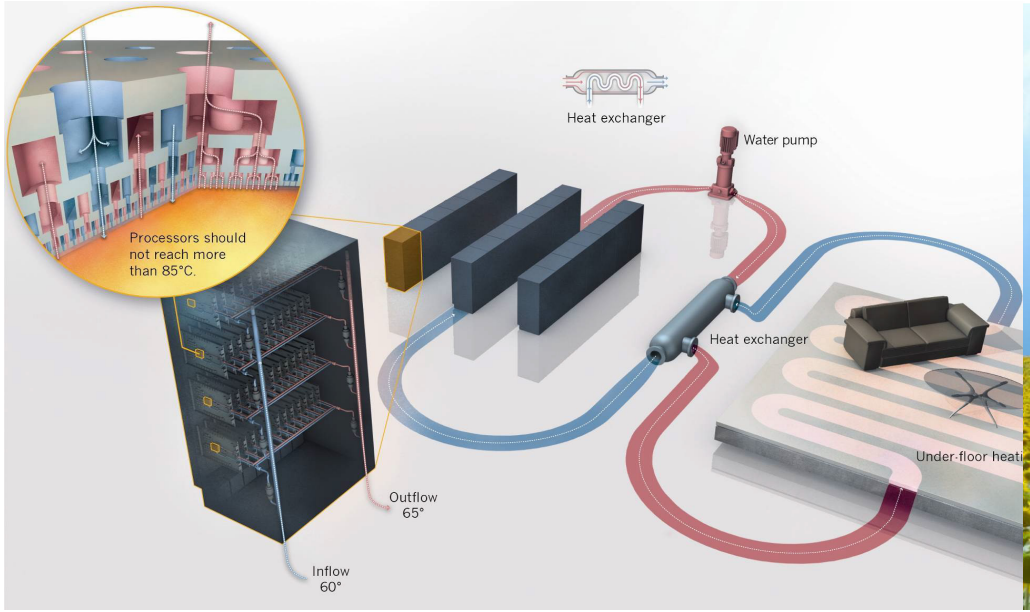
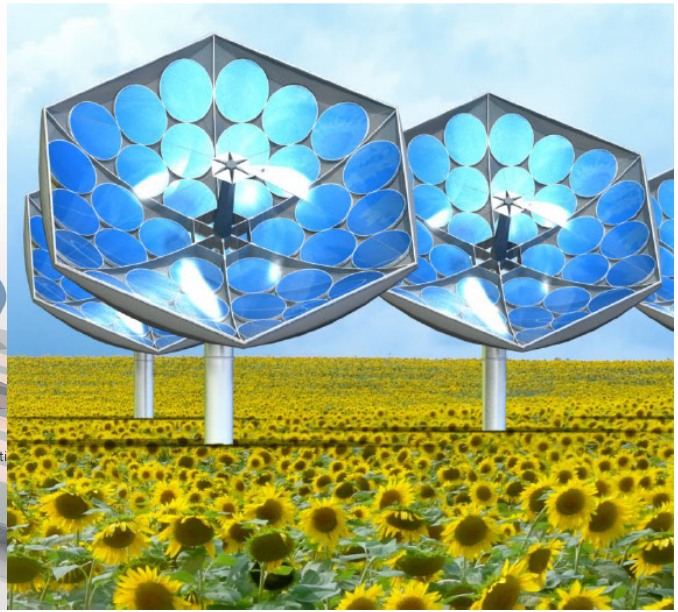
Industry-Scale Harvesting and Re-Use of Low Grade Heat enabled by Micro Technology





S. Gerke, P. Ruch, S. Paredes, I. Meijer, E. Lörcher, N. Wiik, J. Ammann and B. Michel

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COP21 – Paris (2015)

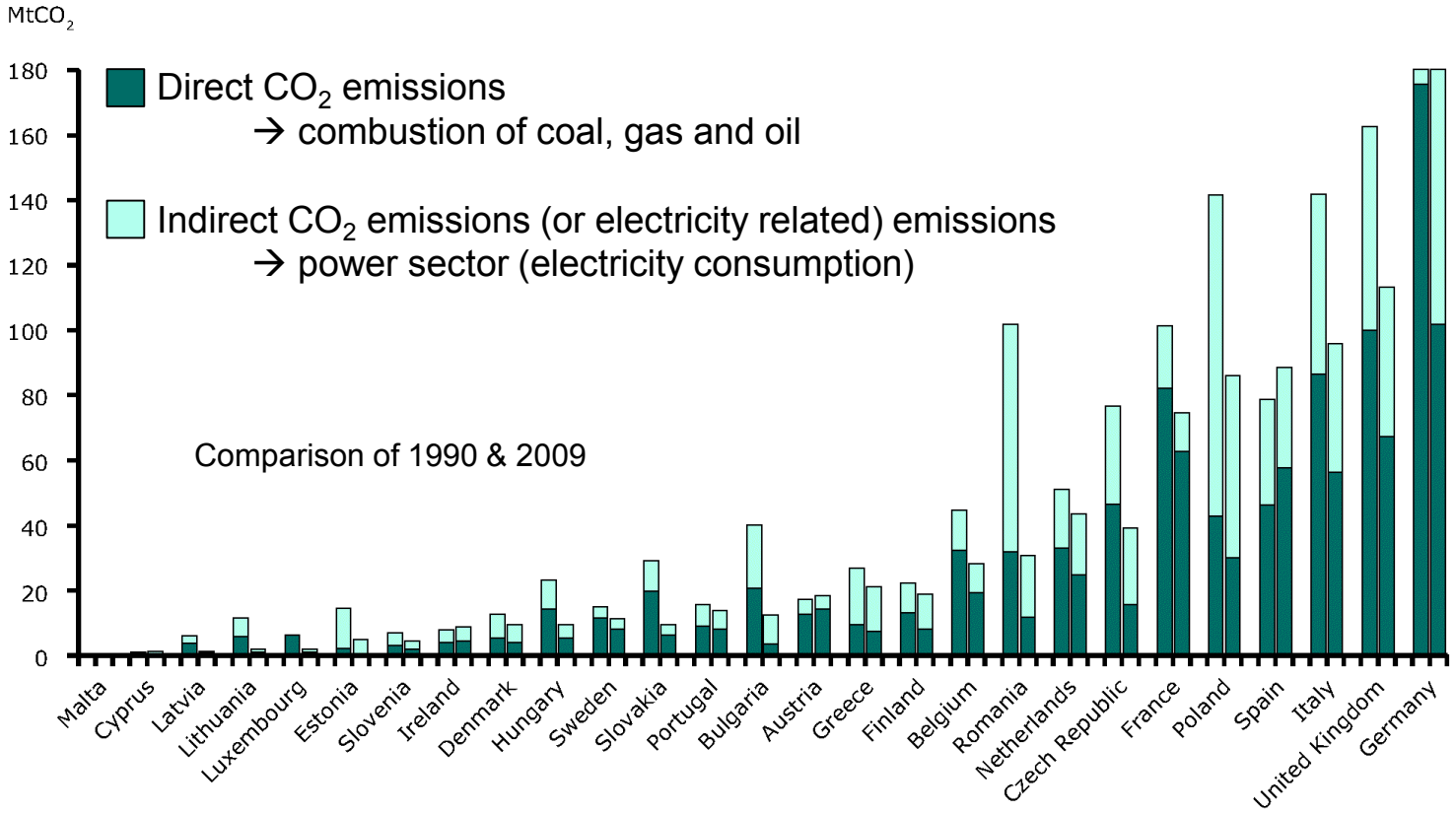
- Limit the **rise** in **global temperatures** by **2100** due to global warming to **under 2°C**
- The **participating countries** have **agreed** that one of the main means to **achieve** this **objective** is to **lower** the global **output** of the greenhouse-gas **CO_2**
- In addition, **several nations** have **decided** to make the change **without using fission energy**
- Achieving both these goals is a big challenge for the future



COP21: 'United Nations Framework Convention on Climate Change, 21st Conference of the Parties'

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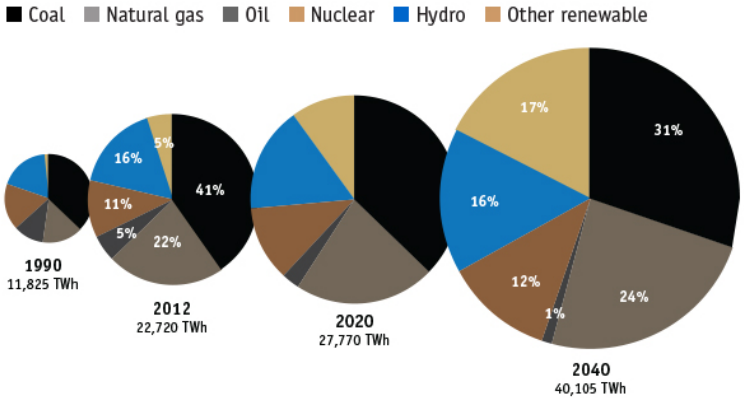
CO_2 emissions in the industry in EU Countries



