***D**utch program for the*
***A**cceleration of*
***S**ustainable*
***H**eat Management in industry*

SCOPING STUDY FINAL REPORT APRIL 2017

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ECN-E—17-083

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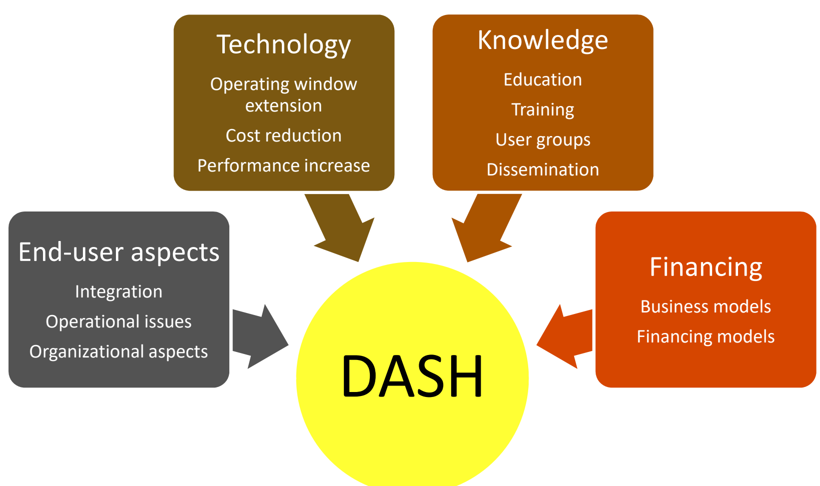
Major considerations (1/2)

- The use of heat within industry is responsible for more than **80%** of the final energetic energy use. Heat is used for heating feedstock, enable reactions, and to drive separation processes.
- Heat pumps will play a major role as conversion technology between renewable sources (including waste heat) and the end-use of heat, both low-temperature heat as well as high-temperature heat.
- Electrically driven industrial heat pumps are a robust choice in a future energy system that is progressively electrified by an increasing share of renewables.
- Potential fossil energy savings range from **80 PJ/year** with today's electricity park to **180 PJ/year** based on completely renewable electricity production.
- Potential CO_2 emission reductions range from **2.5 Mton/year** with today's electricity park to **10 Mton/year** based on completely renewable electricity production.

Major considerations (2/2)

- There is significant interest in NL for a ‘mission driven innovation program’
- There is growing momentum and a pipeline of projects already in development to demonstrate heat pump technology in NL
- Analysis of the technology, applicability and market impact show significant advantages for NL to forge ahead quickly in terms of employment (~**2000 jobs**) commercial activity (**€350M** per year) in addition to the emission reduction and integration of renewable energy already mentioned.
- The Dutch Program for the Acceleration of Sustainable Heat management in industry **DASH** shall focus on
  1. Technology development
  2. End-user aspects
  3. Knowledge development
  4. Financing

DASH heat pump program



Next Steps

1. Launch ‘DASH’ program with small number of NL early adopter supporters
   - Eg Dow, Smurfit Kappa, Akzo Nobel, Friesland Campina, ECN …
2. Assign leading consultancy (Roland Berger or other) to lead the consortium
3. Develop key technology lines and roadmap within program based on initial findings in this report
4. Define top line ‘goal’ / objectives to gain attention & momentum
5. Facilitate funding for major program objectives

ECN is keen to continue to be involved in this development and to push boundaries to achieve maximum introduction of heat pumps in NL and abroad

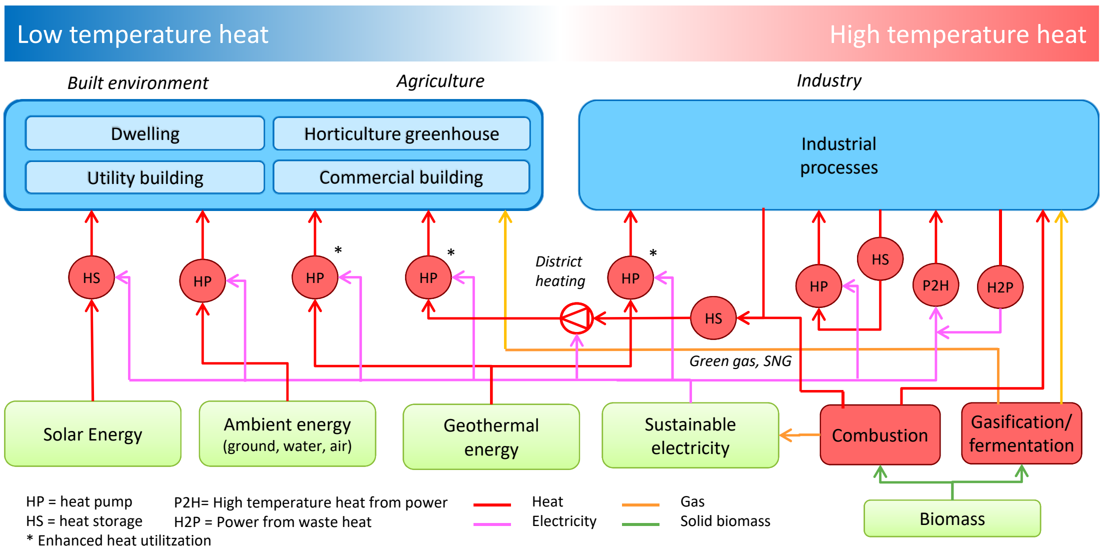
Setting the scene

- The Dutch ‘Topsector Energy’ has ambitious goals for energy innovations that contribute to the reduction in costs and CO_2 emissions, the development of renewable energy sources and the smarter utilisation thereof. The TKI Energy & Industry is one of the cornerstones of the Topsector Energy framework as funded and supported by the RVO. One of the 3 focus items of the TKI Energy & Industry is “Heat”
- The use of heat within industry is responsible for more than 80% of the final energetic energy use. Heat is used for heating feedstock, enable reactions, and to drive separation processes. A number of technology options can be envisioned that would valorise waste heat, ranging from internal reuse to heat distribution to others sectors or electricity production. Given the heat requirements in industry, the temperature level thereof, and the expected operating range of industrial heat pumps, an energy saving potential of 80 PJ/year is estimated for Dutch industry. This would save Dutch industry 640 M€/year and reduce CO_2 emissions by at least 2.5Mton/year. In addition, industrial heat pumps are an innovative product, for which a worldwide market exists, therewith creating new business for equipment manufacturers.

Role of heat pumps in future heat system

- Five sources of renewable heat
  - Biomass
  - Sustainable electricity
  - Geothermal energy
  - Ambient energy
  - Solar energy
- Heat pumps will play a major role as conversion technology between these sources (including waste heat) and the end-use of heat, both low-temperature heat as well as high-temperature heat.

Energy system for renewable heat



Scope of Work

- The main scope of this work is
  - Technology Development : latest status (International) R&D for heat pump technologies
  - Stakeholder engagement : the involvement of end-users from different industrial sectors (chemical, paper, steel, food etc) during the development trajectories in which technology suppliers and technology suppliers are involved
  - Applicability : Establish the applicability of industrial heat pumps in a wider perspective (operating window, capex, opex, integration aspects etc per high potential industrial sector)
  - Awareness : Raising awareness with end users and technology developers of heat pump technologies and their operational characteristics and their potential impact in an industrial setting.
  - Platform Management : Prepare plan for the follow up towards market implementation.

