WORKING PAPER

LOCALIZING NUCLEAR CAPACITY? SAUDI ARABIA AND SMALL MODULAR REACTORS

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The cover picture is an aerial image of the nuclear reactor site in King Abdulaziz city for science and technology, Saudi Arabia. Photograph: Google Earth

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INTRODUCTION

In recent years, Saudi official statements and policy documents have emphasized the importance of localizing energy technologies. For example, "Saudi Vision 2030", championed by the now crown prince, Mohamad Bin Salman identifies localization of portion of the value chain within the sector as a new pillar of the kingdom's economy ("Saudi Vision 2030" 2016). A second trend in Saudi energy policy has been to promote the development of indigenous capacities in a variety of different electricity generation technologies with the aim of reducing the reliance on the oil and gas sectors. Currently almost all of Saudi Arabia's electricity comes from fossil fuel sources (Demirbas, Hashem, and Bakhsh 2017).

One result of the latter trend is that over the last decade Saudi policy makers have been talking about building nuclear power plants. Of late, these calls have been coupled with an emphasis on localization. The National Transformation Program 2020 (NTP 2020) document released in 2016 stresses the importance of increasing the number of developed and localized technologies in the electricity sector, including nuclear energy, and increasing job opportunities in the renewable and atomic energy sector ("National Transformation Program" 2016). NTP 2020 also laid out localizing a percentage of the nuclear and renewable energy sector as strategic objectives.

According to the 2016 National Transformation Plan, Saudi policy makers seem to think that the way to achieve a significant degree of localization in the nuclear sector is to invest in new nuclear reactor designs called Small Modular Reactors (SMRs). The kingdom has initiated a joint venture with South Korea to develop one SMR design called SMART (IAEA 2015; Lee 2016). It has also entered into agreements with China to explore high-temperature gas-cooled reactors, another class of SMR designs (WNA 2017b). The underlying belief seems to be that such technologies have a high potential for deployment in the Middle East and North Africa (MENA) region.

In this paper, we examine how compatible SMRs are with Saudi Arabia's interest in localization, and assess the potential for localizing SMRs in Saudi Arabia. It starts with two sections that summarize the background for Saudi Arabia's interest in nuclear power and in SMRs, and some of the claims made about the benefits of SMRs. This is followed by a section discussing localization. We end with a brief comparison of localization in another realm: Solar photovoltaics.

NUCLEAR POWER AND SAUDI ARABIA

Saudi Arabia has been interested in Nuclear Power since the 1970s (Fitzpatrick, 2008). Government officials claimed the need for nuclear energy as it will be used for desalination, electricity production, and industrial processes (Melibary and Wirtz 1980). The current wave of interest in nuclear power started in 2006, when the countries belonging to the Gulf Cooperation Council (GCC) declared their intention to establish a joint nuclear energy development program and stressed their right to acquire nuclear technologies for peaceful uses (Fattah 2006). Although a GCC-wide initiative never materialized, Saudi Arabia and the United Arab Emirates did establish concrete plans, with the latter going on to constructing four nuclear reactors, the first of which is expected to become operational in 2020 Saudi Arabia has not started any nuclear reactor construction so far.

Commitment to use nuclear power as part of the electricity mix in the kingdom was reiterated in 2010 through a Royal Decree that identified atomic energy as essential to reduce reliance on fossil fuels and meet the growing demand for desalinated water and electricity. To advance this agenda, the King Abdullah City for Atomic and Renewable Energy (KA-CARE) was established in Riyadh as the leading unit responsible for furthering nuclear power in Saudi Arabia (KACARE 2010).

