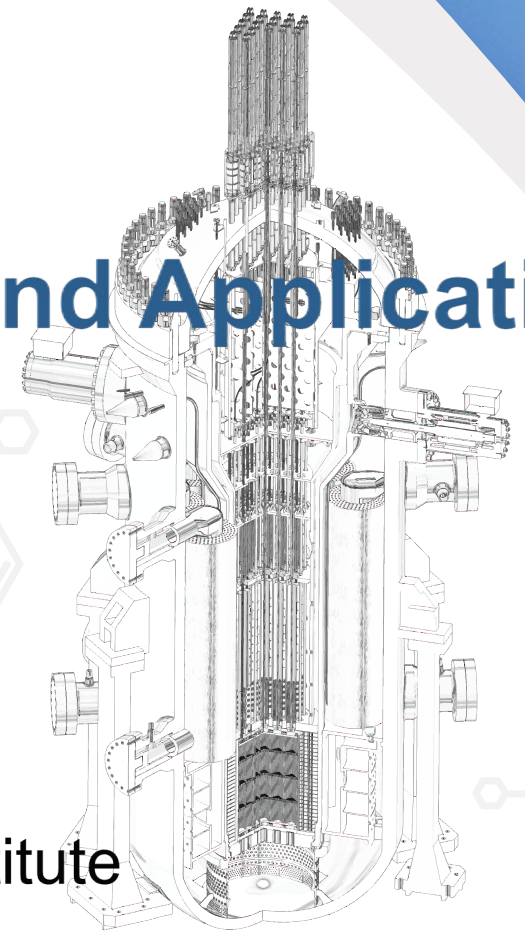
KOREA's "SMART" Road to SMR in CANADA, Jeju ICC, Korea

Korean Nuclear Society
2024 Spring Conference

A nuclear research institute
reshaping the future
based on **peoples trust**

SMART:
Carbon Free Energy for Oil Sand Application



Dr. Han Ok Kang
SMART Development Group

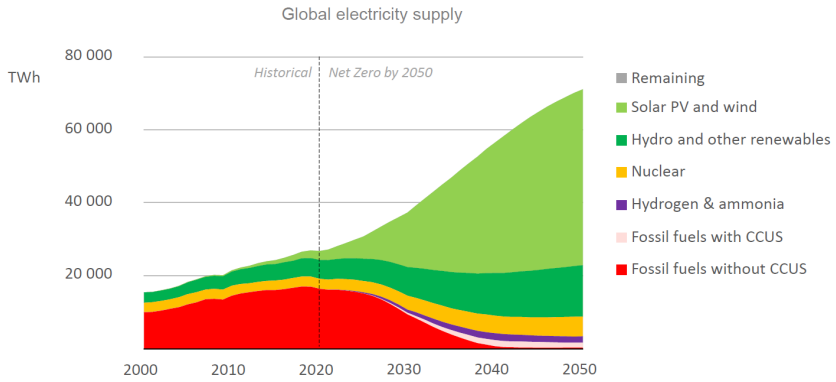
May 8, 2024

Korea Atomic Energy Research Institute

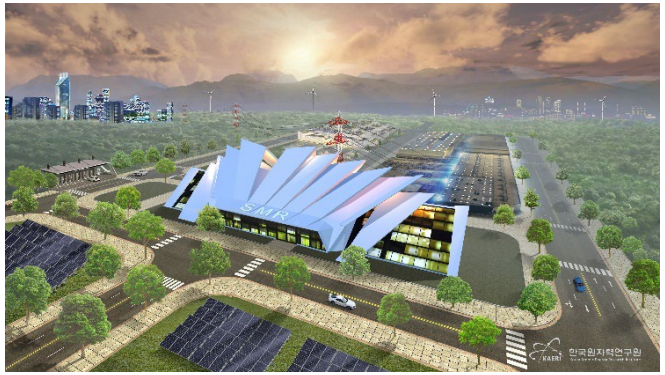
Carbon Neutrality

Korea Atomic Energy Research Institute

- **(Electrification) Energy transition to renewable electricity for achieving carbon neutrality**
  - **The share of nuclear energy rises along with the growth of renewable energy.**
  - **SMRs can supplement the intermittency of VRE and geographical transmission limitation.**

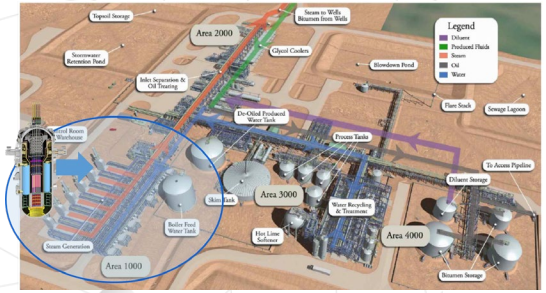


Brent Wanner, Korea Atomic Power Annual Conference, 27 April, 2022

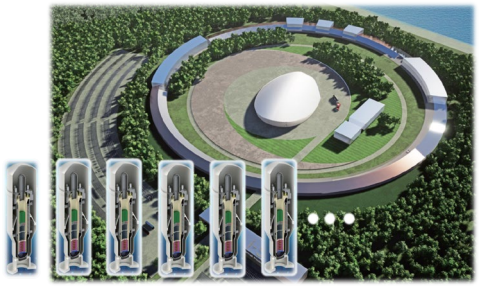


< SMR Net Zero City >

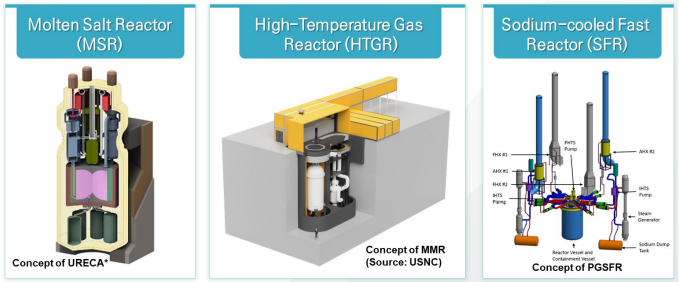
- **(SMR) Roles of SMR in Net Zero Emissions**
  - **Replacement of coal plants to supply on-grid power**
  - **Replacement of fossil fuels in heavy industry, off-grid mining and district heating**
  - **Hydrogen production, desalination and merchant shipping**



