Backing visionary entrepreneurs

European Innovation Council
Data centre cooling: Research trends in efficient low-carbon solutions

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Programme manager energy and green tech
Denver, 19 October 2023

Contents

- Horizon Europe and the European Innovation Council
- The pathfinder challenge on clean cooling
- The problem of data centres cooling
- Emerging research and innovation trends

Horizon Europe Structure

European Innovation Council

HORIZON EUROPE

SPECIFIC PROGRAMME: EUROPEAN DEFENCE FUND

Exclusive focus on defence research & development

- Research actions
- Development actions

SPECIFIC PROGRAMME IMPLEMENTING HORIZON EUROPE & EIT*

Exclusive focus on civil applications

Pillar I
EXCELLENT SCIENCE

- European Research Council
- Marie Skłodowska-Curie
- Research Infrastructures

Pillar II
GLOBAL CHALLENGES & EUROPEAN INDUSTRIAL COMPETITIVENESS

Clusters

- Health
- Culture, Creativity & Inclusive Society
- Civil Security for Society
- Digital, Industry & Space
- Climate, Energy & Mobility
- Food, Bioeconomy, Natural Resources, Agriculture & Environment

Joint Research Centre

Pillar III
INNOVATIVE EUROPE

- European Innovation Council
- European innovation ecosystems
- European Institute of Innovation & Technology*

WIDENING PARTICIPATION AND STRENGTHENING THE EUROPEAN RESEARCH AREA

- Widening participation & spreading excellence
- Reforming & Enhancing the European R&I system

EURATOM

- Fusion
- Fission
- Joint Research Center

* The European Institute of Innovation & Technology (EIT) is not part of the Specific Programme

EIC Programs

Pathfinder (TRL1-4)

- **For consortia (open and challenge calls) and single entities (challenge call)**
- Early stage research on breakthrough technologies
- **Grants up to €3/4 million**

Transition (TRL 4-6)

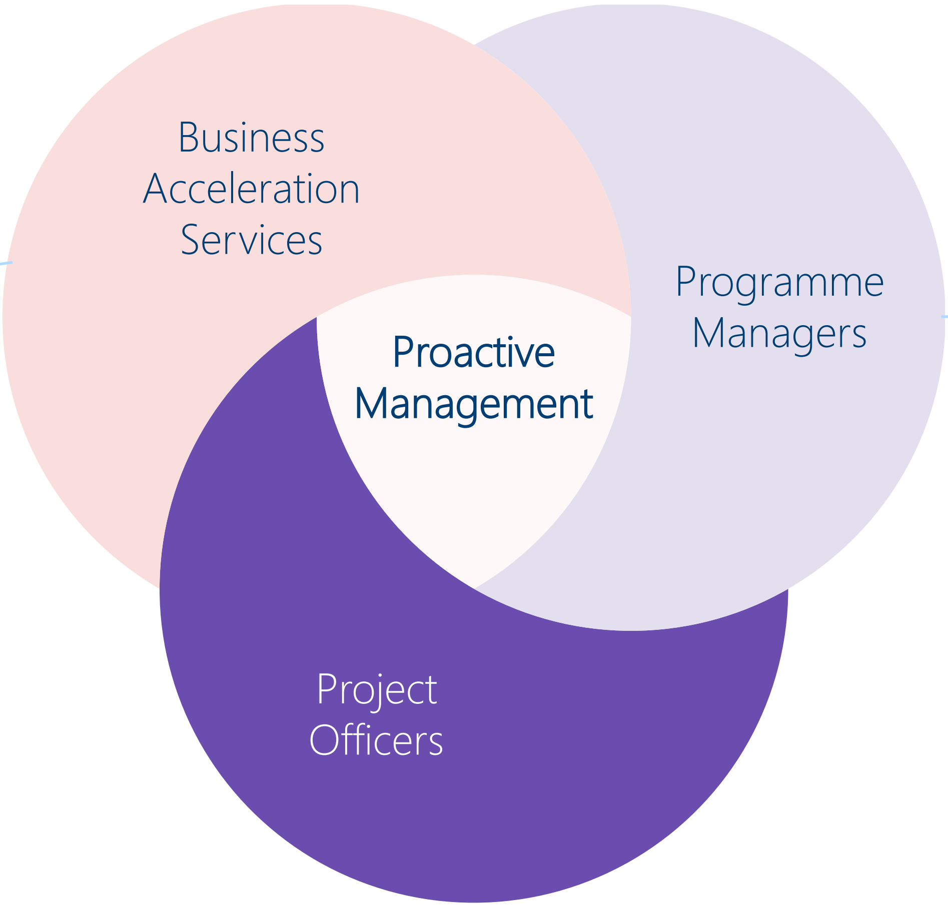
- **For consortia and single entities**
- Technology maturation from proof of concept to validation
- Business & market readiness
- **Grants up to €2.5 million**

Accelerator (TRL 6-9)

- **For individual SMEs**
- Development & scale up of deep-tech/ disruptive innovations by startups/ SMEs
- Blended finance (**grants up to €2.5 million; equity investment up to €15 million or above**)

With proactive management the EIC aims to maximize its support to success of the entrepreneurial journey

- Access to entrepreneurs
- Access to mentoring
- Access to ecosystems
- Access to partners, peers
- Access to trainings
- Access to workshops
- Access to expert advice
- Access to recruitment
- Access to industry



- Health, Biotech
- MedTech
- SpaceTech
- Quantum, electronics
- Greentech materials
- Greentech
- AEC
- Agri-food
- Responsible electronics
- Bio-fuels, E-fuels

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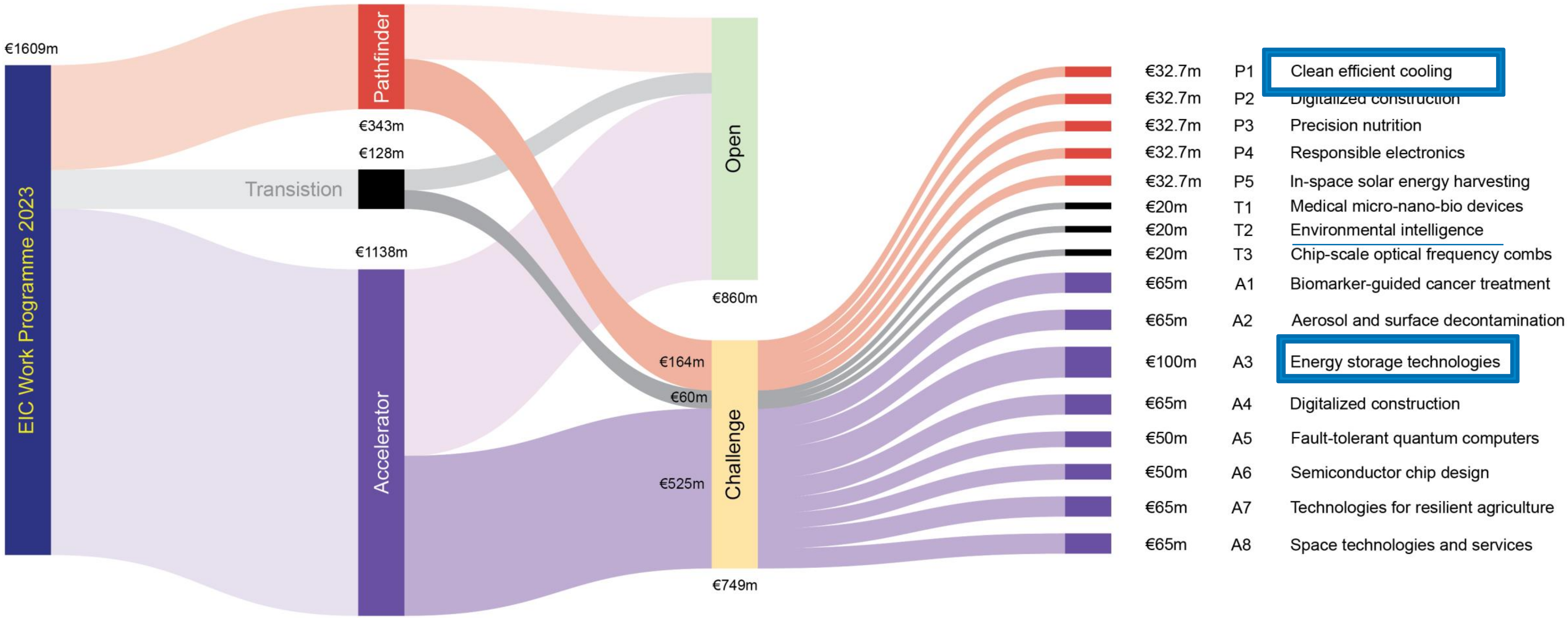
Challenges
Portfolios
Outreach

In 2023 EIC allocates ~€1.6bn to Open and Challenge calls by its Pathfinder, Transition, Accelerator programs



Priorities to identify the challenges in energy

- Energy demand (saving and efficiency, storage, demand response)
- Security of supply (critical dependencies of fuels and material) and Technological autonomy
- Sustainability: defossilize the whole supply chains
- Systems level thinking (recycle and reuse, merit order of end uses, water/food/energy nexus, integration of technologies)

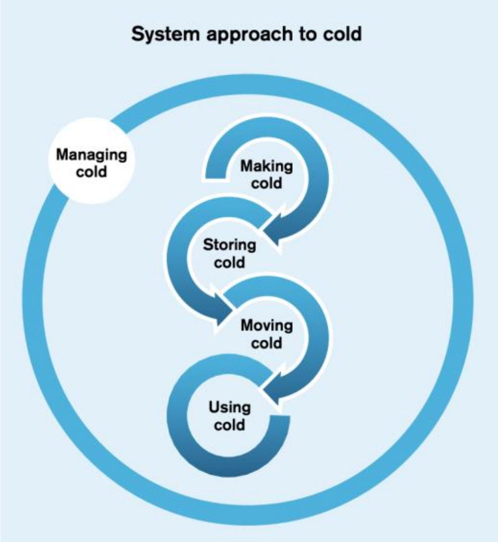
Focus of 2020-23:

- Green hydrogen generation
- Mid long duration energy storage
- CO2 and N management and valorization
- Clean cooling technologies

- Fit for 55%
- RepowerEU
- **Green deal industrial plan**
- **Net zero industry act**
- Critical raw materials act
- Chips act
- Electricity market design

The challenge on clean cooling

- **Dirty process**: 10% of CO_2 emissions come from cooling (3 times more than aviation and shipping)
- **Fast increasing**: demand of air conditioning will cover 50% of global electricity demand by 2100
- **Data centres**: around **half of their energy consumption** goes on cooling (up to 100 GW by 2030)
- Current/future **energy carriers** (H_2, NH_3, CH_4) are small molecules : need cooling/ compression
- **Developing countries**: two million **vaccine** preventable deaths each year, and the **loss of 0.2 billion tonnes of food** (and 3.3 billion tonnes of CO_2 emissions, third biggest emitter after US and China).
- Clean cold requires a **fully integrated 'cold economy',** with novel clean cold technologies, the integration of waste and under-exploited energy resources (i.e. wasted cold from LNG)



Need for:

- **transformational research** - displace existing technologies (i.e. functionalized PCM, laser cooling, reversible combustion etc)
- **Integration of renewable energy** for cooling (i.e. passive cooling, radiative and solar cooling, absorption and hybrid heat pumps)
- **Components**: new compression-expander mechanisms (scroll, electrochemical compression), mixed refrigerants, novel cycles configurations
- **store and move cold** (decoupling demand/generation) and system level integration
- **End uses**: management of cold consumption, diagnostics and soft fault detection

Scope/Specific objectives of the call

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Potential broad areas of applications

1) **data centres**, electronics, batteries and superconductors
2) **built environment**, building health and comfort, interoperable urban energy systems
3) **food production** (i.e. vertical farming), processing, storage and refrigerated transport,
4) **cold energy carriers production**, transport and network integration (liquid H2, LNG, ammonia)
5) chemical, metallurgical and **hard to abate industries**

Research and innovation needs:

1) net zero cooling technologies for industrial/residential sector (solar and geothermal, hybrid pumped heat and heat transformers, interoperability of district networks, etc);
2) ultra-energy efficient operations and logistics along the cold supply chain;
3) computational modelling, optimization and validation of heat transfer, working fluids, components;
4) unconventional refrigeration principles (i.e. thermoelectric, magnetocaloric, electrocaloric, elastomeric or barocaloric, photonic cooling).

Objectives and expected outcomes

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New devices, processes, components and materials for cooling, to:

- reduce investment/operational costs
- increase efficiency, operational reliability and interoperability
- avoid the use of critical raw materials or harmful refrigerants and pursue circularity by design approaches

The proposals should refer the expected COP to the **max theoretical COP** of the inverse Carnot cycle and describe how the proposed solution can be **competitive with the state of art at the proposed operating range**. The solutions should aim to achieve **single stage temperature gradients higher than 5 °C** at a competitive COP.

Portfolio composition and proactive management

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Preliminary portfolio composition approach:

- Cooling generation
- Cooling transport and storage
- Operation, control and demand management

Portfolio activities

- Identification of shared components and potential synergies
- Definition of potential common activities and use of same metrics to compare technologies
- Stakeholder mapping and engagement with the innovation ecosystem,
- Development of common exploitation plans and communication activities
- Synergies with other EU funding instruments
- Policy, standards, regulatory bottlenecks to innovation

EIC pathfinder open: relevant research directions

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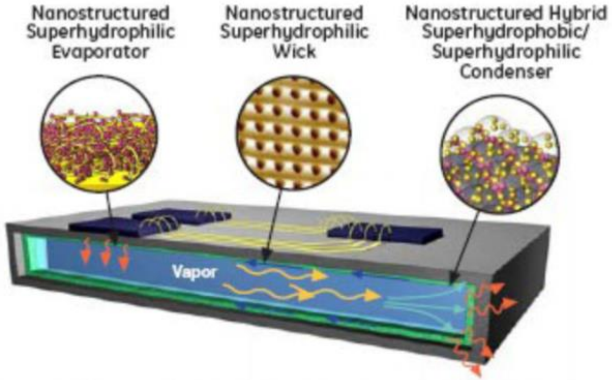
- Dropwise condensation for heat exchange: Harmonic
- Viscoelastic liquid cooling for batteries: i-Bat
- Molecular storage and thermal fuels: Most and E-sim
- Magnetocaloric cooling with non critical materials: CocoMag
- 3D printing heat exchangers: Thermodust
- Deep geothermal for heat discharge: Deep-U

EIC accelerator: start ups

- Kiutra: solid state cryogenic cooling
- Magnotherm: use of high magnetic fields for cryogenic cooling
- Magnetocaloric Heating Cooling



A diagram of GE's advanced thermal material system. Leveraging unique surface engineered coatings that both repel and attract water, GE's system achieves twice the heat conducting properties of copper and can function under extreme forces of gravity. The improved heat properties will enable a wide range of better electronics applications, ranging from faster laptops and more advanced radar systems to better aviation and naval electronic control systems.