European Environment Agency, 2012

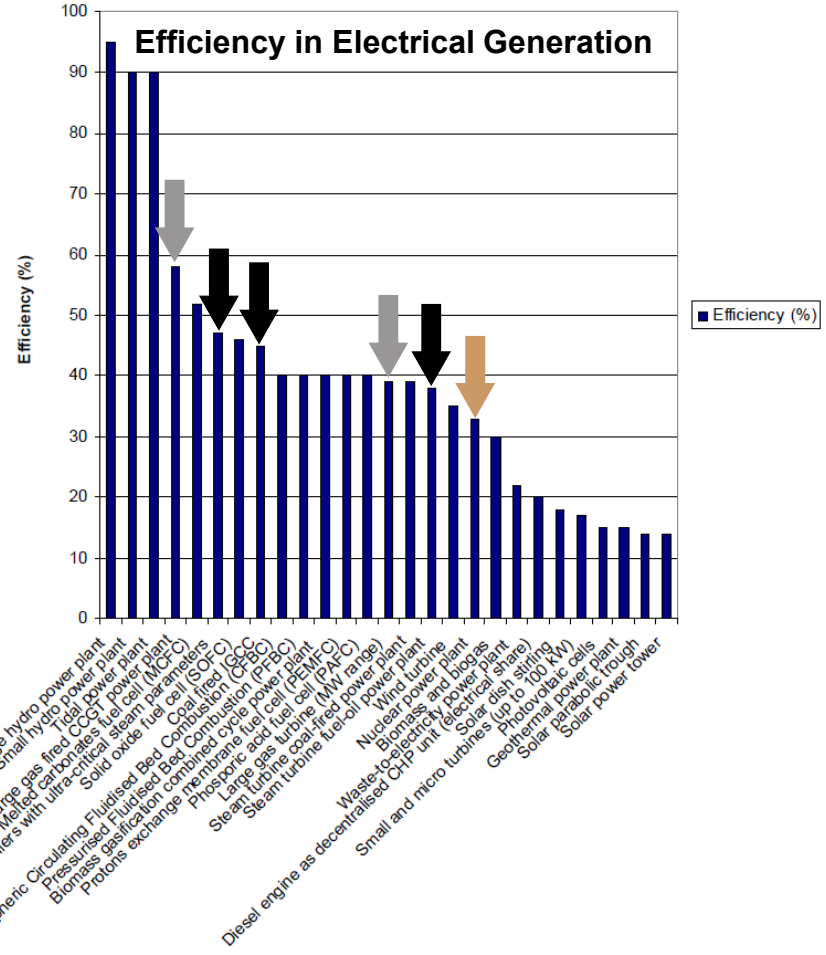
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World power mix





Coal Power Plant Jaenschwalde, Germany

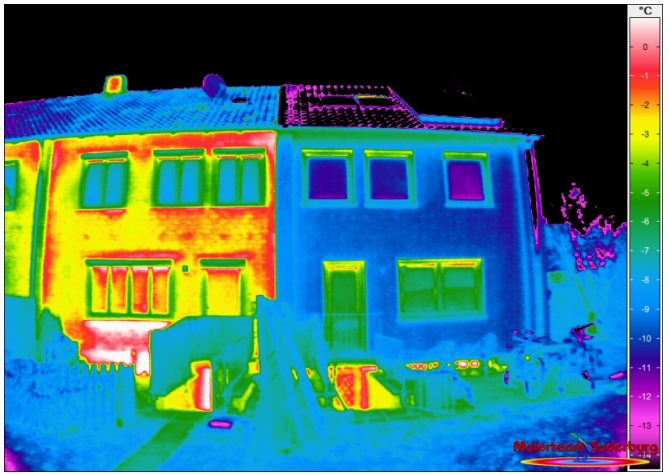


S. Patel, IEA Power 2015
NN. Efficiency in Electrical Generation, 2003

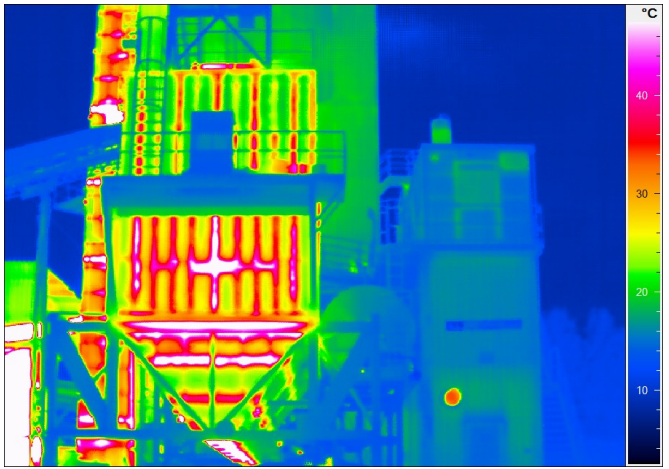
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How we use the energy

- **Waste heat is not used in most of the cases**
- **Only ~25% of the primary energy is used**
- **Only 10% of the energy of combustible materials is used**
  - For energy intensive industries using electrical power



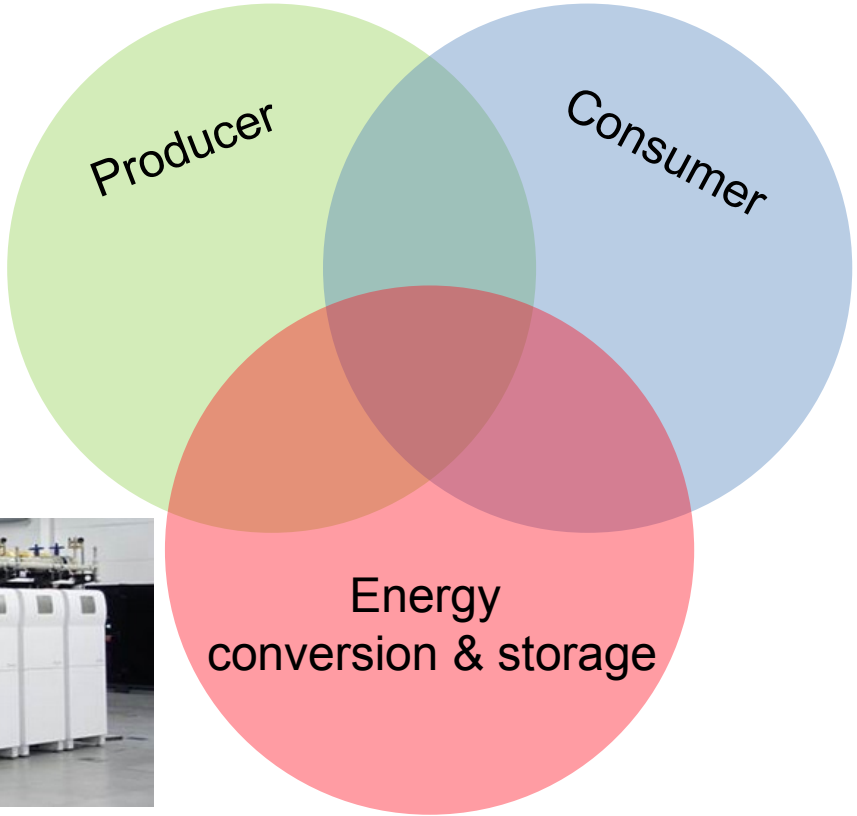




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We have to take action











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Producer

- **Renewable energies have an excellent CO_2 footprint**
  - Nuclear power plants also