< SMART for Heat Supply >



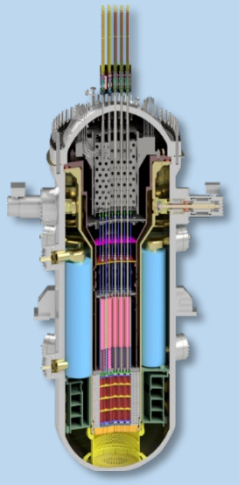
< Innovative SMR >



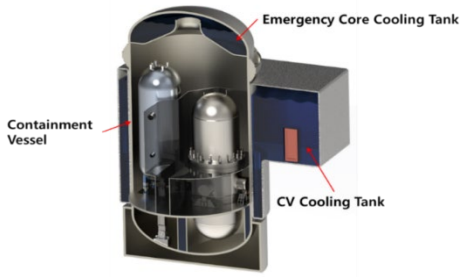
< Generation IV SMR >

K-SMRs

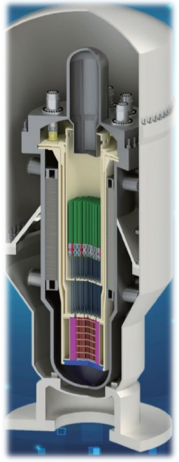
Korea Atomic Energy Research Institute



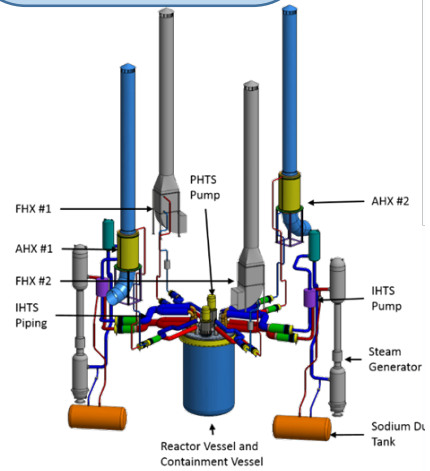
SMART



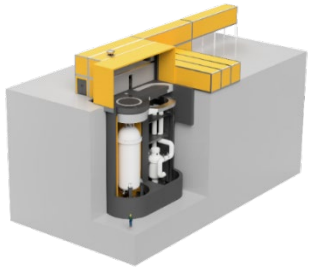
BANDI



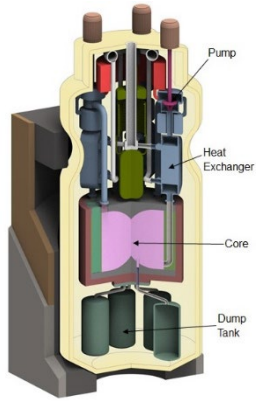
i-SMR



PGSFR



USNC MMR



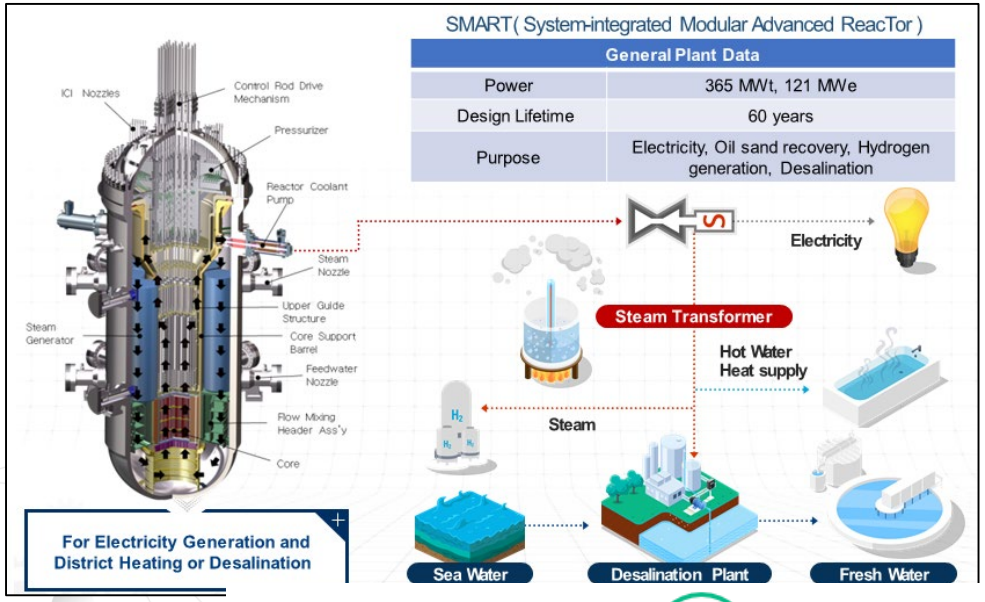
K-MSR

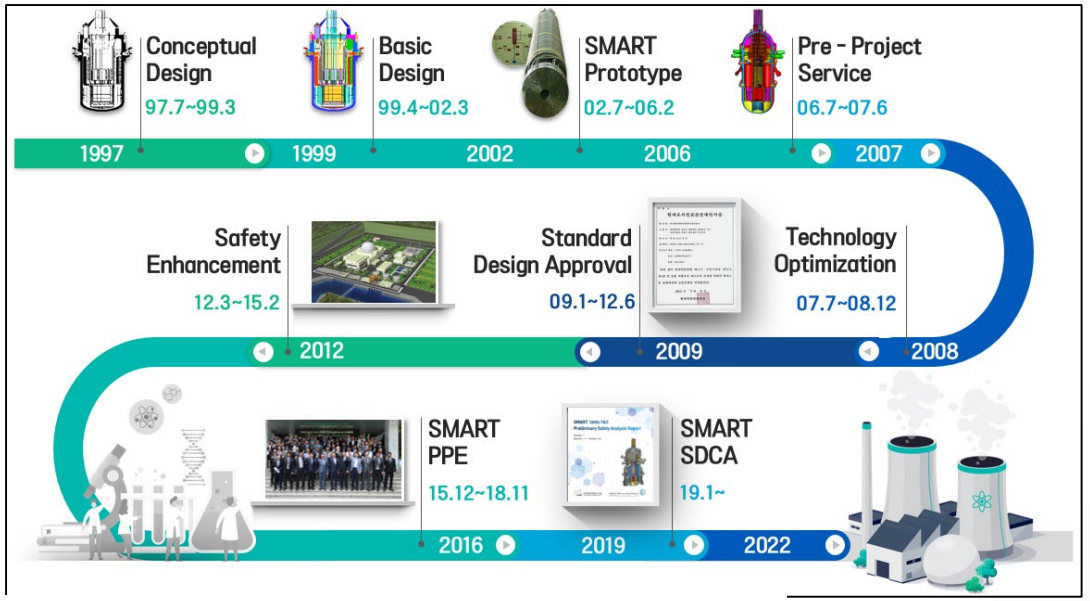
1997	• SMART Project Initiation
2012	• SMART Standard Design Approval
2014	• SMART Safety Enhancement Project
2015	• Korea–Saudi Arabia SMART partnership
2016	• BANDI Conceptual Design
2018	• MMR CNL Demonstration Project (USNC)
2020	• PGSFR Basic Design
2021	• i-SMR Project Initiation
2022	• i-SMR Conceptual/Basic Design
2023	• SMART100 Standard Design Approval
	• K-MSR National Program Initiation

