
Jordan Atomic Energy Commission (JAEC)

SMRs Technology Assessment

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Vienna, Austria

Jordan's Country Profile



- Total Area: 89,213 Km²
- Sea Port: Aqaba
- Coastline: 26 Km
- Population: 9.456 million (2016)*
60% (15- 64)
35% (below 15)
- Climate: Mediterranean & Arid Desert
- GDP: \$38.65 billion (2016)*
- Per Capita: \$4,087 (2016)*
- GDP Growth: 2.0% (2016)*
- GDP Growth: 2.6% ^f (2017-2019)*

* WORLD BANK

^f WORLD BANK - Forecasted

Jordan Atomic Energy Commission

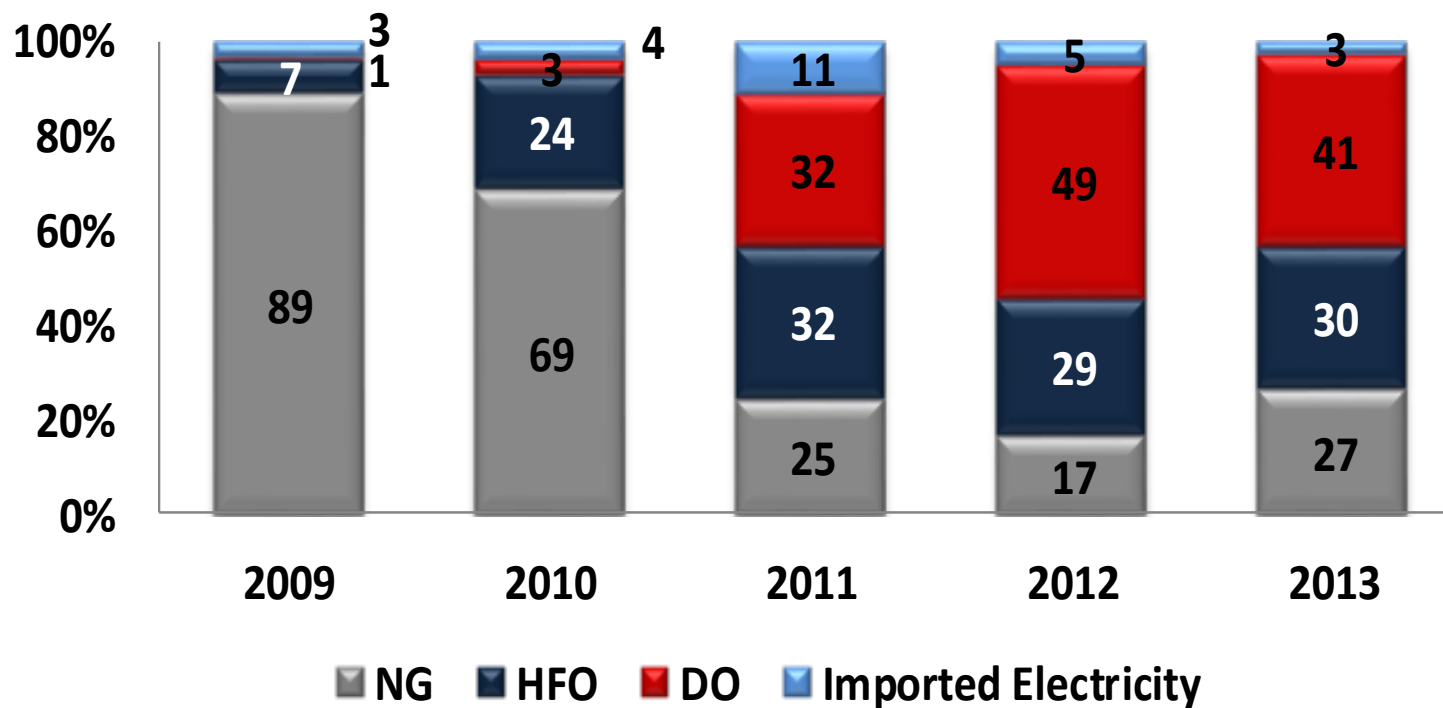


Jordan Energy Problem

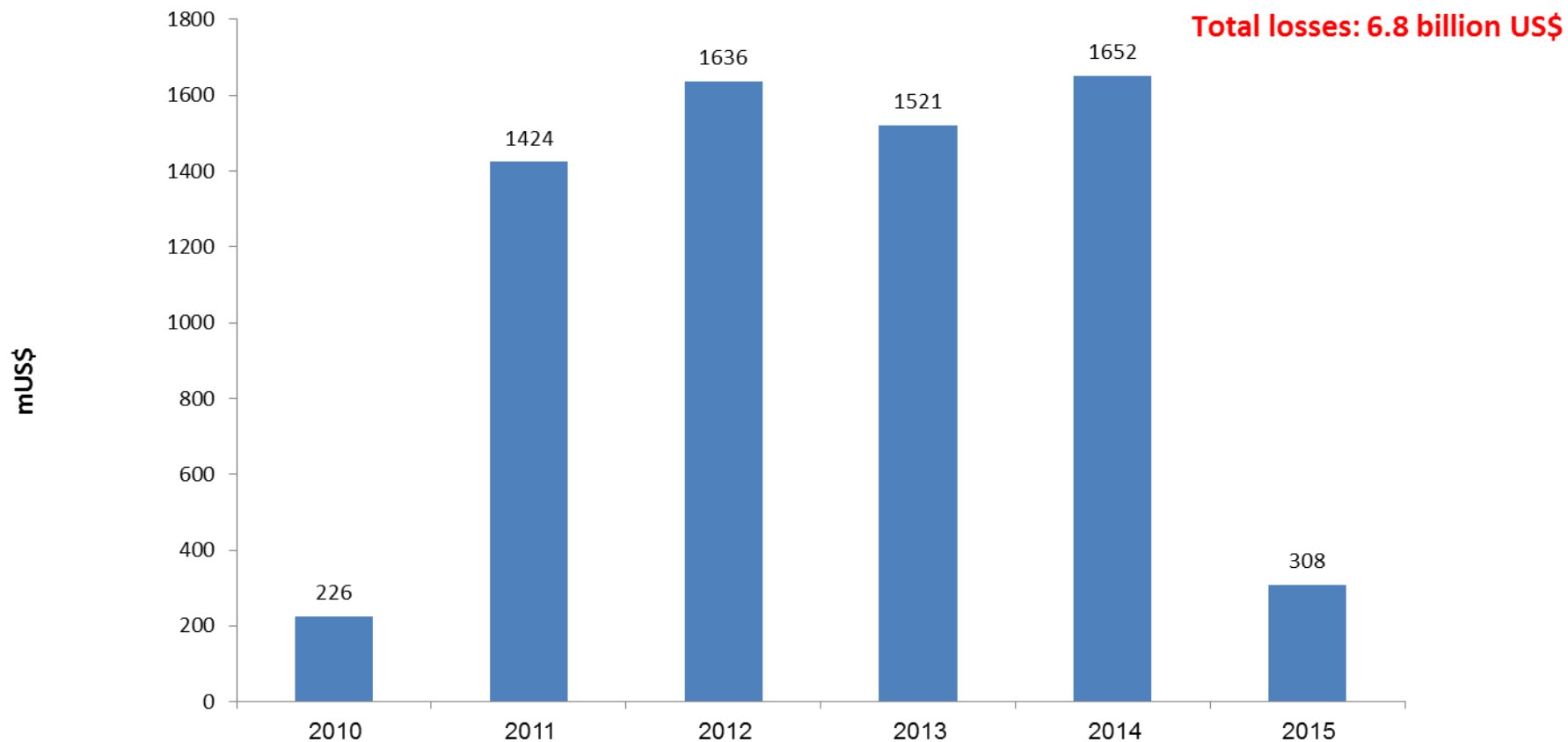
- ❑ Growing demand for energy
 - Primary energy
 - Electricity
 - Desalination
- ❑ Need for reliable and affordable base load power
- ❑ High dependency on imported fuels
 - High and volatile prices
 - Insecurity of supply
- ❑ Lack of indigenous conventional fuel options

