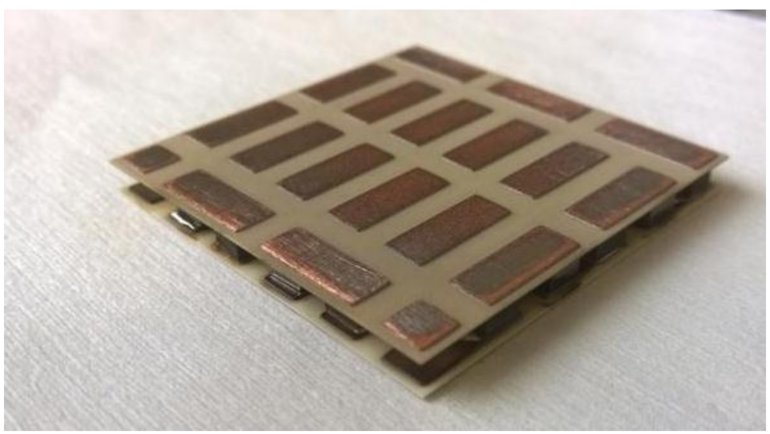


Silicide modules

Module properties

- module area: 50 x 50 mm²
- power density:
  ~0.6 W/cm² @ Δ*T* = 530 K
  ~1.88 W/g
- reasonably stable for several dozen cycles





Thermoelectric at Fraunhofer IPM

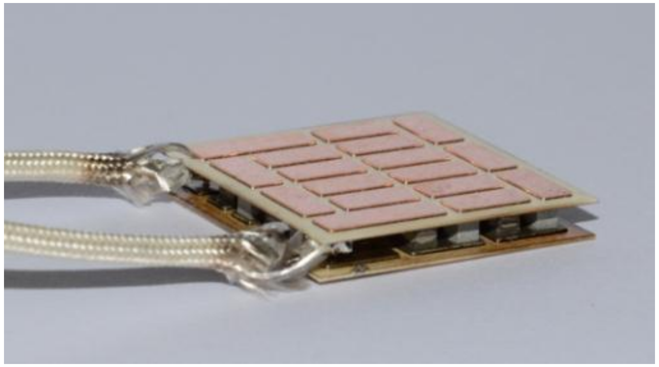
High temperature modules

Chalcogenides

Silicide

Half-Heusler

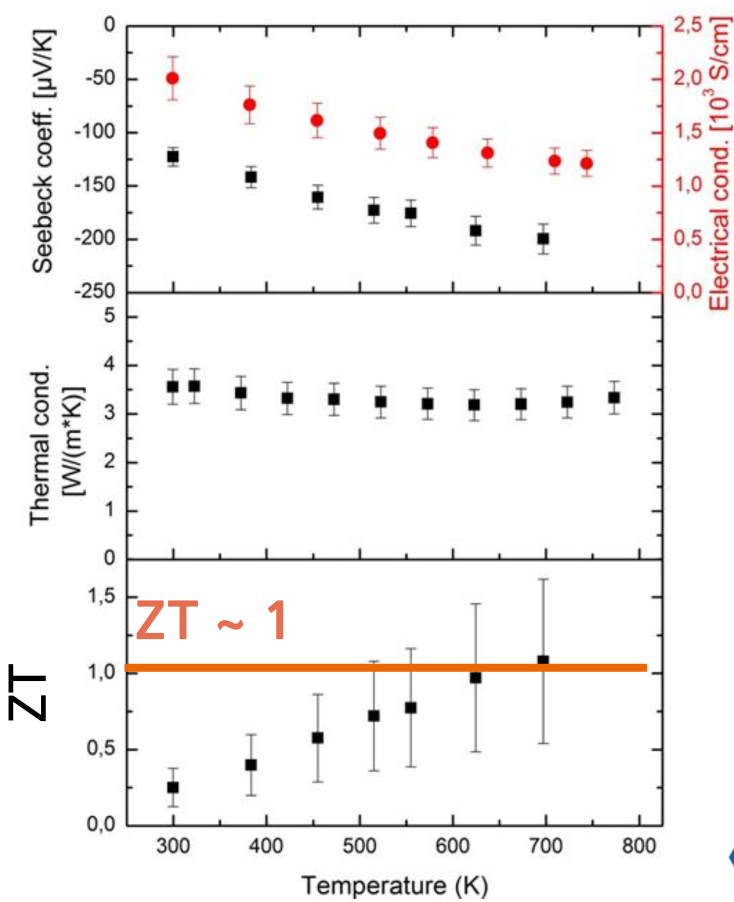
Skutterudite



Skutterudite modules

Material properties

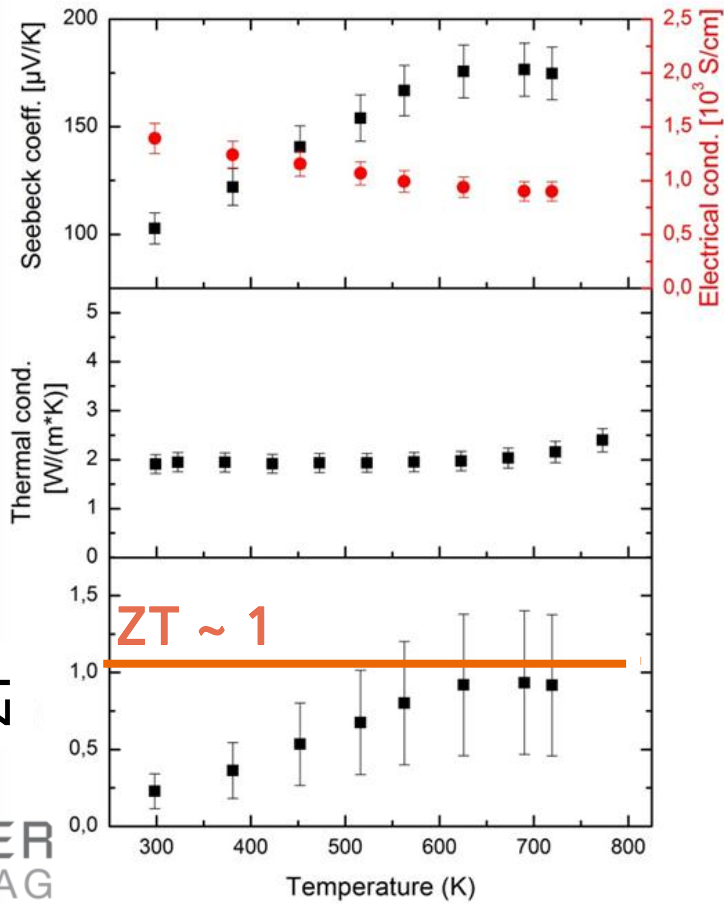
DLR



← n-Typ Rex_18

→ p-Typ Rex_19

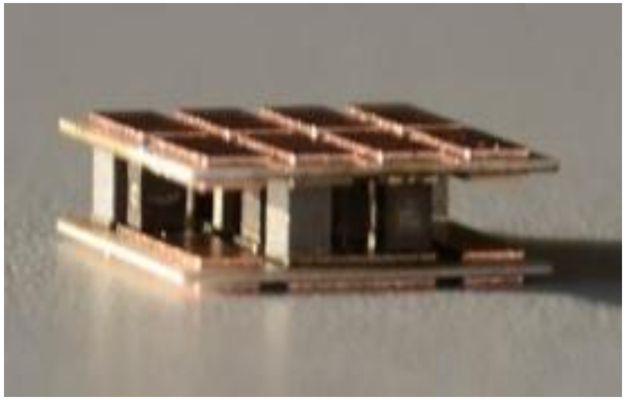
TREIBACHER INDUSTRIE AG

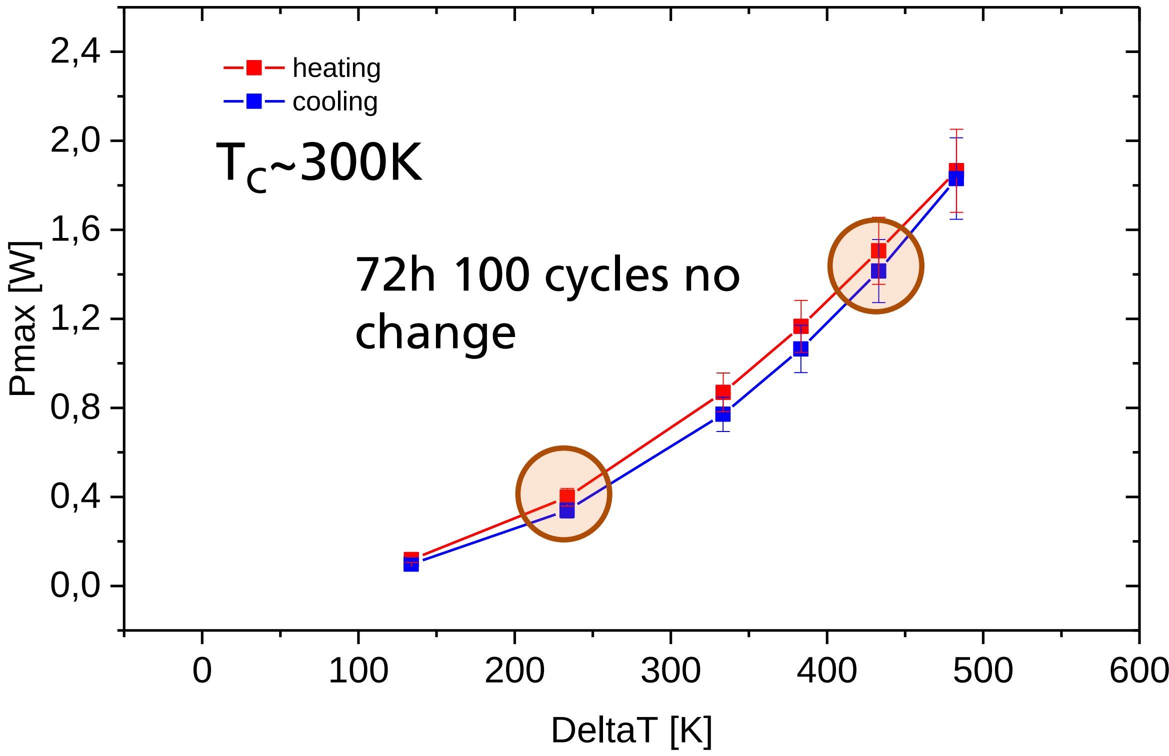


Skutterudite modules

Module properties

- module area: 16 x 16 mm^2
- power density:
  ~0.74 W/cm^2 @ ΔT = 530 K
  ~0.5 W/g
- ~100 cycles in 72h → no changes!





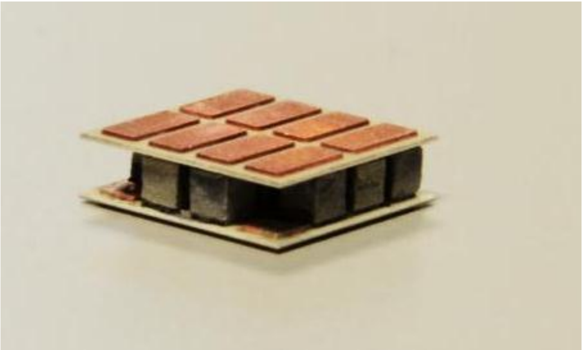
Thermoelectric at Fraunhofer IPM

High temperature modules

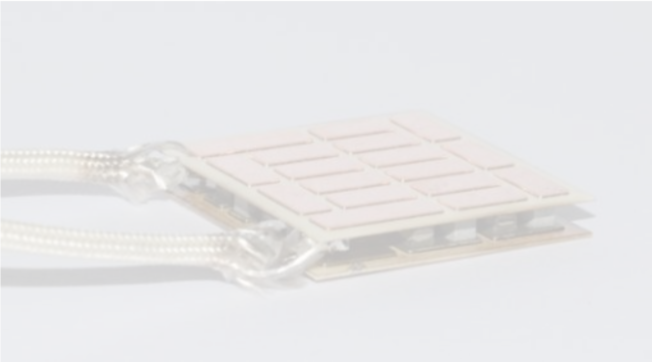
Chalcogenides

Silicide

Half-Heusler

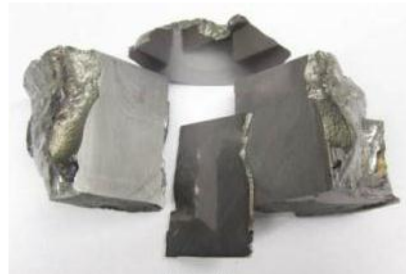


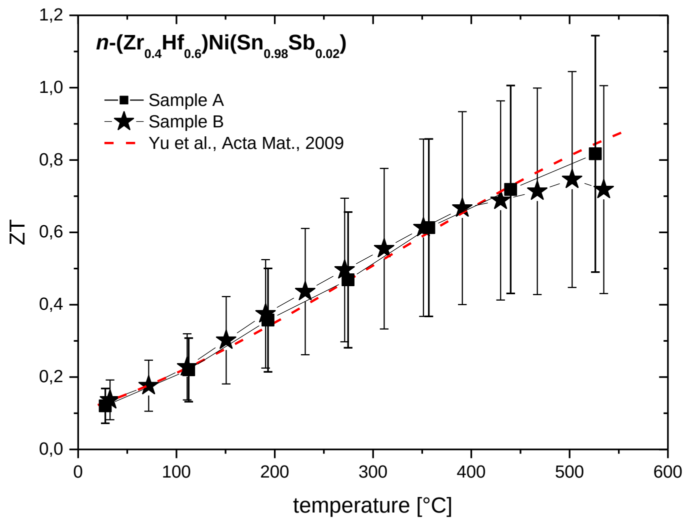
Skutterudite

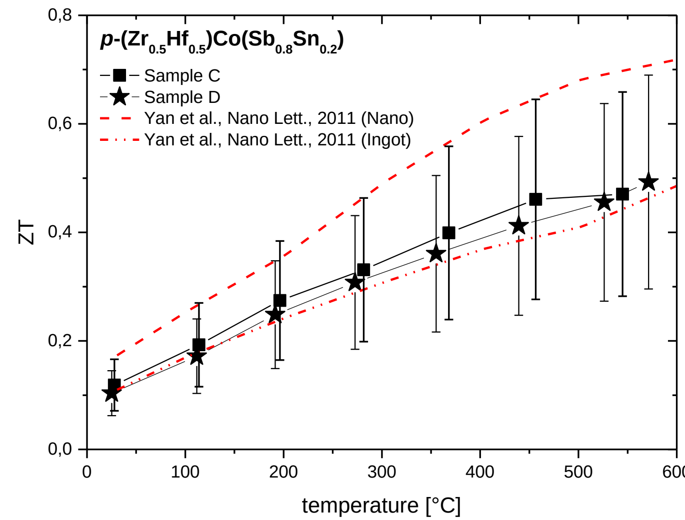


Half-Heusler modules

Material properties







- Data in very good agreement with literature*,**
- Good reproducibility of material properties in production (typically ~10% deviation from run to run)

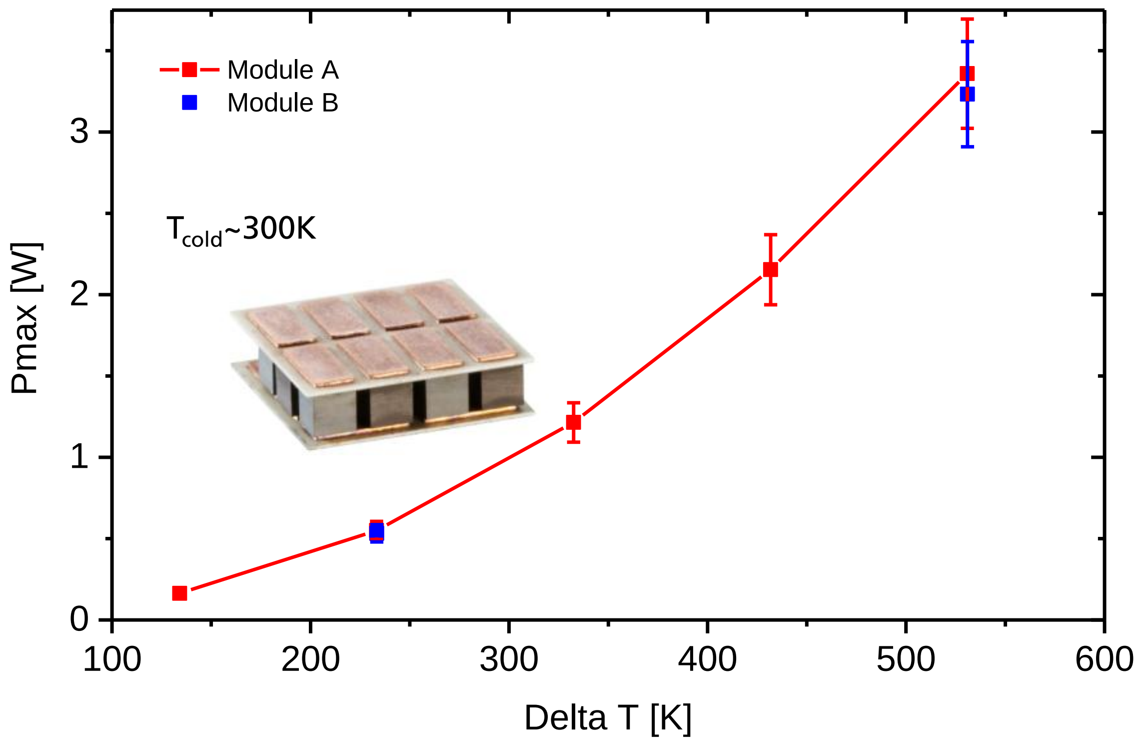
*C. Yu, T.-J. Zhu, R.-Z. Shi, Y. Zhang, X.-B. Zhao and J. He, Acta Materialia **57** (9), 2757-2764 (2009).
**X. Yan, G. Joshi, W. Liu, Y. Lan, H. Wang, S. Lee, J.W. Simonson, S.J. Poon, T.M. Tritt, G. Chen, Z.F. Ren, Nano Letters, 11 (2011) 556-560.

12.12.2014, IAV 2014, Berlin

Half-Heusler modules

Module performance

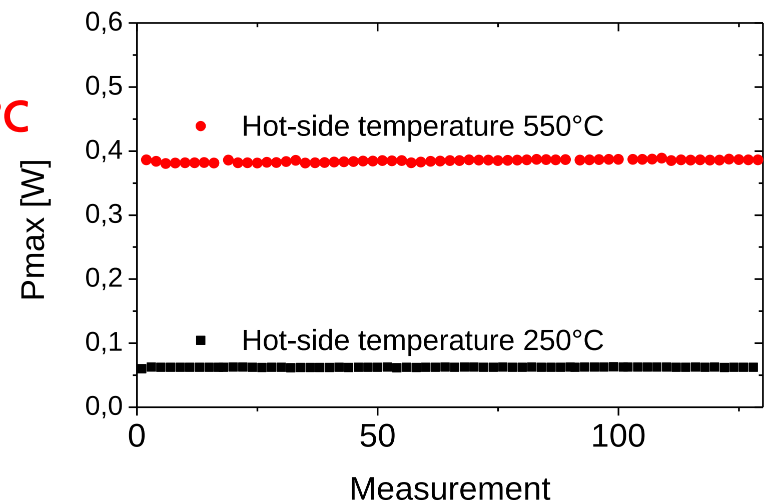
- Module area: 16 x 16mm²
- Power density:
  - 1.27 W/cm²
  - 0.8 W/g
- Efficiency: 5.4%
- Very good reproducibilty!



Module characterization

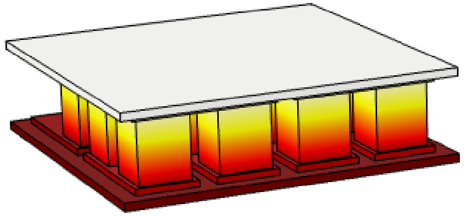
Long-Term stability

1. **cycling** of the hot-side temperature **from 250 °C to 550 °C: 130 times**
2. **Cycling** of the hot-side temperature **from 60 °C to 500 °C** with a heating rate of **50 K/min: 26 times**
3. **Cycling** of the hot-side temperature from **RT up to 600 °C** with a heating rate of **50 K/min: 6 times**
4. **Heat shock** of the module by increasing the hot-side temperature from **100 °C up to 600 °C 6 times** with a heating rate of **100 K/min.**
   → No degradation of the module performance!
5. **Cycling** of the hot-side temperature from **250 °C to 550 °C: 1000 times**
   → <20% degradation of the module performance!



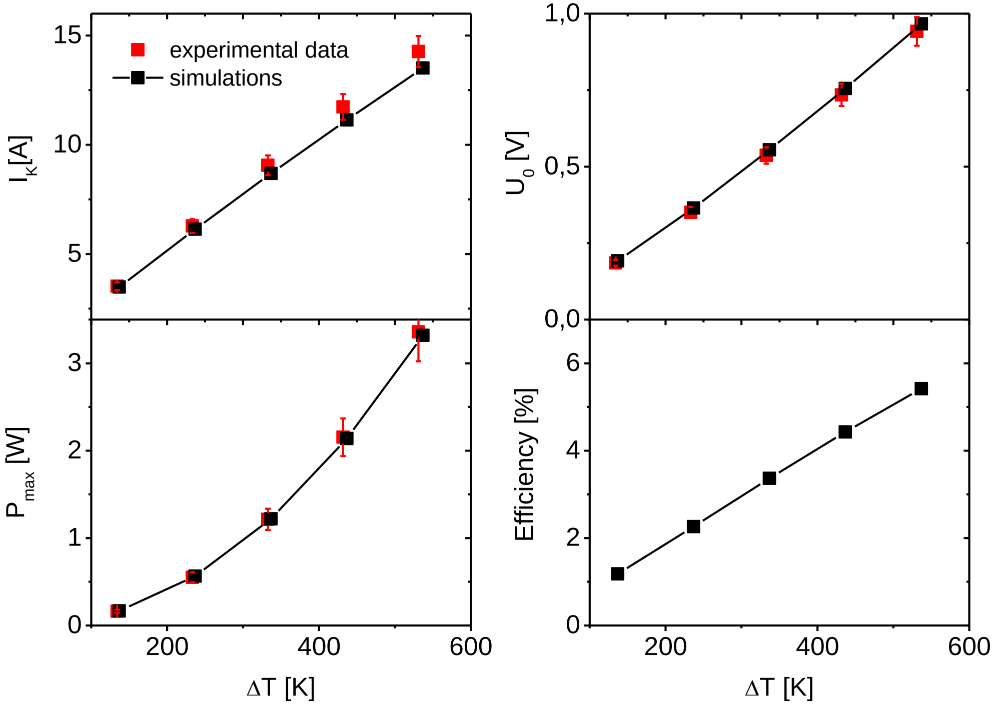
Module characterization

Simulations



Complete module simulations based on Comsol including:

- material data for TE-Material determined with IPM-SRX (Seebeck & el. cond.) and Netzsch-LFA (therm. cond.)
- material data for electrodes and Al_2O_3 from Comsol Library
- thermal contact conductance: 7000 W/(m²K)
- electrical contact resistances: 10^{-10} Ωm²
- Thermal bypass: convection + radiation



Thermoelectric at Fraunhofer IPM

High temperature modules

material	power density [W/cm²]	power density [W/g]	efficiency	material availability	pros / cons
PbTe	0.5	?	?	>kg	+ high ZT - contains Pb + Te
Silicide	0.6	1.88	5 %	kg	+ light weight + very good n-type - need for encapsulation - p-type
Skut-terudite	0.74	0.5	8 %	>kg	+ high ZT + good reproducibility - need for encapsulation
Half-Heusler	1.27	0.8	5.4%	>kg	+ stable + good reproducibility

Thermoelectric modules built with new high-temperature materials

Content

- Introduction:
  Module production process
- High-Temperature Modules
- **Cost considerations**
- Summary

Thermoelectric Module

Cost considerations: Skutterudites

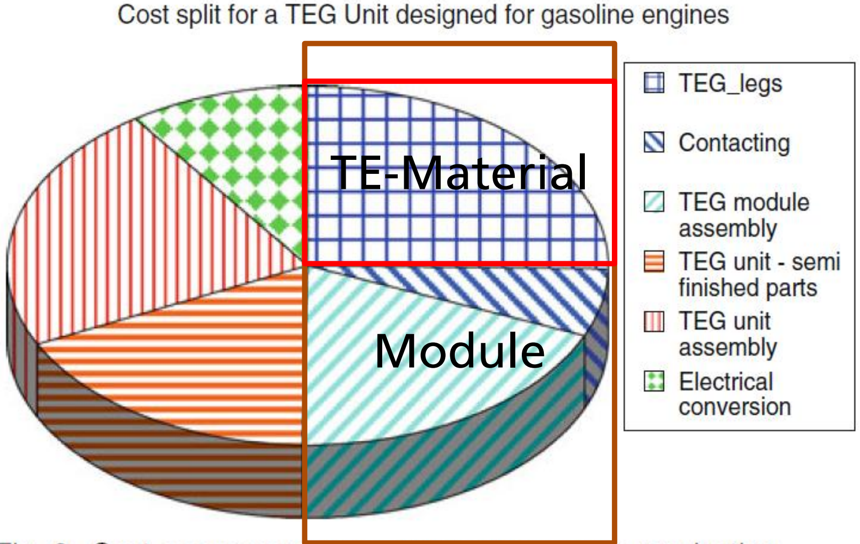


Fig. 8. Cost assessment for a TEG unit for mass production.

K. Salzgeber,(AVL) et al JEMS, Vol. 39, No. 9, 2010 DOI: 10.1007/s11664-009-1005-y

TE-Material: 50% of module costs
TE-Module: 50% of system costs

Thermoelectric Module

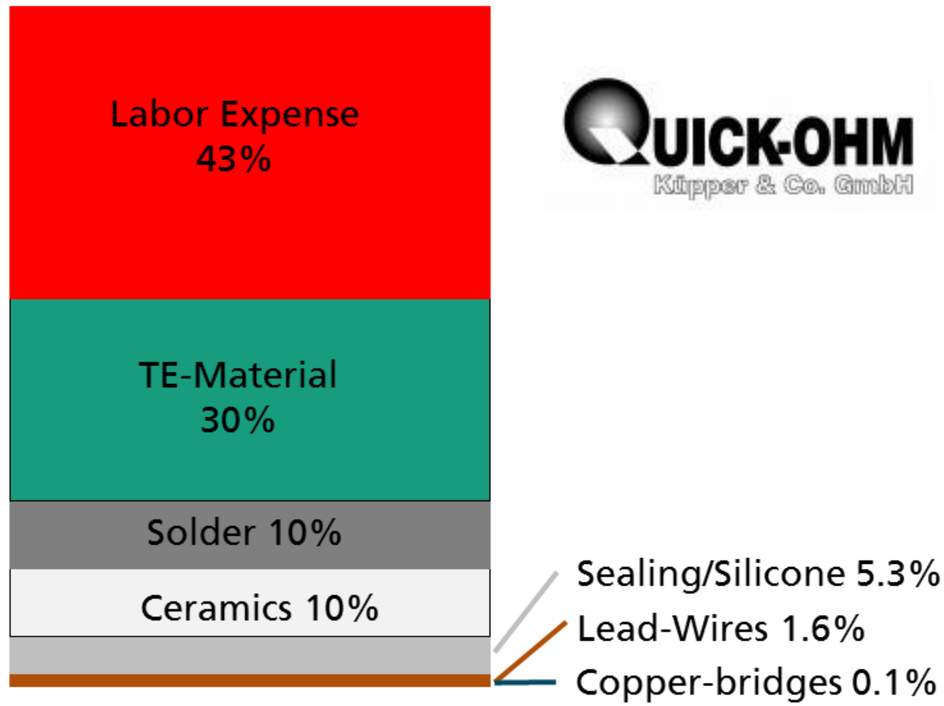
Cost considerations: current Bi_2Te_3-Modules

cost analysis “standard module”:

- 4cm x 4cm
- 127 pairs of legs

module costs for 100.000 modules / year

- 7€ module costs, containing:
  - 3€ labor expense
  - 2€ TE-material



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Thermoelectric Module

Cost considerations: current Bi_2Te_3-Modules

hand-made process!