Cooling and global warming

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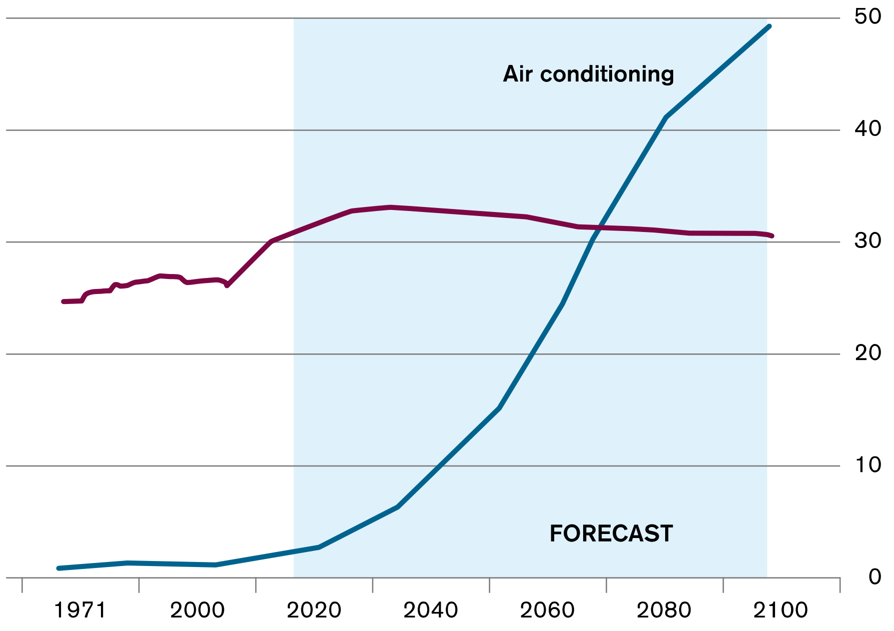
Global energy demand for cooling could exceed that for heating from around 2070



Isaac & van Vuuren (2009) Energy Policy, 37, 507-521

It is crucial to consider energy demand for cooling for net-zero 2050

Greenhouse gases and their contribution to the global warming

GWP and Atmospheric Lifetime for Various Greenhouse Gases

Greenhouse Gases	Chemical Formula	Global Warming Potential (GWP) for a 100-year Time Horizon	Lifetime (Years)
Carbon Dioxide	CO_2	1	Variable
Methane	CH_4	25	12
Nitrous Oxide	N_2O	289	114
HCFC-12	CHClF2	1,810	12
Tetrafluoroethane	CF4	7,390	50,000
CFC-12	CCl2f2	10,900	100
Hexafluroethane	C2F6	12,200	10,000
Nitrogen Trifluoride	NF_3	17,200	740
Sulphur Hexafluoride	SF_6	22,800	3,200

Lashof & Ahuja (1990) Nature, 304, 529-531; www.ourworldindata.org

Refrigerants can have a significantly higher GWP than CO_2 over a 100-year horizon

ICT sector contribution to carbon emissions

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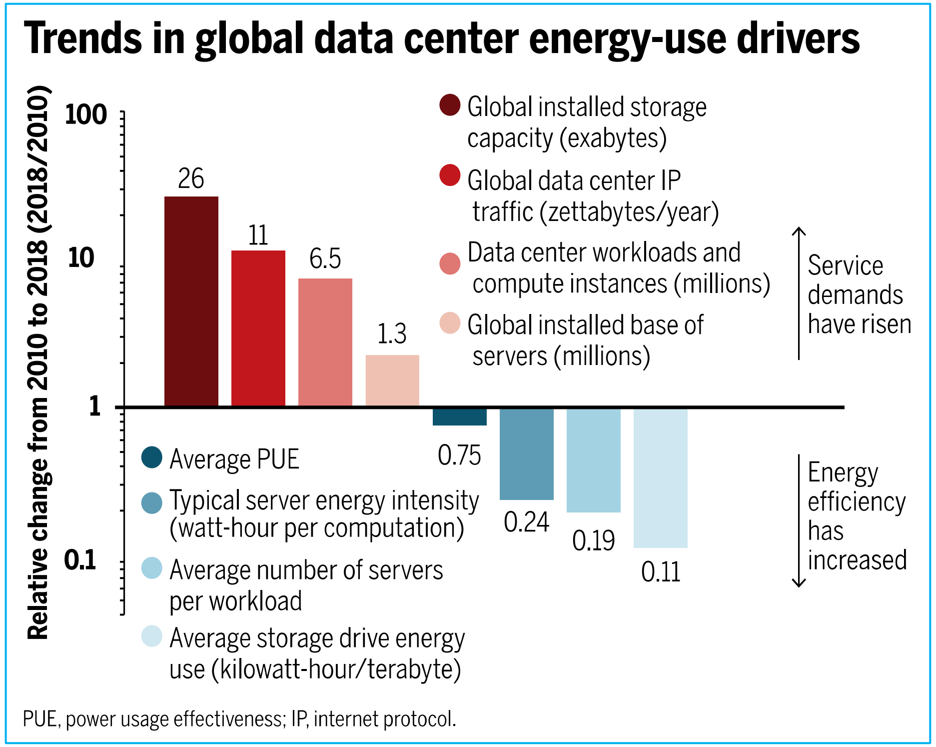
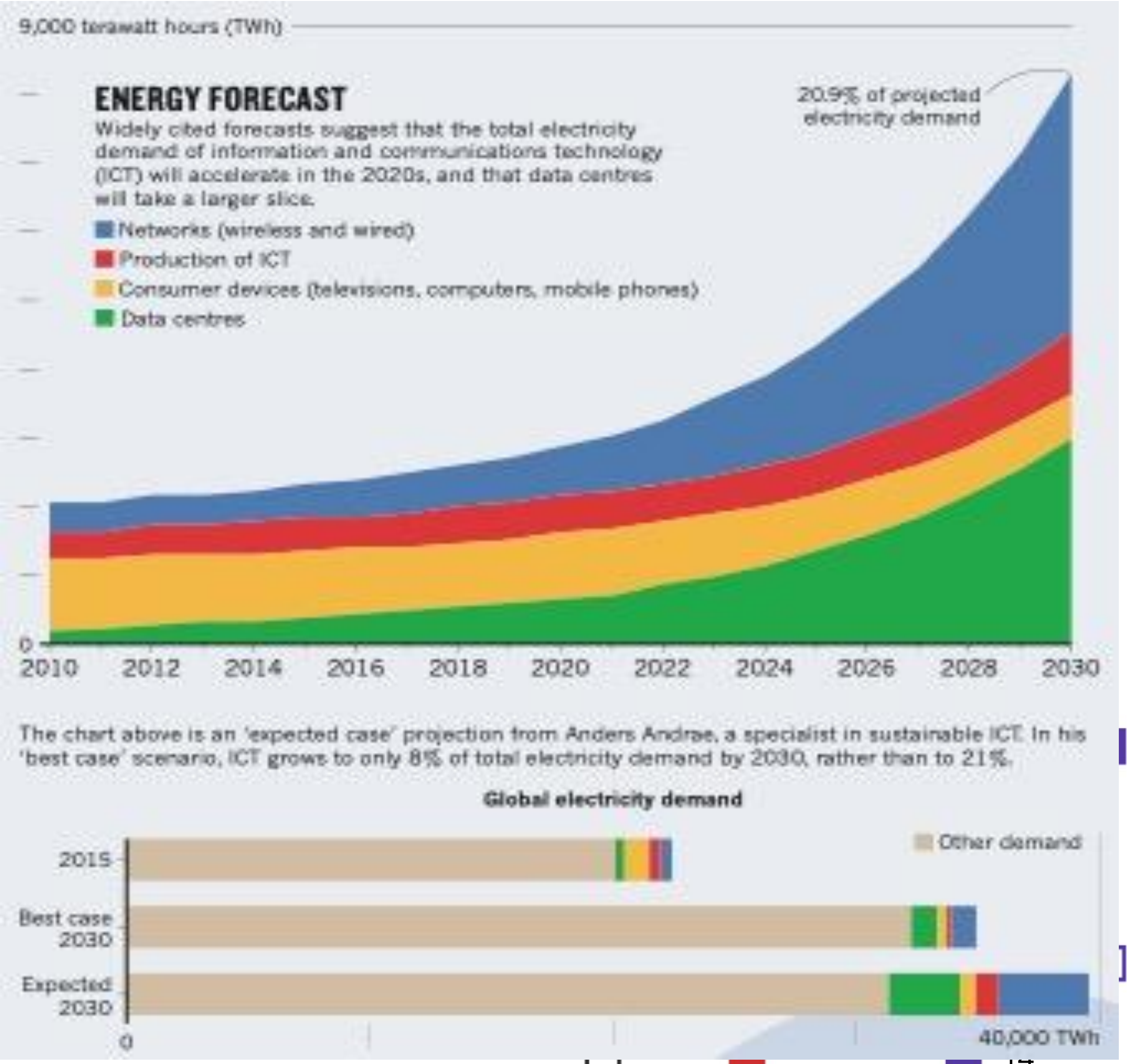
Increased telecommunication capabilities, intensified use of AI & Autonomous Vehicles drive the rapid acceleration and transfer of computing tasks to data centres





- **Data centres consume some 300TWh electricity in 2020, ~1.5% of global electricity demand and ~1% of energy GHG emissions**
- **Demand projected to double in 2030 and tripled in 2040.**
- **Some 40% of the electrical consumption lost as heat**

Masanet et al (2020) Science, 367, 984-986; Jones (2018) Nature 561, 163-166.

Demand is booming!

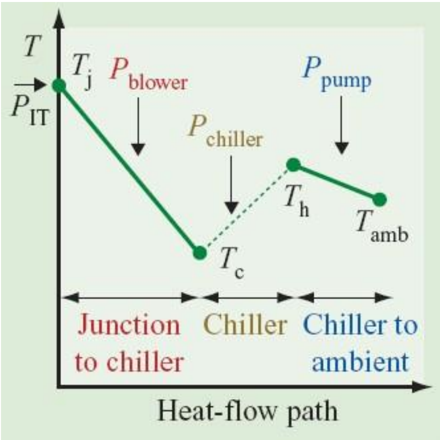
AND

Cooling is about 40% of the energy demand

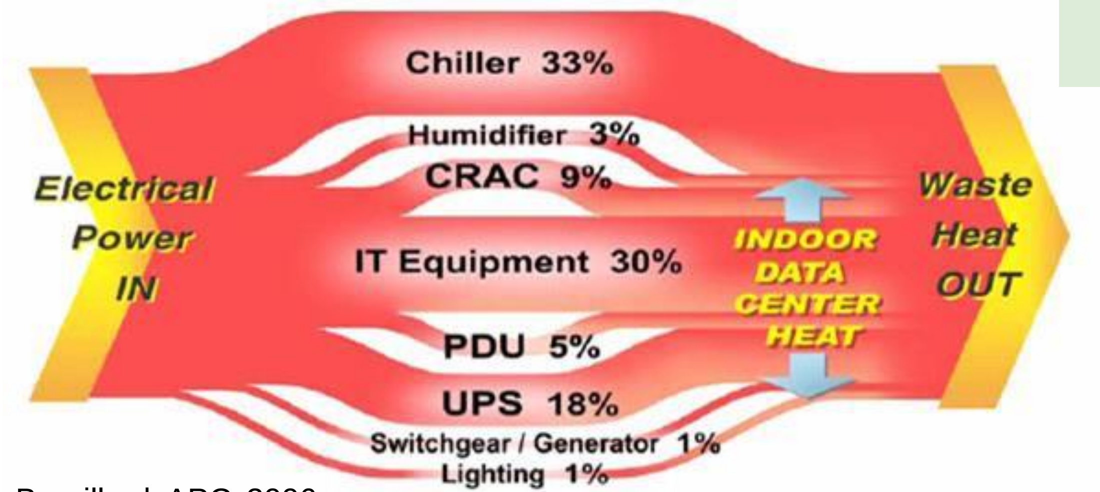
	2015	2022	Change
Internet users	3 billion	5.3 billion	+78%
Internet traffic	0.6 ZB	4.4 ZB	+600%
Data centre workloads	180 million	800 million	+340%
Data centre energy use (excluding crypto)	200 TWh	240-340 TWh	+20-70%
Crypto mining energy use	4 TWh	100-150 TWh	+2300-3500%
Data transmission network energy use	220 TWh	260-360 TWh	+18-64%

