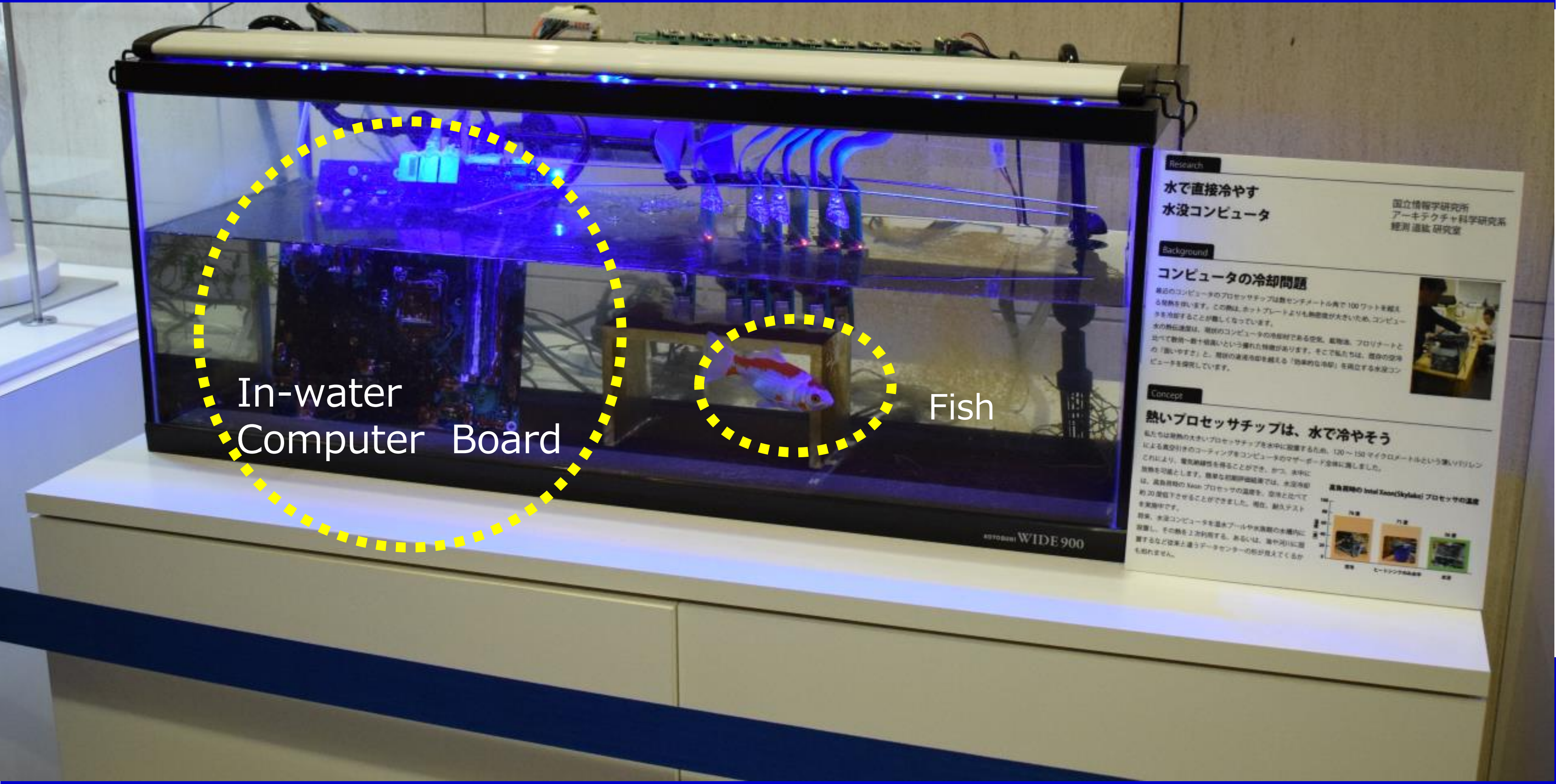
The Case for Water-Immersion Computer Boards



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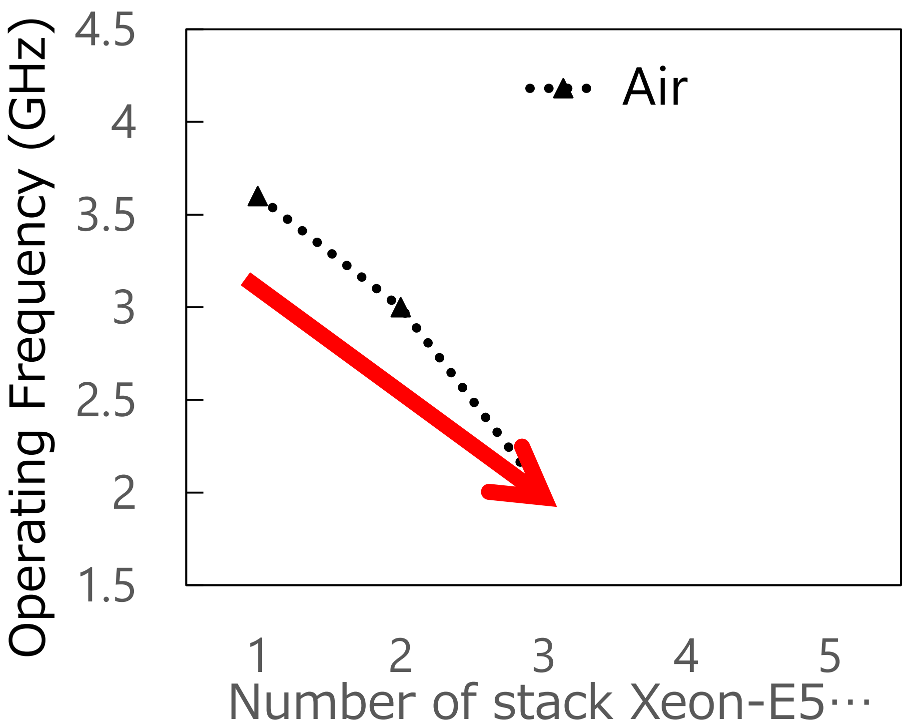
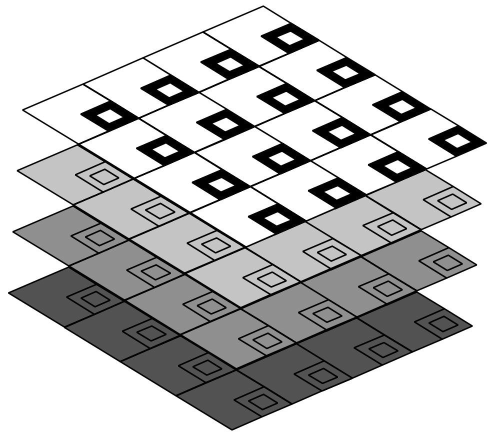
Index

- **Problem Statement**
- Solution: In-Water Computer
- Evaluation
- Related Work
- Conclusions

