Aalto University
School of Engineering

Heat Pumps and Renewable Heat Sources

Thermal Energy Storage Systems Theory

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Heat Pumps

Learning Outcomes

- Describe main types of heat pumps and operating principles
- Describe the benefits of heat pumps over other heating technologies
- Describe emissions impact of using heat pump arrangements

What is a heat pump?

A machine that moves heat energy from a low temperature to a higher temperature.

[2]

[1]

Heat pumps are energy converters, not energy sources!

Why do we use heat pumps?

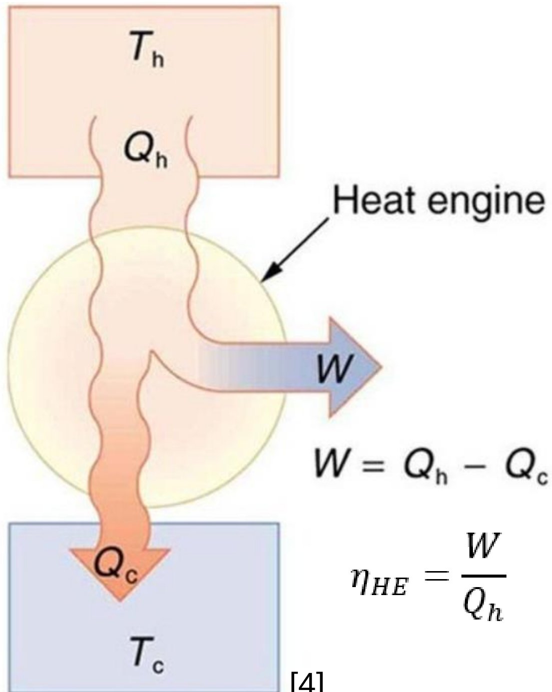
- To move heat energy from low to high temperature
- To access resevoirs of low temperature energy
- Very efficient heat production
- Can both cool and heat

For all these reasons, heat pumps offer a path to low carbon heating

[3]

Helen, Katri Vala

Heat Engine



[4]

Carnot determined for an ideal engine

$$\frac{Q_c}{Q_h} = \frac{T_c}{T_h}$$

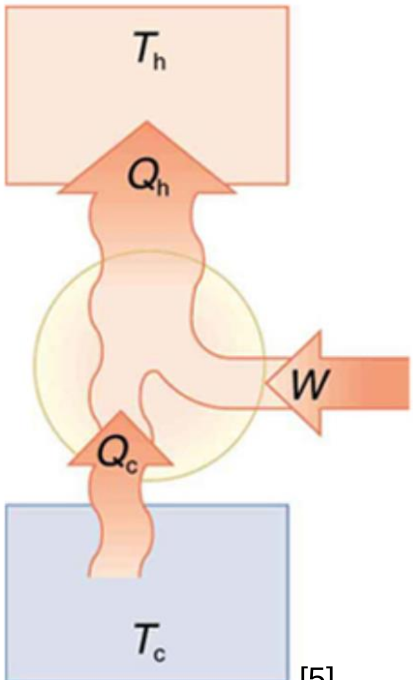
Heat engine efficiency can be shown as

$$\eta_{HE} = 1 - \frac{T_c}{T_h}$$

Actual Efficiency always less than ideal due to irreversible processes

- Friction, heat loss

Heat Pump



[5]

COP Coefficient of Performance

- The useful output over the required input
- Depends on service

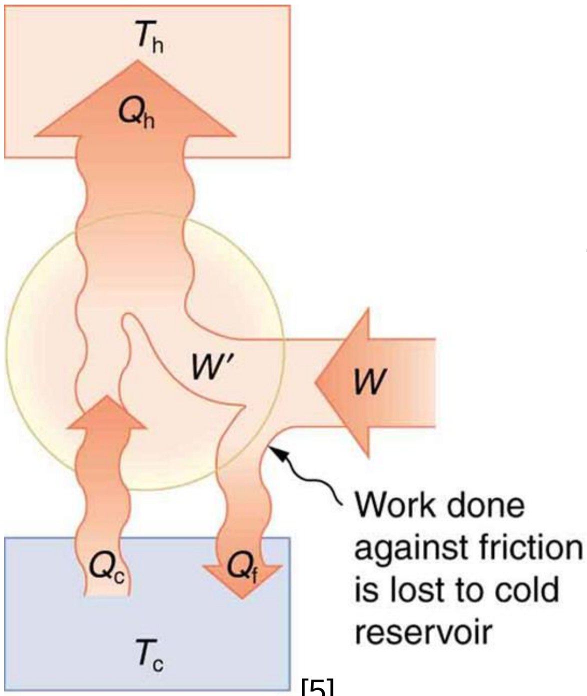
$$COP_{heating} = \frac{Q_h}{W} \qquad COP_{cooling} = \frac{Q_c}{W} = \frac{Q_h}{W} - 1 \qquad COP_{combined} = \frac{Q_h + Q_c}{W}$$

COP is inverse of heat engine efficiency

- Depends on temperature difference

$$COP_{heating} = \frac{1}{\eta_{HE}}$$

Heat Pump



[5]

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- Depends on temperature difference

$$COP_{heating} = \frac{1}{\eta_{HE}}$$

Impact of Temperature on COP

COP rises as ΔT shrinks

- As source temperature rises, COP rises for same sink temp
- COP varies throughout the year