In 2011, the KA-CARE announced its plan to construct 16 nuclear power reactors to generate 17 GW by 2032. The target date has since been pushed back to 2040, however, there is some unofficial, but verified, information obtained by the authors stating that the kingdom has decided to scale back on the 2011 KA-CARE plan.[1] The project claims that it will produce 20% of the electricity generated in Saudi Arabia at an estimated cost of $80 billion (Adams 2017). To support the development of nuclear projects, KA-CARE signed a Memorandum of Understanding (MoU) with Areva, a French nuclear technology supplier, in 2014. Areva was to support technical and industrial skills of local Saudi corporations to set up a local supply chain that would provide some components of nuclear reactors (WNN 2014). In 2015, France and Saudi Arabia entered into a second agreement to assess the feasibility of the construction of two European Pressurized Reactors (EPR) reactors and providing training on waste disposal and improving safety (WNN 2015a). More recently, KA-CARE

1 KA-CARE website is still stating the Kingdom's intention to build 17.6 GW of nuclear power; https://www.kacare.gov.sa/en/FutureEnergy/Pages/nucularpower.aspx signed a "program of cooperation in the peaceful uses of nuclear energy" with Rosatom, a nuclear technology supplier owned by the Russian government (WNN 2017c).

In October 2017, the kingdom sent out a request for information (RFI) to international suppliers to build two nuclear power plants (Westall and Shamseddine 2017). The RFI envisions the construction of two large nuclear power plants of roughly 2.8 GW combined power capacity (Chaffee and Cooke 2017). There is some expectation that the kingdom will sign its first contracts for building nuclear reactors by the end of 2018 (Gamal and Paul 2017); however, no contracts were signed as of the time of writing.

There has been a parallel set of agreements signed by the kingdom on SMRs. Unlike the current generation of operational and marketed reactors that typically generate around 1000 MW (or 1 GW) of electricity, Small Modular Reactors are defined as reactors that generate less than 300 MW. These are all relatively new designs, and none have been made operational even though many nuclear vendors have been developing plans and designs for more than a decade now. In 2015, KA-CARE signed a nuclear cooperation agreement with the Korea Atomic Energy Research Institute (KAERI) to support the development of KAERI's SMART reactor (ANS 2016; WNN 2017b). Later, Saudi Arabia signed two MoU with China: the first, in 2016, to build High-Temperature Gas-cooled Reactors (HTGRs), and the second, in 2017, to study the feasibility of building HTGRs (WNA 2017b). The Appendix briefly describes these two reactor designs.

A timeline of the development of the Saudi nuclear power program is shown in Figure 1.

Saudi Arabia's interest in SMRs has been interpreted in the local language media as a sign of the country moving towards a more diversified economy. Arabic media has also reflected a sense of Saudi ownership of the SMART reactor, and a real partnership with South Korea (Al-Hamad 2013; Al-Hayat 2017; Al-Jazira 2015). These suggest that there is a real possibility that Saudi Arabia might proceed with its SMR plans and provides us with the motivation for a careful assessment of these plans.

Motivations for Saudi Arabia's interest in SMRs

Official statements and authors' interviews with Saudi policy makers offer two main justifications for Saudi Arabia's interest in SMRs. The first is that SMRs offer higher safety standards, a significant reduction in cooling requirements, a reduced emergency planning zone, and easier grid integration requirements.

The second, and perhaps more important, motivation is that there will be a high level of technology and knowledge transfer into Saudi Arabia. There is some logic to this argument. Unlike the well-established, and mature, large nuclear reactors, many SMRs are still at relatively early stages of development. There are no factories to manufacture SMRs anywhere else. Saudi officials offer even more ambitious plans; they claim that this technology transfer could give the kingdom a chance to become a global hub for SMR development and even exports. There is no evidence, however, that there is an export market for SMRs. None of the developing countries that are expected to buy SMRs are actually putting in the necessary investments (Ramana and Agyapong 2016; Ramana and Ahmad 2016)