SMART

Korea Atomic Energy Research Institute

ALL-IN-ONE: Significant safety enhancement has been achieved with passive heat removal as well as an advanced LOCA mitigation concept





Innovative Concept

- All Major Components in Rx Vessel
- Modularization for Field Installation and Maintenance
- Passive Safety System
- Fully Digitized Control System

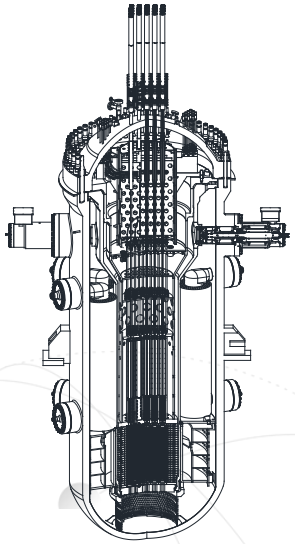
Proven Technologies

- 17 x 17 UO_2 Proven Fuel Technology
- Control Rod Drive Mechanism
- Reactivity Control Concepts Using BP and Soluble Boron

SMART Design Features

Korea Atomic Energy Research Institute

Design Features of SMART



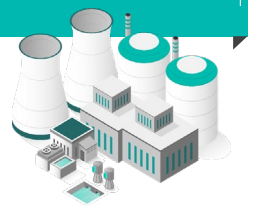
SMART Reactor Assembly

General Information

- Thermal Power : 365 MWt
- Electric Power : 100~110 MWe
- Desalination : 40,000 ton/day
- Design Life : 60 years

Reactor Coolant System

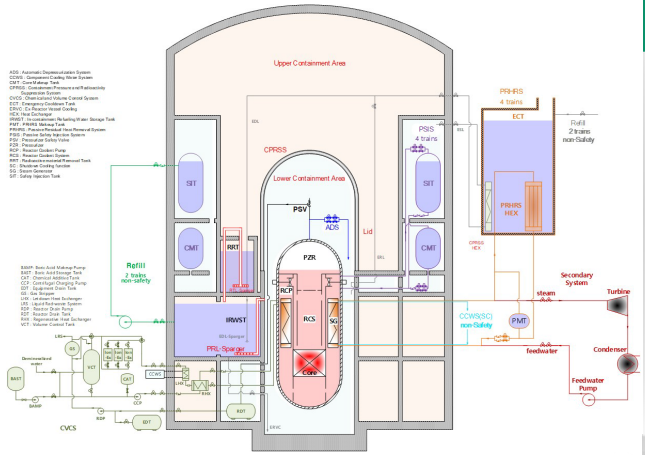
- Design Pressure : 17 MPa
- Operating Pressure : 15 MPa
- Design Temperature : 360 ℃
- Core Inlet/Outlet Temperature : 295.5/322 ℃



Fuel and Reactor Core

- Fuel Type : 17×17 Square FA
- Fuel Material : UO2 (< 5.0 w/o)
- Active Core Height : 2.0 m
- Refueling Cycle : 30 months

Passive Safety Systems



Design Bases of Passive Safety Systems

- To maintain a reactor in the safe condition for 72 hours without any operator action at the postulated design basis accidents
- All safety systems can operate not depending on electrical power from emergency diesel generator for 72 hours.
- Safety-grade batteries provide necessary DC power for valve initiation and post accident monitoring.

Passive Safety Systems

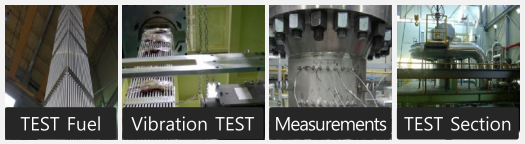
- Passive Safety Injection System
- Automatic Depressurization System
- Passive Residual Heat Removal System
- Containment Pressure and Radioactivity Suppression System

Comprehensive SMART Technology Validation Program

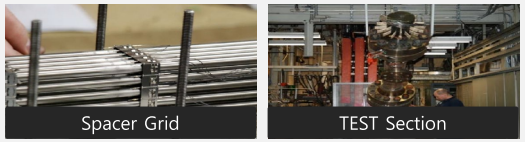
Korea Atomic Energy Research Institute

Fuel TH Tests

- Fuel Performance Tests

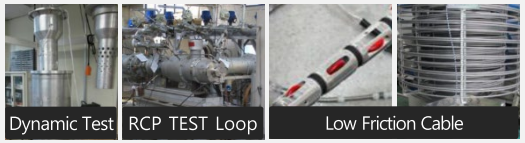


- CHF Measurement Test

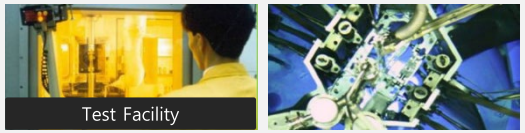


Mechanics and Components

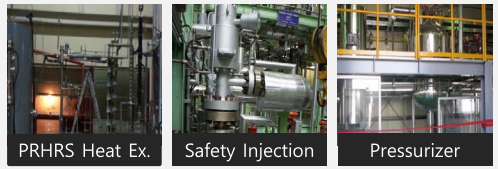
- RPV Dynamics Test, RCP Mockup Test and Helical ISI Test



- SG Tube Material (A690) Irradiation Test



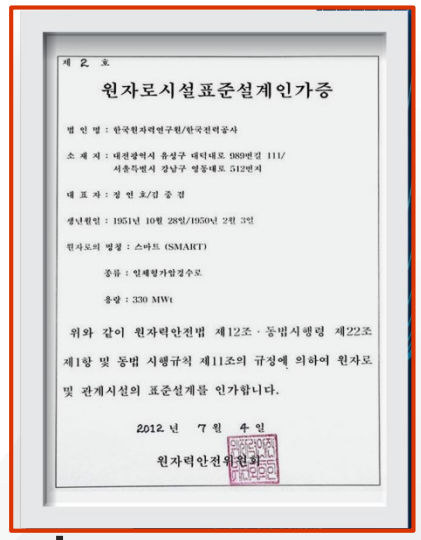
Thermal - Hydraulics Experiment



SMART – ITL [1)]

- World's Unique and Largest Full Scope Accident Simulation
  1:1 Height, 1/49 Volume

SMART - MCR [2)] Simulator



제 2 호

원자로시설표준설계인가증

법 인 명 : 한국원자력연구원/한국전력공사

소 재 지 : 대전광역시 유성구 대덕대로 989번길 111/
서울특별시 강남구 영동대로 512번지

대 표 자 : 정 연 호/김 중 경

생산원일 : 1951년 10월 28일/1950년 2월 3일

원자로의 명칭 : 스마트 (SMART)

종류 : 일체형가압경수로

용량 : 330 MWt

위와 같이 원자력안전법 제12조 · 동법시행령 제22조 제1항 및 동법 시행규칙 제11조의 규정에 의하여 원자로 및 관계시설의 표준설계를 인가합니다.