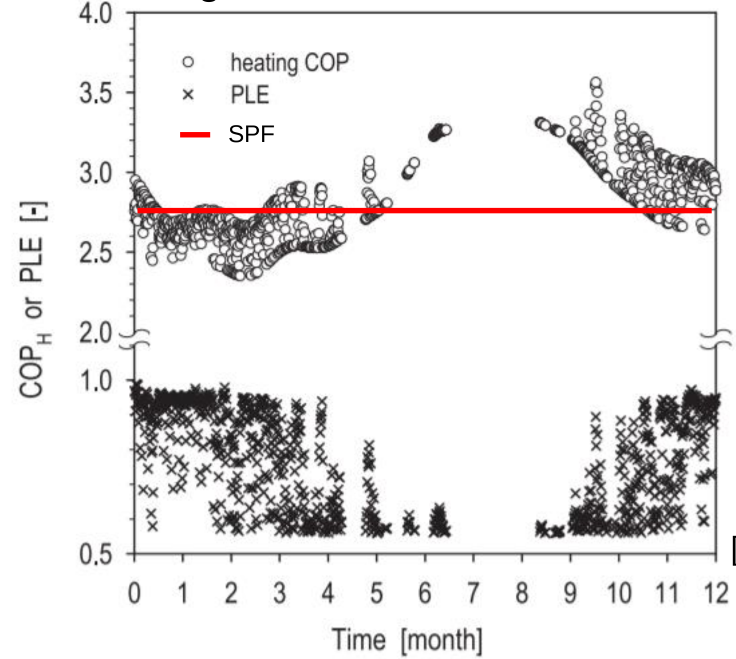
Seasonal Performance Factor

- SPF is the annual average COP

$$SPF_{heating} = \frac{Q_{h\ annual\ total}}{W_{annual\ total}}$$

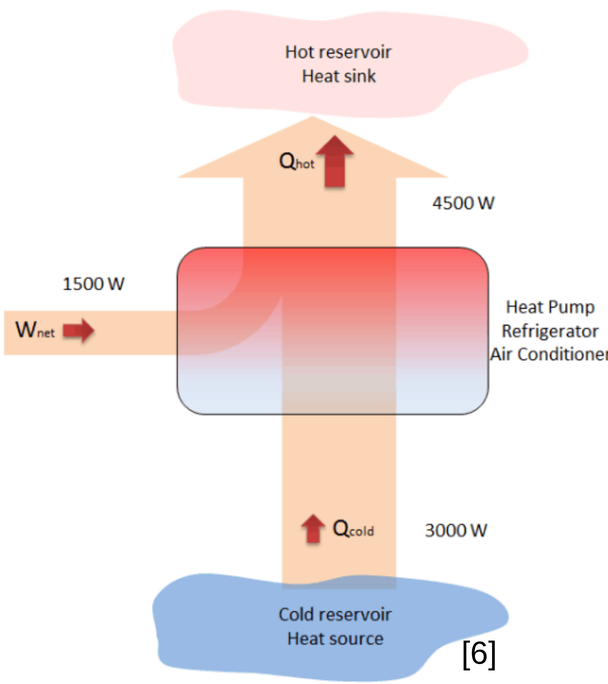
- Periods with higher load factors weighted more heavily

COP of heat pump for residential heating in Korea, seawater source



[6]

Example



[6]

Depends on Service

As Heater

$$COP_{heating} = \frac{Q_h}{W} = \frac{4500}{1500} = 3$$

As Air Conditioner, Refrigerator

$$COP_{cooling} = \frac{Q_c}{W} = \frac{3000}{1500} = 2$$

Combined heating and cooling

$$COP_{combined} = \frac{Q_h + Q_c}{W} = \frac{4500 + 3000}{1500} = 5$$

Types of Heat Pumps

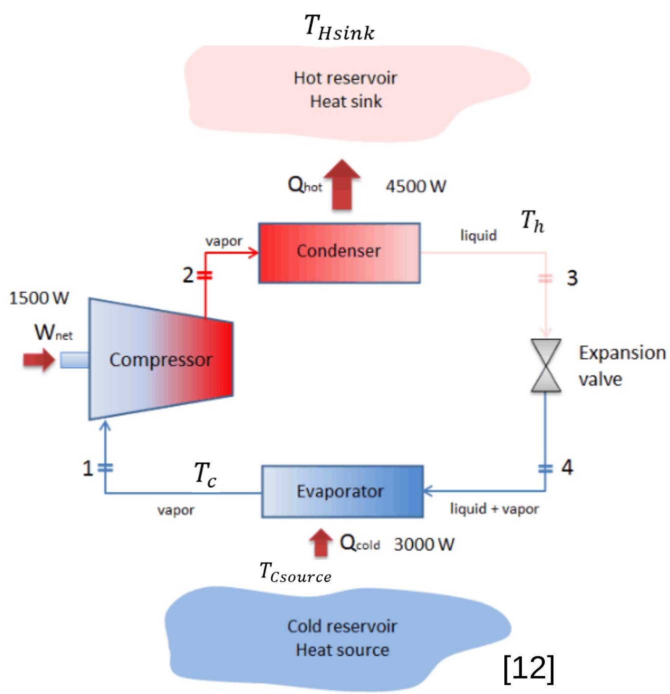
Compression

- Use mechanical energy
  - Typically an electric motor
- Refrigerent alternates between vapour and liquid state
- Service COP 2.1-5.4 [8]

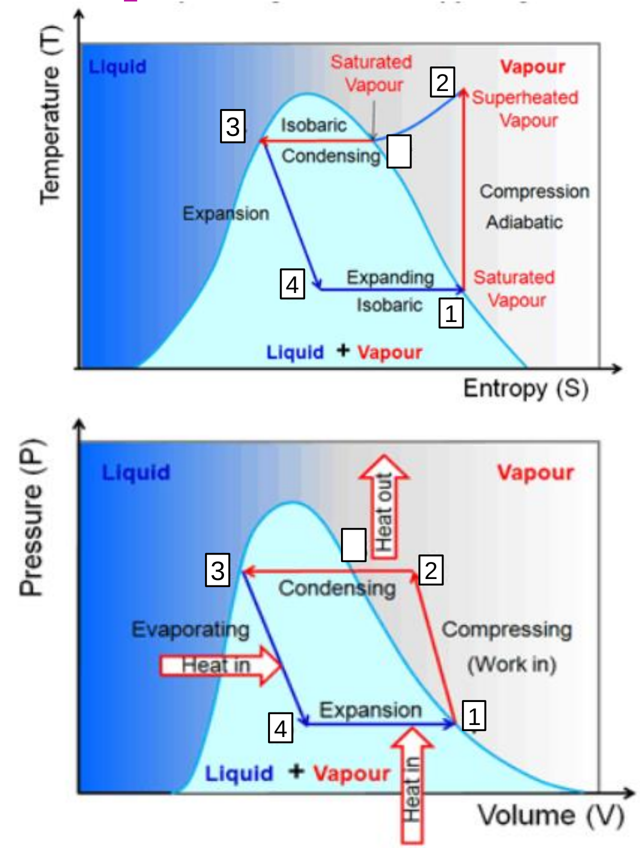
Absorption

- Uses heat energy
  - Waste heat, steam, natural gas
- Refrigerant alternates between being absorbed in a liquid and a vapour
- Service COP 0.7-1.7 [9,10]
- More often used for cooling [11]

