Operational experience for energy efficiency on Fugaku and the Next

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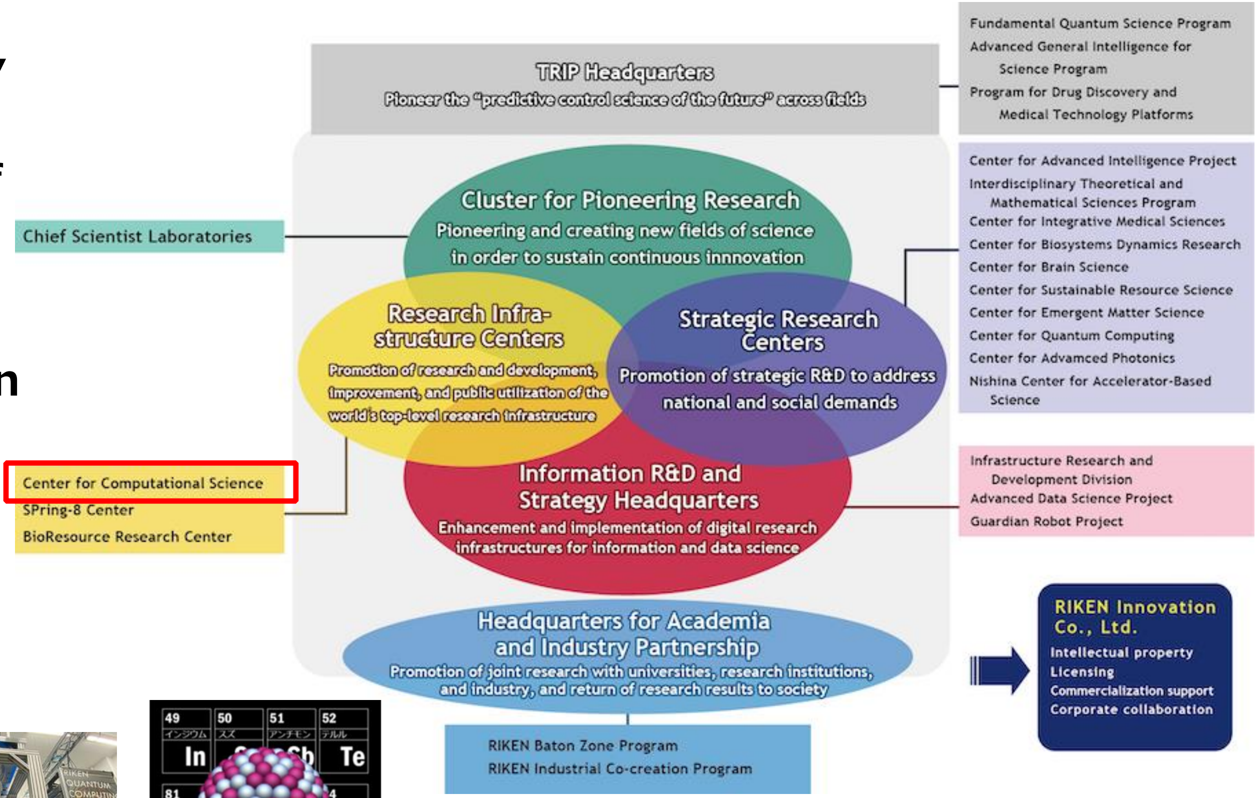
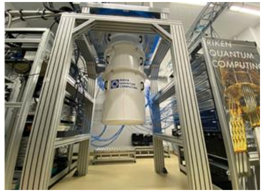
Advancing Energy and Resource Efficiency in Data Centers@SCAsia2025

RIKEN

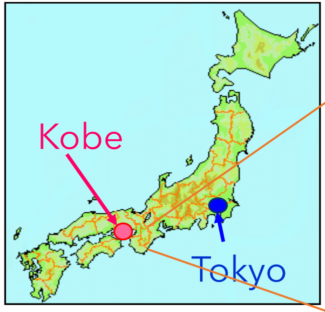
- One of three "Designated" National Research and Development Institutes of Japan
- Founded in 1917
- about 3,000 researchers in various scientific domains from over the world
- RIKEN consists of many research centers



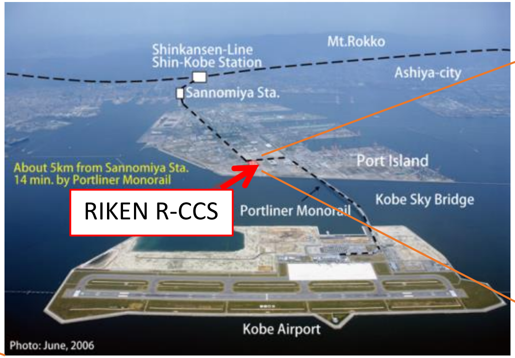



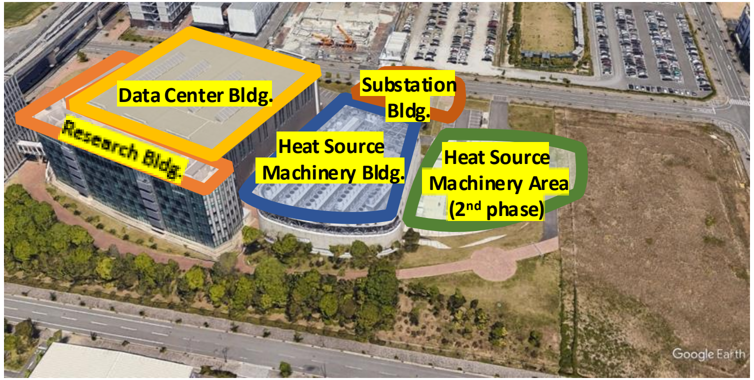

RIKEN Center for Computational Science (R-CCS)

- **Established on April 1, 2018 (former name: RIKEN AICS(2010-2017)).**
- **Missions**
  - Manage the operations and enhancement of the Fugaku.
  - Promote collaborative projects with a focus on the disciplines of computational and computer sciences.
  - Plot and develop Japan's strategy for computational science, including defining the path to next-generation supercomputing.