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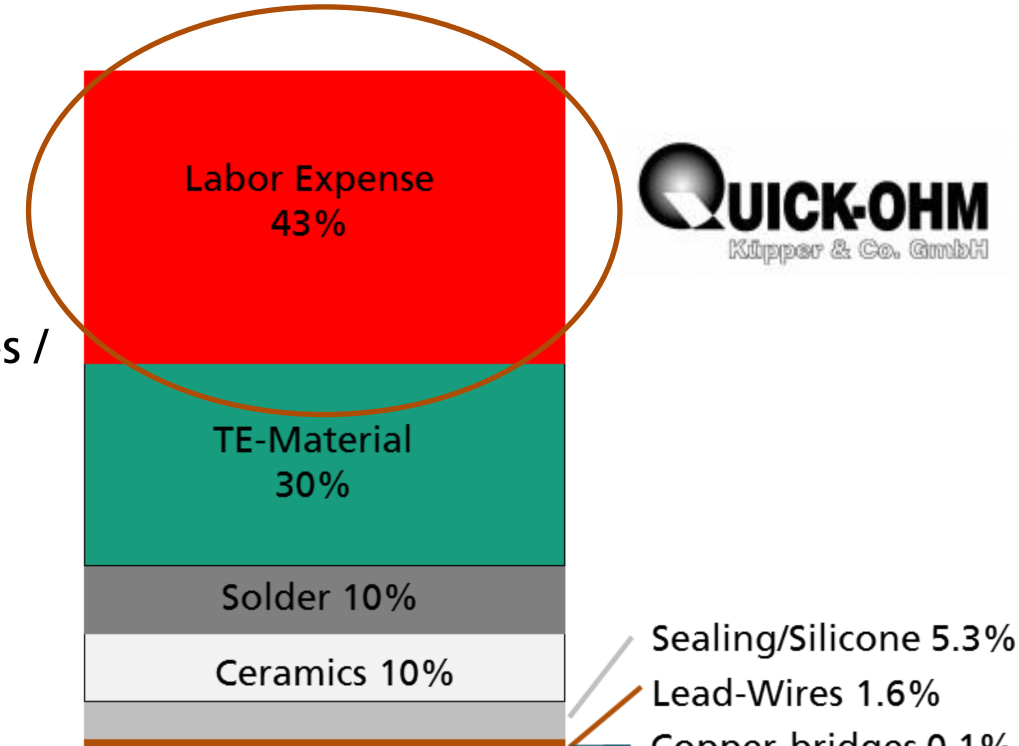

Thermoelectric Module

Cost considerations: current Bi_2Te_3-Modules

hand-made process!

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- 4cm x 4cm
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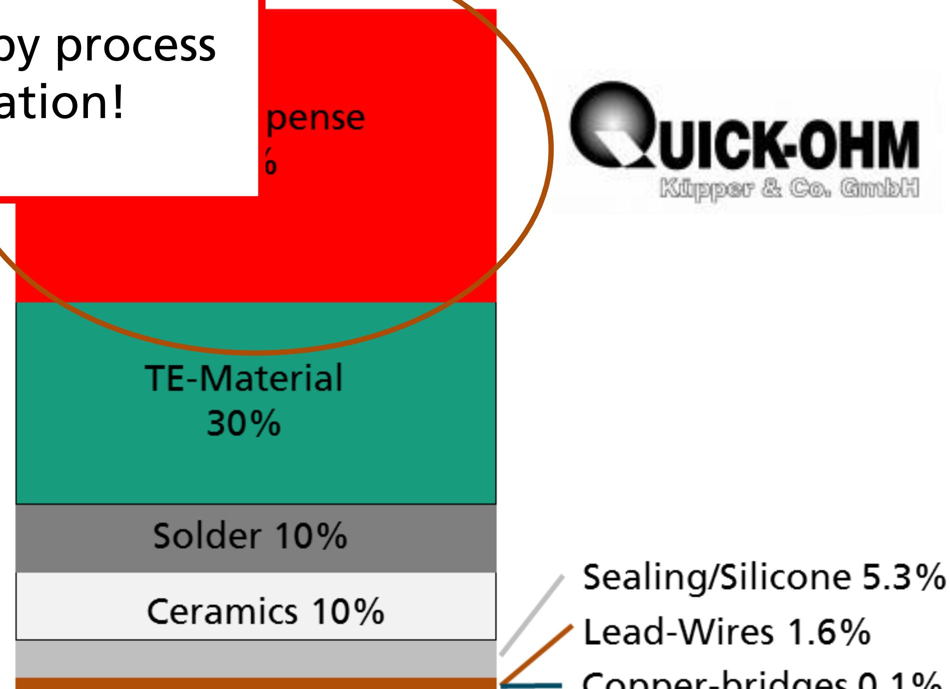
Cut down by process automation!



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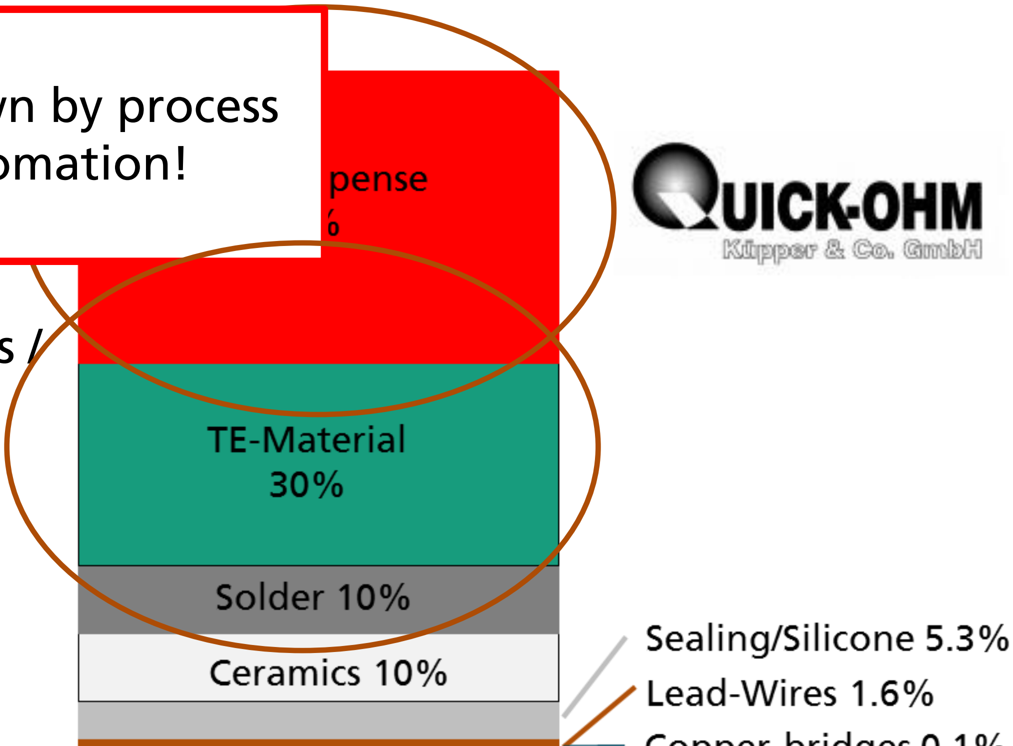

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Thermoelectric Module

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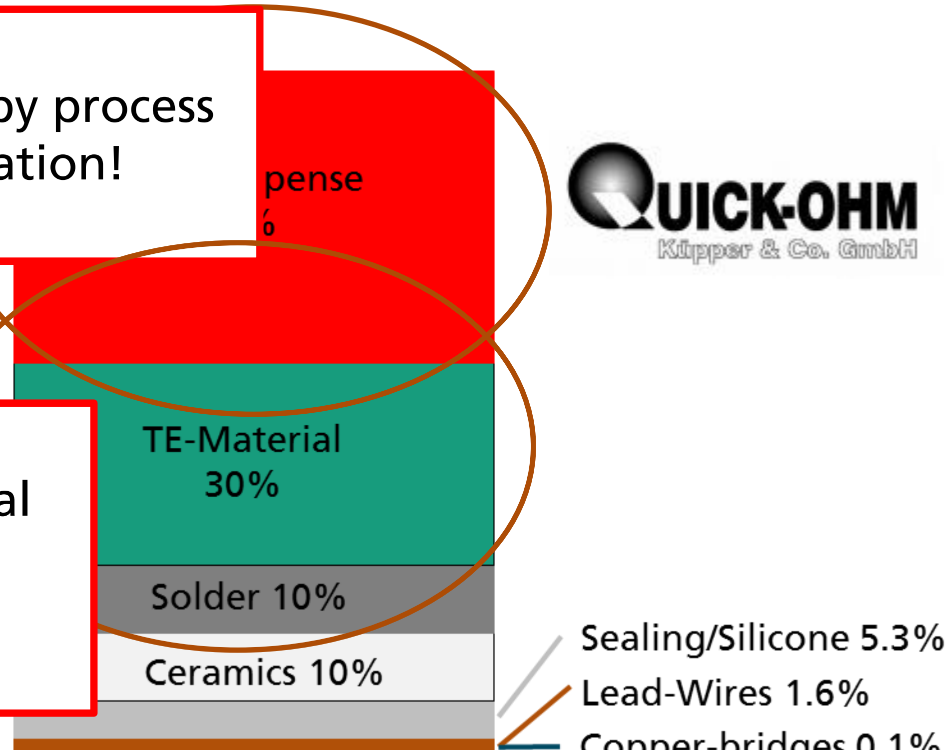
  - 2€ TE-ma

G. Nolas: “Material costs are not an issue!”
??



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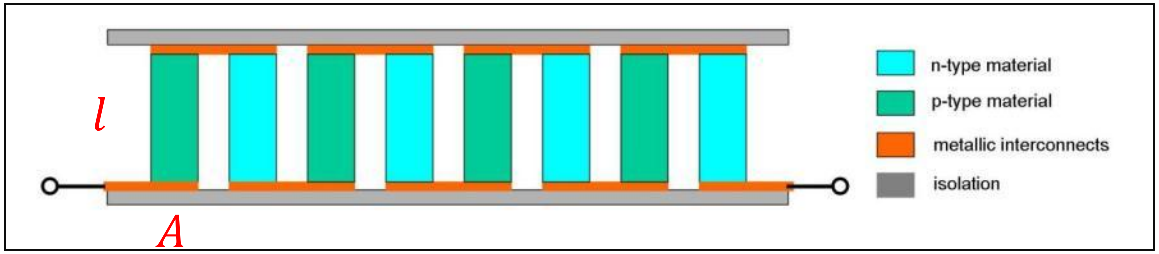
Cost Reduction

Optimization of Module Geometry

Idea: Reduce amount of TE-Material while keeping thermal and electrical properties of TE-module



- electrical resistance of TE-module:

$$R^{el} = nR^{el}_{TE} + \mathcal{O}(R^{contact}) \approx n\rho\frac{l}{A}$$

- thermal resistance of TE-module:

$$R^{th} = \frac{1}{n}R^{th}_{TE} + \mathcal{O}\left(\frac{R^{th}_{TE}}{R^{bp}}\right) \approx \frac{1}{n\lambda}\frac{l}{A}$$

Cost Reduction

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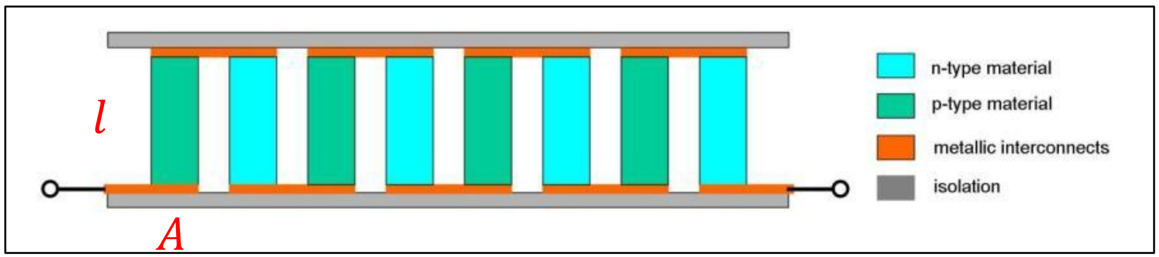


- electrical resistance of TE-module:

$$R^{el} = nR_{TE}^{el} + \mathcal{O}(R^{contact}) \approx n\rho \frac{\sqrt{k}l}{\sqrt{k}A}$$

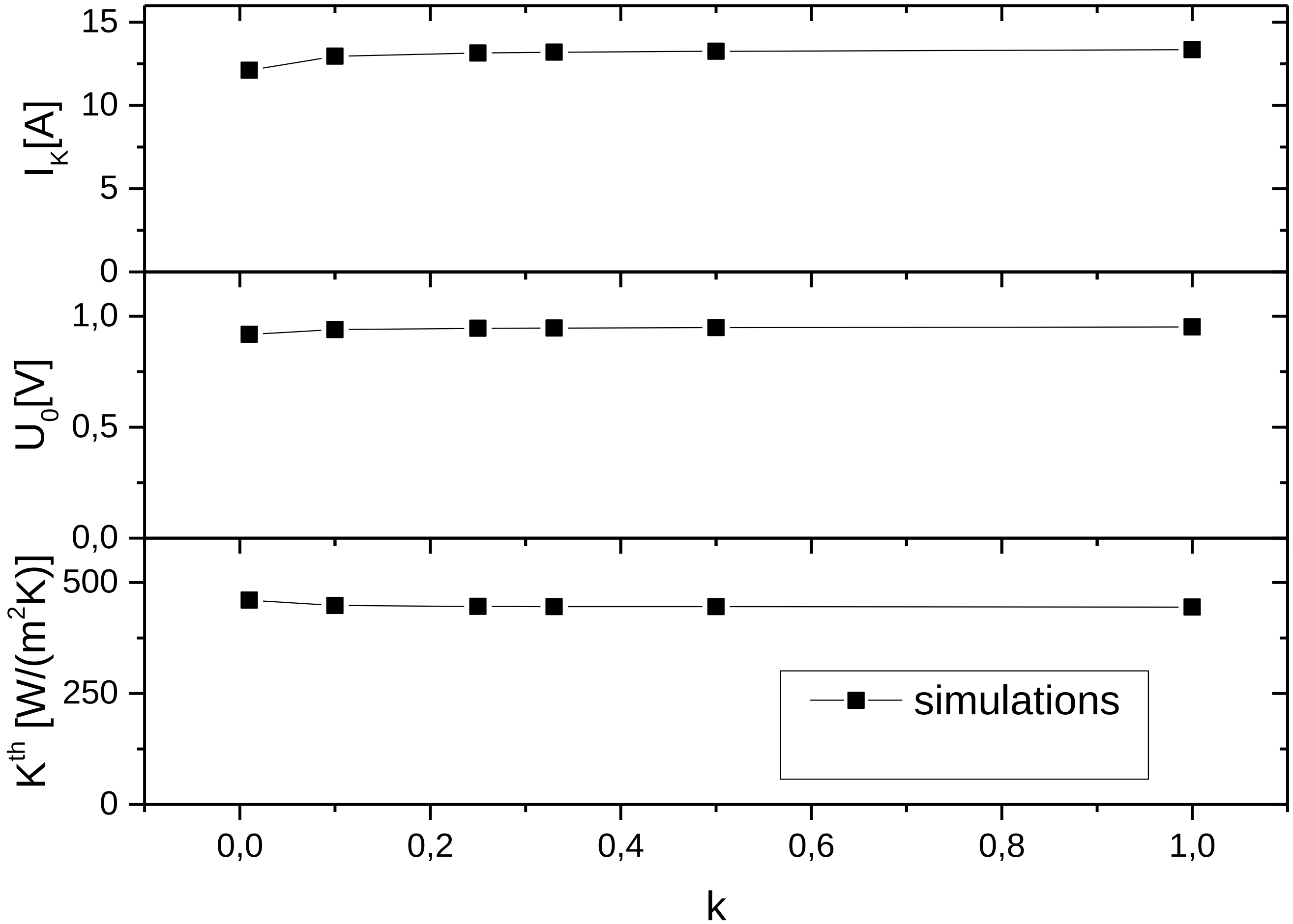
- thermal resistance of TE-module:

$$R^{th} = \frac{1}{n} R_{TE}^{th} + \mathcal{O}\left(\frac{R_{TE}^{th}}{R^{bp}}\right) \approx \frac{1}{n\lambda} \frac{\sqrt{k}l}{\sqrt{k}A}$$

Identical scaling of l and A leaves thermal and electrical properties of module unaltered!

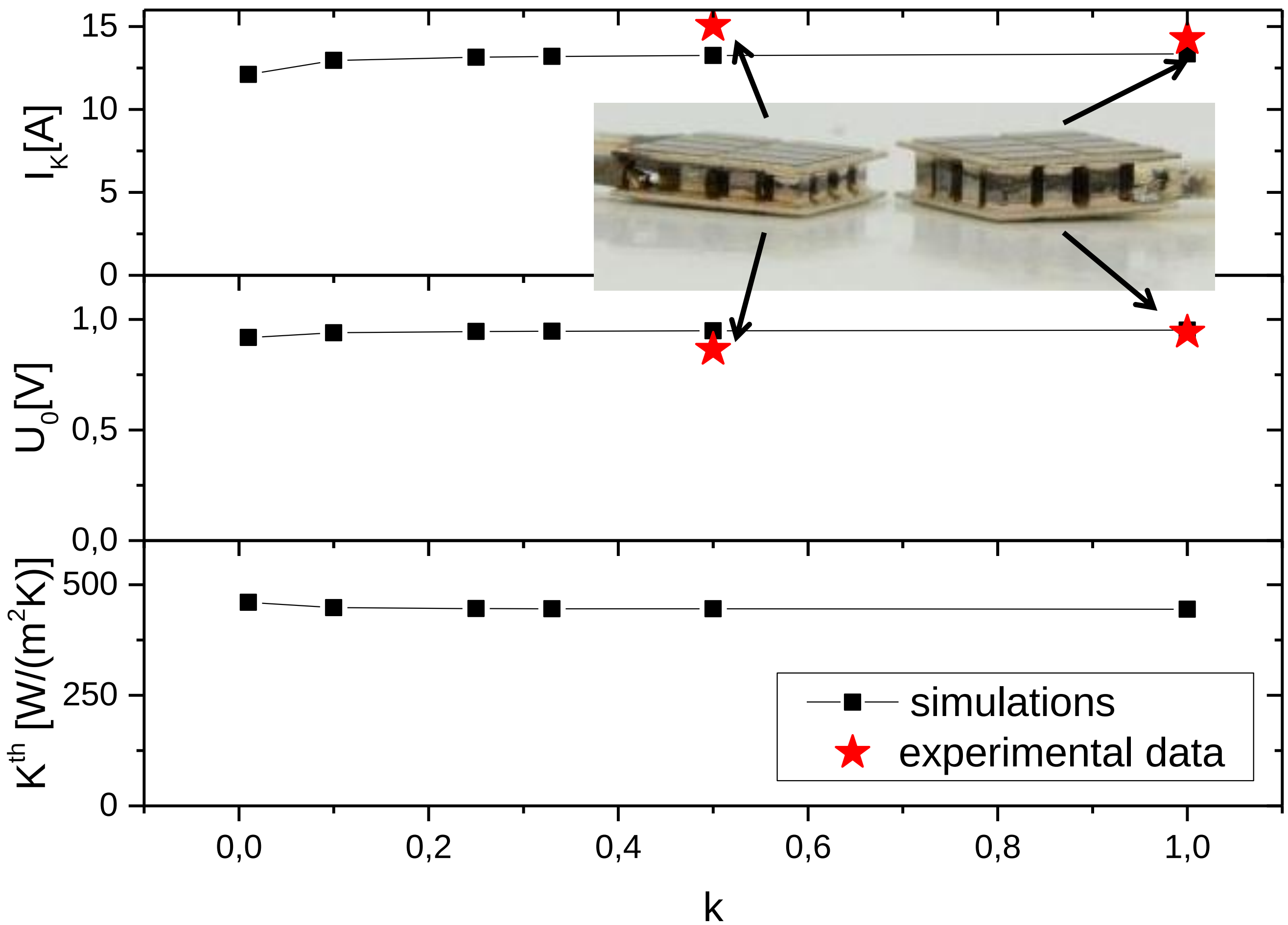
Optimization Module Geometry

Reduction of TE-Material



Optimization Module Geometry

Reduction of TE-Material



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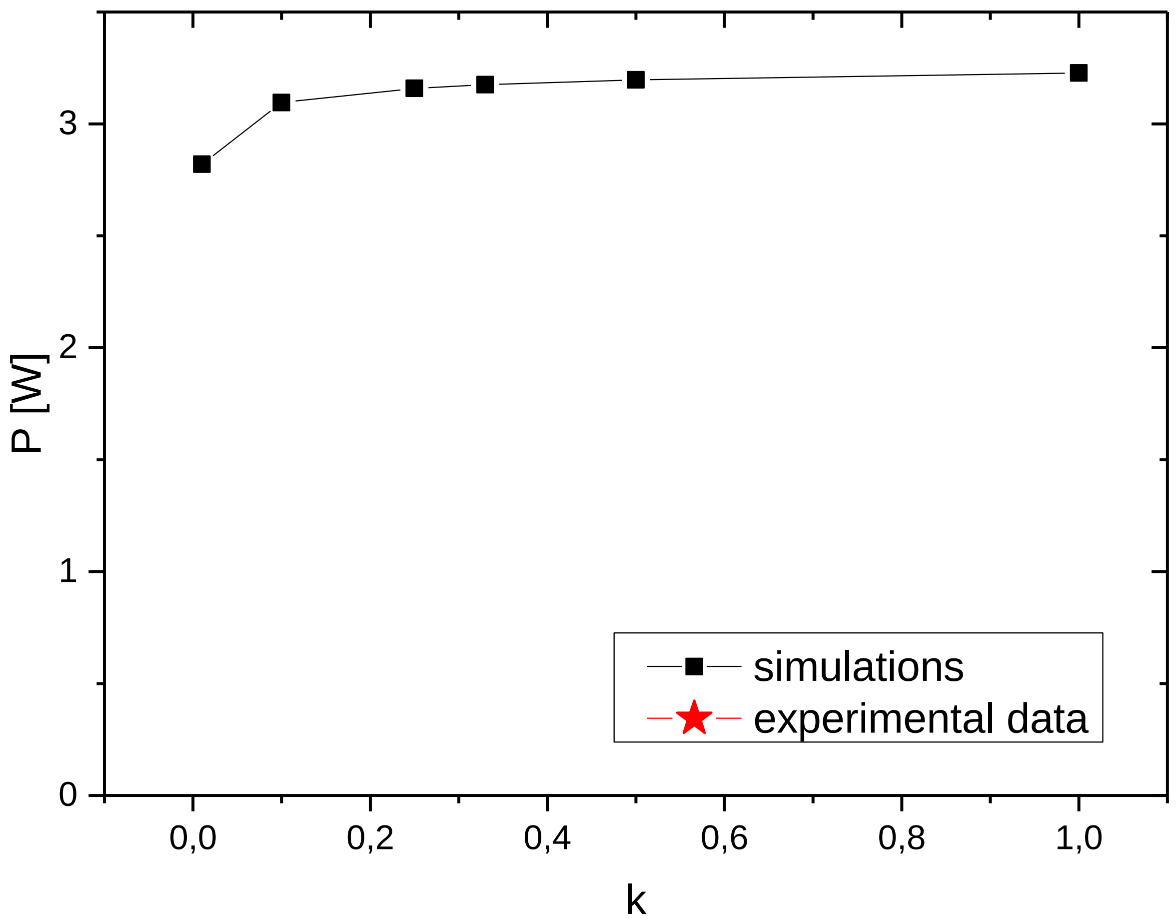
Optimization Module Geometry
Reduction of TE-Material