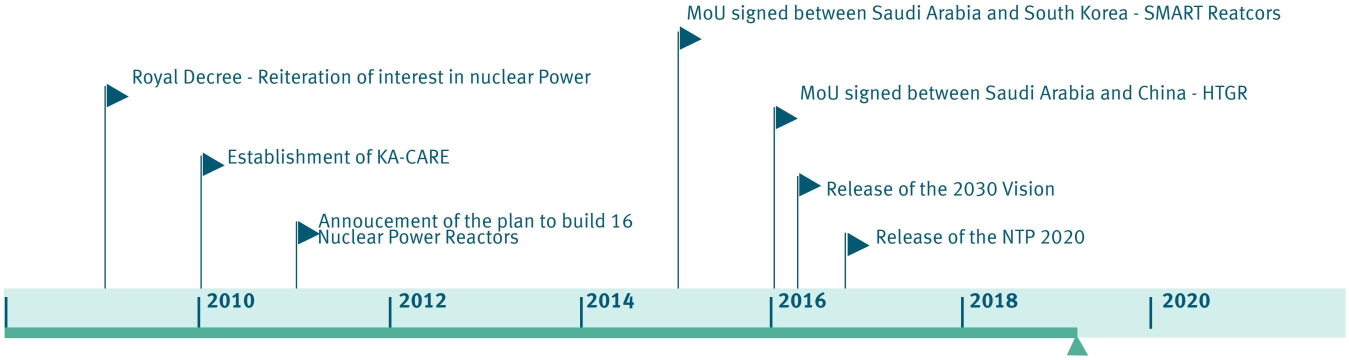

Figure 1: Timeline of Saudi Arabia's nuclear power program

Regionally, Jordan may appear, on paper, as the most promising market for an SMR that is co-developed and financed by Saudi Arabia. At the same time, despite the recent nuclear cooperation agreements between Jordan and Saudi Arabia, including one on SMRs (WNN 2017b), there are some countervailing trends that could derail the possibility of a Saudi-Jordan SMR project. The first is a mismatch of time scales. It would easily take a decade, and quite likely much more, for the Saudi plan to manufacture SMART in the kingdom to materialize. In the meanwhile there has been a surge of cost effective renewable energy projects across Jordan, the most recent of which is the 200 MWe solar farm financed by Abu Dhabi's Masdar (Carvalho 2018). It is quite likely that Jordan would have found more economical and quick answers to its energy challenges well before the first SMART reactor is built in Saudi Arabia.

ASPECTS OF THE LOCALIZATION OF NUCLEAR POWER IN SAUDI ARABIA

The World Bank defines localization as a "policy that has evolved from creating backward linkages by supplying input to the local economy through transfer of technology, the creation of local employment opportunities, and increasing local ownership and control" (World Bank 2013). It also requires the use of locally produced goods and services in other production processes (Stephenson 2013). In principle, localization aims to stimulate economic development and producing sustainable social and economic outcomes (World Bank 2016). The potential benefits include supporting technological advancement, transferring know-how from other countries, developing the private sector, increasing the diversity of locally produced goods and services, and supporting the training of citizens (Stephenson 2013). On the other hand, localization policies could have negative effects such as increasing production costs in the targeted industry, reducing trade, and potential economic isolation (OECD 2016).

In the case of the energy sector, countries often seek to introduce local content requirements to promote public support to cover any additional cost, support new (and more diversified) industries until they gain competitive power in the market, add more "green jobs", and achieve additional environmental benefits (Stephenson 2013). Saudi Arabia has established a center for local content and investment, which serves as a platform to share data regarding investment regulations and rules of Saudi Arabia with both private and public organizations (Asharqia Chamber 2013).

According to the Saudi Vision 2030, the localization pathway starts with research and development and proceeds to manufacturing in future steps ("Saudi Vision 2030" 2016). In the follow up document, NTP 2020, the Saudi government expressed the aim of promoting local content in the nuclear and renewable energy sector simultaneously. As shown in Table 1, for the nuclear energy sector, the kingdom plans to introduce nuclear power to the electricity mix of the country with a target of 25% to 30% local content. As for renewables, an addition on 3.45 GW of electricity from various sources, especially solar, is planned with a target of 25 to 35% of local content ("National Transformation Program" 2016).