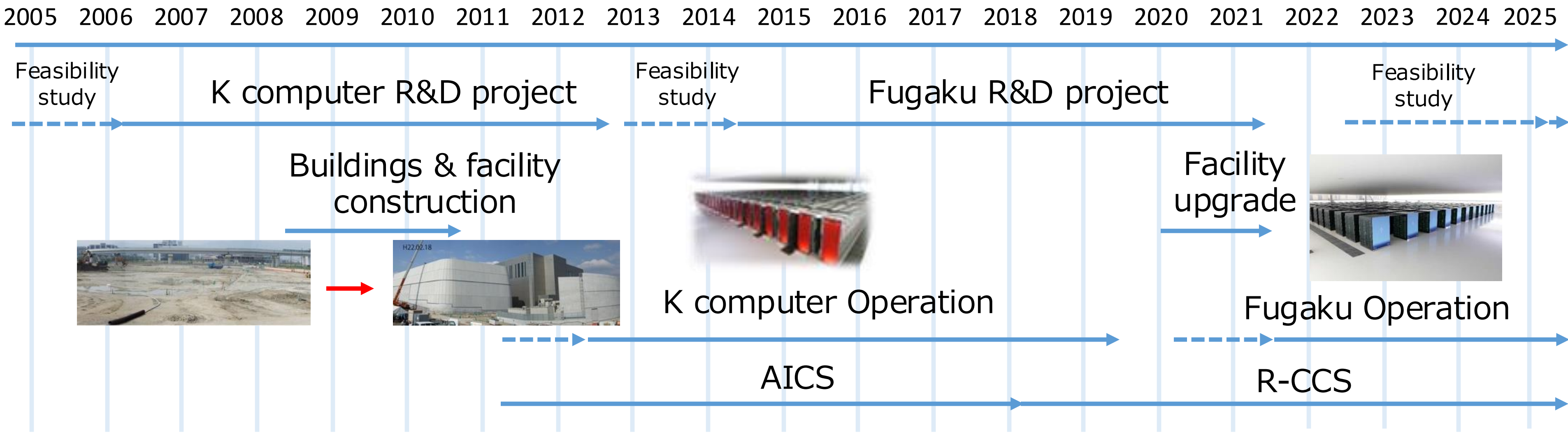


423km (263miles) west of Tokyo





A brief history of AICS and R-CCS



- RIKEN was selected as the developer of the next-generation supercomputer (later K computer) in October 2005
- The next-generation supercomputer (later K computer) development project started in 2006
- K computer was ranked as the No.1 HPC system on the TOP500 list in 2011
- K computer official service has started in 2012 (to 2018)
- Flagship2020 project (Fugaku development project) started in 2014
- Fugaku was ranked No.1 in major four benchmark rankings in 2020
- Fugaku official service has started in 2021
- ACM Gordon-Bell Prize/Special Prize winner 2021/2022
- Feasibility study for “Fugaku next” has started in 2022
- ”Fugaku next” R&D project is going to start since April 2025

Fugaku: "Exascale", "Application First" Supercomputer

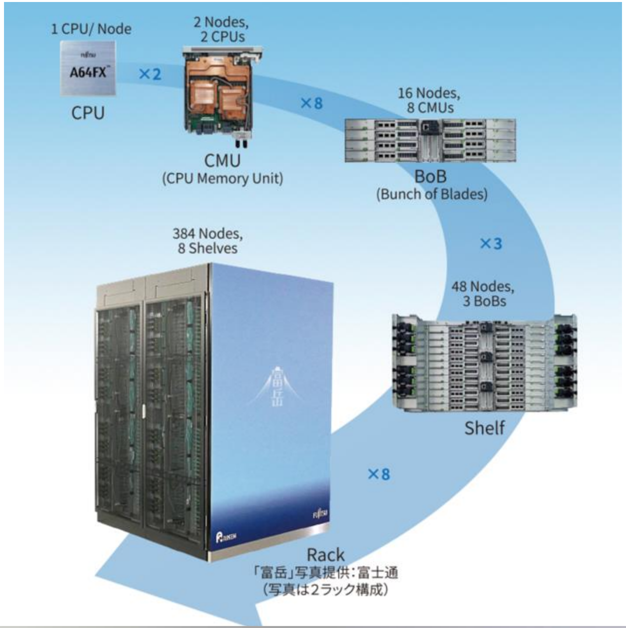
High-Peak --- Acceleration of Large Scale Application (Capability)

