



SMALL MODULAR REACTORS

MARKET POTENTIAL FOR NEAR TERM DEPLOYMENT

Sama Bilbao y Leon

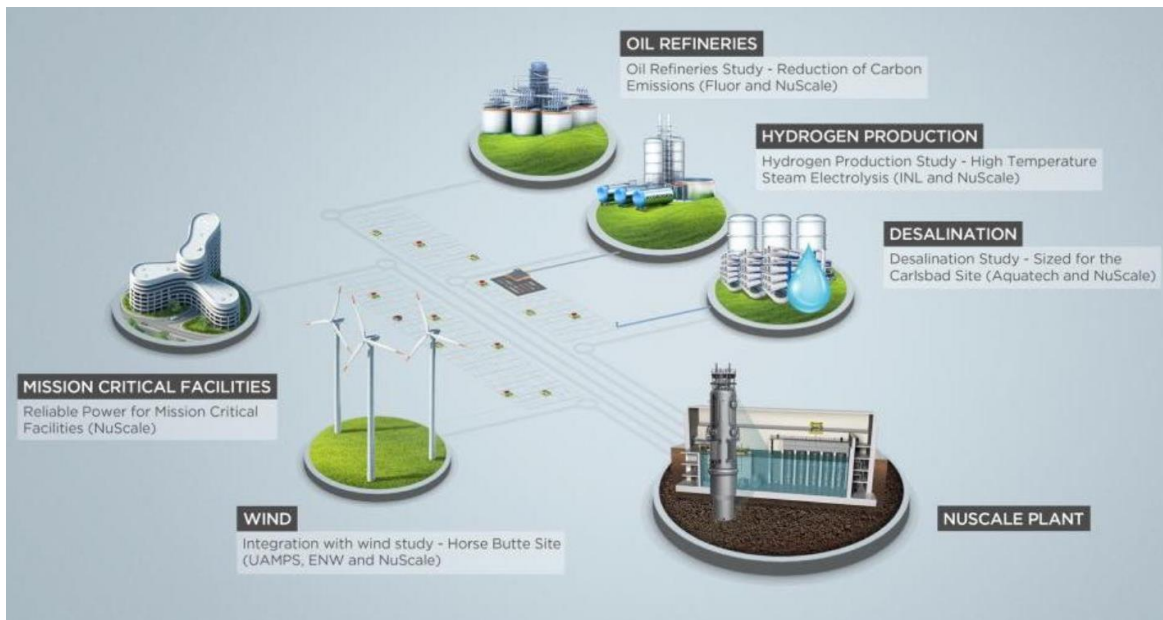
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2019 IEA Workshop on Nuclear Power – February 25, 2019

What are SMRs

- Small-sized nuclear reactors < 300 MWe
- Micro-reactors < 10 MWe
- Factory fabricated and assembled on site
- A power plant may be composed of several reactor modules
- Many technologies: water-, gas-, liquid metal-, molten salt-cooled
- “Traditional” and “Non-traditional” refuelling cycles
- Various levels of Technology Readiness (TRL) and Licensing Readiness (LRL)