From 2017 to 2022: **average server rack density** up from 5 kW to 8-10 kW in US

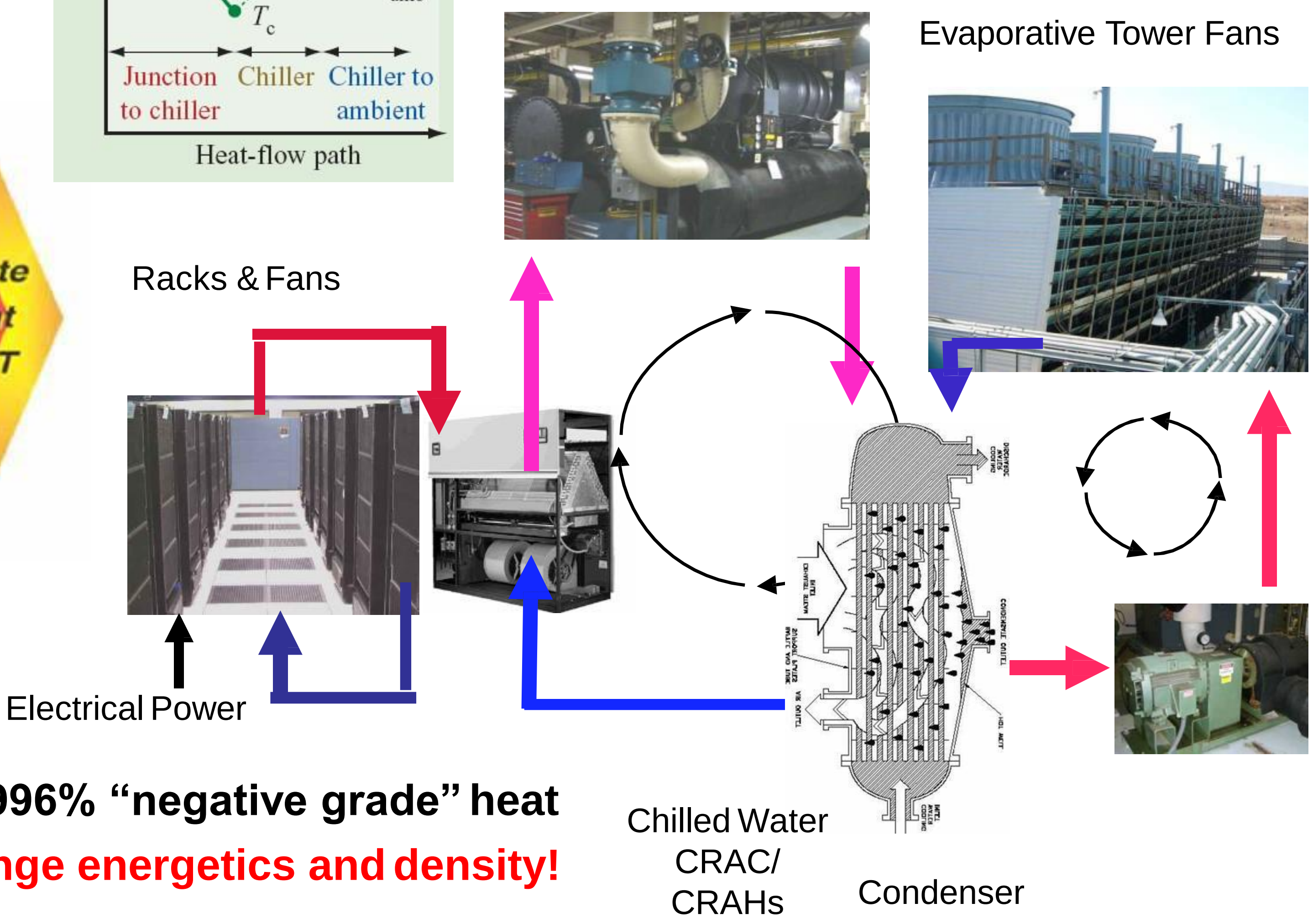
Low Datacenter Efficiency



- **Efficiency is 0.000’004%**
- **Volume used for compute is <1 ppm (part per million)**



Brouillard, APC, 2006



- **A computer is an inefficient “joule heater” “producing” 10-20ºC “heat”.**

The output is 0.000’004% ICT and 99.999’996% “negative grade” heat

- **Consequence: We have a lot to do to change energetics and density!**

Courtesy of IBM Research-Zurich, Bruno Michel, bmi@zurich.ibm.com

Data centre cooling: why and how?

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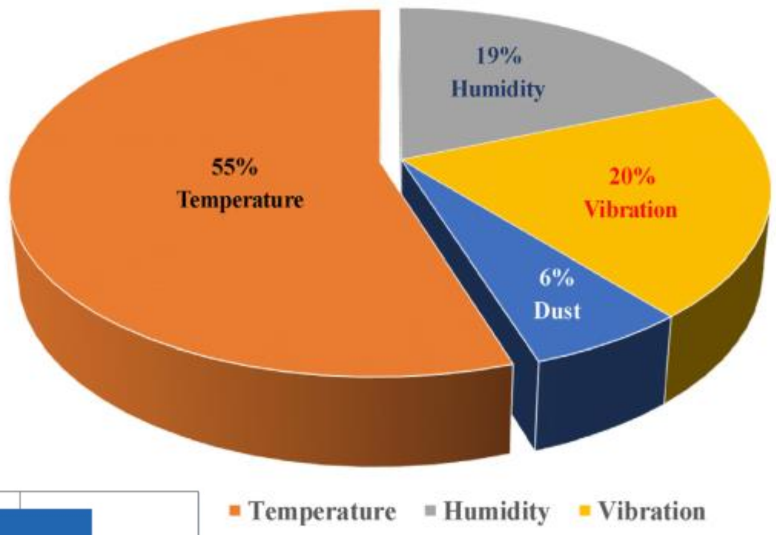
- Increased workload increases heat dissipation and rack T
- High T causes failure and/or low performance
- High thermal power in racks difficult to dissipate
- Racks cooled with air or heat pipes not anymore the solution
- Liquid cooling: high U factors but dielectric materials durability risks and accessibility for maintenance/operations
- Streaming requirements: data centres location constraints (not possible anymore to optimize the location)

High T is the major cause of electronic failures AND **low performance**

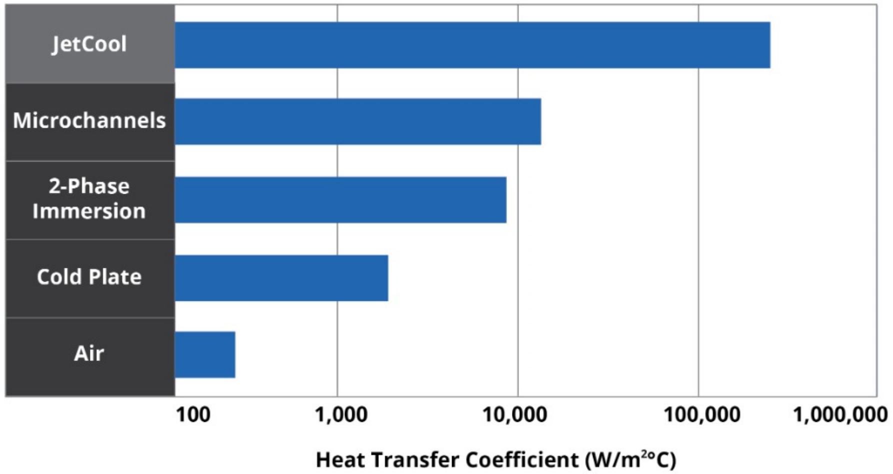


Ziqiang H, et al Energy 2021; 216: 119223. https://doi.org/10.1016/j.energy.2020.119223.

The need
High workload and internal T of 40-50°C
Cool chip with **ΔT = 20ºC** instead of 75ºC

Solution 1
High T of chips
Limit 85-100 °C

Solution 2
High U factors
up to 100 kW/m2 C



Zhang Y, Ding Y et al. Journal of Cleaner Production 2022;334: 130280. https://doi.org/10.1016/j.jclepro.2021.130280.

Cooling methods to save energy

Cooling methods

Liquid cooling

Free cooling
(radiative, thermophotonic, geothermal, etc)

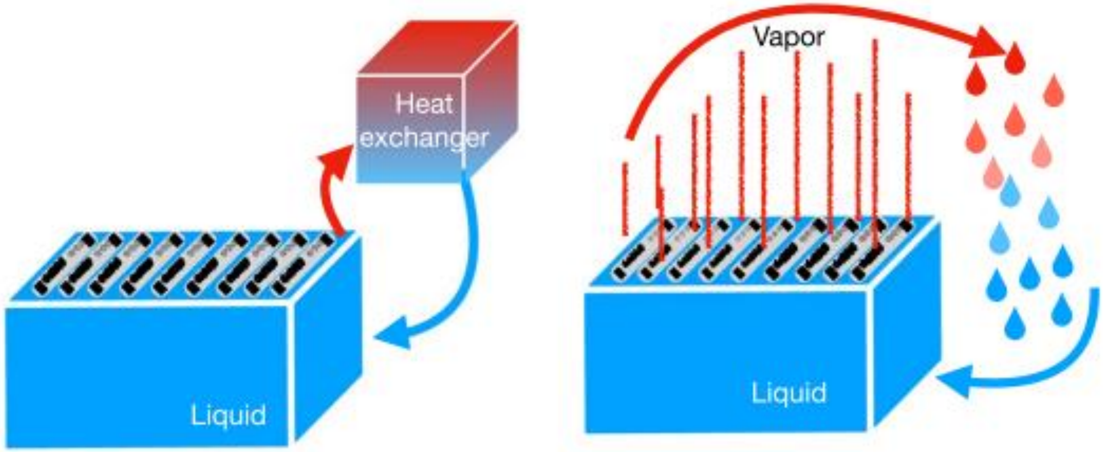
TES-based and systems integrated cooling

Solid state cooling

Liquid cooling

- Liquid is transferred through servers
- Higher heat transfer coefficients
- Types:

1. Cold plates connected to server
2. Servers immersed in cooling liquid (one phase or two phases)



Zimmermann S, Meijer I, Tiwari MK, Paredes S, Michel B, Poulikakos D. 2012. Aquasar: a hot water cooled data center with direct energy reuse. Energy 2012; 43: 237–245. https://doi.org/10.1016/j.energy.2012.04.037.

Direct-to-Chip immersion Cooling

Technology description

Liquid cooling technique where a liquid coolant is delivered to a chip via flexible tubes to absorb heat with **direct contact to the chip**

Level of maturity

Not commonly used in Data Centres

Benefits

- Reduced need for fans
- Able to support higher CPU and GPU densities
- Reduced space (less need for additional heat removal systems)
- Reduced downtime due to equipment overheating

Density supported

- **Around 175 kW/rack**
- Suitable for future generations of processors in the range of 200 Watts TDP and more

Downsides / Challenges

- Only a portion of server components are cooled with liquid, fans are still needed
- High-pressures / Water treatment

Most relevant technical aspects

- Uses a heat transfer module (cold plate or heat sink) placed on the server board to directly cool the high-power rack components
- **Waterless (non-flammable dielectric fluid instead)**
- The two-phase liquid cooling uses a highly-efficient two-phase boiling and condensation process

Performances

- **Heat transfer coefficient higher than 1,000 W/m^{2}C**
- **PUE down to 1.08**

Key players

AKCP Est. USA 1981

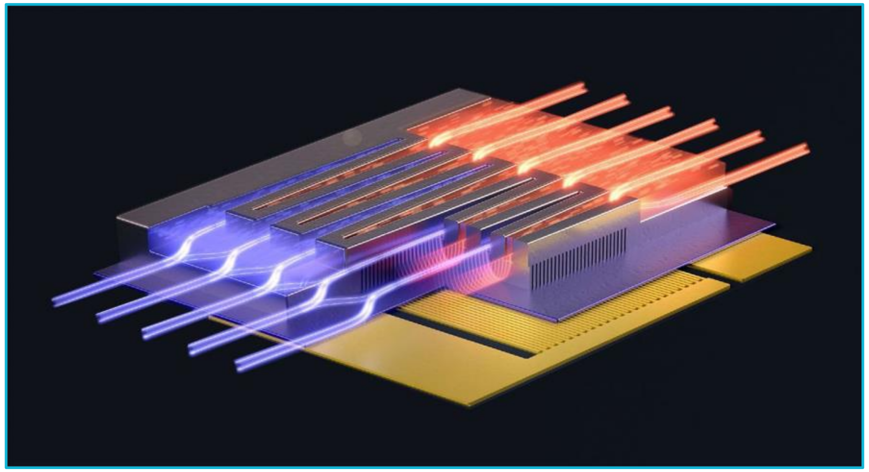
jetcool

ATS Advanced Thermal Solutions, Inc. Innovations in Thermal Management®

Asetek

CHILLDYNE Liquid Cooling Solutions

Microchannel liquid cooling



- **Technology description**

An extension of direct-to-chip liquid cooling with the addition of **sealed metal plates** that allow to spread the heat generated in the device into small internal fluid channels

- **Most relevant technical aspects**

- Provides cooling for a large surface area
- The small fluid channels facilitate interaction between the flowing coolant and the heated surface
- Channels may be skived, pin fin, or machined
- Metal plates target CPUs, GPUs, & memory modules
- Requires a thermal interface material to be applied

- **Level of maturity**

All-aluminum microchannel heat exchanging products are now being widely used in the HVAC industry

- **Density supported**

Same density as with a direct-to-chip cooling system

- **Performances**

- Heat transfer coefficient around 10,000 W/m^2C
- 20% to 40% greater overall heat transfer performance

- **Benefits**

- Less refrigerant charge
- Reduced material cost

- **Downsides / Challenges**

- The thermal interface material can sometimes be a limiting thermal resistance layer as thermal design power reaches peak performance
- Keep pressure drops to a low level

- **Key players**

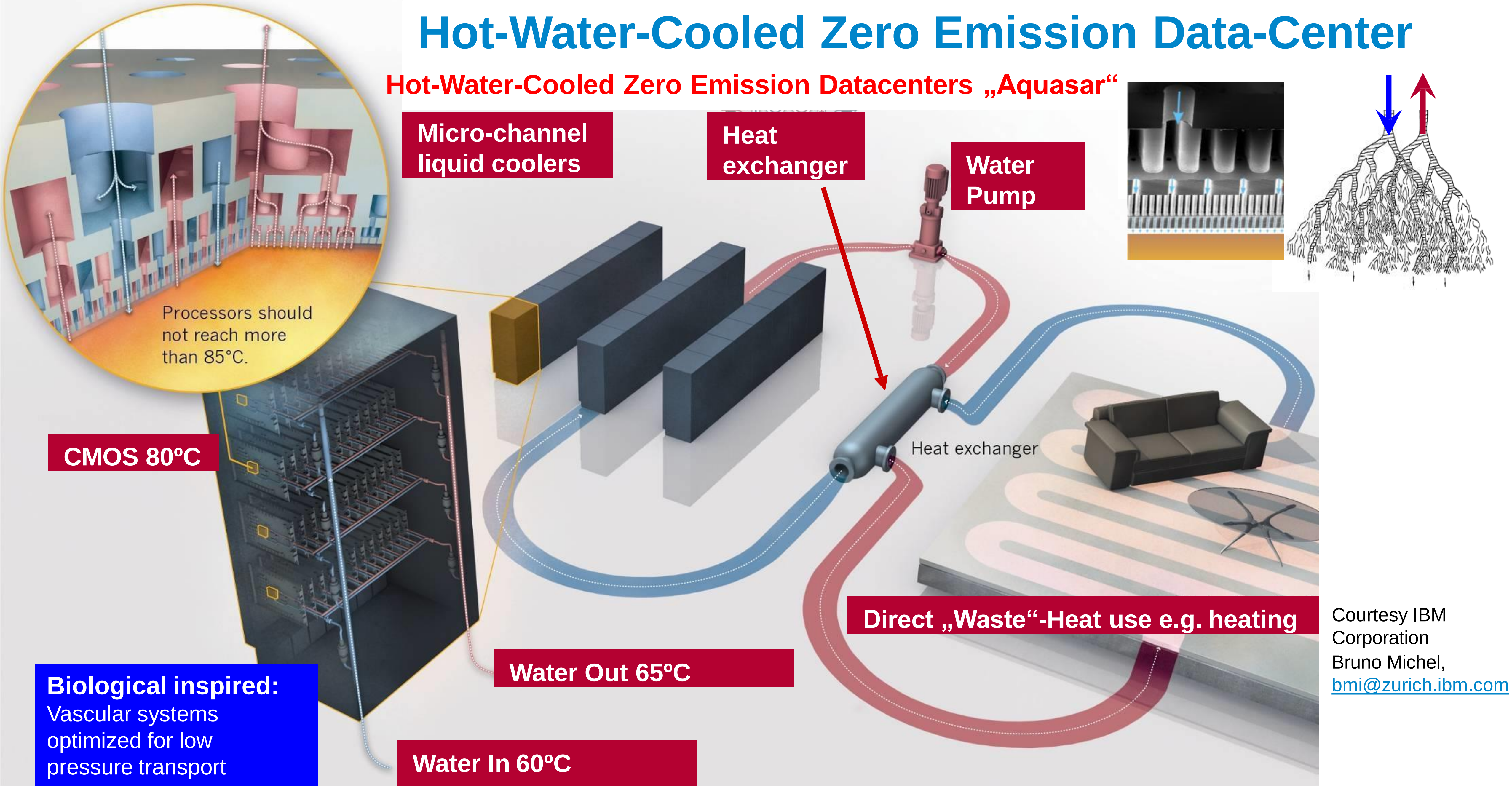
jetcool

KALTRA

ATS ADVANCED THERMAL SOLUTIONS, INC. Innovations in Thermal Management®

Hot-Water-Cooled Zero Emission Data-Center

Hot-Water-Cooled Zero Emission Datacenters „Aquasar“



Micro-channel liquid coolers

Heat exchanger

Water Pump

CMOS 80ºC

Direct „Waste“-Heat use e.g. heating

Water Out 65ºC

Water In 60ºC

Biological inspired:
Vascular systems optimized for low pressure transport

Courtesy IBM Corporation
Bruno Michel,
bmi@zurich.ibm.com

Two-phase immersion cooling

- **Technology description**

Liquid cooling technique that involves the submerging of server electronics into a thermally conductive liquid bath relying on phase change as a form of heat extraction