Mt. Fuji representing the ideal of supercomputing

FU 富 GAKU 岳

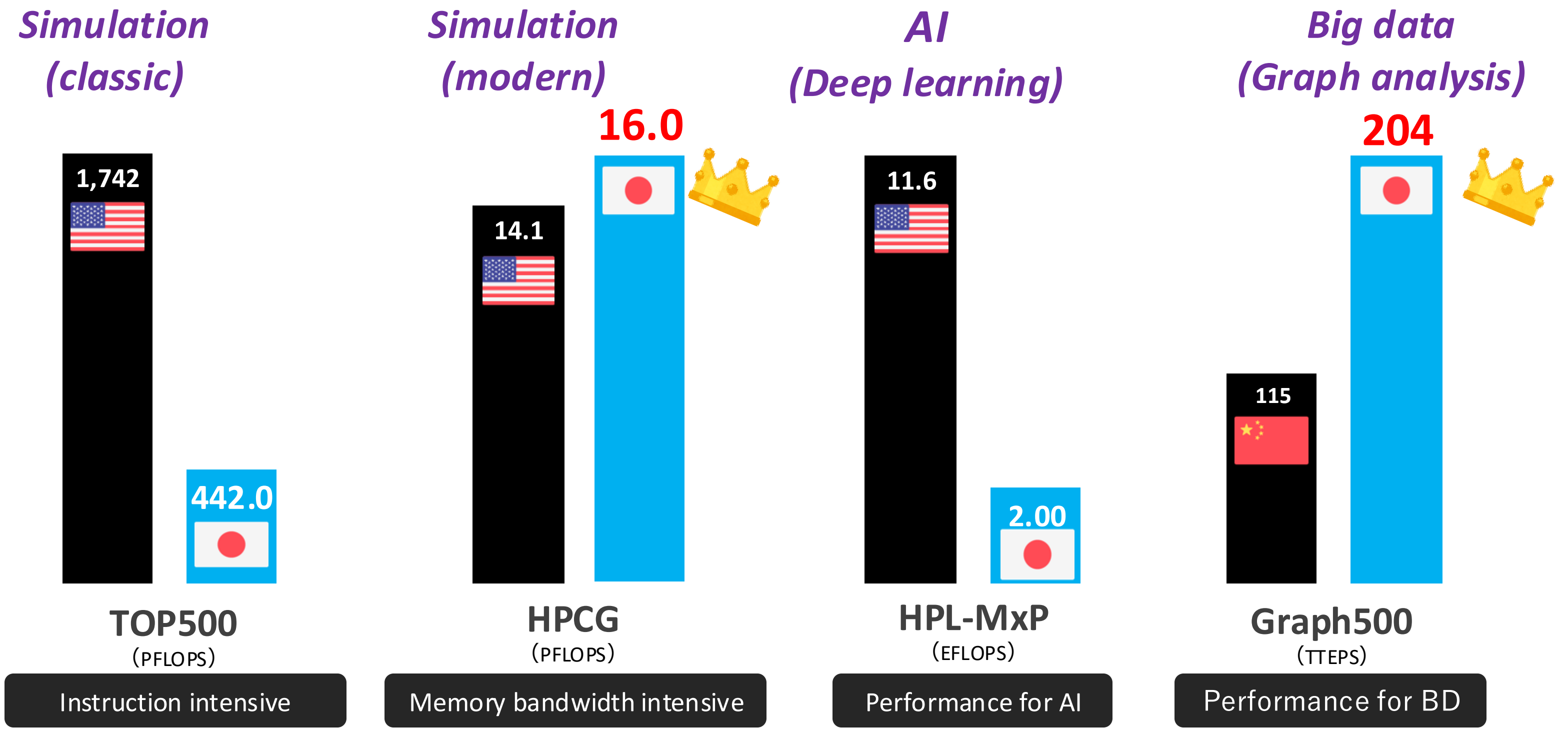
Broad Base --- Applicability & Capacity
Broad Applications: Simulation, Data Science, AI, …
Broad User Bae: Academia, Industry, Cloud Startups, …

Specs of Fugaku



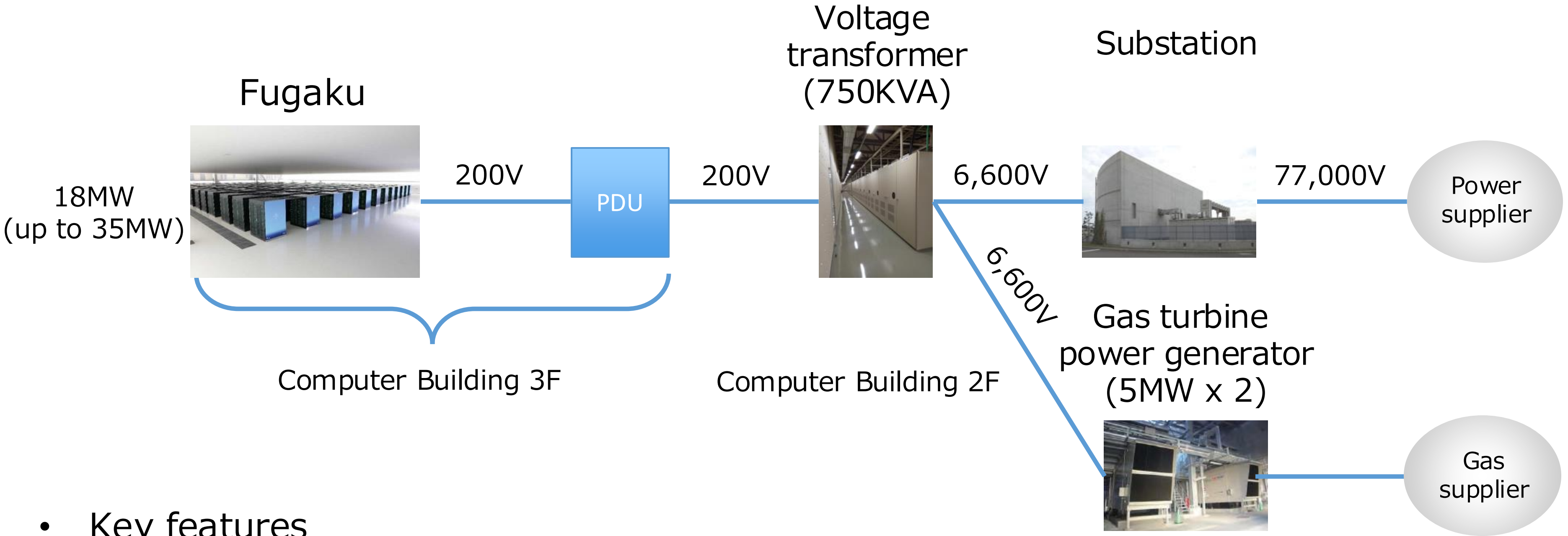
	Fugaku
Service start	March 2021
CPU ISA	A64FX (Armv8.2-A w/ SVE512bit)
# of node (=CPU)	158,976 (no GPUs)
Peak performance per node (2.0GHz case)	3.072 TF(FP64)
	6.144 TF(FP32)
	12.288 TF(FP16)
LINPACK score	442.01 PF (#6, Nov. 2024)
HPCG	16004.50 TF/s (#1, Nov. 2024)
Graph500	204.068 Tera TEPS (#1, Nov. 2024)
Power	18MW (average), 30MW (peak)
Interconnection	TofuD (40.8GB/s x 10 port w/ 6 RDMA engine)

Fugaku in major rankings
(As of Nov. 2024)