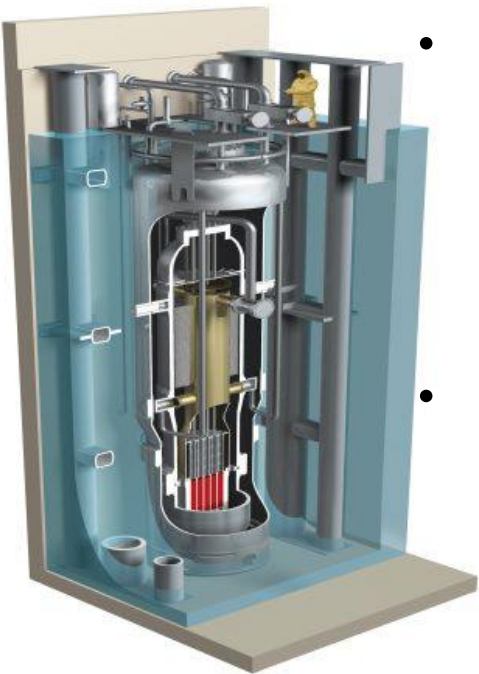
Integration and Diverse Energy Products



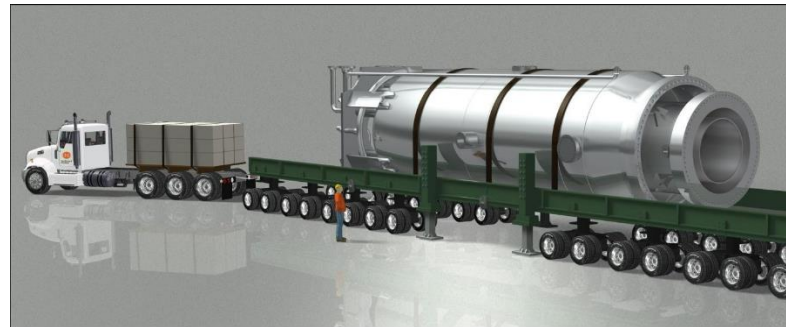
- Remote populations
- Seasonal & remote industry
- Mission critical
- Integration VRE
- Flexibility
- Fresh water
- Heat
- Hydrogen

Source: NuScale

Overall Benefits



- Simplicity
 - Factory fabrication
 - Fewer components
 - Reduced construction time
- Safety
 - Inherent safety
 - Passive safety
 - Integral design



- Flexibility
 - Grid appropriate
 - Match demand
 - Diverse energy products
- Security
 - Below grade

Source: NuScale

SMR Business Case

More Affordable

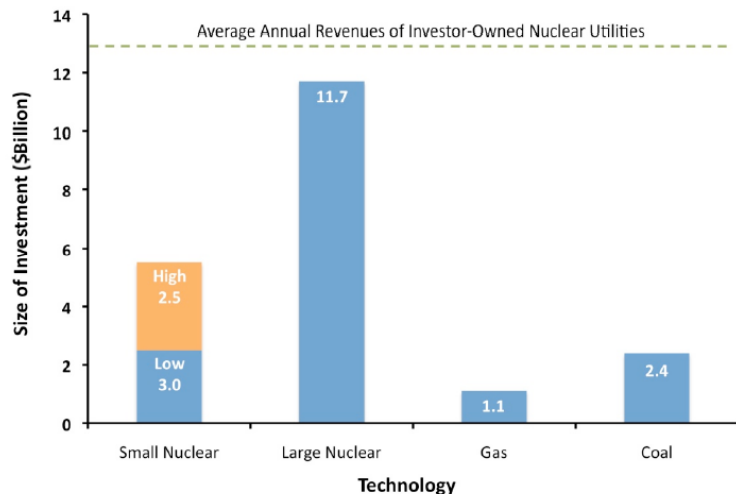


FIGURE 1 Comparison of Size of Investment (i.e., Overnight Cost) with Average Annual Revenues of Investor-Owned Nuclear Utilities¹⁷