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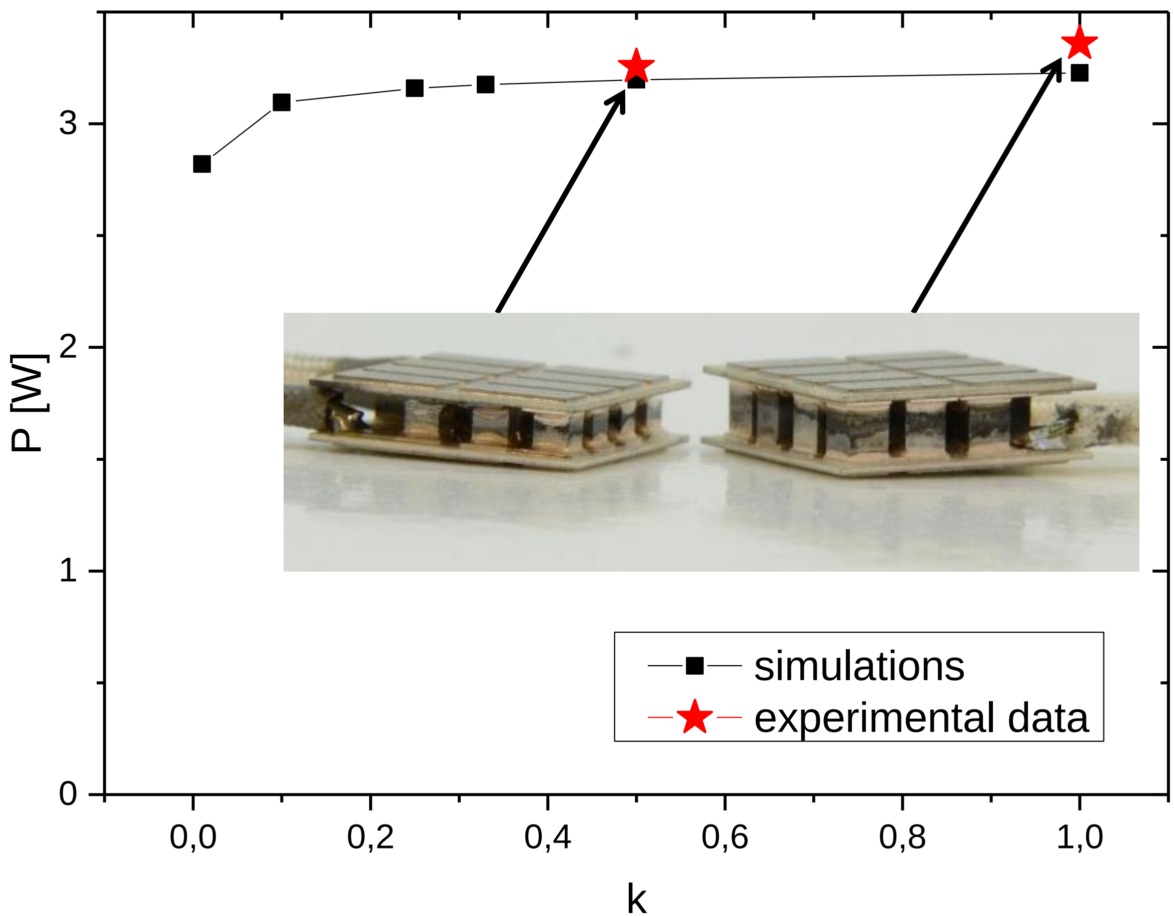
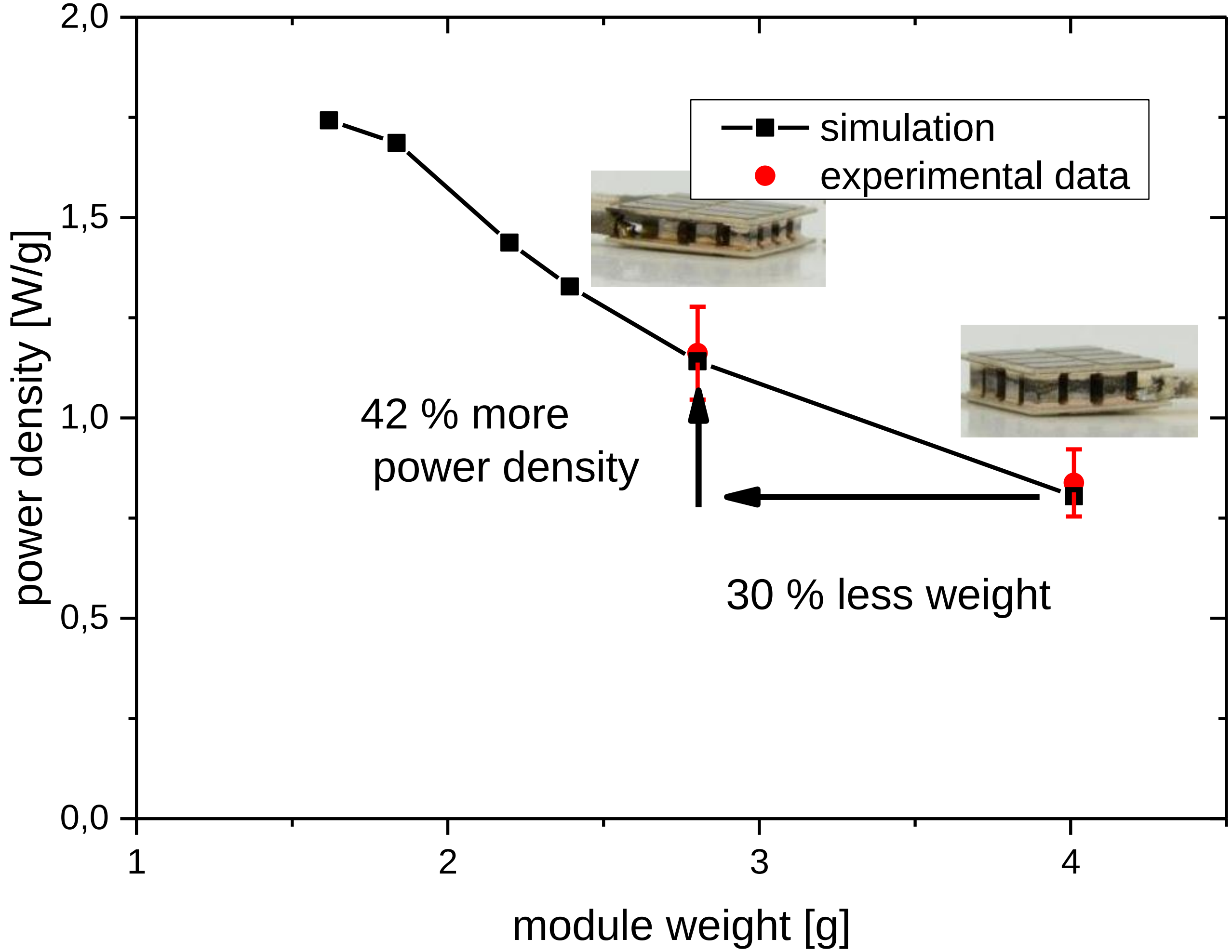
Optimization Module Geometry

Reduction of TE-Material



Optimization Module Geometry

Reduction of TE-Material



Thermoelectric Module

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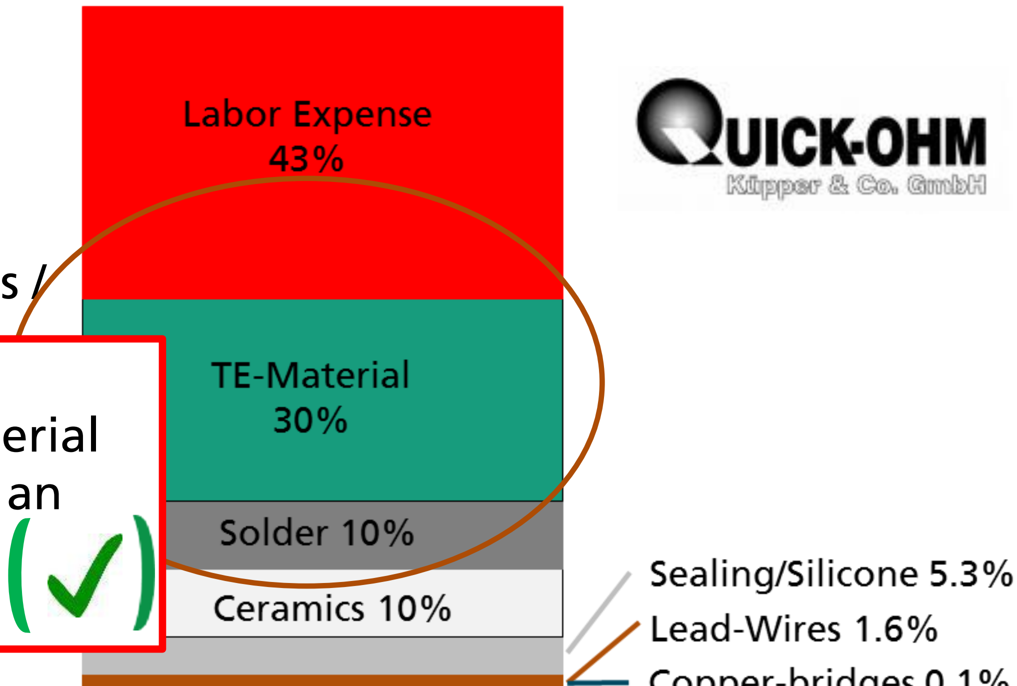

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Thermoelectric modules built with new high-temperature materials

Content

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Summary

Achievements:

- High-temperature **modules are available**!
- **Reproducible production** has been shown
- **Long-term stability** is very promising
- Module's power density is (within certain limits) adaptable:
  → significant **cost and weight reduction** by decrease material content possible!

Future work:

- **Further improvement** of module's performance
- **Upscaling and automation** of module production process for reduction of costs per module
- **Optimal thermal/mechanical** integration of modules in system

Danksagung Projektpartner / Fördergeber

Federal Ministry of Education and Research
PtJ Projektträger Jülich Forschungszentrum Jülich

Federal Ministry of Education and Research
PtJ Projektträger Jülich Forschungszentrum Jülich

Gefördert durch:
Bundesministerium für Wirtschaft und Energie
PtJ Projektträger Jülich Forschungszentrum Jülich
aufgrund eines Beschlusses des Deutschen Bundestages

TEG2020

TEKoCAR

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Good ideas for better solutions

Thank you for your attention!

➡ Visit us on the Internet at
www.ipm.fraunhofer.de/en

ISEL
INSTITUTO SUPERIOR DE ENGENHARIA DE LISBOA

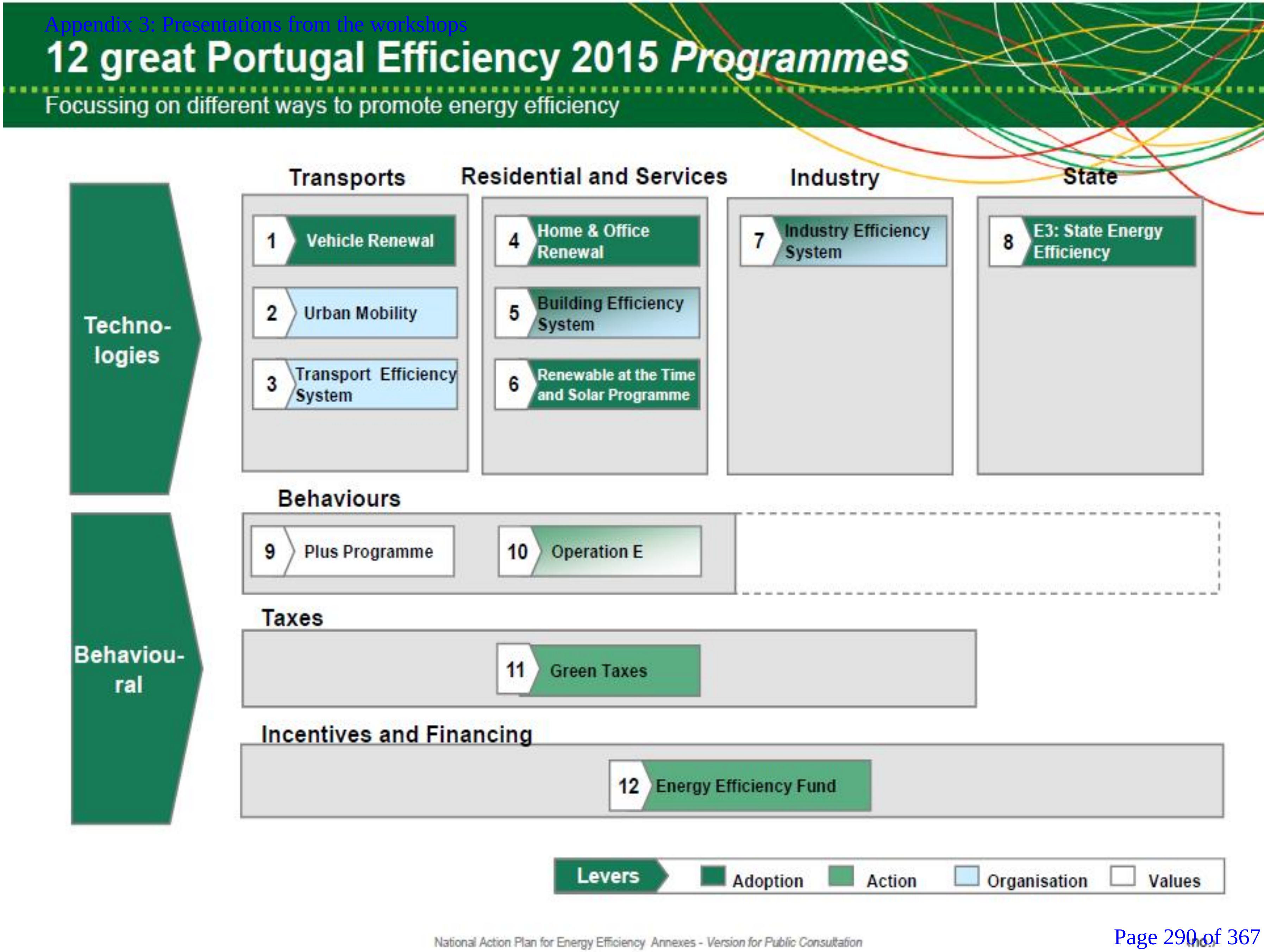
GNIP
Grupo Nacional para a Integração de Processos

Present status for excess heat development in Portugal

João Silva

iets
Industrial Energy-Related Technologies and Systems
An Implementing Agreement established under the auspices of the International Energy Agency

Annex XV final workshop – Copenhagen 24-25 Feb 2015



12 great Portugal Efficiency 2015 Programmes
Focussing on different ways to promote energy efficiency
Techno-logies
Behaviou-ral
Transports
Residential and Services
Industry
State
1 Vehicle Renewal
2 Urban Mobility
3 Transport Efficiency System
4 Home & Office Renewal
5 Building Efficiency System
6 Renewable at the Time and Solar Programme
7 Industry Efficiency System
8 E3: State Energy Efficiency
Behaviours
9 Plus Programme
10 Operation E
Taxes
11 Green Taxes
Incentives and Financing
12 Energy Efficiency Fund
Levers
Adoption
Action
Organisation
Values
National Action Plan for Energy Efficiency Annexes - Version for Public Consultation

Programme of Action for Portuguese Industry: Energy Efficiency System in Industry

- The political and technological measures/strategies for the increase of savings and the EE in Portuguese Industry were set according with EU recommendations and successful strategies implemented in other European countries.

"PNAEE": National Plan of Action for Energy Efficiency

↓

"Programme 7": Energy Efficiency System in Industry

↓ ↓

System for management of Intensive Energy Consumptions ("SGCIE")

Programme for the Competitive Energy in Industry

"Programme 7": Energy Efficiency System in Industry

Objectives	To promote the increase of energy efficiency via modification of manufacturing processes, introduction of new technologies and behaviours changing.

System for management of Intensive Energy Consumptions (SGCIE)

Compulsory energy audits, including a Plan of Rationalisation of Energy Consumption ("PREn") and execution reports and biannual processes

- Enterprises > 1000 toe/year: 6 year periods
- Enterprises > 500 toe/year: 8 year periods

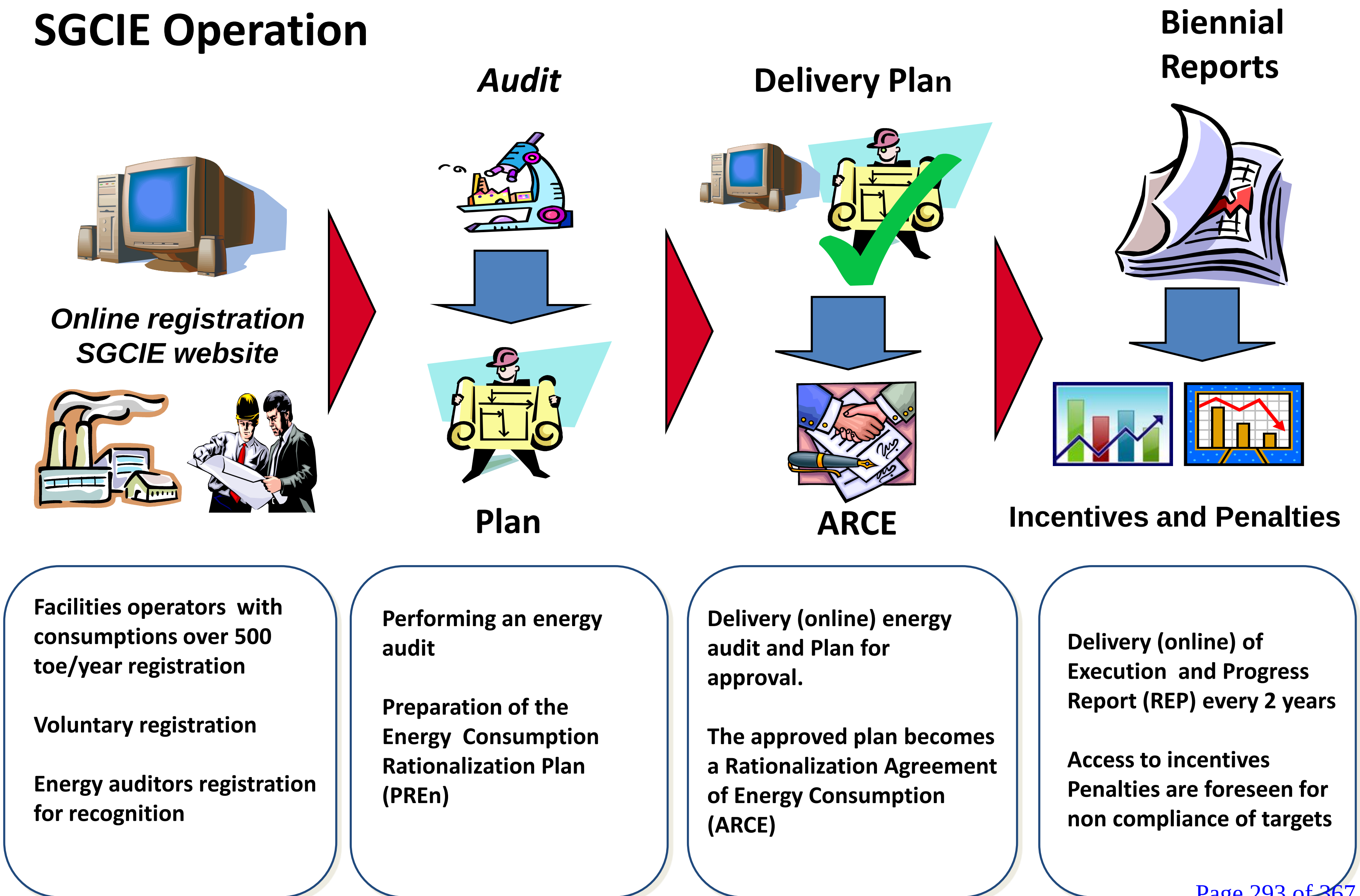
Enterprises with energy consumption lower than 500 toe/year can voluntarily subscribe "SGCIE"

Establishment of targets to be achieved, regarding energy and carbon intensity, according to "PREn" and compulsory implementation of measures with shorter payback

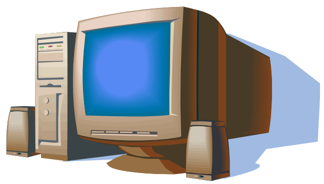
- Implementation of measures with payback < 5 years (enterprises + 1000 toe/year) and < 3 years (remaining enterprises)

In case of failure to comply the targets and measures, payment of a penalty of 50€ per toe, not avoided or refund of received supports and benefits of exemption of "ISP" tax

- Possibility of refund of 75% of the value from penalties if deviations are recovered in the following year


SGCIE Operation
Audit
Delivery Plan
Biennial Reports
Online registration SGCIE website
Plan
ARCE
Incentives and Penalties
Facilities operators with consumptions over 500 toe/year registration
Voluntary registration
Energy auditors registration for recognition
Performing an energy audit
Preparation of the Energy Consumption Rationalization Plan (PREn)
Delivery (online) energy audit and Plan for approval.
The approved plan becomes a Rationalization Agreement of Energy Consumption (ARCE)
Delivery (online) of Execution and Progress Report (REP) every 2 years
Access to incentives
Penalties are foreseen for non compliance of targets

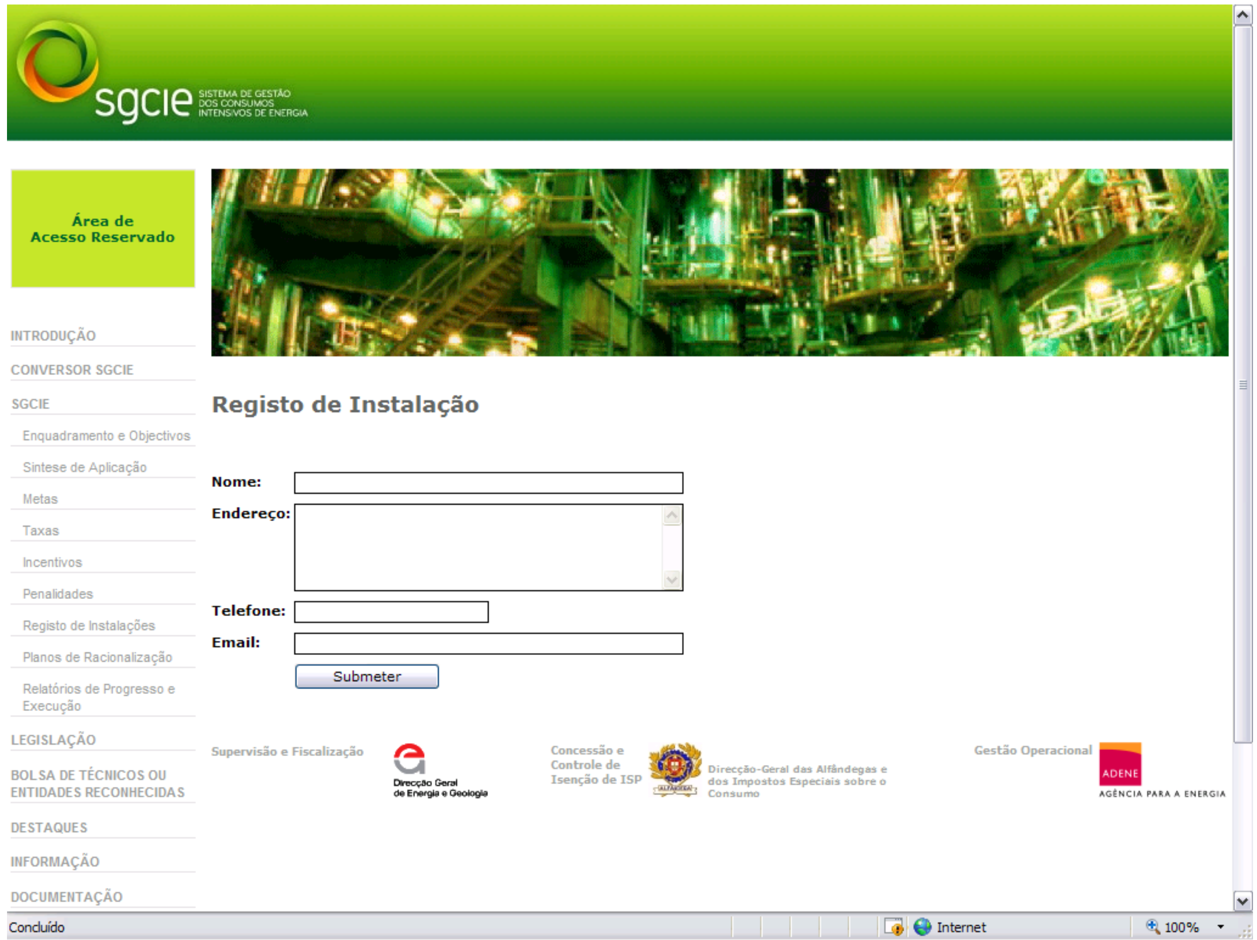
Facilities registration



Online registration

SGCIE Portal:

http://www.adene.pt/pt-pt/SubPortais/SGCIE/Paginas/Homepage.aspx



"Programme 7": Energy Efficiency System in Industry

Objectives

To promote the increase of energy efficiency via modification of manufacturing processes, introduction of new technologies and behaviours changing.

System for management of Intensive Energy Consumptions (SGCIE)

Compulsory energy audits, including a Plan of Rationalisation of Energy Consumption ("PREn") and execution reports and biannual processes

- Enterprises > 1000 toe/year: 6 year periods
- Enterprises > 500 toe/year: 8 year periods

Enterprises with energy consumption lower than 500 toe/year can voluntarily subscribe "SGCIE"

Establishment of targets to be achieved, regarding energy and carbon intensity, according to "PREn" and compulsory implementation of measures with shorter payback

- Implementation of measures with payback < 5 years (enterprises + 1000 toe/year) and < 3 years (remaining enterprises)

In case of failure to comply the targets and measures, payment of a penalty of 50€ per toe, not avoided or refund of received supports and benefits of exemption of "ISP" tax

- Possibility of refund of 75% of the value from penalties if deviations are recovered in the following year

Programme for the Competitive Energy in Industry

Dinamisation of Transversal Saving measures and specific measures in the 12 industrial sub-sectors

- **Transversal:** Optimisation of electric motors, efficient cool and heat production, efficient illumination and process efficiency
- **Specific** (e.g. Optimisation of ceramic kilns, gasification and drying of pulp and paper, new operations for separation and new catalysts in chemical sector, ...)
- **Training courses and awareness actions for energy managers**
- **Monitoring of measures included in the Agreements for Rationalisation of Energy Consumption**

Support to operators with Agreements for Rationalisation of Energy Consumption

- Exemption of "ISP" tax
- Partial Refund of energy audits costs
- Refund of 25% of the investment in equipment and managing and monitoring systems for energy consumption

Promotion of setup and conversion of cogeneration systems

- Revision of tariffs and licensing regime with incentive for conversion to natural gas and biomass.

Support measures to efficiency in "QREN"

- Open call for submission in energy efficiency inserted in the Incentive System for Qualification and Internationalisation to Small-Medium Enterprises ("PME's")
- Financing up to 35% of expenses with energy efficiency in applications for the Incentive System for Innovation

Improvement measures are classed as general industrial and sector-specific

Reduction

General industrial measures — 6.5%

- Electric motors
- Heat and Cold generation
- Lighting
- Industrial process efficiency / Other

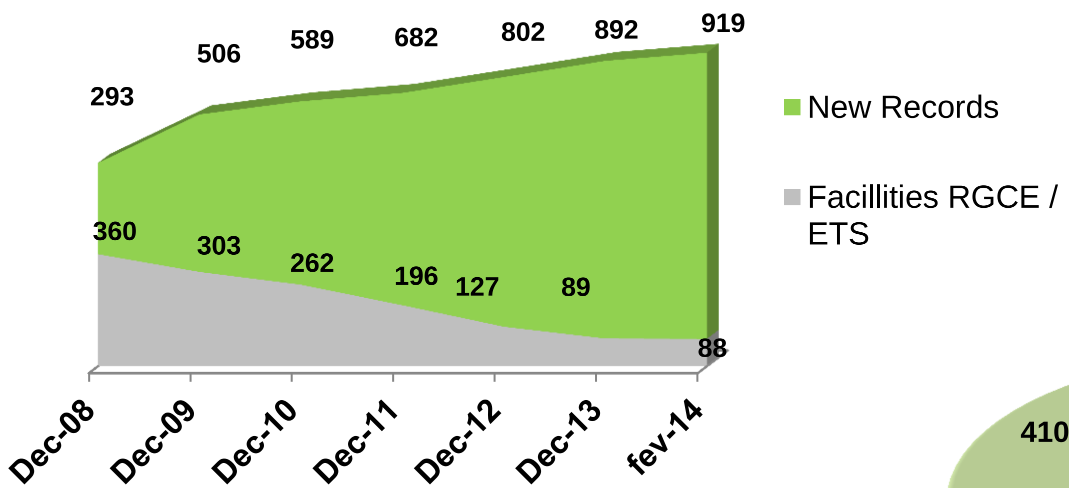
General sector specific (12 sectors[1]) — 0.8%

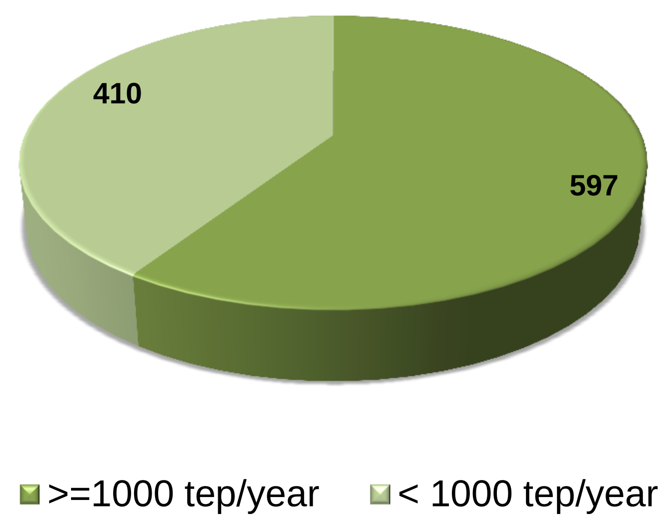
- Food, Beverages and Tobacco
- Textile
- Paper
- Chemicals, Plastics and Rubber
- Ceramics
- Metalworking and Foundry
- Glass
- Cement
- Clothing, Footwear and Leather
- Iron and steel works
- Wood and wood Articles
- Metal and electrical machinery

Summary table of the total potential of energy saving expected in "PNAEE"-Industry Group in a 5 years horizon

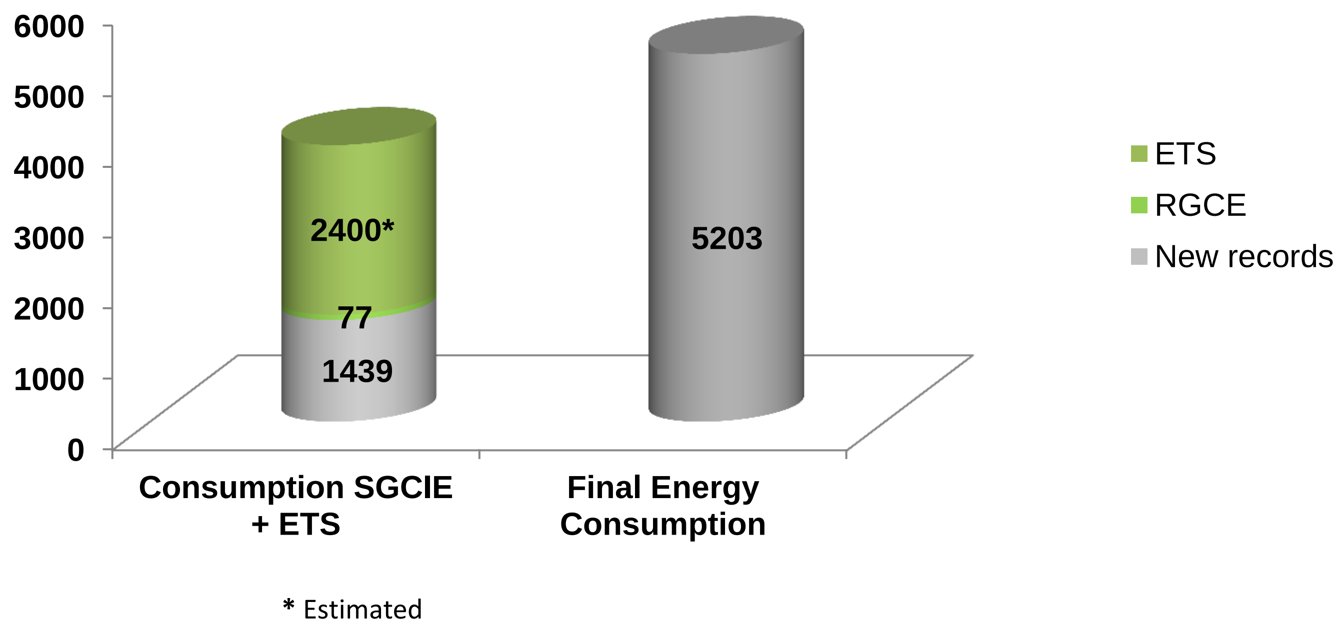
Potential of Energy Saving (values of 2005)	***toe / year***	***%***
Total of Transversal Measures	**348 583**	**6.45**
Total of Sector Measures	**44 256**	**0.82**
Global Total (Transversal + Sector)	**392 839**	**7.27**

919 new facilities of a total of 1007 records were registered in SGCIE (including Plans RGCE still ongoing).