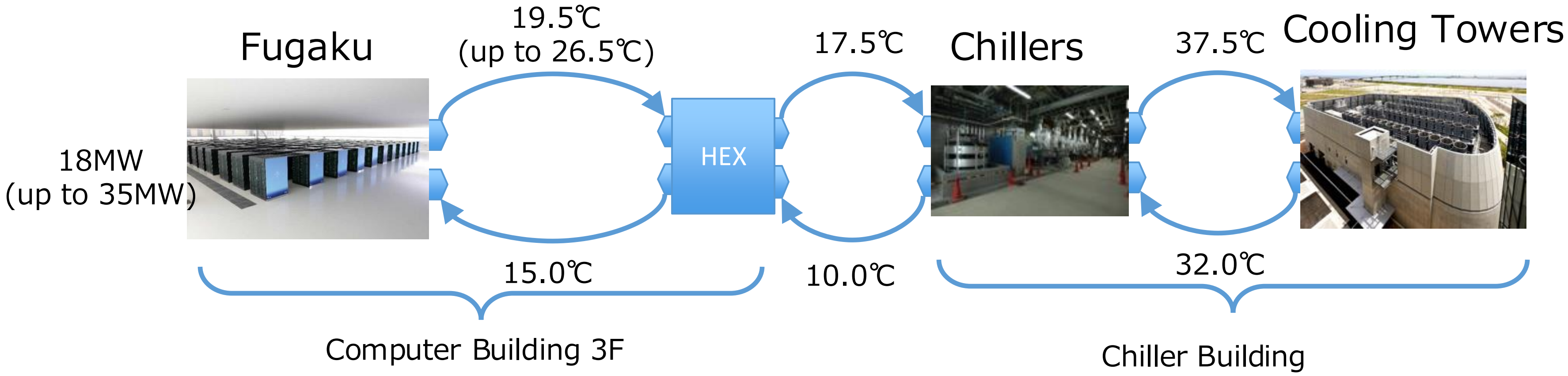
Even after four and a half years since its first appearance, it still have higher competitiveness in the world.

Power delivery system for Fugaku

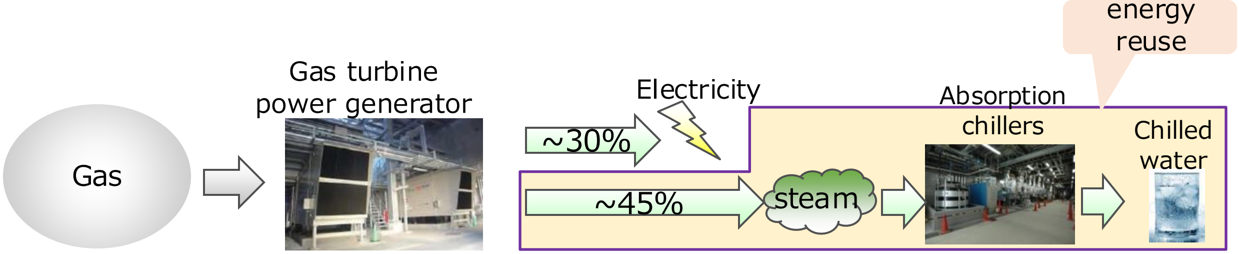


- Key features
  - **2 sources**: from power supplier and on-premise power generation from Gas
    - Power generators cover 20-25% of the site's total power consumption and wo rk as a backup power supply for data storage when a power outage occurs.
  - **2-stage voltage transformation**
    - 77,000V->6,600V->200V

Cooling system for Fugaku



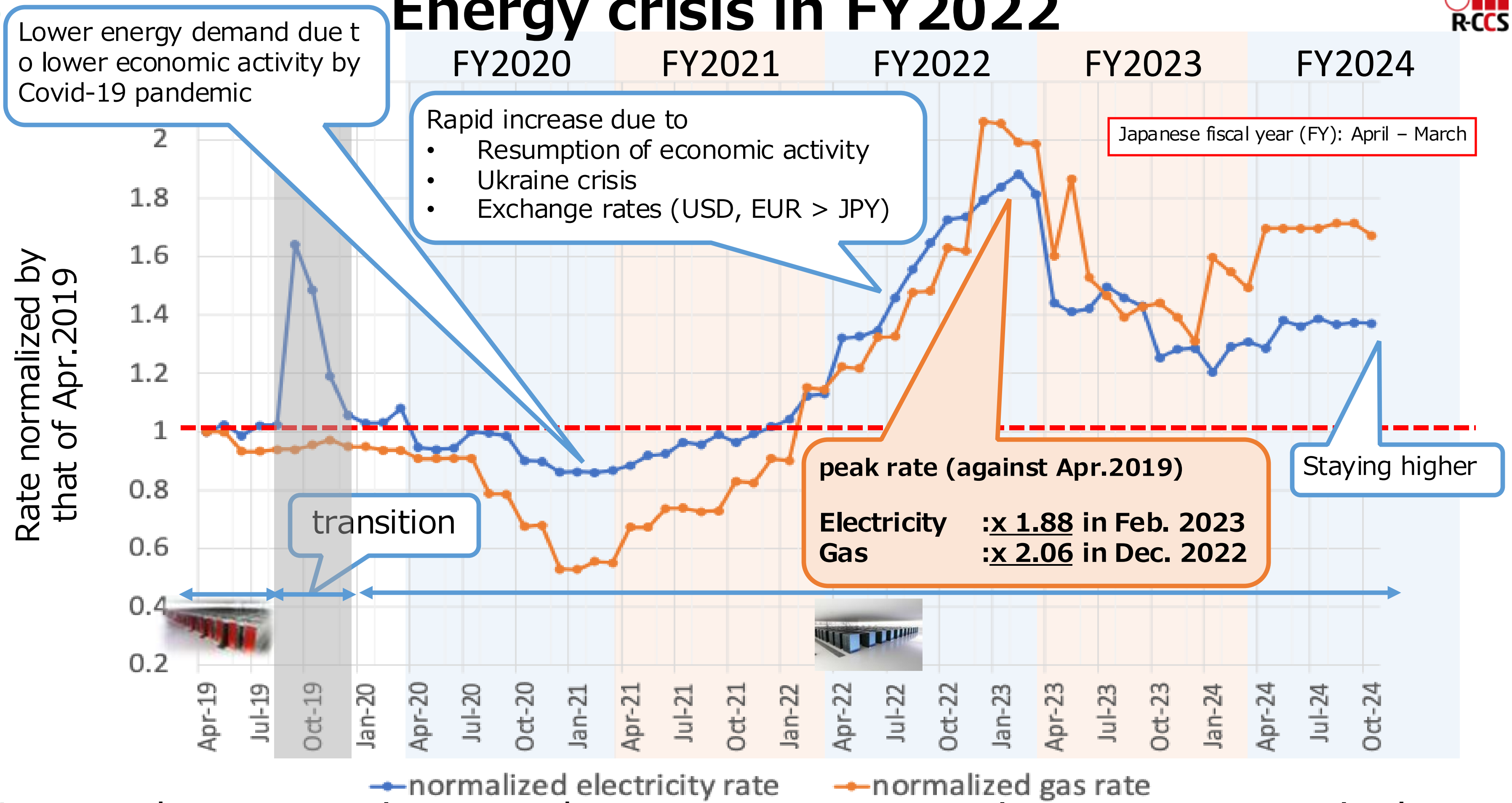
- Key features
  - Cold water based (inlet:15.0℃)
    - for CPU reliability (Fugaku consists of 158,976 CPUs)
  - Co-Generation system (Gas turbine power generator & absorption chiller)
    - for energy efficiency and active backup power supply for data storages