Less Risky

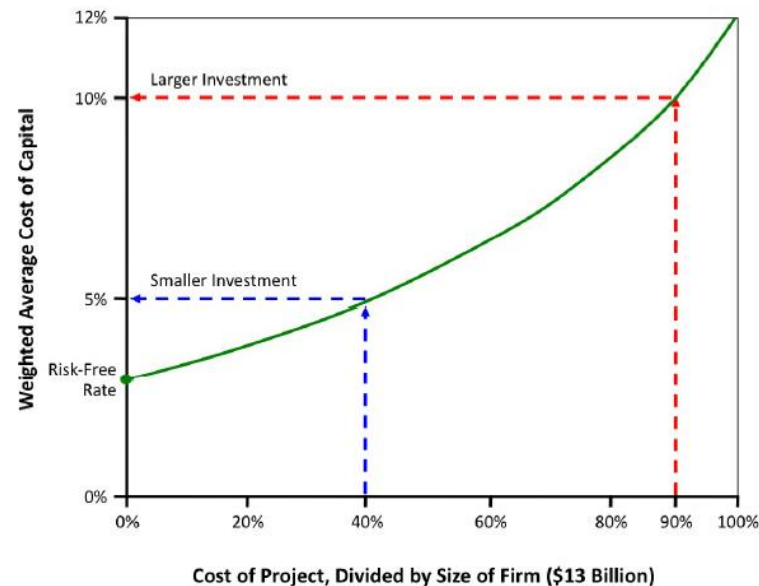


FIGURE F.1 Firm's Investment in Nuclear Reactor Project for SMRs and GW-LWRs⁸²

Source: "Small Modular Reactors – Key to Future Nuclear Power Generation in the U.S.", University of Chicago, Nov 2011

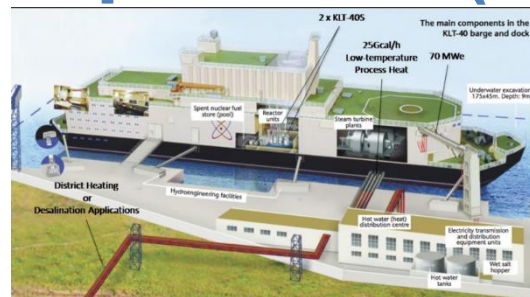
Some SMRs Under Development

DESIGN	POWER [MWe]	TYPE	DESIGNER	COUNTRY	STATUS
CAREM	30	PWR	CNEA	Argentina	Under construction
ACP100	100	PWR	CNNC	China	Basic design
SMART	100	PWR	KAERI	Korea	Certified design
NuScale	50 × 12	PWR	NuScale Power	USA	Licensing process
SMR-160	160	PWR	Holtec International	USA	Preliminary Design
KLT-40S	70	Floating PWR	OKBM Afrikantov	Russian Federation	Under construction
HTR-PM	210	HTGR INET	Tsinghua University	China	Under construction
SC-HTGR	272	HTGR	AREVA	USA	Conceptual Design
Xe-100	35	HTGR	X-energy LLC	USA	Conceptual Design
4S	10	LMFR	Toshiba	Japan	Detailed Design
EM2	265	GMFR	General Atomics	USA	Conceptual Design
IMSR	190	MSR	Terrestrial Energy	Canada	Basic design
ThorCon	250	MSR	Martingale Int	USA	Basic design
BWRX-300	300	BWR	GEH	USA	Conceptual Design

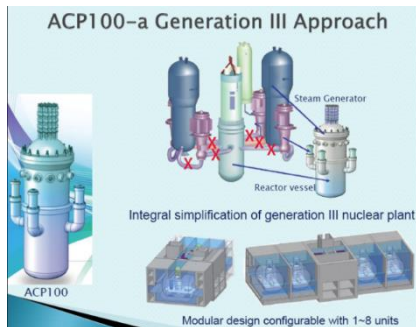
Some ongoing development... (1/3)



CAREM (Argentina, 25MWe): under construction, commercial operation > 2019



KLT40s (Russia/OKBM, 2x35 MWe): fuel loaded, commercial operation > 2019



ACP100 “Linglong One” (China/CNNC, 100MWe): under development



ACPR50s (China/CGN, 60MWe): under construction, commercial operation > 2020

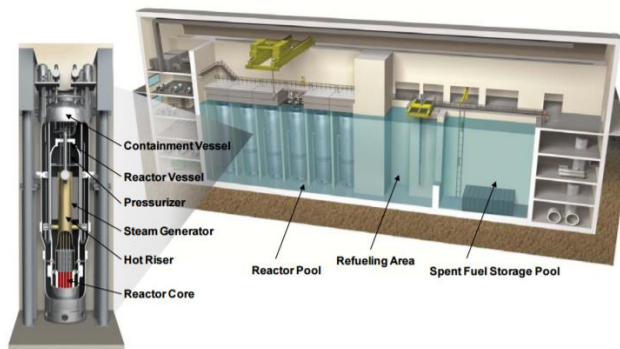
Some ongoing development... (2/3)