Heat Dissipation Problem on 3D CMPs



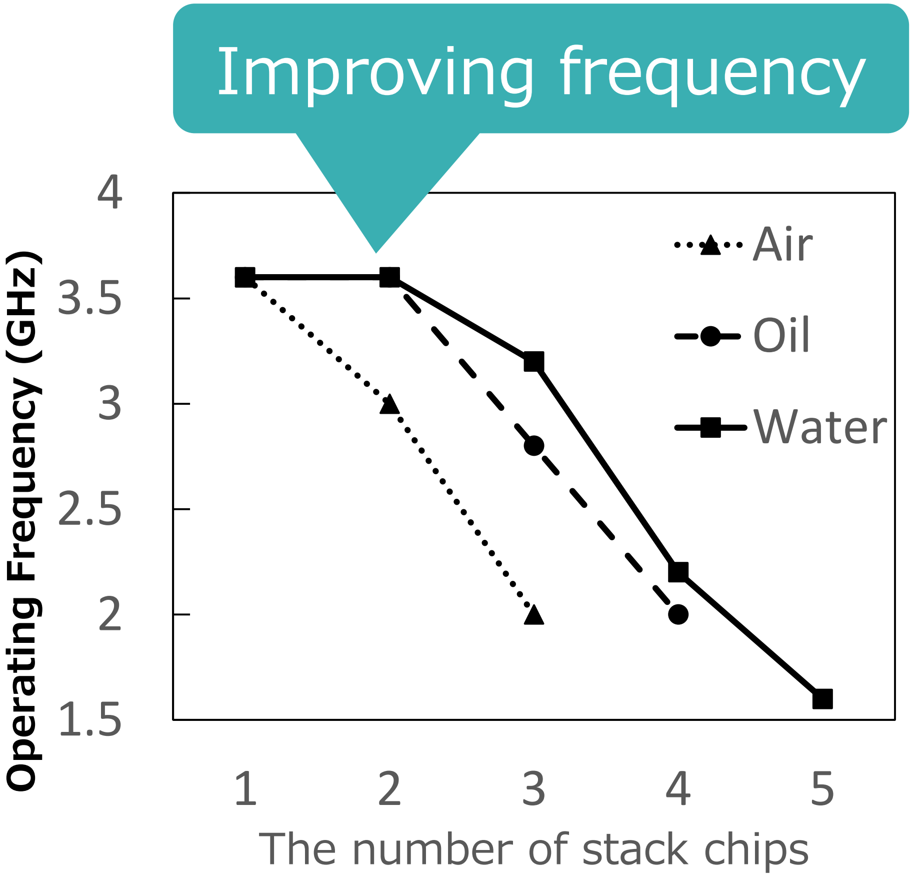


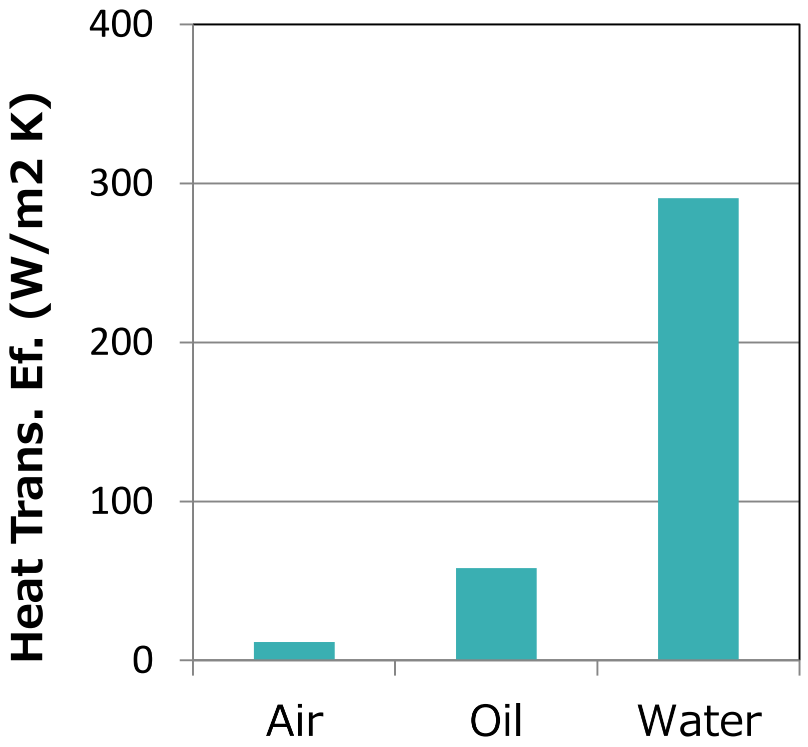
HotSpot v6.0 temperature simulation

Temperature constraint	78 degree
Freq	1.2 GHz – 3.6 GHz
Power	31 - 91 W per chip

Heat dissipation problem limits power → Low frequency

Our Solution: In-Water Cooling





Other Pros: Low safety concerns + low cost of coolant
Cons: no electric insulation