- **Level of maturity**
  - While fairly new, the technology is gaining some market traction
  - As of April 2021, Microsoft is testing two-phase immersion cooling on a hyperscale Azure Data Centre

- **Benefits**
  - Immersion protects electronics from harsh amb. environm. & dust debris
  - Reduced failure potential as no cooling fans are required
  - Lessens the pumping infrastructure
  - Reduced space / able to support hyperscale data centres

- **Density supported**

Suitable for future generations of processors in the range of 200 Watts TDP and more

- **Downsides / Challenges**
  - Complex installation / hardware requires modifications to allow for long lifetime operation
  - The dielectric fluid is expensive and must be kept in contamination-free containers

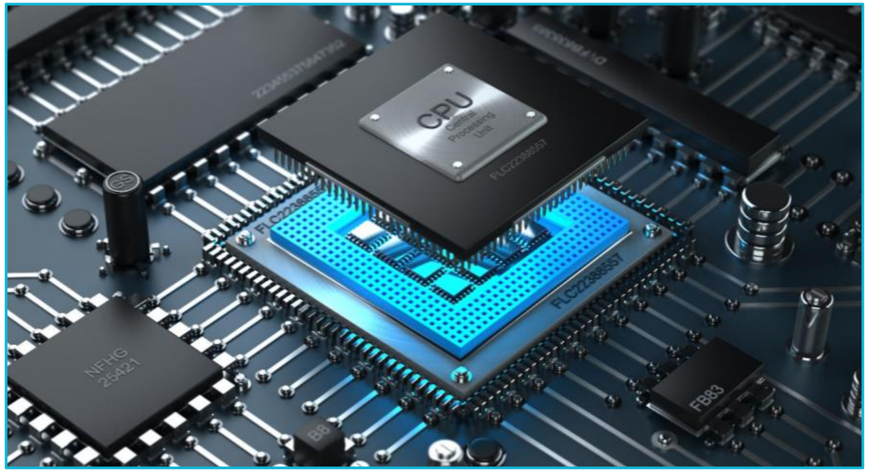
- **Most relevant technical aspects**
  - As the dielectric fluid heats up to boiling point, heat is removed by latent heat transfer where liquid converts into vapour
  - No longer a need for heat sinks
  - Boiling point of 50° C

- **Performances**
  - Heat transfer coefficient around 10,000 W/m2C
  - PUE down to 1.06

- **Key players**

ALLIED CONTROL IMMERSION COOLING
BOYD CORPORATION
GIGABYTE
TAS
liquidstack
GRC GREEN REVOLUTION COOLING The Immersion Cooling Authority
Asperitas IMMERSED COMPUTING

Microconvective liquid cooling



Technology description

Hotspot-targeted embedded liquid cooling that uses numerous small fluid jets within compact cooling modules

Most relevant technical aspects

- Directs fluid through an array of small jetting nozzles straight to the hot surface (perpendicular turbulent flow onto the device)
- Coolant can be any liquid including water, glycols, dielectrics, and refrigerants
- No use of thermal interface materials

Level of maturity

A relatively new technology

Density supported

Suitable for the densest compute profiles (more than 1,000 Watts TDP)

Performances

- **Heat transfer coef. > 100,000 W/m^{2}C i.e. 10 × greater than competing approaches** (microchannel liquid cooling, two-phase immersion)
- **PUE down to 1.02**
- technology reported to save up to 8% in data centre energy costs

Benefits

- Offers exceptional cooling performance for high-power electronics
- Minimizes thermal resistance by eliminating all thermal pastes and interface materials
- Enables faster compute times

Downsides / Challenges

No particular downsides or challenges reported (apart from accessibility and manteinance)

Key players

jetcool

Immersion Cooling: Value Chain & Innovator Landscape

Software

Energy Efficiency Computing Technology

- Raritan (Know more. Manage smarter.)
- LANCIUM
- ENCYCLE (SMARTER ENERGY)
- FieldView Solutions
- RackWare
- e4c eco4cloud
- NUTANIX
- CONCERT Technologies
- CLOUD & HEAT

Digital Twins

- COMMSCOPE
- RED DOT ANALYTICS
- Future Facilities

Automation

- LUNAVI
- azeti
- Sherlogic
- HashiCorp
- POWER ASSURE

AI & ML

- interact.
- Vigilent

Hardware

Liquid & Immersion Cooling

- incooling
- Asetek
- submer
- GRC Green Revolution Cooling (The Immersion Cooling Authority)
- CoolIT Systems
- OptiCool Technologies
- STULZ
- ICEOTOPE
- ferveret
- Energy Cool
- Asperitas (Immersed Computing)
- LiquidCool Solutions
- liquidstack
- CHILLDYNE (Liquid Cooling Solutions)
- VERTIV (Architects of Continuity)
- U Systems
- jetcool
- ZUTACORE
- DCX
- Munters
- motivair (Cooling Solutions)

Waste Heat

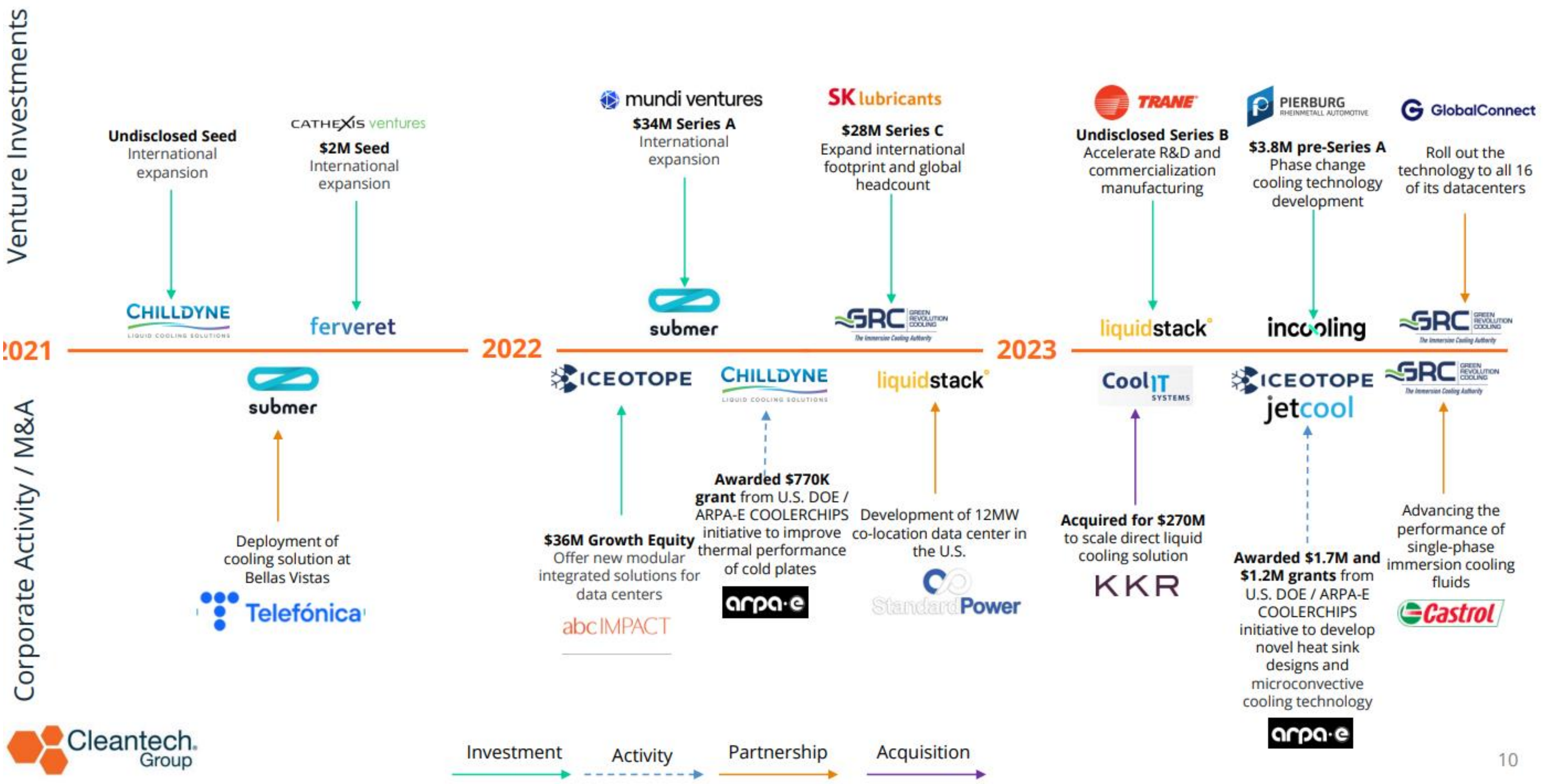
- Hydrokapillare
- Danfoss
- STULZ
- tera cool
- VERTIV (Architects of Continuity)

Renewable Power Generation

- LANCIUM (Balancing Energy)
- enphase Energy

Courtesy Cleantech, 2023

Immersion Cooling: Investment / Corporate Activity



Cleantech Group

Two-phase cooling

European Innovation Council

Two-phase change (liquid-vapour) to benefit from latent heat

No mechanical parts

Decoupling with racks for safe operations and manteinance

- **Heat-pipe-based cooling**

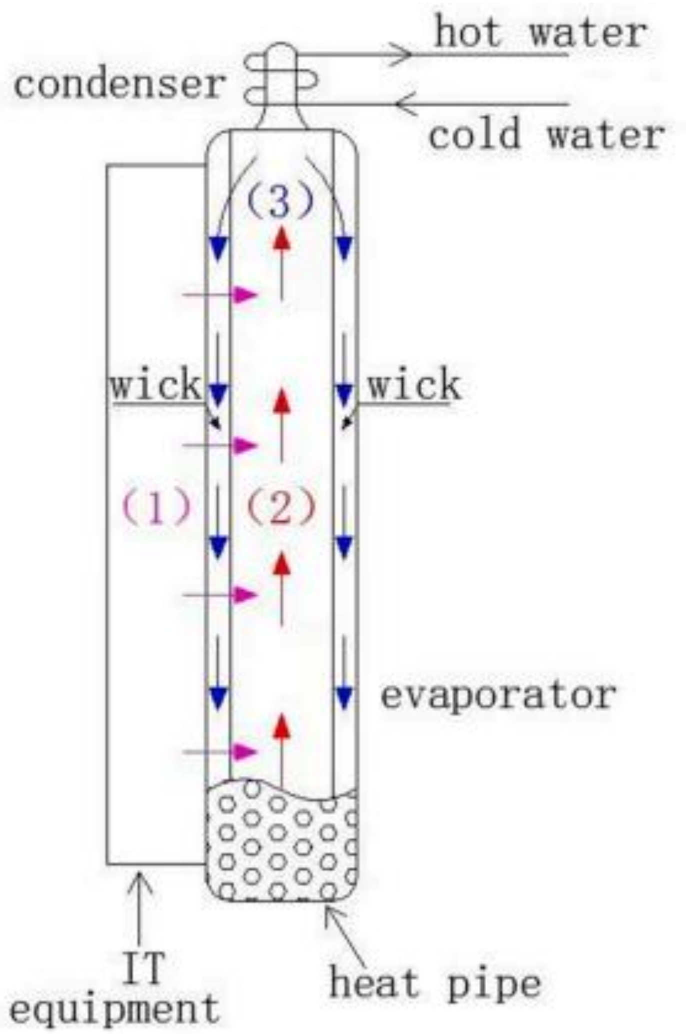
  Heat pipes: tubes filled with structured material and a working fluid

  Three sections: evaporation, adiabatic and condensation

  Smaller temperature differences than standard CRAC systems

- **Thermosiphon-based cooling**

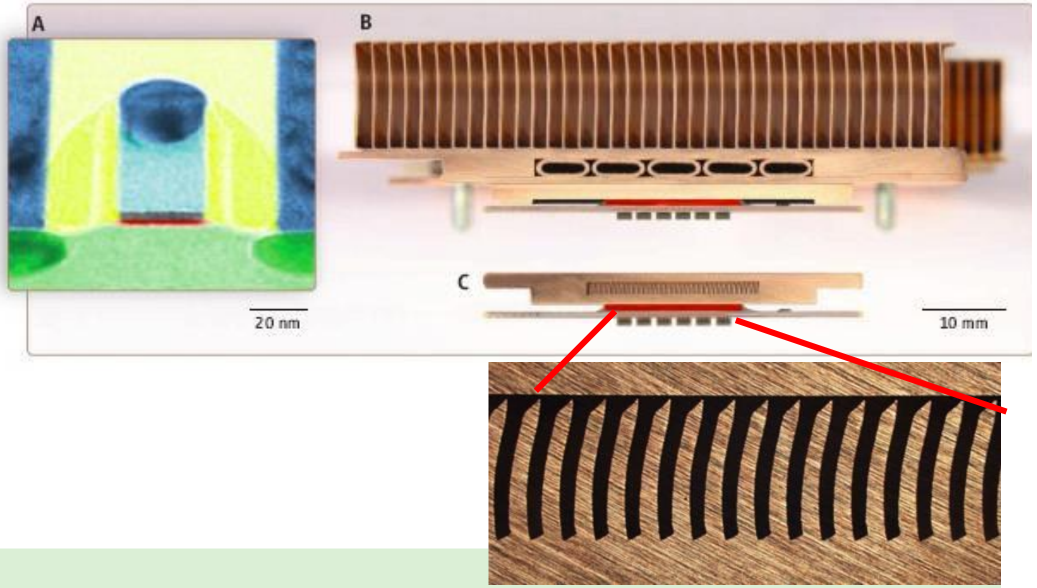
  Gravity causes fluid to move from condenser to evaporator