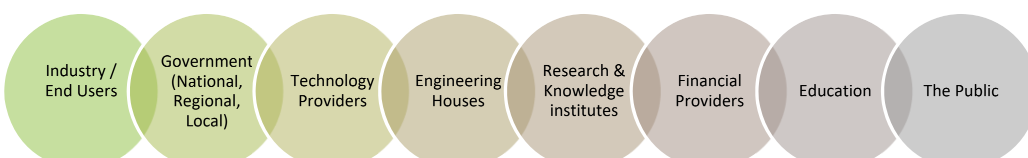
2 concurrent projects, ECN and ISPT

Final reports are separate, co-ordination of the activities has taken place during the project for maximum synergy, although the findings and recommendations may differ.

SUB TOPIC	ROLE ECN	ROLE ISPT
Technology Development	End responsible	Contributor
Stakeholder engagement	Contributor	End responsible
Applicability	End responsible	Contributor
Awareness	Joint responsible	Joint responsible
Platform management	Contributor	End responsible

Stakeholder Engagement

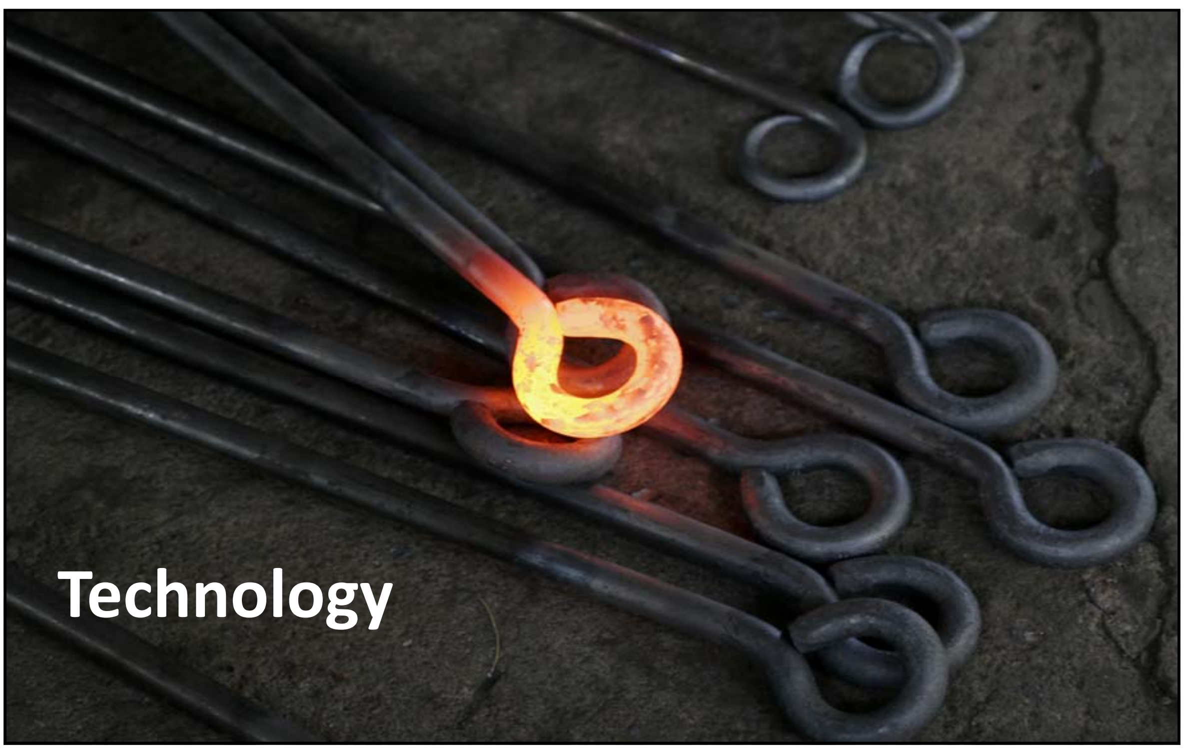
- Optimizing industrial heat management requires participation and action by a large number of stakeholders as shown by the diagram below



Participants workshop

Bedrijf	Naam
AkzoNobel	R. Morssinkhof
AkzoNobel	D. Berghuis
Balcke-Dürr en Wallstein	J.A. Toebes
Bosch	A. Winkelhorst
BRONSWERK	G. ten Brink
Bronswerk	S. Brouwer
Bronswerk	J. van der Kamp
Corbion	H. Pelt
Corbion	H. de Vries
COSUN	M.van Dijk
Crown & Van Gelder	M. van de Pol
De Kleijn energy C&E	M. Smeding
DOW - ISPT	K. Biesheuvel
DUYNIEGROUP	J. Knops
ECN	S. Spoelstra
ECN	R. Groen-Marks
ECN	S. Bollwerk
Enpro	R. Kleiburg
Emmtec Services	D. Buitenwerf
Emmtec Services	E. Olde
EnergQ	T. van Ewijk
Energy Consulting	van As
Energy Matters	J. Grift
ENGIE	E. Hoogendoorn
ENGIE	H. van Twillert
ENGIE	J. Vroon
Equinix	H. Schelvis
FME	H. van der Spek
FRAMES-GROUP	N. ten Asbroek
FrieslandCampina	P. Berden
GEA refr.NL	J.van Rooijen
Geelencounterflow	S. Geelen
Geelencounterflow	B. Joris
Geelencounterflow	F. Verdonschot
Heineken	C. Versteegh

Bedrijf	Naam
Heineken	M. van Nuus
Heineken	I. de Sera
Hexion	M. Oudshoorn
Huhtamaki	R. Vos
IEE	E. Klop
IF-technology	R. Kleinlugtenbelt
Innecs	G. Schimmel
IOI - Loders Croklaan	J. Keizer
ISPT	A. ten Cate
ISPT	K. Rietkerken
Johnson Controls	F. van Mierlo
Kapp	A. Trisscheijn-Nooteboom
Kapp	R. Algera
KCPK	L. de Vries
KH Engineering	L. Disse
KWA	F. Pennarts
Phetradico	O. Kleefkens
Qpinch	C. Heeren
RHDHV	J. Varwijk
RVO	B. Manders
RVO	J. Otten
RVO	J. Nauta
RVO	M. Clement
Sitech	W. Spierenburg
Stora Enso	M. Marcus
Tebodin	S. Clevers
TKI E&I	P. Alderliesten
TKI E&I	R. Kreiter
Uniper Energy	H. Peters
Uniper Energy	Anne van der Marel
Witteveenbos	H. Smit
Witteveenbos	WJ. van Spierenburg



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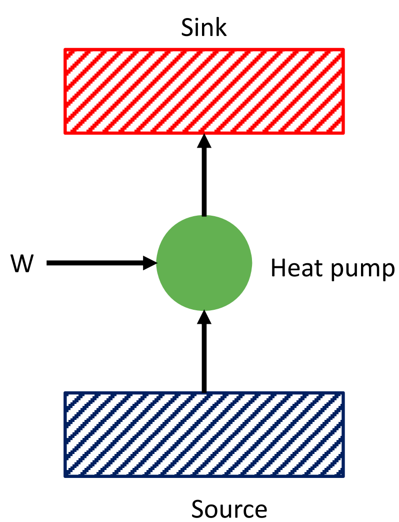
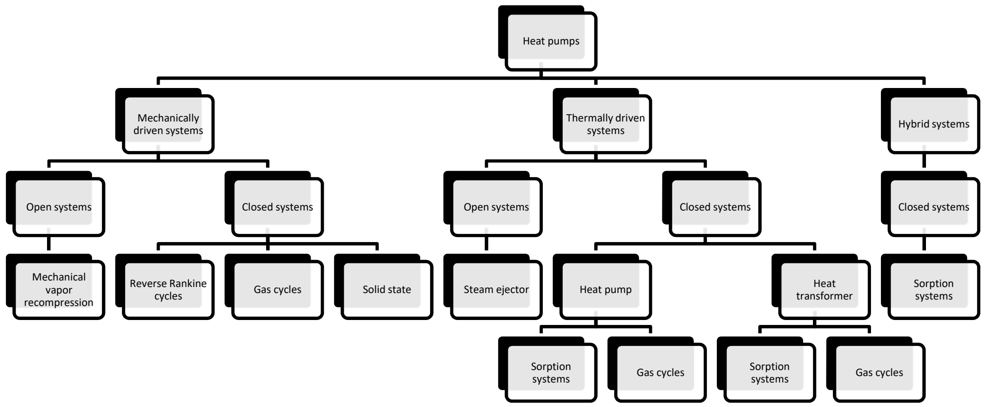
Heat pump definition

