Sustainability Issues in Asian Accelerator Laboratories

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Agenda

01 Energy Consumption & Environmental Impact

02 Present Situation in the Asian Accelerator Laboratories

03 Economic Viability & Funding Models

04 Implementation Process for Green Labs

05 Key Difficulties & Barriers

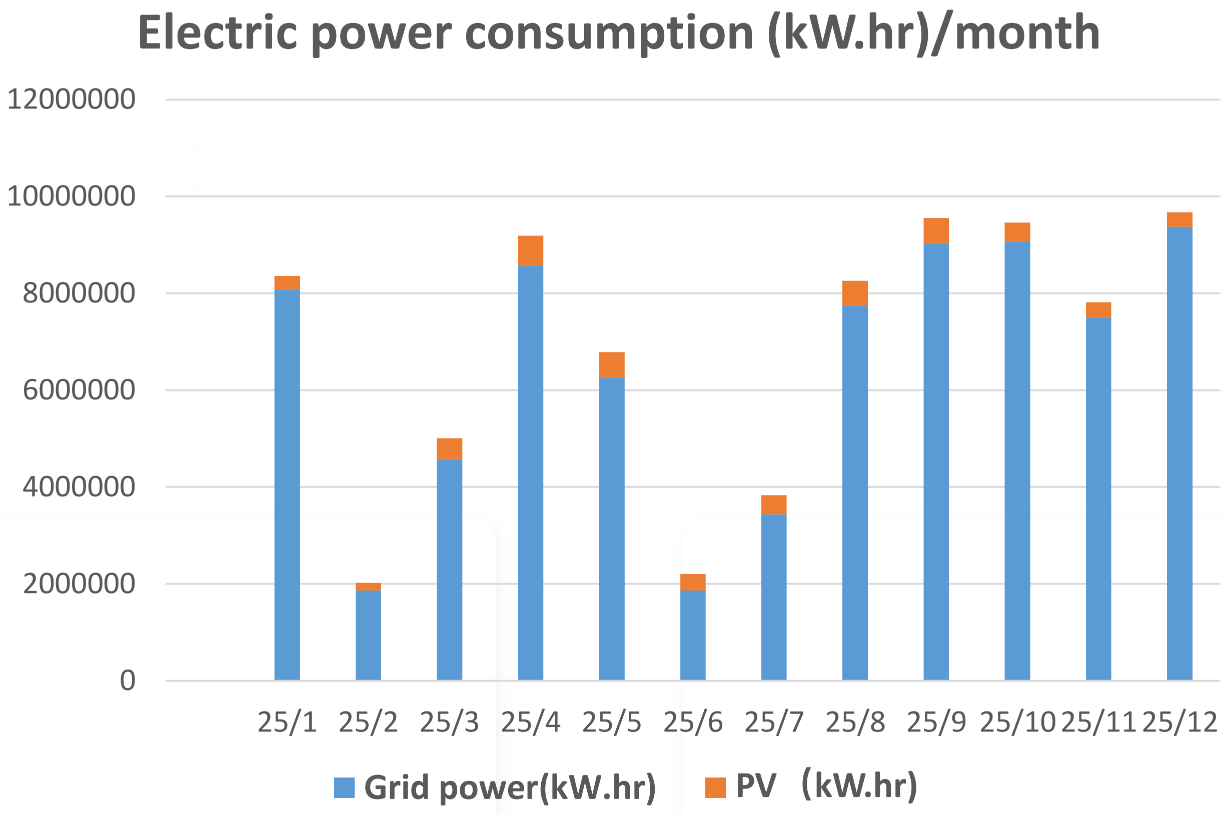
06 Future Outlook

Let's Build a Sustainable Future Together

1. Energy Consumption and Environmental Impact

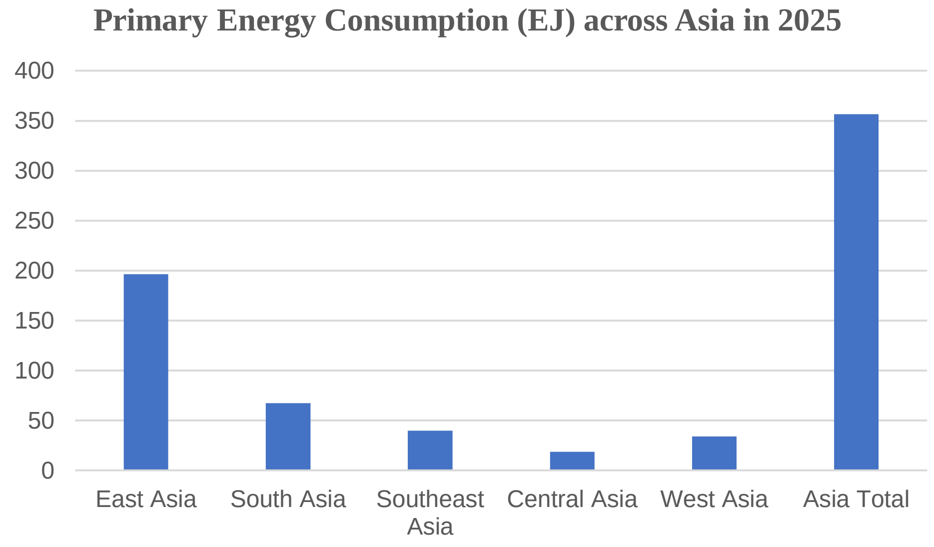
Core Energy Consumption

Annual draw: GWh scale for large facilities (HEPS, SPring-8).
Key load: >85%from SC magnets, SRF, cryogenics & UHV.
Inefficiency: Obsolete klystrons, constant cryo loads & HVAC waste.