2012 년 7 월 4 일

원자력안전위원회

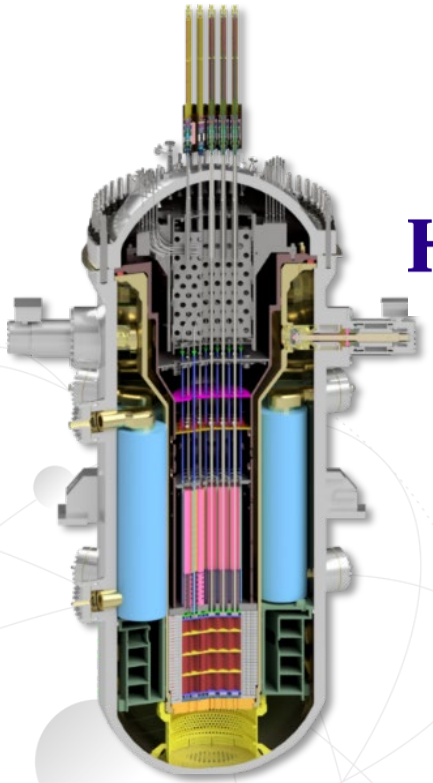
- **Systems, Component, and Design Tools have been fully Developed and Licensed.**
- **SMART Standard Design Approval in 2012 (Meet the Most Country's Licensing Requirements)**

Supply Chains for SMART

Korea Atomic Energy Research Institute

DOOSAN Enerbility

WOOJIN INC.