Jordan's Power System

Electricity generation by fuel type:



Direct Losses due to Natural Gas Interruptions



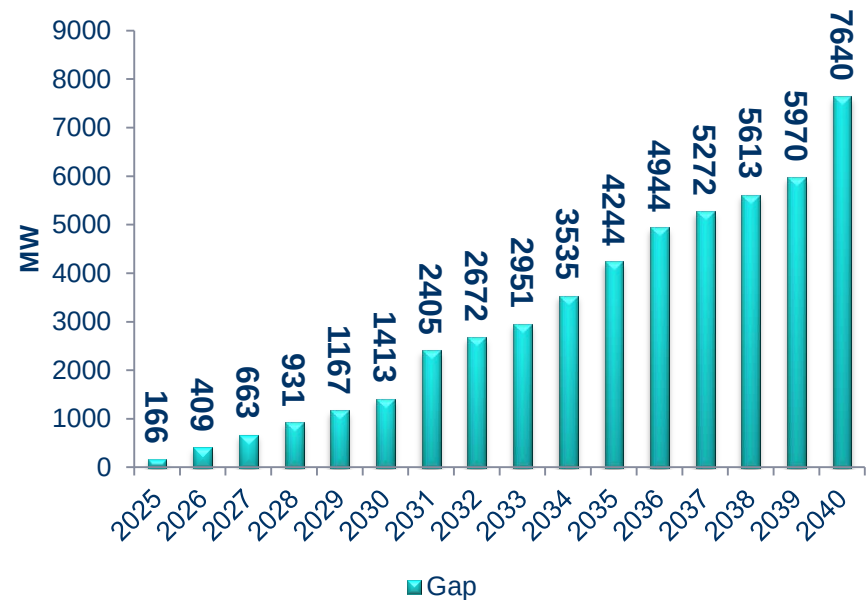
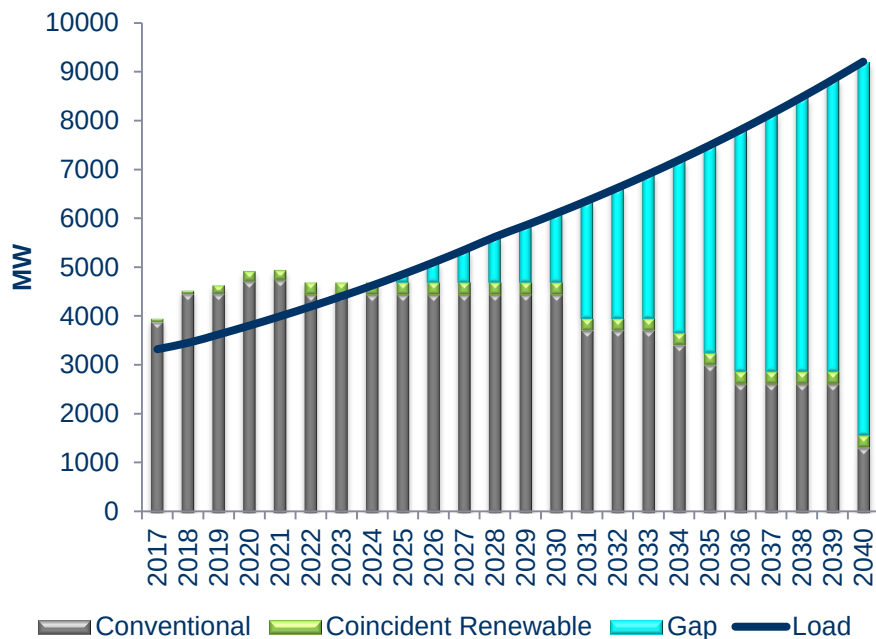
Jordan's Energy Options

- Available energy options are limited:
 - ❑ Natural Gas:
 - A short term option
 - Not a reliable energy source for medium and long terms
 - Cost is subject to market volatilities
 - ❑ Renewable Technologies:
 - Limited utilization
 - Cannot be a base load option
 - ❑ Oil Shale:
 - Only a limited medium-term option
 - Reserved for special uses
 - Not an environmentally friendly option
 - ❑ Nuclear Energy



Jordan Power Balance (2017-2040)

[2018]



Jordan Nuclear Strategy

Pursue two parallel tracks:

A. Small Modular Reactor

A. Large Nuclear Reactor

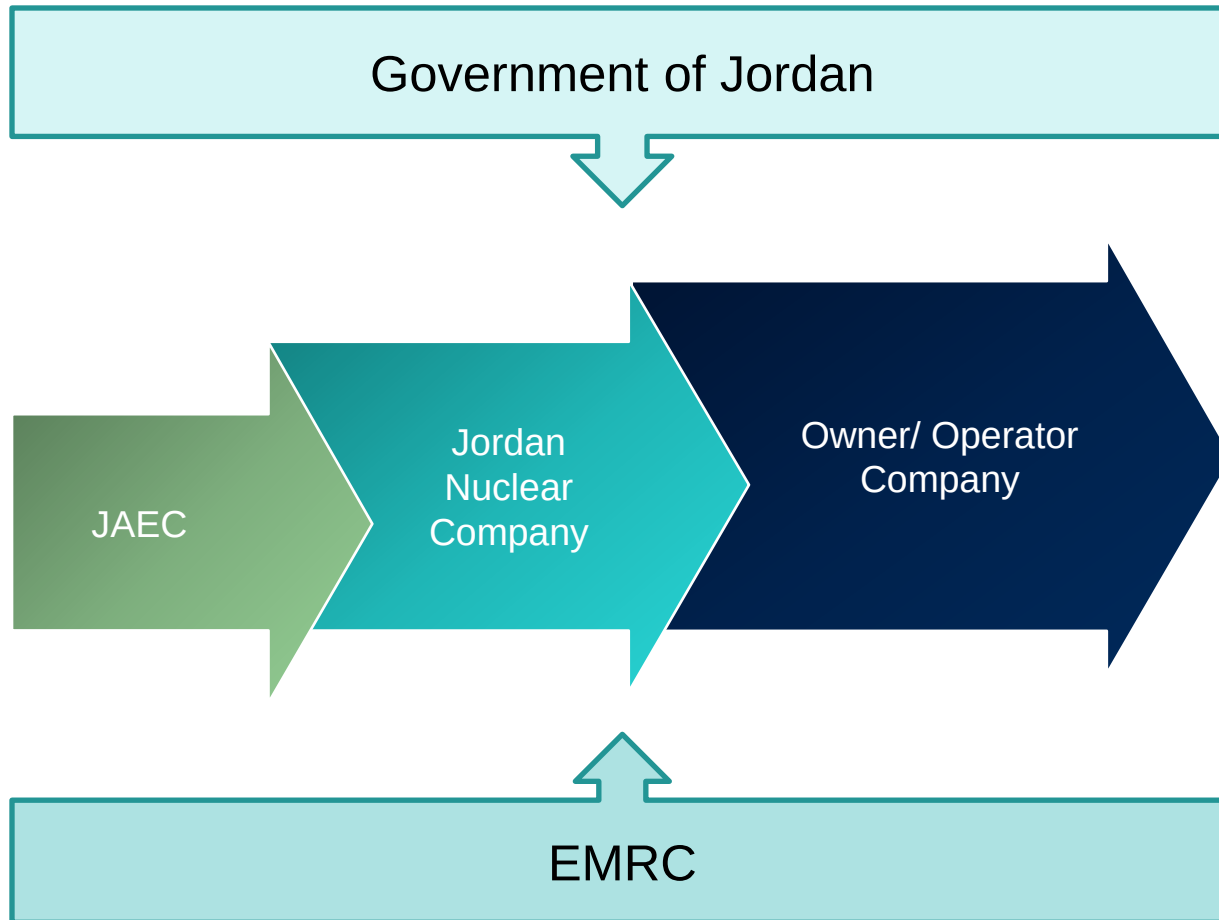
Financing Challenges for Jordan in Particular

- Scale of the investment relative to Jordan's GDP
- Limited Government financing available – unlike many other Arab countries
- Jordan's credit rating and IMF restrictions are hurdles for financing and ability to provide sovereign guarantees (which are likely to be required)
- First nuclear power plant – no track record of construction or operation
- Regional issues

Risk Mitigation

- **Schedule Risk** - Two project phases:
 - ❑ Early Works Phase - develop project definition and reduce project risk
 - ❑ Project realization phase for which financing/investment solutions will be investigated
- **Construction Risk** - EPC contract with major vendor
- **Political Risk** - Direct Government of Jordan investment in the project
- **Fuel Risk** - Secure fuel supply agreement
- **Market Risk** - Long term Power Purchase Agreement (PPA) & loan guarantees from GCC
- **Operating Risk** - Strong international operator
- **Nuclear Risk** - International treaties, decommissioning and spent nuclear fuel policy

Project Implementation



NPP Sites Comparison

Discipline		Geosciences			Cooling		EHIH	Flooding	Borders	Environment
Criteria/Attributes		OBE (g)	SSE (g)	Land Topography	Pipe Length (km)	Pumping Power (Mwe)	Stationary and Mobile Sources		Distance to Border (km)	Sensitive Habitat/Species
Select ed Sites	Aqaba	0.18	0.3-0.50	variable	9.5-30	>10			10-20	
	Magdal	0.10	0.28	Undulating	10.5	≤5			< 32	
	Amra	0.04	0.20	Flat	72	5-10			> 32	