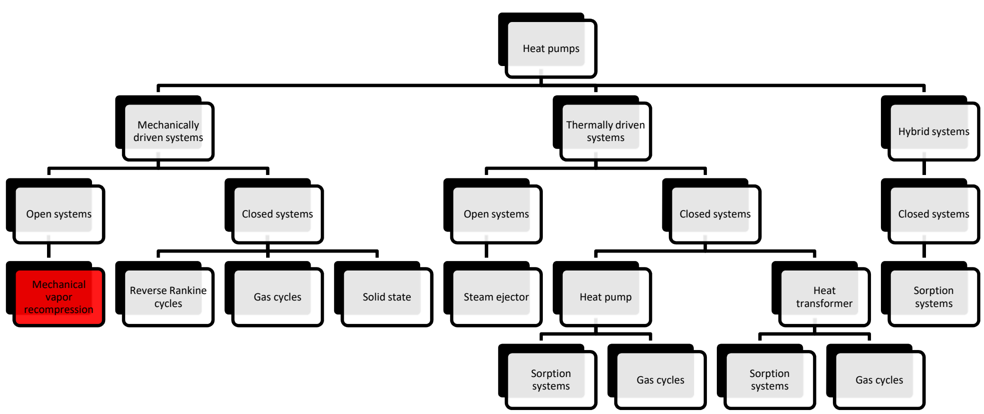


- Device that moves heat in the opposite direction from a low temperature source to a high temperature sink
- Mechanical work is needed to accomplish this
- Heat is withdrawn from the source
- Heat is supplied to the sink
- Thermodynamically the reverse of a work cycle (conversion of heat to power)
- Heat pump concept can be realized through a variety of thermodynamic cycles

Heat pump technology classification



Heat pump technology classification



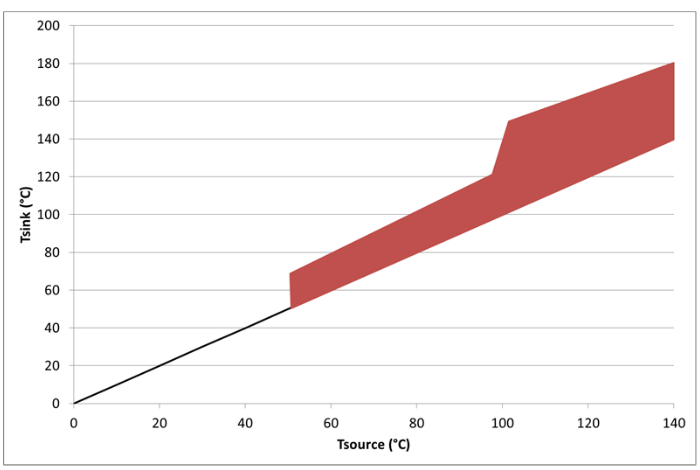
Mechanical vapor recompression

- Direct compression of process medium to higher pressure & temperature
- Applicability depending on process medium
- High efficiency
- Multistage compression to obtain high temperature lifts
- Applied in food & chemical industry
- Best known example: steam compression

Status : In commercial use

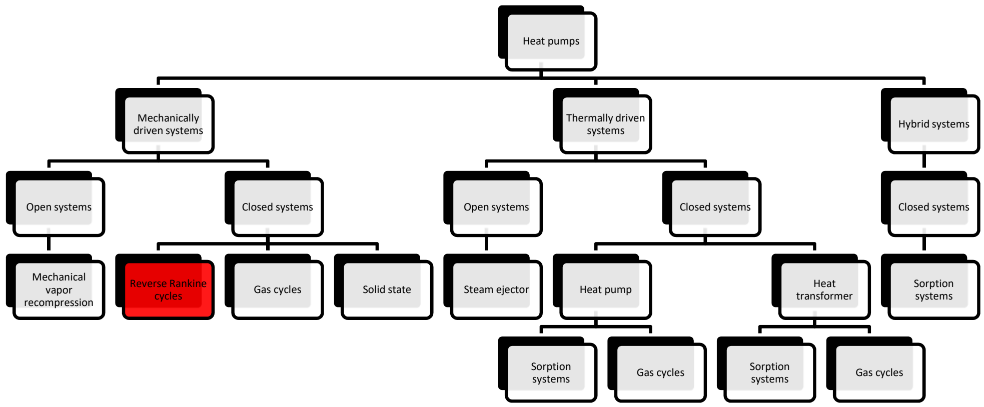
Suppliers : AtlasCopco, MAN-turbo, Howden, Siemens, Piller, Turbo Claw, SpiraxSarco, Spilling, Heliex, ..

Application area



Thermal power size up to 60 MW

Heat pump technology classification

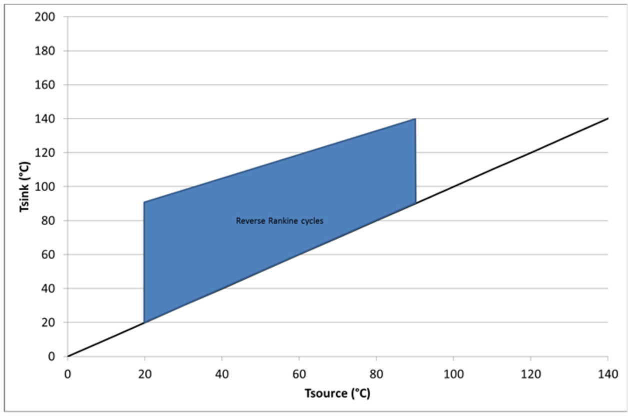


Reverse Rankine cycles

- Technology originating from refrigeration
- Operating range determined by working medium
- Multistage compression for high temperature lifts
- Refrigerants subdivided into synthetic and natural (CO_2, NH_3, hydrocarbon)
- Commercially available for sink temperatures up to 90 - 100°C
- On request available for sink temperatures up to 120 - 140°C
- Under development for sink temperatures > 140°C, using either hydrocarbons or newly developed synthetic refrigerants

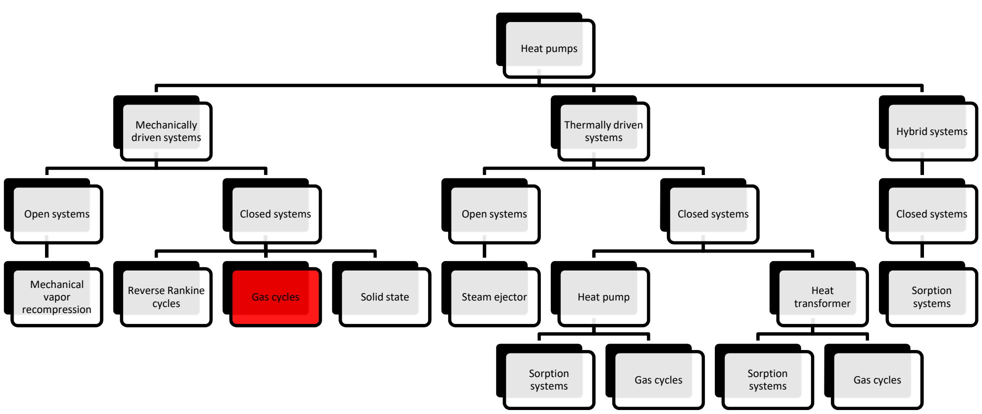
Status :	In commercial use
Suppliers :	Durr, Emerson, Enerblue, ENGIE, Friotherm, GEA, Hybrid Energy, IBK, Johnson Controls, Kobe steel, Mayekawa, Mitsubishi, Ochsner, Star refrigeration, Thermea, Viking, …