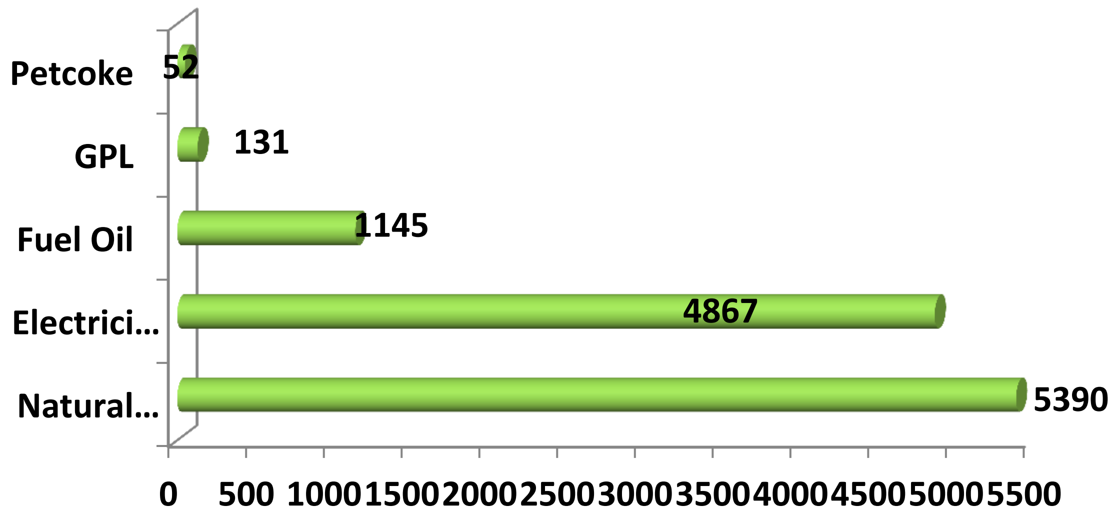




Records in SGCIE equivalent to 1.516 ktoe and represent 29% of final energy consumption in the sectors of Agriculture and Fisheries, Mining, Manufacturing and Construction and Public Works

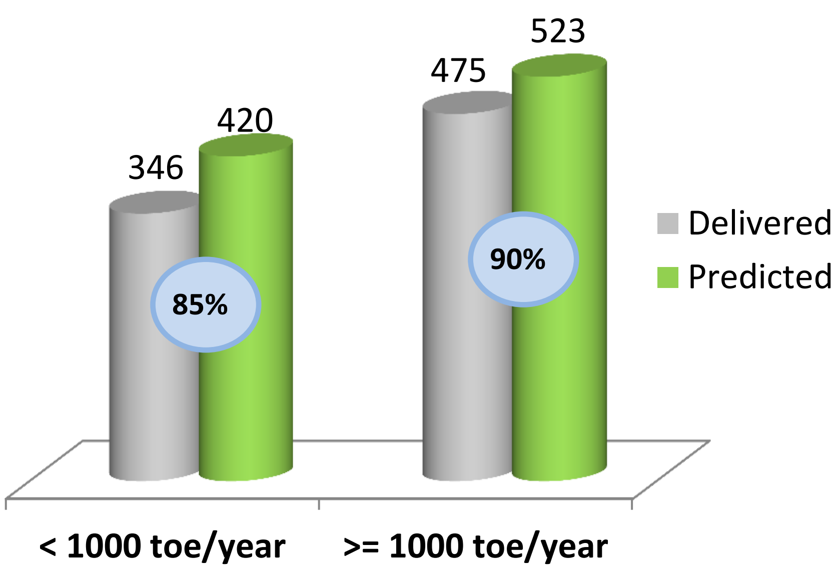


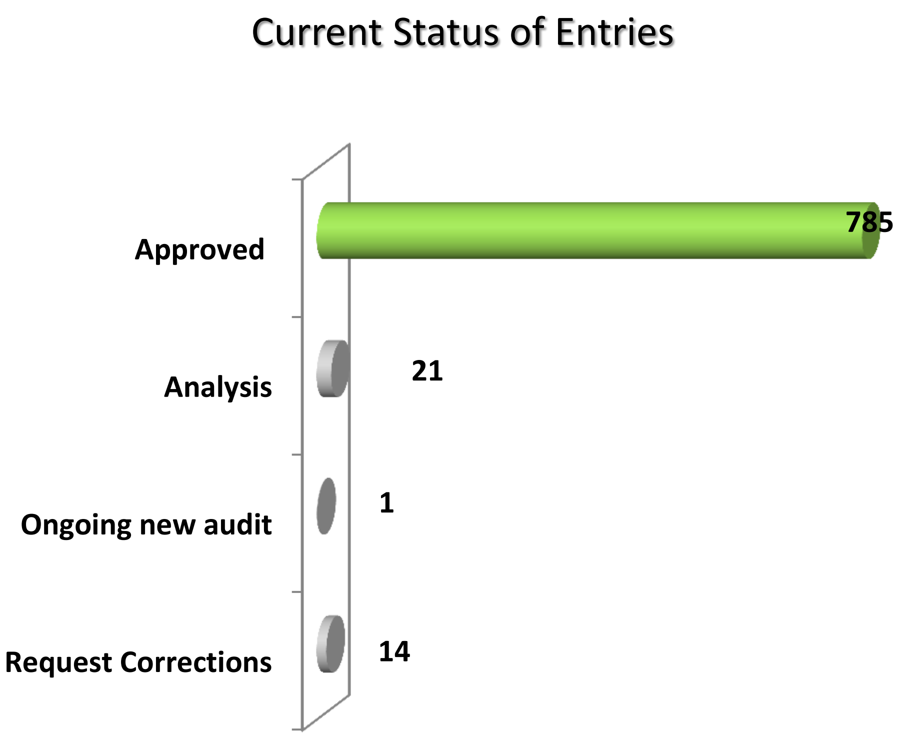
Excise duties exemption (ISP) of Rationalization Plans approved (amounting about 11.600 kEuro/year) with inclusion of natural gas and electricity since 2013.



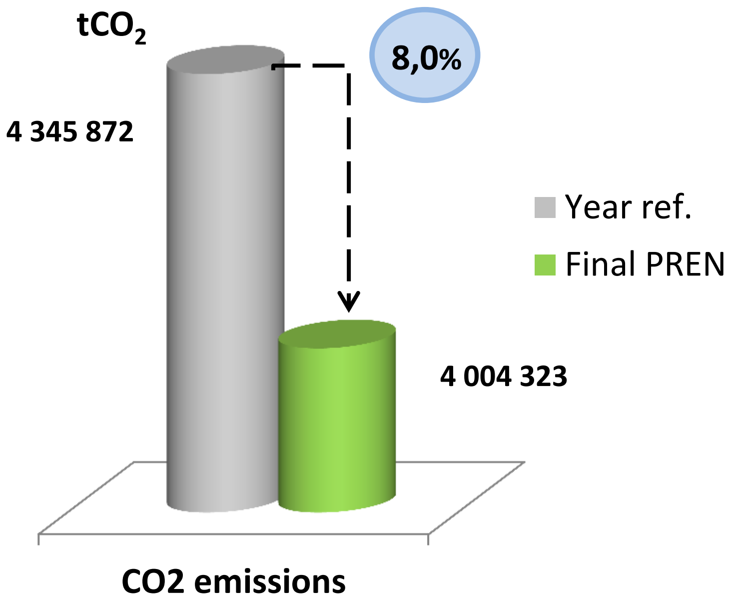
	Fuel Oil	LPG	Petcoke	Natural Gas	Electricity
Number of Facilities	109	278	4	398	780
Average by facilitie (kEuro/year)	10,5	0,5	13,0	13,6	6,24

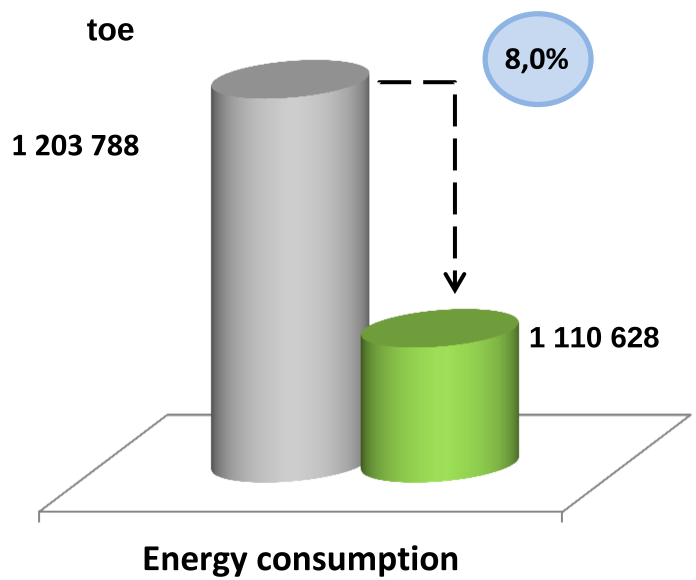
Records of 821 Rationalization Plans of Energy Consumption (943 foreseen up to Dec. 2014) - Global Execution Rate of 87%.



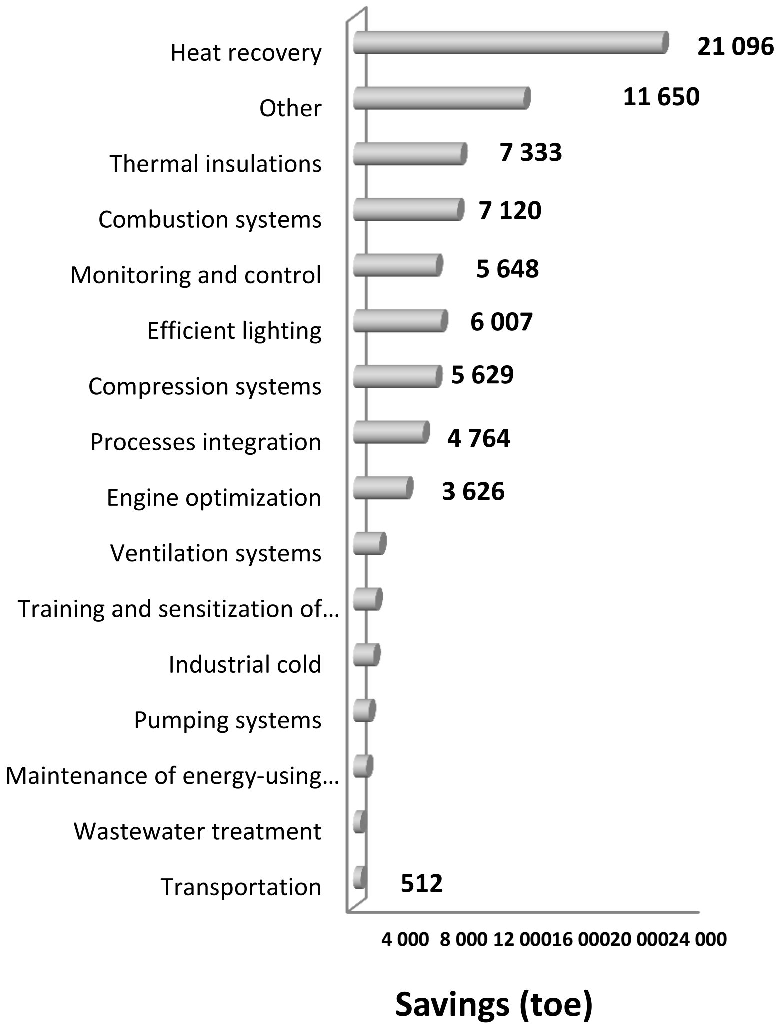


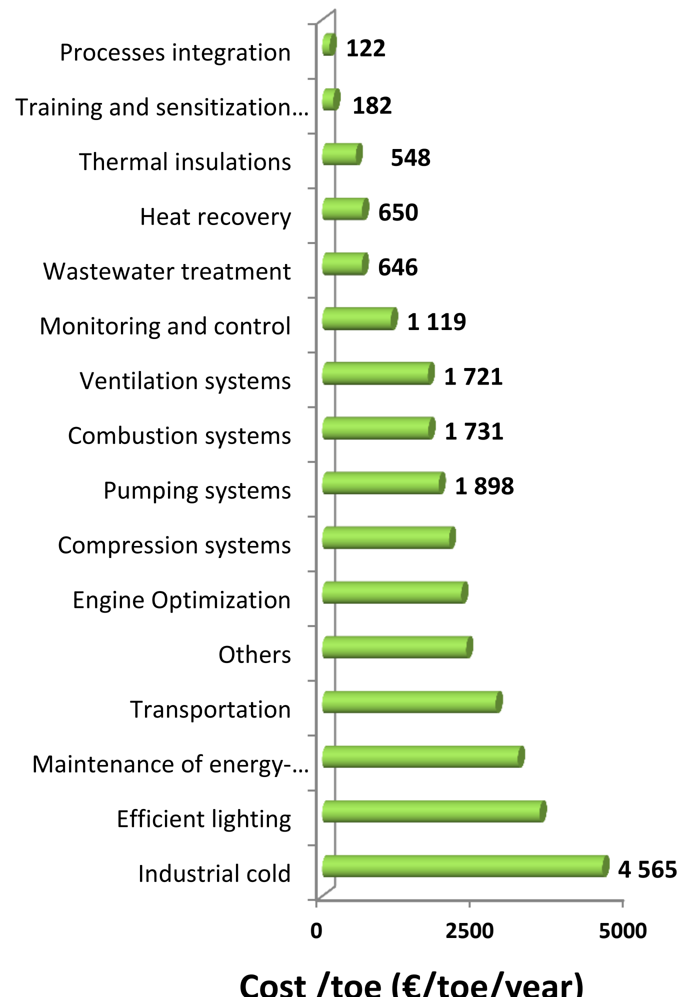
The 785 Rationalization Plans approved will reduce energy consumption by 93.160 toe and emissions by 341.550 tCO_2.



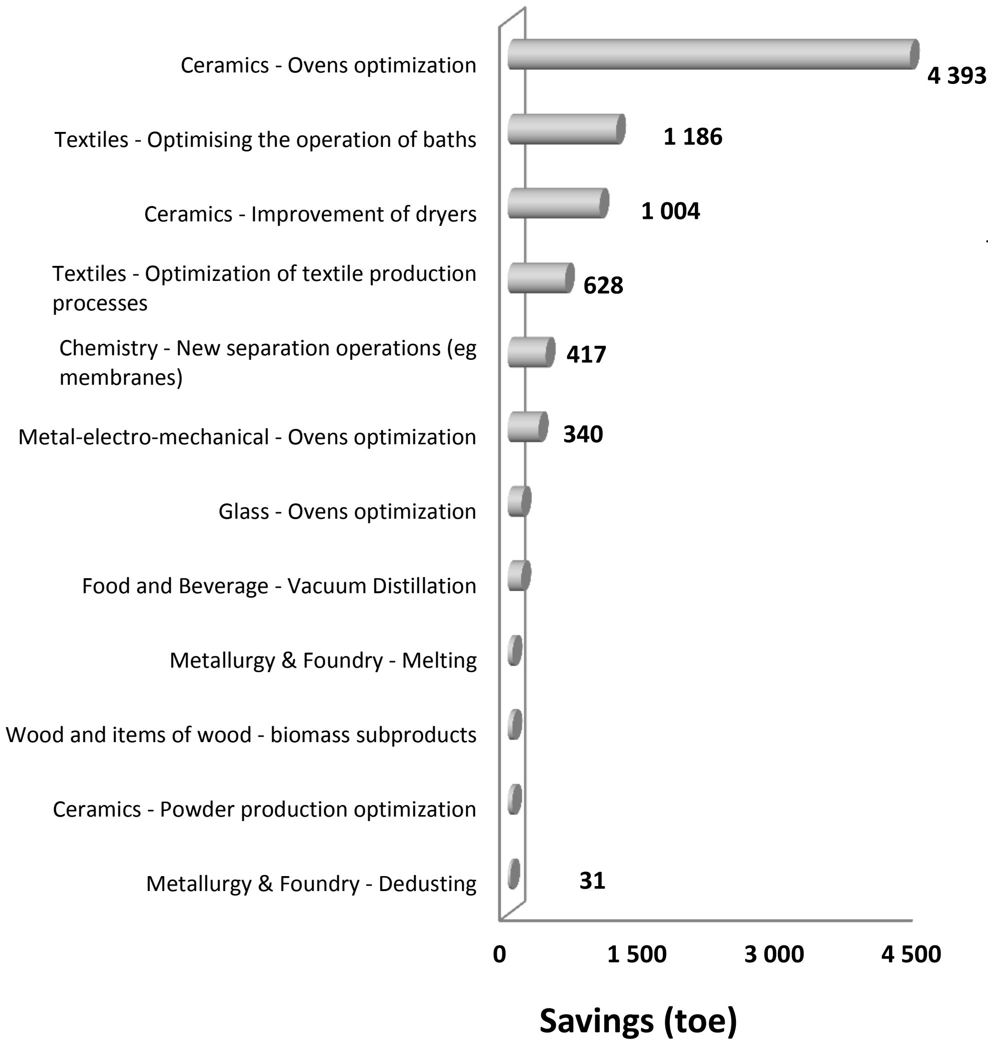


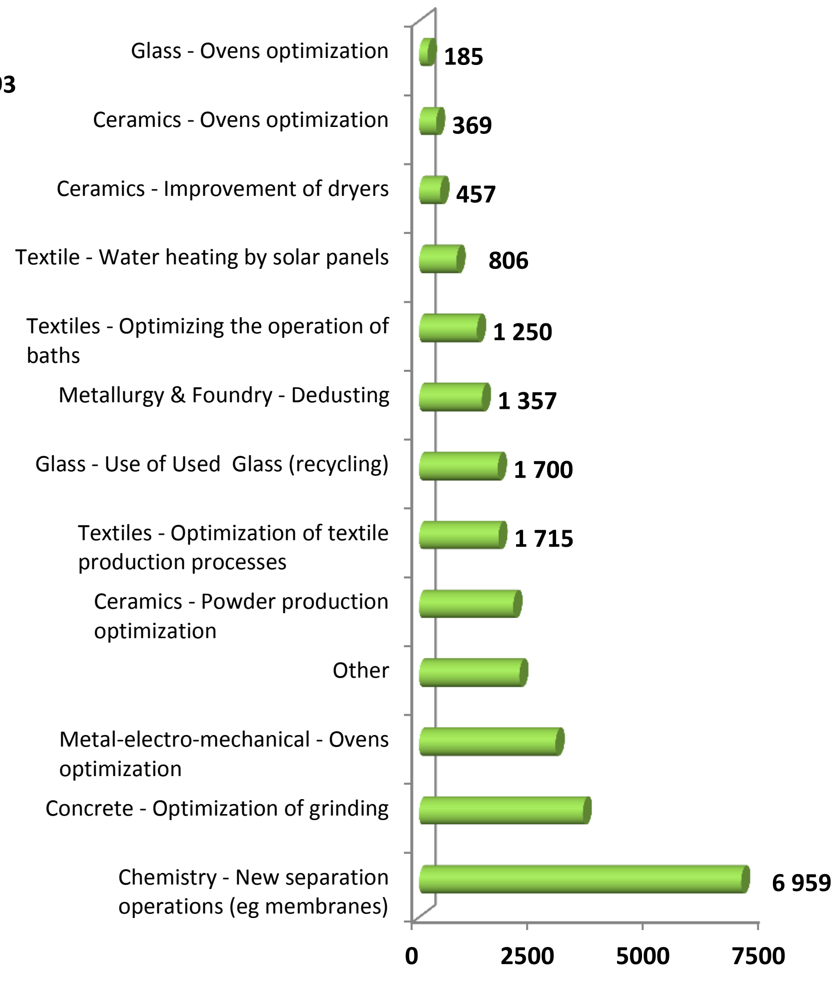
Potential energy savings by type of measure in approved PREn (Transversal measures)



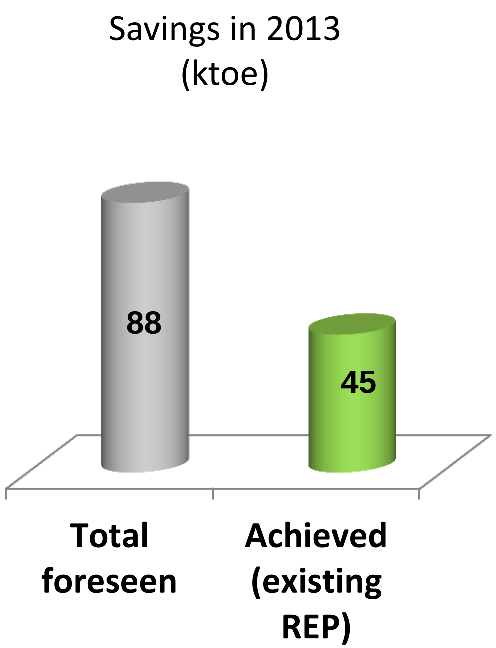


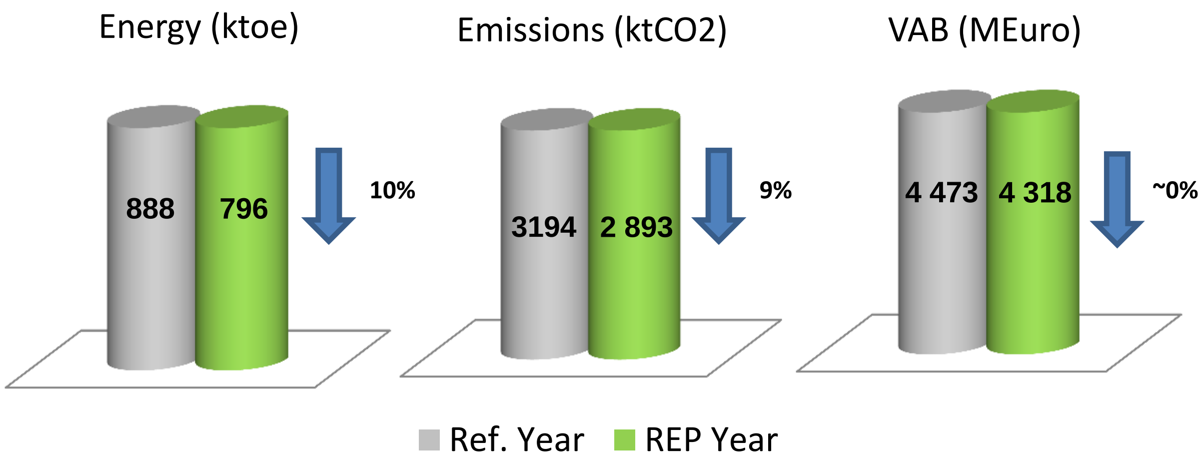
Potential energy savings by type of measure in approved PREn (Sectorial measures)

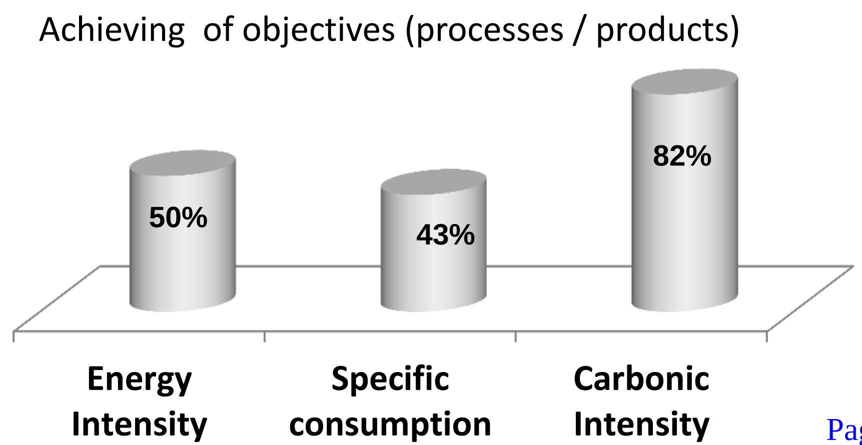




Records and evolution of the main variables and indicators of Execution and Progress Reports (749 records - 550 for 2009 and 2011 and 199 for 2010 and 2012).







Conclusions

- SGCIE implementation contributes to achieve better energy efficiency.
- After the first's years the results are almost according with the previsions.
- In the industrial sector, some projects of heat integration are underway contributing to the reduction of excess heat.
- The internal use of excess heat is the principal way chosen.
- In some chemical clusters we find some common utilities resources (heat and power).