SMART (Korea/KAERI): under development,
MoU with Saudi Arabia – desalination,
deployment > 2024




HTR-PM (China/CNEC – 2 units/210 MWe):
under construction, operation > 2019



NuScale (US, 50MWe – up
to 12 modules)
March 2017: Design
Certification Application
accepted by NRC
Demonstration by 2027

Some ongoing development... (3/3)



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Canada Mapping a Strategy for the Next Generation of Nuclear Reactor Technology

News Release

From [Natural Resources Canada](#)

February 22, 2018 Ottawa Natural Resou

Canada has been a world leader in nuclear energy. The next generation in nuclear technology

Parliamentary Secretary Kim Rudd, on behalf of the Minister, announced that the Government will provide funding under the Energy Innovation Program to explore


A Call to Action:

A Canadian Roadmap for Small Modular Reactors



job creation and low-carbon
in a low-carbon economy.

and a road mapping process technology in Canada.


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Policy paper

Advanced Nuclear Te

Updated 5 February 2018

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The advanced nuclear sector is a key part of the [Industrial Strategy](#) building on the UK's natural advantages in nuclear while supporting the transition to tackling the [Clean Growth](#) Grand Challenge.

SMRs for newcomer countries?

- Several “newcomer” countries are expressing interest in SMR technology:
 - Indonesia – interest for High Temperature Reactors
 - Saudi Arabia – interest in desalination applications (SMART) and Chinese-design HTRs
 - Jordan – interest in HTR (X-Energy) and LWR-based SMRs (Rolls Royce), as well as with Rosatom-designed SMRs.
 - Poland, HTR roadmap
 - **Could SMRs help the introduction of nuclear energy? a first step towards the deployment of larger LWRs or GenIV reactors?**

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Rolls-Royce to conduct SMR study for Jordan

09 November 2017

Rolls-Royce said today it has signed a memorandum of understanding with state-owned Jordan Atomic Energy Commission (JAEC) to conduct a technical feasibility study for the construction of a Rolls-Royce small modular reactor (SMR) in the Middle Eastern country. The signing took place today at the British Embassy in Paris between Alan Woods, strategy and business development director at Rolls-Royce, and Kamal Araj, JAEC vice chairman.



Experimental Power Reactor (I-EPR)

Location:	PUSPIPTK SERPONG
Power:	10 MWth
Technology:	HTGR
Construction:	2016-2022
Commissioning / Operation:	2022-2023
Project Status:	Completion of pre-project

- Development of the experimental power reactor of I-EPR is an innovative way and one of the entry points in the utilization of nuclear energy in Indonesia
- In line with the regulation in which BATAN has an authority to build and operate non-commercial NPP
- Development of I-EPR is also a strategic effort for mastering nuclear energy project management, engineering capacity building and human resource development to strengthen the role of Technical Supporting Organization (TSO).
- I-EPR will be a FOAK (First of a Kind) for future Indonesia's commercial NPPs



China, Saudi Arabia begin HTGR feasibility study

17 May 2017

China and Saudi Arabia have held their first meeting to discuss the feasibility of constructing high-temperature gas-cooled reactors (HTGRs) in the Middle Eastern country. The joint working group aims to complete the feasibility study report later this year.