To support the legislative efforts, building infrastructure,

Table 1: Overview of Saudi Arabia's proposed nuclear and renewables localization activities (Source: NTP 2020)

Local content contribution	NTP 2020's Localization Target (%)
The nuclear energy sector	30 – 25
The renewables energy sector	35 – 25
Nuclear and Renewables Localization Activities	
Develop needed qualitative human capabilities for atomic and renewable energy sector	
(Localization of small nuclear reactors compact (SMART Technology	
Localization of nuclear fuel cycle in uranium production, achieving investment return	
Localize needed renewable energy technologies to support the kingdom's power and water desalination sectors	

training human capabilities, localizing renewables technology, SMRs, and the nuclear fuel cycle, 5 Billion SR (1.33 Billion USD –2017) have been budgeted for spending before 2020 (Shearman & Sterling 2016).

Although this investment might seem substantial, it pales in comparison to the investments needed to initiate and sustain new industrial and manufacturing activities. Even for a country like Saudi Arabia with significant financial resources, the investment cost for nuclear energy is extremely high. Nuclear power plants have among the highest costs per MW of installed capacity; adding fuel cycle facilities to support this capacity would make it even more expensive.

Vendor Policies and Interests

The above discussion has focused mostly on the plans and motivations of Saudi Arabia to engage in localization. What of the willingness and interest of international nuclear vendors and foreign governments to offer technological know-how to Saudi Arabia? A priori, this should seem like a non-problem, given the offer from South Korea's KAERI to manufacture the SMART reactor in Saudi Arabia. However, this proposal might run into problems and it is by no means definite that the South Korean government will support KAERI's plans.

This is because of the reluctance of the nuclear industry to bear the complete investment costs of developing SMRs, or any other new reactor design. Instead, in most countries, SMR vendors have sought government support and subsidies to carry out their research and development. In order to procure such financial support, they have offered the claim that manufacturing these reactors and exporting them would generate lots of jobs, and thus boost the domestic economy. The U.S. based lobbying organization, Nuclear Innovation Alliance, for example, claims that "a U.S. SMR industry could create or sustain hundreds of thousands of American jobs" (NIA 2017). That claim, of course, is exaggerated because nuclear power creates relatively few jobs per unit of investment. But the thrust is clear: The government should support the development of SMRs because it would create jobs, which political figures could take credit for in their attempts to win elections. The United States is not unique in this regard by any means. KAERI or other SMR vendors have also promoted their designs domestically with similar claims, although perhaps not in such an exaggerated fashion.

Such a strategy to obtain government support for developing SMRs sets up a conflict of interest between the vendor nation and the importing nation. Even ignoring the limited job creating capacity of nuclear power, the basic problem with such claims is that such jobs can be created in the country that supported the development of the SMR design or the country that seeks to import these designs, but not both. If some aspects of the manufacture are conducted in the home country and some aspects are pursued in a country like Saudi Arabia, then it would reduce the already miniscule job creation capacity of nuclear power.

Localization of Nuclear Fuel Cycle Activities

Saudi Arabia's idea of localization is not limited to just nuclear power plants. Saudi policy makers have larger ambitions. In 2010, Saudi Arabia asked Poyry, an international consulting and engineering firm, to evaluate the economic and technical feasibility of the kingdom's involvement in various stages of generating nuclear power, including uranium production and enrichment (Bakr 2010). Plans to extract domestic uranium have been affirmed by Hashim Yamani, the then head of KA-CARE, at a 2017 conference in Abu Dhabi, where he announced that uranium extraction makes economic sense to the kingdom (Westall 2017). Yamani did not specify if Saudi Arabia was interested in enrichment of uranium and reprocessing of spent fuel. The minister of energy reiterated the kingdom's intent to "localize the entire value chain with nuclear energy" while maintaining the authority to produce domestic nuclear fuel (Gamal and Paul 2017).[2]

If Saudi Arabia is serious about establishing a uranium enrichment program, it can do so through establishing a joint venture with one of the technology owners such as URENCO. Such an opportunity depends upon the interest of a technology holder to establish a plant in the Middle East (Heinonen and Henderson 2014).