ISEL
INSTITUTO SUPERIOR DE ENGENHARIA DE LISBOA

GNIP
Grupo Nacional para a Integração de Processos

INSTITUTO SUPERIOR TÉCNICO

Energy Optimization in a Biodiesel Production Process

José Palmeira (ISEL)
João Silva (ISEL)
Henrique Matos (IST)

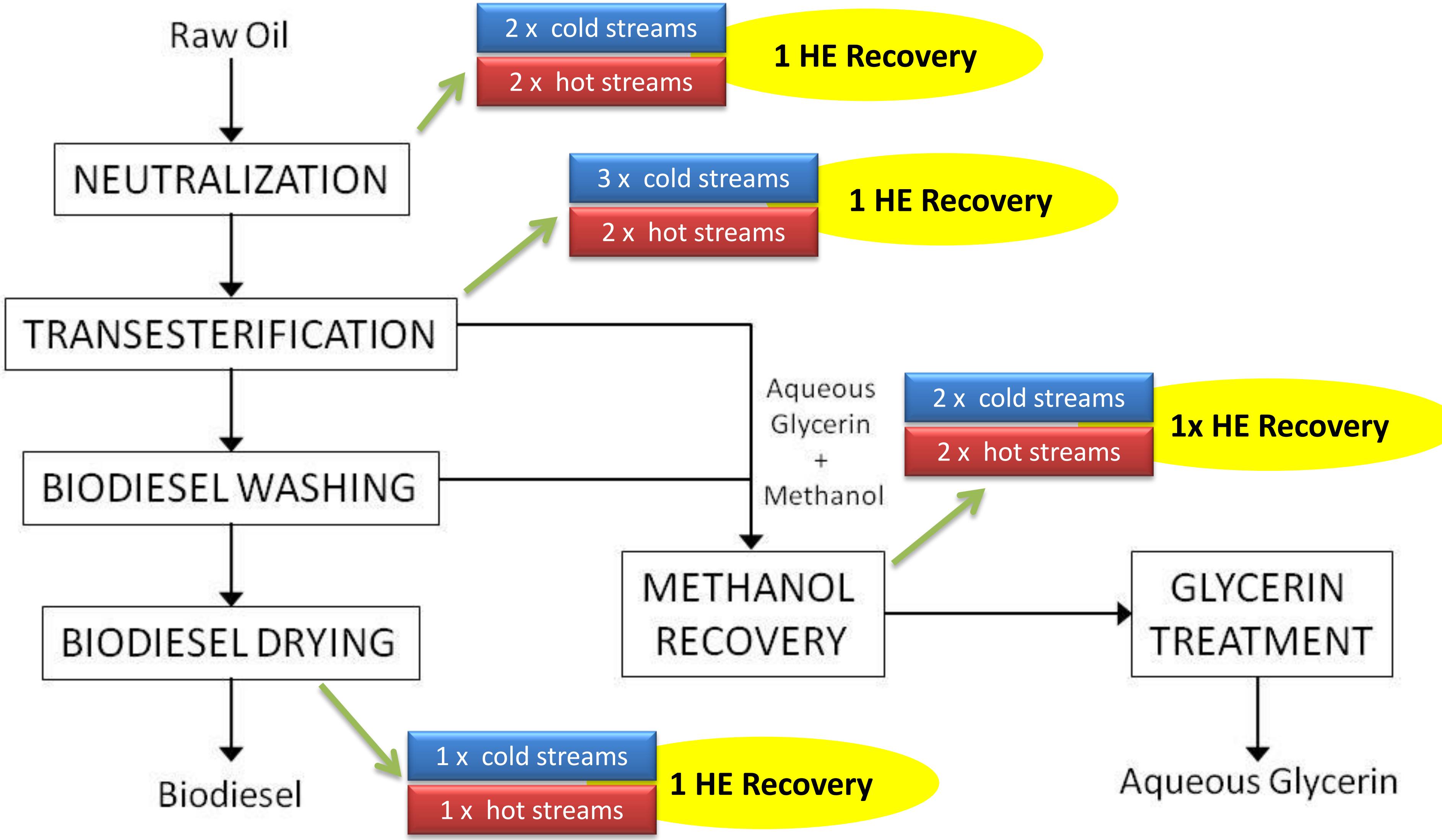
Annex XV final workshop – Copenhagen 24-25 Feb 2015

iets
Industrial Energy-Related Technologies and Systems
An Implementing Agreement established under the auspices of the International Energy Agency

Case Study Description


- Main product: Biodiesel
- Subproduct: Aqueous glycerin
- Raw materials: vegetable oils (palm, soybean, rapeseed)
- Utilities: steam at 2.5 bar, 134 °C
  cold water

Case Study Description

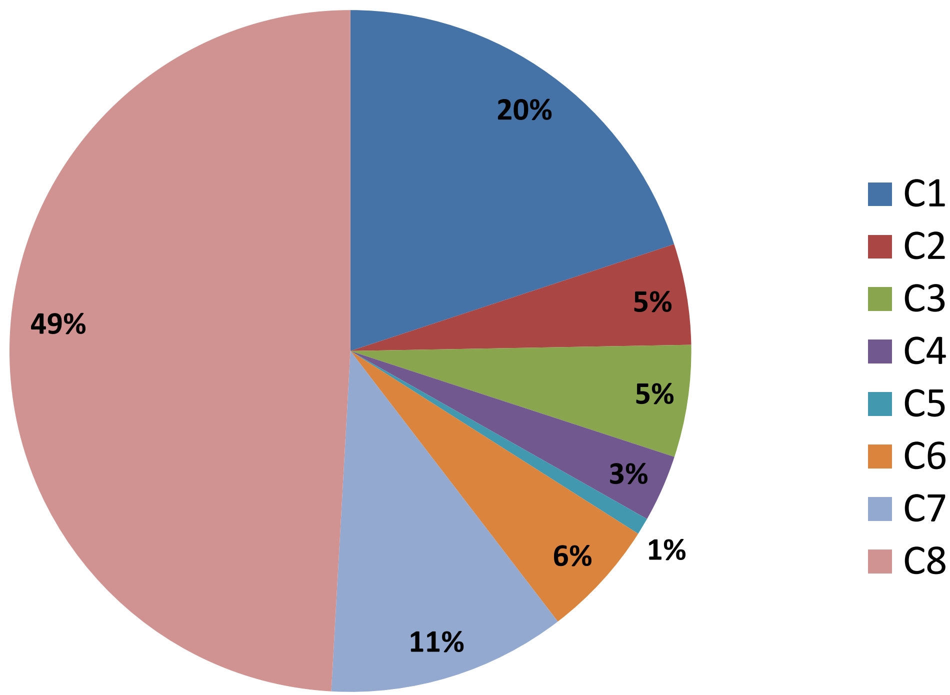


Case Study Description

Cold Streams Description

Stream Description	C1 Raw oil	C2 Process Water	C3 Neutral Oil	C4 Raw FAME	C5 Glycerine phase	C6 Column Feed	C7 Washed FAME	C8 Reboiler Feed
T in (ºC)	29	26	45	36	35	48	50	104
T out (ºC)	90	88	62	45	62	75	85	104
Duty (kW)	446	107	119	71	18	125	253	1099
Total duty (kW)	2239							

Energy distribution of cold streams

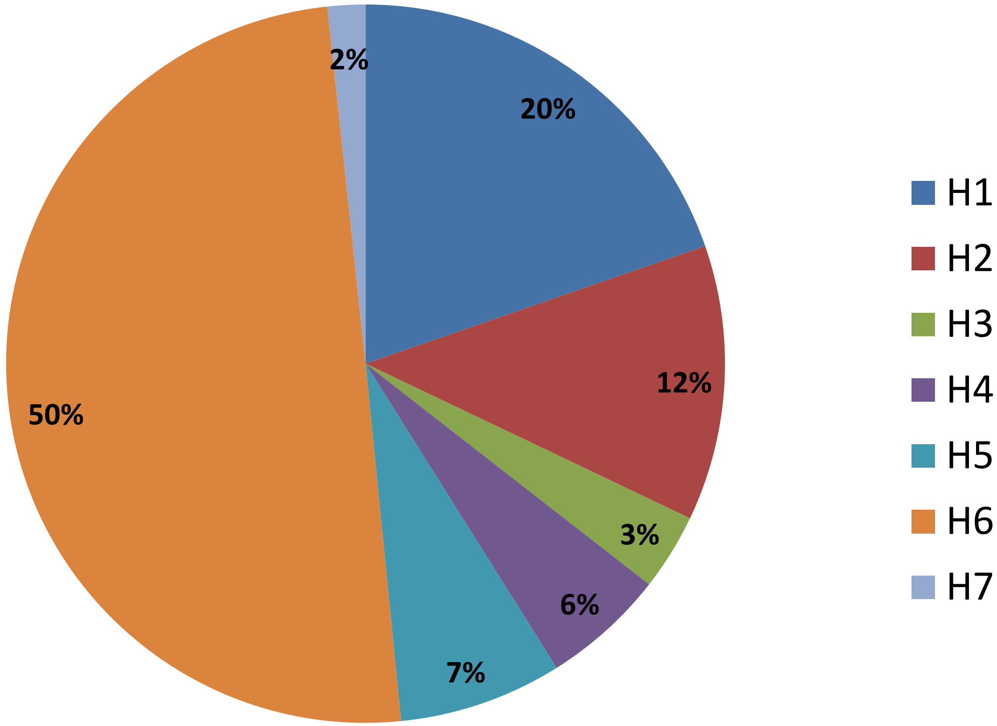


Case Study Description

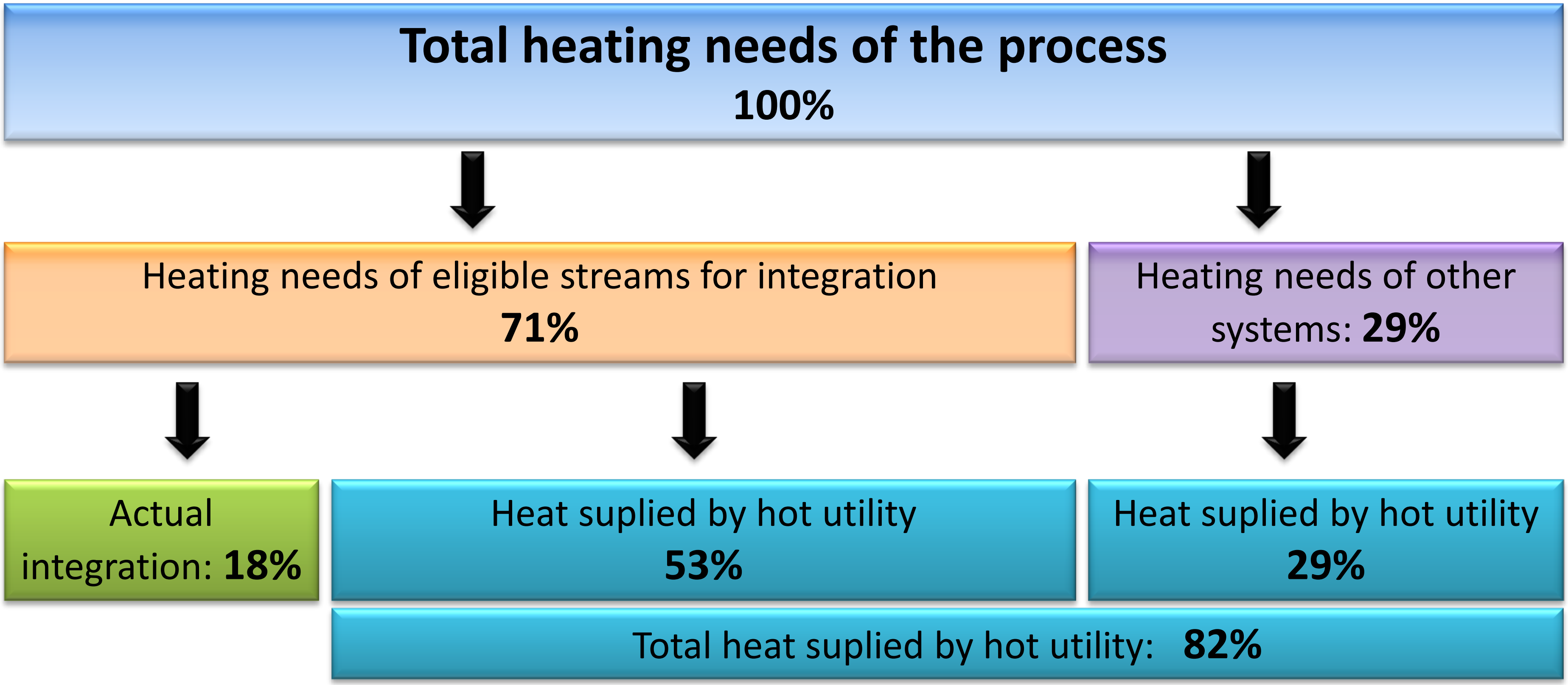
Hot Streams Description

Stream Description	H1 Dried FAME	H2 Neutral Oil	H3 Reactor Effluent 1	H4 Reactor Effluent 1	H5 Aqueous Glycerine	H6 Methanol distillate	H7 Vacuum steam
T in (ºC)	90	80	60	49	104	65	134
T out (ºC)	35	45	52	36	66	65	27
Duty (kW)	394	248	69	111	147	998	34
Total duty (kW)				2001			

Energy distribution of hot streams



Case Study Description



Pinch Analysis – second approach

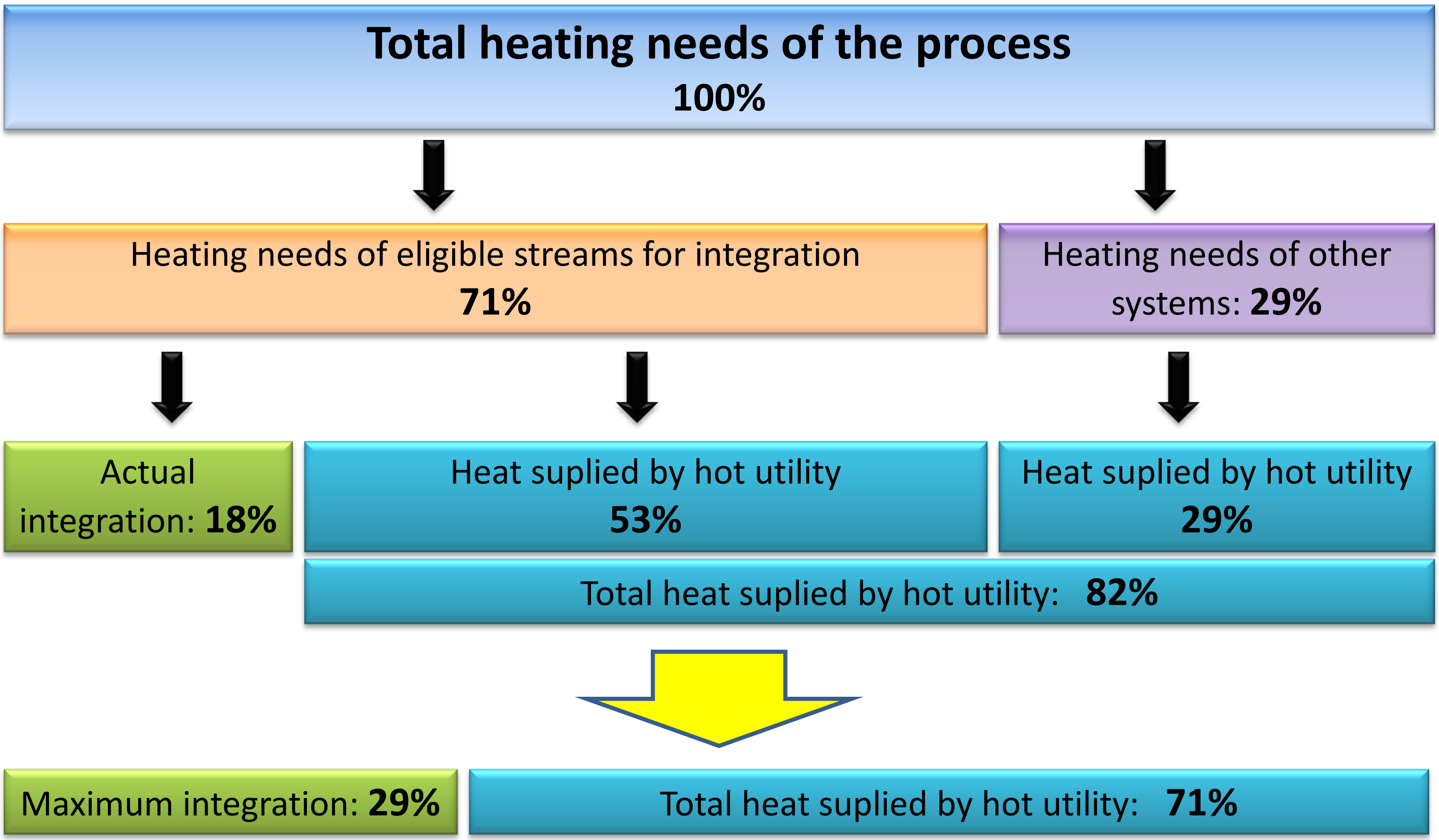
HOT Streams Description

Stream	H1	H2	H3	H4	H5	H6	H7
Description	Dried FAME	Neutral Oil	Reactor Effluent 1	Reactor Effluent 2	Aqueous Glycerine	Methanol distillate	Vacuum steam
T in (ºC)	90	80	60	49	104	65	134
T out (ºC)	35	45	52	36	66	65	27
Duty (kW)	394	248	69	111	147	998	34
Total duty (kW)			**969**	2073			

COLD Streams Description

Stream	C1	C2	C3	C4	C5	C6	C7	C8
Description	Raw oil	Process Water	Neutral Oil	Raw FAME	Glycerine phase	Column Feed	Washed FAME	Reboiler Feed
T in (ºC)	29	26	45	36	35	48	50	104
T out (ºC)	90	88	62	45	62	75	85	104
Duty (kW)	446	107	119	71	18	125	253	1099
Total duty (kW)			**1140**	2239				

Pinch Analysis – first approach



Restrictions to a grassroots' design

- ✓ Actual Heat Exchangers for energy recovery violates PINCH rule of heat exchange prohibition across pinch temperature

↓

HEN based on Pinch Analysis must not account the actual Heat Exchangers

↓

This would mean a full revamp of the actual Heat Exchanger Network

- ✓ Constrains:
  - Layout issues
  - High investment costs
  - Necessary stoppage time

Methodology used for the proposed HEN

✓ Keep existing 4 Heat Exchangers used for heat recovery

↓

Search for additional heat recover opportunities

↓

Generate several Heat Exchanger Networks

✓ Criteria for choice:

- Recovered Energy
- Additional Pressure loss in critical streams
- Distance between heat exchanger streams
- Available area for new HE

Proposed HEN

Set of final HEN's for final analysis

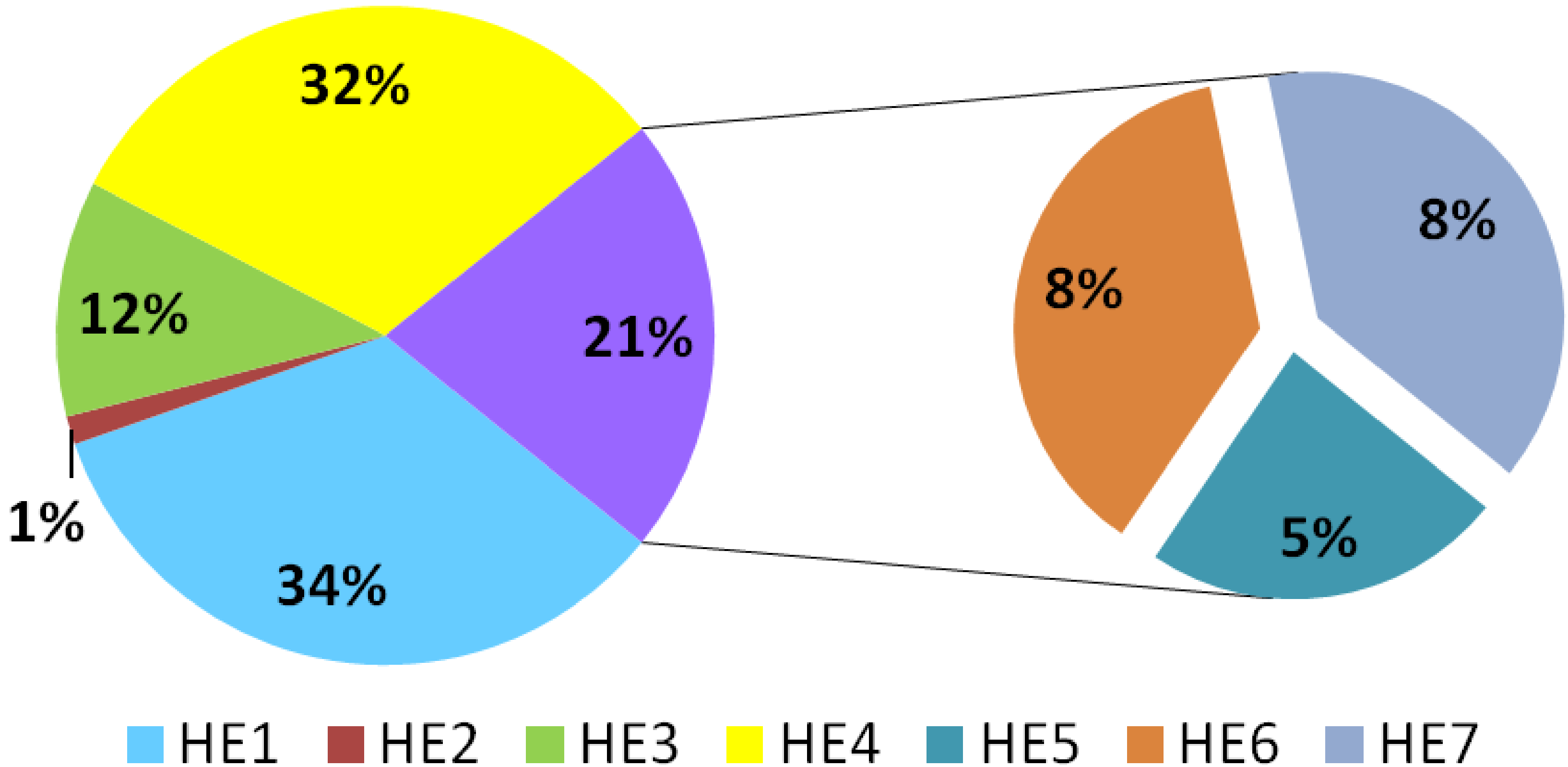
	HEN1	HEN2	HEN3	HEN4	HEN5	HEN6	Actual HEN
HE1	√	√	√	√	√	√	√
HE2	√	√	√	X	x	√	√
HE3	√	√	O	√	O	O	√
HE4	√	√	√	√	√	√	√
HE5	C2/H1	C4/H1	C2/H1	C2/H1	C2/H1	C4/H1	X
HE6	C4/H3	C2/H3	C4/H3	C4/H3	C4/H3	C2H3	X
HE7	C3/H5	C3/H5	X	C3/H5	X	X	X
Total duty (kW)	734	747	712	734	712	725	575

Heat Exchange Duties for HEN1

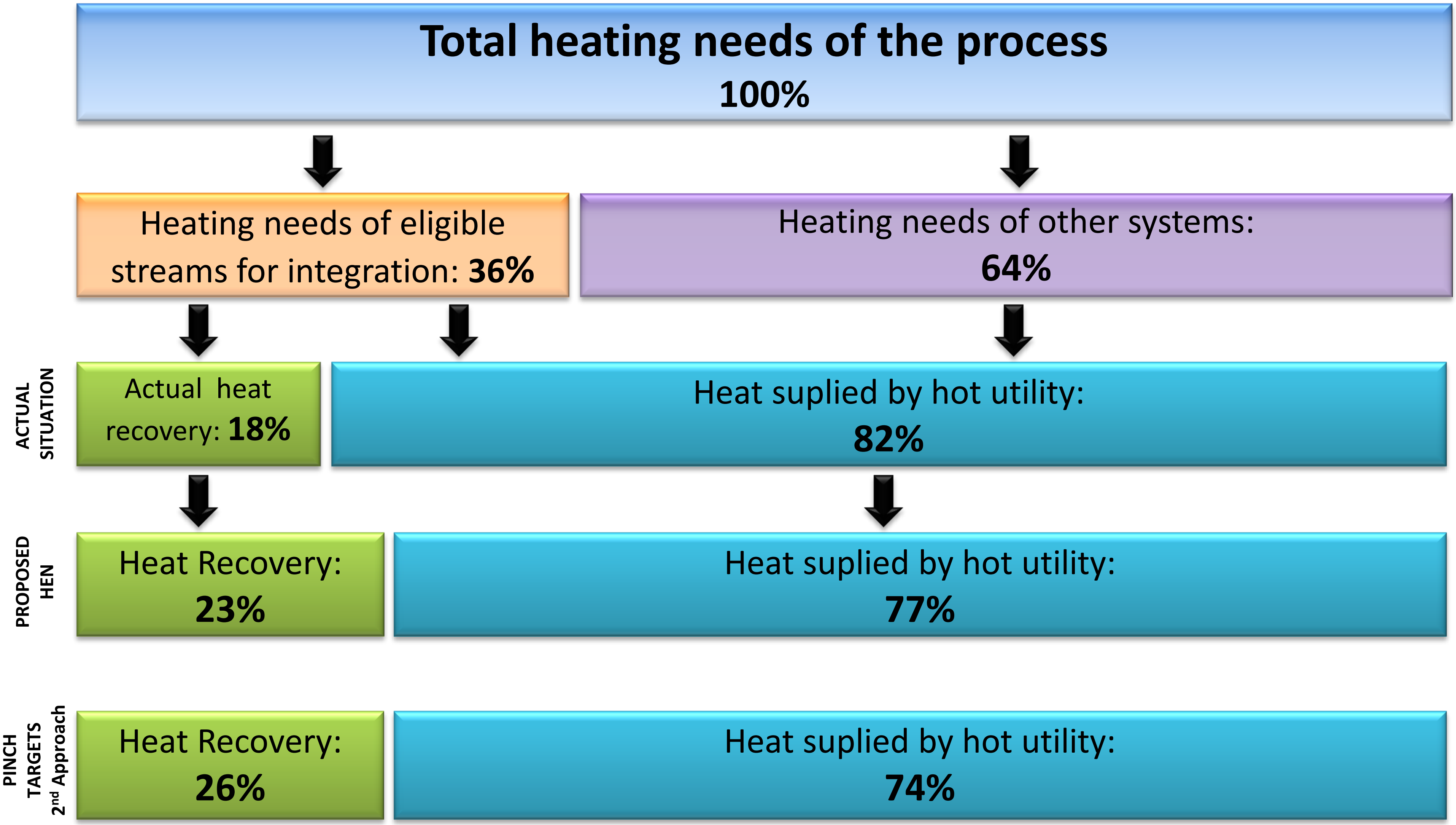
Heat Exchanger	HE5		HE6		HE7	
Streams	C2	H1	C4	H3	C3	H5
T in (ºC)	26	58	36	59	45	82
T out (ºC)	48	52	44	52	54	66
Duty (kW)	38		59		62	
Total duty (kW)	159					

Proposed HEN

Recovered energy distribution by Heat Exchangers



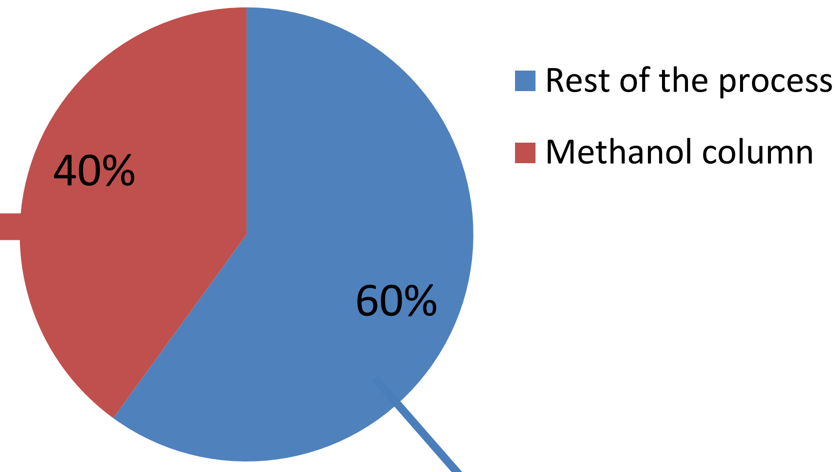
Proposed HEN

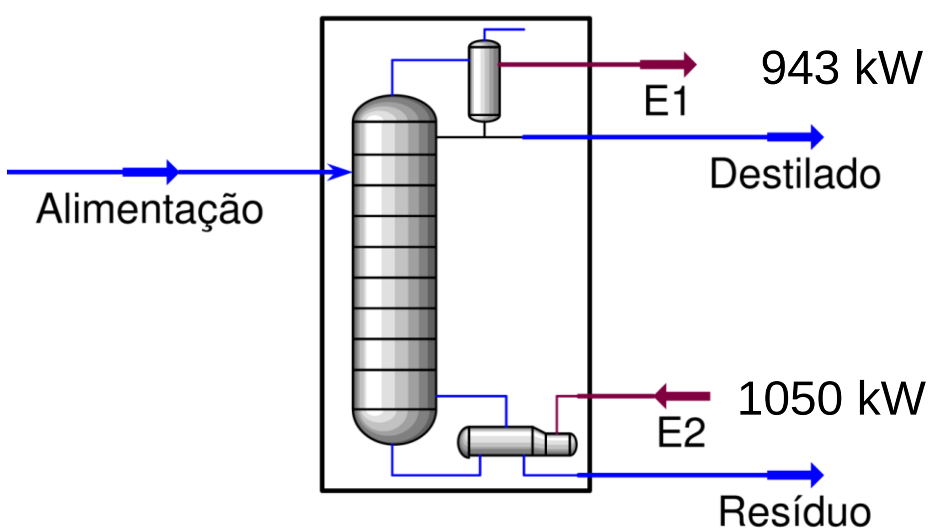


Some Conclusions

- The energy optimization in a running process plant is a multi-step task.
- Pinch analysis was useful to establish maximum expected income from a HEN retrofit.
- The proposed HEN will increase the actual recovered energy from 18% to 23% of total heating needs.
- The expected economic benefit is estimated in 35 k€/year.
- About 1MW of available heat at about 65°C was left without any use. Novel heat recovery solutions should be explored.