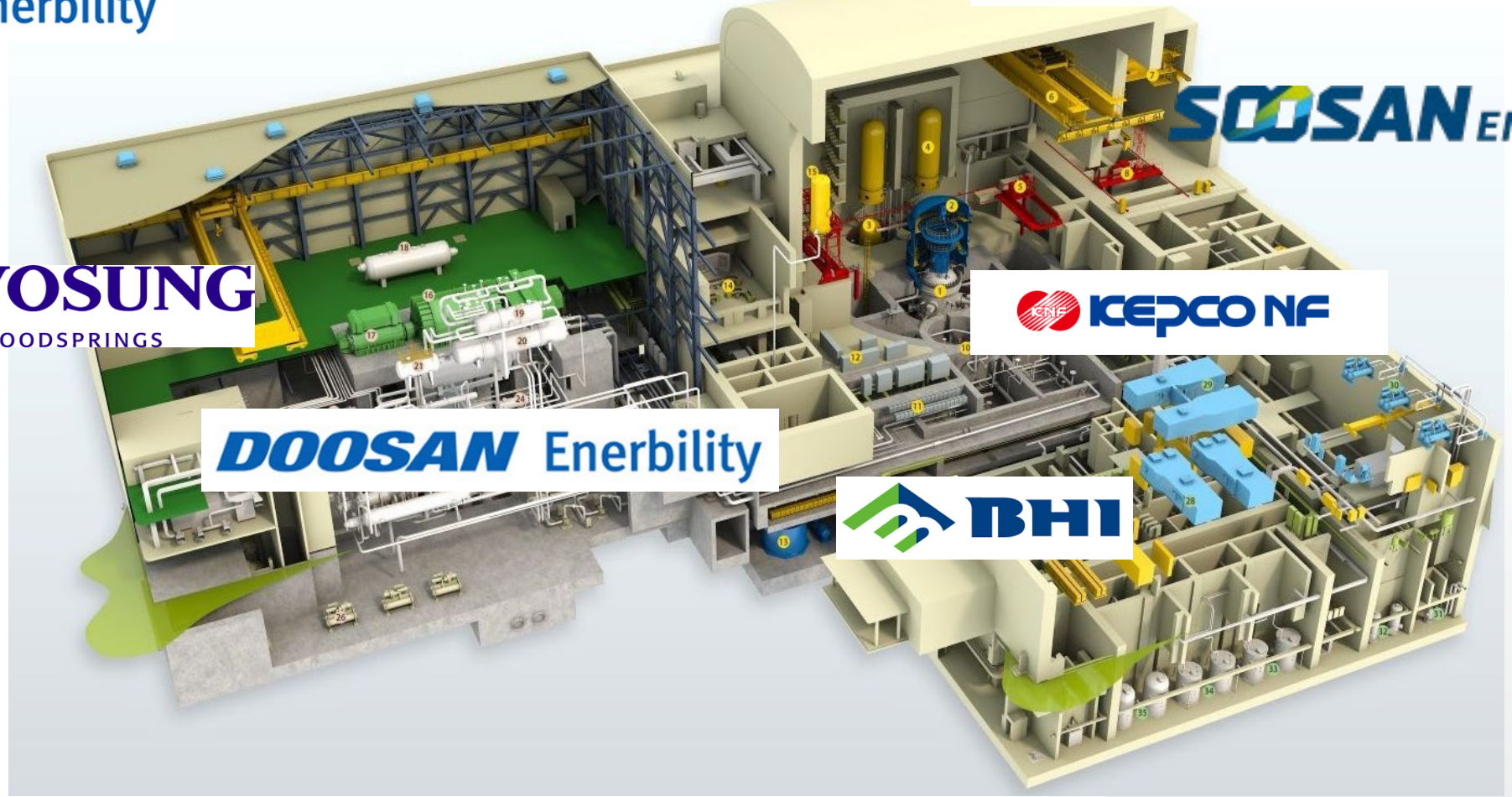
HYOSUNG GOODSPRINGS

SOOSAN ENS

KEPCO NF

DOOSAN Enerbility

BHI

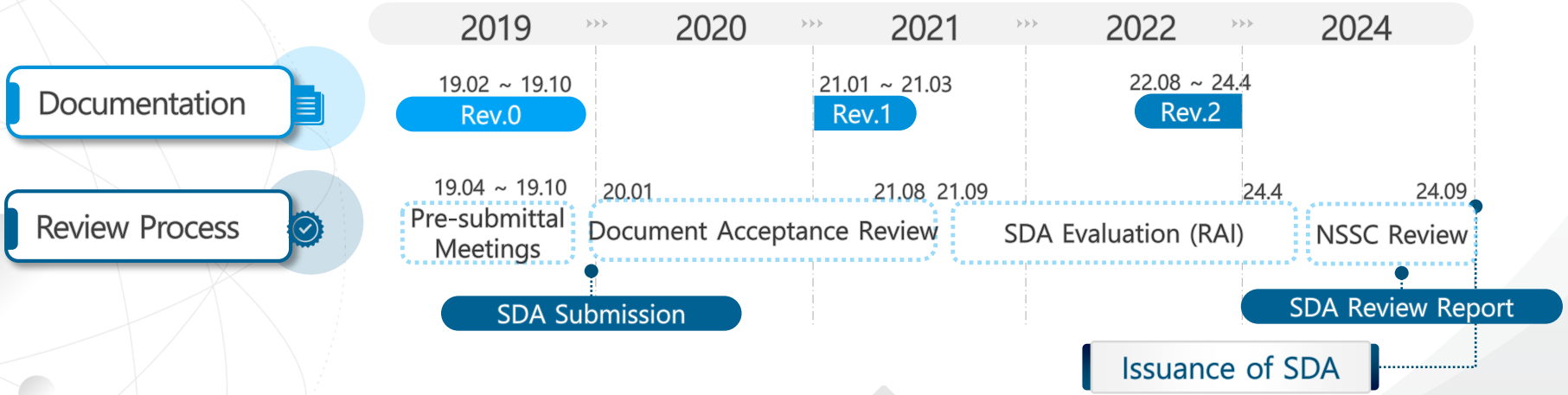


DOOSAN Enerbility

Current SMART R&D and Licensing

Korea Atomic Energy Research Institute

- (R&D) Development is complete, while further improvements for various applications are still on-going.
  - Little risk in terms of safety, operation, licensing, supply chain and fuel supply (technical maturity is comparable to other PWRs, such as VOYGR and BWRX-300)
  - Targeting different markets, design improvements are still on-going (e.g. SMART-C for SAGD process in oil sands)
- (Licensing) SMART SDA with passive safety systems under way
  - Standard Design Approval (with partially passive safety system) in 2012
  - Standard Design Approval (with uprated power and fully passive safety system) to be completed in year 2024



SMART100 Standard Design Approval

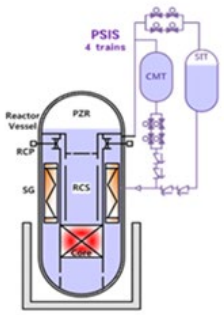
Korea Atomic Energy Research Institute

Dates	Activities
Dec. 2019	Submission of SMART100 SDA to NSSC
Aug. 2019	Confirmation of compliance review and technical review plan
Jan. 2023	RAIs (total 2,620/KAERI 1,441) * SMART SDA(2012): 2,200, APR1400 DC: 2,225
May.2023-July, 2023	Pre-reporting to NSSC Advisory Committee (SDA, design features)
Dec.2023-Jan.2024	Working Committee for Passive Safety System
April. 2024	Safety Evaluation Report

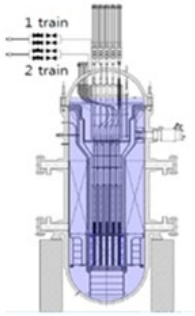
- MSLB Accident Dose Evaluation: stable safe condition, cold shutdown condition
- Condenser Decontamination Factor: dose evaluation based on release path of each accident

NSSC Working Committee

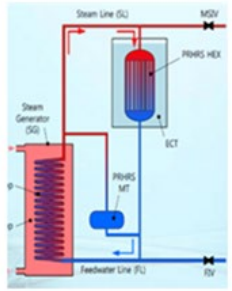
- Passive Safety System and Safety Analysis Code Validation
- Non-safety AC Power System



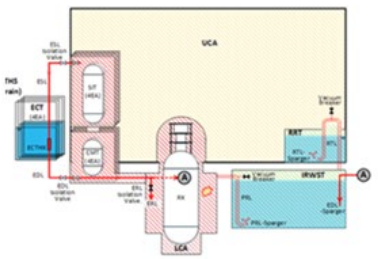
PSIS



ADS



PRHRS

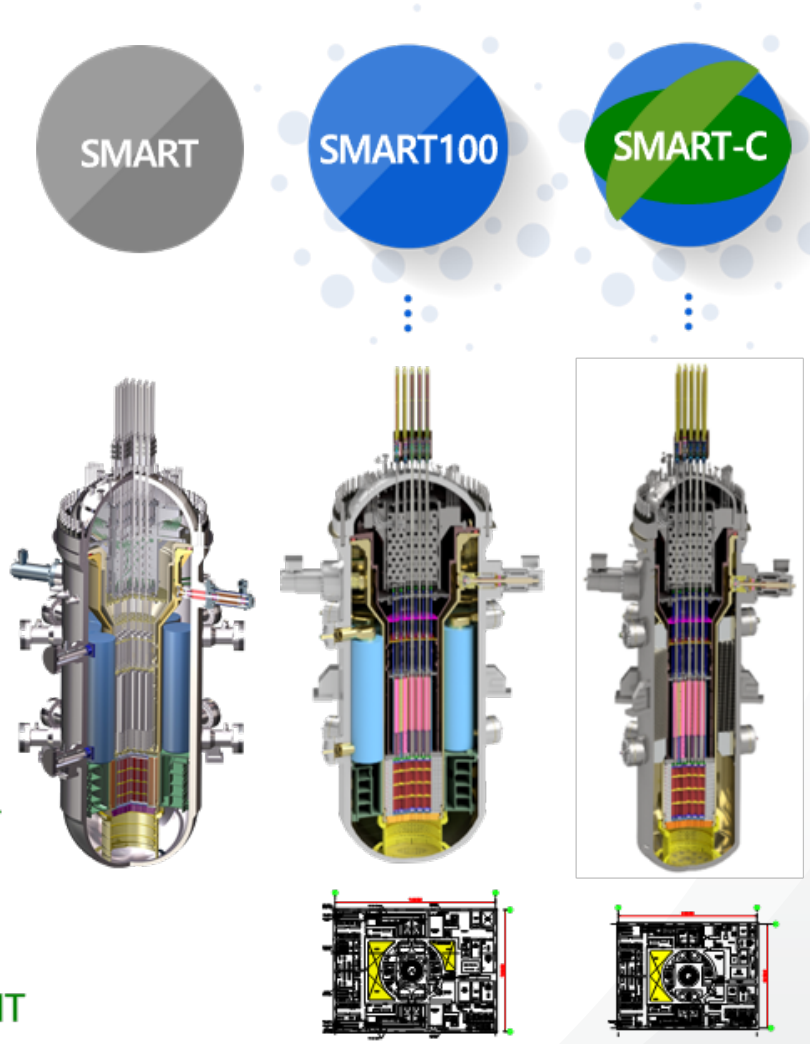


CPRSS

SMART-C (Compact, Customized, Canada)