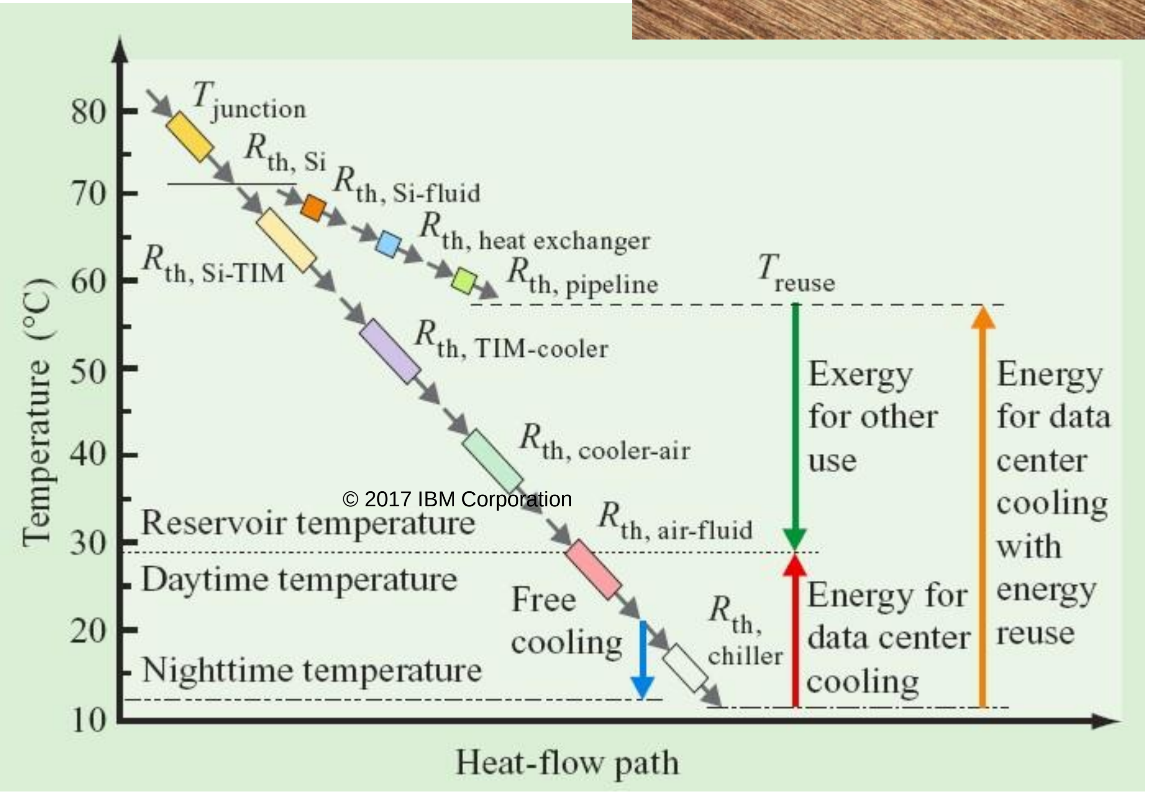


Haghshenas K, et al. Enough hot air: The role of immersion cooling. Energy Informatics 2023; 6: 14. https://doi.org/10.1186/s42162-023-00269-0.

Integration in District heating

- **High-performance chip-level cooling improves energy efficiency AND reduces carbon footprint**
  - Cool chip with **ΔT = 20ºC** instead of 75ºC
  - **Save chiller energy:** Cool with T > 60ºC **hot water**
  - **Re-use:** Heat 700 homes with 10 MW datacenter
- **Need carbon footprint reduction**
  - Chillers use ~50% of datacenter energy
  - Space heating ~30% of carbon footprint
  - Chips can be used as heaters for DH
- **Zero-emission concept valuable in all climates**
  - Cold and moderate climates: **energy savings** and **energy re-use**
  - Hot climates: Free cooling, desalination
- **Europe: 5000 district heating systems**
  - Distribute 6% of total thermal demand
  - Thermal energy from datacenters absorbed

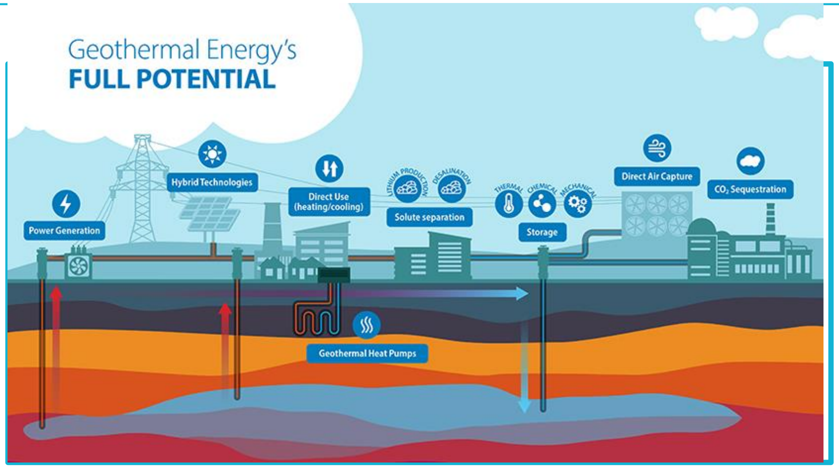




Courtesy IBM Corporation

Bruno Michel, bmi@zurich.ibm.com

Passive cooling: Geothermal resources



▪ Technology description

- Ground-coupled cooling process that transfer heat from the IT environment into the relatively-colder soil (geo-exchange)

- Generation of cooling and power to serve energy demand for data-centres; good matching generation and demand.

▪ Level of maturity

The technology has been around for quite some time, but is not yet widespread for data centres

▪ Density supported

Same density as with a conventional chilled-water cooling system

▪ Benefits

- Lower operating costs
- Little maintenance
- Environm. friendly / quieter
- Does not depend on amb. temperature (improved reliability)
- Long equipment life (ground loop components can last over 50 years)

▪ Downsides / Challenges

- High upfront installation costs
- May require significant landscape alterations

▪ Most relevant technical aspects

- **It maintains the traditional CRAC/CRAH units**
- the closed-loop piping system is filled with water or coolant that runs through vertical underground wells filled with a heat-transferring fill

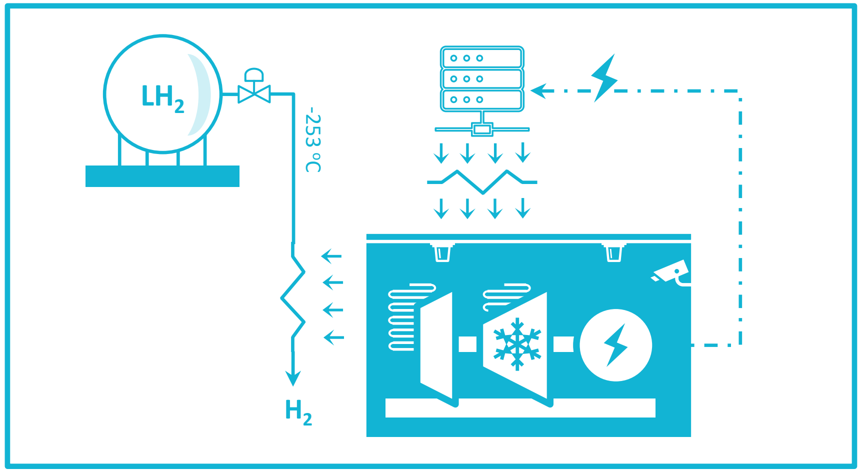
▪ Performance

25% to 50% less electricity usage than traditional HVAC systems

▪ Key players

WaterFurnace
ENERGY STAR
ClimateMaster
Renewable Energy World
Mississippi Power

Systems integration: Cryogenic Cogeneration



- **Technology description**

Thermodynamic process that uses the enthalpy difference between a low-boiling-point cryogen (LN_2 or LNG or LH_2) and the waste heat from the server racks to **generate power and cooling in customized turbines and heat exchangers at the same time.**

- **Level of maturity**
  - TRL 3-4 (Lab-scale demo at TESLAB @NTU) – EU & US Patent
  - Collab. agreement between Engie and NTU for the development of a 200-kW_e demo platform (2021)
  - Keppel DC joining the demo phase (2023) for LH_2-driven syst.

- **Benefits**
  - Lower operating costs (free cold energy)
  - Environm. friendly (zero emission)
  - Does not depend on amb. temperature (improved reliability)
  - Long life cycle (> 25 years)

- **Density supported**

Same density as with a conventional chilled-water cooling system

- **Downsides / Challenges**
  - Requires proximity to LNG or LH_2 maritime terminals
  - Requires high storage capacity if about LN_2-fueled cryo-cogen.

- **Most relevant technical aspects**
  - Utilization of the high-grade cold energy content in the LNG or LH_2 terminals for a continuous and stable cogeneration
  - Solution also applicable for backup power generation with an LN_2-fueled open-cycle cryo-cogenerator
  - It maintains the traditional CRAC/CRAH units and eliminates the use of chillers and cooling towers

- **Performance**
  - An LH_2-driven cryo-cogenerator coupled to a small-size terminal (1 k.TPD) would deliver up to 15 MW of power and 50 MW of cooling
  - PUE around 1.1

- **Key players**

NANYANG TECHNOLOGICAL UNIVERSITY SINGAPORE

TESLAB@NTU THERMAL.ENERGY.SYSTEMS.LAB

ENGIE Lab

Keppel Data Centres

Integration of data centre, biogas fuel cell and DH

Demonstration site

LULEÅ (Sweden)

Using Fuel Cells to Address Energy Growth and Sustainability Challenges in Data Centers

PowerHour webinar series for consulting engineers
Experts you trust. Excellence you count on.

April 2, 2020 2:00pm Eastern Time / 11:00am Pacific Time
(1 PDH issued by Cummins Inc.)

4 tonnes of biogas stored at 200 bar.

Covered trench with gas line, power and data.

Building with DH network

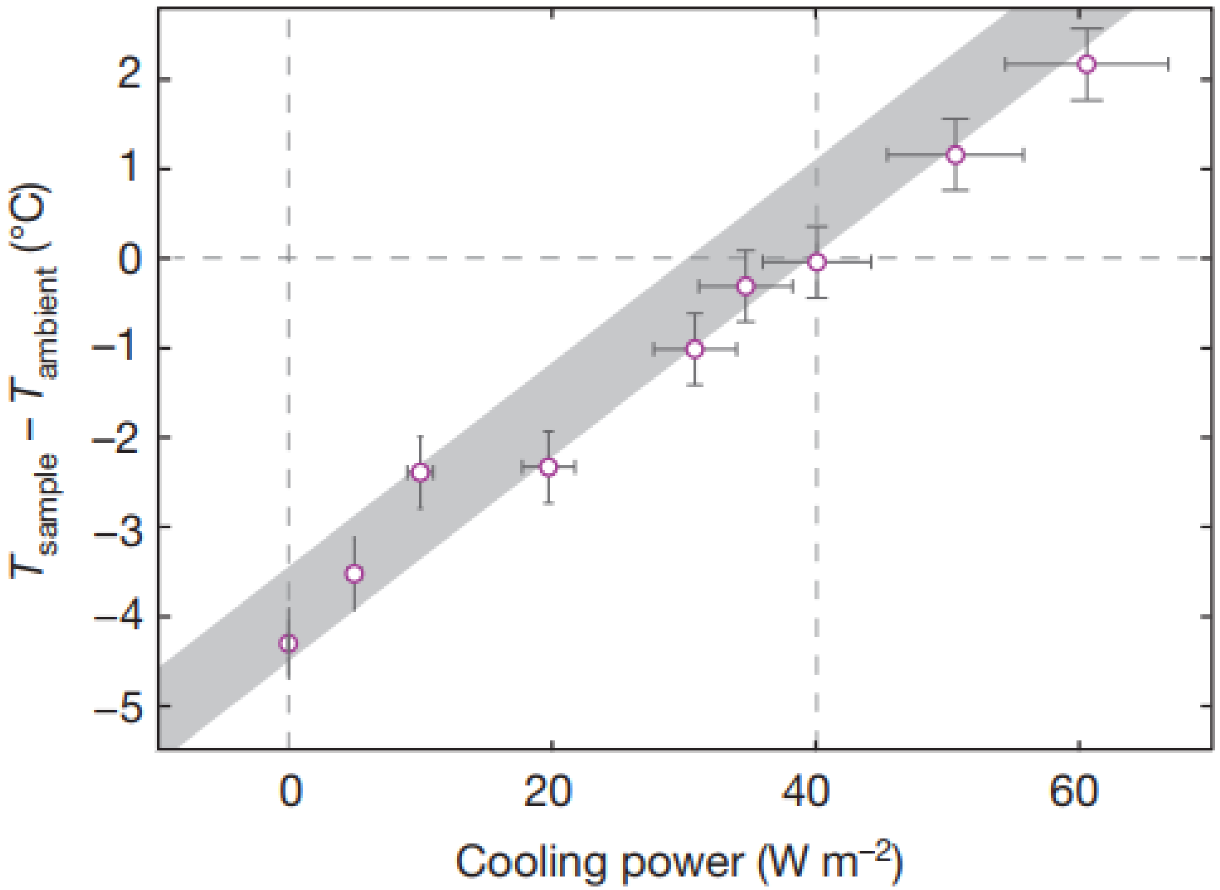
Fuel cell container with 9 fuel cells

Data centre container

Passive cooling: radiative cooling below ambient temperature

European Innovation Council

- Photonic radiative cooler was found to reflect 97% of incident sunlight and cool 5 °C below ambient air temperature
- Could be directly integrated with chillers and HVAC systems



Raman AP, Anoma MA, Zhu L, Rephaeli E, Fan S. Passive radiative cooling below ambient air temperature under direct sunlight. Nature 2014; 515: 540-544. https://doi.org/10.1038/nature13883.