The second possibility is through developing its own technology which would take a decade to design a centrifuge and build a commercial scale process (Heinonen & Henderson, 2014). Saudi Arabia has some experience in the mining and milling. However, no relevant activities have been identified in the fields of conversion, enrichment, fuel fabrication, and reprocessing (Acton and Bowen 2010).

In any case, the localization of nuclear fuel cycle activities in Saudi Arabia faces two major challenges on the international front. The first challenge involves the policies adopted by most countries regarding export of sensitive nuclear technologies. There is a major focus on multinational ownership of nuclear fuel cycle facilities (Noh, Choi, and Hwang 2017) .

The challenge is even greater because of the deepening sectarian divide and increased hostility between Saudi Arabia and Iran. Attempts by organizations in countries like the United States that seek to profit from selling nuclear technology to Saudi Arabia will be opposed by other organizations that are interested in maintaining and strengthening non-proliferation norms. Another problem is the growing concern about the capacity of non-state actors, or for that matter states, in the region to engage in violent attacks on sensitive facilities. This capacity was underscored in December 2017 when a rebel group in Yemen claimed that it had launched a missile at the Barakah nuclear power plant that is under construction in Abu Dhabi (Ahmad 2017; Almosawa and Erdbrink 2017). A summary of the challenges the kingdom is expected to face is shown in Table 2.

Table 2: The potential effects of various challenges associated with the localization of the nuclear fuel cycle.

Challenge	Potential Effects
Cost	Substantially increases investment costs, particularly if only one or two reactors are built
Human resources	Training programs are costly and take a long time; reliance on expats seems inevitable
Suppliers' policies	Suppliers may be reluctant to share technology and request further assurances such as the signing of the 123 agreement, which prohibits enrichment and processing
Geopolitics	Spread and empowerment of non-state actors in the region may add pressure on the kingdom to forgo building sensitive facilities that may be used as targets

2 The economic case for having a domestic uranium enrichment program is weak. Even if the kingdom builds 16 nuclear reactors, it would still be more economic for the kingdom to buy enriched fuel from the international market given current market conditions (Ahmad, Salahieh, & Snyder, 2017).

SAUDI ARABIA'S LOCALIZATION POTENTIAL IN OTHER ENERGY SOURCES

The above analysis does not extend to other energy sources and there is definitely scope for Saudi Arabia to localize production of other low-carbon technologies. Saudi Arabia has ample renewable energy resources (Demirbas et al. 2017). The most importance of these is solar photovoltaic (PV) technology. The abundance of solar insolation in Saudi Arabia and declining costs for PV technology—the global average has come down from 0.347 $/kWh in 2010 to 0.085 $/kWh in 2018 (IRENA 2018)—make solar energy an attractive option to explore and deploy. This has already started happening to a very limited extent but this is expected to grow in the future. The International Renewable Energy Agency, for example, has predicted that about 68,600 jobs will be created in the PV and CSP industries in Saudi Arabia by 2030 (IRENA 2016).

Bidders for wind and solar plants are expected to spend 30% of their invested capital through local companies and workers. As the Saudi capacity develops over the years, local content requirements will be increased (Landberg 2017).

Localization requirements have begun to play a part in choices made by Saudi policy makers. A total of 27 companies were shortlisted for the first round of the kingdom's first renewable energy project consisting of a tender of 300 MW of Solar Power (NREP 2017). Eight bids were submitted and the lowest price was submitted by Masdar and EDF at 1.79 cents/kWh (Graves 2017b). The cost will play a major role in the final selection; however, the "30% saudization compliance requirement", and the technical, financial, and regulatory compliance will also have a role (Kenning 2017). The kingdom declined the Masdar/EDF offer and shortlisted Saudi Arabia's ACWA POWER and Japan's Marubi who submitted respectively bids of 2.34 cents/KWh and 2.66 cents/KWh (Kenning 2018). In other words, Saudi policy makers are willing to pay more for electricity if there is some localization of the technology. Lately, the Renewable Energy Project Development Office of Saudi Arabia is planning to tender additional PV projects, with a total capacity of 2.22 GW in 2019. The kingdom's target for solar energy has been revised from 5.9 GW to 20 GW by 2023, and to 40 GW by 2030 (Bellini 2019).