Amra Region

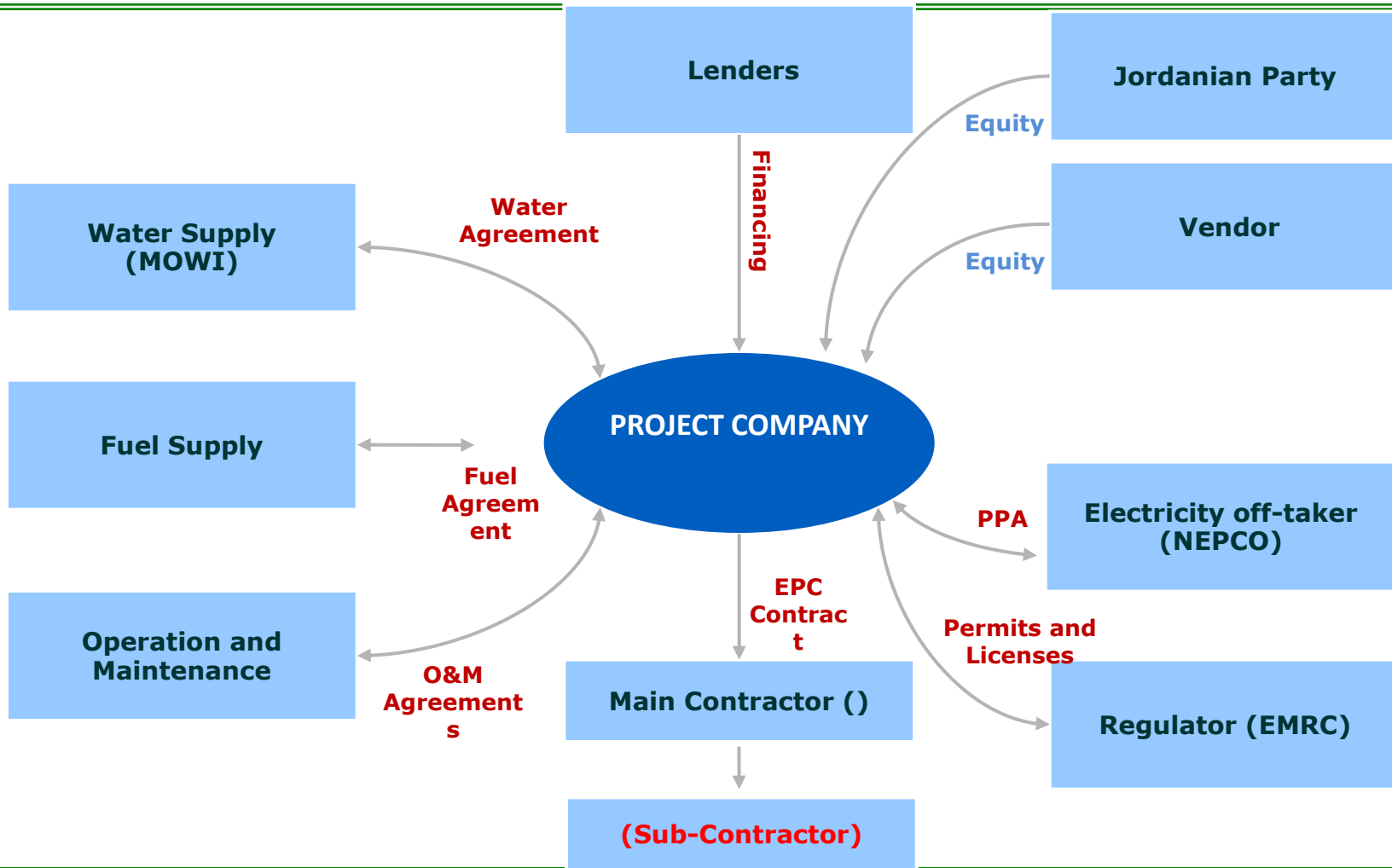


Palo Verde Inland NPP Site – Arizona, USA

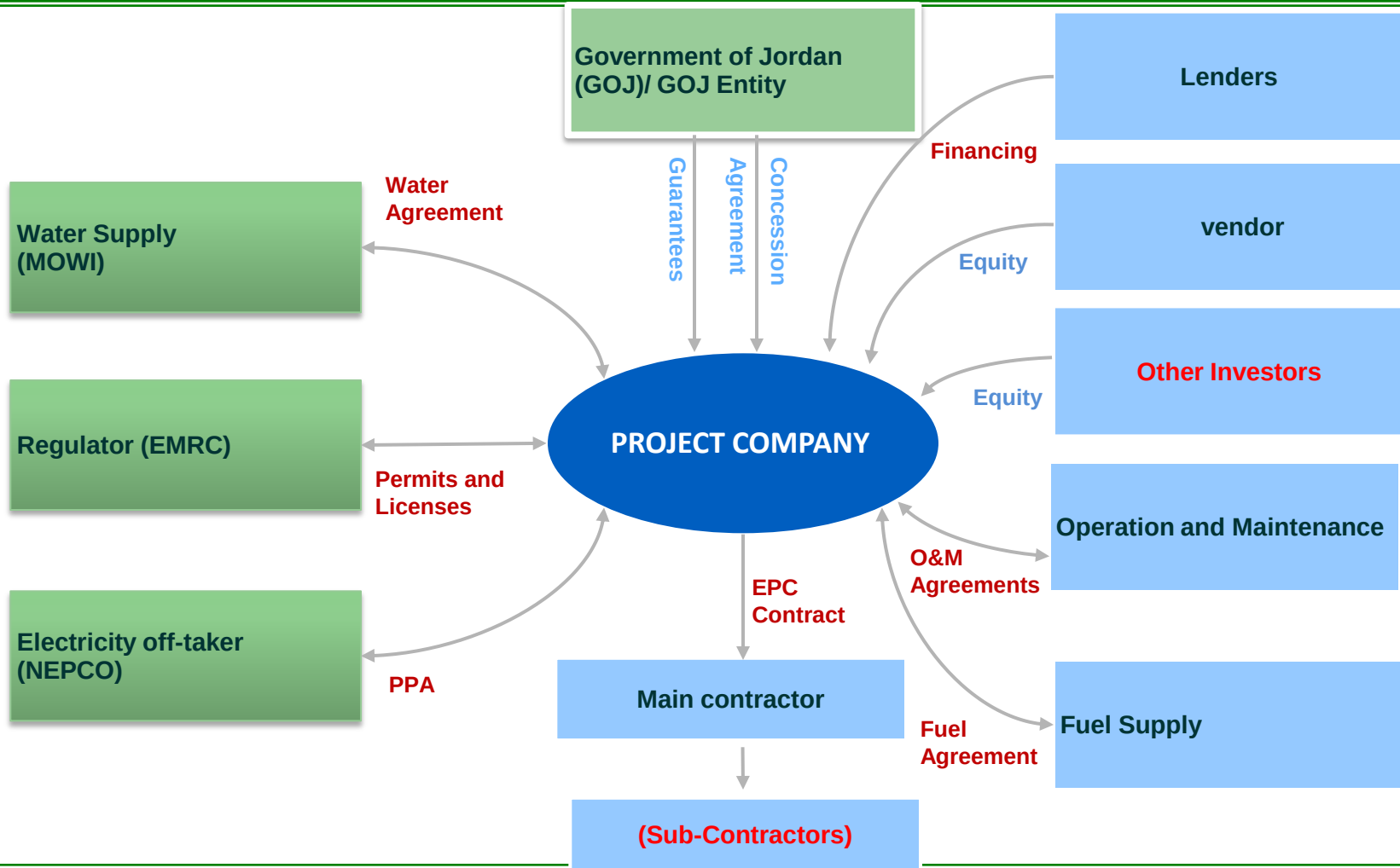
Example of inland NPP using wastewater for cooling



Generic Project Structure



BOT / BOOT Project Structure



 Agreements With the Government of Jordan (and affiliates)

Jordan Atomic Energy Commission



Nuclear-Renewable (N-R) Synergy Pathway in Jordan

1. Jordan is a small country with a regulated market, single off-taker, anticipated growth in both electricity and water needs that have to be addressed.
2. Jordan will require a multitude of generation and desalination solutions, both short and long term, and any synergies that will minimize any disturbances or instabilities in the system are always a plus (as long as they are sustainable, and especially if they are also cost effective).
3. Short term, mutually exclusive plans that do not address problems in a long term strategic manner are destined to meet many technical and financial, obstacles, and not to mention the wrath of decision makers.