Compression Heat Pumps

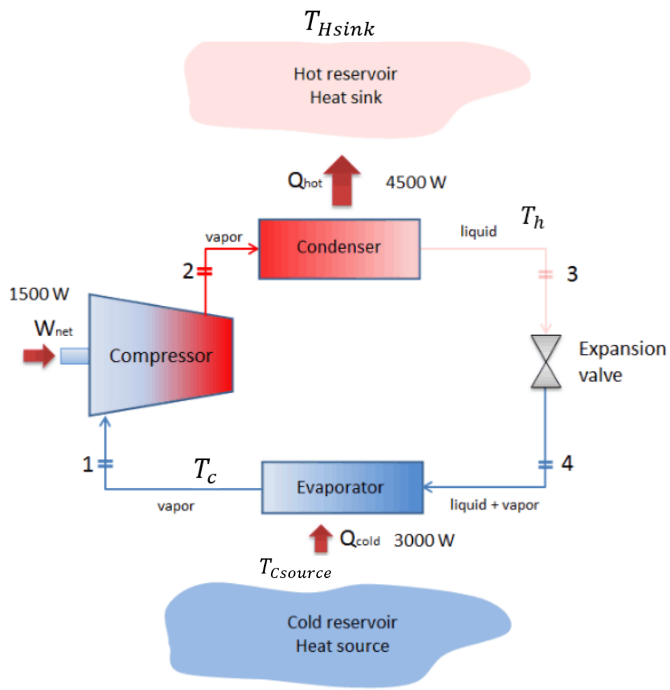


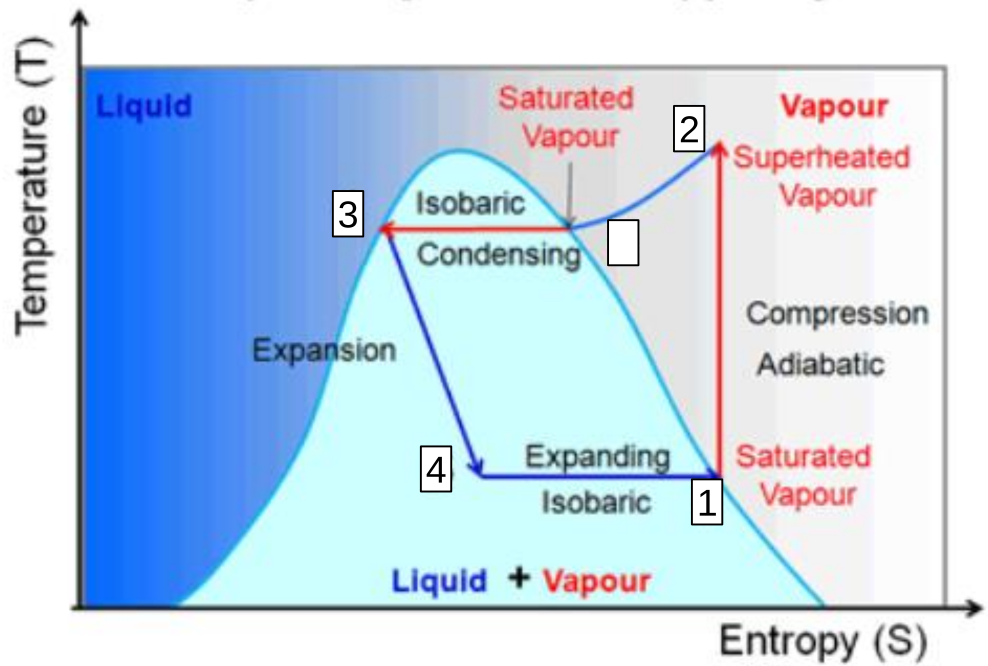
[12]



[13]

Compression Heat Pumps





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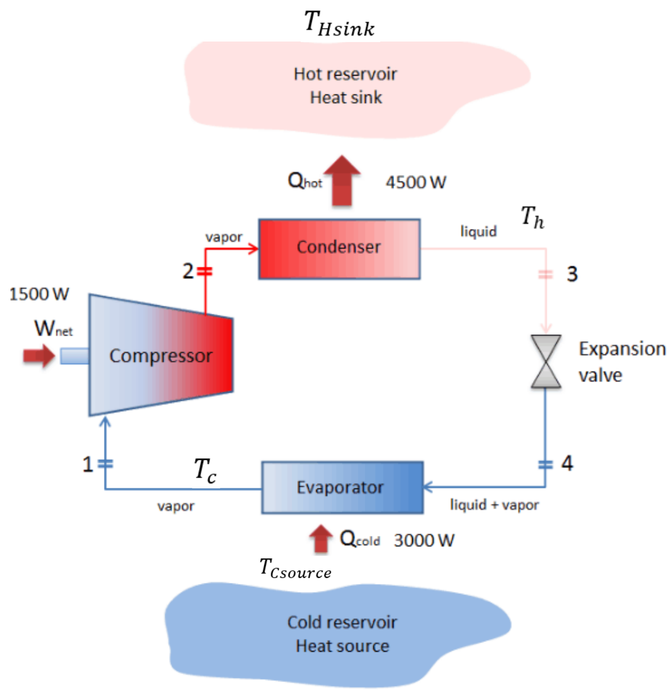
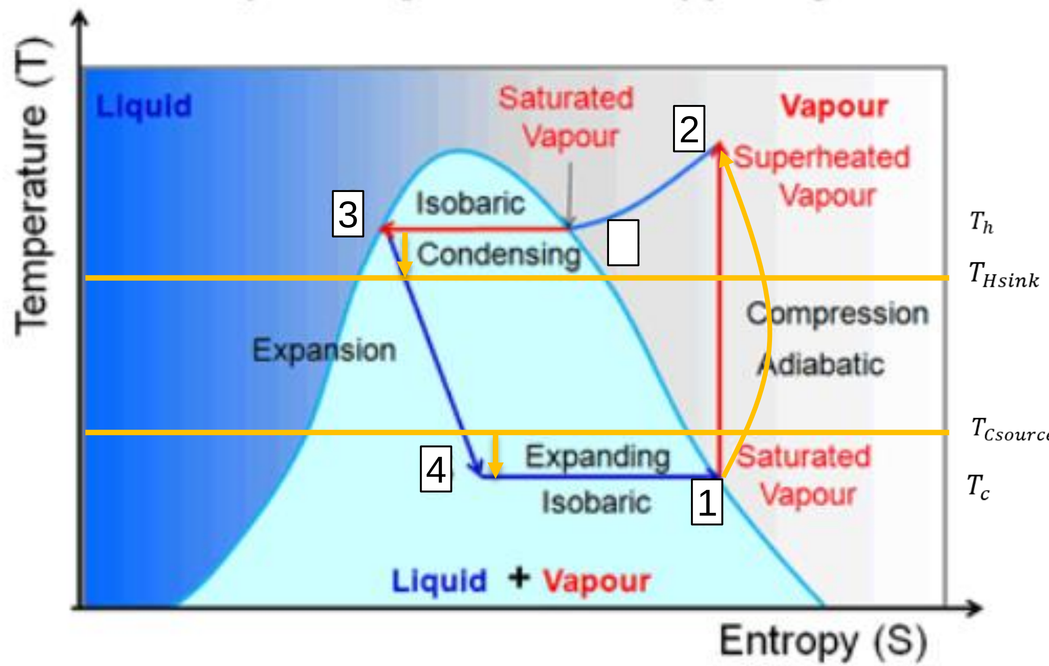
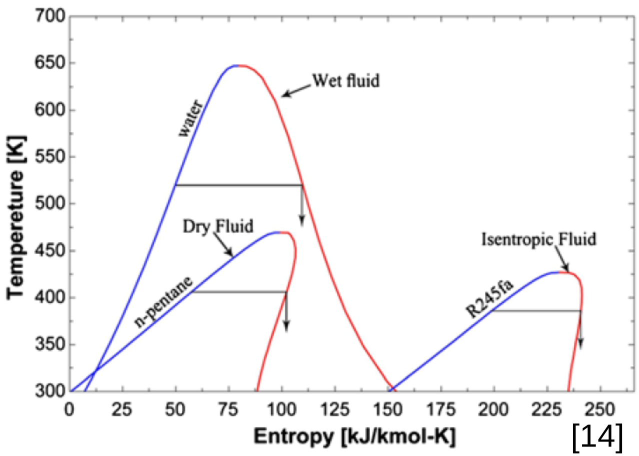