There is also investment into developing the capacity for local manufacture of renewables. A renewable energy office was established in 2017, and is managed by a board that includes the energy minister, officials from KA-CARE, Saudi Aramco, and the state electricity company (Landberg 2017). Saudi Aramco, the national oil company, has so far resisted the nuclear option for the kingdom[3] and is more interested in renewables and their potential (Reed 2017; Saudi Aramco 2017). Saudi Aramco is also working on establishing partnerships such as the one with Masdar to work on renewable energy (Graves 2017a). In addition, the company is aiming to diversify from oil production by considering to invest $5 billion in renewable energy companies, and bringing foreign expertise into the kingdom (Martin 2017).

Local Saudi companies could benefit from partnering with other established providers of technology, and EPC (Engineering, procurement, and construction companies). After gaining experience, and developing local capabilities, local companies could have a higher role in the industry (IRENA 2016) .

So far, all the renewable energy projects in the GCC import foreign manufactured equipment. However, local providers are responsible for, and profit from, sales and distribution. The role of each party is defined based on their capabilities. Examples are shown in Table 3 (IRENA 2016) . Consortia of foreign and local EPC companies and developers could promote a successful partnership that supports the localization plans in the long term.

Based on the experience of other countries (Germany, Italy, France and the US), the potential of solar PV localization is high if a market is available. To compete with competitive suppliers such as China, manufacturers need to focus on niche technologies.[4] These require skilled workers and R&D efforts. Work in

3 This information was obtained by one of the authors during a visit to Riyadh in November 2017 and meeting with key energy officials in the kingdom.

4 For example, the first PV inverters were launched in the kingdom through a partnership between a Saudi company AEC in 2015 (Advanced Electronics Company) and KACO, a solar PV inverters manufacturer in Germany. The production line will produce up to 1 GW or 2,000 units (ranging from 20 KW to 2 MW) per year (Colthorpe, 2015). The initial contribution in the BOS through production of inverters is a promising step towards the development of some parts of the value chain of PV.

Table 3: Renewable Energy Projects in the GCC Countries (Source: IRENA)

Stakeholders	Role in the value chain	DEWA 13 MW	DEWA 200 MW	SHAMS 1 100 MW	OURZAZATE I 1
Equipment Providers	Manufacturing, Assembly and Distribution	First Solar ABB	First Solar	Abengoa Solar First Solar Schott Solar Flabeg	Flabeg SENER
Developers and/or EPC	Project planning, construction, and operation and maintenance	First Solar	ACWA Power TSK	Total Masdar Teyma Abengoa Solar	ACWA Power SENER Acclona TSK Arles
Utility(ies)	Mainly support functions including: Grid connection, decision making and system planning	DEWA DSCE	DSCE	Masdar ADWEC	MASEN
Financing	Financial services	DEWA	First Gulf Bank Samba NCB	NBAD KfW BNP Paripas Société Générale SMBC MUFG	KfW EIB Afdb World Bank AFD

the installation, construction, and system integration could be done by local workforces.

As the earlier discussion of the numbers of educated workers in Saudi Arabia demonstrates, there should be enough potentially employable Saudis that can be trained to work in the renewable industry. The difference with nuclear manufacture is that this training need not be as extensive nor are there the grave safety implications of inadequate training.

CONCLUSION

Saudi Arabia faces some major energy policy choices as it pursues its long-term goal to reduce economic reliance on fossil fuels. In recent years, there has been a new argument made to justify continued pursuit of nuclear energy: the idea that Saudi Arabia could become a manufacturing hub for Small Modular Reactors. This has been promoted as one way to fit the emphasis on localization that the kingdom has adopted as part of its development plans. There are indeed good reasons for Saudi Arabia to pursue localization of new energy technologies. But, as we have argued in this paper, if this criterion were to be applied to its energy choices, the results are clear.