N-R Synergy Pathway in Jordan

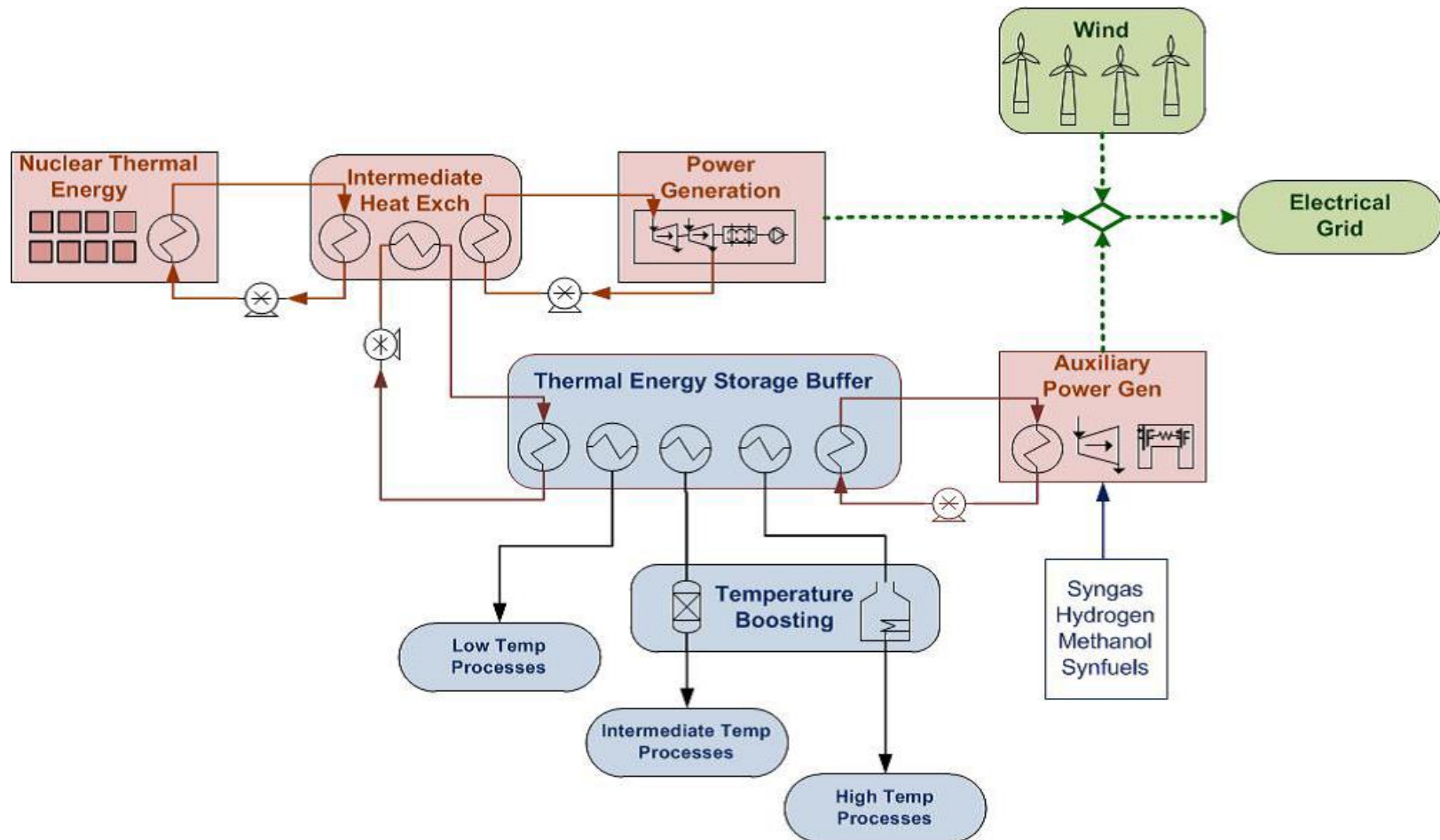
4. Current technologies might suffice in creating the allure and basic foundation for this synergy, but for a small market like Jordan, inter-regional N-R Synergies might work with evolving technologies upon their successful deployment. These will include SMRs, Smart Grids, etc. These might be an integral part of the solution.
5. To solve Jordan's problem, centralized large generation or desalination/treatment systems might not be as optimal as smaller and strategically located ones that work within a N-R System.
6. The issue facing Jordan, is that any solution that needs to be deployed has to make sense financially and carry as little risk as possible.

N-R Synergy Small Grids - Optimum

1. Deployment of nuclear power with load following capability.
2. Deployment of wind and solar projects.
3. Upgrade of the grid system (Transmission, Metering, Management, etc.)
4. Make available reserve generation/natural gas turbine suitable for the stability of the grid.
5. Use excess generation for desalination of the water as water and energy utilization are problems that tend to go hand in hand.



Jordan should explore Hybrid System



SMR Direction

JAEC has been considering SMRs and their potential in Jordan in various capacities since 2011.

The advantages of SMRs are many for Jordan but it has always been the maturity of the technologies for deployment, and constructability at a competitive price that were the hindering factors.

In deciding to proceed forth today, JAEC took into consideration many factors that are bespoke to SMR.

Why SMRs? Technical

- Because of their small size and modularity, SMRs could almost be completely built in a controlled factory setting and installed module by module. This improves the level of construction quality and efficiency, thus mitigating some of the construction risks typically associated with large reactors.
- Their small size and passive safety features lend them to countries with smaller electricity grids and less experience with nuclear power.
- Potential for sub-grade (underground) location of the reactor unit providing more protection from natural (e.g. seismic earthquakes or tsunami according to the location) or man-made (e.g. aircraft impact) hazards.
- The compact architecture enables modularity of fabrication (in-factory), which facilitates implementation of higher quality standards.
- The modular design and small size support having multiple units on the same site.
- Ability to remove reactor module or in-situ decommissioning at the end of the lifetime.
- Lower requirement for access to cooling water – therefore suitable for remote regions and for specific applications such as mining or desalination.

Why SMRs? Economics

- Achieving 'economies of scale' for a specific SMR design will reduce costs further. Most SMRs are designed with series production in mind.
- Size, construction time, and efficiency along with passive safety systems (requiring less redundancy) lead to smaller investment requirement for SMRs compared to that of large nuclear. In turn, procuring the funding and financing for these projects should in turn be easier or a less complex process.
- From commitment of Equity to Commissioning, SMRs require a shorter time to construct. This is a more attractive proposal for investors.

Applications of Interest for SMRs (Jordan)

- Replace aging fossil plants.
- Can be located close to population areas.
- In-land away from water sources.
- Mid to high seismicity
- Cogeneration of heat & electricity.
- Water and Air Cooled Condensers
- Island Mode and Load following Capabilities
- Preferably underground design with all safety systems underground.



Jordan Requirements

- ❑ GIII+ or better technology
- ❑ Demonstrated safety level with passive safety features
- ❑ Grid compatibility
- ❑ To be deployable in 2025-30 time frame as Nth of a kind
- ❑ Plus for ability for co-generation, process heat, etc.
- ❑ Reduced water make-up per MWe
- ❑ Limited EPZ to site boundary
- ❑ Possibility of dry cooling
- ❑ Design to withstand 0.3 g or greater
- ❑ Enhanced protection against external hazards
- ❑ LCOE competitive to average generation price
- ❑ Transportability (for in-land sites)

Jordan Technical Requirements

SMR design shall ensure the fundamental safety functions:

- Control of the reactivity
- Heat removal
- Confinement / No radioactive releases

The SMR design shall be such that its sensitivity to Postulated Initiating Events is minimized with no severe accidents.