Index

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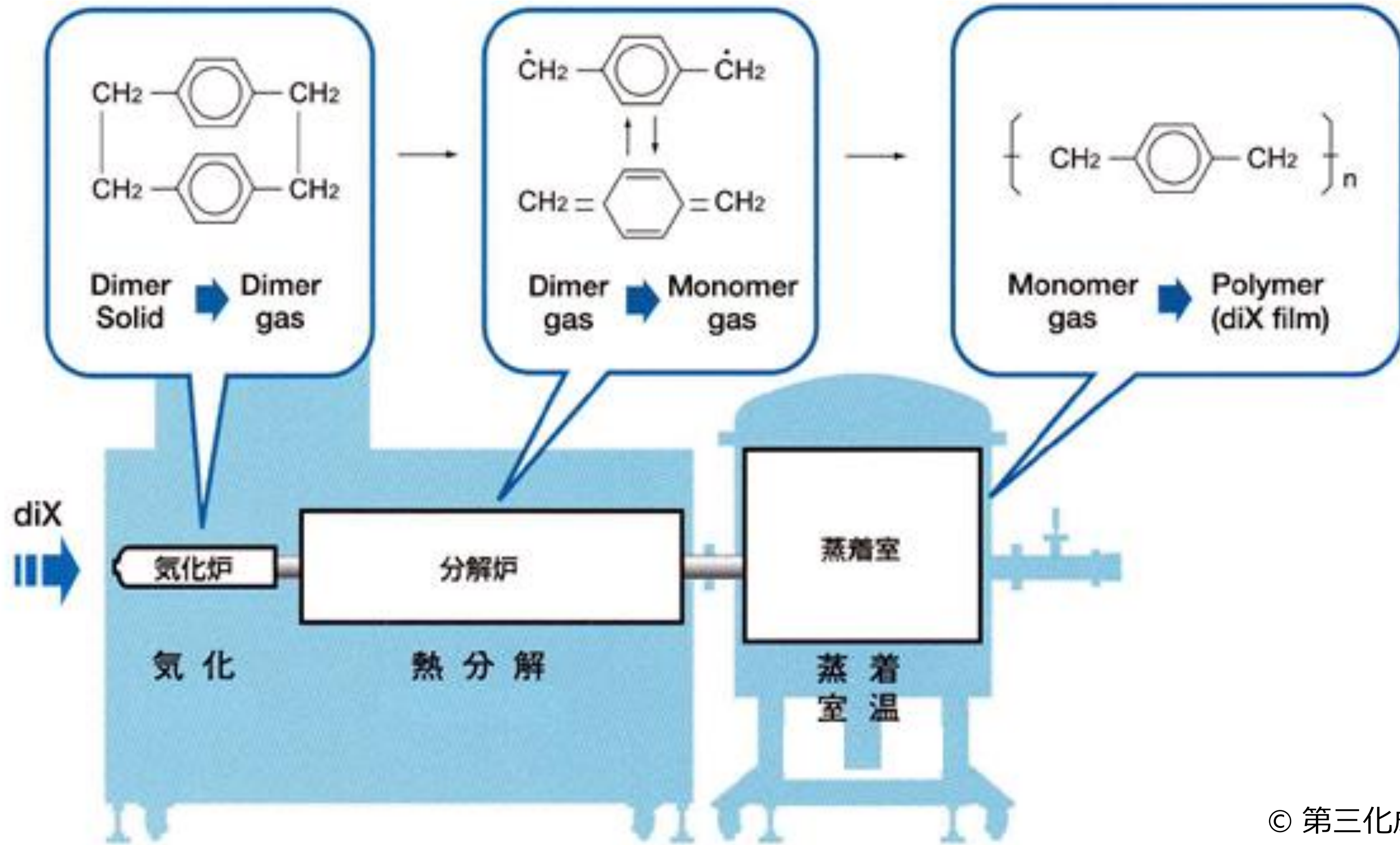
Parylene film insulation coating

- CVD (Chemical Vapor Deposition) for compute board
  - 120μm and 150μm films provided by KISCO Ltd
  - CVD operates at room temperature → No damage ICs



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Two Drawbacks of Parylene Coating

A. The coating may raise chip temperature

→ Modifying the coated compute board

(1) Coat the compute board except CPU's heatsink
(2) Break the parylene film on CPU's surface
(3) Replace it by Thermal Interface Material

- **Tightly applied to the heat-spreader surface**

Step 1

Step 3

B. The parylene film has unknown lifetime when used for in-water computers

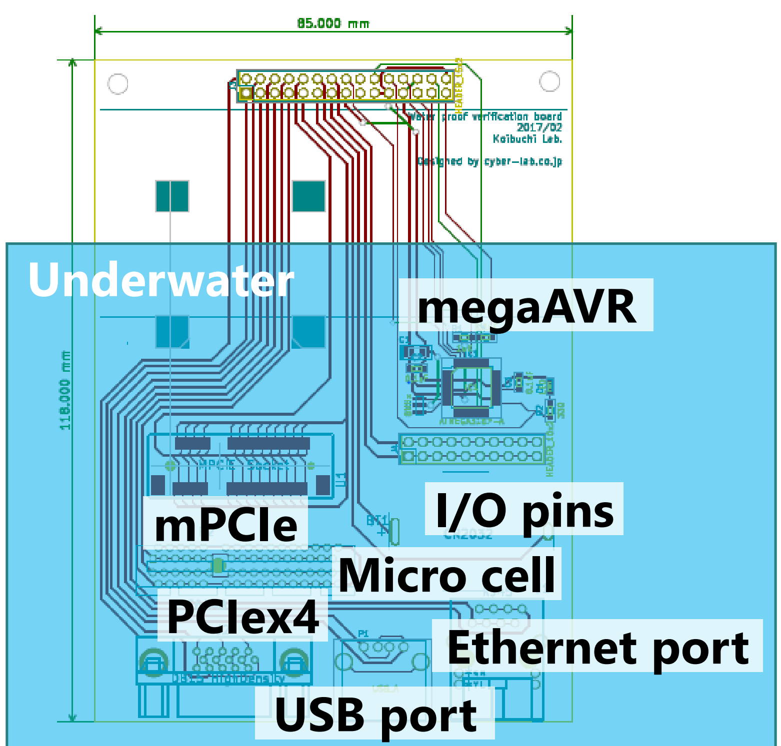
Two Drawbacks of Parylene Coating

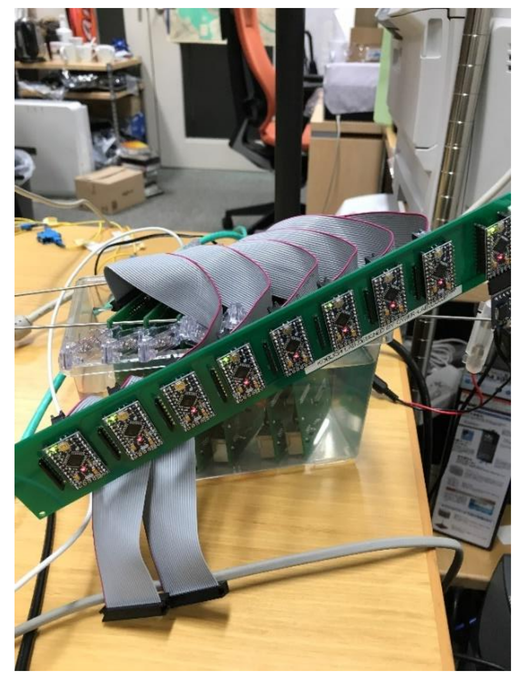
A. The coating may raise chip temperature

B. The parylene film has unknown lifetime when used for in-water computers

→ Durability test (2 years +counting)