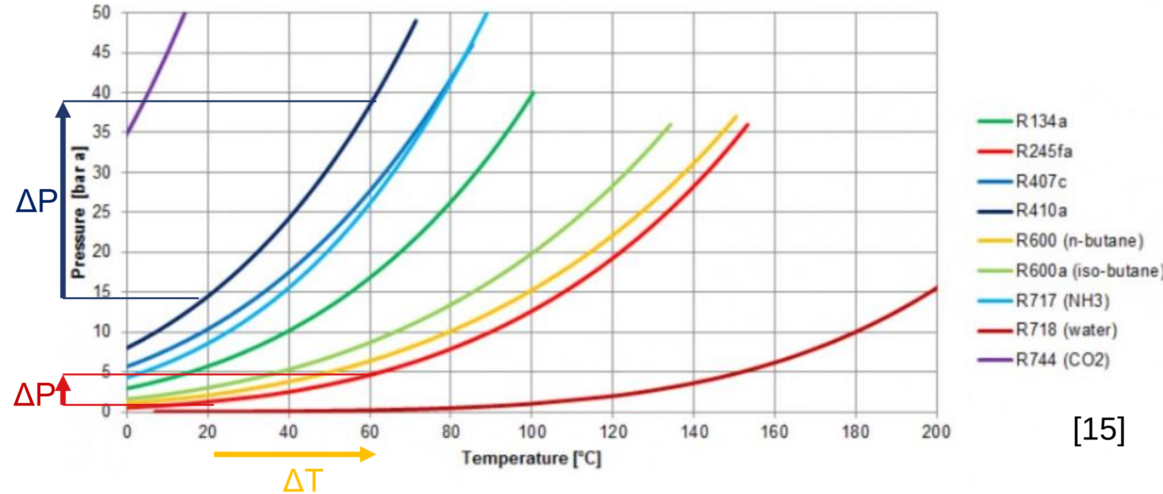


$T_h > T_{Hsink}$ $T_{Csource} > T_c$

Refigerant Properties



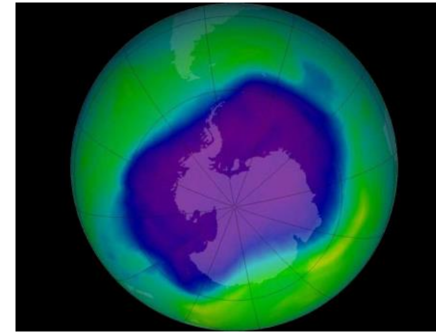
[14]



[15]

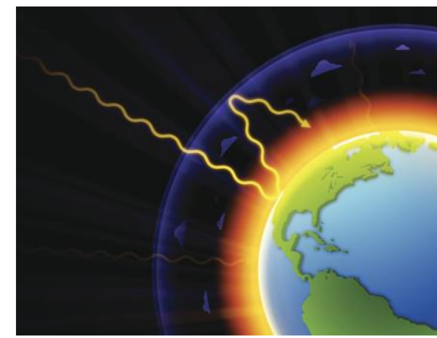
Refregerant Property	Impacted Design Parameter
Heat of Evaporation	System mass flow
Density	Component sizing
Pressure Ratio	COP, Pressure rating
Saturation Curve Shape	System Arrangement
Material Compatability	Material choice, Safety precautions

Refigerant Improvements


[16]

CFCs
Chloroflourocarbon

- High Ozone Depleation Potential
- Very high Greenhouse Warming Potential
- Phased out by Montreal Protocol 1987


[17]

HFCs
Hydroflourocarbon

- No Ozone Depleation Potential
- Very high Greenhouse Warming Potential
- Phased out by Kigali Amendment 2016

HFOs, NH_3, CO_2, butane, pentane are common low ODP & GWP
Hydroflouroolefins

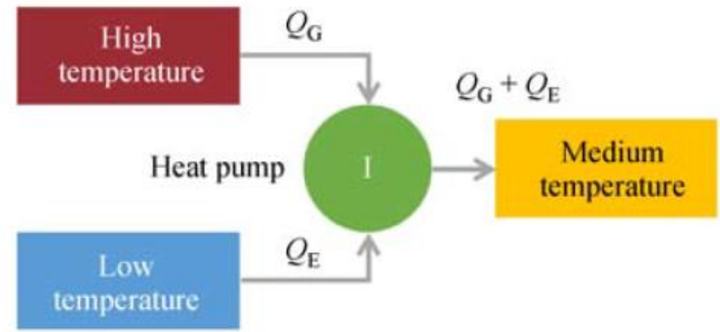
Absorption Heat Pumps

Similar operating principle to VCHPs

- Use heat energy rather than mechanical
- The compressor is replaced by a generator/absorber pair to move the refrigerant from low to high temperature
    - Typically require hot source of >120ºC

Services

- More often used for cooling than heating
- Common uses include refrigerators, ice rinks, and camping appliances
- $COP_{heating}$ 1.25-1.9, $COP_{cooling}$ 0.7-1.0



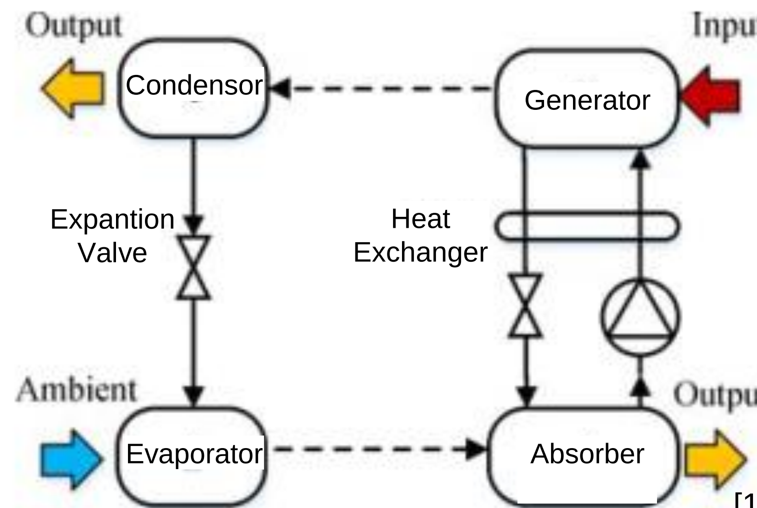
[18]

Absorption Heat Pumps

Main Components

- Comprised of a generator, absorber, heat exchanger, and pump.
- Condensor, expander, and evaporator unchanged.
- Typically a two part working fluid:
  - Refigerant and absorbant

- This is the best technical explaination I have seen of an absorption heat pump
  - Keep in mind, the arrangement described is for cooling. For heating the Cooling Tower would be replaced by your heating load, and the chilled water would be sourced from the cold source
- Can be more complex, see here for more