To ensure that the overall safety concept of defense in depth is maintained in all circumstances.

Jordan Technical Requirements (2)

Appropriate measures against the effects of single failure or common cause failures shall be taken as far as practicable in SMR plant design:

- Redundancy
- Diversity
- Independence (through functional isolation or physical separation)

The SMR designs shall incorporate the lessons learnt from Fukushima accident

A modern digital I&C technology (no common cause failure between the different I&C for each module).

Jordan Technical Requirements (3)

Safety goals

- Core damage frequency (CDF) and large early release frequency (LERF) of SMR shall be lower than the best GIII+ large NPP
- The grace period of SMR plant shall be higher than the best GIII+ large NPP

Fuel supply security

- A nuclear fuel procurement on the competitive open market;
- Long term refueling cycle (greater than 3 years).

Jordan Technical Requirements (4)

Aircraft impact resistance

- The design shall meet Jordan's requirement for the plant to be designed to ensure the safety of the plant in the event of a large commercial airplane crash.

Proven Design and Licensability

Preferred internationally certified SMR design for commercial deployment and generic design approval.

Site Considerations

Seismicity

- The design shall withstand high seismicity level, to 0.3-0.5

Cooling water

- The design shall minimize usage of water and has the option of dry cooling

Meteorology and Environment

- The design shall minimize the influence on the environment and ecology, example; minimizing the construction work and site preparation activities

Population

- The design shall have small EPZ (limited to site boundary)

External Hazards

- The design shall withstand individual and combination of external hazards associated with the site. (Underground option could be a plus).

Technology Assessment (1)

- ❑ Preliminary Assessment of different SMR technologies is being conducted and in two main phases.
- ❑ The first phase will be the generic assessment phase with the aim of down-selecting the most advanced and competitive technologies that are deployable and viable in Jordan.
- ❑ Suitable technologies that are potentially viable for Jordan will be assessed in this phase.

Technology Assessment (2)

- ❑ To be able to make a proper assessment and therefore, down-selection, the first phase will entail exchange of information with the Technology Providers.
- ❑ This information will be matched to a initial assessment criteria matrix.
- ❑ The next phase will be the preparation of a Feasibility Studies (FS) based on the short-listed technologies or issuance of BIS.
- ❑ As per the results of the Assessment or FSs, a Justification of Investment analysis will be made to proceed forward with the selected SMR.

Methodology (1)

- To achieve the purpose of the tasks at hand, the works will be following the following steps:
 1. Generic technology data collection **(completed)**
 2. General assumptions and criteria **(completed)**
 3. Viable technology selection for Jordan **(completed)**
 4. Detailed vendor sourced data collection **(in progress)**
 5. Assessment of different SMR technologies **(in progress)**
 6. Information verification with Technology Providers **(in progress)**

Methodology (2)

7. Technical/Economic assessment for technologies
8. Selection of shortlisted technologies
9. Issuance of BIS or commencing on detailed technical/economic analysis for the purpose of FS preparation
10. Preparation of report containing analysis and results for the Justification of Investment.

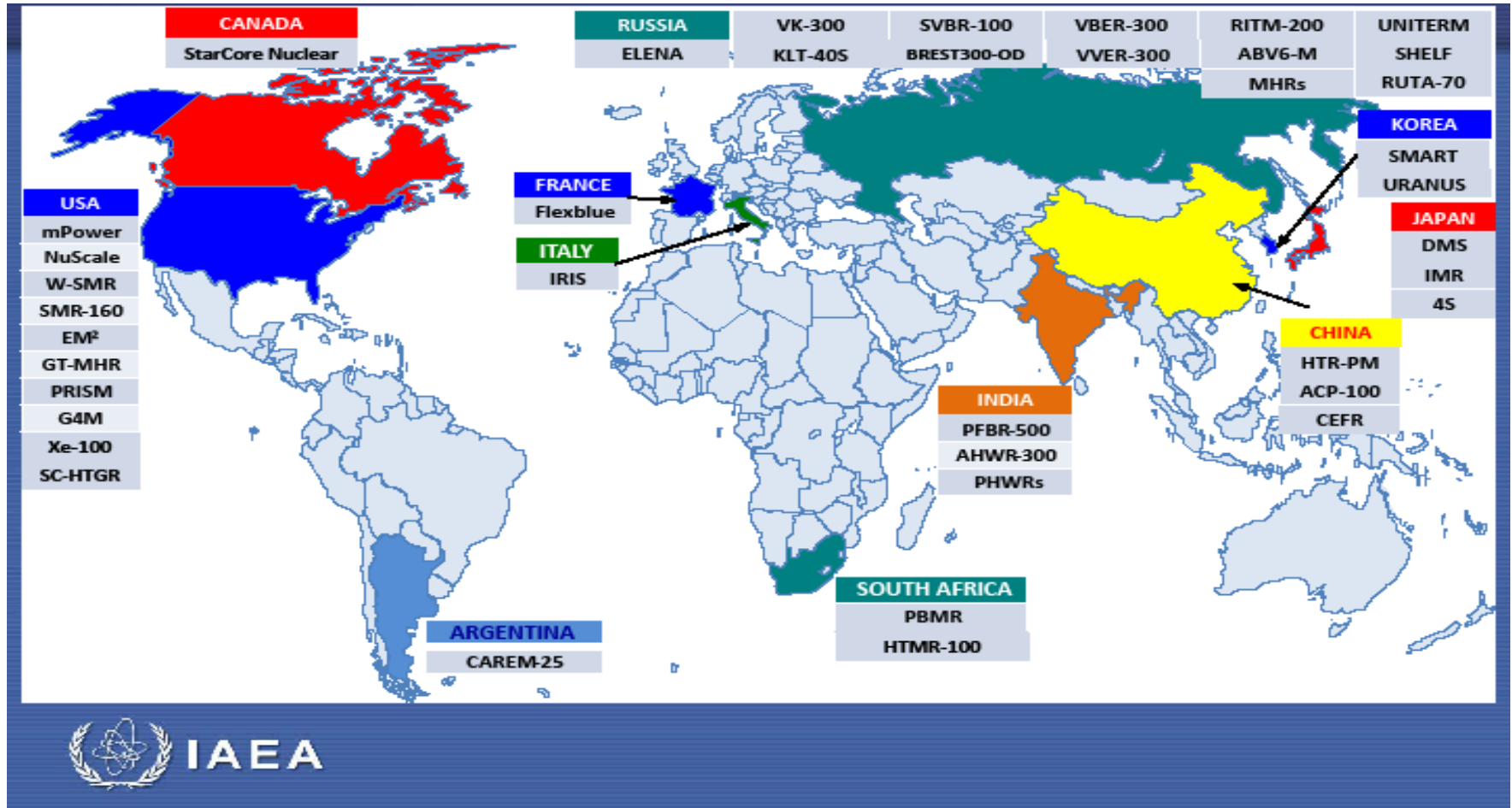
Data Collection (1)