Total power consumption for HEPS last year:
82148520 kW.hr (PV 4784160kW.hr)

1. Energy Consumption and Environmental Impact



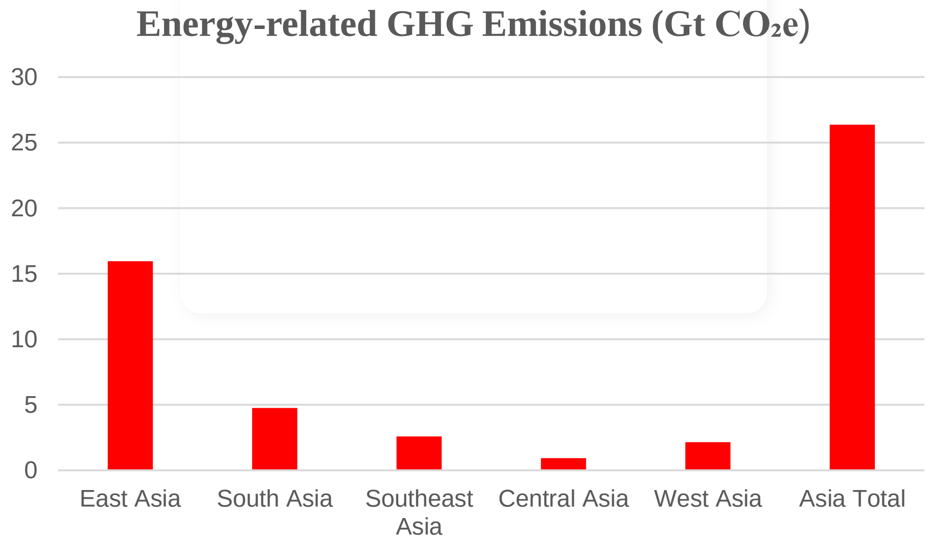
Environmental Impacts

Carbon Footprint: High GHG emissions from fossil-fuel grids in Asia.
Resource Burden: Massive cryogen/ cooling water demand.
Recycling: Limited waste heat recovery in legacy systems.

GHG = Greenhouse Gas

Gt CO_2e = Gigatonnes CO_2 equivalent

more than half of
the global total GHG emissions



2. Present Situation in the Asian Laboratories

Asia's Rise as a Global Hub

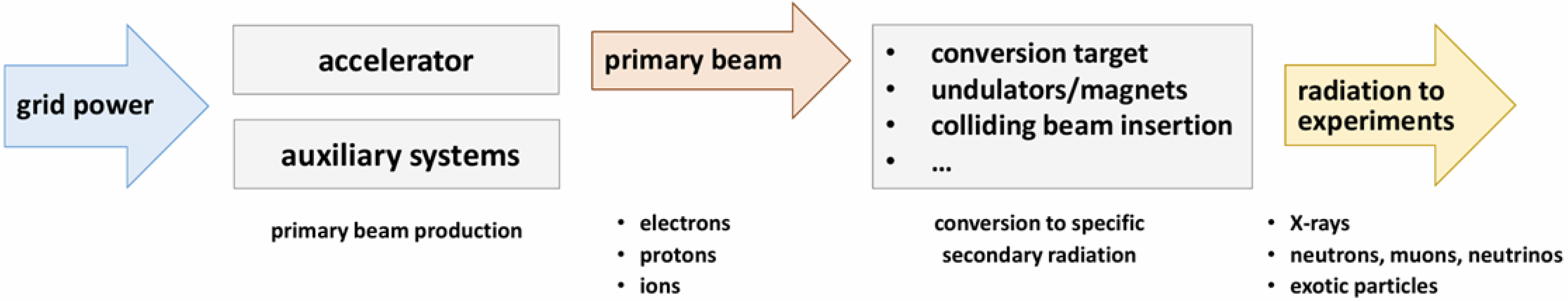
Fastest-growing region: Leading the development of large-scale accelerator infrastructure globally.

Advanced Facilities: Home to 4th-gen light sources, heavy-ion accelerators, and FELs (Free-Electron Lasers).

Key Players: China (HEPS, SHINE), Japan (Super-KEKB, SPring-8), Korea (PLS-II, 4GSR), Thailand, India, and Singapore.