PCIex4, RJ45 and mPCIe are faulty
→
put them above the surface of the water





Index

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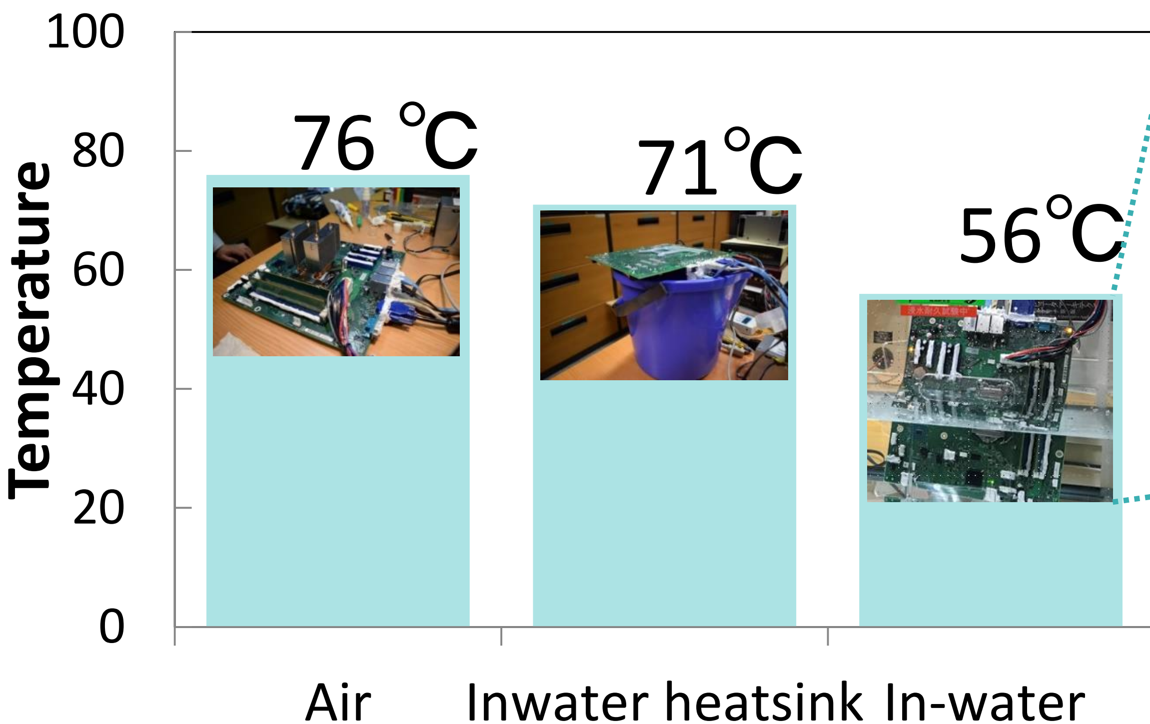
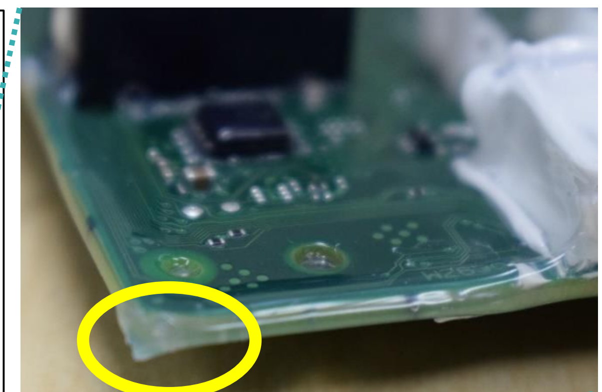
Preliminary Evaluation
Temperature of Real Intel Xeon(Skylake)

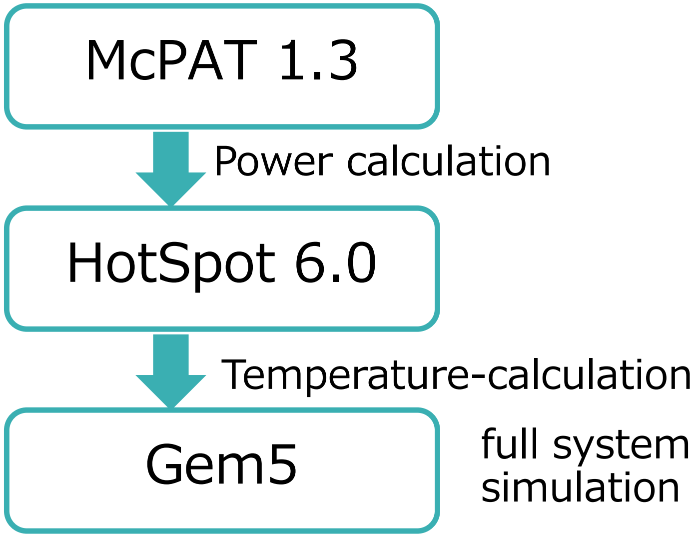
The significant potential thermal benefits of in-water computer



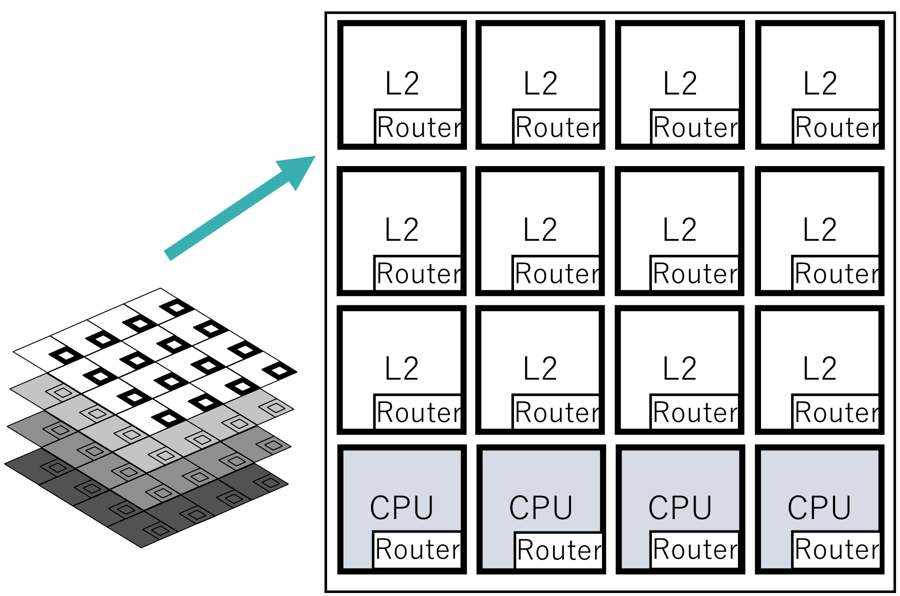


PRIMER-GY TX1320 M2 server (Xeon E3-1270v5(3.6 GHz), 4 GB DDR4 2133 MHz

Simulation Evaluation of 3-D CMPs
McPAT (Flooplan) + Hotspot(Temp.) + Gem5(App perf.)