Application area



Thermal power size up to 20 MW

Heat pump technology classification



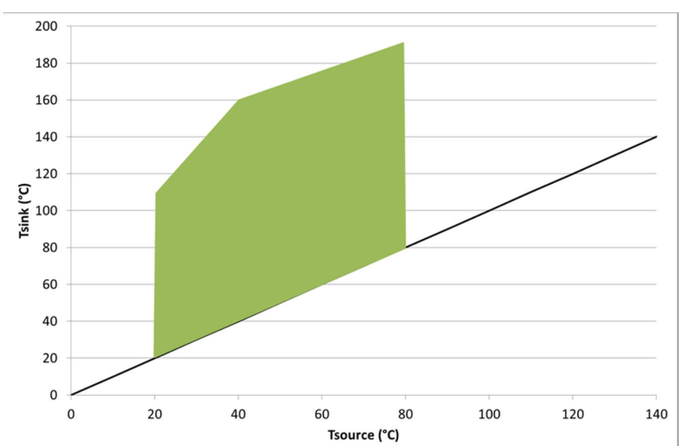
Gas cycles

- Use gas as working medium therewith providing flexibility in operating range
- Working medium usually noble gas
- Stirling/thermoacoustic, Brayton cycles
  - Stirling heat pump commercially available
  - Brayton heat pump (ECOP) entering market, no installation in operation

Status : In commercial use

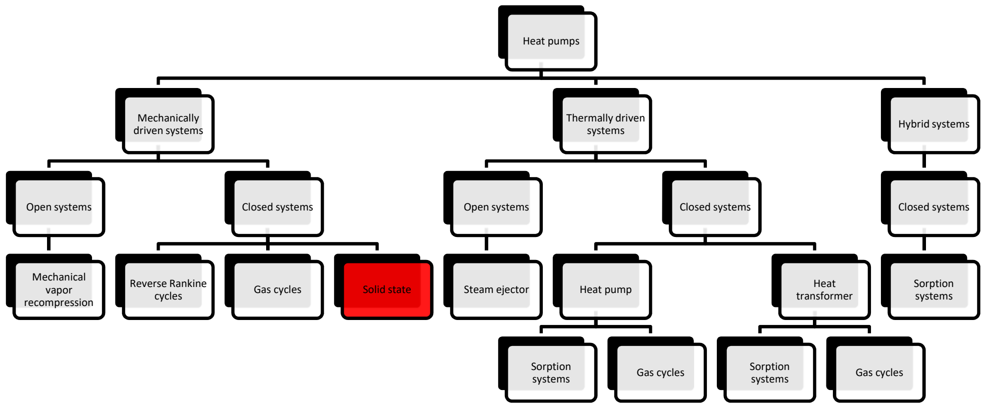
Suppliers : SPP

Application area



Thermal power size up to 500 kW/unit

Heat pump technology classification



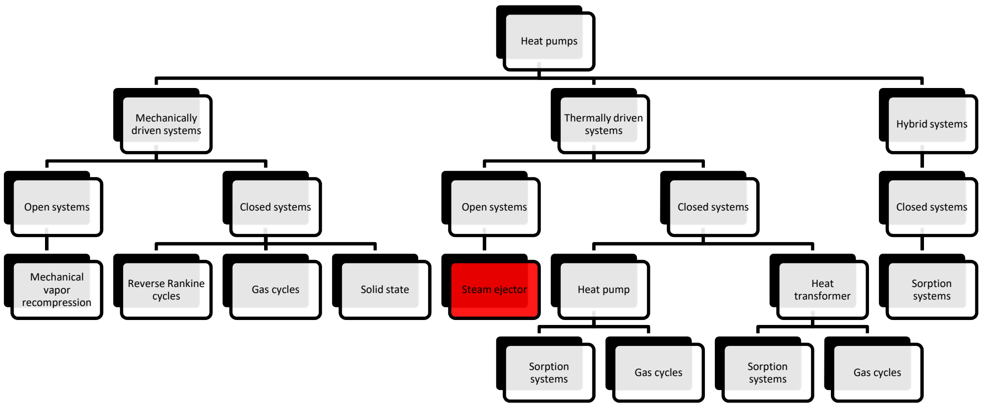
Solid state systems

- Use of solid state materials to generate heat pumping effect
- Examples
  - Magnetocaloric
  - Thermoelectric
  - Elektrochemical
- Thermoelectric cooling commercially available at small (household) scale
- Other technologies in development stage, probably more suited for small scale applications

Status : Under development

Suppliers :

Heat pump technology classification



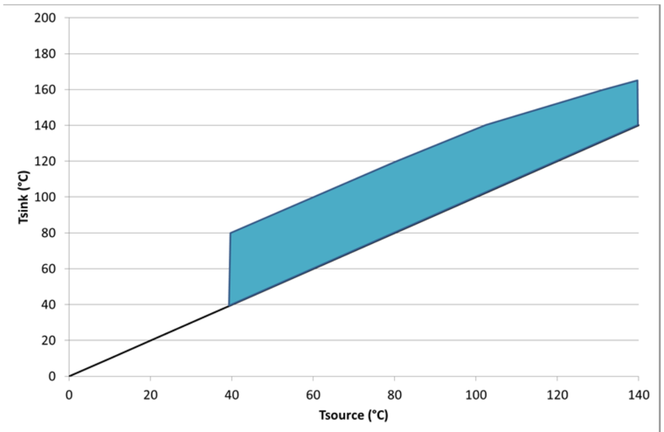
Steam ejector

- Simple
- No moving parts
- Use of medium/high pressure steam
- Low efficiency
- Low costs

Status : In commercial use

Suppliers : GEA, Kadant, Koerting, SpiraxSarco,

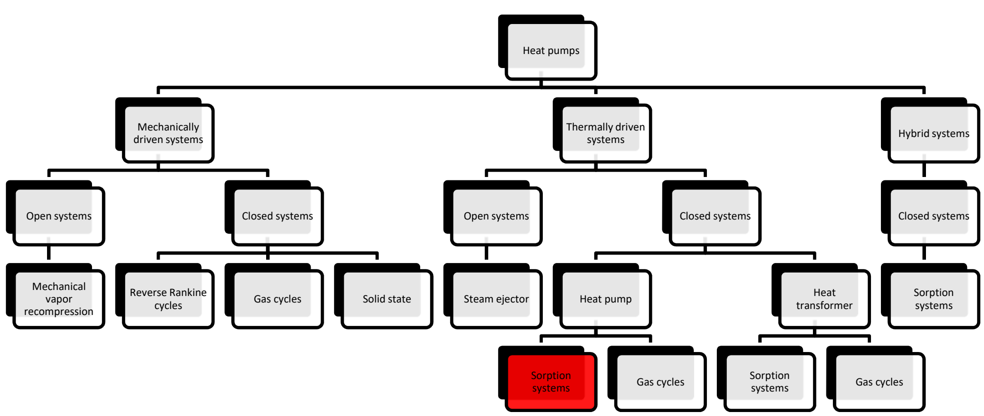
Application area



Steam of 10 bara needed to drive system

Thermal power size up to 100 MW or more

Heat pump technology classification



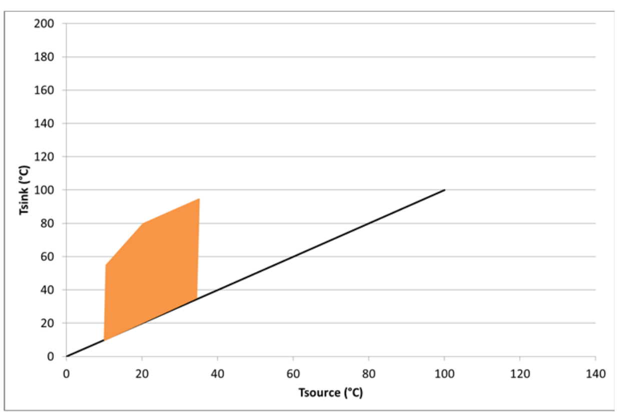
Thermally driven sorption heat pump

- Liquid sorption
  - H_2O/LiBr, NH_3/H_2O
- Solid sorption
  - Silicagel/Water, Zeolite/water
  - C/Ammonia, C/Methanol
  - Metal/ H_2
  - Salt/Ammonia, Salt/Water
- Mostly available as heat driven cooling systems
- Limited availability as heat driven heat pump (only H_2O/LiBr)