Grid power → X-rays or particles

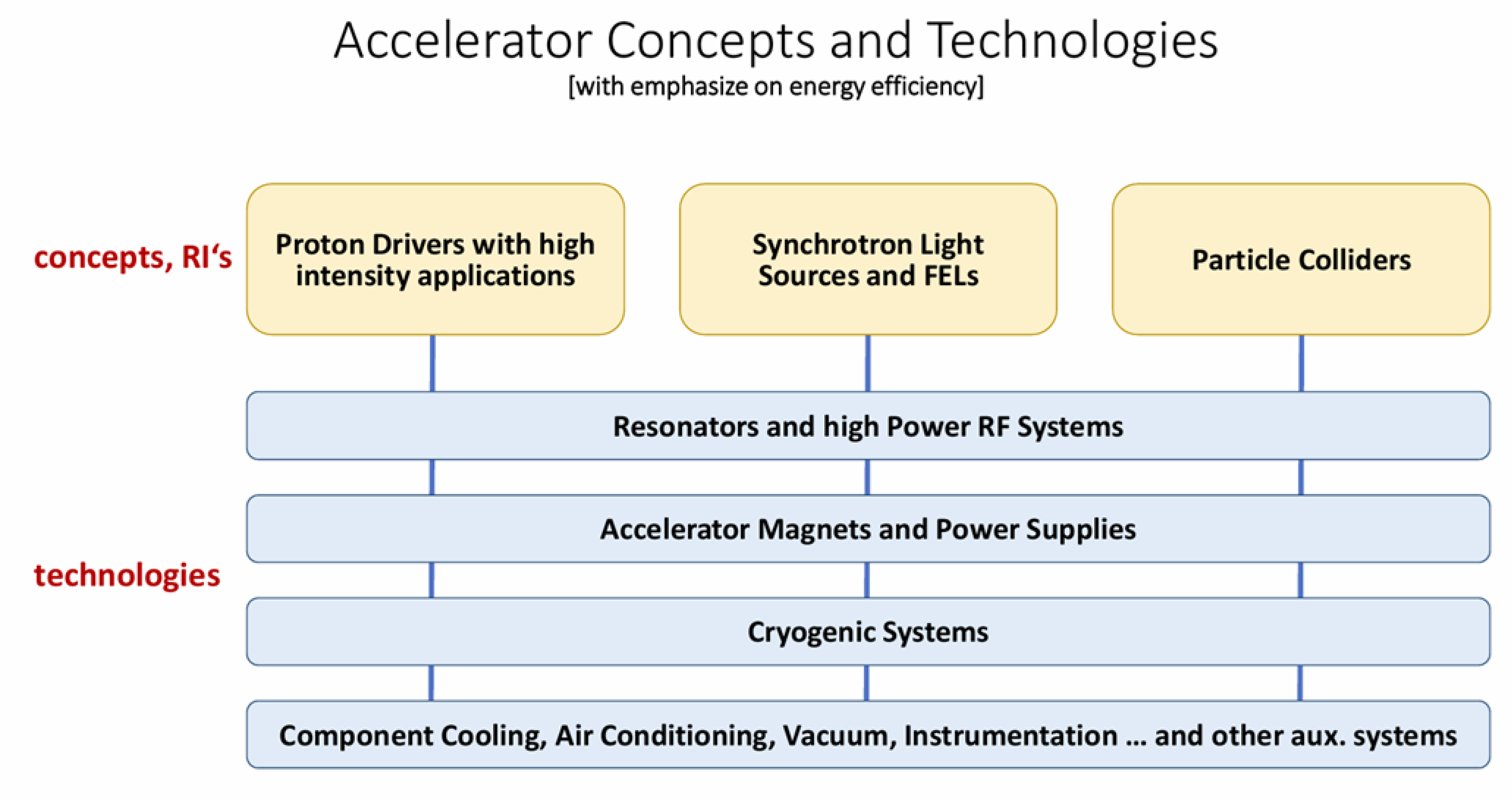
Accelerator driven Research Infrastructures (RI)



high level goal:

Science output per grid power, per operating/investment cost.

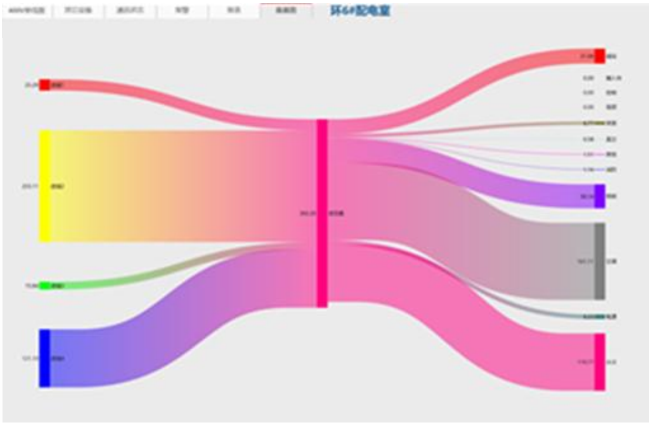
Efficient Accelerator Technologies



Green energy design of HEPS

Energy conservation design

- Building envelope thermal insulation performance
  - Heat-transfer coefficient K ≤ 0.45W/m^2.K
  - Air tightness
- Efficient mechanical and electrical equipment
  - EC fan, and variable frequency motor
  - LED lighting
  - Vacuum boiler
  - Permanent magnet
  - Convertor, transformer, chiller, etc.



- To minimize the line losses
  - Pumps, transformers, convertors are closed to points of use as could as possible
  - Electrical power factor ＞96% （98%） , by reactive power compensation
  - To increase differential temp. for primary cooling water (8℃) and chilled water (6℃)
- Smarter energy management
  - To optimize device operational parameters to be more efficient
  - To develop energy monitoring schemes in order to analyze and improve efficiency of energy utilization.

Green energy design of HEPS

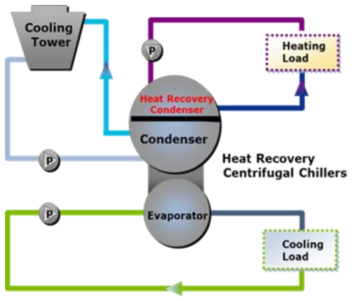
Heat recovery

Heat recovery chillers

To reuse the heat dissipated by HEPS machine

to supply hot water for the campus heating system by 9MW.