Processor family	x86-64
Number of cores	4
L1 I/D cache size	32/128 KiB (line:64B)
L1 cache latency	1 cycle
L2 cache bank size	12 MiB (assoc:8)
L2 cache latency	6 cycles
Memory size	4 GiB
Memory latency	160 cycles
Area	169 mm^2
Frequency	1.2 - 3.6 GHz
Power	14.0 - 56.7 Watts
Router pipeline	[RC][VSA][ST/LT]
Buffer size	5-flit per VC
Protocol	MOESI directory
# of VCs	3 (one VC for each message class)
Control / data packet size	1 flit / 5 flits

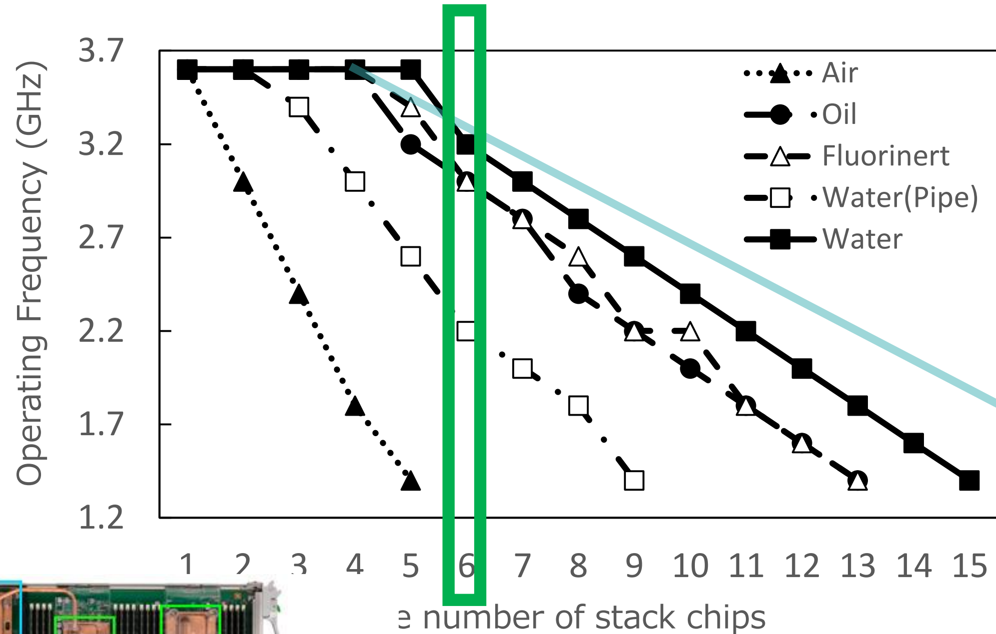


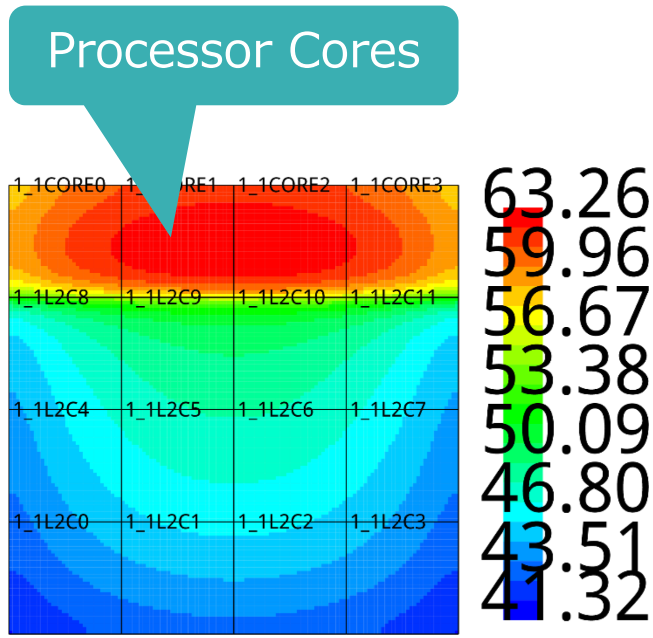
Heatsink	$12\times12\times3$ cm, 400 W/mK, 0.3024 m^2
Heat spreader	$6\times6\times0.1$ cm, 400 W/mK
Parylene film	120 μm, 0.14 W/mK
TIM / Glue	20 μm, 0.25 W/mK
Outside temp.	25°C

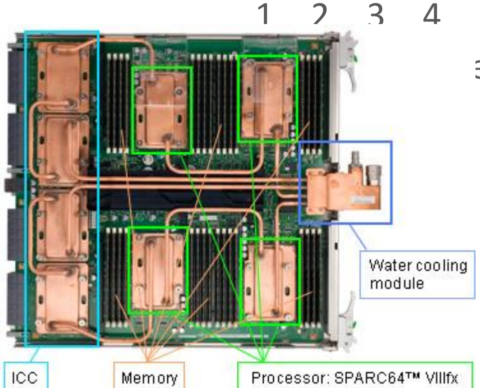
Simulators are available from
https://github.com/KoibuchiLab/