When it comes to nuclear power, the kingdom presents low technical capabilities, with moderate political support. Despite the local desire for localization, the international community is not likely to be supportive of Saudi acquisition of the know-how. There will also be pressure from SMR vendor states to do as much of the manufacture of SMRs as possible within their own borders. As a result, any acquisition of nuclear fuel cycle capabilities or SMR manufacturing capabilities by Saudi Arabia will be, at best, slow and limited. The kingdom's plan to leverage its partnership with South Korea's SMART developers to become an SMR supplier is risky. There is no evidence that there is actually an export market for SMRs. None of the developing countries that are expected to buy SMRs are actually putting in the necessary investments.

In contrast, the localization of renewables is endorsed politically and there are moderate technical capabilities within the country. Saudi-owned solar energy companies are involved in several flagship projects across the Middle East and now have the required expertise to domestically fulfill the kingdom's need of renewable energy. Thus, large scale investment into renewable energy technologies is clearly a more appropriate choice.

APPENDIX: SAUDI ARABIA'S SMR OPTIONS AND THEIR TECHNOLOGY FEATURES

There are two leading SMR designs that Saudi Arabia is interested in, SMART and HTR-PM, and a brief description of their designs is presented below. Claimed added value and challenges of SMART and HTR-PM are listed in Table 4.

SMART

The System Integrated Modular Advanced Reactor (SMART) is a pressurized water reactor (PWR) designed by KAERI. The reactor design was licensed in 2012 and was declared to be ready for commercial deployment (IAEA 2014). The SMART is designed to produce 100 MW of electricity (MWe). The design also allows for some of the heat produced in the reactor to be used for water desalination (Seo, 2013). According to its promoters, the construction duration is 3 years and the lifetime of the design is 60 years (IAEA 2014).[5]

After a period of unsuccessful marketing to domestic Korean utilities, which all seem to have rejected the idea of building SMART reactors in South Korea because of the high per unit costs, KAERI is now promoting SMART reactors in foreign markets, especially in the Middle East (Green 2015). Saudi Arabia's KA-CARE and South Korea's KAERI have agreed to conduct a preliminary study for three-years to assess the feasibility of building SMART in the kingdom (WNN 2015b).

At this stage, KAERI intends to share some of the intellectual property rights associated with the SMART design with KA-CARE to advance the reactor's commercial prospects (Green 2015). KA-CARE claims that the first two SMART units will be constructed in Saudi Arabia, and then sales to other countries will follow (KACARE 2017). There is no evidence so far of commercial interest on the part of other countries to buy SMART reactors from either South Korea or from this combination of Saudi Arabia and South Korea.

The first SMART unit is estimated to cost $1 billion (WNN 2015b). Although there is no identified site so far for the construction of SMART, there is some expectation that such reactors will be built inland in Saudi Arabia rather than on

5 The construction duration of both the SMART and HTR-PM are very ambitious, especially when compared with a global trend of time overruns in nuclear new build projects.

Table 4: Claimed added value and challenges of SMART and HTR-PM

Design	Claimed added value	Main challenges and risks
SMART	Based on more familiar light water technology Can be used for desalination Short construction duration (3 years)	Dry-cooling may not be efficient due to hot weather Lack of home support with anti-nuclear government currently in power in South Korea Higher levelized costs
HTR-PM	Can be used for co-generation of electricity, heat and hydrogen High operating temperature may be used for variety of industrial purposes	Shorter lifetime compared to water reactors (40 years) Significant safety and economic risks when deployed in petro-chemical industrial complexes Higher levelized costs

the coast. Therefore, KAERI is working on replacing the existing water cooling system with an air cooling system to adapt the reactor to the country's conditions (Min-hee 2015). Dry cooling, however, is unreliable in hot weather (WNA 2017a), and this could create safety problems.