- **Renewables do not ‘waste’ combustible materials**

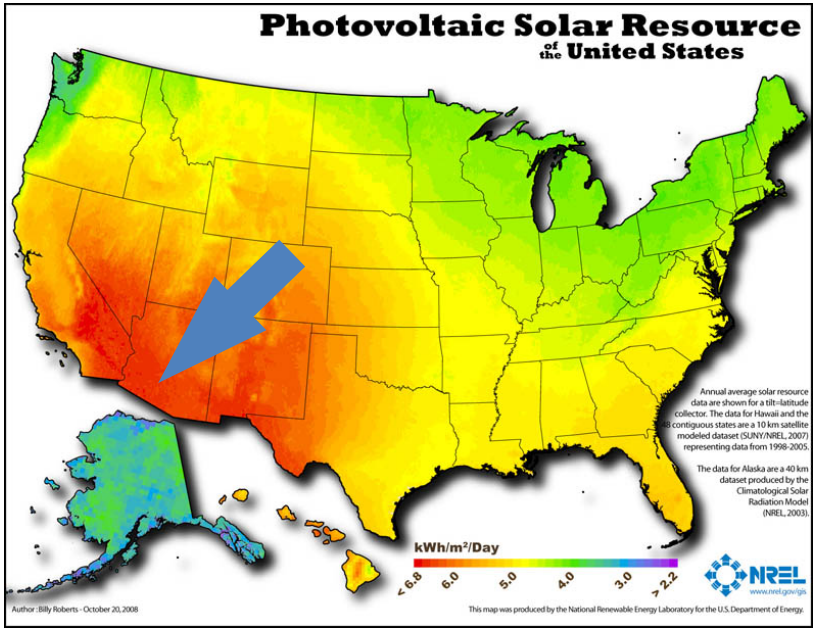


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Producer

- **Renewable energies have an excellent CO_2 footprint**
  - Nuclear power plants also
- **Renewables do not 'waste' combustible materials**
- **Example: Phoenix Arizona**
  - Annual insolation: ~ 2000 kWh/m²/year
  - Annual harvesting: ~ 400 kWh/m²/year
    20% Module efficiency

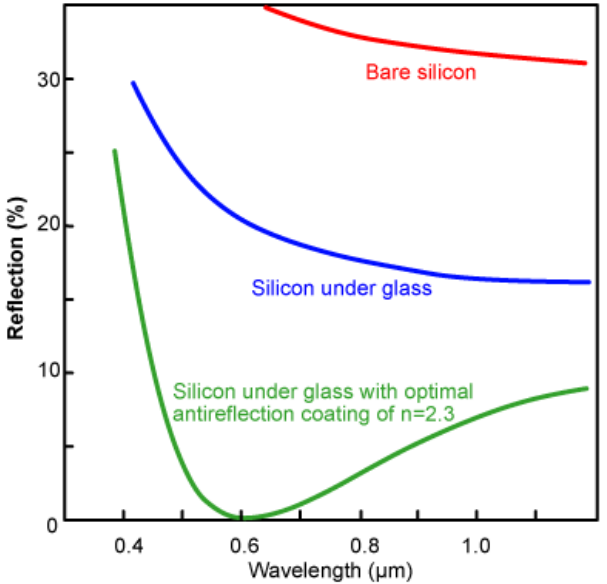




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Producer

- **Example: Phoenix Arizona**
  - Annual insolation: ~ 2000 kWh/m^2/year
  - Annual harvesting: ~ 400 kWh/m^2/year
    20% Module efficiency
  - Overall absorption: ~ 94%
  - **74% transformed into thermal energy**
    → ~ 1480 kWh/m^2/year





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Producer

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  - **White roofs reduce urban temperatures for cities in the Sunbelt while solar panels cause a heat island effect**







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➢ **Passive action can be more effective**







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Producer

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➢ Passive action can be more effective

Why waste the thermal energy?







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HCPVT Sunflower

- **High Concentrated PhotoVoltaic and Thermal (HCPVT)**
  - Mirror area of 40 m^2
  - Concentration in the focus of ~2000 suns
  - ~30% electrical efficiency
  - ~50% thermal efficiency
  - Captures >80% of irradiated solar energy

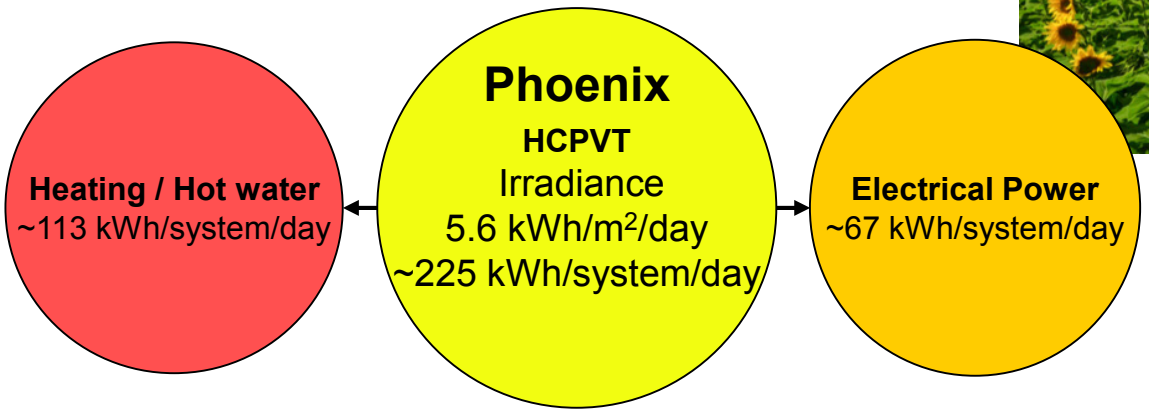


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HCPVT Sunflower

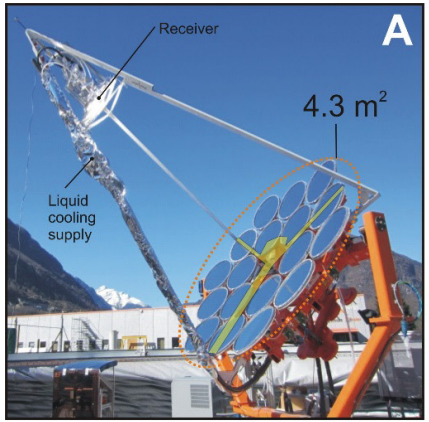
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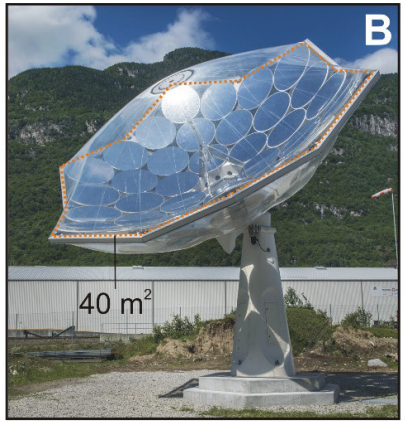


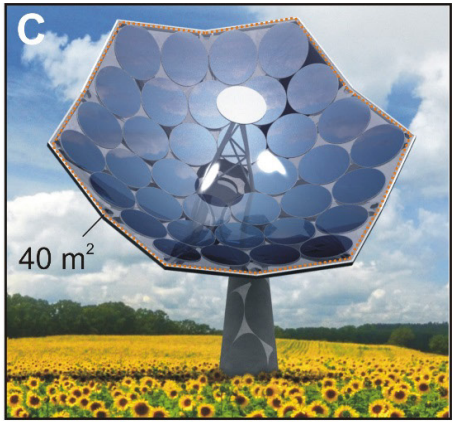


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State of work







Stage 1: Prototype (2015)

- 4.3 m^2 area
- 18 dish-mirrors (vacuum-actuated)
- Sun tracking (2 axis)
- Receiver mounted in center via peripheral tripod (resulting in shadowing)

Stage 2: Early Adopter

- 40.0 m^2 area
- 36 dish-mirrors (vacuum-actuated)
- Sun tracking (2 axis)
- Receiver mounted in center via central mount
- Currently being assembled

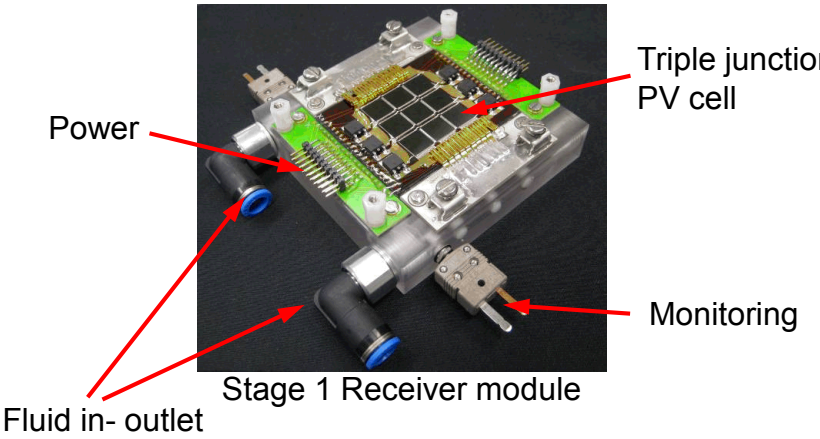
Stage 3: Final Product (2018)