Maximum Operating Frequency

In-water cooling leads to
the best results:
run chips at higher frequencies



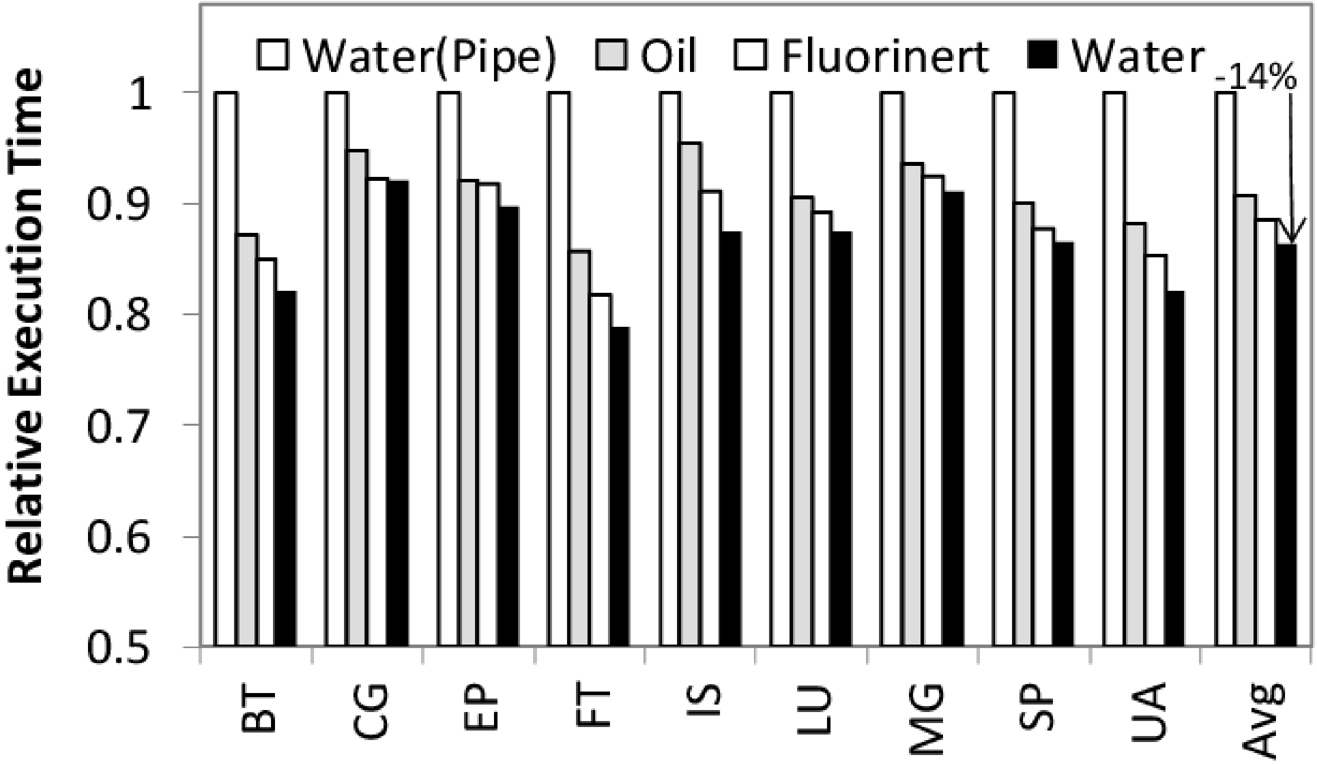




Example of Water(Pipe)
© 2019, Fujitsu

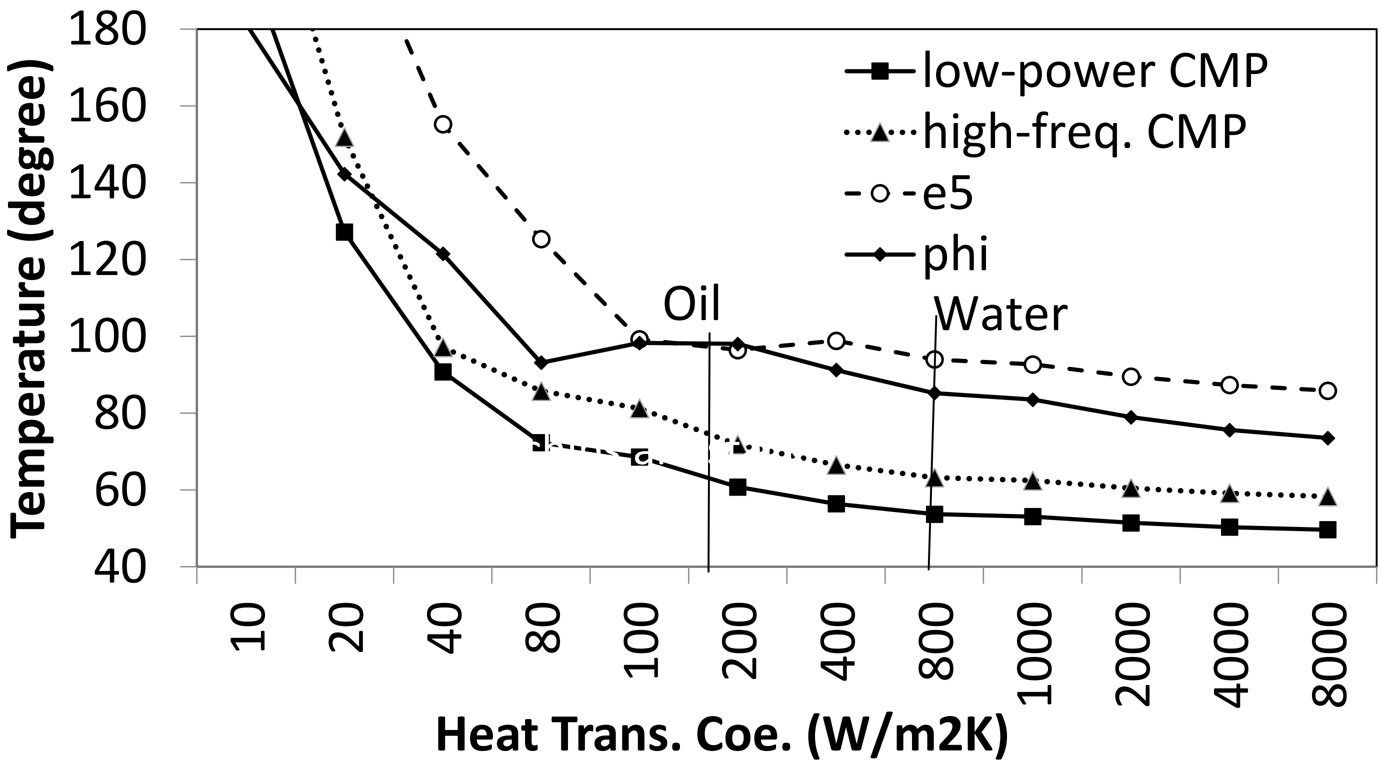
Application Performance
(6-chip stack)

- In-water cooling improves the execution time of NPB Benchmar 3.3.1(OpenMP) due to high freq.



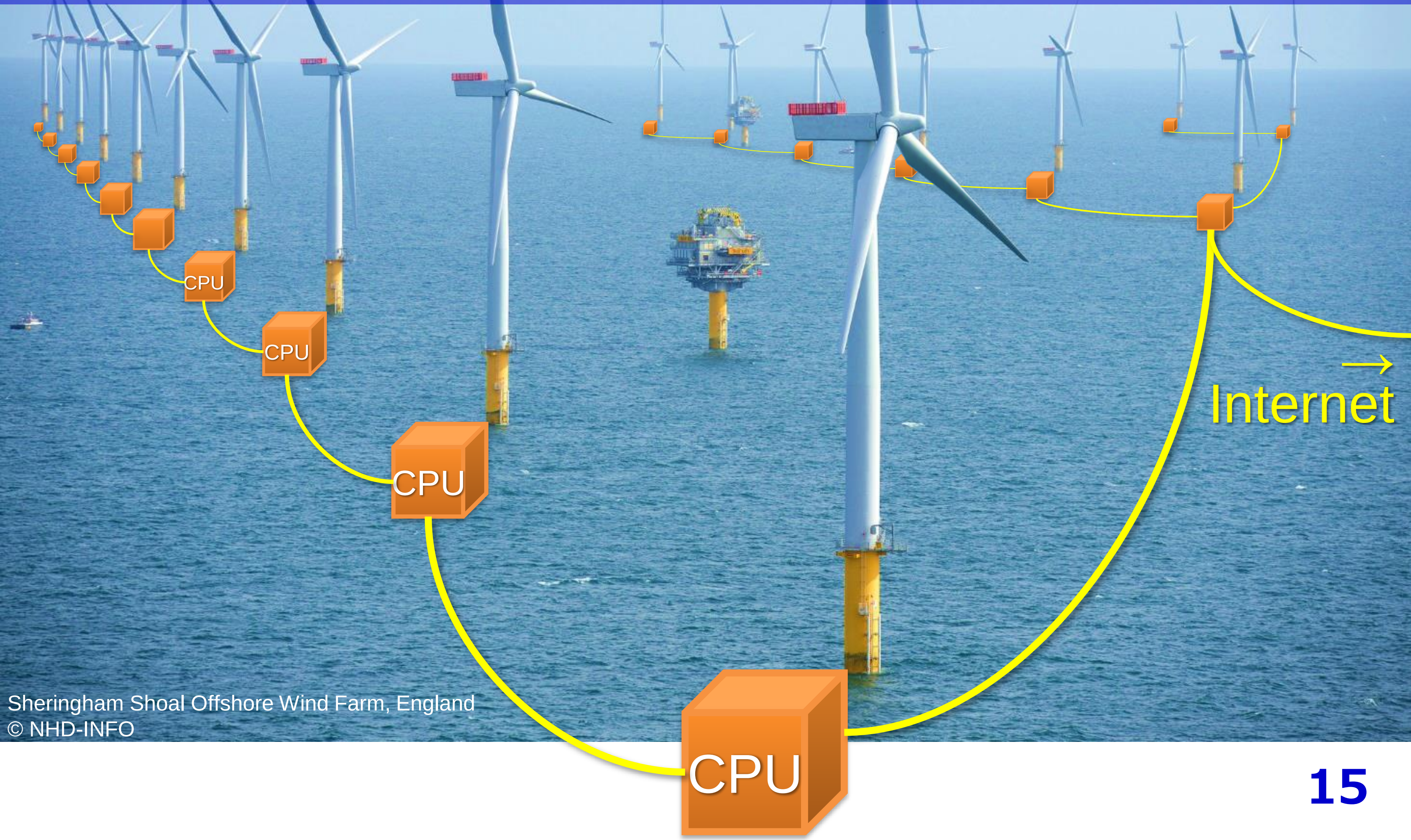
Further Consideration 1:
Heat Transf. Coeff.