HTR-PM

The HTR-PM (High-Temperature Reactor – Pebble Bed Module) is one instance of a class of designs called High-Temperature Gas-cooled Reactors (HTGRs) and has been developed by researchers from China's Tsinghua University on the basis of experiences in Germany and a smaller pilot scale test reactor that has been operating in China. HTGR designs involve heat from the core being transported away using a gas, typically helium, at relatively high temperatures (approximately 750 C) (Englert, Frieß, and Ramana 2017). According to its promoters, the construction duration of the HTR-PM is 5 years and its lifetime is 40 years (IAEA 2014).

HTGRs are promoted by developers as safer power plants since the design is not vulnerable to a meltdown (Ohashi et al. 2014). However, the design can still undergo accidents that result in releases of radioactive materials, primarily as a result of ingress of air or water (Englert et al. 2017). In addition, the operational experience with HTGRs that have been constructed in the United States and Germany have been disappointing, with reactors being prone to a variety of failures and being shut down ahead of targeted lifetimes; in turn, the shorter lifetime for HTGRs will increase the levelized costs of produced electricity (Ramana 2016).

Since HTGRs operate at a higher temperature compared to water-cooler reactors, they can be used to generate process heat and hydrogen production as well as electricity. On paper, Saudi Arabia could deploy HTGRs in their industrial regions such as petrochemical compounds and heavy oil recovery systems. Given the importance of the oil and petrochemical sector for the Saudi economy, this is a risky proposal due to the potential for accidents at HTGRs. If the reactors are co-located with industrial facilities, the consequences of any accident are likely to be immense.

The construction of the first demonstration HTR-PM started in December 2012 in Shandong province in China and was expected to become operational by the end of 2017 (WNN 2017a). As of July 2019, it had not become operational. When construction of the HTR-PM power plant was starting, there were plans for eventually constructing a further 18 units of the same type at the same site (NucNet, 2013). But that is not the case anymore (WNN 2016b).

Instead, the promoters of the HTR are talking about a new 600 MW design with six reactor modules connected to one steam turbine/generator set in order "to improve project economics" (Yuan & Qi, 2017). The reason for requiring an improvement in economics is that the HTR-PM has failed in this regard: the cost of generating electricity in it is reported to be 60 fen (¢ 0.9) per kilowatt hour, significantly higher than the average 43 fen/kWh for Gen III reactors, and this has been listed as one of the "key challenges" confronting HTGRs in China (Yu, 2016).

It is against this background of failure to succeed in the domestic market that we should view China's efforts to promote the HTR-PM design overseas. The country signed several MoUs with several countries including Indonesia, UAE, South Africa, and Saudi Arabia to study the feasibility of constructing HTGR plants in these locations (Mcdonald 2016; WNN 2016a).

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ABOUT THE PROGRAM

The Energy Policy and Security Program

The Energy Policy and Security Program is an interdisciplinary platform to examine the intersection of energy and security in the Middle East region. The Program closely monitors the changing energy landscape in the region. It also aims to inform policy makers and the public on the challenges and opportunities of the shift towards alternative energy sources with a focus on nuclear power. The Program was established in 2016 with support from the John D. and Catherine T. MacArthur Foundation.

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The Issam Fares Institute for Public Policy and International Affairs (AUB Policy Institute) is an independent, research-based, policy-oriented institute. Inaugurated in 2006, the Institute aims to harness, develop, and initiate policy-relevant research in the Arab region.

The institute is committed to expanding and deepening policy-relevant knowledge production in and about the Arab region; and to creating a space for the interdisciplinary exchange of ideas among researchers, civil society and policy-makers.

Main goals

- *Enhancing and broadening public policy-related debate and knowledge production in the Arab world and beyond*
- *Better understanding the Arab world within shifting international and global contexts*
- *Providing a space to enrich the quality of interaction among scholars, officials and civil society actors in and about the Arab world*
- *Disseminating knowledge that is accessible to policy-makers, media, research communities and the general public*

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