About $7*10^5$ m^3 of gas can be saved during the winter heating months.



- Solar green energy
  - Solar photovoltaic array (465Wp/550Wp)

    The equivalent annual average utilization hours are 1035.85h
    - PV array on the roof of ring building
      - Total capacity: 7816.6kWp
      - To be connected to utilities substation for chiller plant
    - PV array On the roof of office, guesthouse buildings
      - Total capacity: 2134.32kWp
      - To be connected to substation for office building
    - Phase II: on the ground inside of ring (7314.45kWp)
  - Now to provide approximately 6% of electric energy

Energy Saving in the SHINE Cryogenic system

SHINE

➢ VFD & Floating Pressure Control for Compressor Optimization

- **Design**: Main warm helium compressors are equipped with Variable Frequency Drives (VFD) and utilize floating discharge pressure control logic;
- **Impact:** Eliminates "idle" power waste. During partial-load operations (e.g., fluctuating RF loads), the Megawatt-scale compressor station can dynamically scale down power, saving 20% to 30% of electrical consumption.

➢ Advanced Cold Compressors for 2K Efficiency

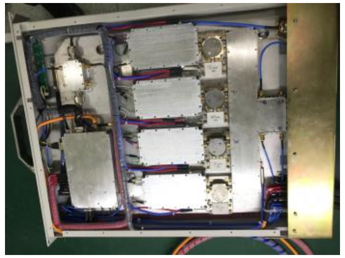
- **Design**: Utilizing multi-stage centrifugal cold compressors for the 2K pump-down process.
- **Impact**: By avoiding the massive thermodynamic penalty of warming gas to 300K for pumping, it boosts the overall system COP (Coefficient of Performance) by nearly 30% compared to traditional room-temperature setups;

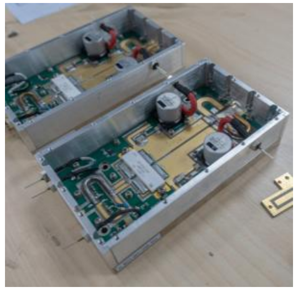
➢ Multi-Channel Cryogenic Lines for Heat Leak Reduction：

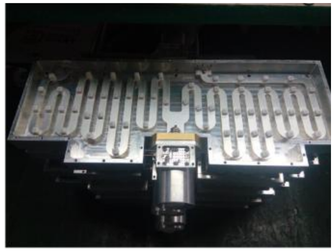
- **Design**: Optimize the thermal performance of 1.2-km multi-channel cryogenic transfer lines.
- **Impact**: Decreases the overall surface area and thermal bridges, cutting static heat leakage by >30%. This effectively recovers 5%~10% of the baseline cryogenic cooling capacity, preserving valuable 2K refrigeration power for the superconducting cavities..

RF Power Souces

	L-band Buncher	1.3GHz SC-cavity	3.9GHz SC-cavity	216MHz VHF-gun
Quantities	1	442	16	2
Power Source	15kW SSA	5.2kW SSA	2kW SSA	60kW SSA

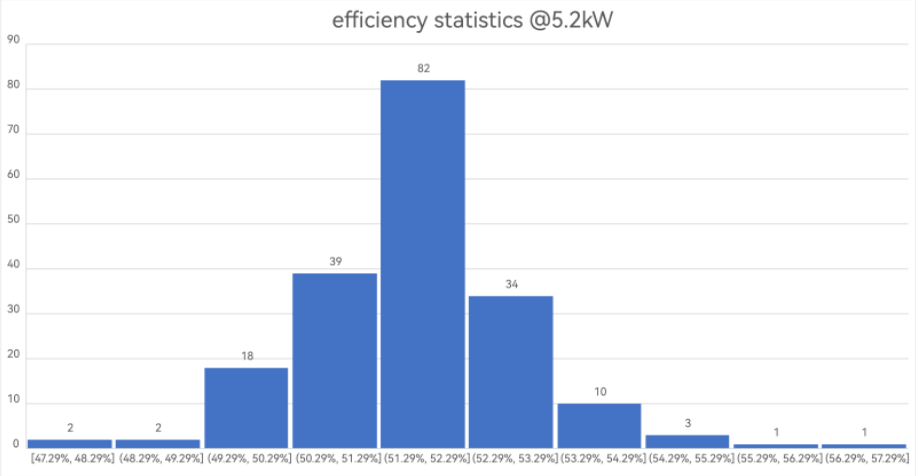






Solid State Aplifier (SSA)：

- Features:
  - ✓ Adopts modular and pluggable design for easy maintenance
  - ✓ 192 sets use GaN power amplifier transistors, RF conversion efficiency higher than 50% (better than traditional LDMOS solution, ~40%), a rough estimation for power saving would be several hundred kWs



Efficiency statistics of 192 sets 1.3GHz/5.2kW SSAs (GaN)