System integration: TES-based cooling

European Innovation Council

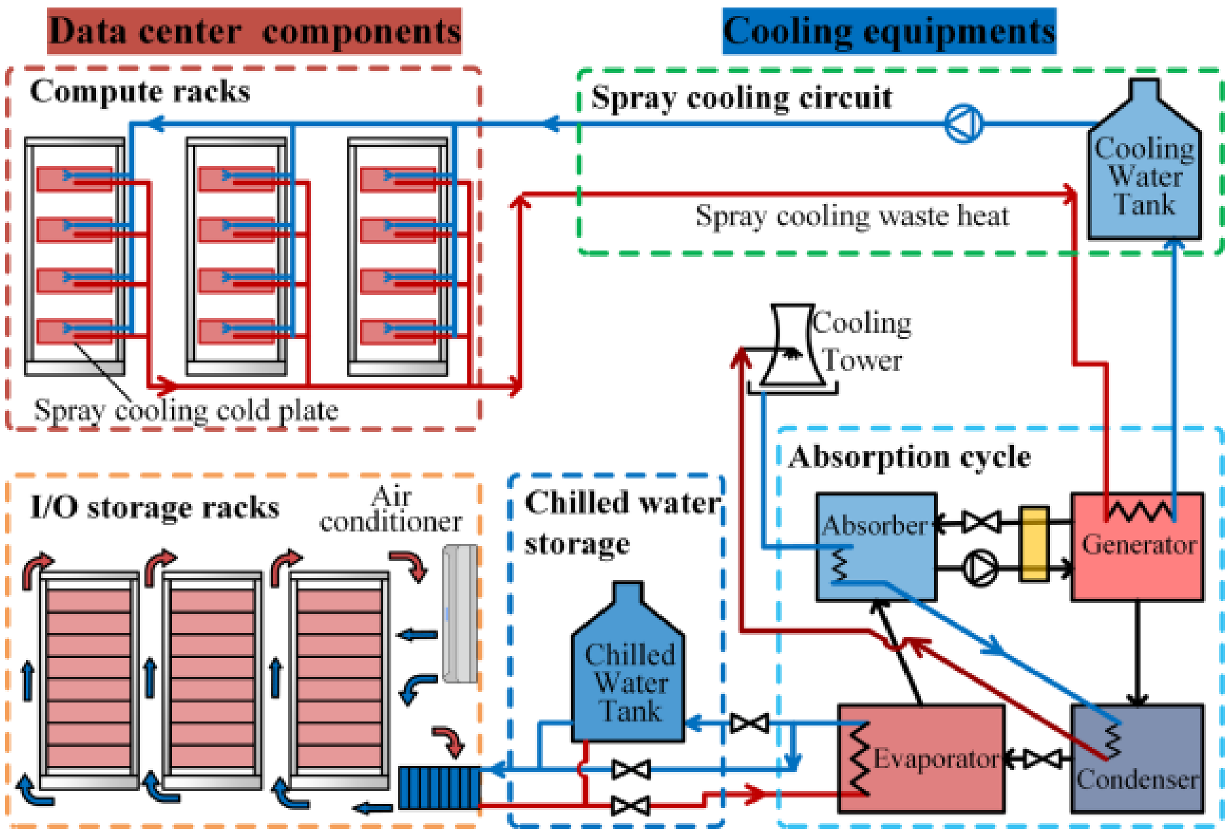
- Thermal Energy Storage: Decouples cooling requirements and electricity supply
- EIC pathfinder on duration storage 2022
- Used in conjunction with previous techniques

Examples:

Free cooling with lake water and cold water tank

Liquid cooling with heat pipes and PCM

Spray cooling with cold water tank and absorption chiller

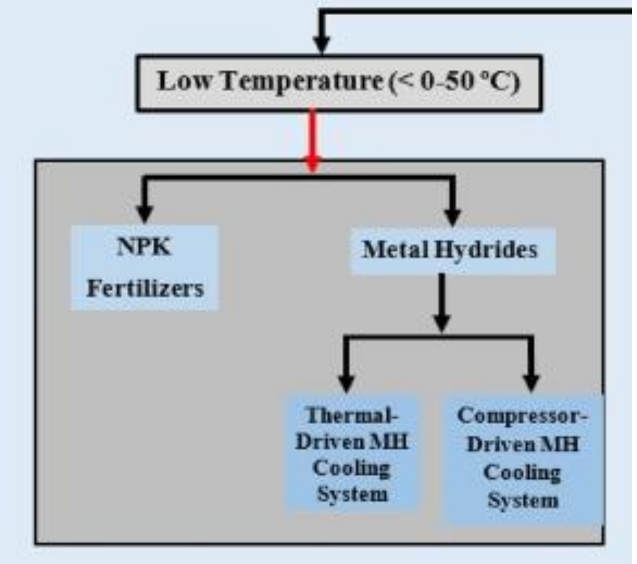


Chen H, Peng Y, Wang Y. Energy Convers Manag 2019; 183: 427–439.
https://doi.org/10.1016/j.enconman.2018.12.117

Thermochemical energy storage and absorption chillers coupled to cooling

European Innovation Council

- Chemical reaction-based energy storage system that receives thermal energy during the **endothermic** chemical reaction and releases it during the **exothermic** reaction
- Low-temperature (<0–50 °C) cooling applications are possible
- Could **waste heat from data centres** be used to drive thermochemical-energy based cold production or absorption chillers? **Data centres cool itself**
- **Direct rack-integration of adsorption** reduces installation and piping cost considerably and is a route to easy and fast implementation of energy and space savings.



Desai F, et al. Thermochemical energy storage system for cooling and process heating applications: A review. Energy Conversion and Management 2021; 229: 113617. https://doi.org/10.1016/j.enconman.2020.113617.

Absorption chillers and data centres cooling

Examples in Germany: IT Cooling at Leibniz Data Center Munich

Facts & Figures

- LRZ is the largest German data center for supercomputing
- IT compute rack inlet temp.: 45-55°C
- Adsorption chiller cooling circuit temperature: 21°C
- Re-cooling circuit temp.: 25°C to 30 °C
- Avg. driving power (IT): 120kW, Avg. cooling power: 50kW (for storage)
- Adsorption chillers still installed separately.
- **First real size installation to prove this technology. Currently, no other adsorption chillers exist, which may be used in this application.**
- **Partners: IBM/Lenovo - Intel**

Courtesy of Sorption technologies

Results

- 120 kW heat removed from computer
- 50 kW cold produced for storage units
- 9 kW electricity needed
- Upscaled to the entire data center this means that no compression chiller is necessary anymore:

The data center cools itself.

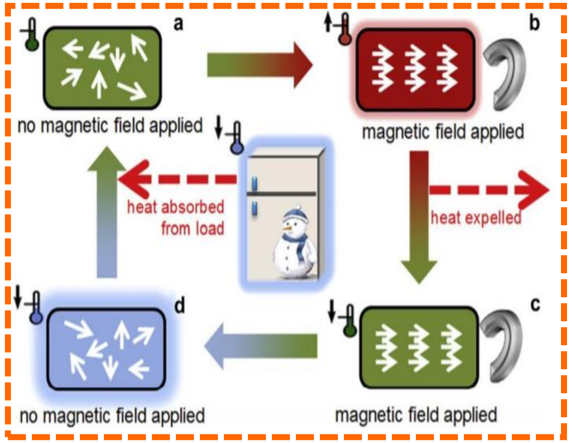
Solid-state systems for cold storage and use

European Innovation Council

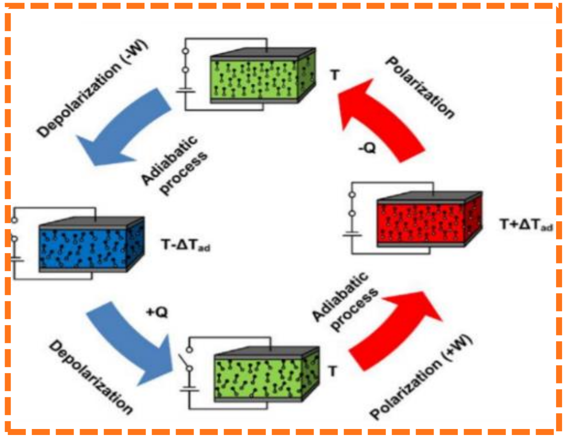
- Traditional refrigeration systems use gases or liquids
- **What about using solids?**
- Solid-state systems: a reversible **thermal change occurs in certain materials** when subjected to a time-varying magnetic field, strain or electric field
- When a barocaloric material is subjected to a pressure change, it undergoes a phase transition, from a solid to a liquid or vice versa
- During phase transition, the material either absorbs or releases heat

Solid-state cooling systems

European Innovation Council

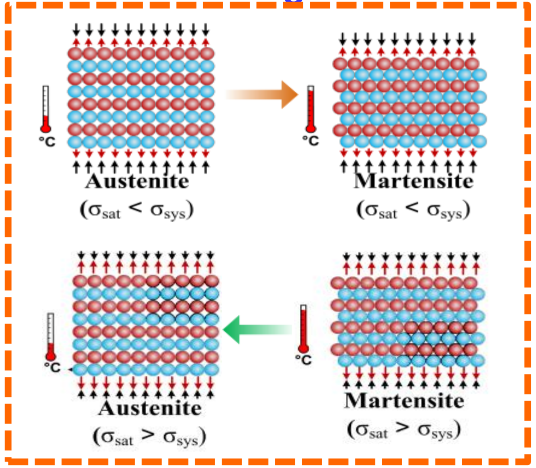


Magnetocaloric

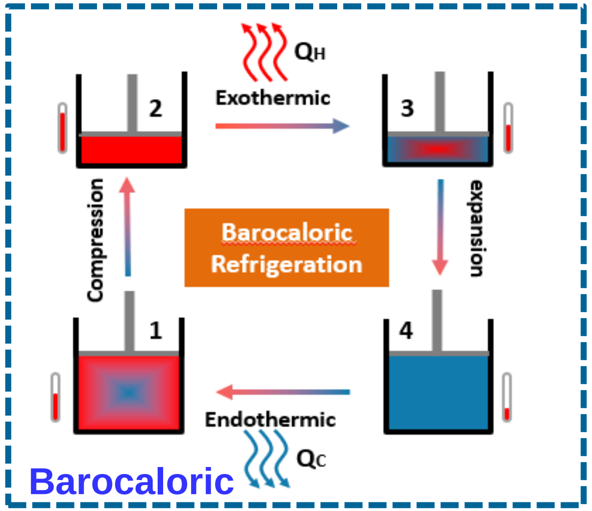


Electrocaloric

Ren et al. (2022) Nature Communications, 13, 2293; Dai et al (2023) Advanced Functional Materials, https://doi.org/10.1002/adfm.202307822



Elastocaloric



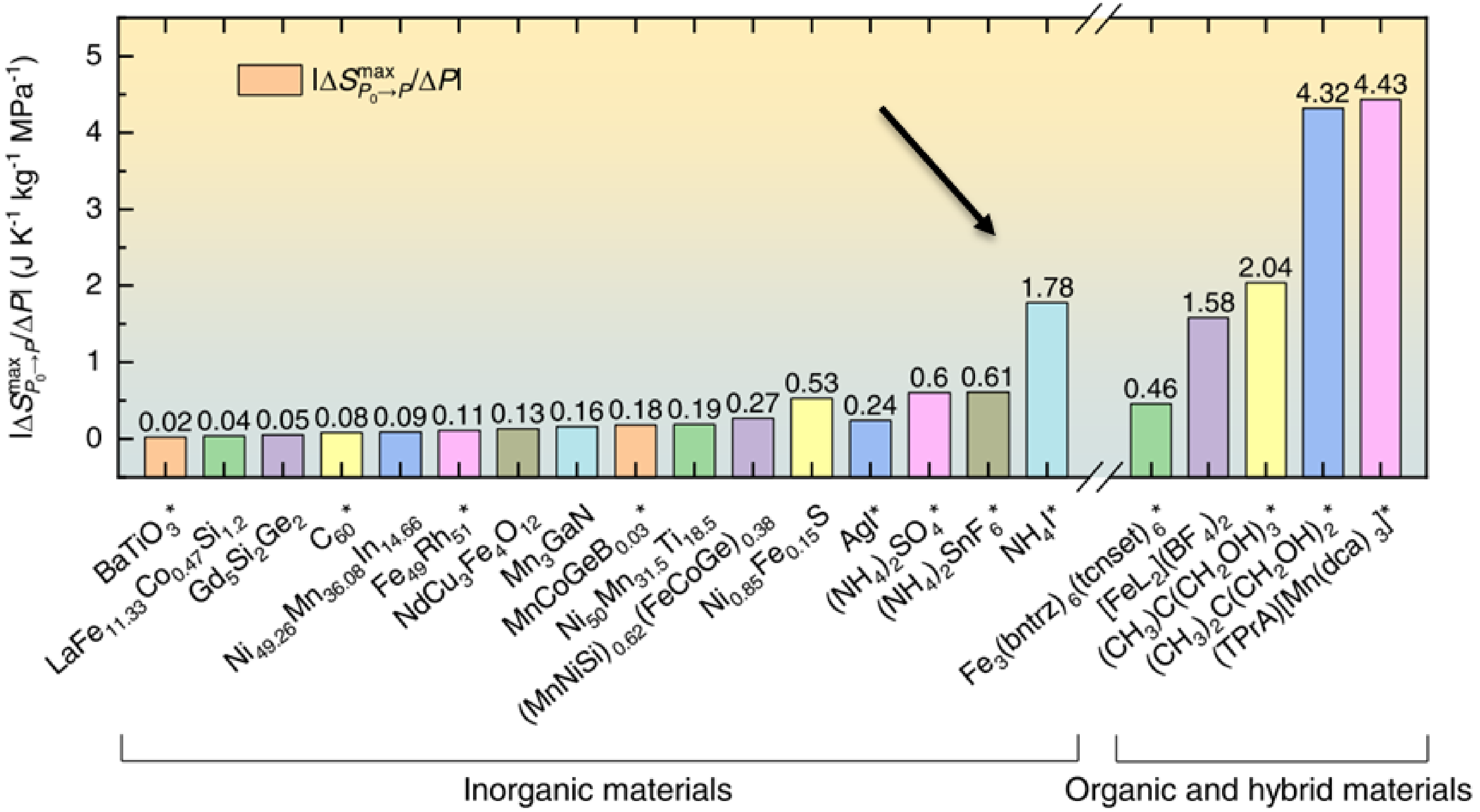
Barocaloric

Challenges: (a) how to engineer materials to achieve cold production at a right temperature range for data centre cooling ~6-11°C; (b) how to translate the materials scale performance to device and system level performance; and (c) how to scale up the process and equipment?