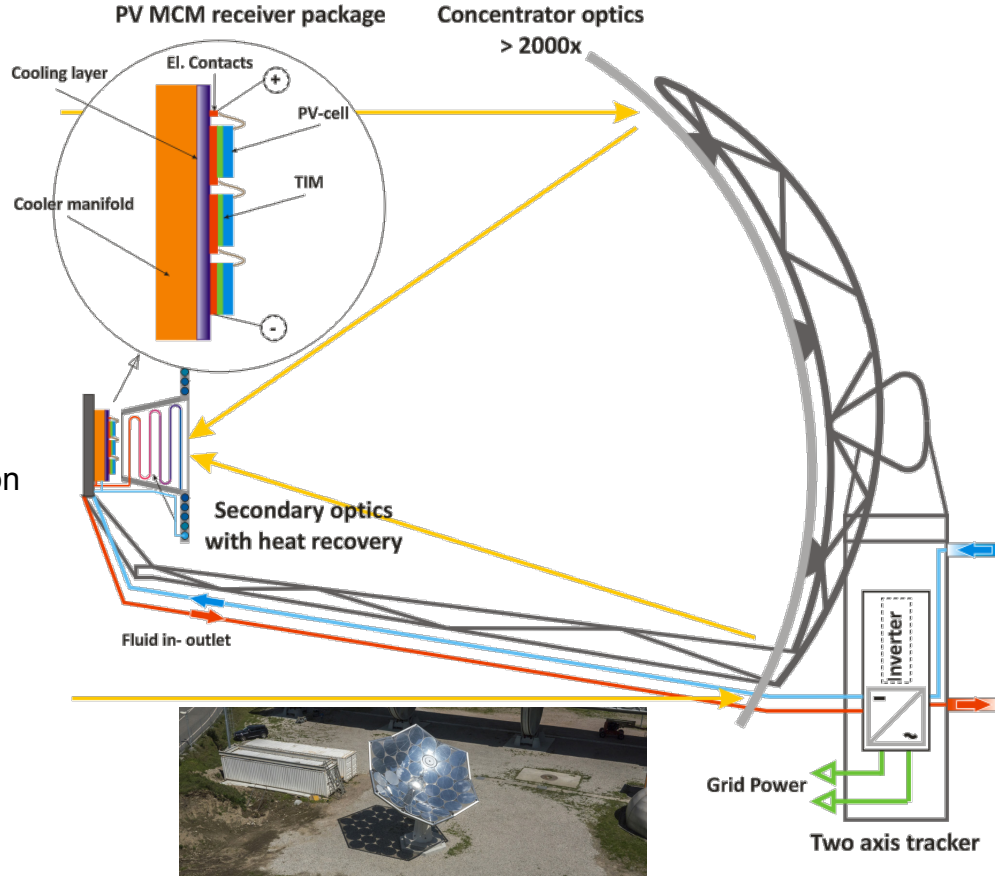
- 40.0 m^2 area
- 36 dish-mirrors (vacuum-actuated)
- Sun tracking (2 axis)
- Receiver mounted in center via central mount
- Final product in 2018 (rendered picture)

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Overview

- **HCPVT system**
  - Swiss KTI funded Project
    IBM Research, ETH Zurich,
    NTB Buchs, Airlight Energy Biasca
  - 250 $/m^2 aperture
    - ~1$/Wpeak
    - <0.1 $/KWh (sunny locations)

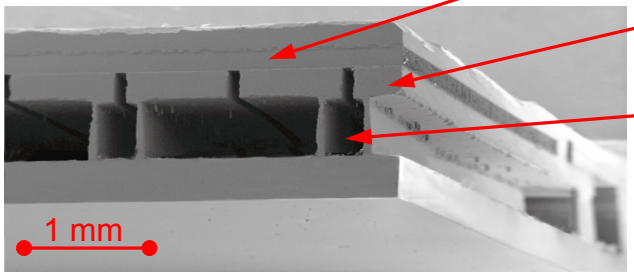


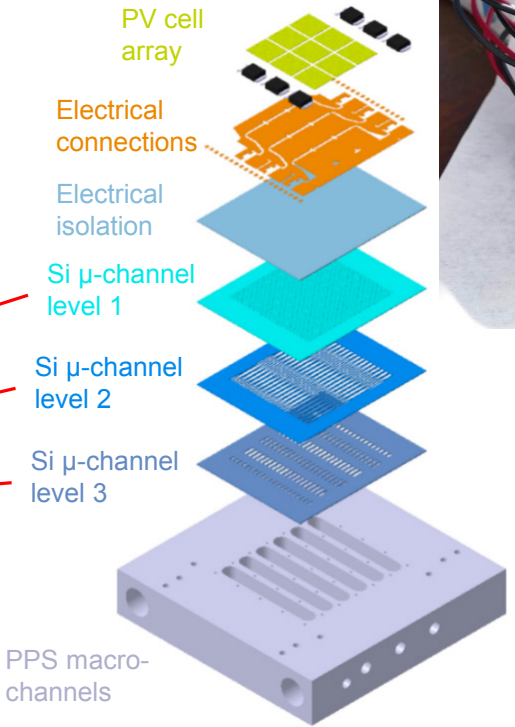


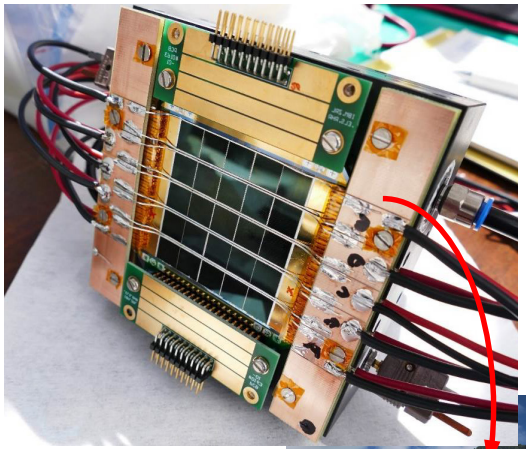
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Micro technology

- **Advanced micro integration for heat collection**
  - Heat harvesting (cooling) of the receiver is very important, as the spot in the focus is able to melt steel
  - Integrated micro technology enables high heat flow









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Consumer - Datacenter

- **Today datacenters around the world use more than 120 TWh of electrical energy**



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Datacenter efficiency

- **Today data centers around the world use more than 120 TWh of electrical energy**



- **How efficient is the computing of a modern data center in %?**

a) < 1 % **b) ~10 %** **c) ~34 %**

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Datacenter efficiency

- **Today data centers around the world use more than 120 TWh of electrical energy**



- **How efficient is the computing of a modern data center in %?**

a) < 1 % **b) ~10 %** **c) ~34 %**

  - **Efficiency is ~4 ppm**

Brouillard, APC, 2006

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Datacenter efficiency

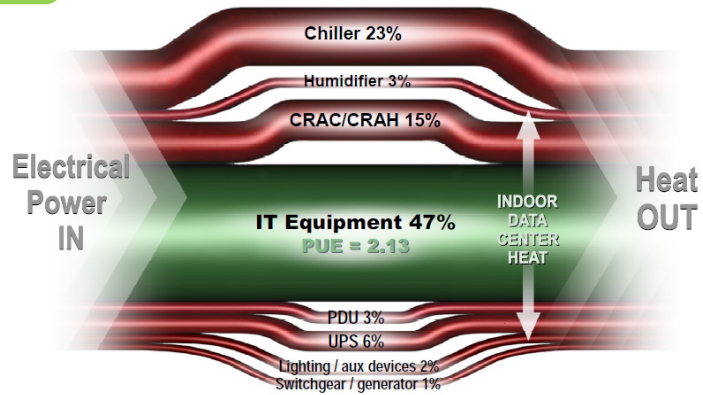
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Brouillard, APC, 2006
APC Whitepaper #154 Rev. 2, 2010

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Datacenter efficiency

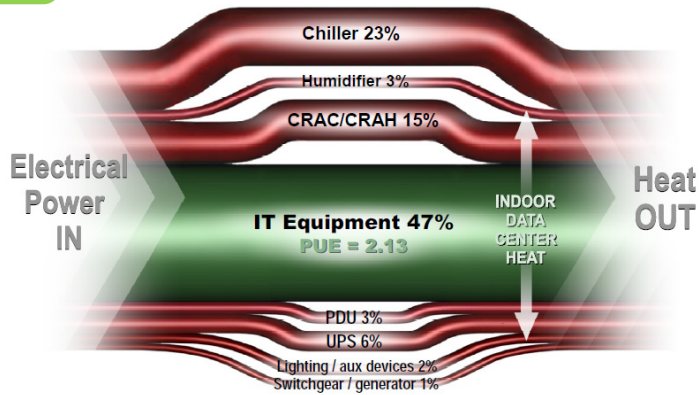
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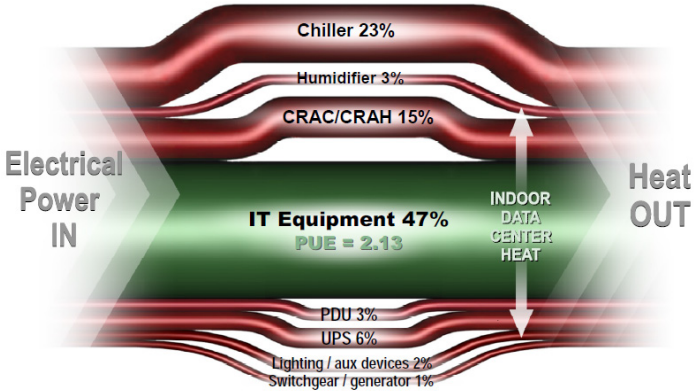