SHINE

Japan

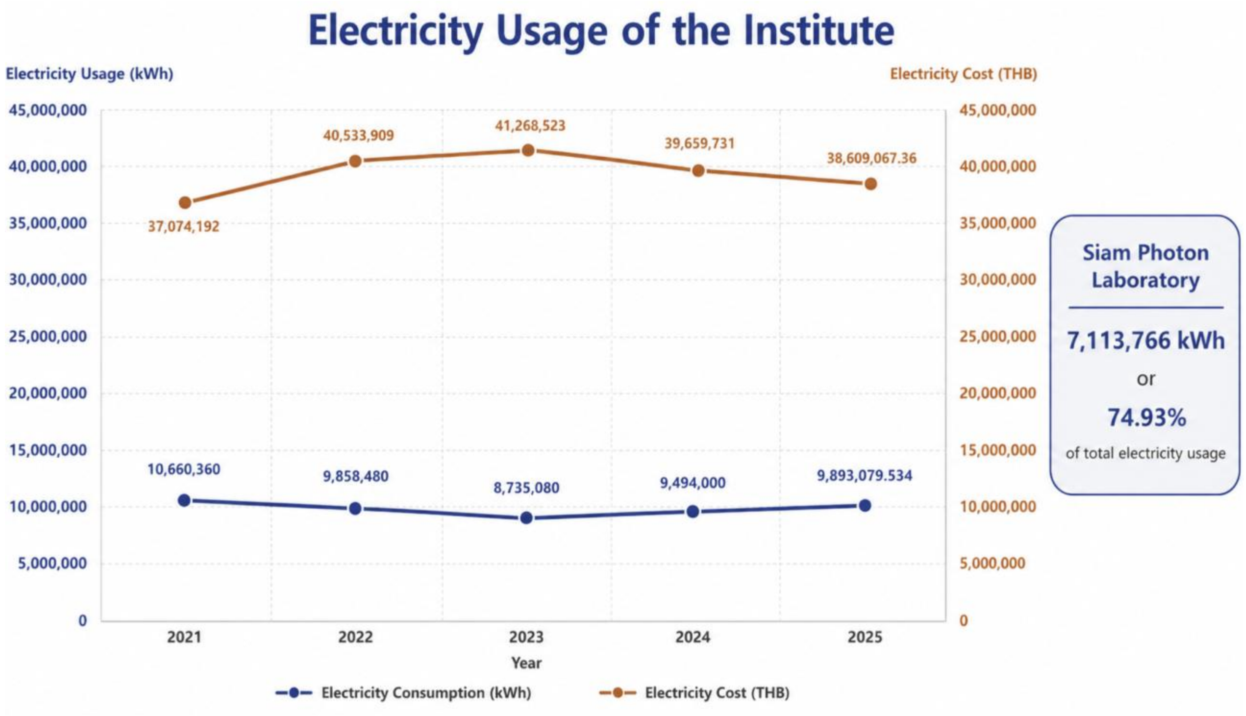
Big picture (Japan accelerator sustainability model)

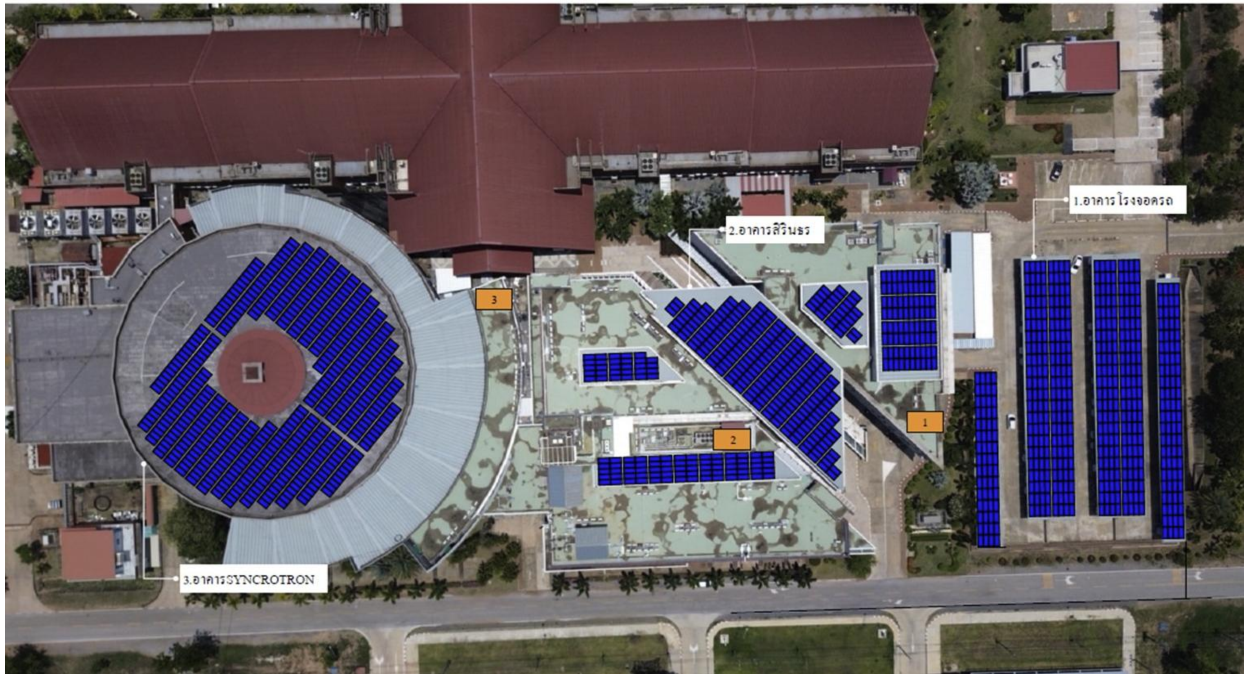
Japan’s strategy (KEK, SPring-8, J-PARC ecosystem) is:

- Recover heat instead of dumping it
- Reduce beam energy(Spring-8 => Spring-8 II) instead of increasing power
- Replace electromagnets with permanent magnets
- Add distributed renewables (PV)
- Reuse infrastructure instead of rebuilding

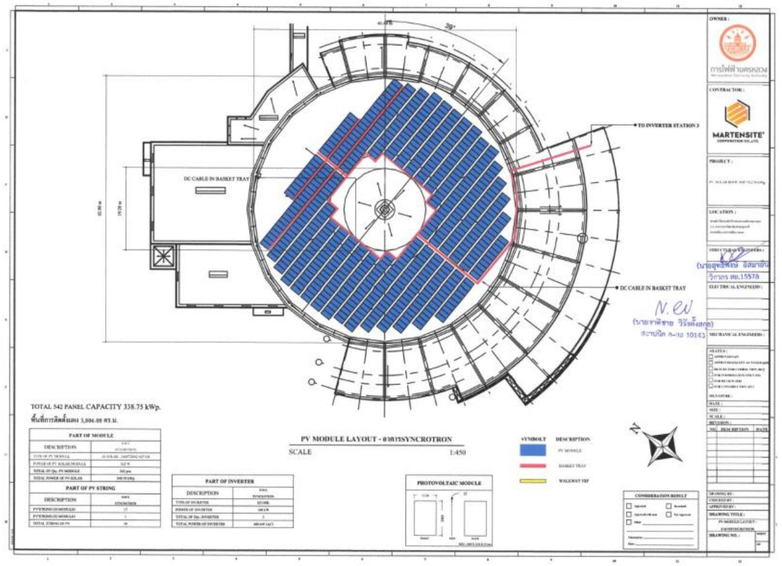
Present situation on energy consumption: SPS-I(Thailand)

- Electricity costs increased significantly in 2023–2024 due to the Russia–Ukraine war. Despite this, SLRI maintained stable electricity cost per beamtime by optimizing facility operation and energy management.
- **Solar rooftop with 911 kW** capacity is now installed to reduce electricity cost.
- Expected annual electricity generation from solar rooftop: **1.26 million kWh/year.**

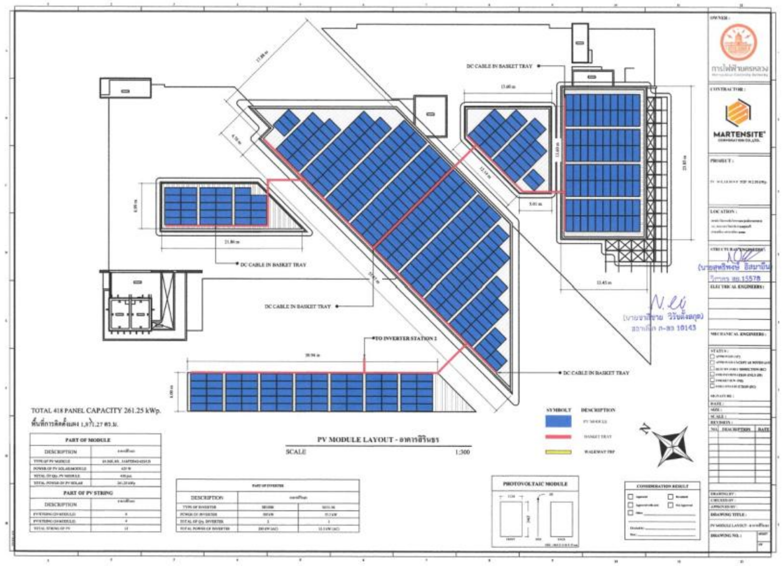




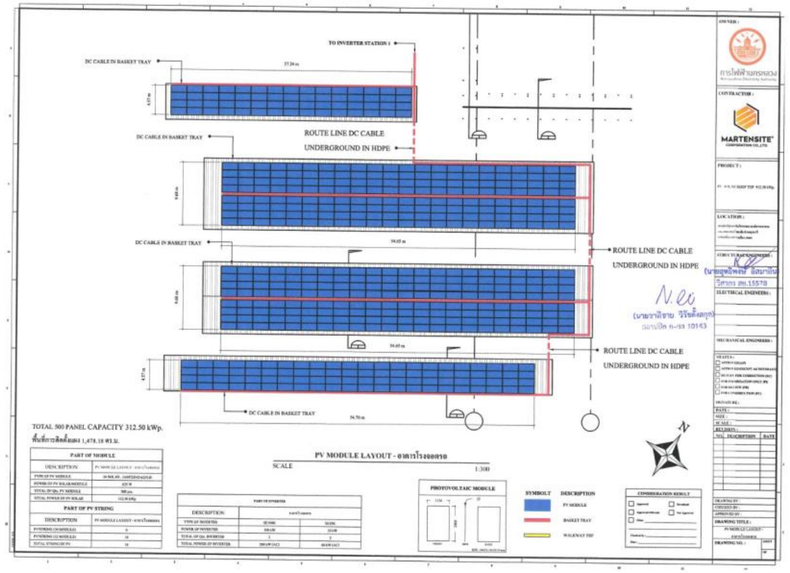
Present situation on energy consumption: SPS-I



Synchrotron bldg.: 467.50 kW



Office bldg.: 171.60 kW



Parking lot: 272.80 kW

Total: 911.90 kW

3. Economic Viability and Funding Models

Economic Challenges

High Capital Expenditure (CapEx)

Mega-facilities require multi-hundred-million budget upfront investment.