Status : In commercial use

Suppliers : Thermax, York, …

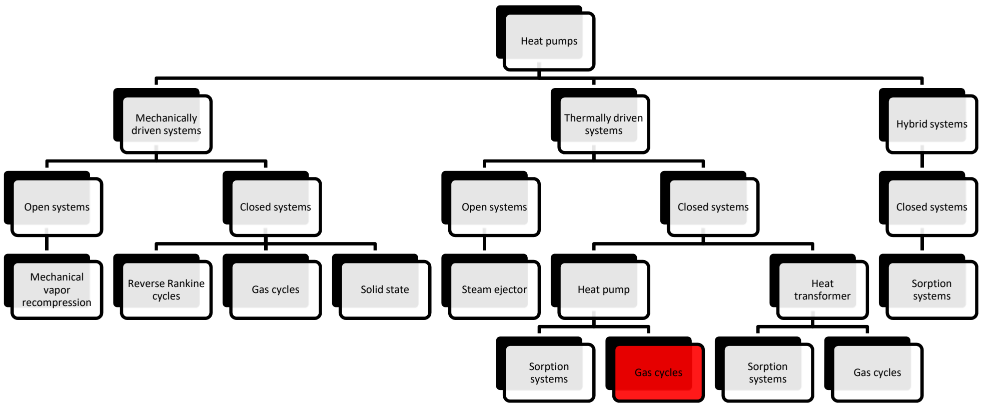
Application area



Steam (or natural gas) of about 5 barg needed to drive system

Thermal power size up to 20 MW per unit

Heat pump technology classification



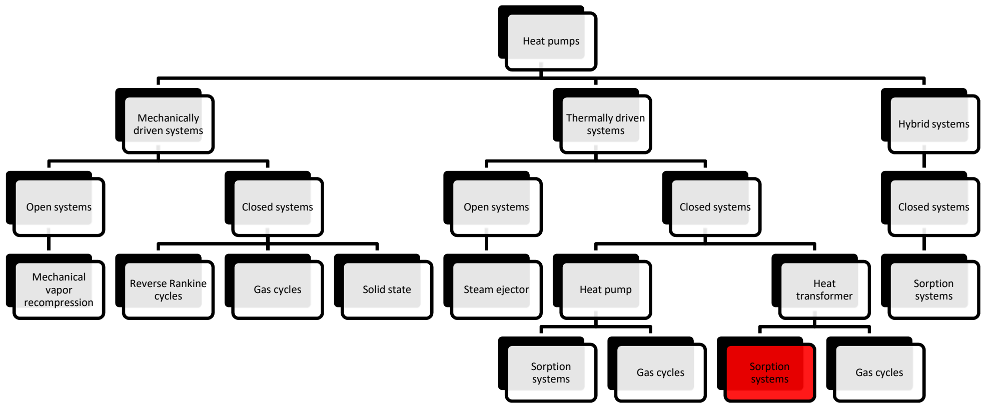
Thermally driven gas cycle heat pump

- Duplex systems
  - High temperature part driving the system (engine)
  - Heat pump part driven by the engine part
- Thermodynamics
  - Stirling / Vuilleumier
  - Thermoacoustic
  - Brayton
- Developments for residential applications
- No industrial applications

Status : Under development

Suppliers :

Heat pump technology classification



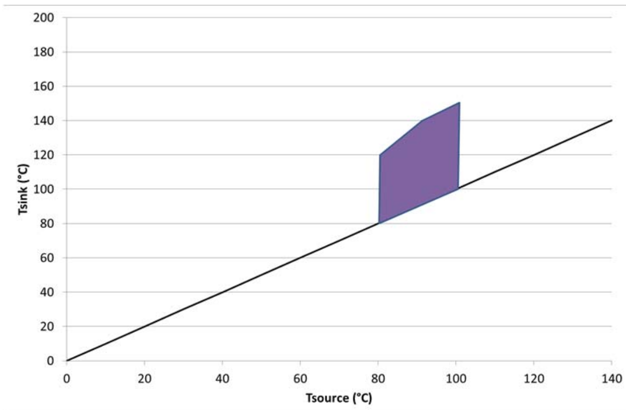
Thermally driven sorption heat transformer

- Liquid sorption
  - H_2O/LiBr
  - PPA/H_2O
- Solid sorption
  - C/Ammonia, C/Methanol
  - Metal/ H_2
  - Salt/Ammonia, Salt/Water
- H_2O/LiBr heat transformer is only commercially available technology at this moment
- PPA/H_2O system at pilot scale

Status : In commercial use

Suppliers : Broad, Thermax, York, …

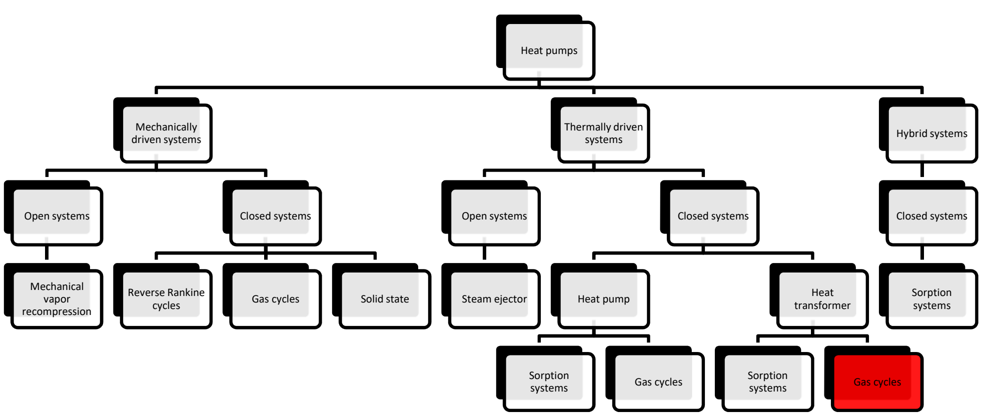
Application area



Cooling water of 20-30°C required

Thermal power size up to 10 MW/unit

Heat pump technology classification



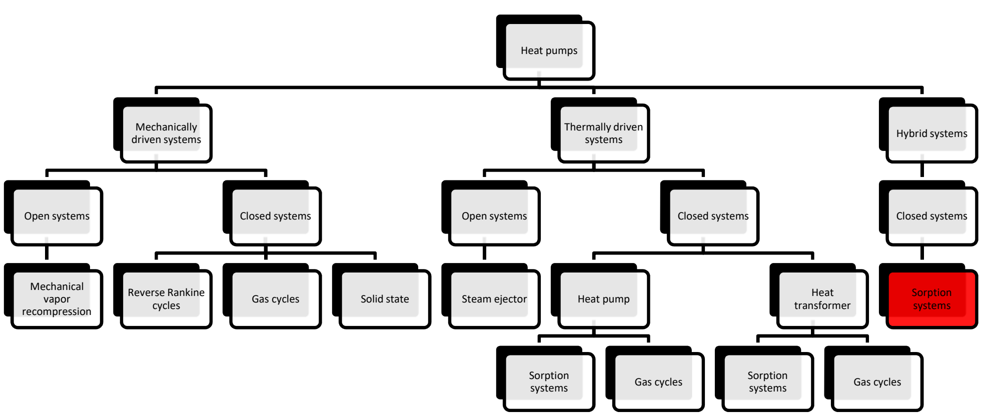
Thermally driven gas cycle heat transformer