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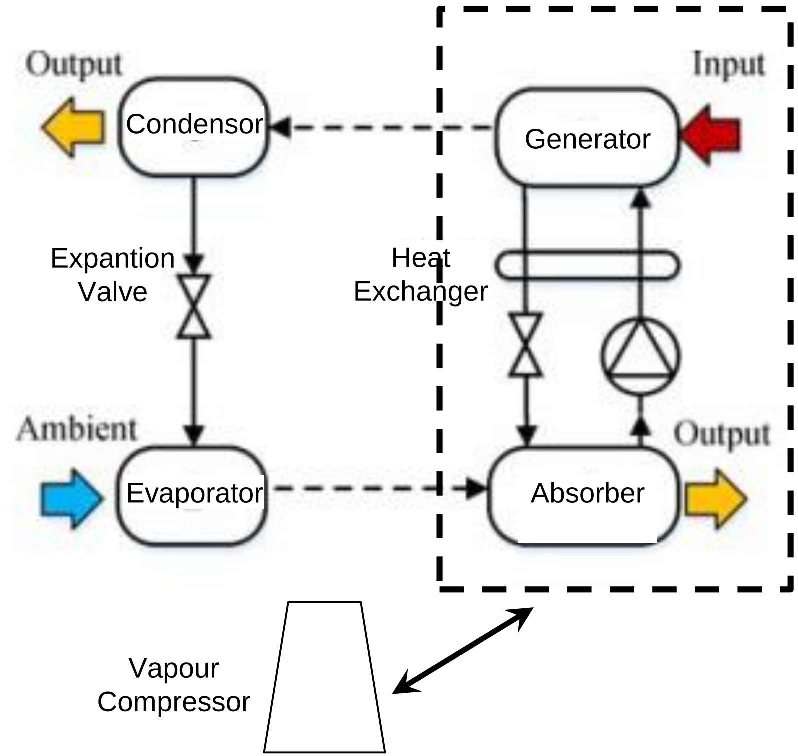
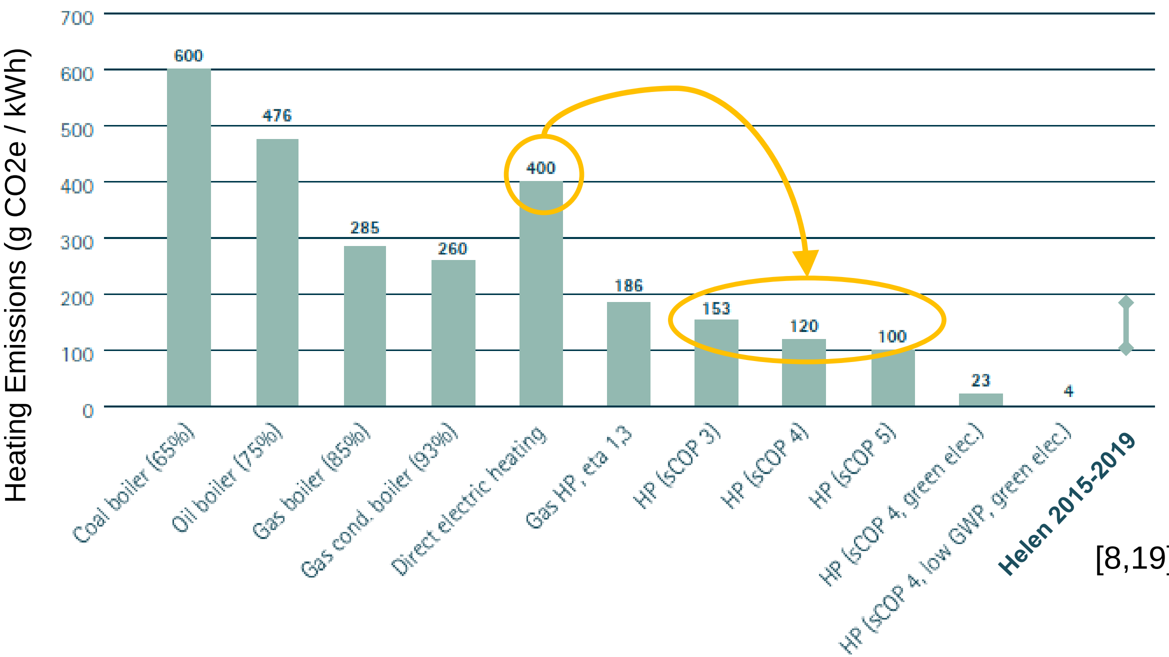


Heat Pump Emissions

$$e_{lifetime} = e_{energy\ source} + e_{leakage} + e_{disposal}$$



[8,19]

Contributors

Source Energy

- Electricity Mix
- Renewable?

COP/SPF

- Higher is better
- Decreasing returns

Refrigerants

- Proper disposal
- Low leakage
- GWP

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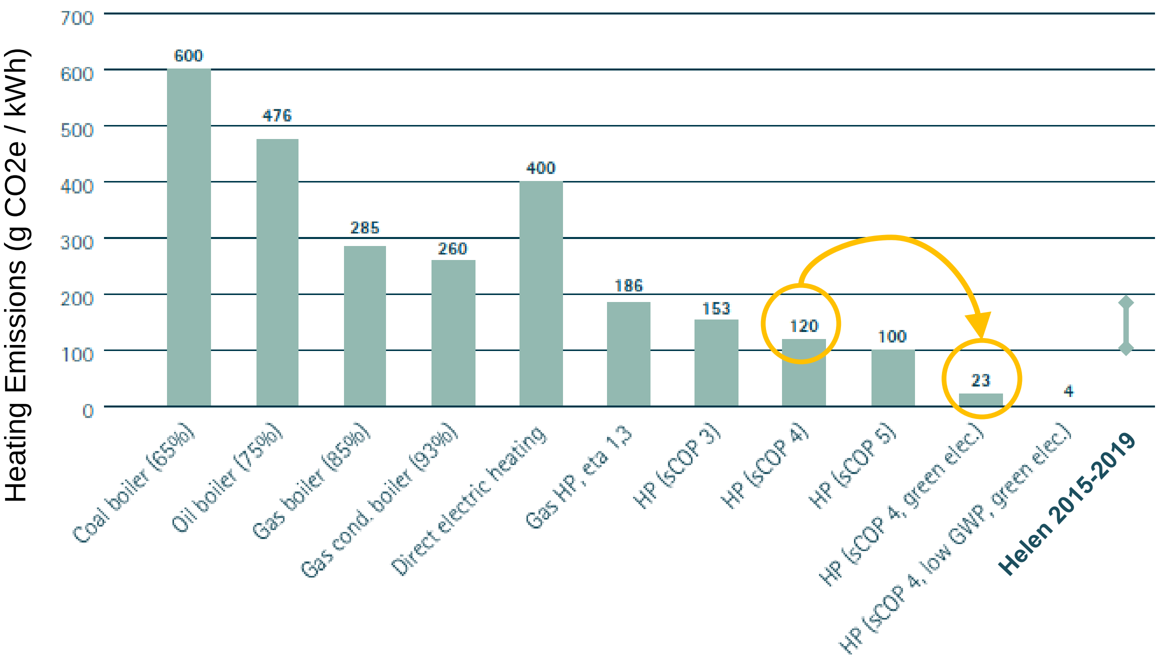

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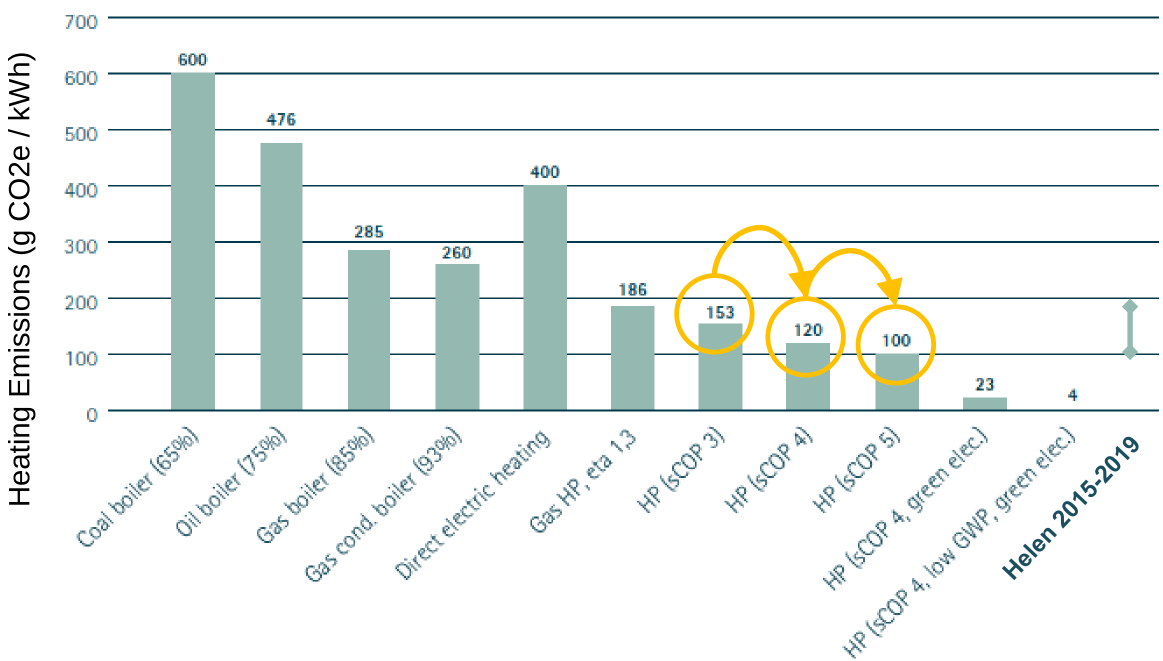