There are currently many SMRs being developed worldwide and in various stages (some are still on drawing board while few are under construction):

JAEC's interest is the SMR's that are either:

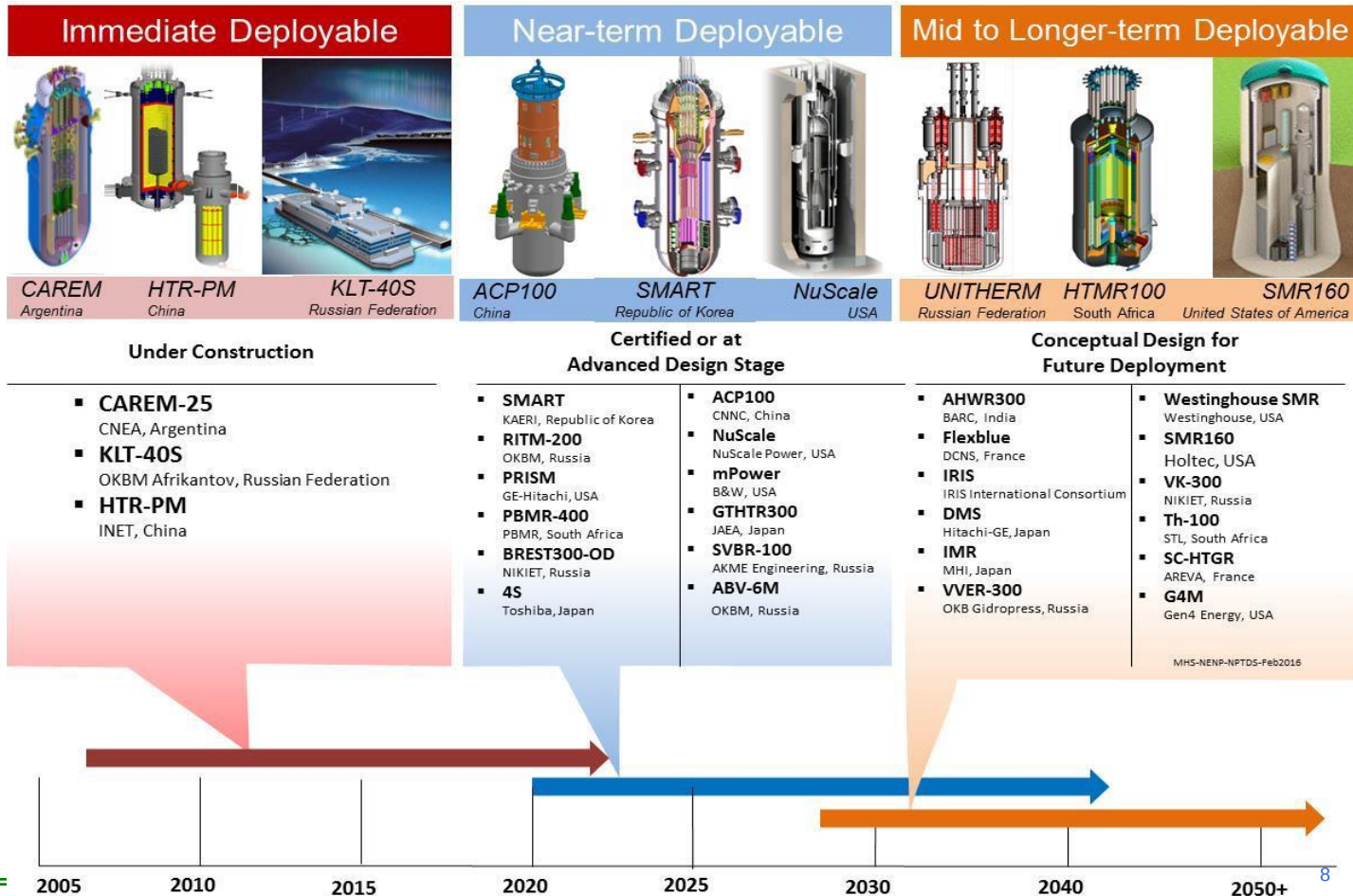
- **immediate deployment** and
 - **Near term deployment**
- In the assessment, we will only consider technologies that fall under **immediate and near term deployment** (deployment by 2025-2030)
- The selection of the technologies, data collected, and discussions with vendors will be focusing on the SMRs which will be deployed by 2025-2030.

Map of Global SMR Technology Development



SMRs status worldwide

SMRs Estimated Timeline of Deployment



Data Collection (2)

- In effect, there are a multitude of reactors (around 15), matching our criteria some of which are at an advanced licensing stage. Included in the list are Light Water Reactors (LWR), Gas Cooled Reactors (GCR) and Fast Reactors (FR).

Immediate (before 2020)			Near term (before 2030)		
CAREM	CNEA, Argentina	iPWR,	NuScale	NuScale, USA	iPWR
KLT-40s	OKBM, Russia	FNPP	ACP100	CNNC, China	iPWR
HTR-PM	INET, China	Gas Reactor	SMART	KAERI, Korea	iPWR
			UK SMR	Rolls Royce UK	Compact PWR
			Xe-100	Xe-Energy	HTR
			RITM	OKBM	iPWR

General Assumptions (1)

- In the initial phase of assessment (prior to direct discussions with vendors) the goal was to limit the technologies to those that are most viable and fit our criteria and requirements.
- General assumption:
 - Deployment time: by 2025-2030 operational in Jordan.
 - Mature technology and vendor: only LWRs and HTGRs
 - Size: micro reactors are excluded, less than 50 MWe.
 - Only land based reactors: FNPP and submerged are excluded

Excluded SMRS

❑ The following reactors types were excluded:

➤ **Floating Nuclear Power Plants (FNPP) and Submarine SMRS**

- High cost (cost of NPP + cost of Submarine or barge)
- Security (only Aqaba a coast, very close to borders)
- Environment (close to people, industrial port, tourism, aqua life)

➤ **Micro reactors**

- All micro reactors like 5 or 10 MWe were excluded, these have special use and not feasible for electricity generation.