Korea Atomic Energy Research Institute

	SMART	SMART100	SMART-C
Thermal Output	330 MWt	365 MWt	365 MWt
Electrical Output	100 MWe	110 MWe	110 MWe
Reactor Type	Integral PWR	Integral PWR	Integral PWR
RV Diameter	Appr. 6 m	Appr. 6 m	Appr. 4.5 m
Refueling Cycle	36 Months	30 Months	30 Months
SG Type	8 Helical OTSG	8 Helical OTSG	1 Helical OTSG
Safety System	Partially Passive	Fully Passive (4 Trains)	Fully Passive (2 Trains)
Emergency Power	EDG	Battery	Battery
Driving Forces	AC + Natural	DC + Natural	DC + Natural
Grace Time	30 Min.	72 Hours	72 Hours
Core Damage Frequency	< $1.0X10^{-6}$ / RY	< $1.0X10^{-7}$ / RY	< $1.0X10^{-7}$ / RY
Containment Building	Dome/Cylinder	Arch / Rectangular	Reduced[1] Arch / Rectangular



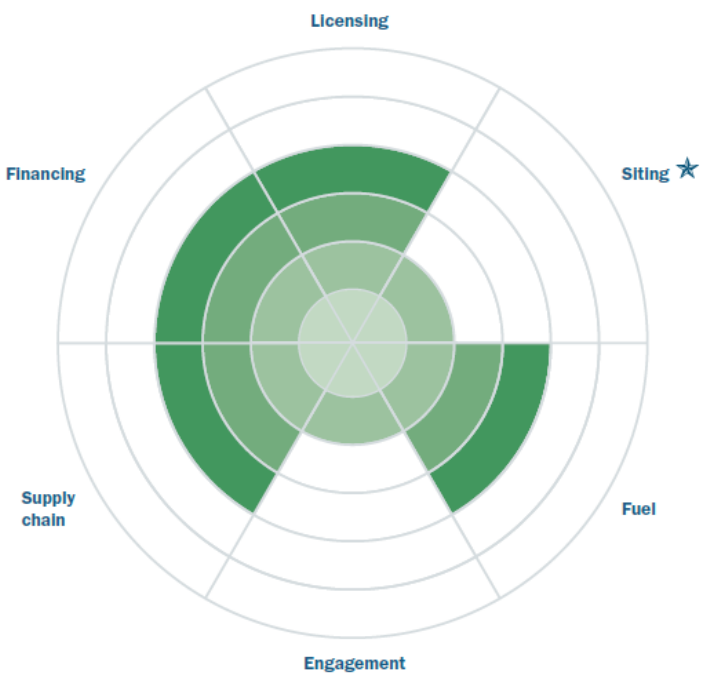
1) Due to Reduction in IRWST & HVAC and Integration of CMT & SIT

※ IRWST (In-Containment Refueling Water Storage Tank)

HVAC (Heating, Ventilating & Air Conditioning)

NEA SMR Dashboard - SMART

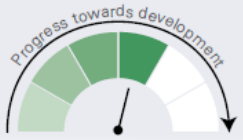
Korea Atomic Energy Research Institute



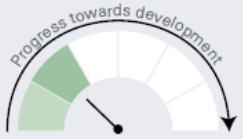
★ Active in multiple jurisdictions or countries.

Design organisation	Korea Atomic Energy Research Institute (KAERI)
Thermal power (MWth)	365
Outlet temperature (°C)	322
Spectrum (thermal/fast)	Thermal
Fuel type	UO_2 pellets
Fuel (LEU/HALEU/HEU)	LEU

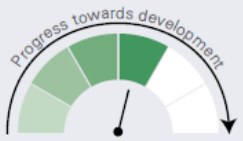
Licensing



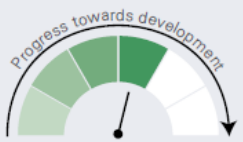
Siting ★



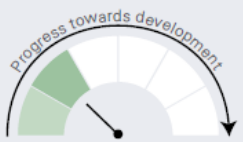
Financing



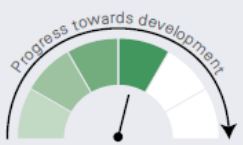
Supply chain



Engagement



Fuel



Licensing

The System-integrated Modular Advanced ReacTor (SMART) SMR developed by the Korea Atomic Energy Research Institute (KAERI) is a 365 MWth land-based pressurised light water reactor. KAERI received a Standard Design Approval for the SMART SMR from the Korean Nuclear Safety and Security Commission (NSSC) in 2012.

Siting ★

In 2015, KAERI signed a Memorandum of Understanding (MoU) with King Abdullah City for Atomic and Renewable Energy (K.A.CARE) in Saudi Arabia to assess the potential of siting multiple SMART SMRs at K.A.CARE. In 2023, KAERI signed a MoU with the Government of Alberta, Canada to collaborate on the possible deployment of SMART SMR technology in the Canadian province.

Financing

The Government of Korea, Korea Electric Power Corporation (KEPCO), and various others, including POSCO, Daewoo and STX Heavy Industries have contributed KRW 310 billion (USD 270.9 million) in financing the development of the SMART SMR plus an additional KRW 170 billion (USD 148.6 million) to support the Standard Design Approval process. In 2015, the South Korean Ministry of Science and ICT announced that KAERI was partnering with K.A.CARE on pre-project engineering (PPE) to construct SMART units in Saudi Arabia, supported by investments by the two partners totalling USD 130 million (USD 100 million from Saudi Arabia and USD 30 million from South Korea).

Supply chain

KAERI and K.A.CARE have established the joint venture "SMART EPC". Korea Hydro & Nuclear Power (KHNP) is leading this project, which intends to involve both Korean and Saudi enterprises. KHNP also signed an MoU with KEPCO Engineering & Construction (E&C) to jointly develop SMART units in Saudi Arabia. For the SMART reactor: KEPCO E&C and POSCO conducted the balance of plant design; KEPCO Nuclear Fuel designed the fuel; Hyosung Goodsprings developed the reactor coolant pumps and conducted reactor coolant pump performance testing; BHI designed the fuel handling system; Soosan ENS verified the reactor protection system and engineered the safety feature component control system; and Doosan Enerbility is providing design and engineering services for major components.

Engagement

The Korea Atomic Energy Cultural Foundation and KAERI signed an MoU to collaborate on enhancing public understanding and awareness of nuclear technology, including the SMART SMR, in 2009. KAERI and Government of Alberta signed an MoU to utilise SMRs, including SMART, for emissions reduction in Alberta.

Fuel

SMART utilises the same fuel as the current industry standard for similar design water-cooled reactor technologies. Given this, no barriers are expected in the fuel supply chain for this SMR.