- Duplex systems
  - Waste temperature part driving the system (engine)
  - Heat pump part driven by the engine part
- Thermodynamics
  - Stirling / Vuilleumier
  - Thermoacoustic
  - Brayton
- Commercially not available

Status : Under development

Suppliers :

Heat pump technology classification



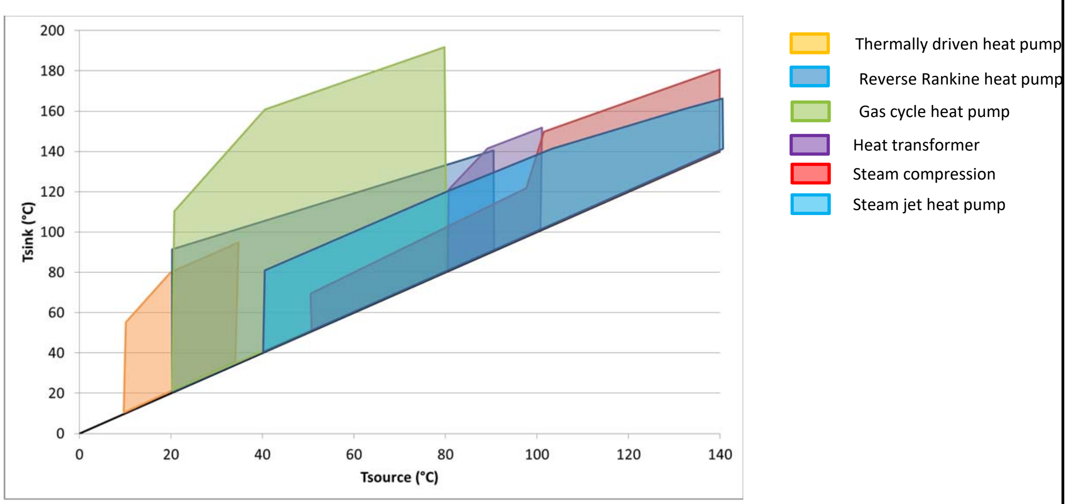
Hybrid systems

- Systems driven both by waste heat and electricity
- Usually sorption systems with additional compressor
- Examples
  - Metal hydrides - compression
  - Solid state sorption – compression
- Technology not available commercially as heat pump

Status : Under development

Suppliers :

Overall view of application area

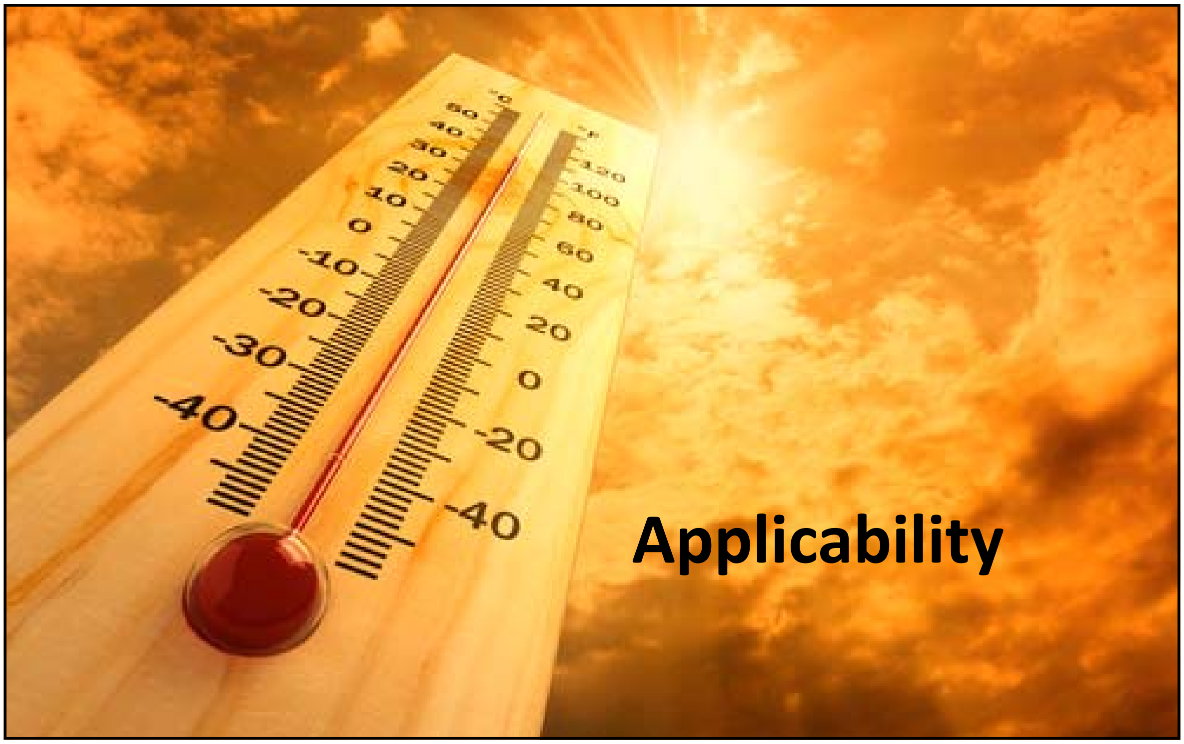


Final remarks

- Multiple thermodynamic cycles available for heat pump applications.
- Wide range of operating temperatures already commercially available in the market, however
  - A temperature match does not necessarily indicate a match in capacity
  - Technically feasible does not mean economically feasible
  - Efficiencies are not included in the application area graphs and have large influence on economic feasibility
  - Individual companies may impose specific requirements with respect to working media on their sites

Recommendations

- Cost reduction by standardization and series production
- Technologies
  - Reverse Rankine cycles for higher temperatures
  - General purpose gas cycles for high temperatures
  - Economical feasible steam compression for smaller capacities (up to 10 MW)



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  - Bottom up approach
- Investment costs & integration aspects
- Business case end-user
- Societal benefits
  - Environmental benefits
  - Employment

Approach to estimate industrial heat demand

- Use Eurostat data to obtain consistent data between EU-28 and NL
- Obtain final energy use and electricity use per sector
- Final energy use – electricity use = energy use for heat
- This neglects present use of electricity for heating purposes (direct electrical heating, cooling/refrigeration, …)

Industrial heat demand EU-28 & NL

	EU-28			NL		
	Total (PJ)	Electricity (PJ)	Heat (PJ)	Total (PJ)	Electricity (PJ)	Heat (PJ)
Iron & steel	2045	370	1675	101	9.4	91.6
Non-ferrous metal industry	392	231	161	10.1	7.3	2.8
(Petro)chemical industry	2168	650	1518	275	45	230
Non-metallic minerals	1420	244	1176	24	4.2	19.8
Mining	141	65	76	5.3	0.9	4.4
Food, drink & tobacco industry	1222	418	804	87	23.2	63.8
Textile, leather & clothing industry	187	75	112	3.7	1.3	2.4
Paper and printing	1398	422	976	23.5	8.7	14.8
Transport equipment	338	193	145	3.9	2	1.9
Machinery	772	425	347	20.4	10.1	10.3
Wood & wood products	332	85	247	2.2	0.8	1.4
Construction	283	68	215	23.8	3.1	20.7
Other industries	768	343	425	18	7	11
Refining	1899	131	1768	154	9.3	145
Total	13365	3720	9645	752	132	620