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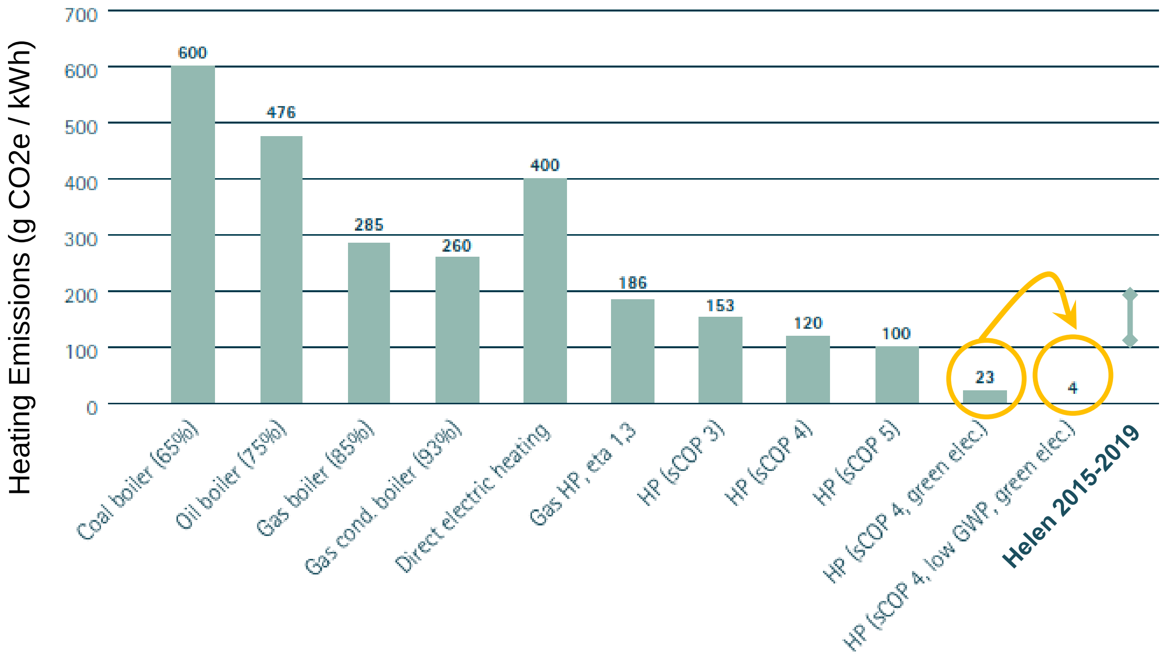

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Conclusions

Heat Pumps

- Both vapour compression and absorption heat pumps are available
- Heat pumps are a very efficient method of heating and cooling
- Low emissions, especially with green electricity and refrigerants
- Existing commercial technology widely applicable to heating homes and industrial applications

Thank you!

Questions? tomson.antle@aalto.fi

Renewable Heat Sources

Learning Outcomes

- Describe the main types of renewable heat available
- Discuss some complications of other heat sources
- Consider the long term impacts of heat sources

RES and TES

Which type of RES source pairs well with TES?

Non Dispatchable

- Must be captured when it is producing or it will be lost

Low or zero cost of marginal generation

- Heat produced at low cost can be stored for later use

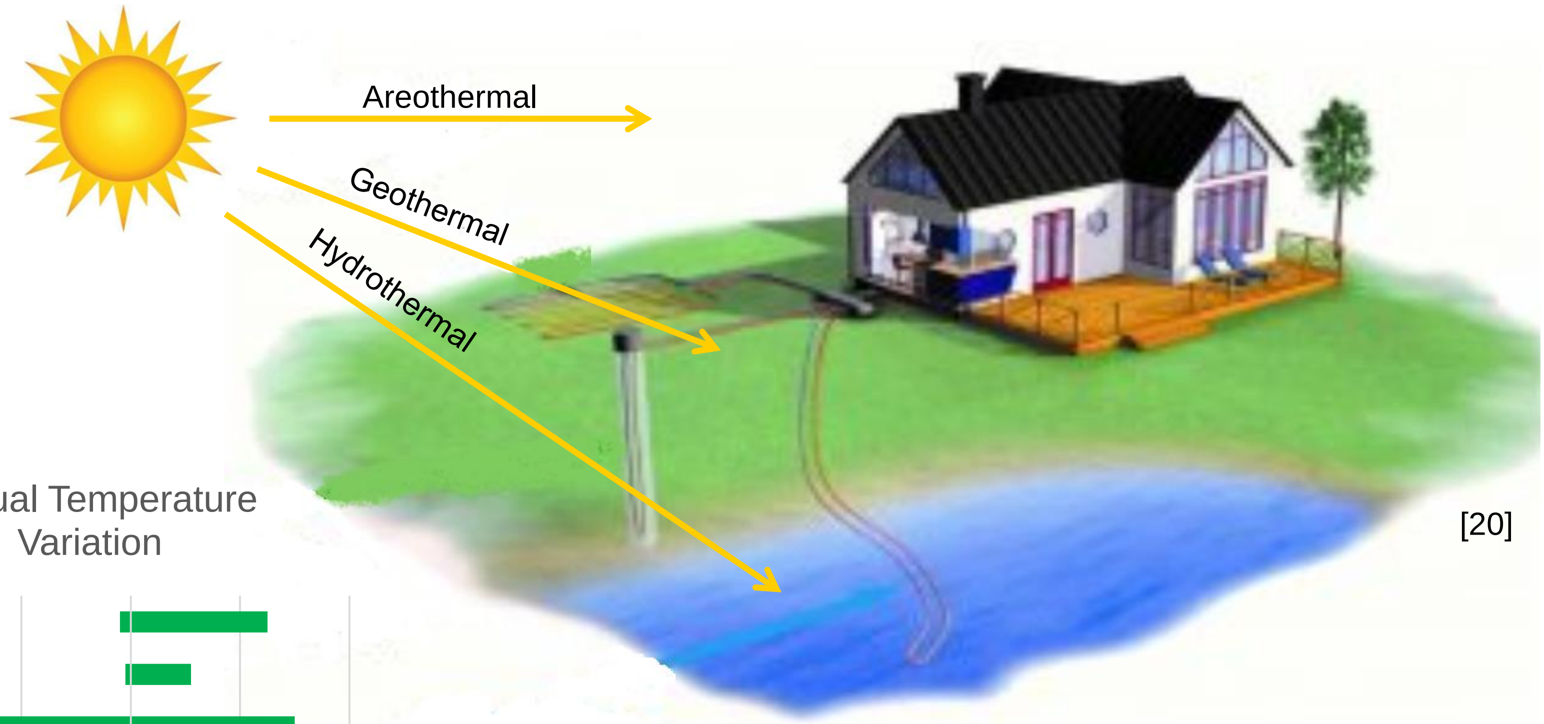
Demand & Supply coincidance problem

- Shifting supply to match demand

BUT

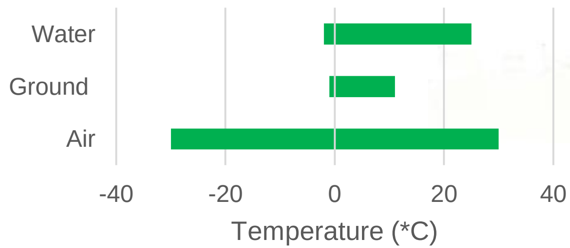
Only use TES if you need too!