Related Story

- Moderator loading starts

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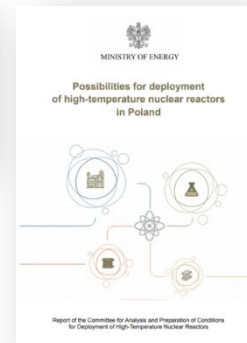
Jordan to consider deployment of X-energy SMR

29 November 2017

The Jordan Atomic Energy Commission (JAEC) has signed a memorandum of understanding (MoU) with X-energy to assess the US company's small modular reactor (SMR). They will look at the potential deployment of X-energy's Xe-100 high temperature gas-cooled pebble bed modular reactor in Jordan.

Related Story

- Advanced agreement signed



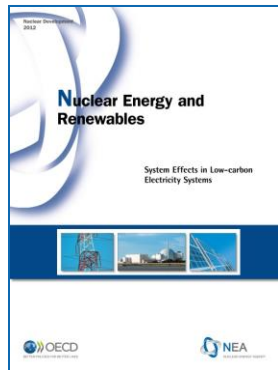
Some takeaway points

- Addressing climate change and air pollution will demand **massive structural changes in the electricity sector**.
- Nuclear, hydro and renewables are the main sources of low C electricity. Due to the intermittency of variable renewables, **flexibility** will be needed (generation, system)
- **Challenges for new nuclear build:**
 - **Cost, finance, electricity markets, public acceptance, policy stability**
- **SMR can potentially play an important role** in future energy markets:
 - Easier financing, public acceptance (safety)
 - Electricity & heat (cogeneration) – flexibility, new market opportunities
 - Competitiveness – need a high build rates to get economics right
 - Facilitate the introduction of nuclear energy in newcomer countries

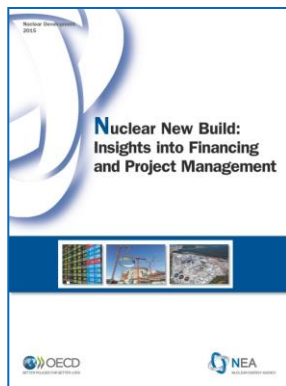
Conclusions

- True economics of SMRs are not yet known
- Risk sharing among governments, power utilities and industry is necessary
- Indispensable collaboration with nuclear regulators to maximize the inherent advantages of SMRs
- Future deployment of SMRs will depend on the success of demonstration and FOAK projects
- Global markets and supply chains required to optimize the economics of SMRs
- Successful SMR deployment will likely require a 'fleet' based approach to operations to benefit from standardization

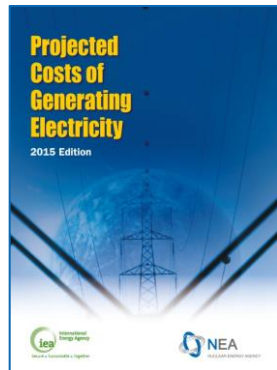
Ongoing OECD NEA Work on Nuclear and Electricity Supply



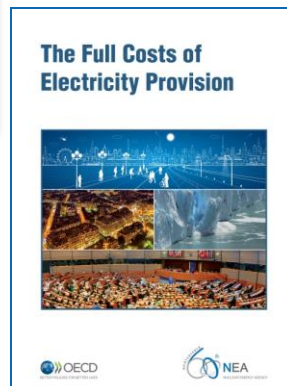
2012



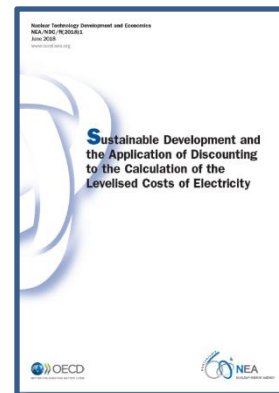
2015



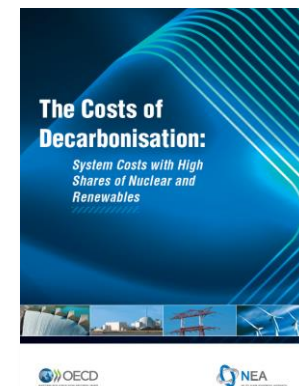
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