Relevant sectors

- Heat pumps will most likely be found in energy intensive process industries with heat demand at moderate temperatures (< 200°C)
- Most relevant sectors
  - Refining
  - (Petro)chemical industry
  - Food, drink & tobacco industry
  - Paper and printing
- Process temperatures < 100°C can be served by commercially available heat pump technology presently on the market
- Emerging and future heat pump market relates to process temperatures between 100°C - 200°C

Heat pump market

- Top-down approach
  - Energy use for heating chemical, refining, food, paper industry
  - % of heat used < 100°C and between 100°C-200°C
  - Assume source of waste heat is always available and of sufficient temperature
- Bottom-up approach
  - Production statistics from Eurostat
  - Heating/cooling profiles per production process
    - Distillation column database (chemicals + refining)
    - Paper industry
    - Food (brewery, milk, potato processing, sugar)
  - Typical plant capacities used to calculate typical heat pump capacities

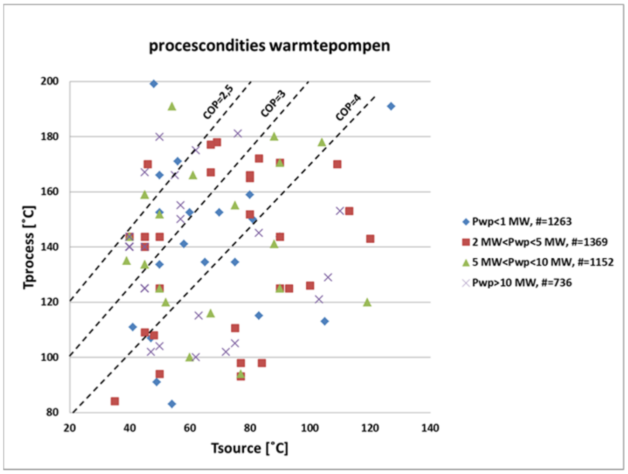
Top-down approach

	EU-28		NL	
	< 100°C (PJ)	100°C - 200°C (PJ)	< 100°C (PJ)	100°C - 200°C (PJ)
Refining	0	265	0	22
(Petro)chemical	0	531	0	81
Food	442	362	35	29
Paper	39	898	1	14
Total	**481**	**2056**	**36**	**146**

Results top-down approach

- Theoretical heat pump market
  - EU-28: 2537 PJ, equivalent to 88000 MW of installed heat pump power, assuming 8000 operational hours per year
  - NL: 182 PJ, equivalent to 6300 MW of installed heat pump power, assuming 8000 operational hours per year
- Present market < 100°C
  - EU-28: 481 PJ, equivalent to 16700 MW
  - NL: 36 PJ, equivalent to 1250 MW
- Emerging & future market 100°C - 200°C
  - EU-28: 2056 PJ, equivalent to 71300 MW
  - NL: 146 PJ, equivalent to 5050 MW

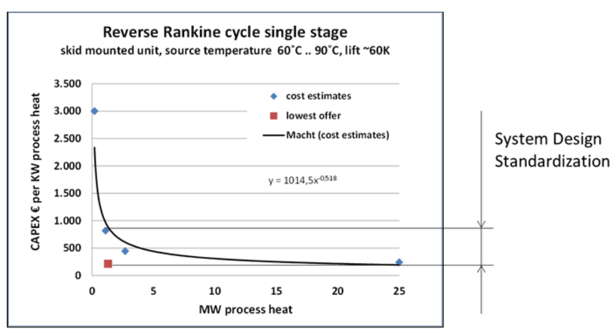
Bottom-up approach



- European market
- Results in actual applications
- Total coverage about 40% of the heat demand in relevant sectors < 200°C
- High quantities of heat pumps are in the range up to 10 MW

Investment costs & integration aspects

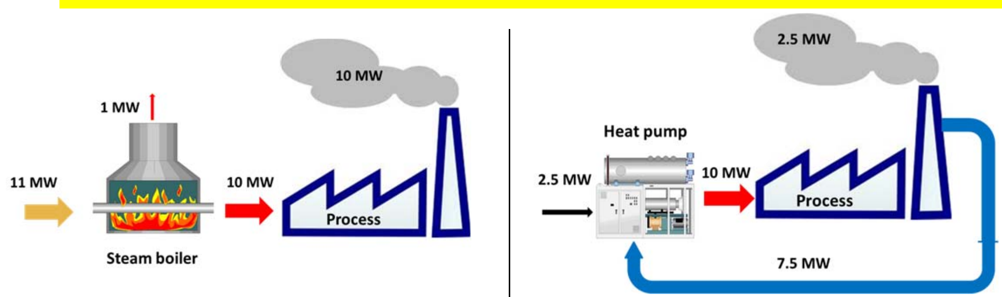
- Investment costs depend on operating temperatures, thermal capacity, and technology
- Typical costs range between 3000 €/kW$_{th}$ for small installations (~100 kW) to less than 200 €/kW$_{th}$ for large installations (> 10 MW)
- Integration costs are highly process and site specific. Typically, integration costs are assumed equal to heat pump costs.



Example application

- Application of 10 MW heat pump to replace steam production by gas-fired boiler
- Gas-fired boiler has efficiency of 90%
- COP of heat pump is 4
- Efficiency of electricity production is 41%
- Steam price is 20 €/ton
- Electricity price is 50 €/MWh
- Operating time is 8000 hours/year

Cost savings by heat pump



Steam boiler		Heat pump	
Steam demand (kton/yr)	128	Steam demand (kton/yr)	128
		Electricity use (GWh/yr)	20
Steam price (€/ton)	20	Electricity price (€/MWh)	50
Primary energy use (TJ/yr)	317	Primary energy use (TJ/yr)	174
Energy costs (M€/yr)	2.6	Energy costs (M€/yr)	1.0

Business case end-user

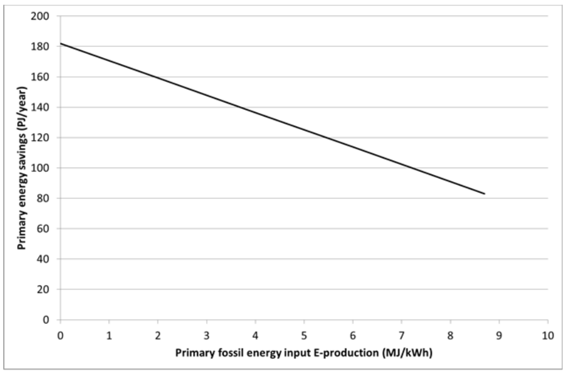
- Investment costs = 4 M€
  - Heat pump assumed 200 €/kW = 2 M€
  - Integration costs assumed identical to heat pump costs = 2 M€
- Maintenance costs assumed 3% of investments costs = 120 k€/year
- Yearly savings on energy costs = 1.6 M€/year
- Simple payback time is 2.7 years