Ambiant



[20]

Annual Temperature Variation



Heat Pump Renewable Energy

- Ambiant Energy produced by a heat pump can be counted towards the renewable energy target under 2009/28/EC
  - Provided a minimum SPF is met

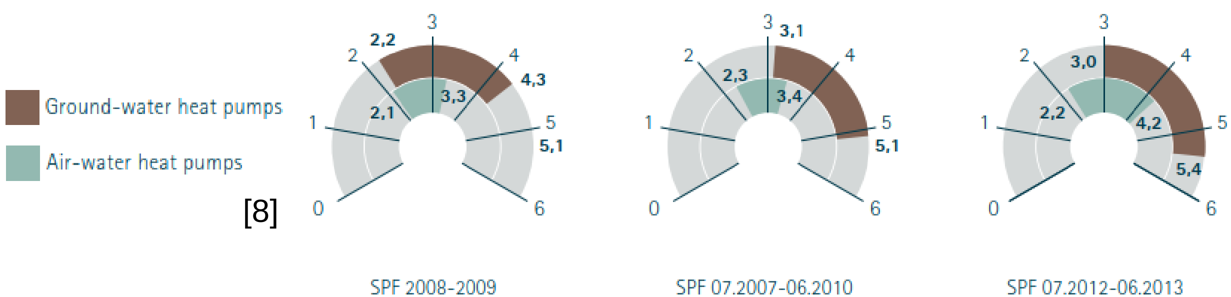
$$E_{RES} = Q_{useable}\left(1 - \frac{1}{SPF}\right)$$

$$E_{Res} = Q_h - W = Q_c$$

- SPF depends on total European electricity generation efficiency
  - As more renewables included (η=1) allowable SPF decreases
  - Current minimum SPF around 2.5

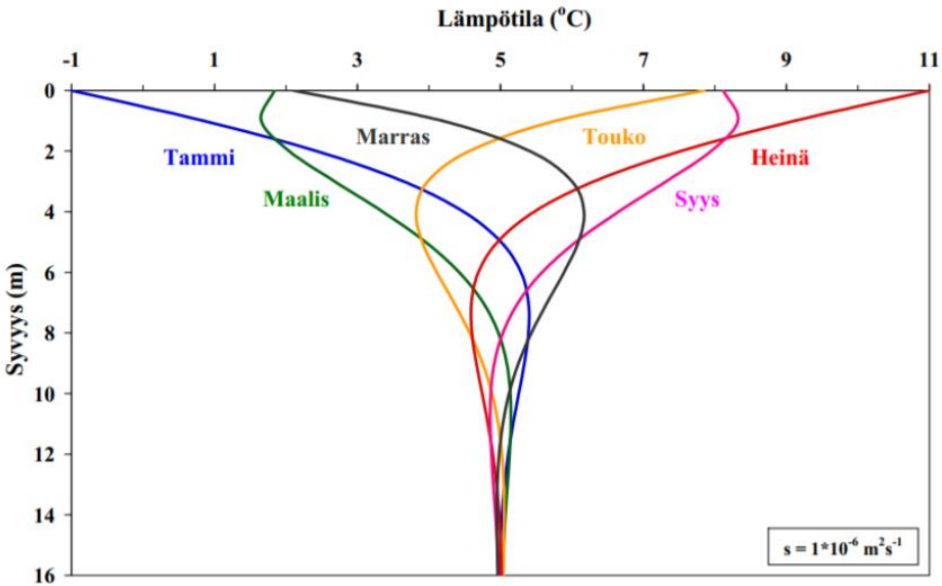
$$SPF > \frac{1.15}{\eta_{EU\ elec}}$$

[21,22]



[8]

Geothermal - Surface



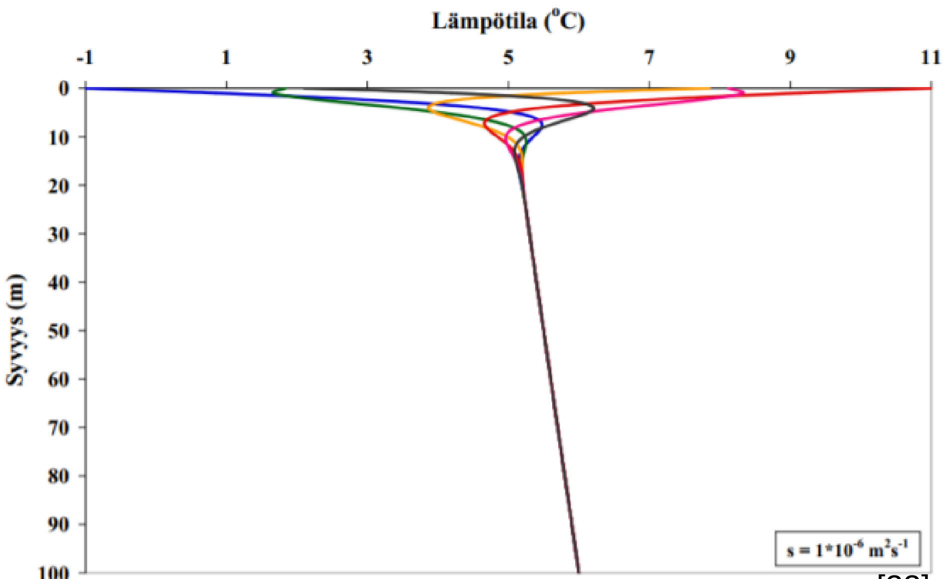
[23]

Surface Level <10m

- Fluctuates seasonally and with depth
- In South Finland usually ±5ºC
- Solar source, minor geothermal
- Accessed with ground array
- This is a Ground Source Heat Pump's (GSHP) energy source

[24]

Geothermal - Depth



[23]

At Depth

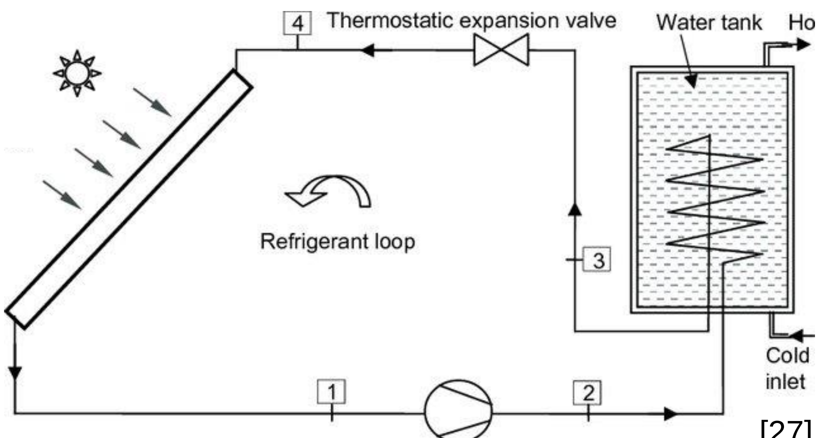
- Constant temperature, increasing with depth (Otaniemi +18ºC/km)
- Geothermal source from interior of Earth
  - Radioactive decay, formation heat
- Accessed with boreholes,
  - Or surface hot springs