Chiller type	Quantity	Capability(MW)
Absorption	4	5.98
Centrifugal	3	4.93
Centrifugal	1	2.46
Heat pump	2	

Trial for energy efficient operation

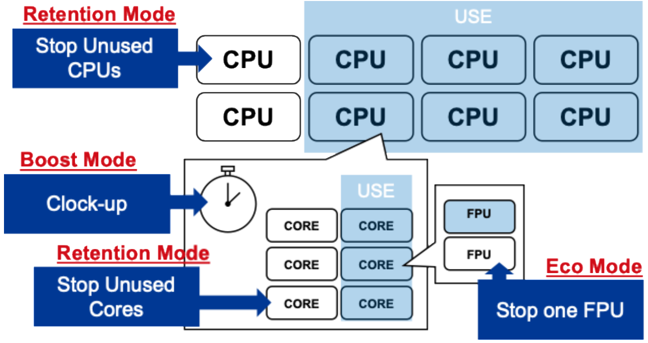
Energy crisis in FY2022



We must keep on trying to reduce energy consumption more aggressively

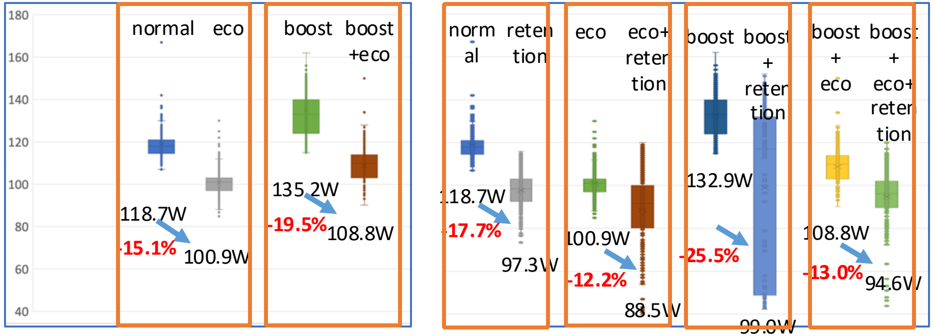
Fugaku point program –incentivizing user cooperation-

- Fugaku equips the power knobs, functions for power-saving

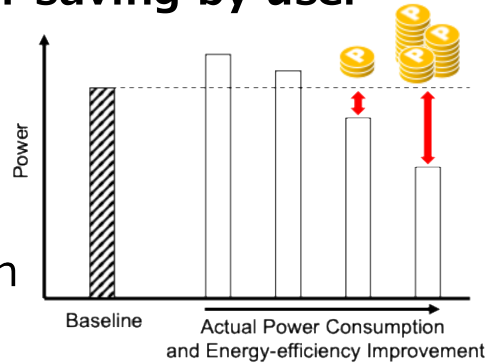


NOTE: The absence of power-saving features is referred to as Normal Mode

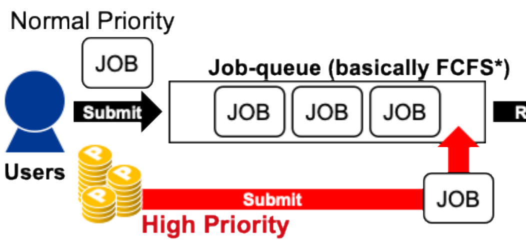
actual power saving



- "Fugaku point" to quantify the user cooperation for power saving by user jobs
  - Users can earn points when their jobs runs with less power consumption than the standard.



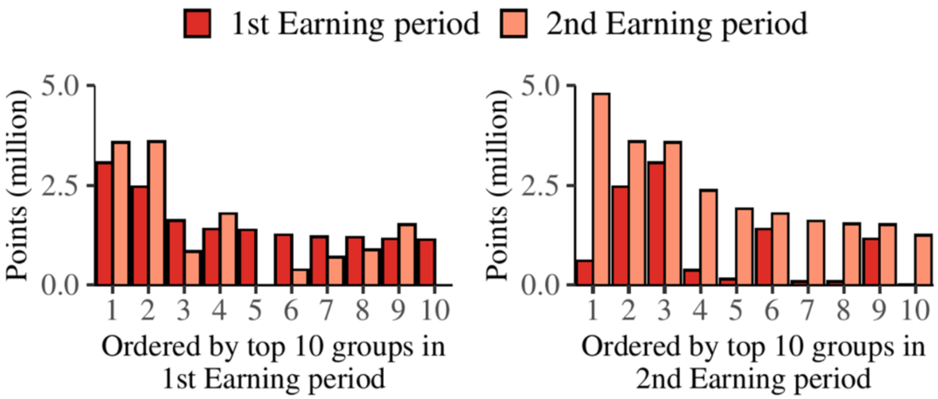
- Users can redeem the points to run their jobs with higher priority.