Crippling Operational Costs (OpEx)

Energy bills consume 30-50% of annual operating budgets.

Long payback cycles due to indirect socioeconomic spillovers.

Dominant Funding Models

Central Government Sole Funding

Stable but rigid, often lacking incentives for cost optimization.

National + Local Co-financing

Common model in China, leveraging local funds for green retrofits.

Multilateral support via IAEA grants & ADB green loans.

4. Implementation Process for Sustainable Accelerators

A Phased Framework

01. Conceptual & Front-End Design

Prioritize low-carbon architecture (SRF, ERL) and embed lifecycle sustainability principles from the start.

02. Construction & Infrastructure

Deploy green campus engineering standards and integrate on-site renewables (PV panels, wind turbines).

03. Operational Management

Implement AI-driven energy scheduling and circular resource operation, such as helium recovery systems.

04. Retrofit & Upgrade

Modernize legacy facilities with efficient components and digital twin simulations.

Regional Implementation Traits

JP Japan: Retrofit Focus

Known for mature post-construction retrofitting strategies, optimizing the lifespan of existing accelerators.

CN China: Full-Chain Integration

Combines full-chain sustainable design for new facilities with large-scale retrofits for older infrastructures.

KR South Korea: Inception Embedding

Integrates sustainable design from project inception (e.g., 4GSR), setting new green benchmarks.

Approaches to a green machine/sustainability operation

CEPC Green Accelerator Technology Development

- **CO2 footprint life-cycle assessment**
  - Civil construction
  - Footprint of construction and operation
- **Improving the key technology energy efficiency**
  - Superconducting technology: High Q SRF cavity and cooling system; HTS magnets
  - High performance & efficiency RF source
  - Novel magnets: dual aperture magnet, permanent magnet
  - Wireless signal transporting technology
  - Application of revolutionary new acceleration technology, i.e. Plasma acceleration
- **Clean energy implement and utility**
  - Solar panel
  - Wind energy
- **Energy/non-renewable resource recovery**
  - Waste energy recovery from cooling water and utility in civilization
  - Energy recovery from klystron
  - Helium recovery

To sustain the accelerator infrastructure in Japan;

(1) research institutes must possess a high level of technical expertise in hardware. At the same time, efforts are absolutely needed to find ways to apply each accelerator technology and technical knowhow to product development in other fields with large scale-markets to ensure a sufficient number of companies continue to manufacture accelerator component equipment.

(2) Research Institutes must strategically pursue the continuous advancement and development of accelerators so as to seamlessly link the large-scale upgrade programs carried out every 20 to 30 years. One specific approach to this is the concept of a ‘green upgrade’, whereby accelerator advancements are implemented in accordance with societal demands for sustainable development.

(3) Cooperation from such companies is essential in Japan. To this end, it has become a critical challenge for research institutes and the government to formulate long-term strategies that take into account the sustainability of these companies, whilst also maintaining the corporate base through international collaboration and other means. This is never an easy task. The current situation in Japan is that no such long-term strategies have yet been established.

The ease with which efforts to maintain accelerator infrastructure varies greatly depending on the purpose for which the accelerator is used. In the case of high-energy accelerators, the outcomes are primarily ‘pure physics research’. On the other hand, one promising model involves returning the various technologies developed during accelerator construction projects to society. One example of this is the introduction of laser-plasma accelerators into high-energy accelerator complexes, a project currently being actively pursued at IHEP. Laser-plasma accelerator technology holds the potential to achieve a level of miniaturization that is in a league of its own, and it has the potential for widespread application in the medical and industrial sectors. Returning such secondary benefits to society could be one way of winning over taxpayers.

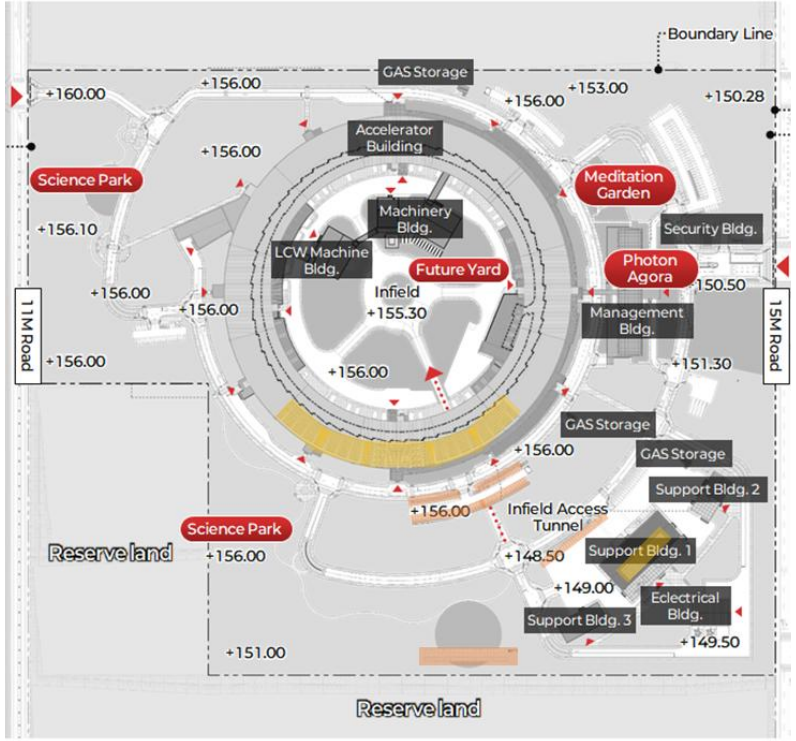
In the field of light source accelerators, the contribution to the transition of the current social system towards a sustainable one is significant. If we can continue to clearly demonstrate these achievements, it is anticipated that the accelerator infrastructure can be maintained for the foreseeable future.