Brouillard, APC, 2006
APC Whitepaper #154 Rev. 2, 2010

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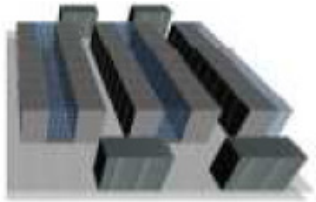
Datacenter efficiency

- **Efficiency is ~4 ppm**
- **Volume used for compute is <1 ppm**
  - **Example: 400 kW IT power**





Air-cooled without containment
2.7 kW per rack
500 m²



Air-cooled with containment
8 kW per rack
155 m²



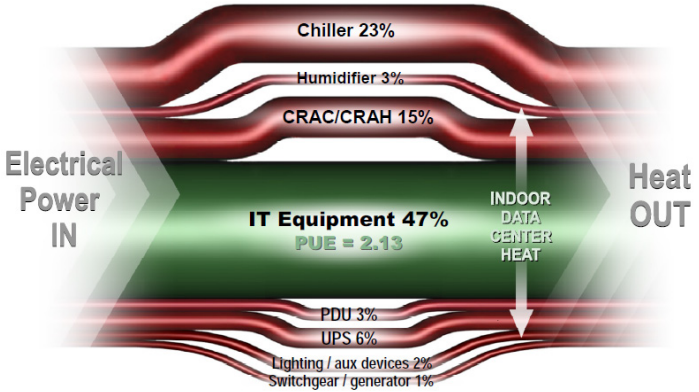
Water-cooled
20 kW per rack
60 m²

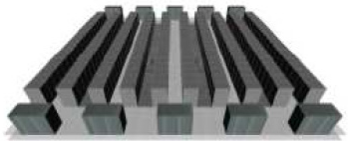
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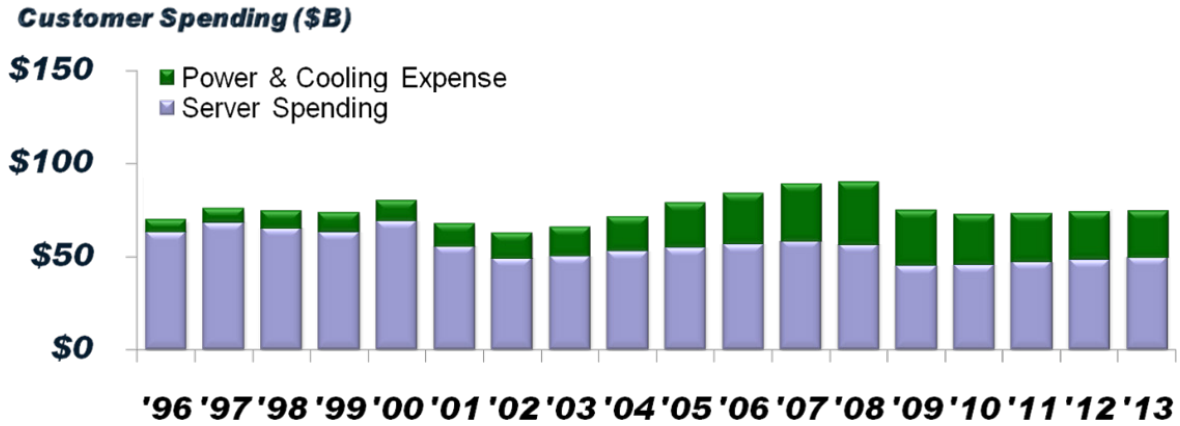




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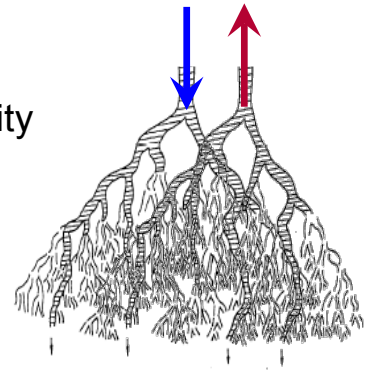
Brouillard, APC, 2006

APC Whitepaper #154 Rev. 2, 2010

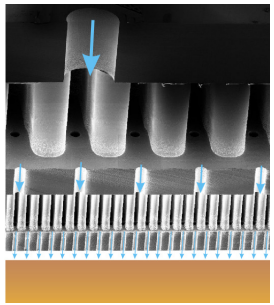
NN., IDC, 2011

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Water cooled datacenter

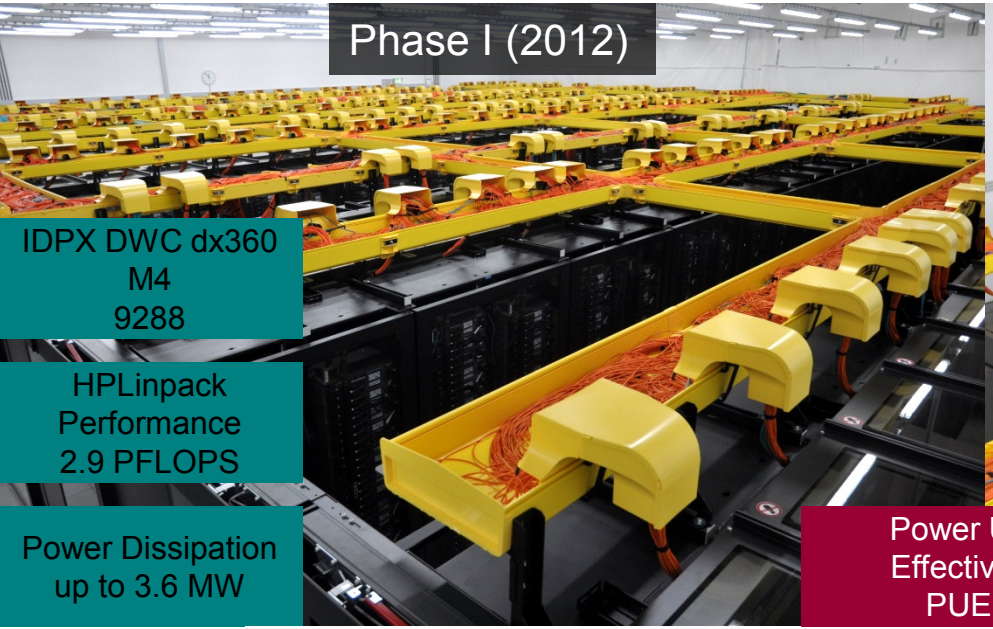


- **Transition from Air cooling to liquid cooling**
  - Water with 4000 times better heat capacity and 30 time better thermal conductivity
- **Microchannels**
  - High aspect ratio ➔ massive surface enlargement
  - Disadvantage laminar flow and large pumping power
- **Concept of branched hierarchical transport**
  - Our blood circulation system reaches best mass transport with minimal pumping power
  - Optimal branching factor
- **Radical miniaturization and use of silicon (dioxide) as structural material**
  - Good thermal conduction
  - No thermal interfaces needed for heat flow
  - Radical miniaturization
- **Better interfaces**
  - Filling materials/gaps with percolation
  - Improved overall thermal conduction due to necking



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Water cooled datacenter SuperMUC