Note: The exchange rate applied is the currency relevant average for 2021. In this case, the price of KRW 1 143.952 equals the price of USD 1.000.

SMRs and SAGD Process

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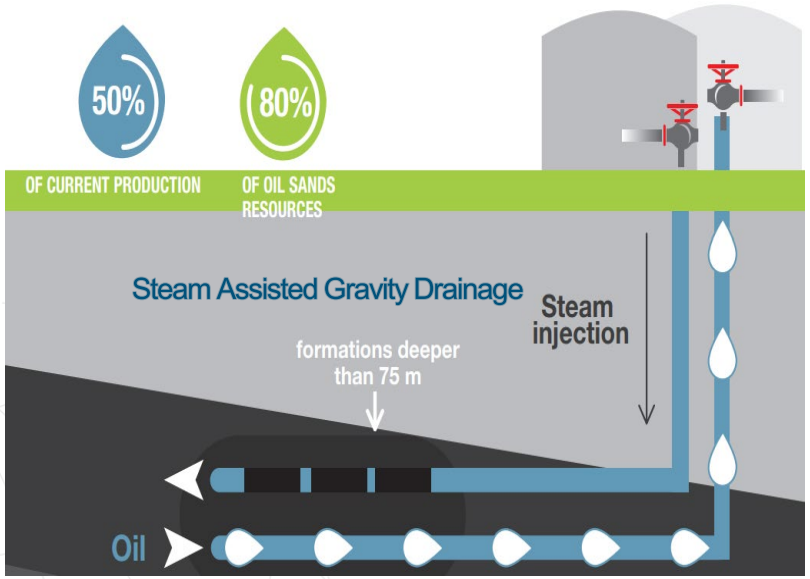
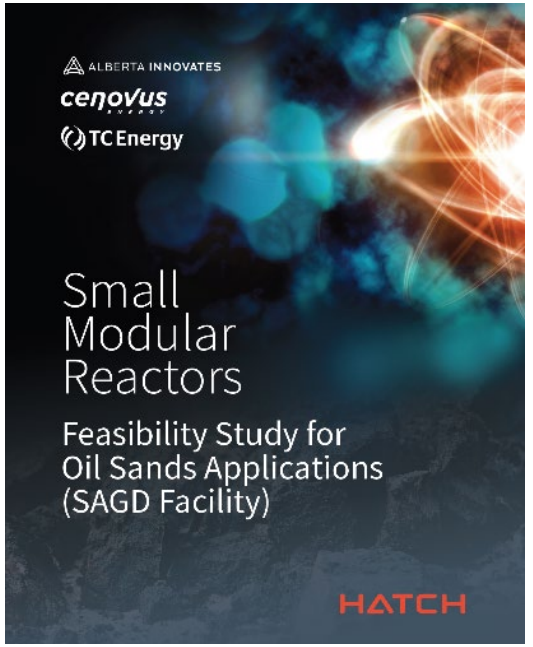
- Steam Assisted Gravity Drainage(SAGD) Process, widely adopted in oil sands, requires a huge amount of high-temperature and high-pressure steam.
  - Current carbon tax system, oil sands industries of Alberta need new carbon-free technology for SAGD.



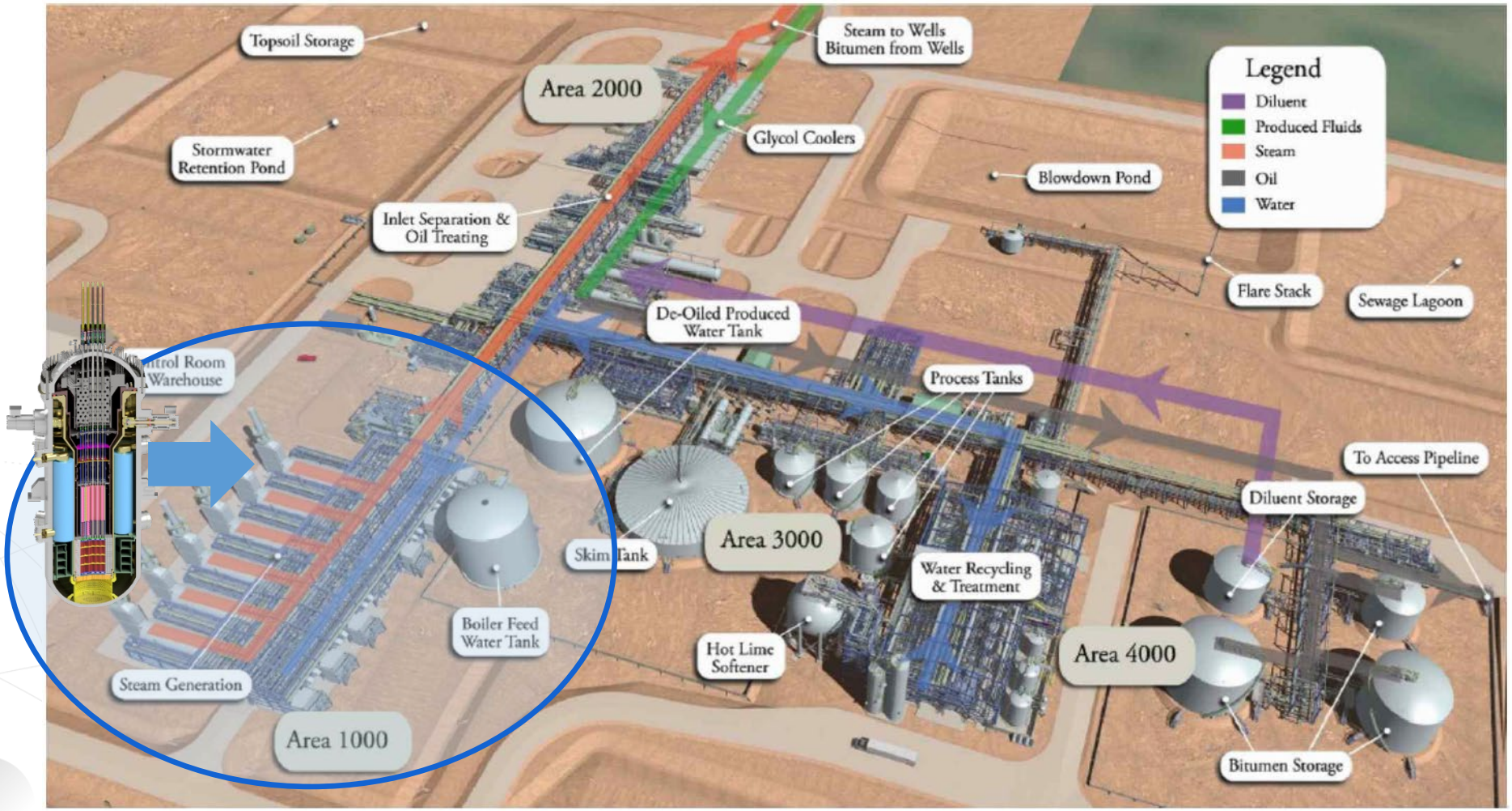
Source : Energy fact book 2021-2022, Canada



- A recent study finds SMRs feasible option for steam and electricity supply to oil sands
  - Low carbon intensity during operation and throughout lifecycle, extended operation periods without refueling, and so on

- Alberta considers SMRs as a low-carbon solution for its oil sands industries
  - Alberta's oil sands reserve is the country's biggest and the 4th largest in the world.
  - While the oil sands industry is eyeing carbon capture and storage (CCS) with bigger interest, the provincial government and industrial stakeholders is already moving towards SMRs as a longer-term alternative.