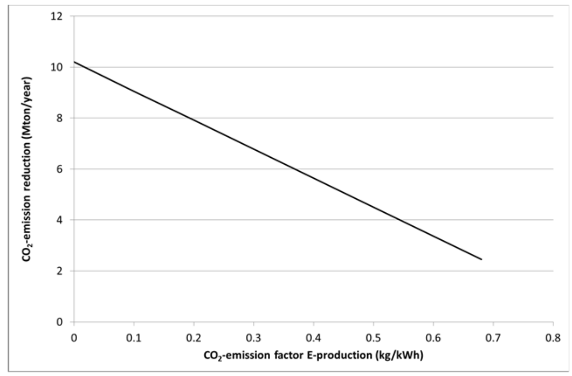
Environmental benefits approach

- Maximum energy savings calculated based on theoretical potential
  - Typical performance heat pump COP = 4
  - Todays efficiency (fossil energy use) of electricity production is 41.4 % (8.7 MJ/kWh)
  - Energy savings are ≈ 46% for todays electricity grid
  - Energy savings will grow with the reduction on fossil energy use for electricity production
- Maximum CO_2 emission reduction
  - Typical performance heat pump COP=4
  - Todays emission of electricity production is 0.68 kg/kWh
  - CO_2 emission reduction ≈ 25% for todays electricity grid
  - CO_2 emission reduction will grow with the reduction on fossil energy use for electricity production

ECN

Environmental benefits results





- Minimum benefits are obtained by today's fossil energy use & CO_2 emission factors of electricity production
- Benefits increase with a more sustainable electricity system => robust technology

ECN

Employment in manufacturing

- Theoretical potential industrial heat pumps in EU-28 is 88000 MW
- Assuming 20% market penetration = 17600 MW
- Turnover heat pumps and integration is assumed 400 €/kW
- Total turnover is about 7 G€
- Assume turnover is realized during 20 years => 352 M€/year
- Average turnover per employee in NL machine manufacturing industry is about 200 k€/year
- This leads to 1760 new jobs in innovative heat pump manufacturing and integration
- This analysis neglects the conservation and extension of employment at industrial end-users due to increased competitiveness
- This analysis neglects worldwide market which is more than 10 times bigger than EU-28

Learnings from "GROW"

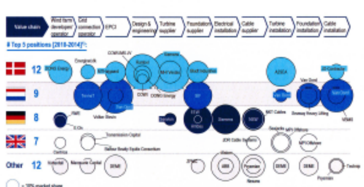


Figure 4 – Ranking of countries in the international offshore wind market[1] - Source: 4COffshore 2010-2014; EWEA 2010-2014; Roland Berger

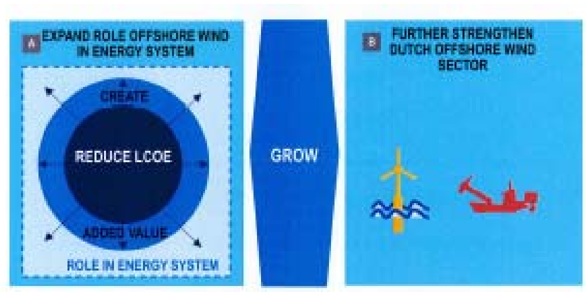


Figure 6 – Objectives of the GROW program

Learnings from GROW

- Set ambitious & visual target objectives
  - Eg 'Twenty for seven' (refers to the number of parties (20) and the financial objective (7 ct per kWh)
- Leverage expert consultants to
  a) define business plan and
  b) recruit senior participation from NL leading stakeholders (including financial contributions)

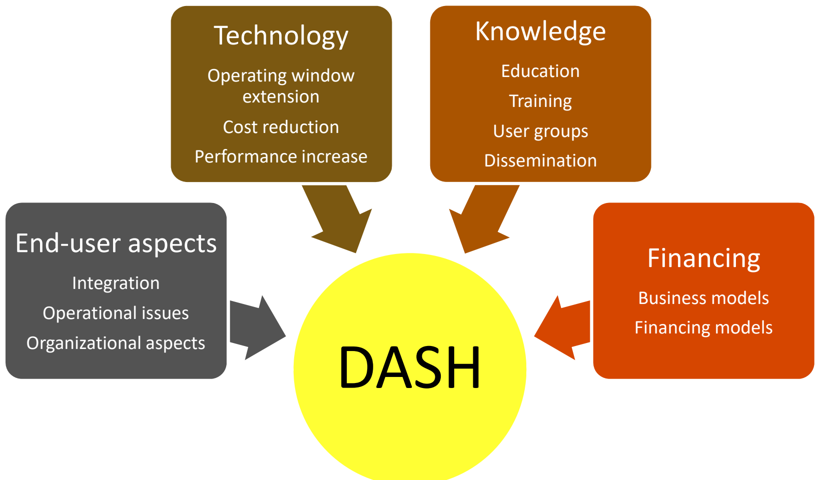
Basis for next steps : ECN perspective

- There is significant interest in NL for a 'mission driven innovation programme'
- There is growing momentum and a pipeline of projects to demonstrate heat pump technology in NL
- Analysis of the technology, applicability and market impact show significant advantages for NL to forge ahead quickly in terms of employment, commercial activity, emission reduction and integration of renewable energy

- Focus:

1. Technology development
2. End-user aspects
3. Knowledge development
4. Financing

DASH heat pump program



Background & vision

- Background
  - Targets on energy efficiency
  - Sustainable heat system
  - Electrification
  - Competitiveness industry
  - Innovation
- Vision
  - Energy efficiency is key to a transition to a sustainable energy system
  - Heat is the dominant final energy carrier for industrial processes
  - Industrial heat pumps will play an important role for heat delivery up to 200°C
  - Innovation is needed to play this role
  - The Netherland is suited because of major industrial end-users (energy intensive industry), manufacturing industry and knowledge infrastructure

Objectives & benefits

- Objectives
  - Demonstration of all technologies available
  - Cost target 150-200 Euro per kw (= ~50% reduction on current prices)
  - 300 MW heat pump installed in 2023 (= 10 PJ heat pump generated heat, 5% total heat demand)
- Benefits
  - Competitiveness Dutch industry
  - Innovation manufacturing industry
  - Reduction in fossil energy use
  - Reduction in CO_2-emissions
  - Robust choice for the future (electrification)

Some suggestions for overall objective

600 in 5
(600 MW installed before 2023)

DASH 5-50-500
(minimum number of projects per year accelerated)

10-20-30
(10% of total industry 10PJ re-used heat by 2030)

DASH 150
(target cost price per Kw)

Just food for thought… Needs creative input / agency to design logo…

Consortium & activities

- Consortium
  - Knowledge partners: ECN, TU Delft, …
  - Manufacturing industry: Durr, Duynie, IBK, BHT, GEA, GeelenCounterflow, JohnsonControls, …
  - Engineering & consulting firms: EnergyMatters, KWA, Kleyn Consulting, RHDVH, WitteveenBos, …
  - Industrial end-users: Chemistry (Dow, AkzoNobel, …), Paper (SmurfitKappa, …), Food (Heineken, Bavaria, LambWeston Meijer, Cosun, …)
  - International partners: ?
- Activities
  - Technology development
  - Knowledge development
  - End-user aspects
  - Financing models

Program lines
Technology development

- Extend application window of industrial heat pumps
  - Reverse Rankine cycles for higher temperatures
  - General purpose gas cycles for high temperatures
  - Small scale steam compression for smaller capacities (up to 10 MW)
- Cost reduction
  - Standardization
  - Production technology
- Integration aspects
  - Standardization
  - Working method
- Operational behaviour/flexibility/life span

Program line description

- State of the art
- Objectives and milestones
- RD&D challenges
- Potential activities
- Partners involved

Next Steps

1. Launch 'DASH' program with small number of NL early adopter supporters
   - Eg Dow, Smurfit Kappa, Akzo Nobel, Friesland Campina, ECN ...
2. Assign leading consultancy (Roland Berger or other) to lead the consortium
3. Develop key technology lines and roadmap within program based on initial findings in this report
4. Define top line 'goal' / objectives to gain attention & momentum
5. Facilitate funding for major program objectives

ECN is keen to continue to be involved in this development and to push boundaries to achieve maximum introduction of heat pumps in NL and abroad


Dutch program for the
Acceleration of
Sustainable
Heat Management in industry