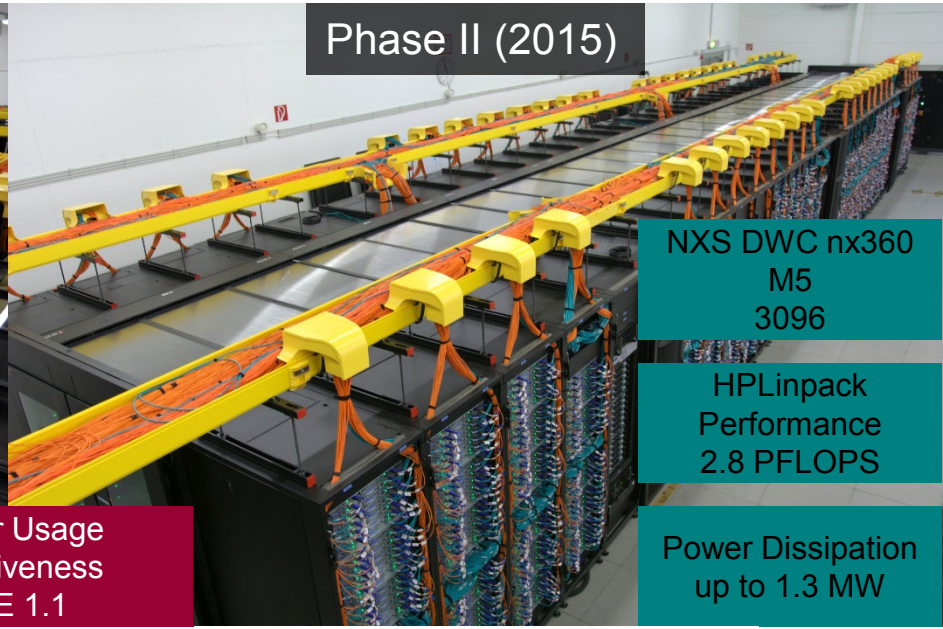


Phase I (2012)

IDPX DWC dx360
M4
9288

HPLinpack
Performance
2.9 PFLOPS

Power Dissipation
up to 3.6 MW



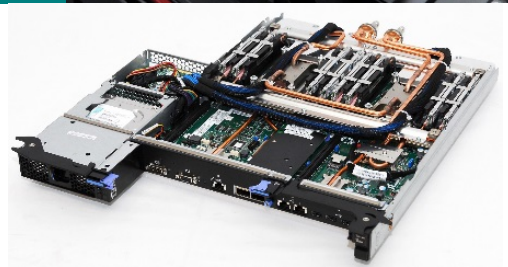
Phase II (2015)

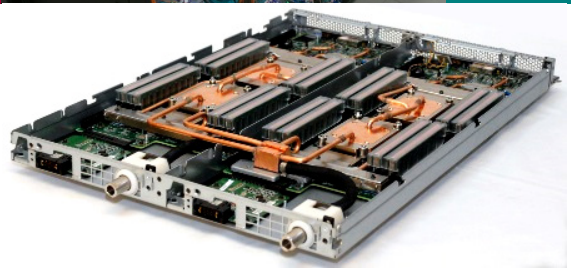
NXS DWC nx360
M5
3096

HPLinpack
Performance
2.8 PFLOPS

Power Dissipation
up to 1.3 MW

Power Usage
Effectiveness
PUE 1.1

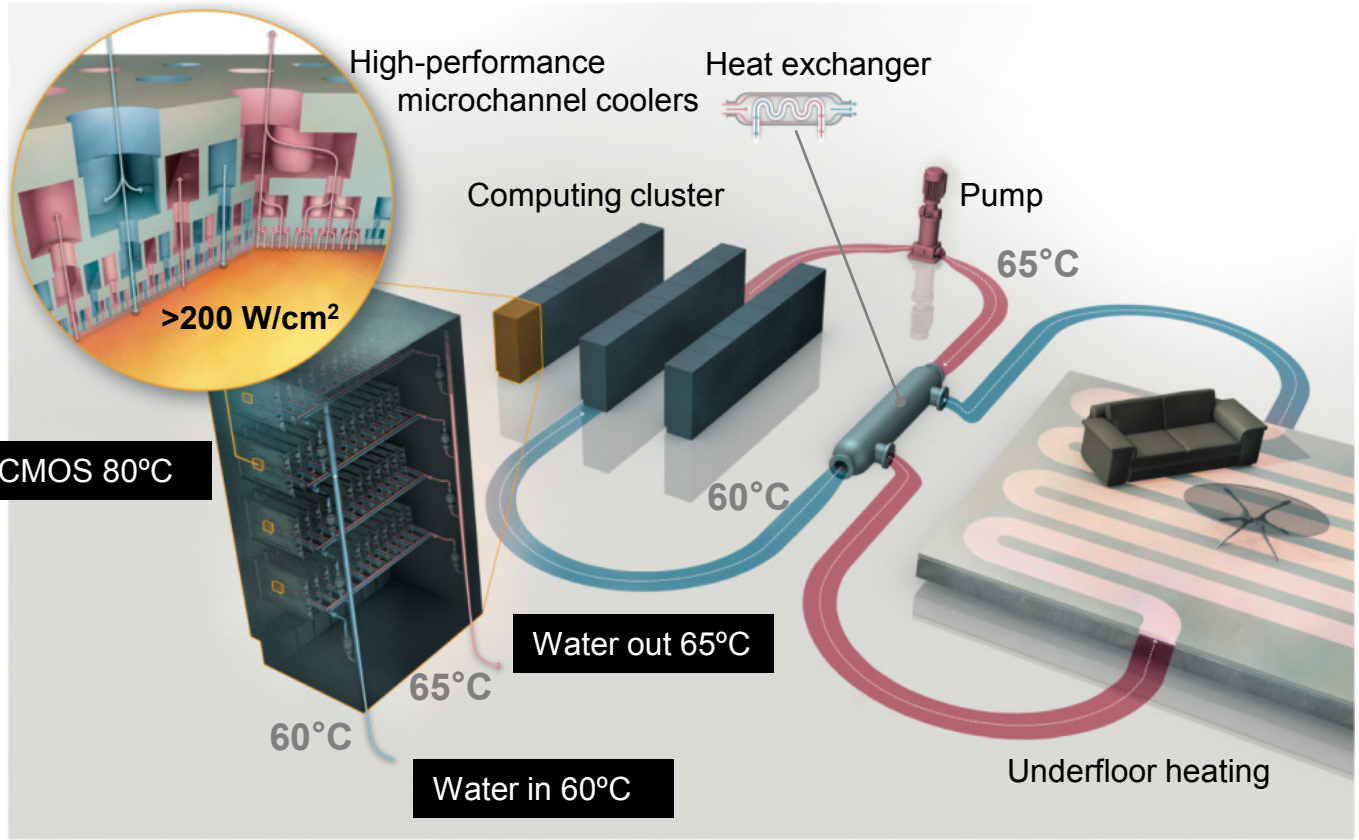




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Cooling concept of SuperMUC

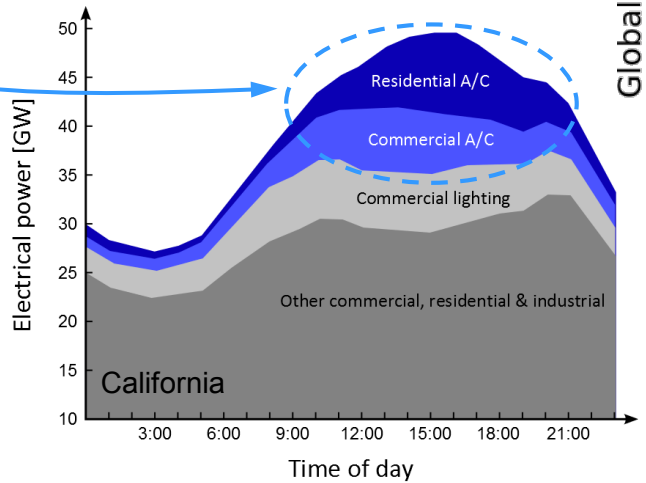
- Economic value of heat reduces datacenter total cost of ownership by 50-70% lower energy cost
- Enables new business areas, as waste heat can be sold to third parties

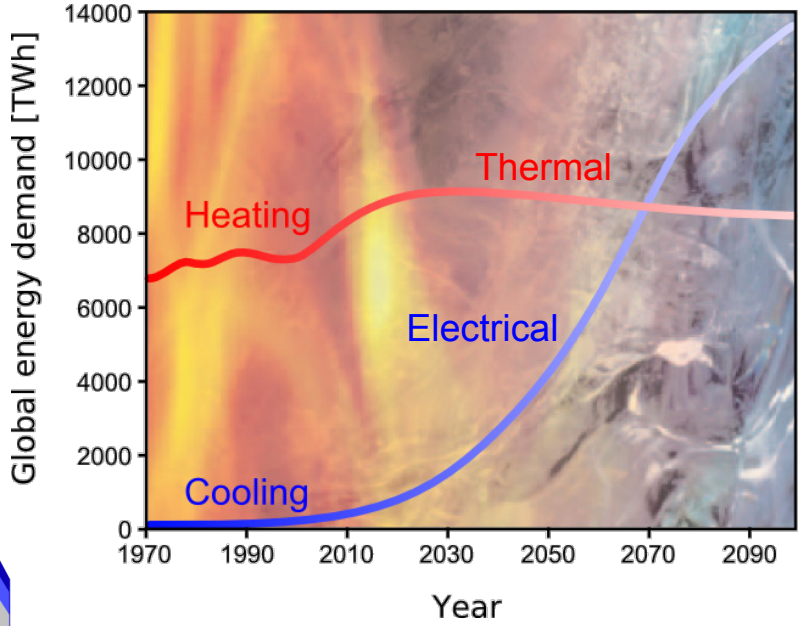


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Energy transformation & storage