[25,26]

Otaniemi ST1: 125ºC at 6.4km

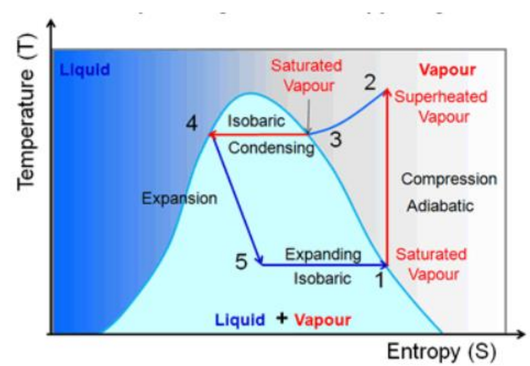
Solar Thermal

Solar Assisted Heat Pump



[27]

- Uses direct solar energy, rather than stored
- Using a solar thermal collector increases source temperature year round, thereby increasing COP
- Several arangements possible
- Higher solar collection efficiencies than STC alone due to lower fluid temp



$$\downarrow \Delta T = \uparrow COP$$

Biomass Combustion

Dispatchable

- Less relevant to the TES discussion
  - Except to reduce plant size

Many discussions on sustainability

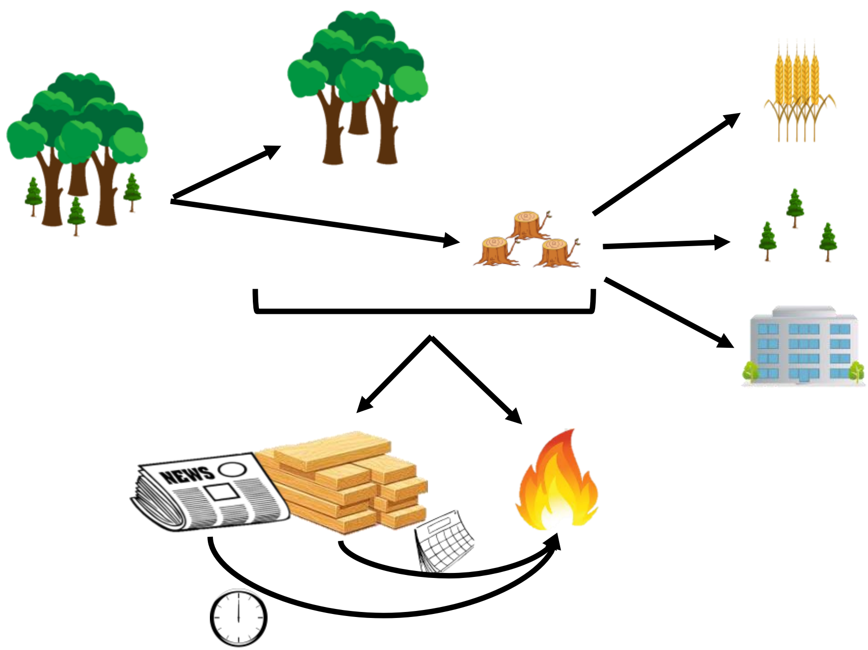
- LULUC emissions
- Carbon payback in light of Paris timelines
- Finite supply of sustainable feedstock

Major source of heat in Finland already

- Pulp mills, district heat

UPM Rauma [28]

Biomass Combustion



Biomass is complicated!
- Compare to reference scenario

How is the biomass harvested?
- Trimmed? Thinned? Felled?

What happens to the carbon in the land?
- Replanted? Cropland? Urbanised?

How much of the biomass is burned?
- How much goes to lumber? paper?
- How long is this carbon stored?

Biomass energy can be done well..or poorly.

Waste Heat

What are the actual emissions?

- What are the emissions from the source?
- How much is available?
- Additionallity – Are more emissions generated to supply the new heat demand?
  - Could be due to quantity or timing
  - Emissions could be alocated by energy, value, or additionallity
- Is this heat offsetting other emissions?

Neste Refinery, Kilpilahti [29]

Waste Heat

- Provides an additional economic benefit to producer if sold to DHN or to offset fuel use
  - Good for local economies
  - Could lead to carbon lock-in
- Does using this heat prolong the economic viability of a fossil source? Or enhance the viability of a renewable source?

- Heat pumps can unlock low temp waste heat from many local sources
  - Cooling water, exhaust air, effluent

Grundfoss, Bjerringbro [30]

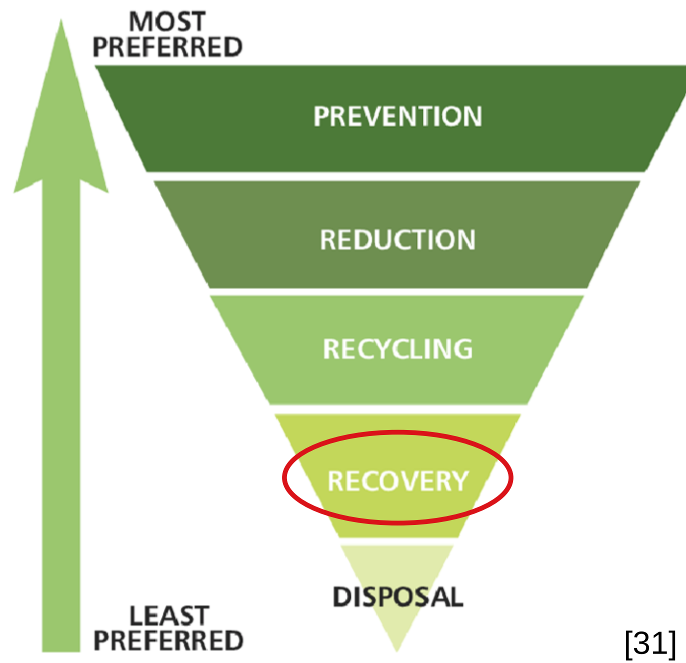
Waste to Energy

Less Dispatchable

- Waste must be consumed year round

Discussions on sustainability

- Still new carbon to atmosphere
  - Mix of Plastics and biomatter
    - Material recovery is a better use of resources
  - One way to offset methane emissions from biomatter decomposition
- Near the bottom of EU Waste Heirchy



[31]

Nuclear

Excellent lecture from VTT on nuclear safety and future possibilities here

Existing Technology

- 52 reactors provide DH in 8 countries – CHP [32]

Technically feasible to build a nuclear reactor for heating only

- Safer due to lower temperatures and pressures
- Low carbon heat source [34]

Major issues may prevent use of nuclear for heat

- Do people want this? Is there societal licence?
- Is it cost effective - New v. Existing
  - Fortum's Loviisa 3 project, heat piped to Helsinki

Fortum, Loviisa [33]

Conclusions

Renewable Heat

- Vast resevoirs of low temperature energy available all around us
- Several types of very low emission heat available
- Accessable with heat pumps and TES
- Not all heat touted as ”Green” is low emission or sustainable.

Thank you!

Questions? **tomson.antle@aalto.fi**

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