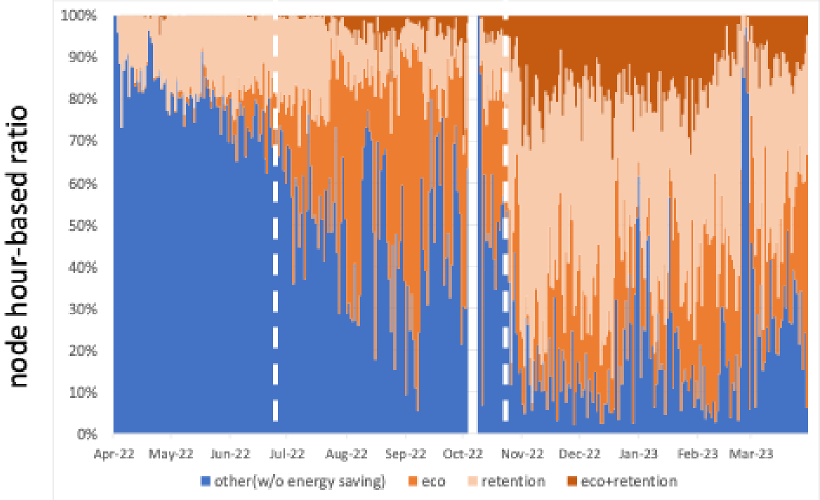
* First-Come, First-Served

Result in FY2023 (April 2023 – March 2024)

	FY2023 1H April-September	FY2023 2H October-March	+/-	
# of projects earned Fugaku point	161	170	+5.6%	
Average of Fugaku point per project	248,303	320,692	+29.2%	
Average power consumption per node(W)	97.69	94.07	-3.7%	-6.86% for FY2022



https://sc24.conference-program.com/presentation/?id=pap400&sess=sess389



- Fugaku point program encouraged users’ awareness for power saving.
- Average power consumption per node is significantly reduced.

Remarks and Next steps

- **An incentive-based Power Efficiency Mechanism works well**
  - raise user awareness of energy-efficient operation
  - facilitate user cooperation for energy-efficient operation
  - achieve an actual reduction of power consumption
- **Next steps**
  - keep fairness among the workloads that have different power consumption profiles
    - memory-intensive vs. instruction-intensive
  - evaluate the reduction of power to solution contribute energy to solution
    - direct comparison between the same workload w/ and w/o power-knobs is needed

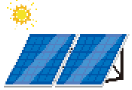
Consideration of infrastructure for “Fugaku next”

Study of Carbon Neutralization for “Fugaku next” (planned to be available in 2030)

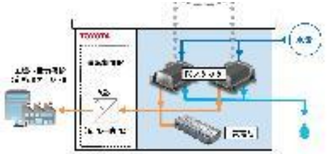
The Japanese government has targeted achieving net zero carbon emissions by 2050 and a 50% reduction in carbon emissions from 2013 by 2030

(1) Use of Renewable Energy

DC's own operations can respond to future energy price hikes.



Hydrogen and Biofuels



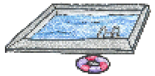
Effect: Stable reuse of electrical energy

Hydrogen
biomass

Carbon Neutral
Procurement of Electricity

Carbon neutral
In-House Generation of Electricity

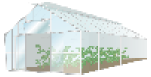
(3) Reusing Waste heat



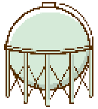
(swimming) pool

bathing facilities

https://datacenterfrontier.com/waste-heat-utilization-data-center-industry/



greenhouse

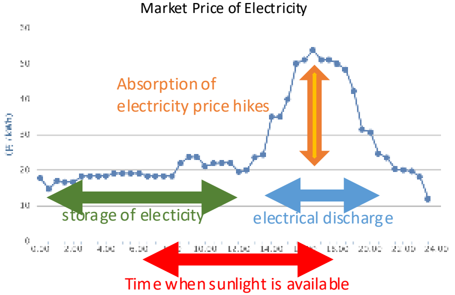


Heat for liquefied hydrogen naturalization

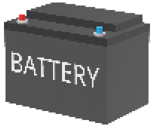
Supercomputer Simulation
Return of results to society

Waste heat

(2) Responding to electricity price fluctuations through the use of renewable energy



Introduction of large storage batteries



Sustainable power

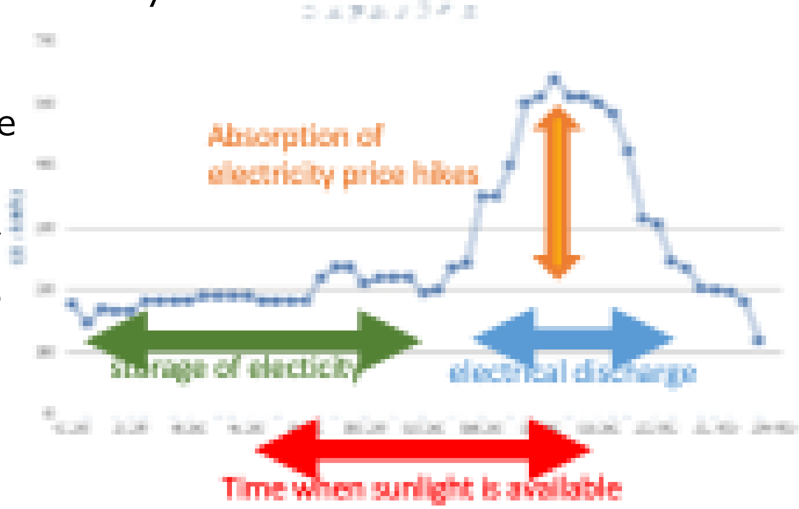
(4) Energy-efficient supercomputer operation

Power saving of the main body of the calculator
- Power efficient programming
- Allocation of computing resources in response to changes in electricity prices

Improved efficiency of cooling facilities
- Higher cooling water temperature
- Highly efficient cooling facilities for free cooling
- automation

Use of Renewable Energy

- **Electricity generated by on-premise power generation**
  - Solar or Wind power generation are not realistic due to large space.
  - Hydrogen power generation equipment is available, but it is unclear whether the establishment of the hydrogen supply chain will meet our timeframe.
  - According to our operation experience of Gas turbine power generators for more than 10 years, energy cost tends to be higher than procured electricity due to maintenance costs.
- **Electricity procured from supplier**
  - It is not easy to estimate the additional cost for renewable energy in 2030
  - If we could procure electricity from the renewable energy market directly, there will be risks, but there will be more opportunities to reduce energy costs.
  - Energy price awarded job scheduling should also be considered.



Large Energy Storage System Case Studies

● Installation Examples in JAPAN

Figure 1: Redox flow battery at the Minamihayarai substation of Hokkaido Electric Power Co.