- **Heat not needed all the time**
- **Global cooling demand is expected to grow >10^{x} in the timeframe 2010-2050**
- **Air-conditioning accounts for >30% of peak load during cooling season**



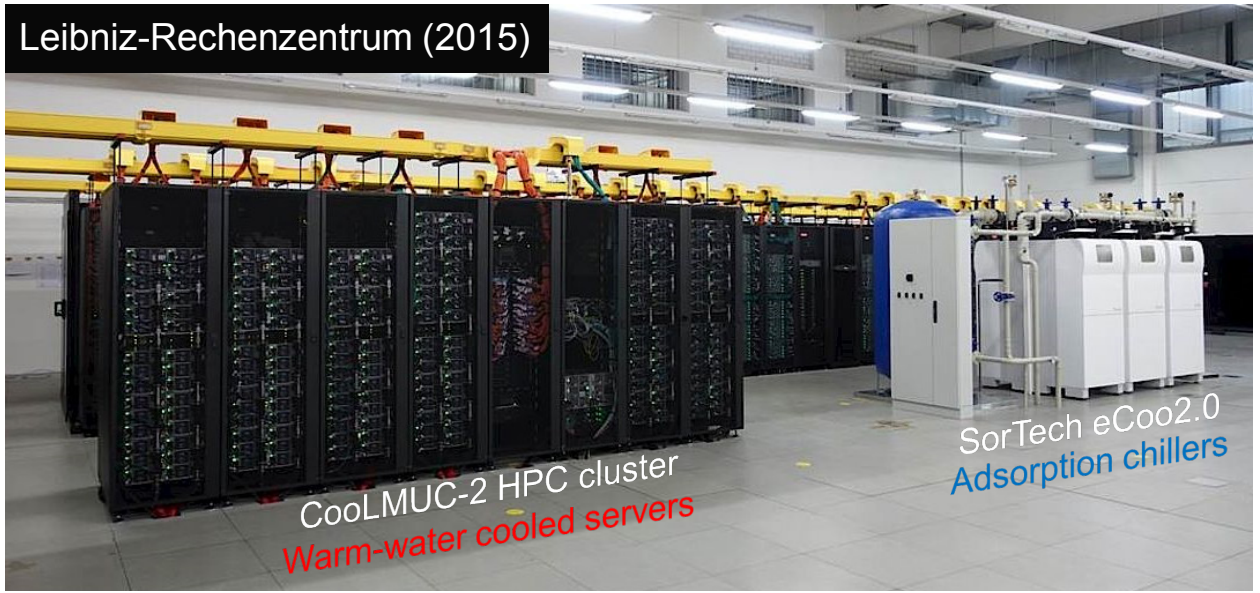


Isaac & van Vuuren, Energy Policy 37, 2009

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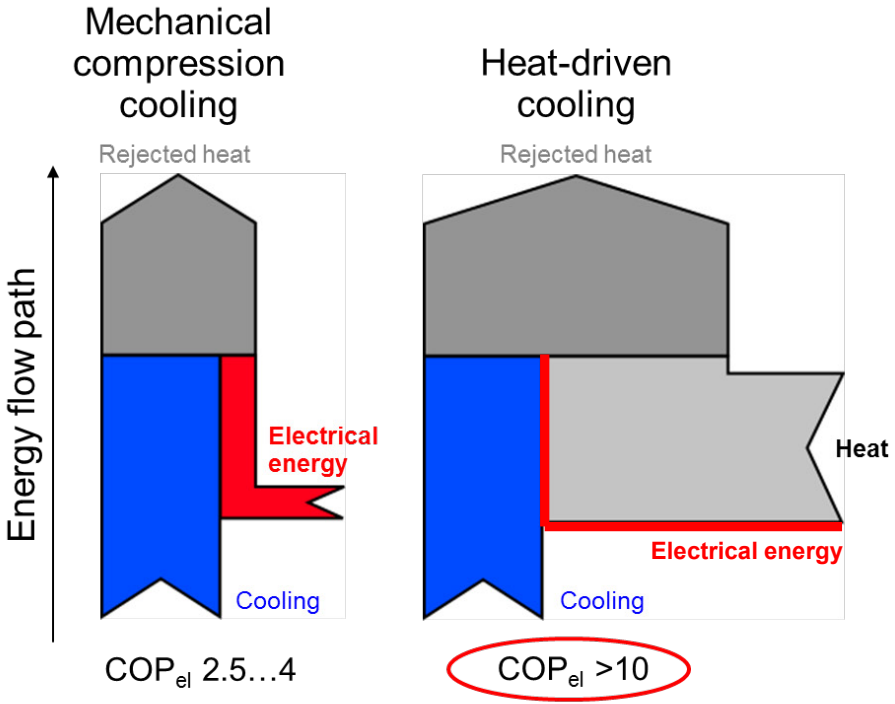
Thermally driven heat pumps

- **Convert waste heat to cooling**
  - Industry processes
  - Datacenters
- **Support power grids**
  - Utilizing available waste heat or renewable heat



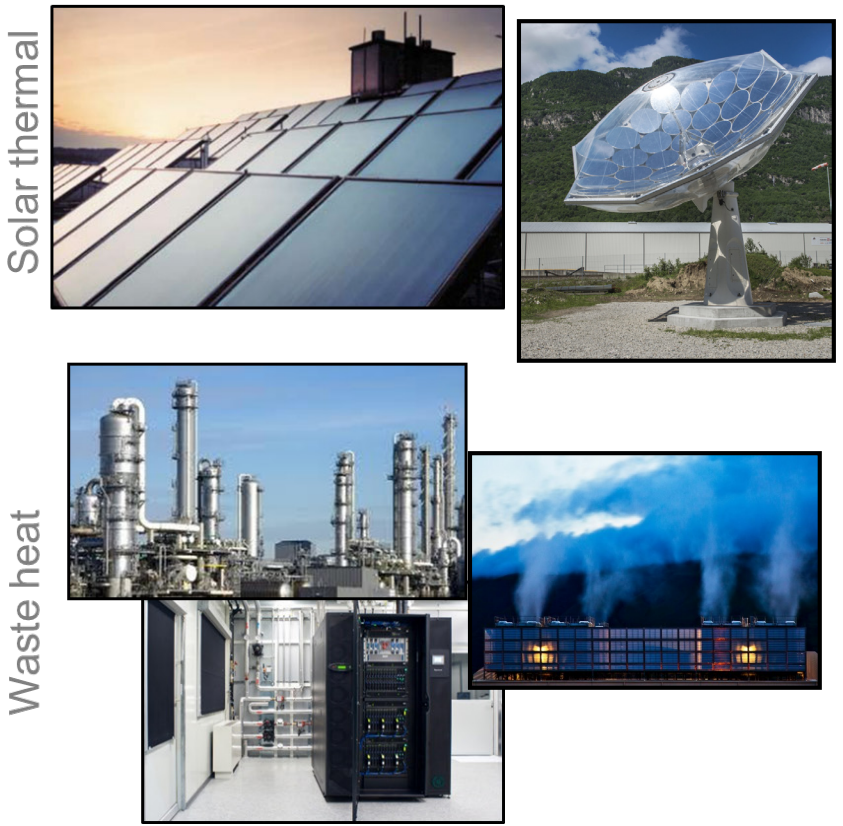
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Thermally driven cooling cycles