Material developments: barocaloric inorganic compound

European Innovation Council

- Ren et al. (2022) performed a thorough study on the inorganic compound NH_4I which exhibits a **giant barocaloric effect** over a broad temperature range
- Results show potential for **efficient and affordable** barocaloric refrigeration

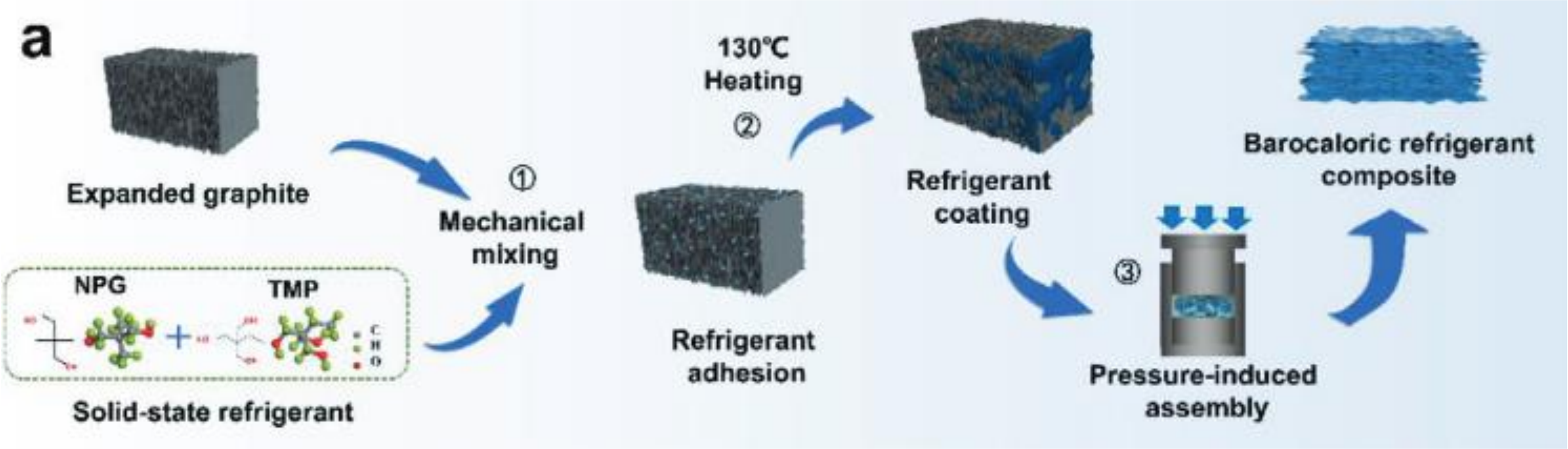


Ren Q, et al. Ultrasensitive barocaloric material for room-temperature solid-state refrigeration. Nature Communications 2022: 13: 2293. https://doi.org/10.1038/s41467-022-29997-9

Material developments: new barocaloric composite

European Innovation Council

- Dai et al. (2023) recently developed a molecular design strategy for novel plastic crystals, showing the potential for composite barocaloric materials in practical applications

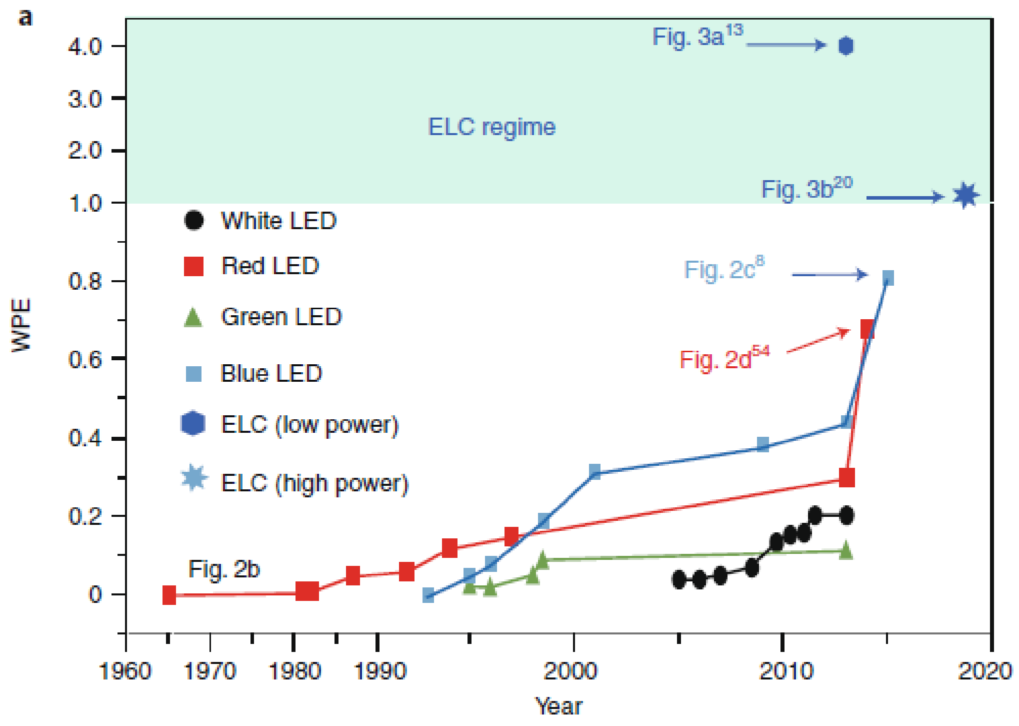


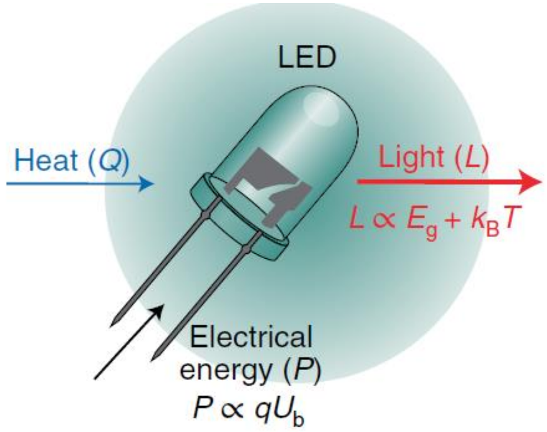
Dai Z, et al Synergistic advancement of molecular design and dual encapsulation technology for high-performance room-temperature barocaloric refrigeration materials. Advanced Functional Materials 2023; 2307822. https://doi.org/10.1002/adfm.202307822

Thermophotonic cooling

European Innovation Council

- Light-emitting diodes could be more than simple electricity-to-light converters, as they are solid-state thermodynamic machines [19]
- High material quality requirements are needed, but recent advances and available experimental data in electroluminescent cooling by LEDs suggest practical cooling could be feasible



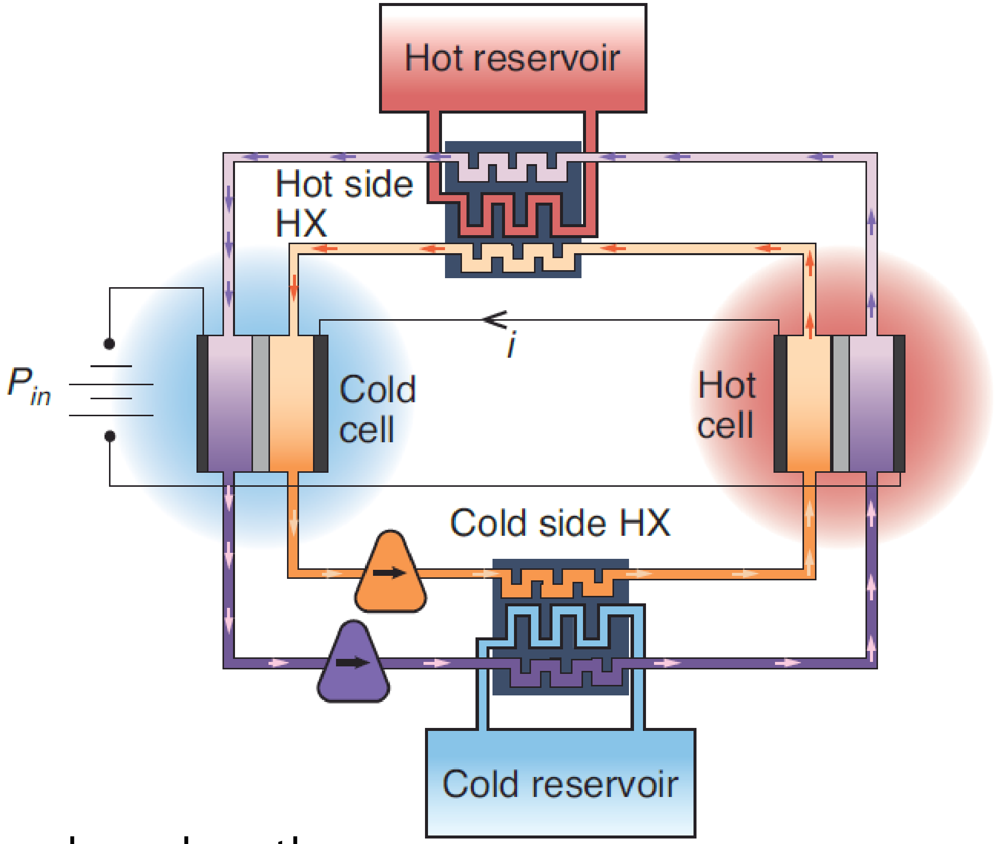


Sadi T, Radevici I, Oksanen J. Thermophotonic cooling with light-emitting diodes. Nature Photonics 2020; 14: 205-214. https://doi.org/10.1038/s41566-020-0600-6.

Brayton electrochemical refrigerator (BECR)

European Innovation Council

- Rajan et al. (2022) developed a system which uses the thermogalvanic effect of two electrochemical cells — one 'hot' and one 'cold' — and two different redox electrolytes to build a cooling cycle
- **Promising efficiency and potential for cold storage**
- Just as flow batteries can store electrical energy in electrolyte tanks, BECRs can store heat and cold in **insulated electrolyte tanks**



Rajan, A., McKay, I.S. & Yee, S.K. Continuous electrochemical refrigeration based on the Brayton cycle. Nat Energy 2022; 7: 320–328. https://doi.org/10.1038/s41560-021-00975-7

Key remarks

European Innovation Council

- Data centres cooling: combination of **efficiency, reliability, safety**
- Need to explore: soft faults detection, modularity, maintenance (drones?)
- Need for fundamental and applied science: computational materials, functionalized materials, thermophotonics, biomimics, etc
- Systems integration opportunities (natural resources, storage, cryogenics)
- Regulatory and voluntary schemes in EU to improve energy efficiency at the component level such as ENERGY STAR and EU Ecodesign Regulations for servers and data storage products

Backing visionary entrepreneurs

Thank you!

Antonio Marco Pantaleo
Programme manager energy and green tech
Denver, 19 October 2023

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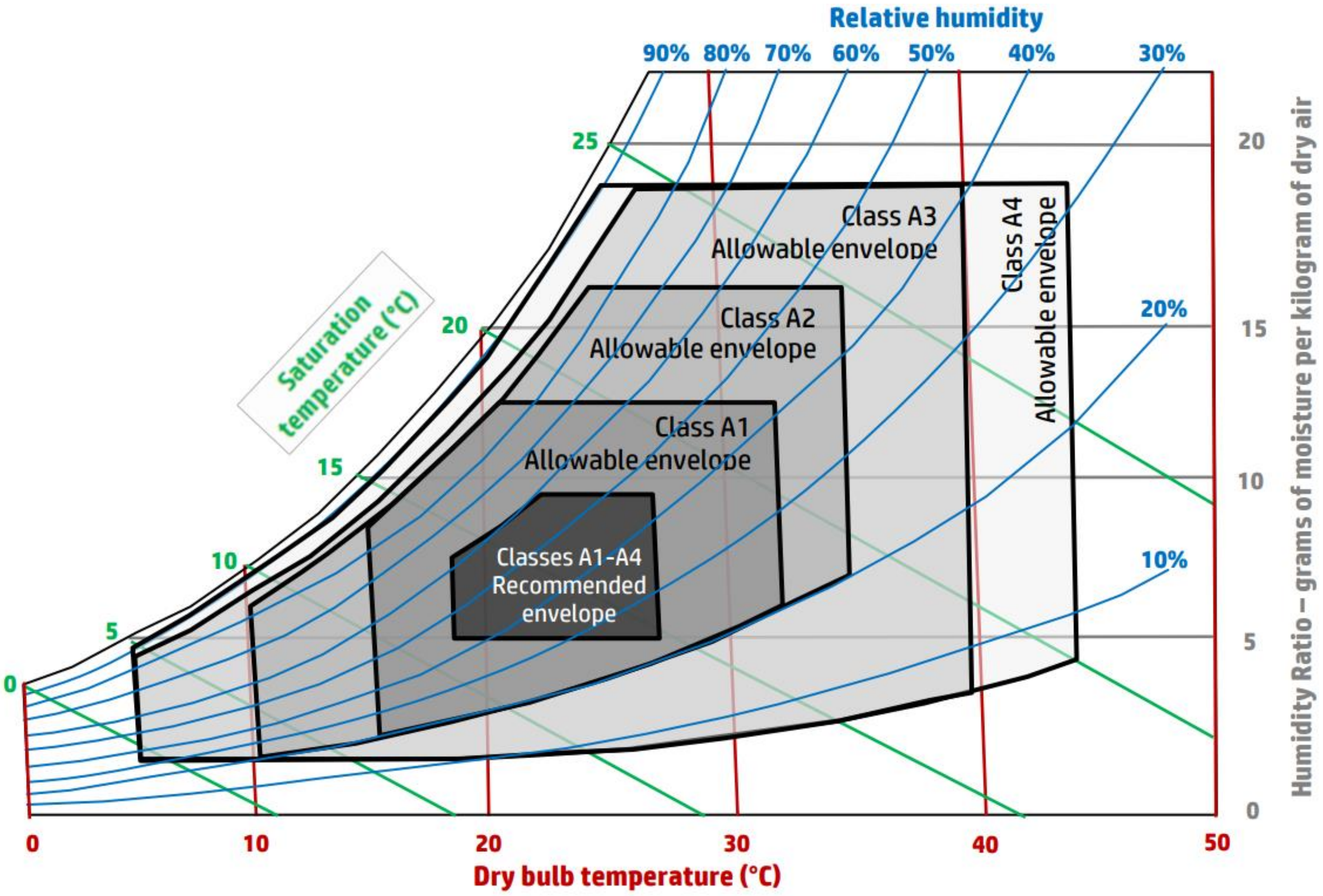
ASHRAE thermal guidelines