Korea-4GSR

National Certification & Energy

Green Regulation Compliance

- ✓ Designed in strict adherence to **ROK sustainability laws** and environmental protection regulations.
- ✓ Applying **Green Building Certification**, Energy Efficiency Rating, and **Zero Energy Building** (ZEB) standards.
- ✓ Mandatory integration of **Solar Systems** including **Photovoltaic (PV)** and **Building-Integrated PV (BIPV)**.



32.06%

RENEWABLE ENERGY SHARE

**Exceeding statutory requirement of 32% (excluding power supplied to equipment).*

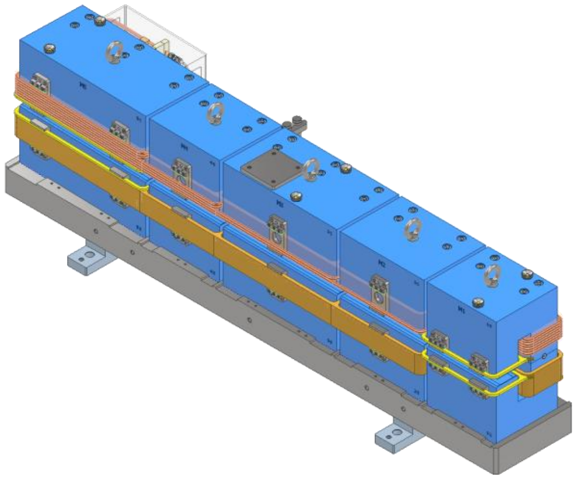
PV

BIPV

Technical Innovation & Strategy

Hardware & Regulatory Strategy

- ✓ Hardware Efficiency: Adoption of **Permanent Magnets (LGBM)** and high-efficiency **Solid State Power Amplifiers (SSPA)** to minimize energy waste.
- ✓ Administrative Strategy: Secured partial certification exemptions through **Local Building Review Committee** for high-power facility components.



Sustainability Roadmap

2024 Detailed Design & Green Certification Planning

2028 Efficiency Verification & System Performance Testing

2029 Full Operational Readiness & Green Verification

LGBM

Future plan: SPS-II in Thailand

- Solar roof is planned from the beginning. The electricity production capacity is **> 2 MW**.
- The synchrotron building is designed to be a **certified green building**.

Economic viability and funding models

- Solar roof and associated infrastructure was installed free of charge by Metropolitan Electrical Authority (MEA).
- Maintenance is the responsibility of MEA.
- Total project duration is 25 years.
- SLRI still pays the cost of generated electricity, but with 20% discount.
- Estimated normal electricity cost for 25 years: 105.8 MTHB
- Estimated discount electricity cost for 25 years: 84.6 MTHB
- Estimated amount of saving by SLRI for 25 years: 21.2 MTHB.

- Advantage of this funding model: **No investment cost, no maintenance cost for SLRI.**

5. Difficulties and Barriers

Technical Challenges

- Intrinsic high energy demand of accelerator physics.
- Core green component bottlenecks(SRF cavities, power sources).
- Helium scarcity and inefficient cryogenic systems.
- Lack of unified sustainability metrics.

Economic & Financial

- High upfront green retrofitting investment required for legacy facilities.
- Funding model rigidity prioritizing short-term scientific output over long-term sustainability.
- Uneven regional economic disparity limiting access to green technology.

Institutional & Cooperative

- Fragmented regional collaboration and lack of global joint initiatives.
- Policy and regulatory gaps in mandating or incentivizing green practices.
- Shortage of interdisciplinary talent combining physics and environmental science.

7. Future Outlook

Short-Term (2026 - 2030)

Widespread energy efficiency retrofits
AI-driven intelligent operation optimization

SRF Technology Mainstreaming
Full adoption of solid-state RF source systems

Expanded On-site Renewables
Seamless clean power grid interconnection

Mixed Funding Models (Green Grants, PPP (Public - Private Partnership))

Mid-to-Long-Term (2030 - 2040)

Next-Gen Sustainable Accelerators
Based on ERL (Energy Recovery Linac) tech

Fully Closed-Loop Circular Operation
Helium recovery & 100% recyclable components

Unified Asian Sustainability Ecosystem
Collaborative green standardization across nations

Lab-Industry Convergence (Co-created Value Chains)

7. Future Outlook & Vision

Major global actor in Science

Asia has the potential to transform from a hub of high-performance research facilities into a major global actor in sustainable large-scale scientific infrastructure.

Key Strategic Enablers

- Dominant renewable energy industrial capacity.
- Deep cross-national technical synergy.
- Successive new-generation facility construction.

The Visionary Goal

Reconcile frontier physics research with global climate neutrality goals, setting a **global benchmark for low-carbon accelerator science.**

Thank You for your attention

ANY QUESTIONS & DISCUSSION