- Negligible temperature reduction at heat transfer coefficients higher than that of water.

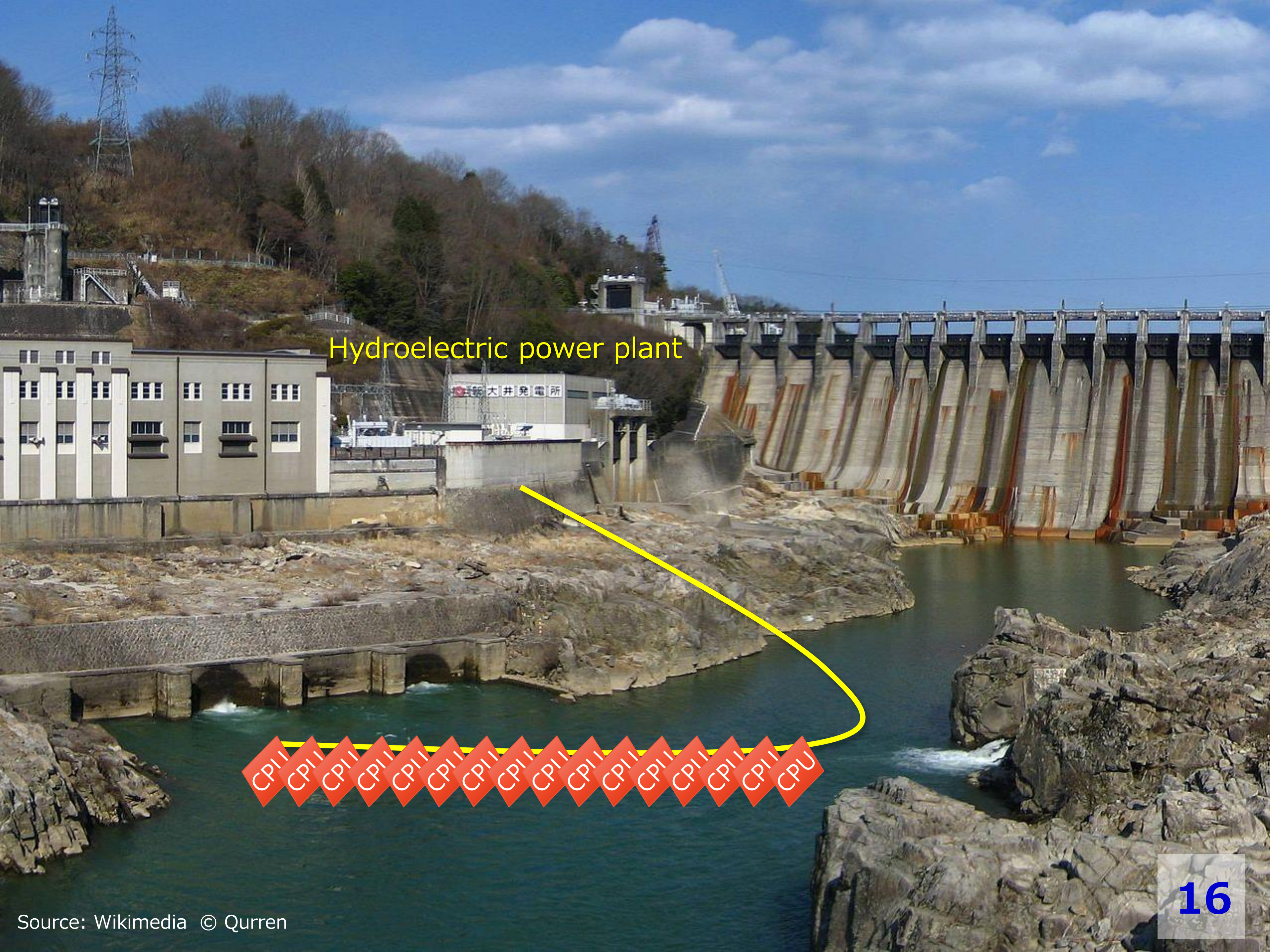


(4 chips are stacked)

Further Consideration 2:
Application to Direct Cooling under Natural Water



Sheringham Shoal Offshore Wind Farm, England



Source: Wikimedia © Qurren

Is this the same as Microsoft?

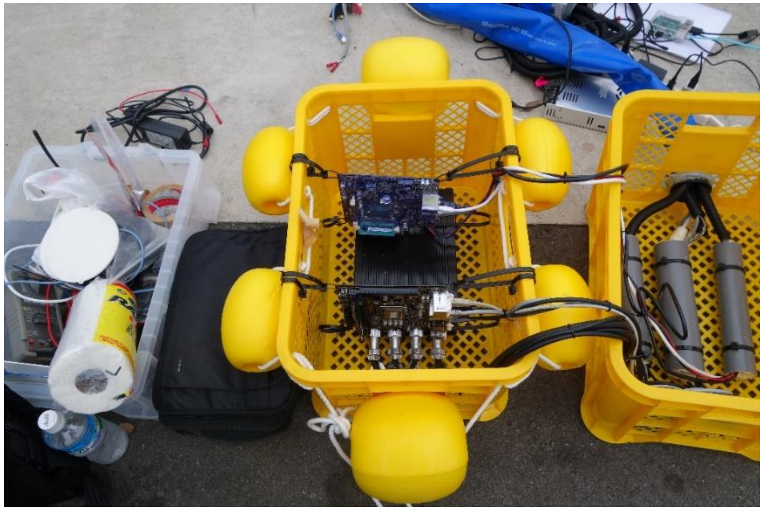
- Ocean is the primary coolant in in-water computer
- “Project Natick”
  - Big facility