Heat consumption:





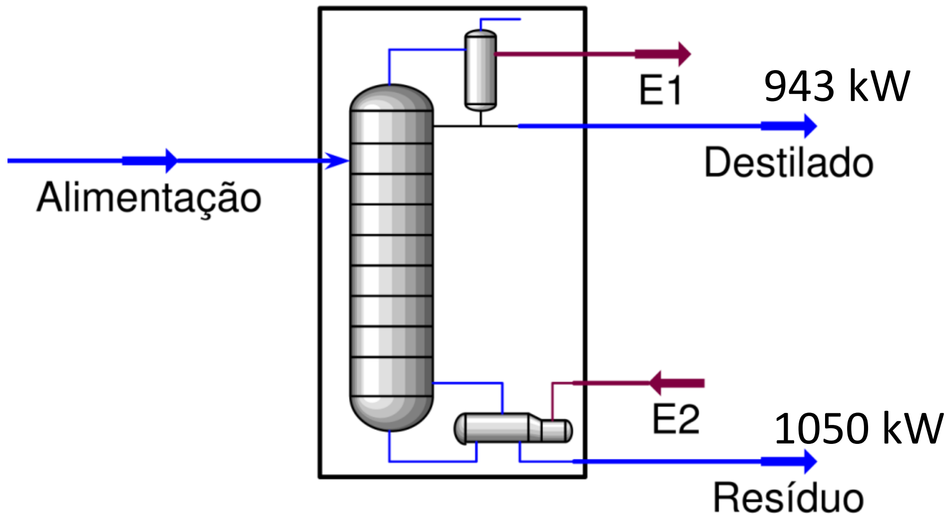
Recommendations:

- Thermal isolation of several plate heat exchangers. Heat loss estimation of 55kW !!!

Data from the distillation column

Reflux ratio= 2.1

4821 kg/h
75 °C
21% methanol
28% glycerol
51% water



1000 kg/h
65°C
< 300 ppm water

3821 kg/h
105 °C
< 1000 ppm methanol

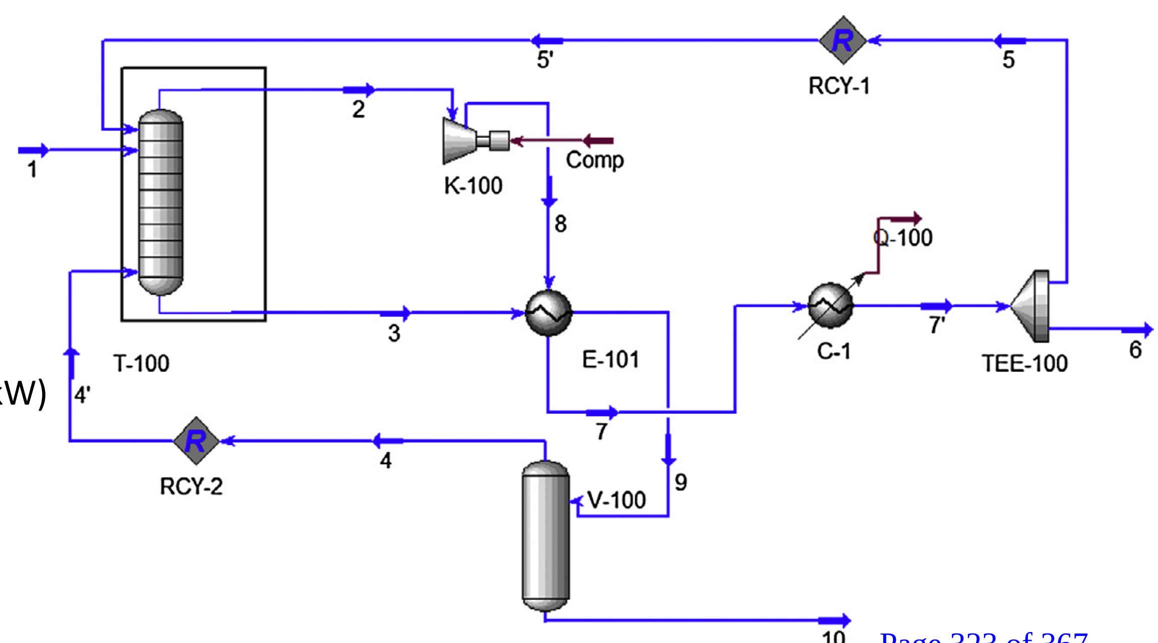
Recompression of the vapour in the top of the column

- The vapour is compressed to elevate the condensation temperature to a value higher than the temperature of the boiler.
- The compression is made with a additional electric power consumption.
- The heat transfer in the boiler is obtained by condensation of the distillate.
- The distillate is expanded after the heat transfer.

2 stages compressor (P_{in}= 1 bar- P_{out}= 9.6 bar)
Temperature for phase change: 135°C
Electric power: 272 kW
ΔT_{lift} : 70°C
COP: 4

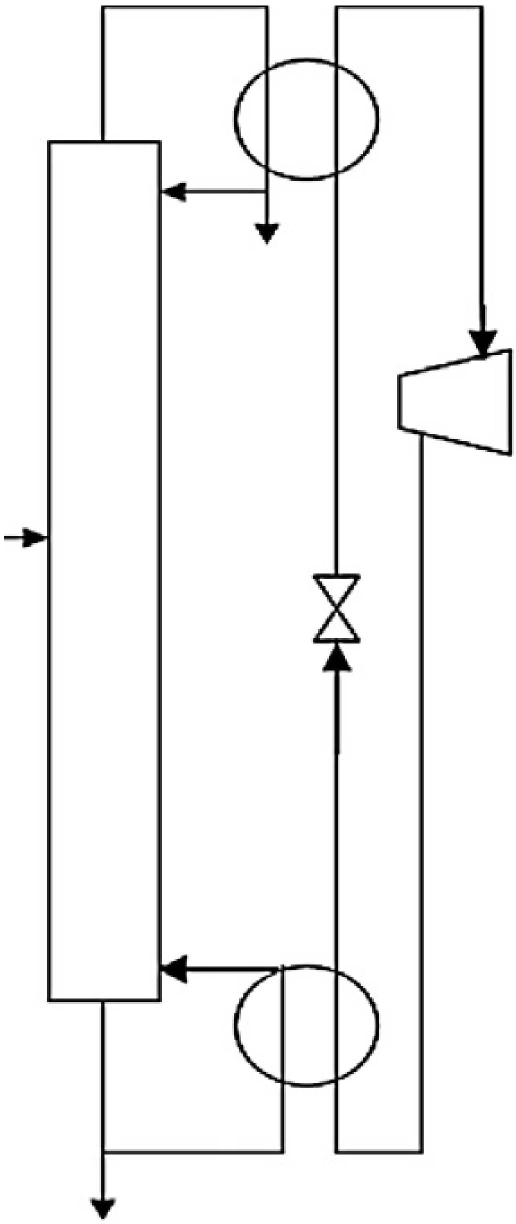
Boiler:
Heat required: 1050 kW
Heat transferred: 974 kW
Heat from steam utility: 76 kW (before 1050 kW)

Condenser:
Heat required: 943 kW
Heat removed by cold water: 242 kW



Compression in closed loop

- Using a external compression loop
- A working fluid is needed
- Is necessary another heat exchanger
- It is need a higher range in the fluid temperature



2 stages compression (P_{in}= 1 bar; P_{out}= 9.2 bar)

Temperature for phase change:	135°C
ΔT_{lift} :	80°C
Electric power need:	431 kW
Caudal R-113	36 ton/h
COP:	2,4

<u>Boiler</u>:

Heat required:	1050 kW
Heat transferred from the cycle:	1050 kW
Heat from steam utility:	0 kW

<u>Condenser</u>:

Heat required :	943 kW
Heat transferred to the cycle:	618 kW
Heat removed with could water:	325 kW

→ Study of different scenarios using vapour recompression.

Problems:

- Direct compression of a toxic product like methanol
- Payback time

→ Study of different scenarios using a closed cycle loop.

Problems:

- What working fluid to use?
- Payback time

Sustainable use of industrial residual heat Trade-offs between enhanced heat recovery and heat export

Simon Harvey
Professor of Industrial Energy Systems, Chalmers
based on the PHD project work of
Lina Eriksson
SP - Energiteknik

SP Sveriges Tekniska Forskningsinstitut

CHALMERS

Purpose: develop methodology for investigating rational use of industrial excess heat as an option for the development of sustainable regional energy system solutions

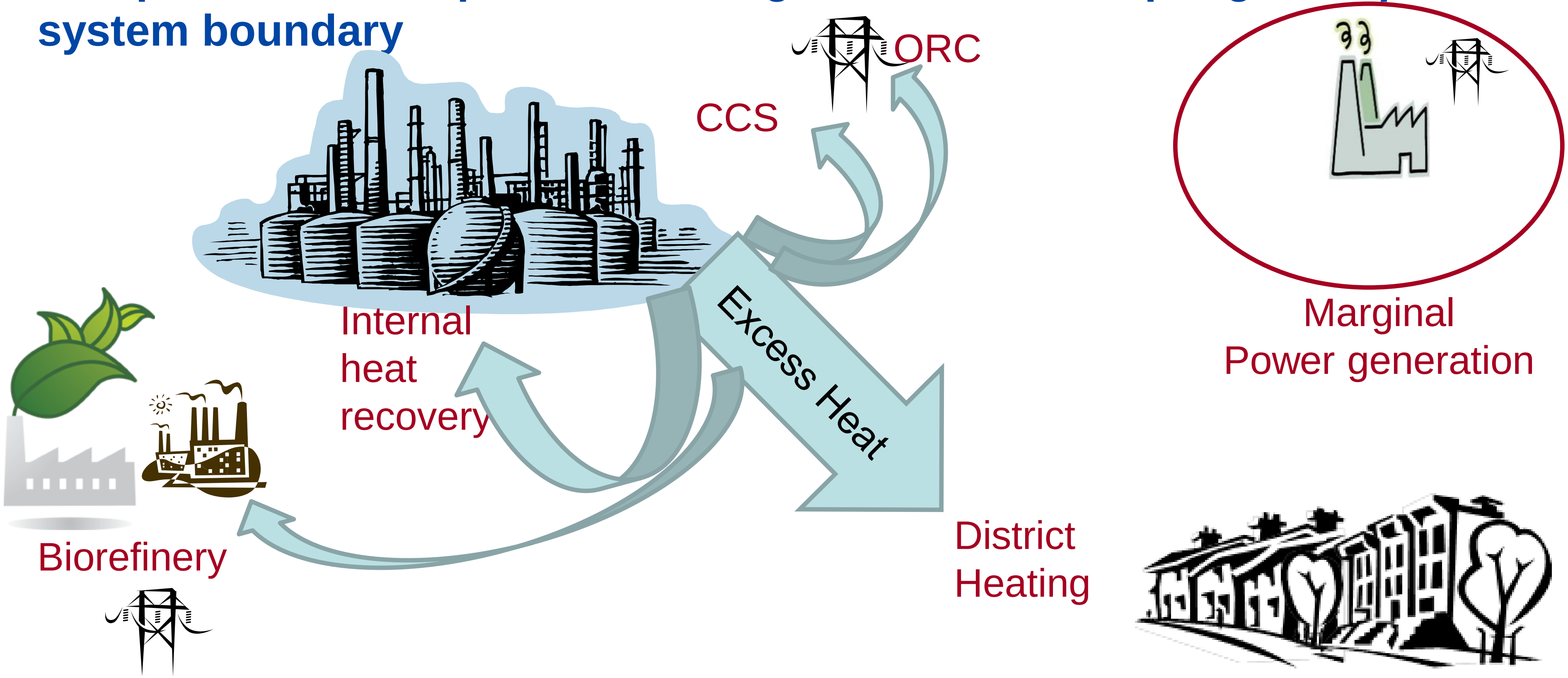
The main aim is to investigate the following:

- Technical feasibility, economic performance and carbon footprint consequences related to export of excess process heat in the form of hot water (district heat) or electric power
- Competition between increased production of these energy carriers and increased use of recovered heat at the industrial process site for e.g. biomass drying, or off-loading utility boilers

SP Sveriges Tekniska Forskningsinstitut

CHALMERS

Compare different options for using excess heat adopting an expanded system boundary



Primary energy savings can be achieved in the district heating (DH) system

How does this compete with

- CHP opportunities in the DH system?
- Primary energy savings that can be achieved at the process plant site through increased heat recovery

The system boundary and time perspective adopted strongly affect the results

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CHALMERS

Case study: chemical cluster in Stenungsund

BOREALIS | INEOS ChlorVinyls | AkzoNobel | Perstorp WINNING FORMULAS | A Member of The Linde Group | AGA




Borealis

- World leader for polyethylene for high voltage cables and piping
- Supplies district heating to the local community

Ineos

- PVC for the building and medical sectors
- Cooking chemicals for the pulping industry

AkzoNobel

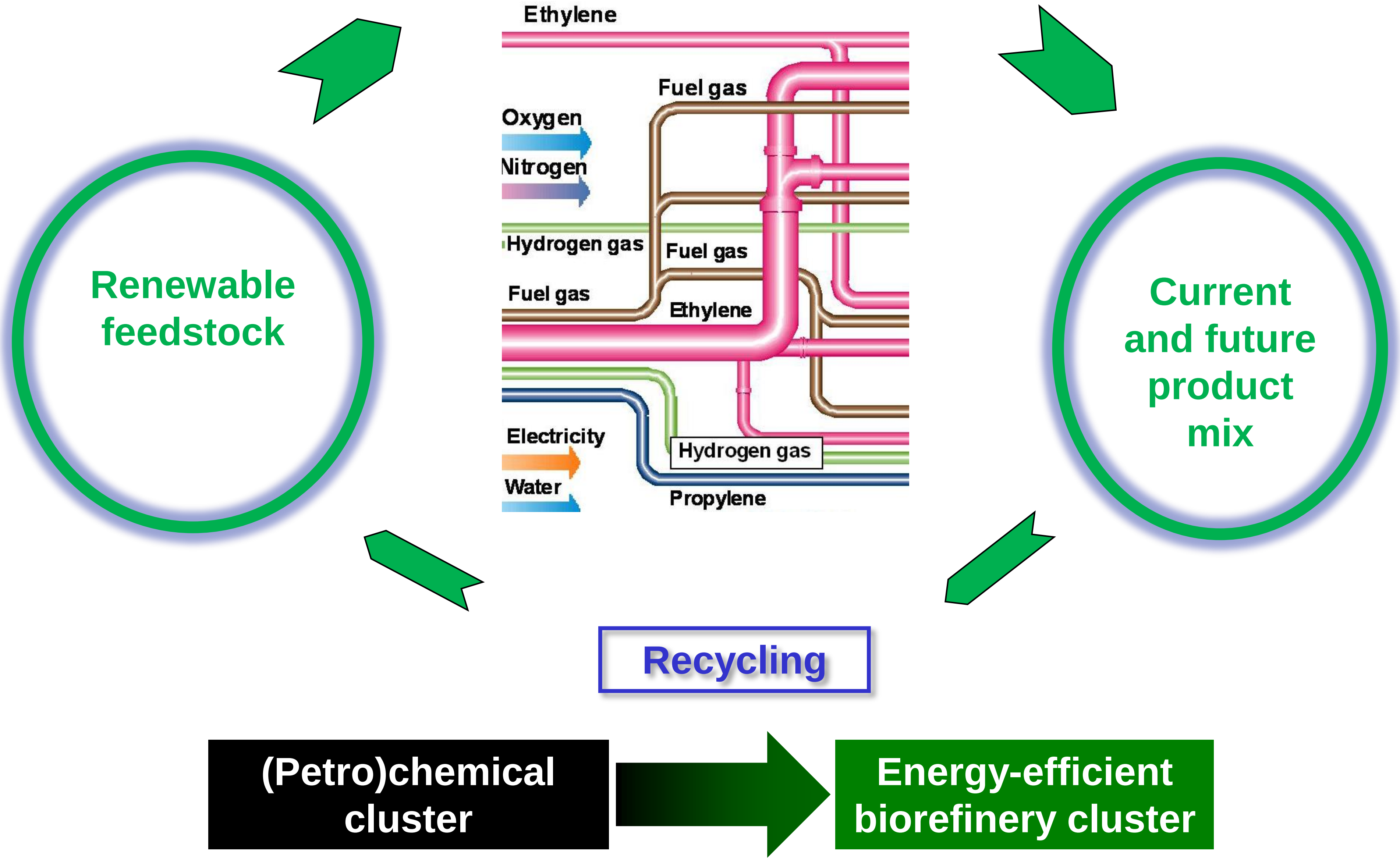
Specialty chemicals for a variety of applications, e.g. detergents, pharmaceuticals, paints and road surfacing

Perstorp

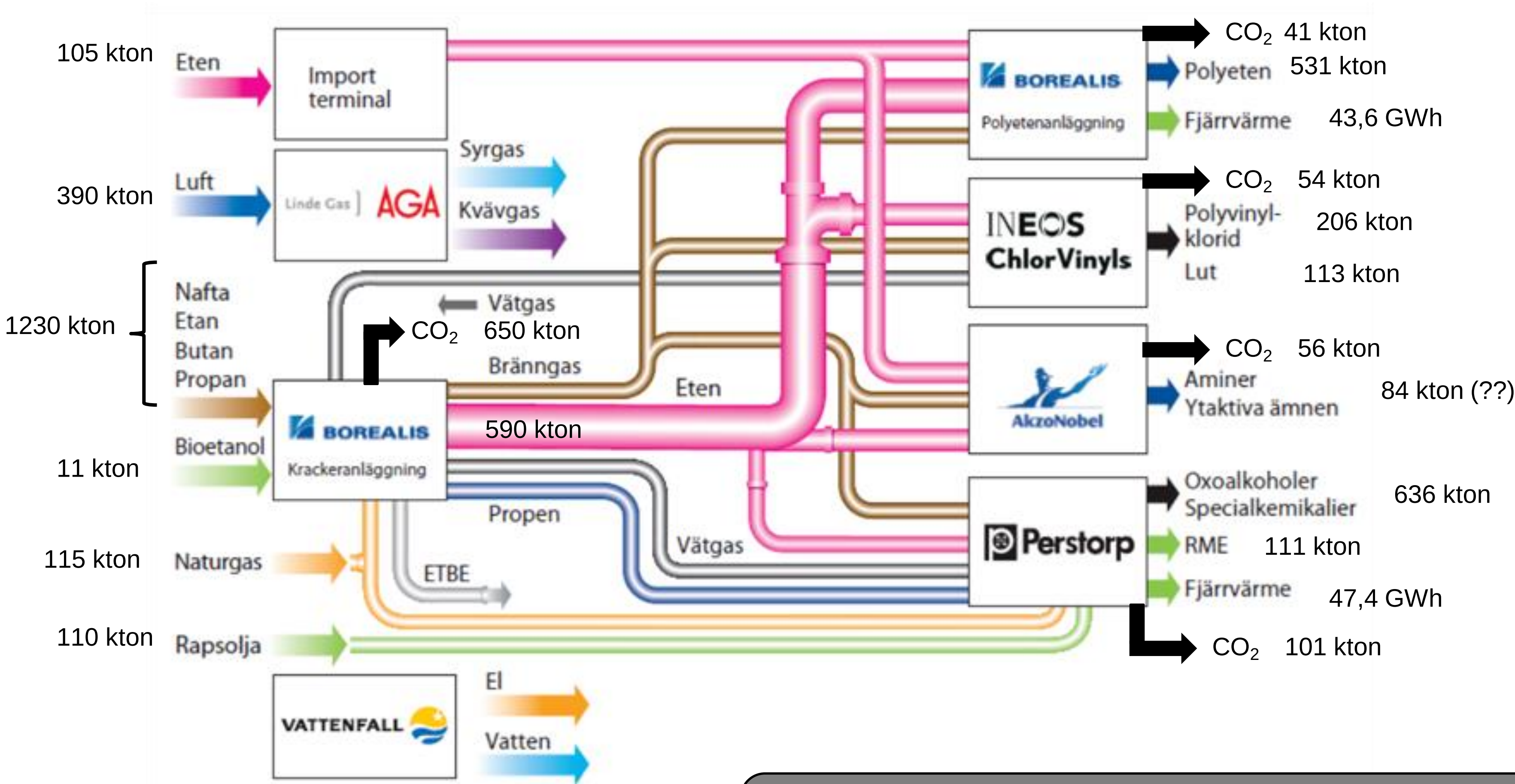
- Specialty chemicals for the construction and automotive industry
- RME Biodiesel
- Supplies district heating to the local community

Aga

Leading supplier of industrial gases

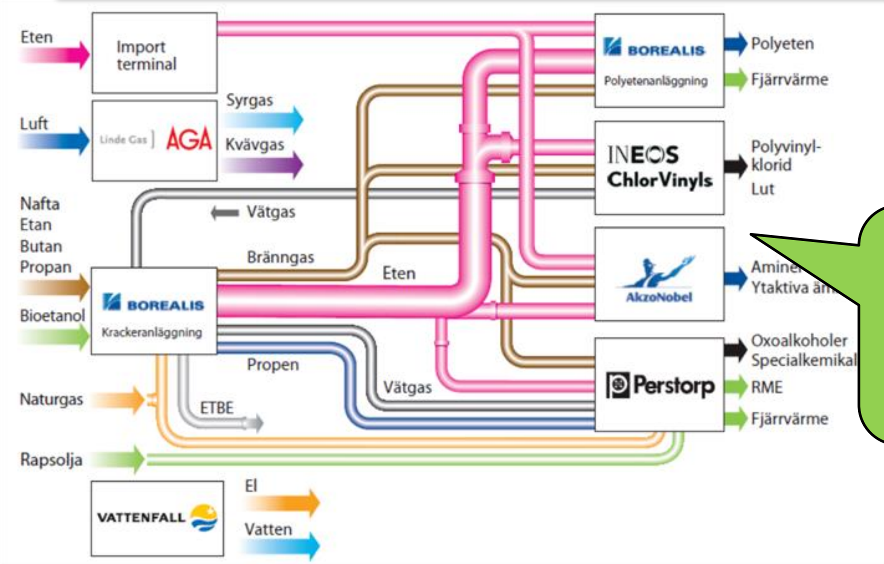

Renewable feedstock
Ethylene
Fuel gas
Oxygen
Nitrogen
Hydrogen gas
Fuel gas
Fuel gas
Ethylene
Electricity
Water
Hydrogen gas
Propylene
Current and future product mix
Recycling
(Petro)chemical cluster
Energy-efficient biorefinery cluster

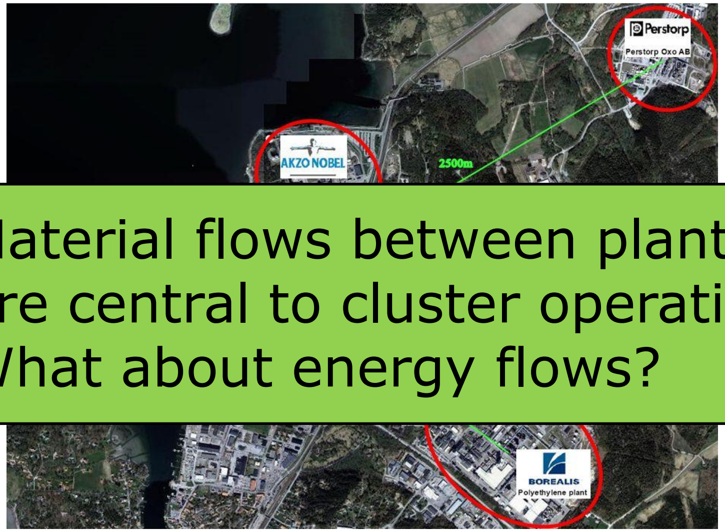
Chemical Cluster Stenungsund: Production & CO_2 emissions 2011



TOTAL emissions of CO_2 approx 900 kton/yr

Targeting for increased energy efficiency in Stenungsund





Material flows between plants are central to cluster operation. What about energy flows?