Figure 2: Lithium batteries at Tohoku Electric Power Company's Nishi-Sendai substation

Figure 3: Lithium batteries at Tohoku Electric Power Company's Minamisoma substation

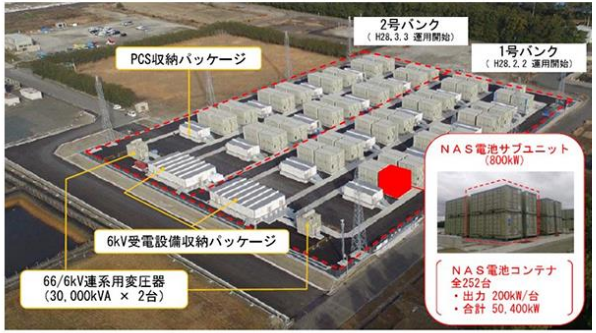


Figure 4: Sodium-sulfur battery at the Toyomae substation of Kyushu Electric Power Co.

Source: New Energy Foundation website, New Energy "Recent Topics/Keyword" Explanation Corner
Figure 1 https://www.nef.or.jp/keyword/sa/articles_sa_03.html Figure 2 https://www.nef.or.jp/keyword/sa/articles_sa_03_02.html
Figure 3 https://www.nef.or.jp/keyword/sa/articles_sa_03_04.html Figure 4
https://www.nef.or.jp/keyword/sa/articles_sa_03_03.html

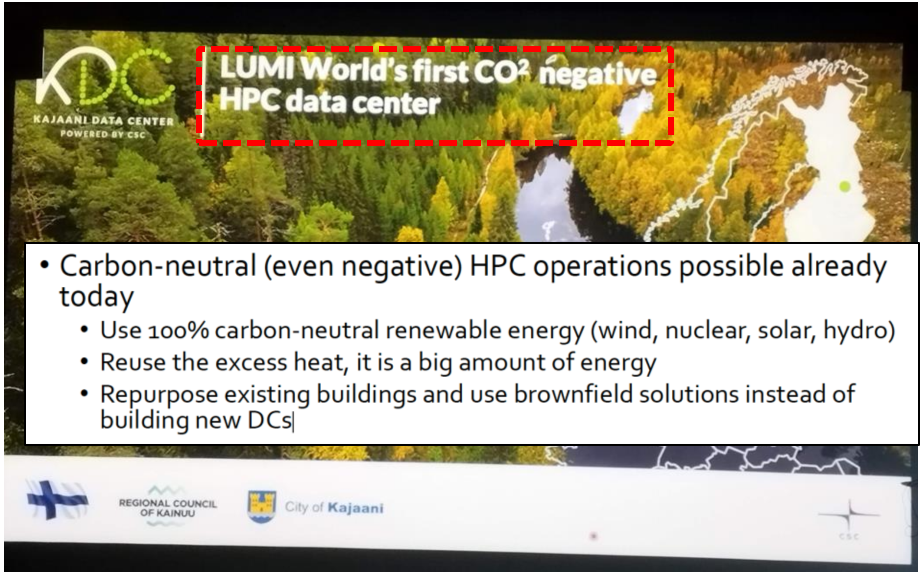
Comparison of Large Energy Storage Systems

	lithium-ion battery	sodium-sulfur battery	redox flow battery
energy density (Wh/l) Product specification values	176 Wh/L	83 Wh/L	15 Wh/L
Charging and discharging efficiency (Storage battery alone) (generally 10% lower in the system)	95 % of	90 % of	85 % of
Discharge rate (Domestic at the time of the survey at the source) (Actual values of cases)	0.50 to 5.0 C	0.17 C	0.25 C
Cycle life	15,000 cycles	4,500 cycles	100,000 cycles
Installation space	0.21 m2/kW, 0.21 m2/kWh	0.28 m2/kW, 0.047 m2/kWh	0.33 m2/kW, 0.083 m2/kWh
Installation cost	308,000 yen/kW, 308,000 yen/kWh	430,000 yen/kW, 70,000 yen/kWh	1.07 million yen/kW, 270,000 yen/kWh
Maintenance cost (maintenance/installation costs)	0.1 % of the total	0.5 % of	0.3 % of the total
Compliance with fire laws	Eligible (over 20 kWh)	Eligible (over 20 kWh)	Eligible (over 20 kWh)
hazardous materials	subject (of taxation, etc.) Electrolyte: Class 4 Petroleum No. 2 (1,000 L)	subject (of taxation, etc.) Sulfur: Class II (100 kg) Sodium: Class III (10 kg)	not subject (to)
qualified or eligible person deployment	If the specified quantity is exceeded, Appointment of Hazardous Materials Safety Supervisor	Appointment of Hazardous Materials Safety Supervisor	-
requirement	• Securing a vacant lot of at least 3m wide for holding • Fixed on a solid foundation • Stored in cubicles or containers (made of steel plate) • Storage battery facilities that comply with the fire and fire prevention regulations of JIS※2 , etc. • Water sprinkler system for cooling when handling hazardous materials more than 100 times the designated quantity	• The room where the sodium-sulfur battery is installed is fireproof • No electrical equipment, etc. other than that related to sodium-sulfur batteries shall be installed. • Ensure safety for single batteries • Ensure safety for module batteries • Safety tests conducted by the Hazardous Materials Safety Technology Association	-

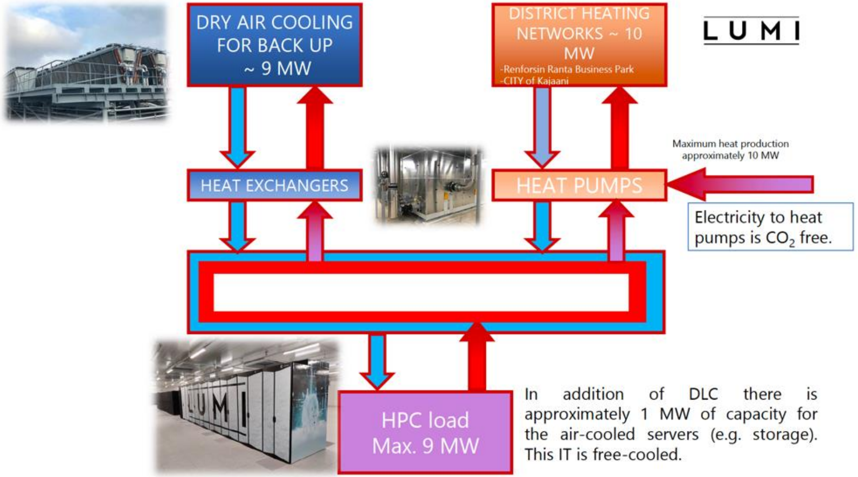
Source: Prepared by NTT-F based on "Storage Battery Utilization and Control Technology in Grid Power," Technical Report of the Institute of Electrical Engineers of Japan, No. 1403, 2017, by the Special Committee for Investigation of Storage Battery Utilization and Control Technology in Power Grid.