https://natick.research.microsoft.com/

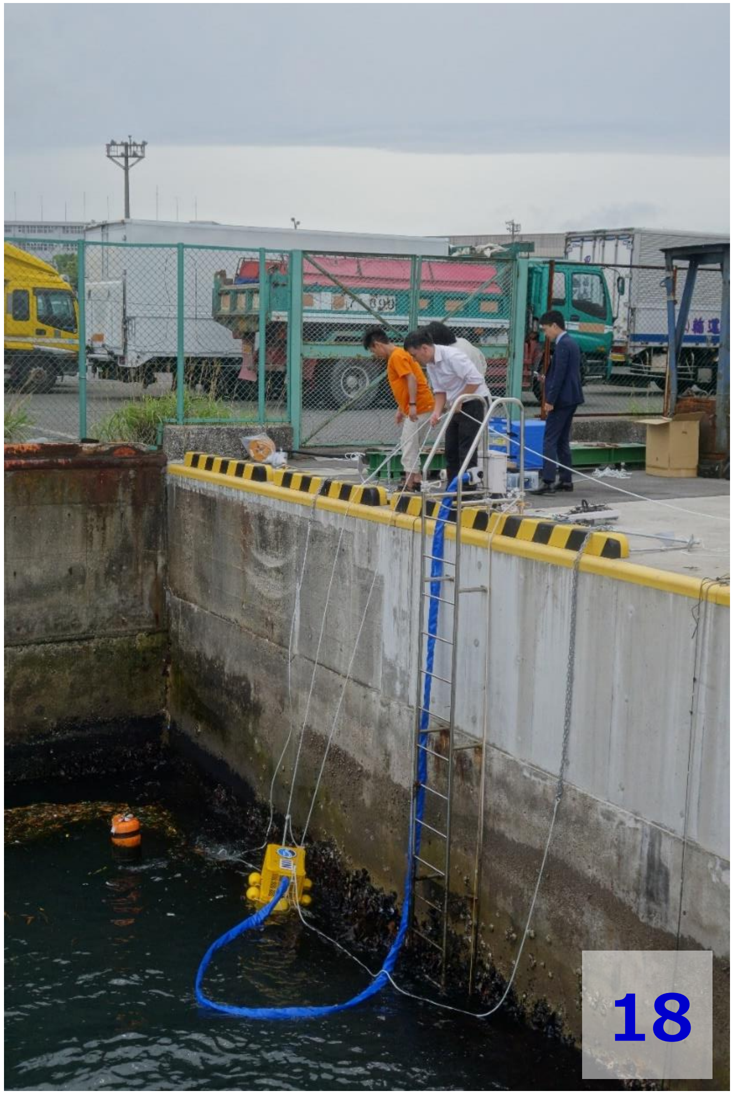
Crazy Feasibility Study in Ocean

- Parylene-coated PC worked for 53 days

Before:



After:



Index

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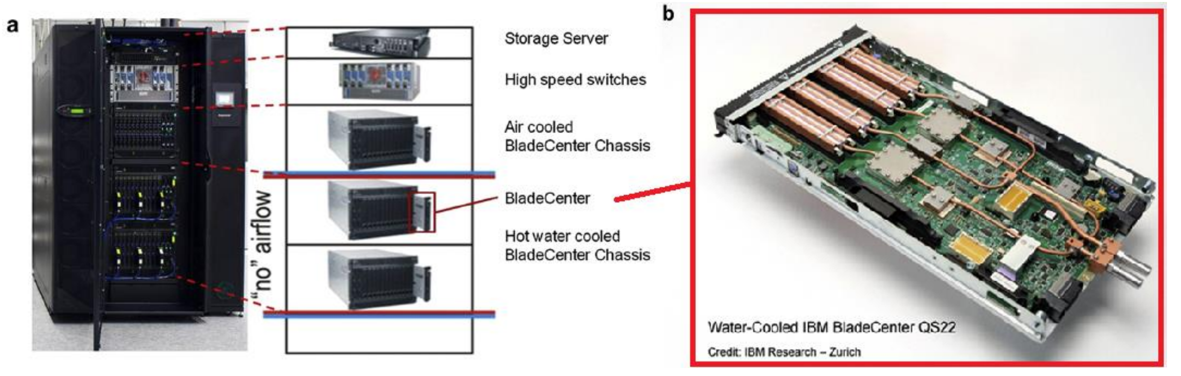
Alternative Emerging Cooling Techniques

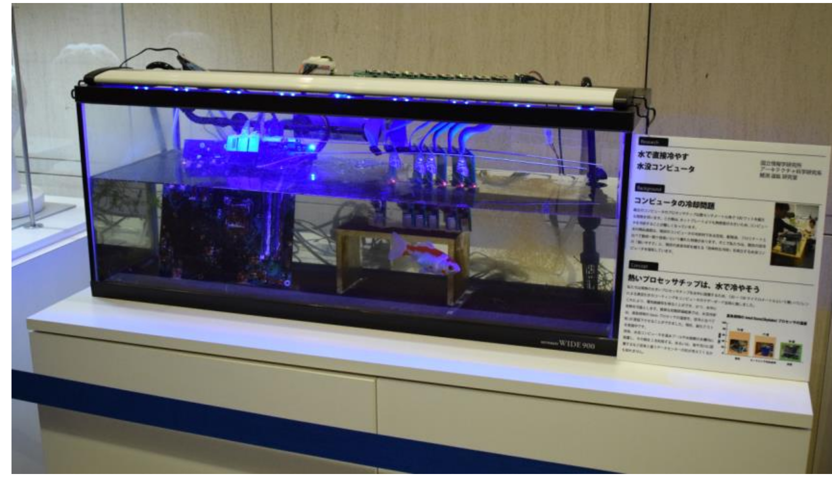
- Motherboard level
  - (products) Water-pipe cooling
    - K-computer, ABCI, Aquaser(Fig.)



    - w/ **thermoelectric cooler** (TEC) [ISCA2019]
  - Phase Change Materials
    - Liquid -> GAS
    - Solid -> Liquid [ISCA2015]
- 3D-Chip Integration Level
  - Microchannel, graphite-sheet
    - ○ TSV
    - × Wireless vertical link

[ISCA2019] ISCA2019:Fine-grained warm water cooling for improving datacenter economy
[ISCA2015] Thermal Time Shifting: Leveraging Phase Change Materials to Reduce Cooling Costs in Warehouse-Scale Computers, ISCA,2015

Conclusions
Exploring Crazy In-Water Cooling



- Low cost of coolants
- Low safety concerns
- High heat transfer coefficient
  - Our in-water cooling enables higher chip freq.

  - +14%(vs. water-pipe) and +4.5%(vs. oil) speed up of NAS Parallel Benchmarks on conv. 3-D CMPs
  - A real compute board w/ parylene coating on display now at NII entrance, Tokyo, JP