➤ **Novel technologies, such as:**

- LMRs
 - LMRs do not have much operating experience
 - Difficult to license in Jordan

Selected List

SMR	Country of origin/Vendor	Type	MoU
NuScale	USA/NuScale Power	iPWR	in
UK-SMR	UK/Rolls Royce	Compact PWR	Y
ACP100	China/CNNC	iPWR	Y
SMART	South Korea/ KAERI	iPWR	Y
RITM	Russia/ Afrikantov OKBM	Compact PWR	Y
HTR-PM	China/ CNEC	HTR	Y
XE-100	USA/XE- Energy	HTR	Y

Methodology and Criteria

- Currently there are 7 potential SMRs
- Next step is to have a 3 shortlisted SMRs (based on matrix evaluation criteria)
- Subsequently down select to one based on matrix criteria, key factors and economic assessment

Technology Evaluation Approach

- The differences between technologies and their impact on Jordan will be assessed through rigorous evaluation methodologies designed to bring full visibility and transparency:
 - ❑ Assessment of the vendor technology towards Key Factors (important for Jordan)
 - ❑ Evaluation Matrix
 - ❑ Best-in-Class for each evaluation criteria
 - ❑ Price under competitive environment

Key Factor Evaluation

Key Factor	1	2	3
General Safety Design Criteria			
Exclusion Zone			
Seismic			
Aircraft Crash			
Fukushima Dai-ichi Lessons			
Digital I&C Systems			
Licensing & Design Certification			
Fuel Supply and Security			
Back End of the Fuel Cycle			
Radioactive Waste Management			
Non-proliferation			
Thermal Efficiency			
Operability & Maintainability (including availability)			
Cooling Water Design			
Vendor Long Term Sustainability			
Total			



Matrix Assessment Criteria

- ☐ General (meeting current international licenseability requirements, areas of risks, vendor and owner responsibilities, etc.)
- ☐ Design (design lifetime, efficiency, design adaptation to Jordan's environment and site characteristics, cooling, foot print and plant layout, etc)
- ☐ Operation and maintenance (refueling outages, regular maintenance, staffing for operation and maintenance, etc.)
- ☐ Construction (Construction period, approach of modular construction and assembly, manufacturing capabilities, transportation of heavy equipment, etc.)
- ☐ Reactor performance (Availability, efficiency, load follow capability, etc.)
- ☐ Nuclear Safety (Defense in depth, operational safety, internal and external hazards, passive safety features, grace period, CDF, LERF, etc.)
- ☐ Fuel cycle, waste management and non-proliferation (Nuclear Fuel design and safety, SNF pool design and capacity, fuel handling system to deal with failed fuel elements, experience in fuel supply, experience in waste management and reduction of waste, etc)
- ☐ Licensing and operating experience (proven design, compliance with IAEA safety standards, reference design, etc.)
- ☐ Vendor long term commitment (vendor readiness, localization, etc.)
- ☐ Economic (Capex, O&M, LCOE)

Matrix Evaluation Criteria

	CATEGORY GROUP	Weight 1	Weight 2
	General	10	5
	Design	7	7
	Operations and Maintenance	10	15
	Construction	10	10
	Reactor Performance	7	10
	Safety of the Reactor Design	20	15
	Fuel Cycle, Waste Management and Non Proliferation	11	15
	International Licensing and Operating Experience	15	13
	Vendor Long Term Commitment	10	10
	Technical	80	70
	Economic	20	30

Best-in-Class

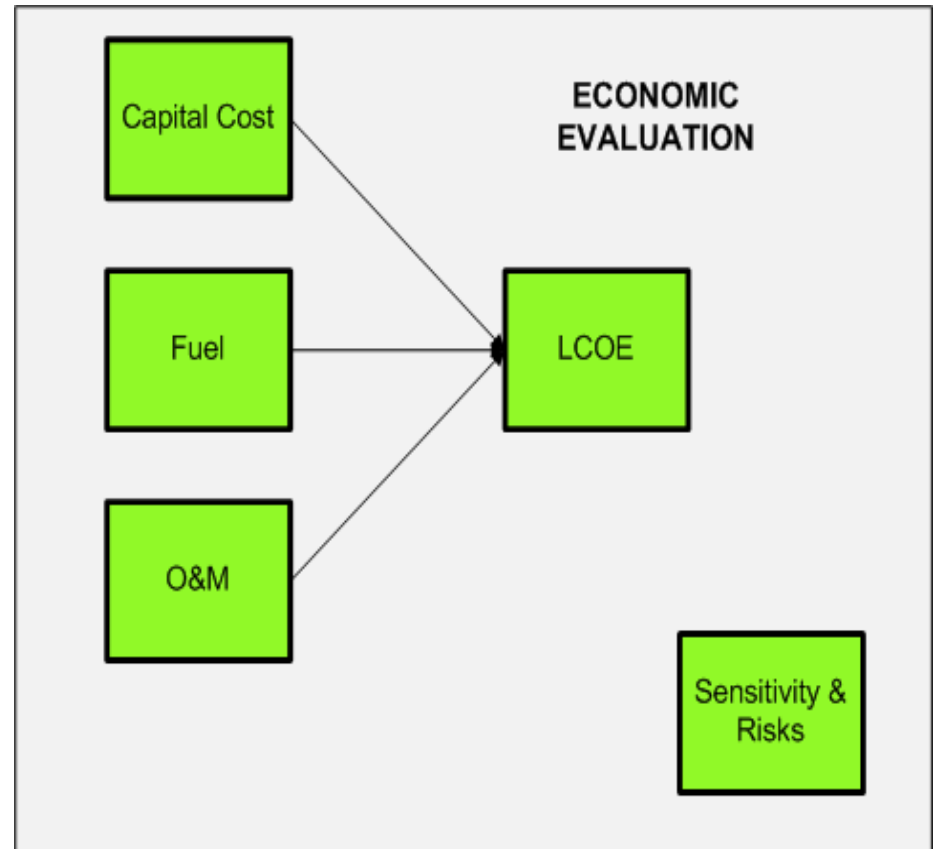
- An alternative way to evaluate the plant technology, and it is intended to complement the evaluation matrix using a simple rule:
 - Best technology for each evaluation criteria is given a gold medal, and the second a silver medal and so on



Economic Evaluation Approach

Economic Evaluation process:

- ❑ Detailed review of Capital Cost and adjustments.
- ❑ Adjusted Capital Cost input to LCOE.
- ❑ Technical Evaluation input for Fuel and O&M prepared for LCOE analysis.
- ❑ Sensitivity and Risks.



Summary Decision Table

Methodology	Unit	1	2	3
Key Factor Evaluation	% of total score			
Evaluation Matrix	%			
Best-in-Class	Number of gold medals out of 88			
Adjusted Price (\$/KWe) LCOE				

Thank You!