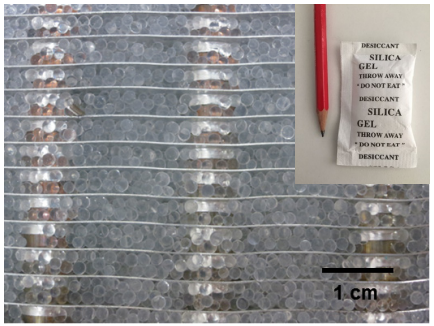
Coefficient of performance

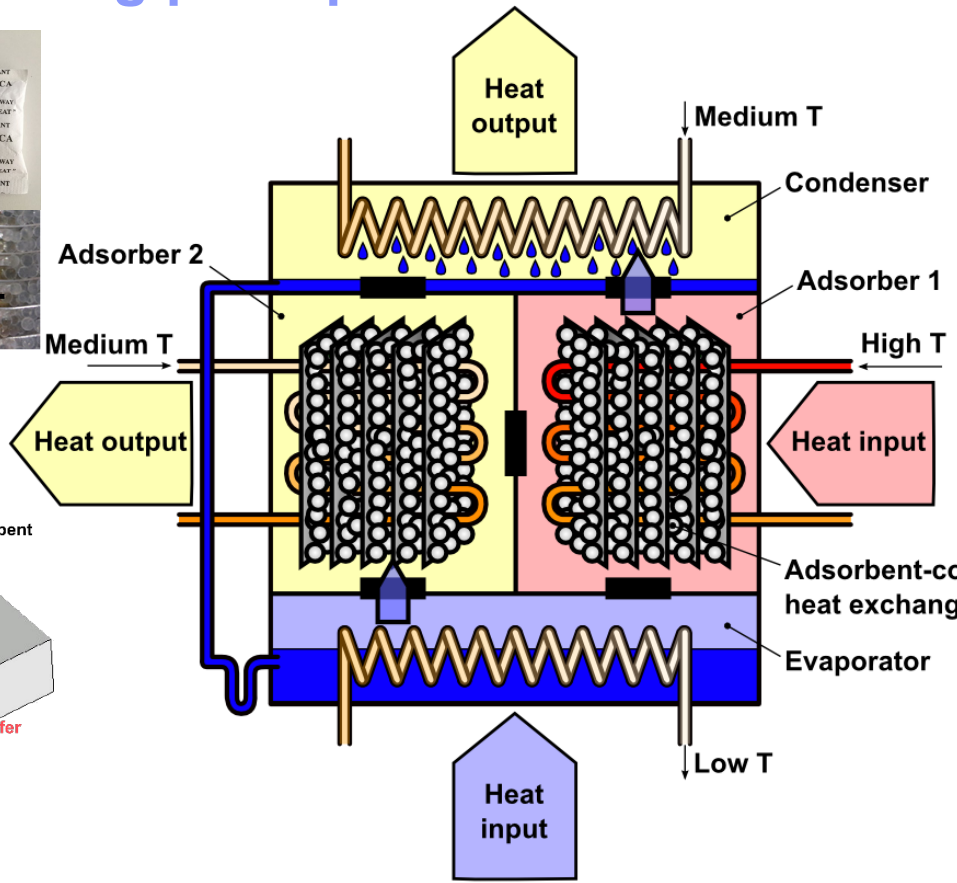
$$COP_{el} = \frac{\text{Cooling}}{\text{Electrical input}} \qquad COP_{th} = \frac{\text{Cooling}}{\text{Thermal input}}$$



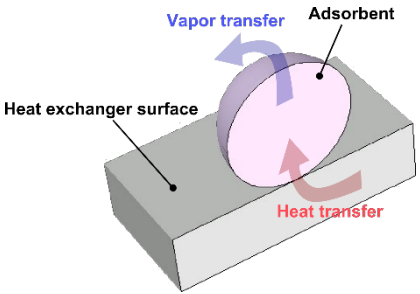
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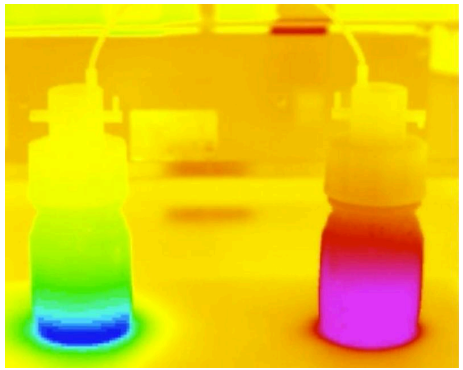
Adsorption cooling principal





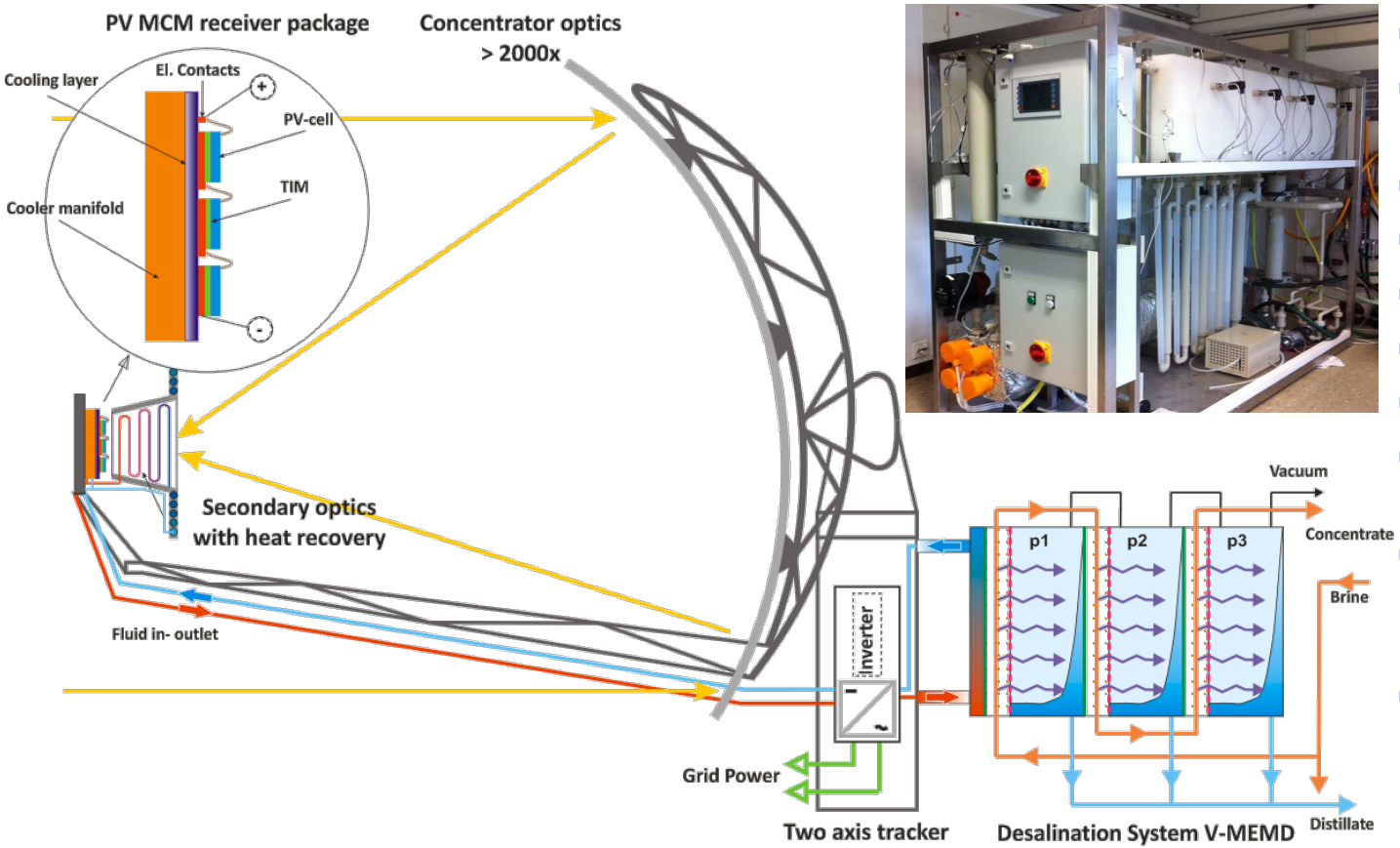






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Vacuum assisted multi-effect membrane desalination



- Heat driven process
- Electrical energy only for pumping
- Thermal power: 12 kW
- Pressure: ≤ 300 mbar
- T_{evap}: ~ 80ºC
- Feed: ~ 6 l/min
- Distillate flux: 1.8 m^3/day
- Thermal efficiency: 160 kWh/m^3
- PTFE Membrane:
  Size: 15.2 m^2
  Pores: 0.2 µm
- Recovery ratio 40-45%

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Summary

- **75% of the primary energy is wasted**
  - Single use of process heat

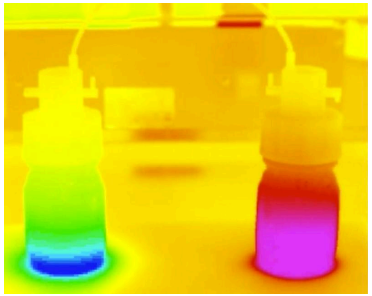


- **Micro technology enables to recover part of the heat and makes it re-usable**
  - Solar electrical and thermal power plant with system efficiency of ~80%
  - Heat recovery of datacenter





- **Heat can be used for:**
  - Cooling
  - Desalination





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Thank you for your attention

- Acknowledgement
  - Binnig and Rohrer Nanotech Center
  - Smart System Integration team
  - Dsolar Ltd

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