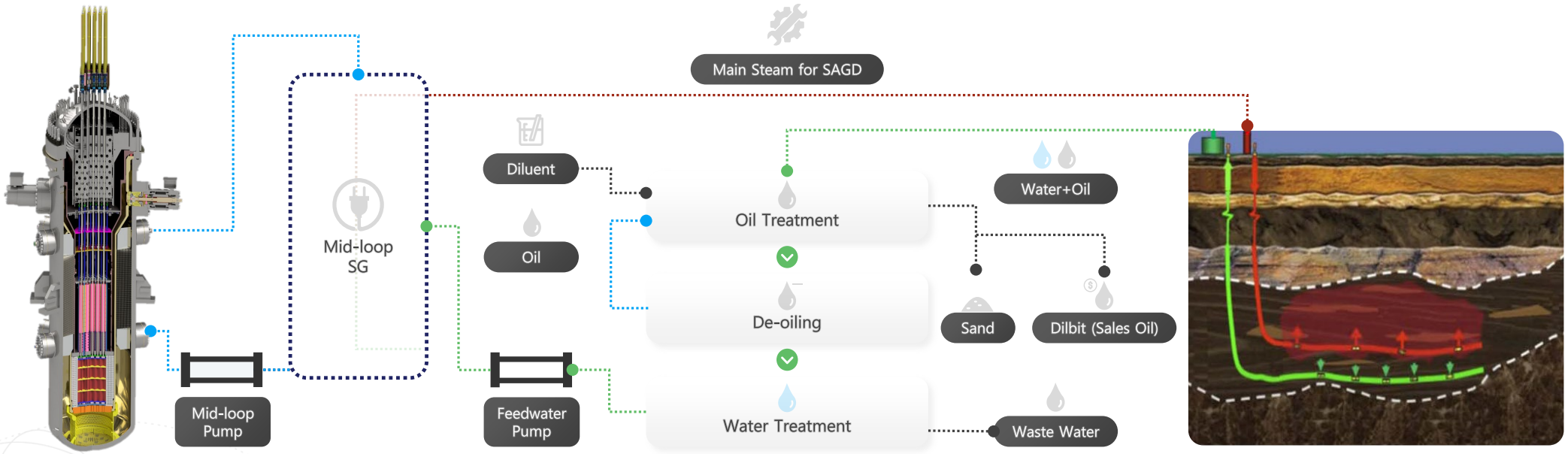
SAGD Facilities Example (Oil Sand)



Devon Jackfish project (2006 annual progress report)

Application of SMART in SAGD* Process

(*Steam Assistant Gravity Drainage)



Design Enhancement

- Slimmer reactor vessel, Optimized steam generator for steam supply

Two or Single Phase Mid-loop

- Heat transfer through mid-loop SG without fluid connection
- Separated water treatment
- Closed secondary system (additional barrier for radioactive materials)

Two-Track Strategy of SMART in Canada

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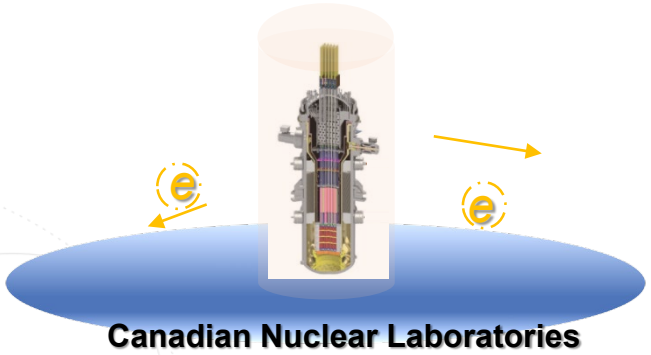
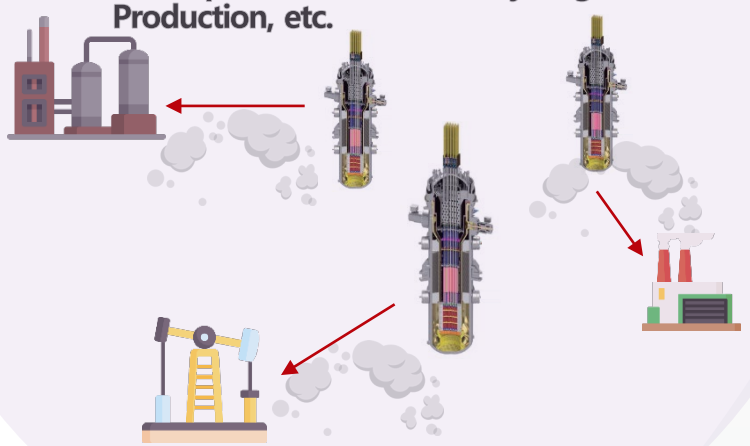
First of a Kind (FOAK)

- FOAK Plant in Ontario
  - Demonstration of the first SMART at CNL site (Chalk River, Ontario)
  - The established nuclear industry is the strength of Ontario as a FOAK site
  - The MOU between KAERI and AECL



Nth of a Kind (NOAK)

- NOAK Plants in Alberta
  - The MOU between KAERI and the Government of Alberta
  - Alberta is the major market for SMART
  - Marketing in Alberta in parallel with demonstration in Ontario
  - SAGD process, Chemicals, Hydrogen Production, etc.



> The KAERI-Hyundai Engineering partnership for SMART demonstration and further SMART applications

- Korean companies are invited to join the partnership as either investor or business partner

Summary and Key Takeaways

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- SMRs are being highlighted as carbon-zero energy sources that complement the intermittent nature of renewable energy in the global power supply sector.
- With their mature nuclear technologies and a robust domestic nuclear supply chain, SMART is capable of meeting the global energy demand in both the power and thermal energy sectors.
- SMART commercialization is ongoing with two track strategy for Canada deployment.

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SMART: Carbon Free Energy for Oil Sand Application

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THANK YOU