Carbon neutral/negative HPC center operation

LUMI@CSC, Finland



- Carbon-neutral (even negative) HPC operations possible already today
  - Use 100% carbon-neutral renewable energy (wind, nuclear, solar, hydro)
  - Reuse the excess heat, it is a big amount of energy
  - Repurpose existing buildings and use brownfield solutions instead of building new DCs



- **Reusing waste heat from the HPC center for district heating networks is popular in Europe**
  - CSC@Finland
    - ~20% of heat demand City of Kajaani(~140,000)
  - CEA@France
    - ~90% of heat demand of CEA centre
  - CSCS@Switzerland
    - ~?MW for City of Lugano(~64,000)

Cooling Facility Configuration –Reuse Waste Heat–

- **Area**
  - Kobe area (ambient humidity: 28.5°C)
- **Main Computing Resource (Fugaku-Next)**
  - Water temperature 32°C/42°C (DLC)
- **Storage**
  - Water temperature 20°C/30°C (RDHx)
- **Waste heat utilization**
  - Assumed to be used by raising the temperature using a heat pump
  - Needs large scale heat consumers near R-CCS

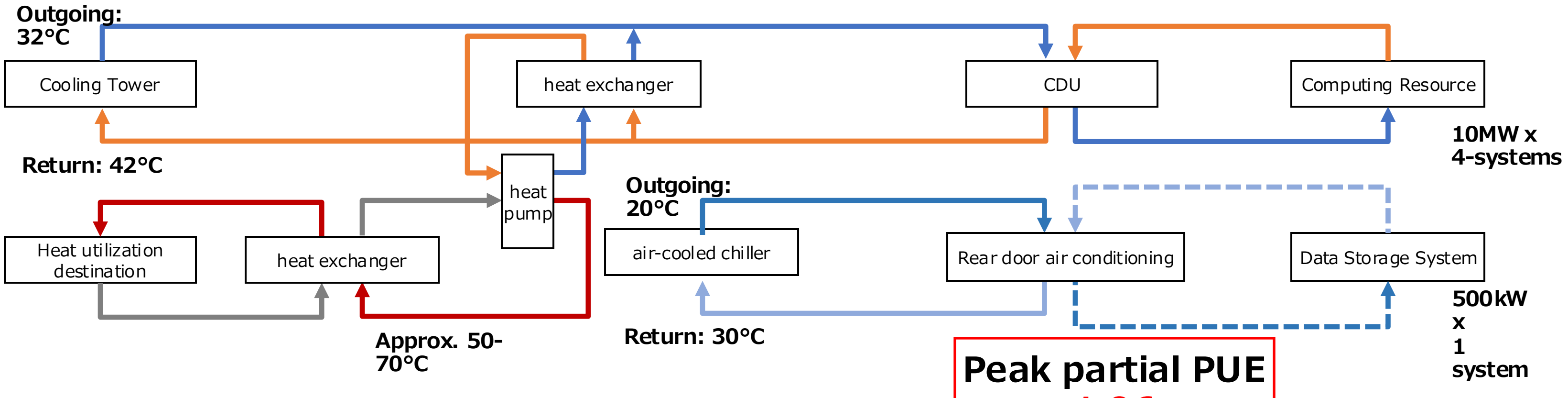
ASHRAE CLIMATIC DESIGN CONDITIONS 2021, there is a 1 in 20 year probability of wet bulb temperature conditions of 28.5°C occurring in Kobe.

Extreme Annual Design Conditions

Extreme Annual WS 1%	Extreme Annual WS 2.5%	Extreme Annual WS 5%		Extreme Annual Temperature Mean Min	Extreme Annual Temperature Mean Max	Extreme Annual Temperature Standard deviation Min	Extreme Annual Temperature Standard deviation Max	n=5 years Min	n=5 years Max	n=10 years Min	n=10 years Max	n=20 years Min	n=20 years Max	n=50 years Min	n=50 years Max
9.9	8.4	7.3	DB	-1.8	35.4	1.6	1.2	-3.0	36.2	-3.9	36.9	-4.8	37.6	-5.9	38.4
			WB	-3.8	27.2	1.5	0.7	-4.8	27.7	-5.7	28.1	-6.5	28.5	-7.6	29.0

(n-Year Return Period Values of Extreme Temperature)

[legend].
water (esp. cool, fresh water, e.g. drinking water)
air
*Differences in color indicate differences in temperature.



Peak partial PUE 1.06

Summary

- **Operation improvements for energy efficiency on Fugaku have been achieved.**
  - An incentive-based Power Efficiency Mechanism works well
    - raise user awareness of energy-efficient operation
    - facilitate user cooperation for energy-efficient operation
    - achieve an actual reduction of power consumption
- **Consideration of infrastructure for "Fugaku next" is ongoing.**
  - Warm water cooling (32°C/42°C) w/o chillers
  - No on-premise generators to avoid higher maintenance costs
  - Heat reusing as possible

Date: January 26 ～ 29, 2026

Venue: Osaka International Convention Center

- Jointly hosted by the leading international conference on HPC: **SCA and HPC Asia 2026**
- Theme : Everything with HPC – AI, Cloud, QC and Future Society
- Co-located Events （in progress)
  - Trillion Parameter Consortium (TPC)
  - Accelerated Data Analytics and Computing (ADAC)
  - Hpc AlliaNce for Applications and supercoMputing Innovation: the Europe - Japan collaboration (HANAMI)
  - ASEAN International HPC School
  - R-CCS International Symposium
- In cooperation with international conferences; ACM, IPSJ, etc.
- Expected number of participants: 1500～3000
- Expected number of exhibits: ～100 companies, universities, and research institutions
- A place where the world's most advanced research and business on supercomputing, AI, big data, cloud, quantum computing, and semiconductors meet!

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