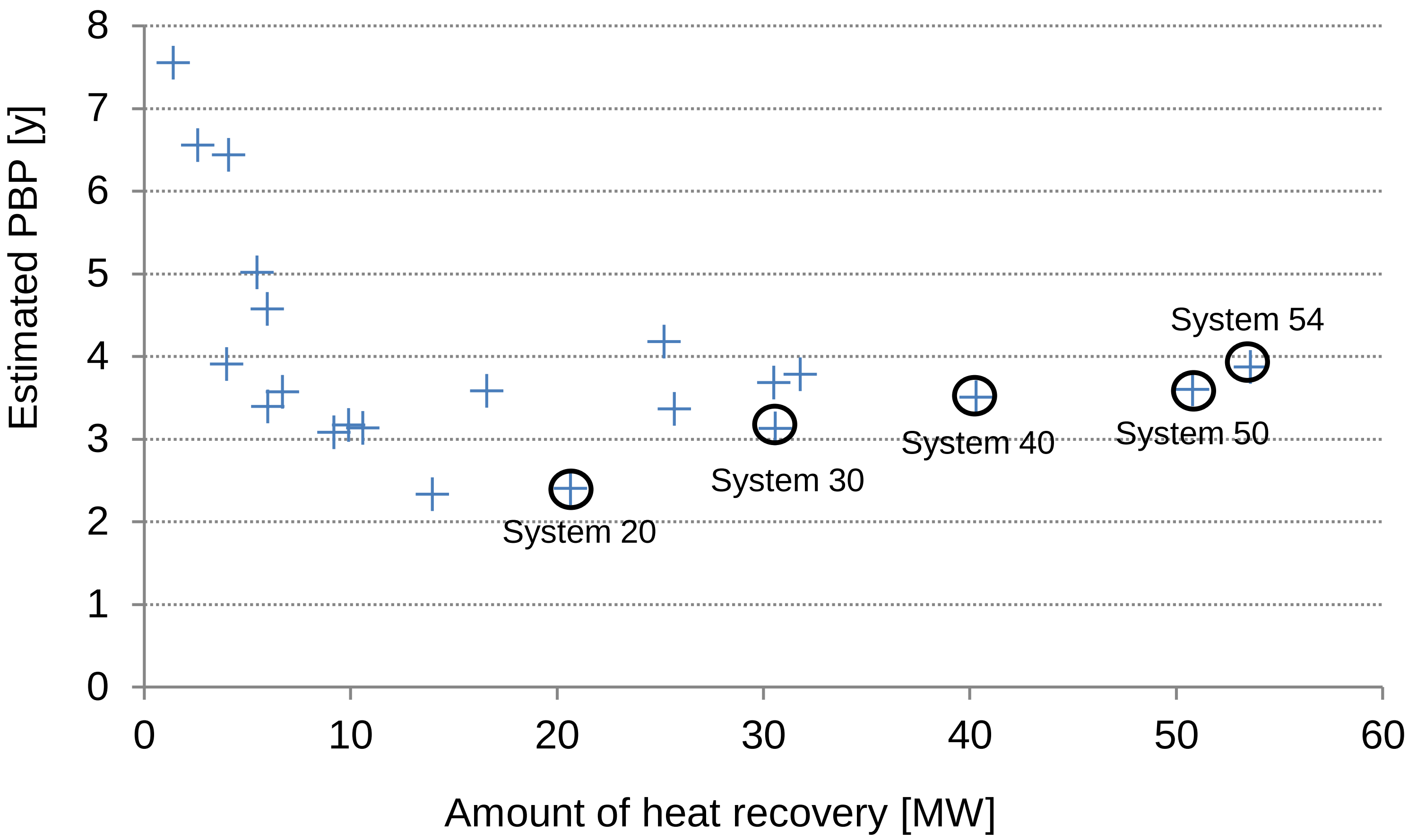
- Total heating requirements: 442 MW of which 320 MW are covered by heat recovery
- Heating requirements covered by utility from boilers fired with purchased fuels: 122 MW
- The heating requirements covered by fired boilers can theoretically be reduced to **0 MW** by efficient heat cascading!

How can this be achieved?

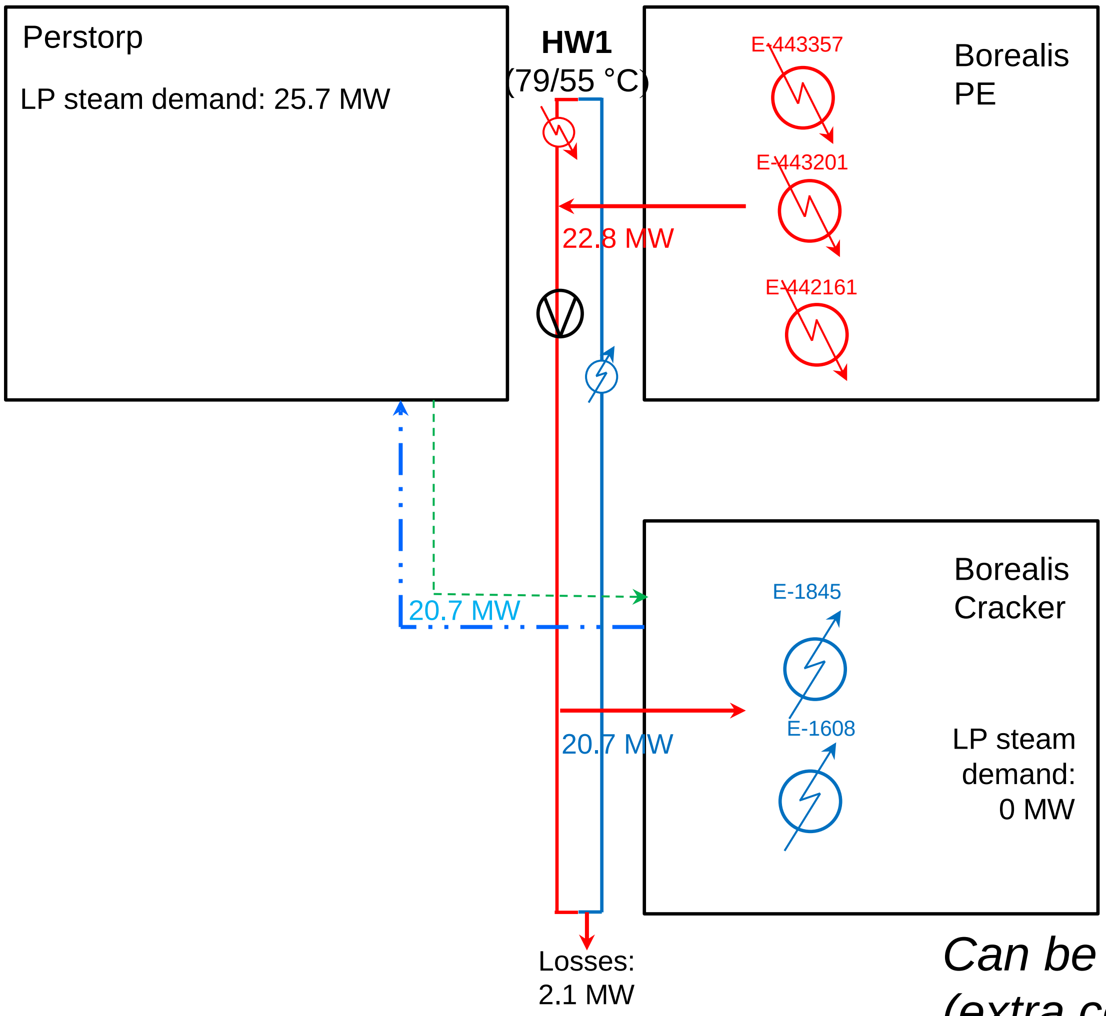
- Site-wide circulating hot water system(s)
- Harmonized steam levels to facilitate exchange of steam between plants
- Use steam at as low temperature as possible
- Process off gases should be fired at the "right" location

Screening for heat recovery systems

Pay-Back Period (PBP) as preliminary screening indicator



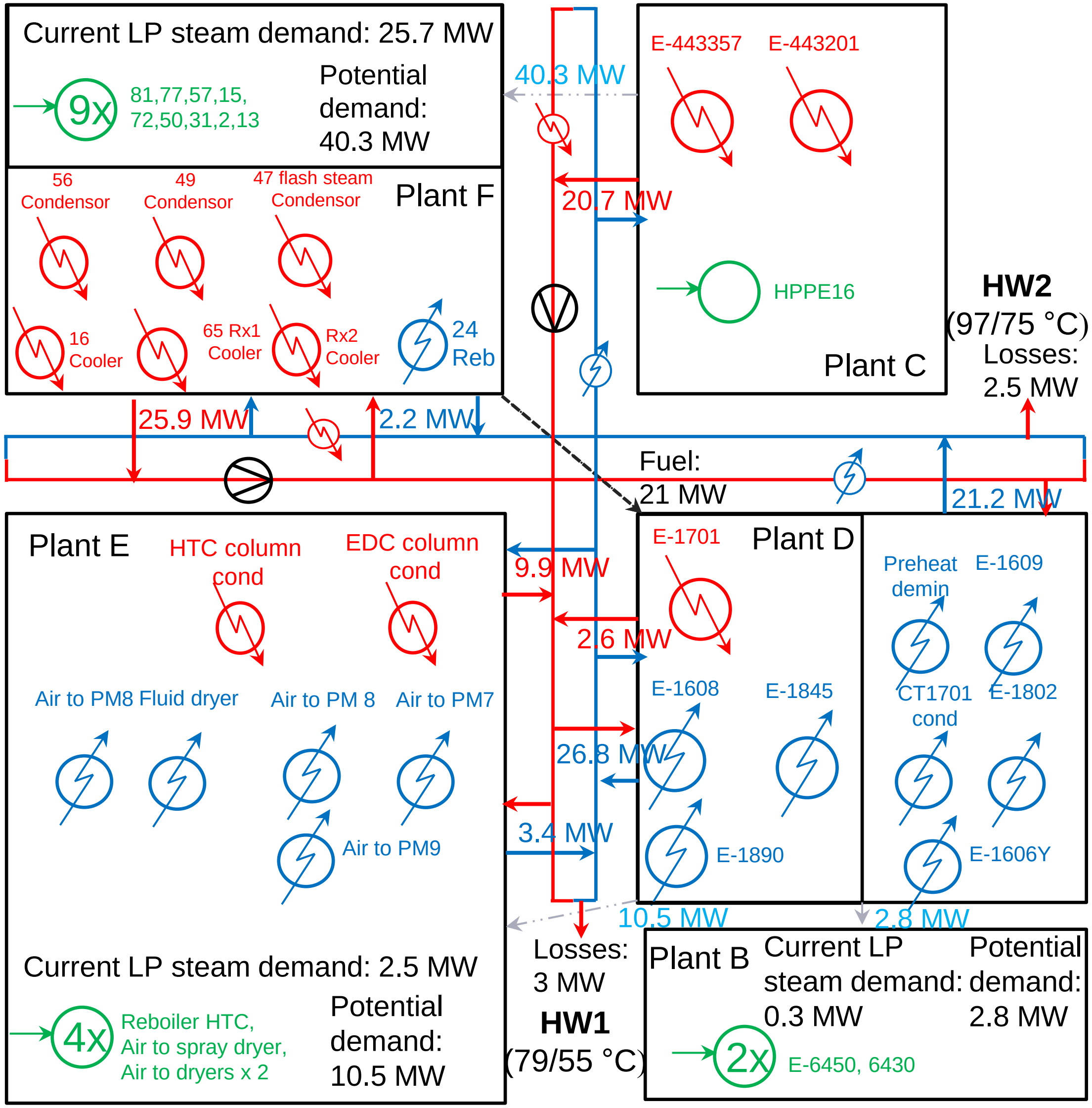
New utility network that saves 20.7 MW



- Heat savings 20.7 MW
- CO_2 savings 42 ktons/yr (5 %)
- 2 collaborating companies
- 5 new HXs
- 1 HW circuit
- 1 new steam redistribution pipe
- Total investment: 200 MSEK
- Operating cost savings: 63 MSEK/yr
- PBP: 3.2 years
- NPV_{15} (i=11 %): 261 MSEK

Can be pre-fitted for further heat recovery (extra cost 19 MSEK)

More complicated network can save 54 MW



- Heat savings 53.6 MW
- CO_2 savings13.6 %
- 4 collaborating companies
- 42 new HXs
- 2 HW circuits
- 3 new steam redistribution pipes
- Fuel redistribution
- PBP: 3.9 years

Trade-offs between enhanced heat recovery and heat export: Case Study Stenungsund

Analysis methodology

- Estimate capital costs (within the cluster) for collecting heat and delivering it to the DH system at the cluster battery limit
- Define the heat delivery mix that minimizes capital costs for collecting a given amount of excess heat for delivery to the DH system
- Conduct sensitivity analysis w r t degree of internal heat recovery within the cluster

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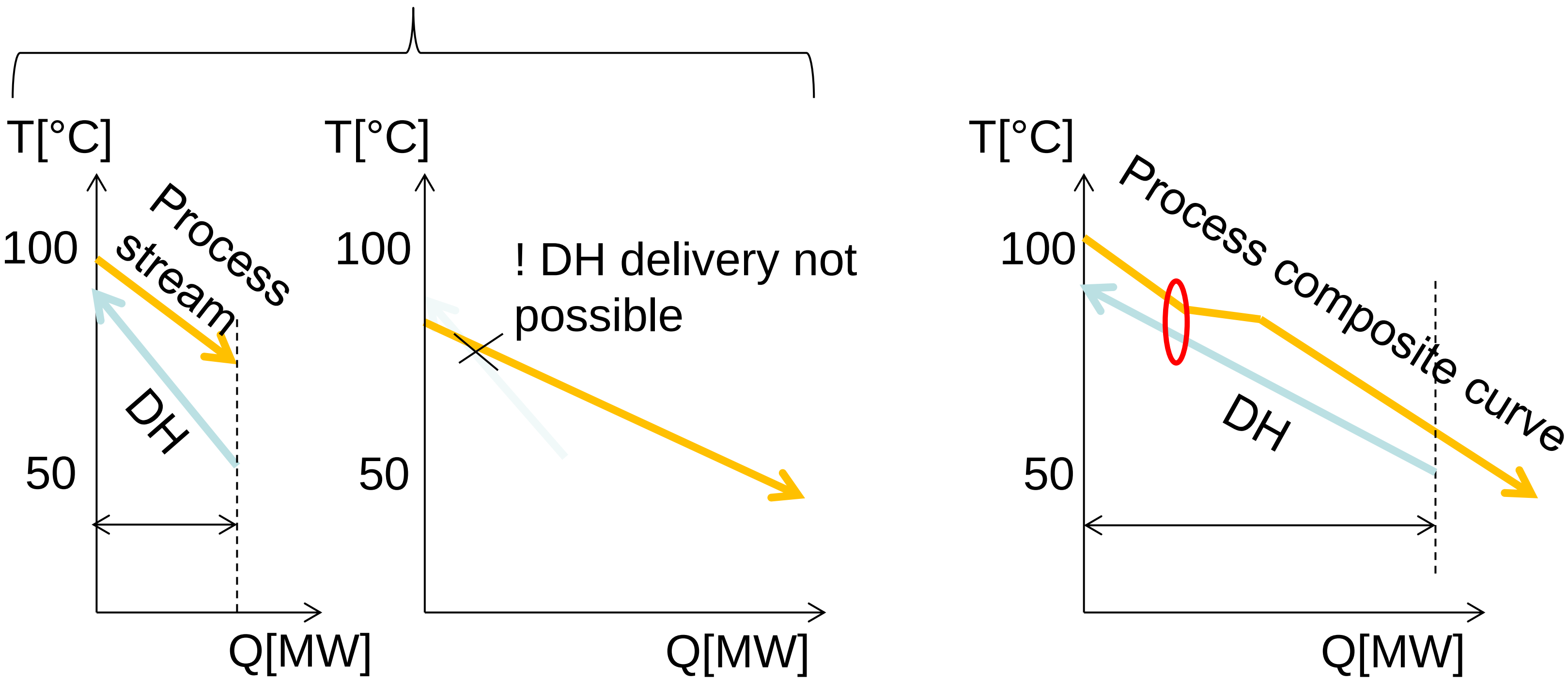
Capital cost estimates– sequential deli… n plant

DH delivery is limited if each process stream containing excess heat must heat DH water to its final delivery temperature

Sequential heat collection assumed WITHIN a given plant, but not between cluster plants.



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Capital cost estimates: ACLC and area targeting

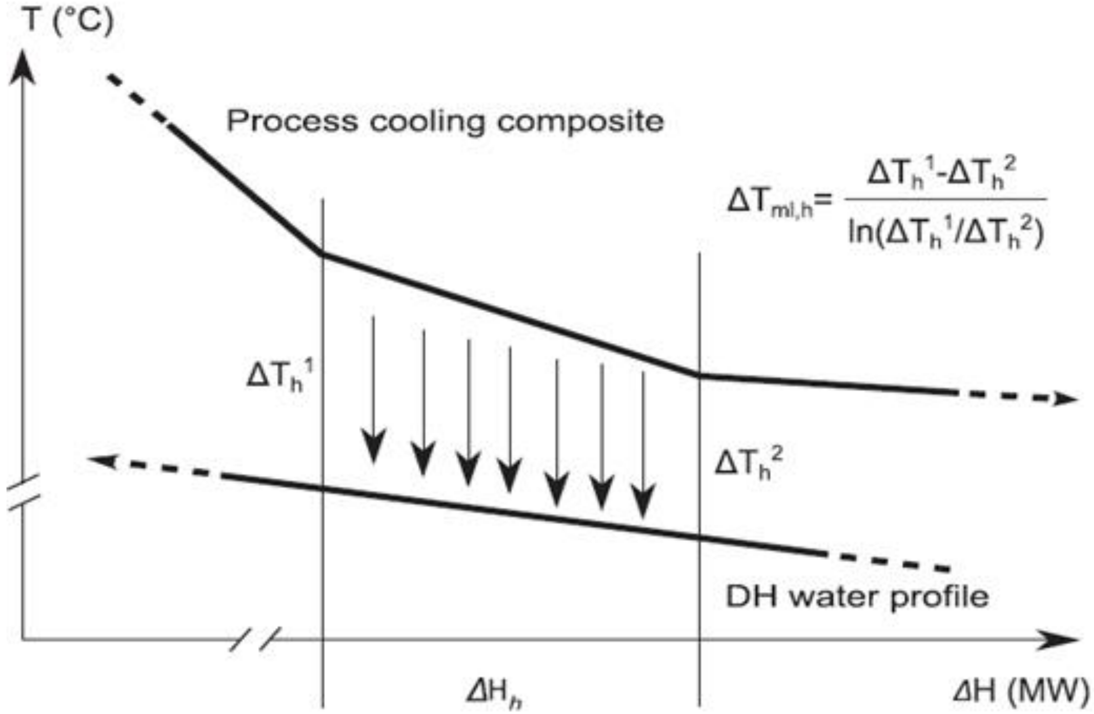

Fig. 2. Principle of vertical heat transfer reading of the composite curves.

$$A_h = \frac{1}{F \cdot \Delta T_{lm,h}} \cdot \sum_{i=0}^{I} \frac{\Delta H_{h,i}}{U_i}$$

- Eligible streams are identified and ranked by size of excess heat content
- For a targeted level of DH delivery, ACLC is constructed by considering a sufficient number of streams (considered in the order of ranking)
- The required surface area is estimated in each enthalpy interval based on ΔT, U och ΔH

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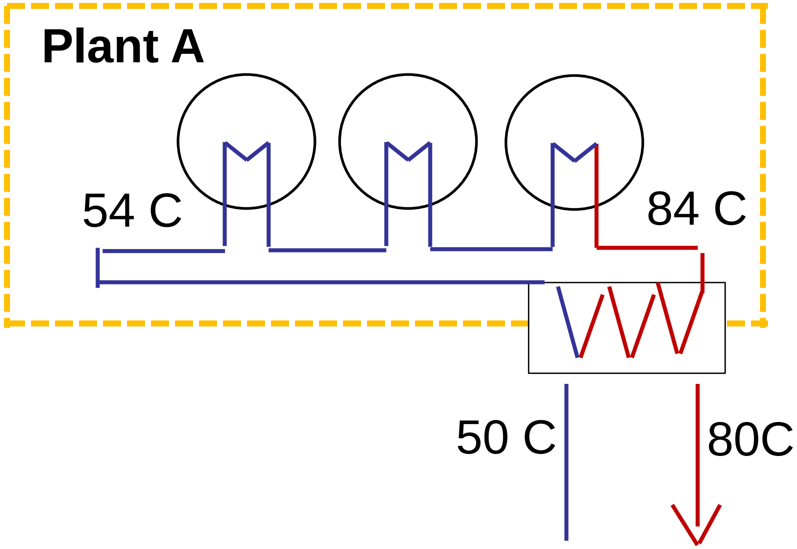
For practical reasons an intermediate circulating water heat collection system is assumed that delivers to the DH system via a plate HX



ΔT_{min} = 10 K for Shell-and-Tube HXs delivering process heat to circulating water loop

ΔT_{min} = 4 K for plate HXs delivering heat to DH system

→ Total cost = $HEN_{tube\&shell}$ (process/vv-loop) + HEX_{plate}(vv-loop/DH)

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Different levels of heat recovery within cluster

3 cases:

a. Existing system with little to no heat exchange between process plants BASE CASE

b. 20 MW of heat recovery within cluster: HREC20

c. 50 MW of heat recovery within cluster : HREC50

– HREC20 heat is recovered from 2 streams at Borealis PE

– HREC50 heat is recovered from 3 streams at Borealis PE and 6 streams at Perstorp

→ These streams are excluded as candidates for delivery of DH

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Results – DH delivery potential for the 3 cases

PLANT	Base case Potential for DH delivery [MW]	Base case Cost functions upper limit DH delivery [MW]	HREC 20 Potential for DH delivery [MW]	HREC 20 Cost functions upper limit DH delivery [MW]	HREC 50 Potential for DH delivery [MW]	HREC 50 Cost functions upper limit DH delivery [MW]
A -BorPE	46	36	36	36	32	32
B- INEOS	6	6	6	6	6	6
C- Perstorp	63	54	63	54	31	31
D- BorC	65	55	65	55	65	55
Total	180	**151**	170	**151**	134	**124**

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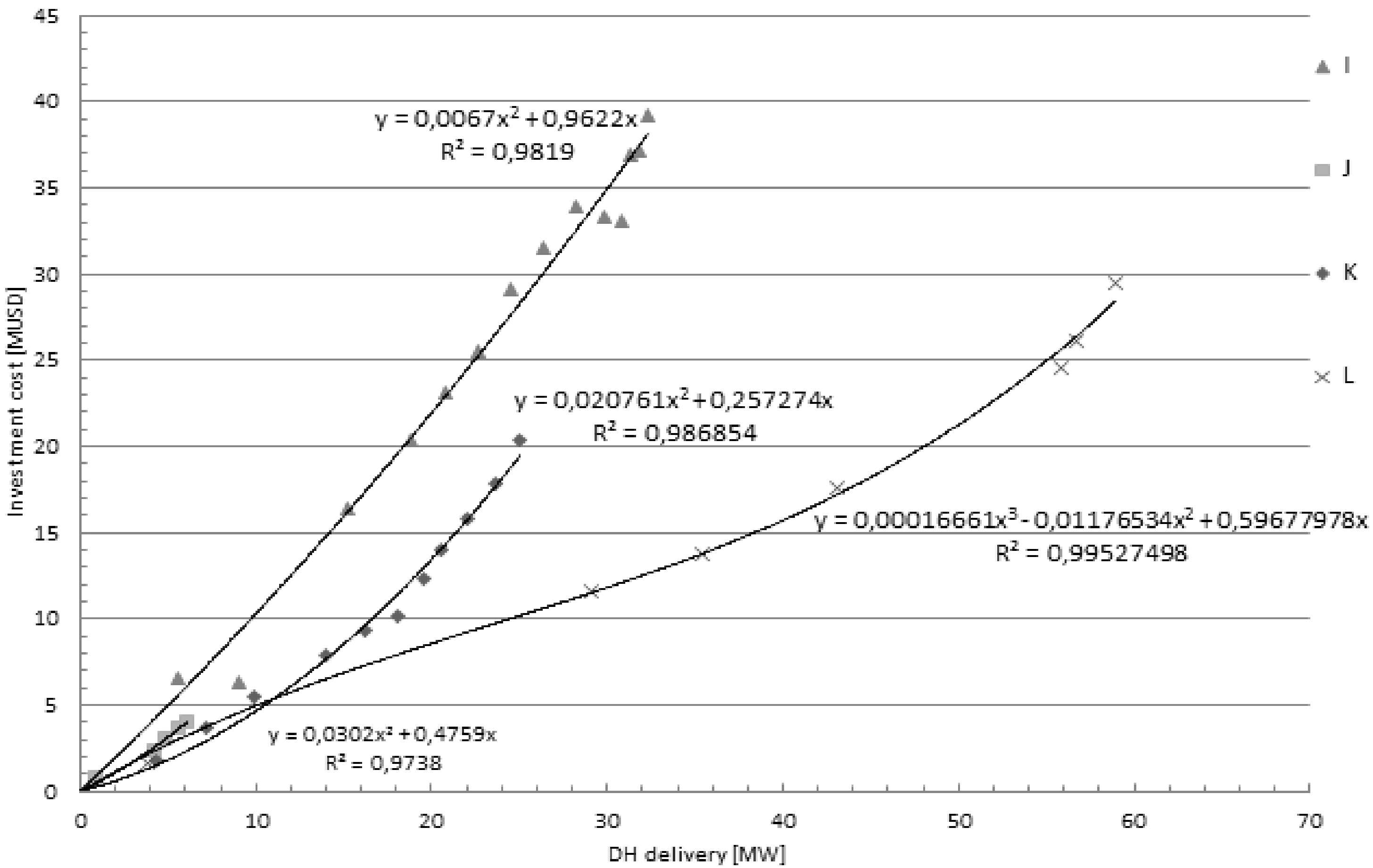
Investment cost for DH delivery from individual plants for HREC50



Each calculated point corresponds to an additional point being considered.