- Data centres are categorised according to environmental requirement levels [5]

Class[a]	Equipment Environmental Specifications for Air Cooling						
	Product Operations[b,c]					Product Power Off[c,d]	
	Dry-Bulb Temperature[e,g] °C	Humidity Range, Non-Condensing[h,i,k,l]	Maximum Dew Point[k] °C	Maximum Elevation[e,j,m] m	Maximum Temperature Change[f] in an Hour (°C)	Dry-Bulb Temperature °C	Relative Humidity[k] %
Recommended (Suitable for all 4 classes)							
A1	15 to 32	-12°C DP & 8% RH to 17°C DP and 80% RH[k]	17	3050	5/20	5 to 45	8 to 80
A2	10 to 35	-12°C DP & 8% RH to 21°C DP and 80% RH[k]	21	3050	5/20	5 to 45	8 to 80
A3	5 to 40	-12°C DP & 8% RH to 24°C DP and 85% RH[k]	24	3050	5/20	5 to 45	8 to 80
A4	5 to 45	-12°C DP & 8% RH to 24°C DP and 90% RH[k]	24	3050	5/20	5 to 45	8 to 80

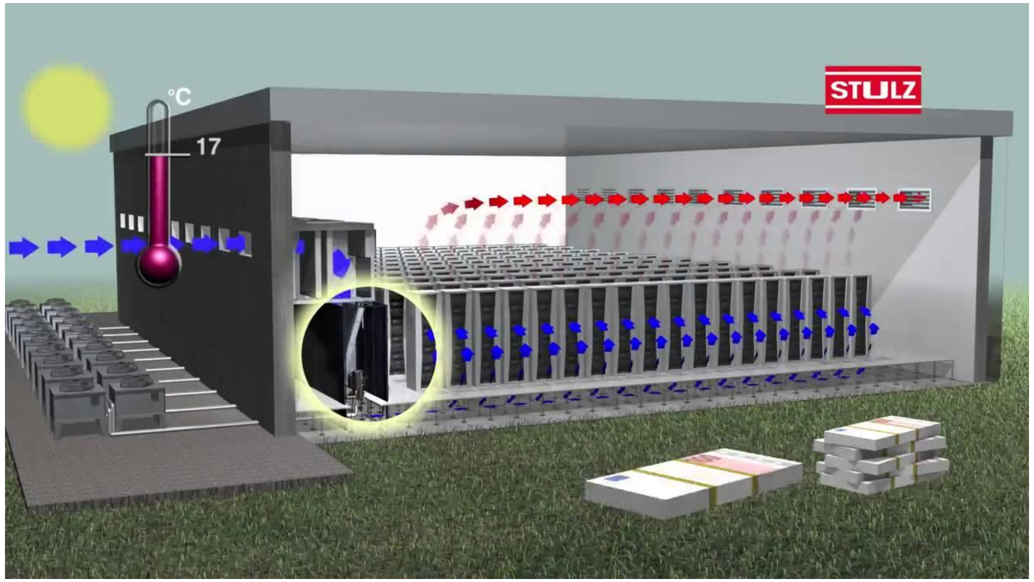
Recommended envelopes

European Innovation Council



Free cooling

- Air-side: **Ambient air** is used to cool down the data centre
- Water-side: **Nearby water** source is used to cool down the data centre
- Free cooling is location-specific
- Humidity control still required



STULZ DFC² Direct Free Cooling [6]

Research organisations and patents

Research centres working on data centre cooling

- Hundreds of papers every year
- Zhang et al.[4] compiled data on the top 10 research organisations working on cooling

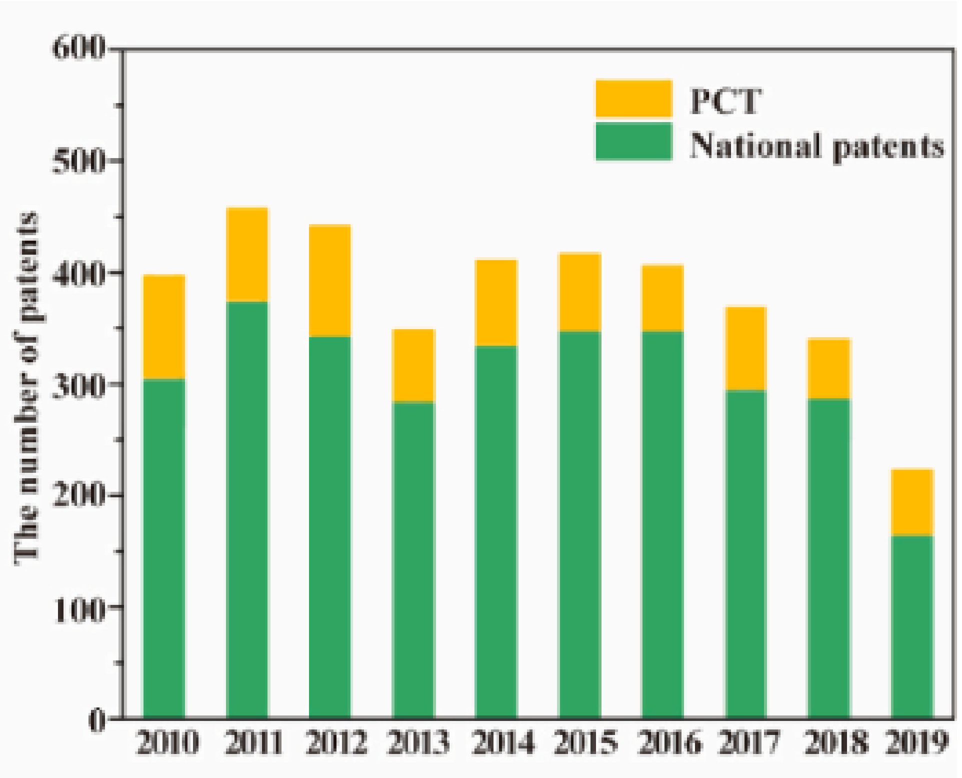
Top 10 research organisation working on cooling technologies for DCs and TBSs.

Research institutions	Number of publications (2010–2019)
Chinese Academy Of Sciences	188
University Of California System	154
Centre National De La Recherche Scientifique	116
Max Planck Society	84
Tsinghua University	77
Massachusetts Institute Of Technology	74
Georgia Institute Of Technology	72
Russian Academy Of Sciences	69
University Of Michigan System	63
University Of Cambridge	61

Granted patent examples

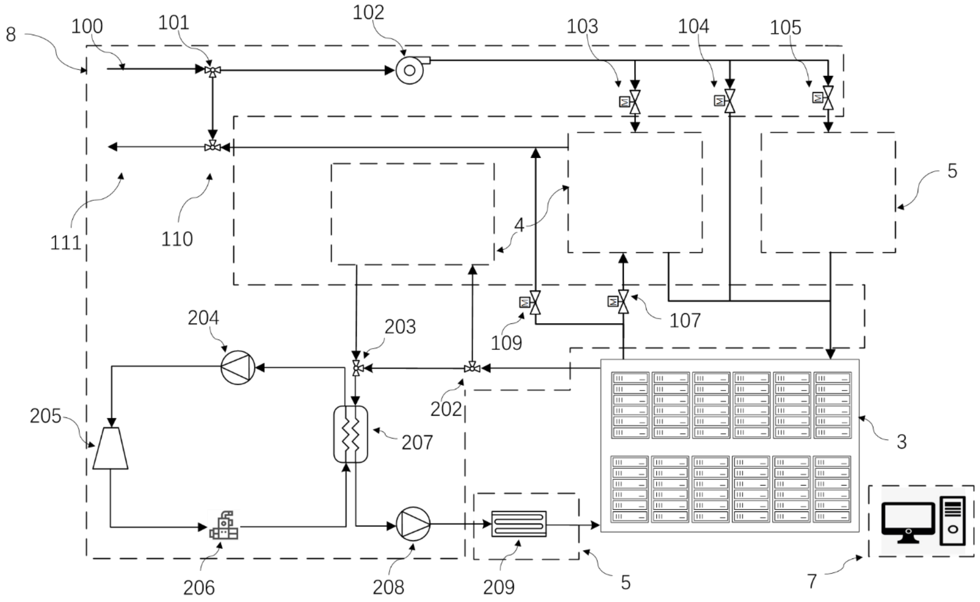
European Innovation Council

- US11076508B2: Cooling systems for **immersion cooled IT equipment**, 2021
- US11240938B2: **Evaporative induction** cooling system for a data center, 2022.
- US20210396422A1: Using **liquid to air membrane energy exchanger** for liquid cooling, 2021.
- US11503744B2: Methods and systems for **managing facility** power and cooling, 2022.



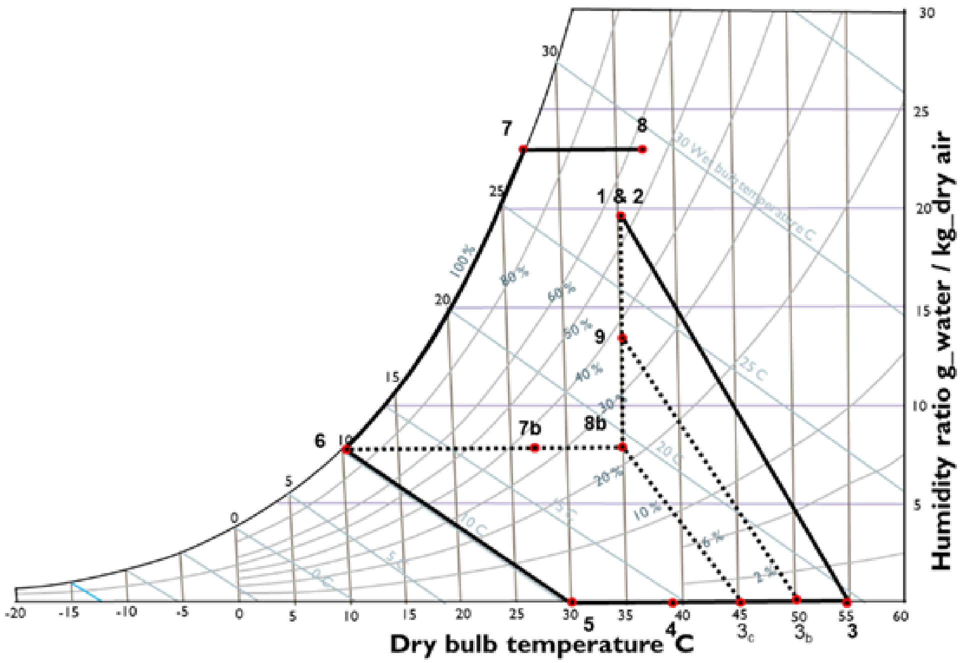
Significant improvement of current cold production technologies

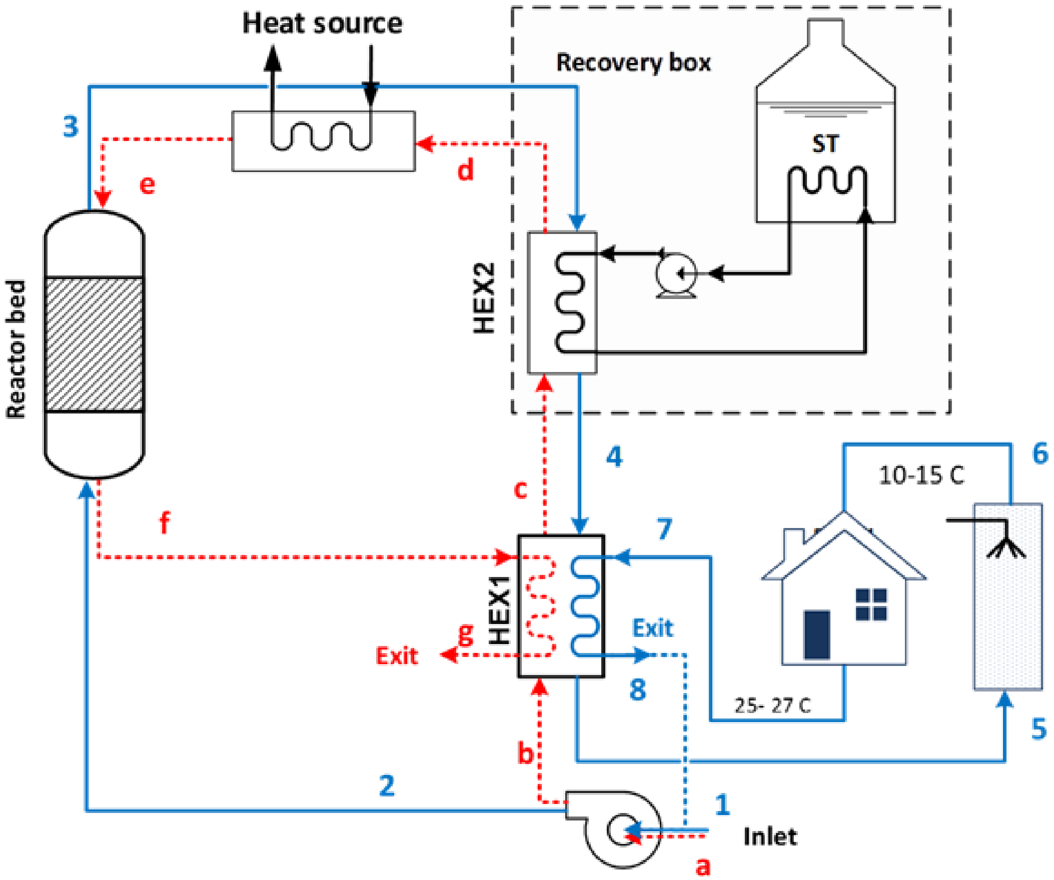
Methods: (a) reduction of energy consumption of compressors; (b) effective use of waste heat from data-centres; (c) effective use of natural energy



Challenges: (a) how to use cold energy storage, e.g. PCM, to deal with peak cooling demand, so that the the power rating of compressors can be reduced substantially? (b) how to use the low-grade heat from data centres to produce cold? (c) how to design the whole cooling system so that natural cold energy can be used in a cost-effective way?

Cold production & storage: Thermochemical based cold production





Challenges: (a) how to use data-centre waste heat to drive thermochemical based cold production system? (b) how to enhance thermochemical material's performance (heat and mass transfer, reaction kinetics, life-span)? (c) how to scale up the process and equipment?

Desai et ail (2021) Energy Conversion and Management 229, 113617; Ahmad & Ding (2021) Energy Conversion and Management 247, 114748