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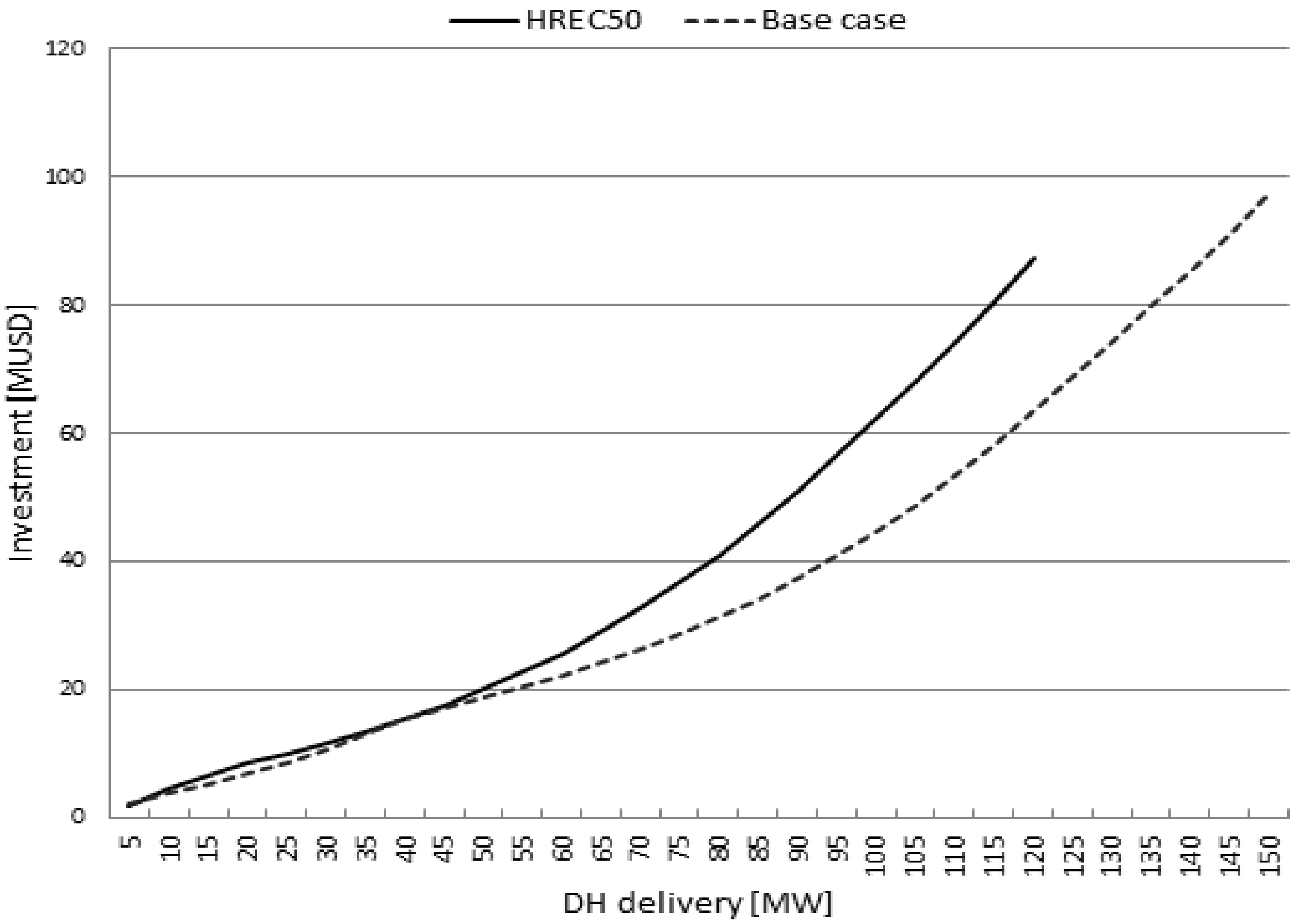
Combine to a single curve for each case



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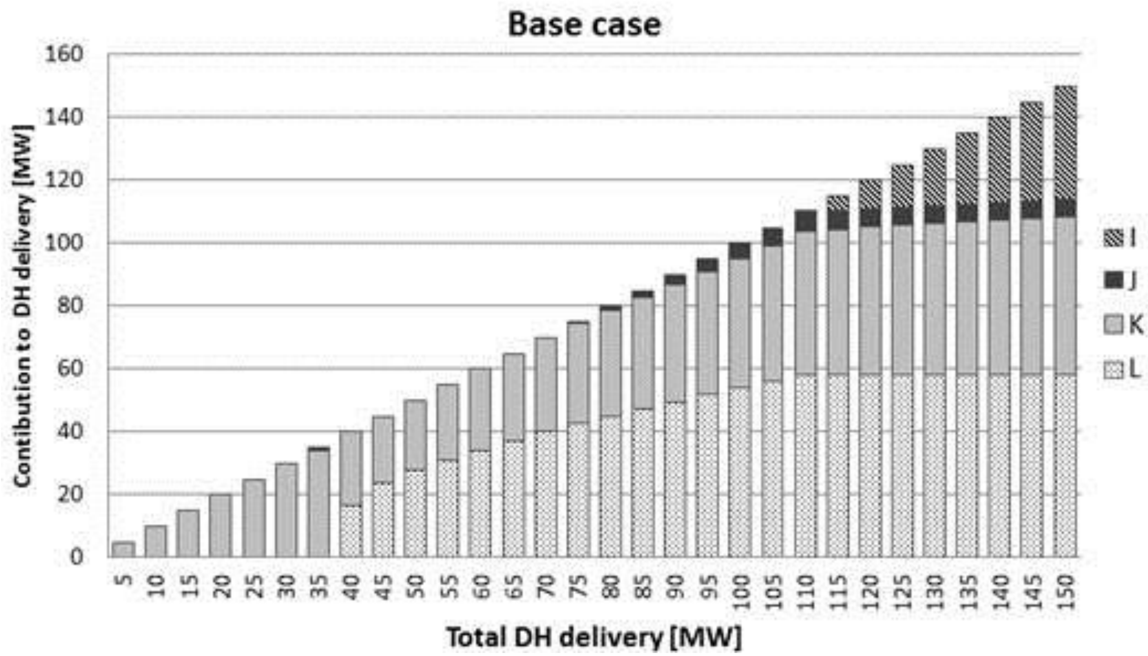
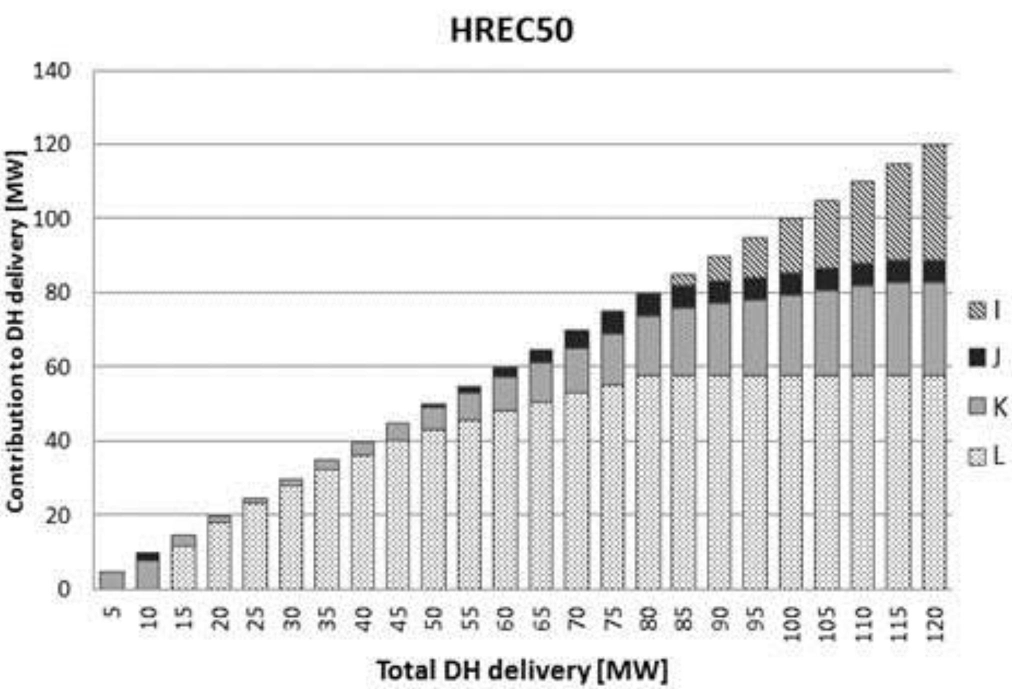
Results

Delivery mix





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Using the results as input to a regional energy system study

Project 1

Estimate **capital costs** (within the cluster) for collecting heat and delivering it to the DH system, for different levels of heat delivery

Assess economic performance and carbon footprint consequences for delivery of excess heat

Project 2

Calculate the **optimal configuration for the regional energy system**

(for different levels of available excess heat from industry and for different energy markets scenarios)

Identify possible purchase price range for industrial excess heat

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Project 2: Environmental and Economic Impacts of Large-Scale Utilization of Excess Heat - Assessment through Regional Modeling

Akram Sandvall, Erik Ahlgren, Tomas Ekvall*

Energy Technology, Energy and Environment Department, Chalmers University of Technology

*Swedish Environmental Research Institutes (IVL)

Research Questions

- How will the energy systems and CO_2 emissions be affected by a large heat network between DH systems and industries that allows for long-distance transmission of Excess Heat (EH)?

- Is the large heat network profitable?

- How is the marginal cost of DH supply affected by such a large heat network?

Climate policy scenarios

- 450PPM (450 ppm)
- NEWPOL (New Policies)

← International Energy Agency (World Energy Outlook)

(Energy prices and CO_2 charge calculated by ENPAC tool)

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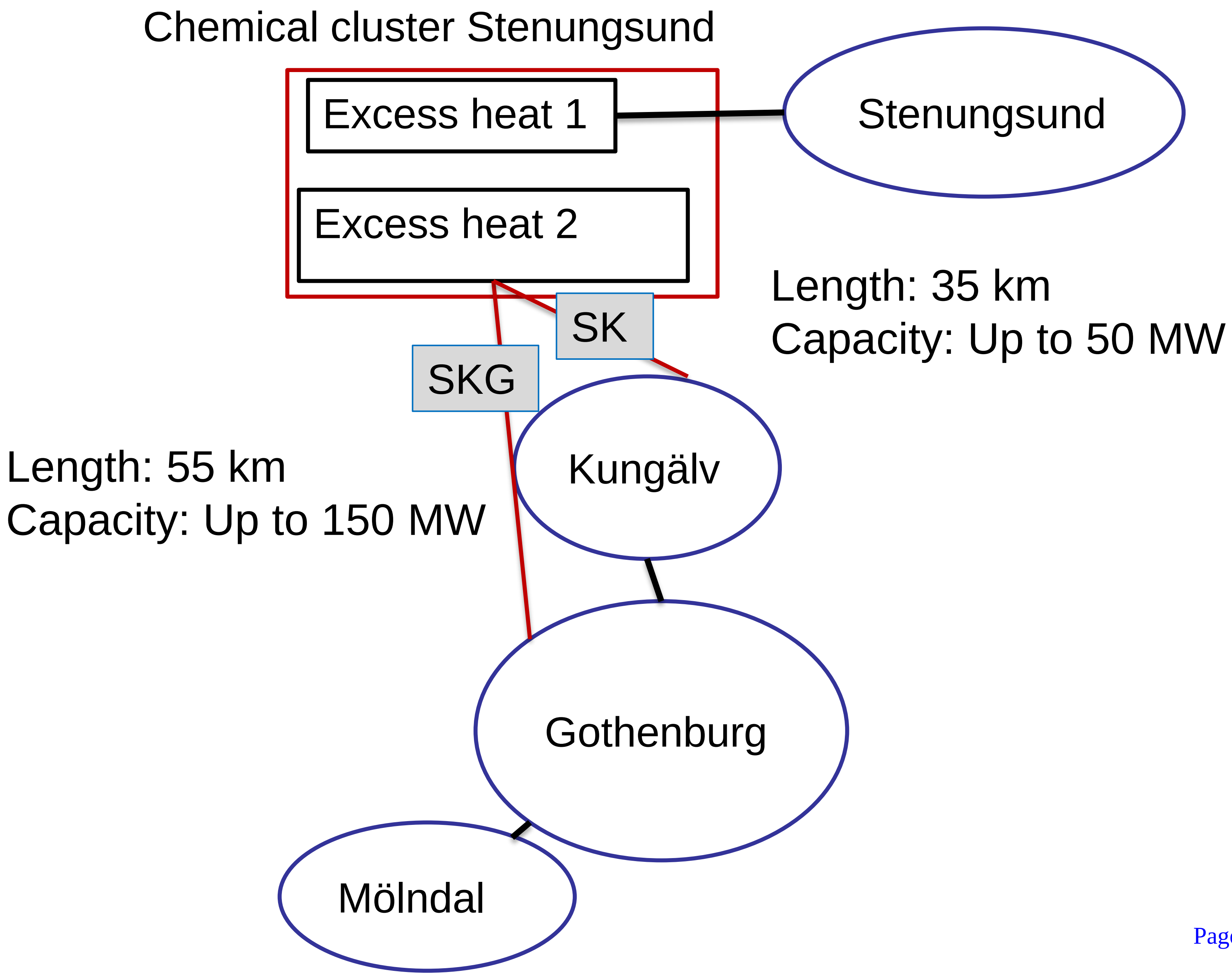
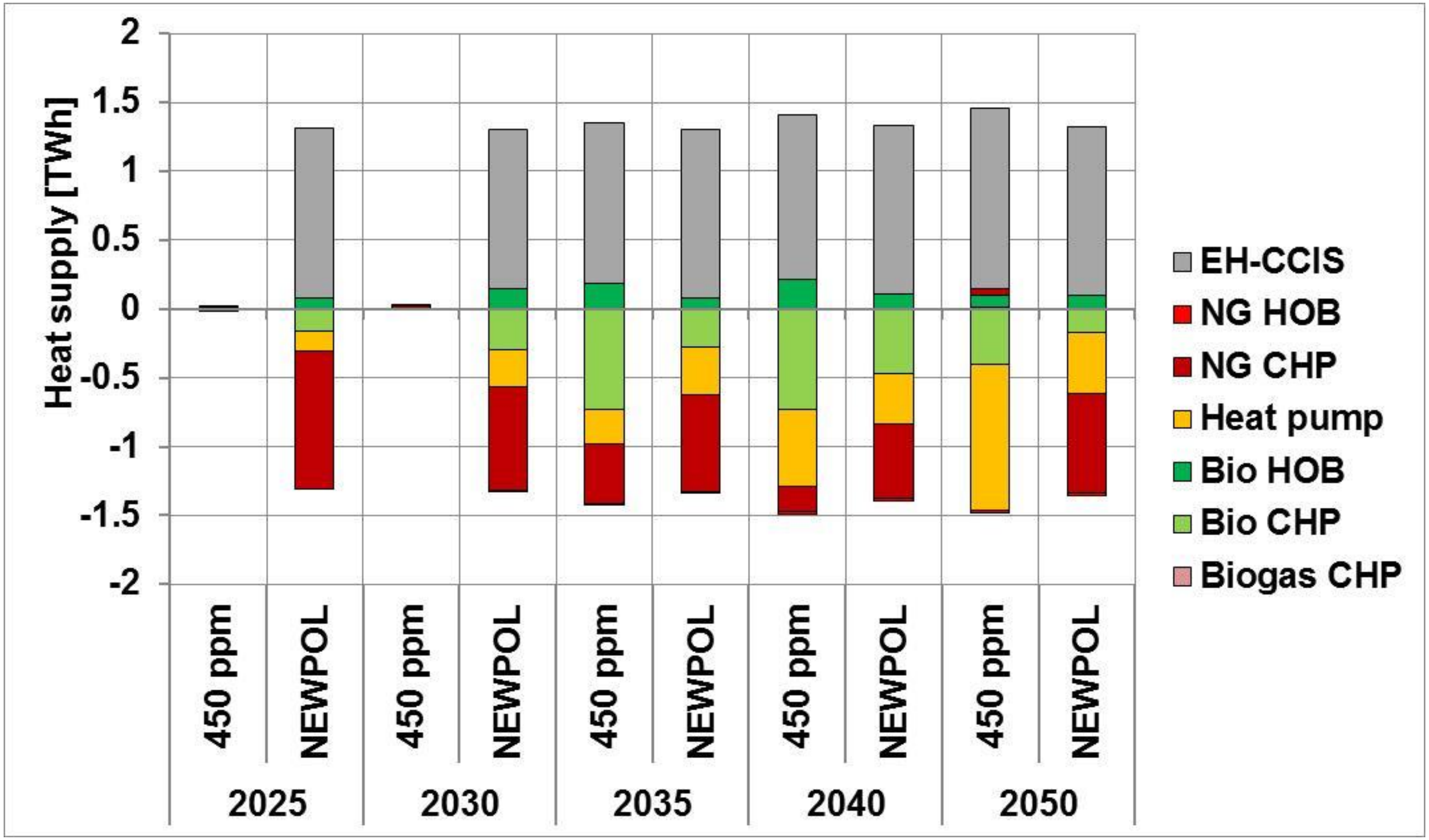
Model

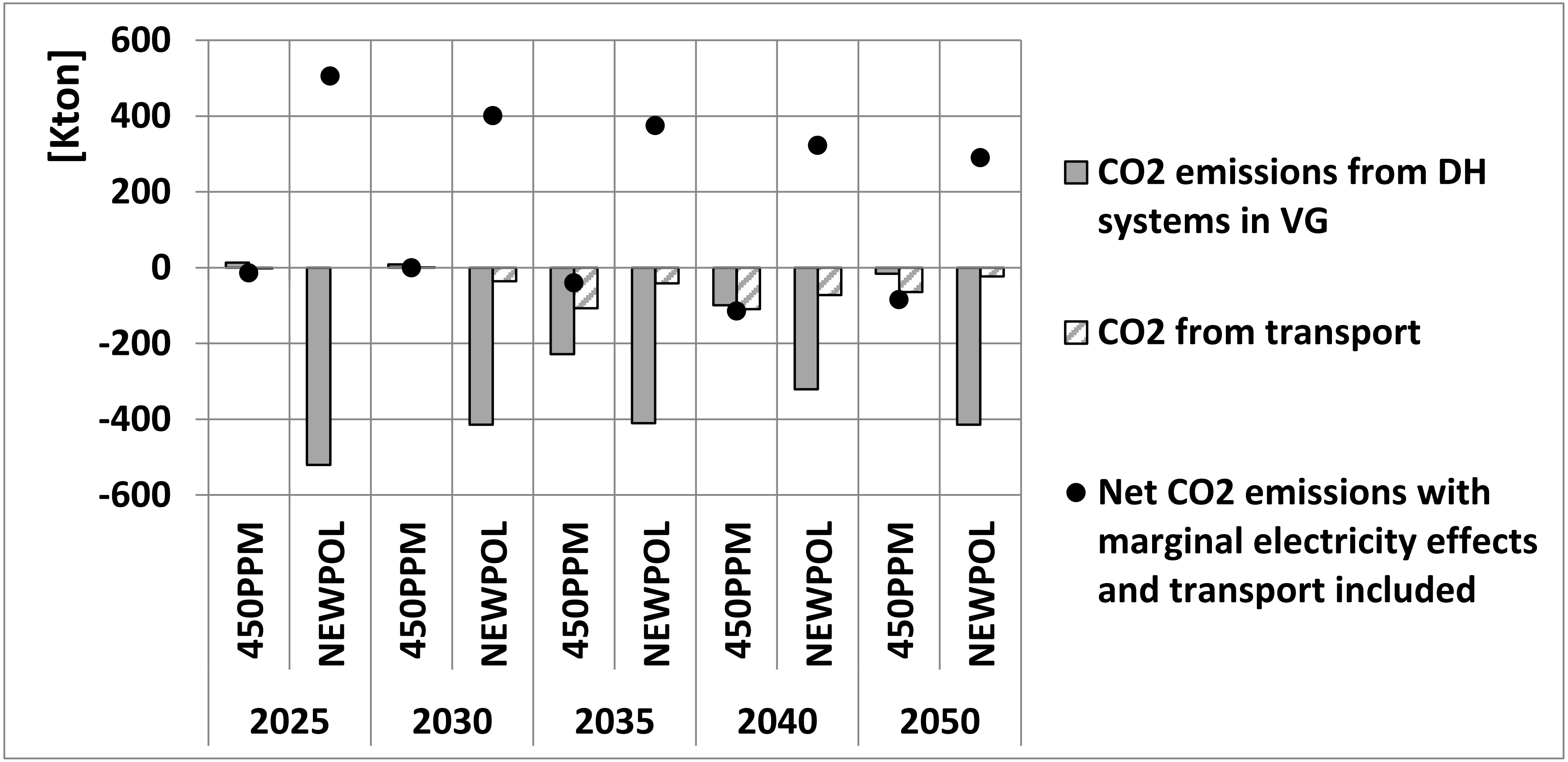


Impact on regional heat production mix



Differences between “connection” and “no-connection”

CO_2 emissions



Low Grade Waste Heat Recovery

2015 Small Business Innovative Research (SBIR) Solicitation

2015 SBIR

Advanced Manufacturing Office requested proposals in four areas:

1. Wide band gap semiconductors
2. Natural gas Feedstock and Fuel Substitution
3. Carbon Fiber Production
4. Novel Low Cost Recovery from Low Temperature Waste Heat

Low Temperature Waste Heat Recovery

- Novel applications sought that would enable cost effective recovery of waste heat below 450 degrees F (~230 degrees C)
- Conversion efficiency between 20-30%
- Manufacturing cost less than $1/watt

Solicitation Process

- Applications due February 3, 2015
- Reviews completed by March 17, 2015
- Award notifications April 27, 2015
- Projects begin June 8, 2015

Waste Heat-to-Power Using Scroll Expander for Organic Rankine Bottoming Cycle

DE-EE0005767

Green Mountain Coffee (field test site)

July 1, 2013 – June 30, 2016

John Dieckmann, TIAX LLC, Principal Investigator (Presenter)

U.S. DOE Advanced Manufacturing Office Peer Review Meeting
Washington, D.C.
May 6-7, 2014

Project Objective

- Primary objective – develop scroll expander technology for organic Rankine cycle (ORC) for power generation from recovered waste heat, with power outputs from 5kW to 50kW
- Key technical requirements are to obtain high expansion efficiency and long operating life
- Challenges
  - Time variation in temperature and/or flow of waste heat stream
  - Different working fluids – but, many ORC's use HFC-245fa
  - Pressure ratio/built-in volume ratio mismatch – larger pressure ratio than practical scroll built-in volume ratio

Technical Approach

- Current ORC expanders
  - Turbo expanders large power output 100 kW up
  - Screw expanders 50kW – 150 kW
  - 5 – 50 kW technology gap
- Scroll well suited to expansion and compression in 5-50kW power range
  - Best efficiency refrigerant compressors from 3kW to 50kW power input (~3 to 50 ton cooling capacity for air conditioning), with proven life and reliability
  - Advantages for ORC expander
    - Self-porting
    - Tolerant of two phase flow/liquid slugs
    - In 5 – 50 kW range, good combination of low flow losses, low internal leakage/bypass losses, and high mechanical efficiency

Technical Approach (continued)

- Advantages for ORC expander (continued)
  - Most ORC working fluids similar to refrigerants, compatible with lubricants
- What is innovative about your project and approach?
  - Applying TIAX-developed radial compliance method and pressure balance and thrust bearing methods to provide axial compliance with low sliding friction loss. Radial and axial compliance minimizes the flank and tip clearances, respectively, between the scrolls, minimizing pocket to pocket leakage loss
  - TIAX and predecessor Arthur D. Little Technology Group have 40 years of experience developing scroll machinery for a wide range of applications

Transition and Deployment

- Who cares? -- Many medium temperature (150°C to 500°C), modest capacity waste heat streams could be utilized with suitable expander technology
- End users – industries with waste heat streams with recoverable heat between 100,000 Btu/hr and 1½ million Btu/hr
  - Thermal oxidizers (used in a variety of industries)
  - Coffee roasting
  - Bakeries
  - Heat treating
- Bottoming cycle for distributed generation and CHP
  - 30 kW – 300 kW
  - Rejected heat from ORC can be high enough temperature for DHW and space heating

Transition and Deployment (continued)

- Waste heat stream can be recovered by packaged ORC system
- Typically, no direct impact on operations, but generates a good return on investment – saved electricity cost vs. projected installed cost
- Commercialization
  - License to ORC system manufacturer or component supplier
  - When expander prototype is operating, with performance data, will contact ORC manufacturers to initiate technology transfer discussions
- Technology sustainment
  - Technology transfer to licensee
  - Long term TIAX commitment to scroll technology

Measure of Success

- Successful development and deployment will increase the number of waste heat streams that can be captured and used for electric power generation
  - Measurement of impact ultimately will be kW's of waste heat powered generating capacity, kWh's generated, CO_2 emissions avoided
- Energy Impact – very rough preliminary estimate
  - In 2020, installed in 5% of identified potential applications, 60 million kWh of electric energy generated, saving 0.6 trillion Btu/hr of primary energy and avoiding 30,000 metric tonnes of CO2 emissions
  - Technical potential, at least 20 x this amount, growing as the installed base grows

Measure of Success (continued)

- Economic impact
  - By 2020, installed in 5% of identified applications, $13.5 million invested in scroll based ORCs, $4.4 million of electricity costs saved

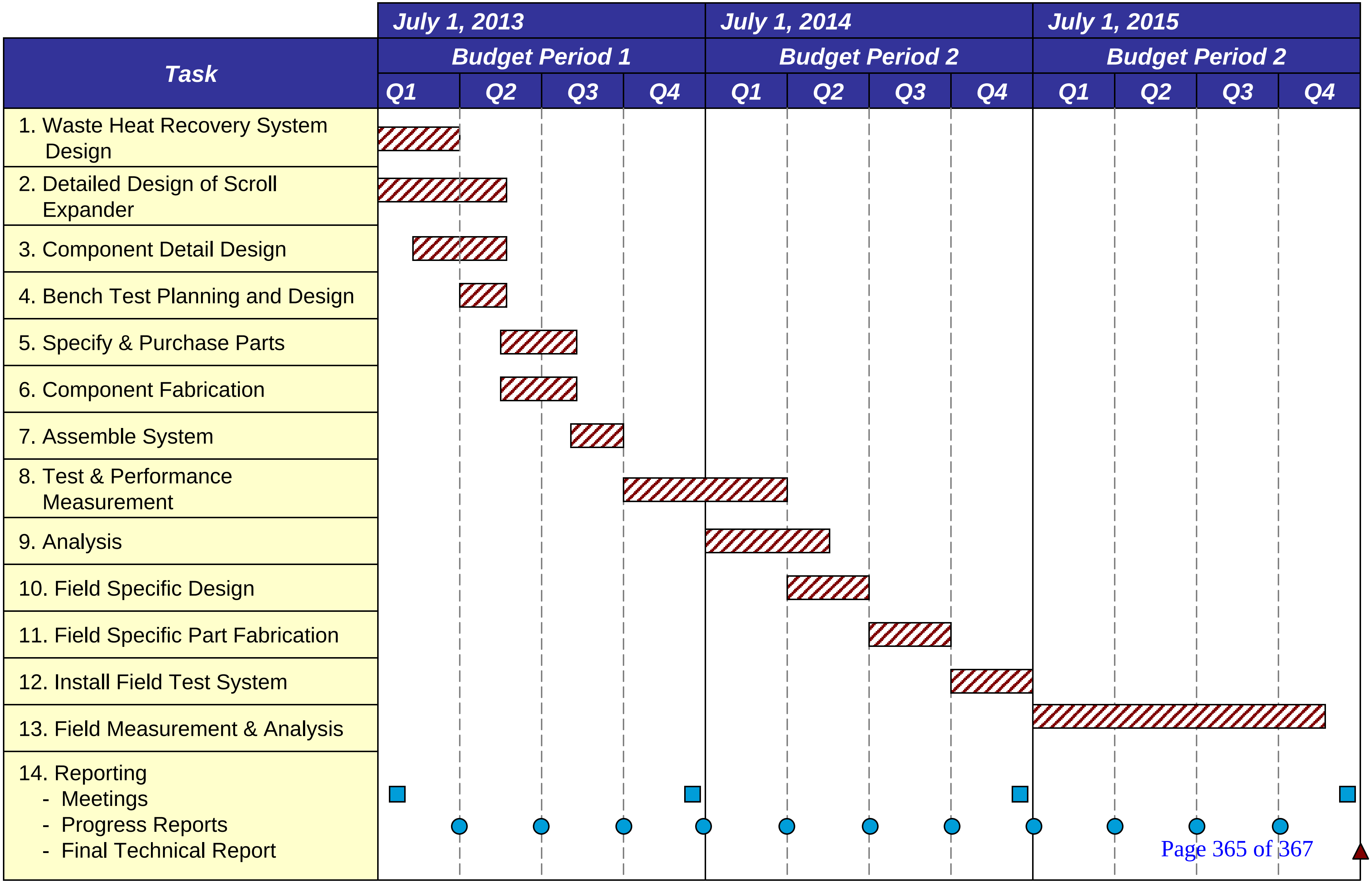
Project Management & Budget

- Project duration 36 months (Gantt chart next page)
- Key milestone schedule

Milestone Description	*Verification Method*	*Planned Completion Date*
Detailed Design of Scroll Expander Completed	Drawing package and solid models reviewed	11/15/2013
Component Fabrication Completed	All components in hand and inspected for conformance with specifications and tolerances	2/15/2014
System Assembly Completed	System assembled	3/31/2014
Scroll Expander Operating	Expander operating	4/30/2014
Scroll Expander Isentropic Efficiency >70%	Test results	6/30/2014
Scroll Expander Isentropic Efficiency >75%	Laboratory test result	9/30/2014
Field Test System Installed and Operating at Design Capacity	Physical installation complete and performance test results	6/30/2015
12 Months of Field Test Operation	Results documented and included in quarterly progress report and final report	6/30/2016

DOE Investment	*Cost Share*	*Project Total*
$2,499,253	$624,813	$3,124,066

Project Management & Budget (continued)



Results and Accomplishments

- Status – completing fabrication of parts for prototype expander, completing laboratory test set up
- Testing will be carried out over next several months
- Work to be completed
  - Budget Period 1
    - Development and performance testing of the expander
  - Budget Period 2
    - Design field test system
    - Fabricate field test system
    - Test field test system
    - Install field test system at GMCR field test site
  - Budget Period 3
    - Run field test

Results and Accomplishments (continued)